GIS-Based Analysis of Wildlife Habitat Suitability and Conservation Strategies in Maasai Mara Reserve

Mingzuo Xiao *, Yuyan Wang, Wenhui Ma

Faculty of Environment, Science and Economy, University of Exeter, Exeter, UK

* Corresponding Author Email: mingzuoxiao29@gmail.com

Abstract. The significance of conducting an animal habitats suitability analysis is to enhance sustainable management in the face of land use modification, population growth, and changing settlement patterns, thereby safeguarding Kenya's natural resources, tourism, biodiversity, resource utilization, and community livelihoods. This paper establishes a habitat suitability analysis of specific animal habitats based on GIS technology. Firstly, key indicators were identified and subjected to the single factor analysis. Secondly, the AHP model was employed to calculate the weights of the indicators. A comprehensive evaluation was then carried out to visualize the animal habitat suitability map. Finally, the results of the animal habitat suitability analysis were overlaid with the spatial data of the road network. Overall, the results show that the suitable habitat for wildlife habitat is concentrated in the eastern and western corners of the Masai Mara Reserve, evenly distributed in the south-eastern corner, with a small amount in the north. The impact of lost opportunities for people living near the reserve will be significantly reduced. A kernel density estimation model was introduced to make predictions based on the first law of geography. The visualized predictions show that the habitable range of animals is relatively close to the results of model 1, which proves that animal populations and the quality of human life are secure.

Keywords: Protecting animal habitats, GIS, AHP, Kernel density estimation.

1. Introduction

1.1. Problem Background

Kenya’s wildlife preserves were originally created primarily to protect wildlife and other natural resources. In order to provide a more equitable model of resource sharing and diverse community management, Kenya's Parliament passed the Wildlife Conservation and Management Act of 2013, after which they amended the loopholes in the first version to provide tougher enforcement against violators and further protect wildlife and natural resources. Protecting wildlife habitats and corridors can help to secure Kenya's natural resources as well as the national interests related to tourism, biodiversity, sustainable use of resources and community livelihoods. Land use modification, human and livestock population increases, and changing settlement patterns will affect the ecosystem of the Maasai Mara region [1]. It is necessary to improve sustainable management.

Several scholars have studied how to guarantee the sustainability of the Masai Mara Wildlife Nature Reserve. Zhang used the MaxEnt model to screen the ecological factors affecting the distribution of the habitat of Fargesia, constructed an evaluation model, and used ArcGIS software to evaluate the suitability of the habitat of Fargesia, and obtained the high, medium, low and unsuitable zones of the habitat of Fargesia nationwide [2]. Muchiri, M. N., & Mureithi, S. M. used questionnaires and in-depth interviews to investigate local community perceptions of and benefits from wildlife conservation [3]; Kipkemoi, J. K., & Wanyama, J. M. used long-term meteorological data and field survey data to analyze the large impact of climate on protected areas, and called on the government to pay attention to the impact of climate [4]; Serengeti-Mara ecosystem project has mapped wildlife corridors in the Masai Mara and demonstrated that the current establishment of roads has a negative impact on animal migration [5-6]. Chen Jianming used ArcGIS software, based on the kernel density analysis method to calculate the geological hazard vector data of the mine [7]. The previous research is instructive and point out the direction for our analysis.

1.2. Research Process Summary

The research process of this paper can be illustrated as Fig.1.

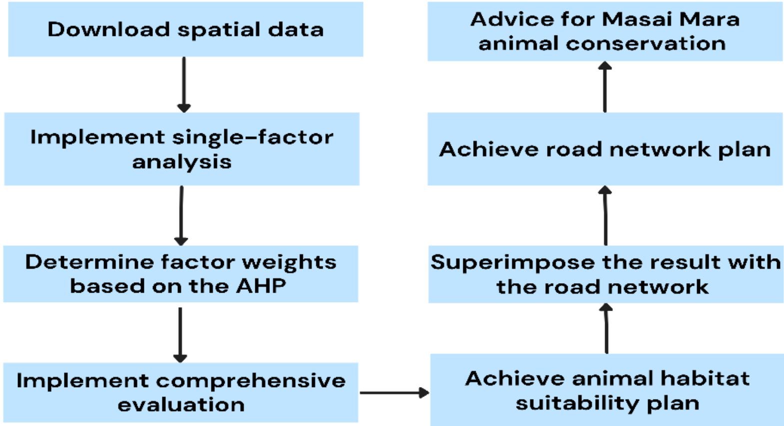

Figure 1. Research process summary

2. Model Preparation

This paper aims to build a geospatial model, and through extensive searches we collected geospatial data on the Maasai Mara Reserve, and in order to predict the development of the Maasai Mara Reserve, we also collected the total number of animals, the number of people and the economy of the Maasai Mara region.

