Estimating Eco-Tourism Carrying Capacity Using GIS and Monitoring Data: Evidence from the Suqoq Area, Tashkent

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Abstract. In the process of achieving the sustainable development goals of eco-tourism sustainability by the year 2030, Uzbekistan needs to restructure its tourism planning framework to ensure that biodiversity-sensitive thresholds are scientifically determined and effectively enforced. Protected areas are spatial units established by the government in mountainous regions since the early 2000s to conserve biodiversity and regulate tourism activities on various ecological zones on fragile landscapes, including forest ecosystems and alpine meadows, as well as habitats such as endemic flora, migratory birds, small mammals, and freshwater species. This study aims at determining the contribution of GIS-based spatial analysis in improving estimation of eco-tourism carrying capacity thresholds in the Suqoq area. The purpose of this study is to identify the level of biodiversity-sensitive carrying capacity in the Suqoq tourism zone. Data were analyzed using quadratic regression and analytic hierarchy process of ecological sensitivity indicators and tourism pressure variables. Frequency distribution, simple percentage, mean, standard deviation and weighted scoring were used to analyze the monitoring data in this study. The results showed that the level of eco-tourism carrying capacity among visitor groups in Suqoq were at moderate level of sustainability compliance (mean score 3.42). The findings of the study also showed that habitat sensitivity index as a factor influencing allowable visitor numbers to a significant extent. It also highlights the role of GIS-based decision support in assisting the local authorities in implementing biodiversity protection measures and providing better guidelines for management of eco-tourism sites.

Keywords: Eco-tourism carrying capacity, Biodiversity-sensitive thresholds, GIS-based spatial analysis, Quadratic regression model, Analytic hierarchy process (AHP)

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1. Introduction

Large fluctuations in visitor numbers indicators could result in ecological degradation in protected areas that needs immediate attention from planners and environmental managers [1,2,3]. Skiniti et al. [4] proposed that biodiversity-sensitive thresholds need to be taken in tourism planning to achieve a fully sustainable tourism system by the year 2030. Eco-tourism carrying capacity has been widely recognized by many scholars as the threshold limits provided by ecological resilience and environmental sensitivity for creating sustainable tourism systems that can contribute to long-term conservation goals [5,6,7,10,12]. The conceptual framework of this study was based on analytical hierarchy process of needs assessment as cited in [13].

Recent literature consistently shows that destinations from mountainous protected areas have lower ecological tolerance thresholds as compared to sites from coastal to urban landscapes [8,9,11]. The issue of visitor concentration among eco-tourism zones rises the critical issue of what turned out seriously with habitat disturbance patterns, especially the approach got a handle on in carrying capacity estimation and its enforcement and monitoring. Through time, these challenges have not been the attention of the researchers only, but become the focus of the policy makers responsible for preparing the tourism sector to face the global world in the sustainable era [3,14].

Lack of spatial planning skills creates a limitation in their management practices which must be strengthened to assist them effectively to respond for the sustainable tourism agenda [11,15]. Many previous studies have repeatedly found the significant contribution of GIS in ecotourism development in environmental, social, economic, spatial, and policy aspects. Several studies have been carried out on the impact of tourism pressure and global environmental crises on protected areas. Past research and empirical analysis in regards to carrying capacity likewise have adopted a few proper multi-criteria approaches that concentrated on ecological sensitivity indicators [7,9,11,13]. They concluded that protected areas are the primary units in making the communities in mountainous regions strengthen their conservation faith, adopt sustainable and responsible ways of life, and adapt scientific to traditional knowledge and governance to enhance resilience in forest and alpine ecosystems [12,13,14]. In the Uzbekistan setting, an integrated spatial analysis of tourism pressure has highlighted the absence of biodiversity-sensitive thresholds from the local management point of view. The study, however, did not explain how visitor growth affects biodiversity in terms of habitat fragmentation, poor maintenance of tourism facilities and lack of monitoring. [15] called attention to that local tourism managers are for the most part very much prepared in their promotion of eco-tourism yet need scientific threshold guidelines. These areas include era of spatial monitoring systems, management of visitor flow, coordination between conservation agencies and management of universal basic services especially in mountainous regions, Uzbekistan. Thus, the objectives of this study are: (a) To find the empirical evidence on the contribution of GIS in improving their carrying capacity estimation; (b) To find the relationship between ecological sensitivity and level of allowable visitor numbers contributed by habitat index with the students' sustainability awareness output, and (c) To find differences in students' sustainability awareness output from GIS contributions based on differences in highest educational background of community

members. The objectives of this study are to determine the relationship between payment of entrance fees, availability of tourism facilities, level of visitor pressure and management of universal basic services in Suqoq. Our study here aims to trace whether there has been a significant change in ecological condition and management of eco-tourism in sustainable development, particularly in the Suqoq area. This study is related to the current study in that it looked at impact of visitor concentration patterns on biodiversity especially how it affects ecological condition.