Table 1. Data collection

Database names	Database websites	Data type
OpenStreetMap	https://www.openstreetmap.org/#map=5/54.910/-3.432	Geography
Landsat	https://landsat.gsfc.nasa.gov/	Geography
Kenya wildlife service	http://www.kws.go.ke/	Government
Google scholar	https://scholar.google.com/	Academic

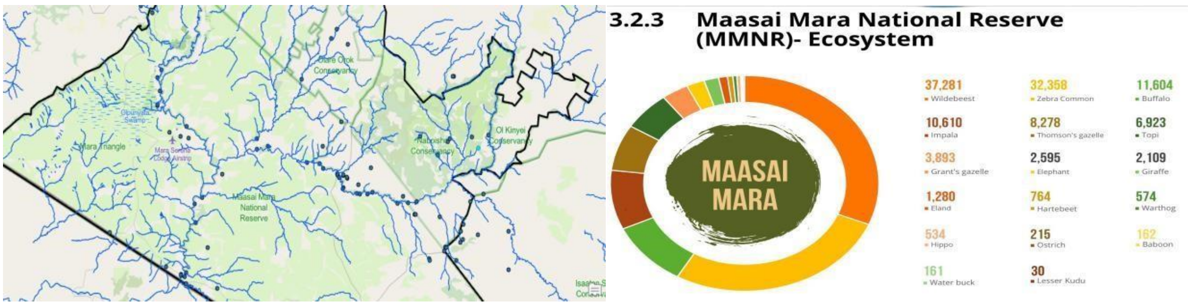

Figure 2. Data screening

3. Animal Habitat Suitability Analysis

3.1. Single Factor Analysis

In order to conduct an accurate animal habitat suitability analysis, this paper screened five key influencing factors for the single factor analysis in the context of the natural and social environment of the Masai Mara region of Kenya [8], namely vegetation, water, infrastructure and residential area, livestock and agriculture, tourism.

3.1.1 Vegetation Factor

This paper takes vegetation as one of the critical indicators and collects vegetation coverage data for our target area. Moreover, this paper performs a feature-to-raster process on the vegetation vectors, including rating quantification of areas covered by vegetation. Assign a numerical grade between 1 and 5 to the vegetation, while 1 and 5 indicate the no-vegetation and vegetation areas, respectively. It is converted by using the element to grid, and the size of the grid value is 30m*30m. The result is shown in Fig.3. The orange areas represent areas with a low score, and the white areas represent high-score areas.

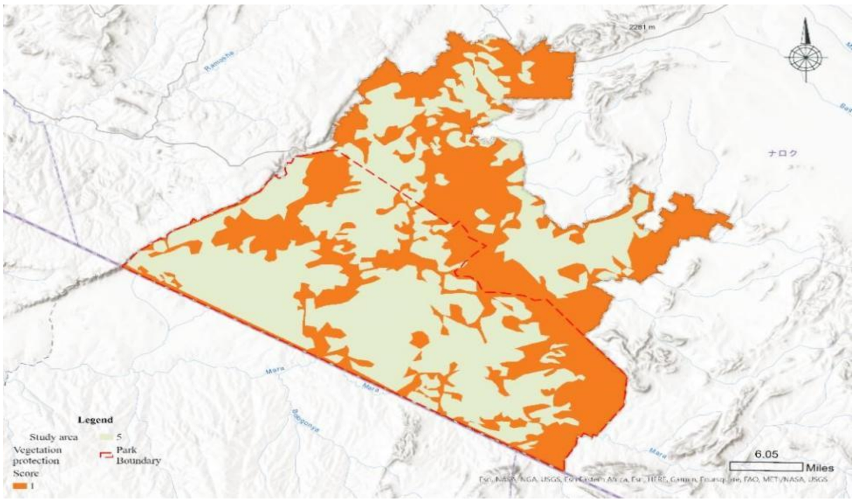

Figure 3. Vegetation factor analysis result

3.1.2 Water Factor

This paper utilizes water system data obtained from OpenStreetMap as the main dataset for conducting multiple ring buffers analysis. The aim is to assess each area individually, assigning higher scores to those closer to the river and lower scores to those farther away. To achieve this, a feature-to-raster approach is applied, resulting in raster values ranging from 1 to 5. The corresponding visualization of the findings can be observed in Fig.4, where the green areas depict regions in proximity to the water source.

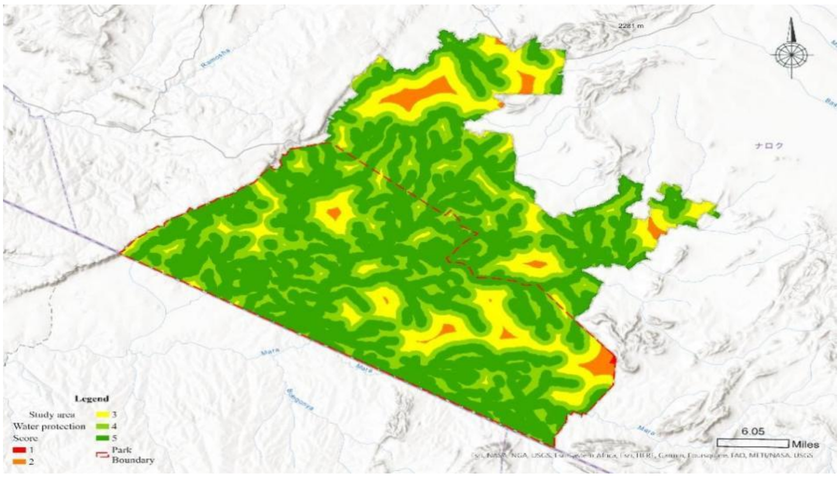

Figure 4. Water factor analysis result

3.1.3 Infrastructure and Residential Area Factor

This paper examines the relevant point-of-interest (POI) data obtained from OpenStreetMap, categorizing them into infrastructure and residential factors. Multiple ring buffers are then analyzed based on this data. Each area is scored individually, with higher scores assigned to regions located farther away from infrastructure and residential areas, while lower scores are assigned to those in closer proximity. To visualize the results, the feature-to-raster method is employed, producing raster values ranging from 1 to 5. The outcome is depicted in Fig.5, with the green areas representing regions situated at a considerable distance from infrastructure and residential areas.

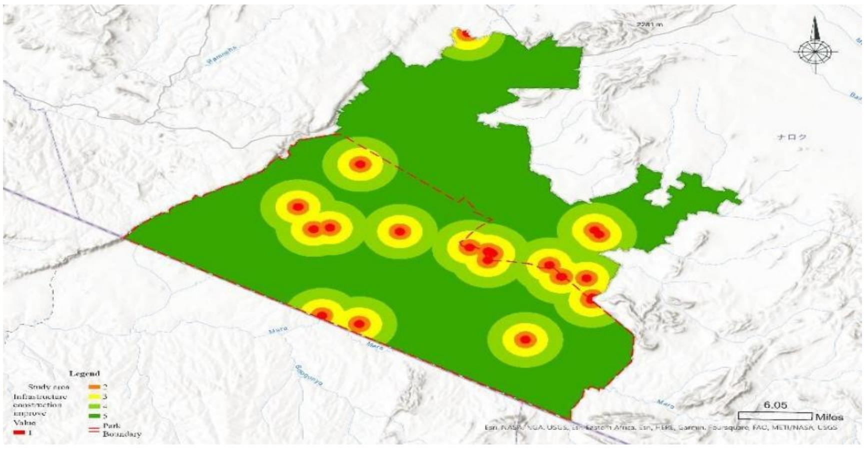

Figure 5. Infrastructure and residential area factor analysis result

3.1.4 Livestock and Agriculture Factor

The single-factor analysis conducted for the livestock and agriculture factor aligns with the previous factor analysis. Each area is scored individually, with higher scores assigned to regions located farther away from livestock and agriculture areas. The outcome of this analysis is visualized in Fig.6, where the green areas indicate regions that are situated at a significant distance from livestock and agriculture areas.