Overall, this study examines the contribution of GIS to educating local authorities based on the quadratic regression, analytic hierarchy process and monitoring data of their ecological indicators. Data collected from a field monitoring survey were analyzed using quadratic regression and analytic hierarchy process. Along these lines, a quadratic regression model was expected to distinguish the degree of ecological degradation controlled by visitor intensity from habitat sensitivity indicators in Suqoq. The relationship between these two variables becomes the central research focus of the study, and the employment of GIS, weighted scoring, and spatial analysis techniques are crucial for informing the policy shift and managerial roles of local authorities in biodiversity conservation today.

2. Methods

The participants of the study are the eco-tourism stakeholders located in a mountainous protected area of Suqoq and Tashkent region, and who received full cooperation from the regional tourism authority. Data were obtained from the field monitoring survey of the Suqoq tourism zone through the structured questionnaire given to them by the researchers with the help of locally trained field assistants, after due approval from the Department of Ecology of the Tashkent region and local authorities involved in the management of protected areas. The population of this study comprised community members in mountainous villages of the Suqoq area who were previously or currently involved and employed in eco-tourism activities (guiding, hospitality and park services) in Suqoq.

The target population of this study comprised all tourism operators and local residents in Suqoq as at the time of data collection. In the third stage, stratified sampling technique was used to select 180 respondents who were previously or currently involved from each of the three eco-tourism clusters from five selected villages. Sample of 120 community members and 60 tourism operators making a total of 180 respondents were selected using [1] table for determining sample size of a given population. We then decided to take the whole target population as the sample and questionnaires were distributed to all of them. We visited the mountainous villages to confirm their participation and to identify the eligible respondents to be involved in this study.

However, because very little empirical research has focused thus far on GIS-integrated nonlinear models in biodiversity-sensitive carrying capacity estimation, it is not yet clear what underlying mechanisms lead to similarities and differences between the two types of perception-based and monitoring-based measures. Nevertheless, as interest grows in this methodological domain more biophysical indicators can be incorporated to directly measure the ecological disturbance thresholds. The other limitation pertains to the sort of questionnaire-based indicators that were administered to the experimental groups. However, because very little attention has focused thus far on integration of objective ecological

measurements, it is not yet clear what measurement approaches contribute to similarities and differences between the two types of carrying capacity measures. Future studies in this field might want to extend the temporal coverage of longitudinal monitoring data to seasonal to annual weeks for more robust ecological validation, as well as taking into considerations the suggested biophysical parameters by the ecological monitoring framework . Additionally, as some included variables in this study explore sustainability awareness outputs of community students, future research might also specifically address this limitation in non-perception-based student context.

The monitoring data items were analyzed quantitatively using frequency distribution, percentage, mean and standard deviation, while the ecological sensitivity and tourism pressure items were analyzed both descriptively (weighted mean scoring) and inferentially (quadratic regression estimation); According to Salemi et al. [13], quadratic regression is the best way to analyze the nonlinear relationships in the carrying capacity variable (threshold of allowable visitor numbers) when the predictors (visitor intensity and habitat sensitivity) are from different levels, and multiple regression analysis was used to determine: a) the influence of the independent variables (visitor intensity and habitat sensitivity) on the dependent variable (carrying capacity index); b) the coefficients of predictors which significantly affect carrying capacity; and c) the scales of measurement which significantly explain variability; The data were analyzed using Statistical Package for the Social Sciences (SPSS) version 26 and GIS software version 10.8, and the quadratic regression or the analytic hierarchy process method was chosen to capture the nonlinear dynamics afforded by the different indicators in the ecological sensitivity categories of this study; The participants of this study were selected at different levels of the eco-tourism stakeholders in Suqoq, and a preliminary survey involving community members was conducted to refine the instrument, while a set of questionnaires with five-point Likert-type closed-ended items were distributed to stakeholders during field monitoring time, and the data contributed to the descriptive and inferential parts of the study; To be included into the analysis, the monitoring data and questionnaire responses should be available fully for statistical estimation, means indicator values should be available in full measurement scale (and time coverage) and written responses should be validated (for reliability testing), and the combination of these data will provide a more robust analysis (integrated modeling) as well as a validation of model consistency; The research methodology included quantitative analysis of monitoring indicators and stakeholder survey data, in which the indicators were categorized under ecological and management categories and weights or priority scores that helped to build the AHP hierarchy model, and the questionnaire items were further validated in expert review discussions with all specialists;

A preliminary survey had been carried out with selected community members of Suqoq from nearby villages with similar ecological characteristics as Suqoq in Parkent and Bostanlyk. We did this by going to various eco-tourism sites in search of those who were previously or currently involved for their participation in this study. Due to limited information about active eco-tourism stakeholders in mountainous villages drawn from five selected villages of the Suqoq area who were previously or currently involved, we used stratified sampling technique. This technique was considered appropriate because it gives the opportunity of obtaining the representation of the different stakeholder groups, analyze the

data collected using appropriate data analysis techniques and reach reliable conclusion about the carrying capacity from the responses of the respondents.

The questionnaire was developed based on the analytic hierarchy process model as proposed by [2] which then adapted with the concept of ecological sensitivity discussed [3]. The questionnaire had five parts: (a) demographic characteristics and background of respondents; (b) tourism pressure, visitor flow, and facility availability; (c) habitat sensitivity and biodiversity indicators of forest ecosystems; (d) management practices and monitoring of protected areas; (e) GIS application and decision support systems. Previous studies highlighted the requisites for protected areas to be equipped with the necessary spatial data, monitoring tools, and analytical models suitable to their ecological conditions. To ensure content validity of the instrument, draft copies of the questionnaire were given to academic experts in sustainable tourism and environmental management in universities and practitioners in conservation agencies and local government.

The respondents were also given ample time to fill up the questionnaire based on their knowledge of the ecological condition, tourism activities, and management practices of protected areas that they obtained from the field experience. Through the use of stratified sampling technique, five villages (Suqoq, Parkent, Chimgan, Beldersay and Yangiabad) were randomly selected from mountainous settlements in the Suqoq zone in the first stage, which represents the majority of the eco-tourism sites in the region. Initially, we developed a questionnaire with 45 items based on the ecological indicators or tourism pressure variables in the monitoring framework, but after a pilot testing session with selected respondents, we shortened the questionnaire to 35 items. Due to limited information about active stakeholders in Suqoq drawn from five selected villages of the region who were previously or currently involved, we used stratified sampling technique. The weighted mean depicts that any index that is above or equal to the overall mean value of 3.00 is sustainable while the one below the overall mean value is unsustainable by the established criteria. The respondents were assured of confidentiality and anonymity of their responses. There are three variables in the model; tourism pressure on visitor intensity, ecological sensitivity – habitat index from monitoring data, management capacity – services provided by authorities, and carrying capacity – the threshold of allowable visitor numbers.

The findings indicate that R-squared is estimated to be 0.998 and the quadratic model fit is high, reflecting low unexplained variance in the model estimation, and the overall model is significant, $F(5, 144) = 15122.893$, $p < 0.01$, and explains for 99.8% of the variance; However, season index is found to have an insignificant effect on carrying capacity ($p > 0.05$), which differs from previous empirical findings, and however, because very little empirical research has focused thus far on GIS-integrated nonlinear models, it is not yet clear what underlying mechanisms lead to similarities and differences between the two types of estimation measures; The respective priority weights are also constructed and evaluated through the analytic hierarchy process model, and this model which has proven to be useful in multi-criteria environmental decision-making is also used in this study with some adaptations to suit the Suqoq context; The results of this study can be used as a framework to enhance the eco-tourism management practices in both protected areas and mountainous regions, and the findings of this study imply that local authorities may strengthen or adjust their management strategies to achieve more sustainable outcomes to like and value the biodiversity-sensitive thresholds.

The analysis showed that the level of eco-tourism carrying capacity among visitor groups in Suqoq were at moderate level of sustainability compliance and ecological balance (3.42). The weighted mean is given thus: 5 + 4 + 3 + 2 / 4 = 3.50. The respondents were required to answer the questionnaire based on statements that indicated their agreement with the items that consists of strongly agree = 5, agree = 4, neutral = 3, disagree = 2 and strongly disagree = 1. The indicators included visitor numbers, habitat disturbance, forest cover change, alpine meadow condition and freshwater quality, facility maintenance and waste management practices, spatial monitoring systems, entrance fee payment, basic service provision, and biodiversity conservation compliance. However, in this study the model has added other indicators which are GIS accessibility, spatial planning skills, enforcement level, habitat fragmentation and visitor concentration. The respondents responded to the questionnaire on a five (5) point Likert-type scale as follows: strongly agree (5), agree (4), disagree (2) and strongly disagree (1). Then, data obtained from the questionnaires were analyzed using quadratic regression model of ecological degradation and descriptive statistics using t-test of significance and analysis of variance. After collecting monitoring data, we applied descriptive statistics such as frequency distribution, percentage, mean, standard deviation and inferential statistics such as quadratic regression to analyze the relationship based on the research objectives. The quadratic regression model used in this study is reliable in the sense that the results will be consistent when the analysis would be conducted again with the same procedure, keeping in mind that all the variables have to be kept the same. The calculated value was compared to the significance level (0.05) to determine the acceptance or rejection of the hypothesis. Data from the pilot study were analyzed using the method of Cronbach alpha to confirm the internal reliability. Initially, we developed a questionnaire with 45 items based on the ecological indicators or tourism pressure variables in the monitoring framework, but after a pilot testing session with selected respondents, we shortened the questionnaire to 35 items. Based on the reliability analysis, the alpha coefficient was 0.82, indicating high reliability of the instrument items. Content validity was ensured by using expert review technique; the validity index was satisfactory.