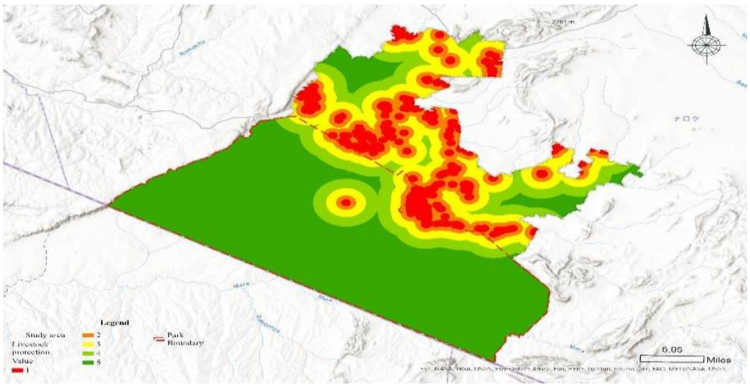

Figure 6. Livestock and agriculture analysis result

3.1.5 Tourism Factor

This paper categorizes the relevant poi data as a tourism factor from the OpenStreetMap and conducts the same analysis as the preceding. To score each area separately, the farther to the tourism area, the higher the score. The result is shown in Fig.7. The green areas represent the areas far from the tourists.

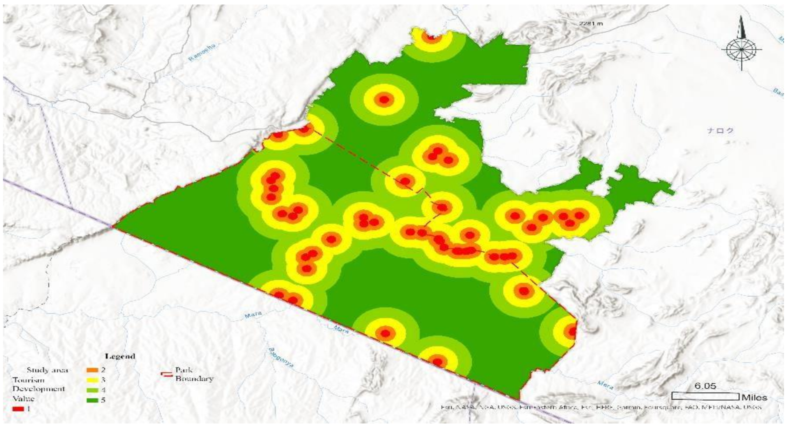

Figure 7. Tourism factor analysis result

3.2. Analytic Hierarchy Process Model

Since multiple factors are involved, the AHP is used as a multi-criteria decision-making method [9]. As required by the AHP, the prioritization problem has been hierarchically decomposed into three levels. The top layer is the target layer M, the middle layer is the criterion layer C, and the lowest layer is the scenario layer P. The hierarchy diagram is shown in Fig.8.

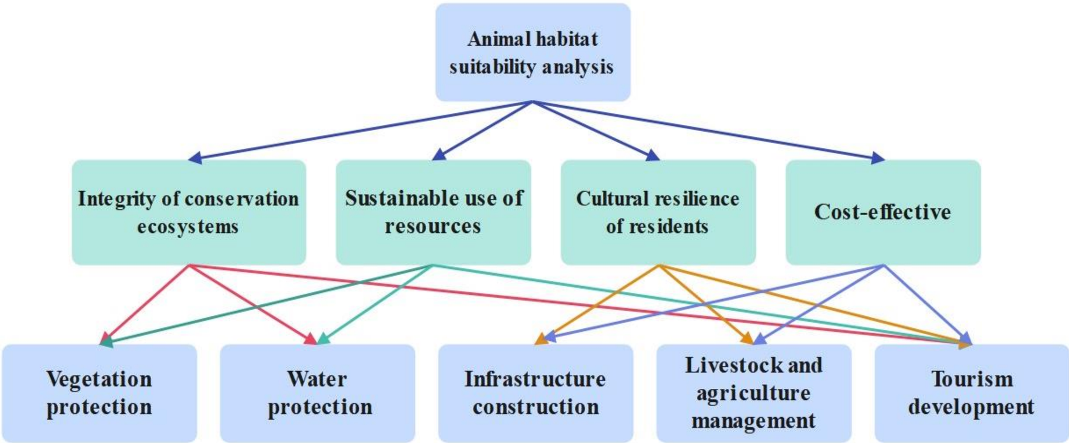

Figure 8. Hierarchy diagram of AHP model

Construct the judgment matrix M-C: compare the four C1, C2, C3, and C4 in the reference layer C. The result is shown in Table.2.

Table 2. M-C judgement matrix

M	C_1	C_2	C_3	C_4	Weight
C_1	1	3	1	5	0.4170
C_2	1/3	1	1/2	2	0.1602
C_3	1	2	1	3	0.3324
C_4	1/5	1/2	1/3	1	0.0904

Establish the judgement matrixes of layer C and corresponding layer P, solving the eigenvectors of the judgement matrixes to obtain the weights. Therefore, the results can be written as:

$$W_{M\text{-}C} = [0.4170\ 0.1602\ 0.3324\ 0.0904]^T \quad (1)$$

$$W_{C1\text{-}P} = [0.4000\ 0.4000\ 0.2000]^T \quad (2)$$

$$W_{C2\text{-}P} = [0.4286\ 0.4286\ 0.1429]^T \quad (3)$$

$$W_{C3\text{-}P} = [0.3874\ 0.1692\ 0.4434]^T \quad (4)$$

$$W_{C4\text{-}P} = [0.2385\ 0.1365\ 0.6250]^T \quad (5)$$

To test the consistency of judgement matrixes, we calculate the Consistency Index (CI) and Consistency Ratio (CR) according to the formula $CI = \frac{\lambda_{max} - 1}{n - 1}$ and formula $CR = \frac{CI}{RI}$, where the correspondence between n and RI is shown in Table 7. Through calcu-lating CR, the consistency values of judgment matrixes are acceptable.

Table 3. N-RI relationship

N	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41

Combining the weights of layer C and layer P, the final weights of scenario layer P are calculated; the result is shown in Fig.9.

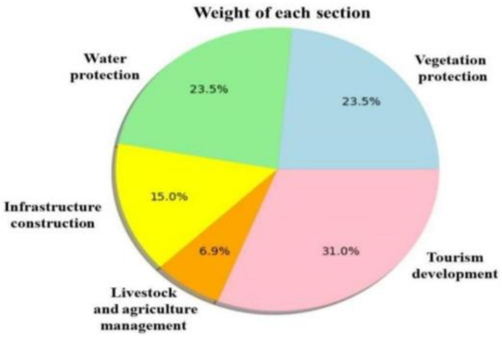

Figure 9. Final weight of AHP model

3.3. Animal habitat suitability analysis

The comprehensive evaluation can be calculated by the normalization formula due to the AHP model [10]. Therefore, the land use suitability analysis (LUSA), which is the target layer, can be written as:

$$\mathrm{LUSA} = \omega_1 \cdot \mathrm{VP} + \omega_2 \cdot \mathrm{WP} + \omega_3 \cdot \mathrm{IC} + \omega_4 \cdot \mathrm{LAM} + \omega_5 \cdot \mathrm{TD} \tag{6}$$

Where $\omega_i = [0.2355\ 0.2355\ 0.1503\ 0.0686\ 0.3102]$, represents the final weights of scenario layer P.

In order to obtain the animal habitat suitability result, executing LUSA expression in ArcGIS software. The visualization picture is shown in Fig.10.

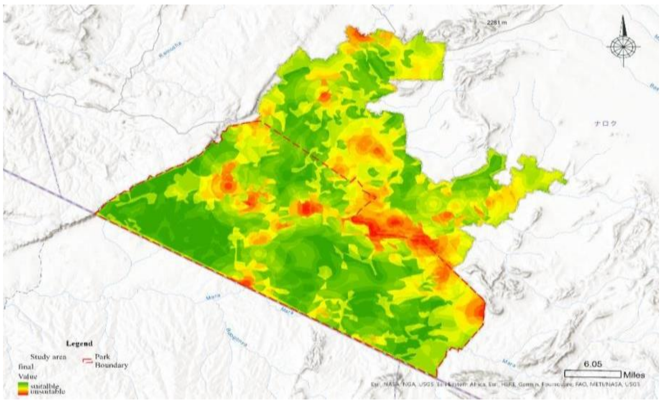

Figure 10. Animal habitat land use suitability result

Areas with greener colors are suitable for animal habitats. According to the generated comprehensive evaluation map, this paper selected the area with a score of more than 80% as the threshold to extract the animal habitat of Maasai Mara, and the result is depicted in Fig.11.

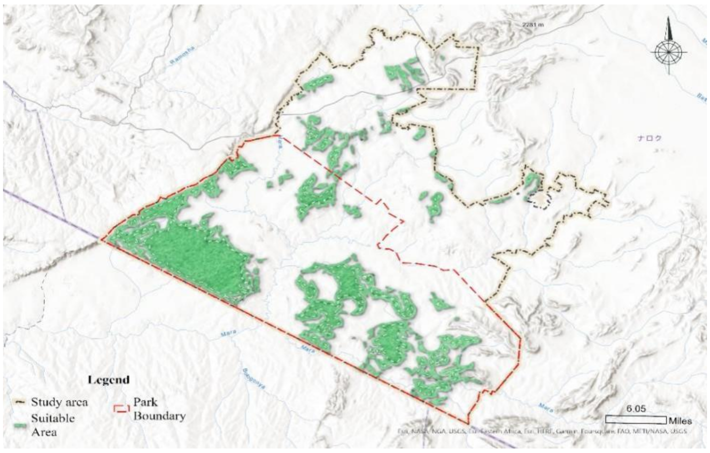

Figure 11. Animal habitat areas in Maasai Mara

From Fig.11, It is clear that the suitable habitat areas of wild animals are mainly concentrated in the east and west corners of the Masai Mara conservation, evenly distributed in the southeast corner, and a small amount in the north side. Affected by human activities, the habitats of wild animals are mainly concentrated in the southern part of the Masai Mara. According to the analysis results, we recommend the following specific future development directions [11]:

- Manage the scope of human activities and relocate areas of human construction that are not necessarily located in the park outside the park. Meanwhile, set up animal monitoring stations and rescue stations in the park.
- Implement inter-community collaboration to strengthen the protection of wildlife habitats outside the park and prevent poaching or damage to the environment as much as possible.
- Intensify efforts to construct infrastructure, aiming at reducing pollution caused by human waste, including plastic bags, leaking camera batteries, metal scraps, and other hazardous items.

3.4. Planning and Analysis of Human Social Activities

To integrate human infrastructure construction, livestock, and tourism development, according to the suitability distribution map generated in section 3.3, this paper superimposes the road network extracted from the OpenStreetMap to set down the planning and construction of the conservation road network for the next 10-30 years. The road network can limit human activities to a certain extent, thereby improving the living environment of wild animals. Therefore, roads that coincide with the habitats of animals are the direction that needs to be improved in the next few decades. This paper superimposes the road network and the animal habitats to produce a visual analysis diagram detailed in Fig.12.

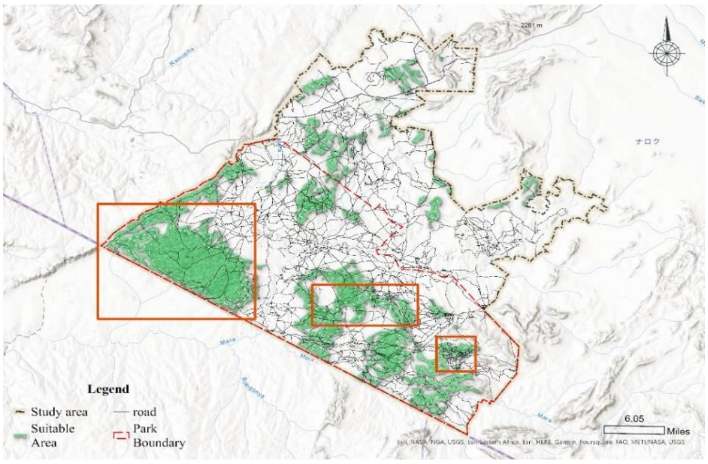

Figure 12. Comprehensive analysis results of road network and habitat

As shown in Fig.12, it is obvious that the suitable animal habitats areas inferred from the section 3.3 still have a large number of road networks. This paper believes that the road networks distributed in suitable habitats areas will affect the lives of wild animals to varying degrees. Subsequently, we recommend a specific policy as follows:

Recultivate part of the road networks that coincides with the suitable animal habitats, consequently reducing the density of the road networks.

4. Conclusion

This paper presents a comprehensive approach to assess the viability of the Masai Mara region for supporting animal habitats. The proposed method encompasses the following key aspects:

Firstly, employing ArcGIS software, a single-factor analysis is conducted to evaluate the suitability of different areas based on five major natural and social factors influencing animal distribution. Secondly, the Analytic Hierarchy Process (AHP) is applied to assign appropriate weights to these factors. By superimposing the weighted factors, the final suitability scores for animal habitats are derived. Lastly, utilizing ArcGIS software, a detailed analysis is performed to identify the most suitable areas for animal habitats within the Masai Mara. This paper makes significant contributions in two primary ways. To begin with, it identifies the optimal range for animal habitats in the Masai Mara region, highlighting the eastern and western corners of the Masai Mara reserve as the primary concentration areas, while also emphasizing the southeastern corner and a smaller portion in the northern side. Consequently, this paper suggests that the government should develop policies to protect wildlife in these areas. Furthermore, this paper includes an extraction and analysis of the road network within the Masai Mara region. Based on the findings, specific maps are presented, along with recommendations for road planning in the area. These insights aim to support sustainable development while minimizing potential disruptions to animal habitats.

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