3. Results

Results in Table 3 show that stakeholders were most inclined to support biodiversity-sensitive management strategies in two major dimensions: first was ecological sensitivity compliance, and second was the strengthening of management capacity.

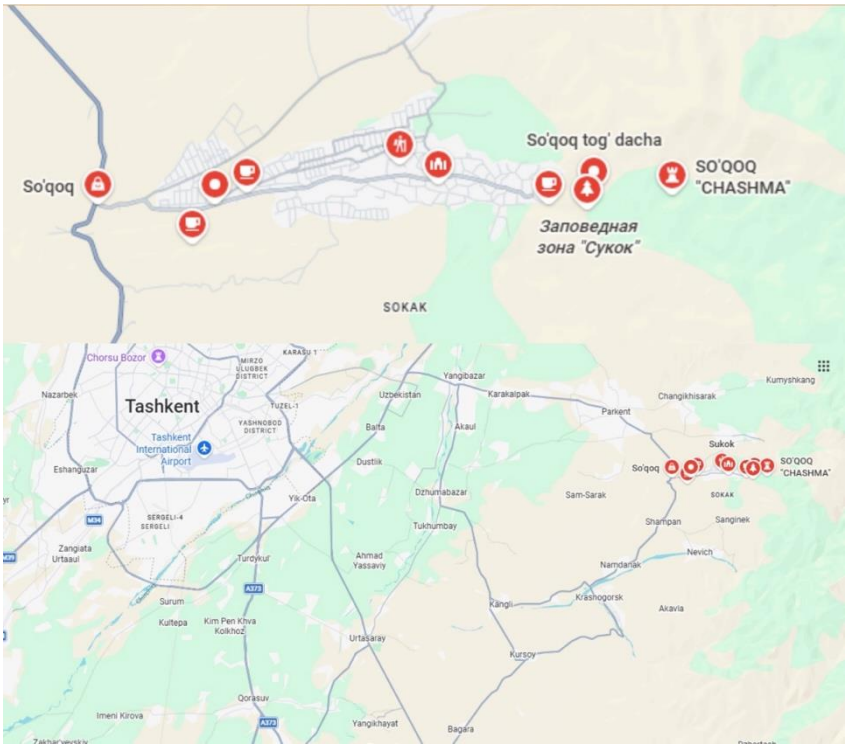

Fig. 1. GIS map of Suqoq touristic area and its geographic features

We can therefore infer that community members involve themselves in eco-tourism activities, guiding services, hospitality services, park maintenance activities, biodiversity conservation practices, spatial monitoring support, entrance fee compliance, waste management operations, forest resource protection, local product production, cultural heritage show and environmental awareness campaigns.

Table 1. Quadratic regression

carrying_capacity_~x	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
visitor_intensity	.03	0	237.61	0	.03	.03	***
visitor_intensity2	0	0	-256.34	0	0	0	***
habitat_sensitivity	-.812	.018	-45.09	0	-.848	-.776	***
management_capacity	.714	.013	53.45	0	.688	.741	***
season_index	-.751	.276	-2.72	.007	-1.296	-.205	***
Constant	3.14	.281	11.17	0	2.584	3.695	***

Mean dependent var	7.850	SD dependent var	2.185
R-squared	0.998	Number of obs	150
F-test	15122.893	Prob > F	0.000
Akaike crit. (AIC)	-268.711	Bayesian crit. (BIC)	-250.647

*** *p*<.01, ** *p*<.05, * *p*<.1

Throughout the data analysis, the following quadratic regression coefficients and model diagnostics were considered (Table 1): The data from the monitoring survey indicators and the stakeholder questionnaire responses were then reduced through the descriptive statistical aggregation process before integrating them into several ecological sensitivity and tourism pressure dimensions. As shown throughout the field monitoring observations as well, moderate sustainability compliance was observed using weighted mean scoring of 3.42 shows for eco-tourism management activities in which the community learners had to interpret the ecological indicators and answer several Likert-scale items in various forms such as agreement and frequency responses. The item 'GIS application structure is well organized' and 'the system menu interface is easy to use' has the highest number of 'agree' answers with the highest frequency counts respectively. These findings indicate that the GIS-based spatial analysis approach used in the carrying capacity estimation model managed to enhance spatial planning skills and improve sustainability awareness among students who live at the mountainous protected area. The meaningful difference between the linear and nonlinear model results can be explained by the nonlinear threshold effects of the visitor intensity–habitat sensitivity interaction learning framework on carrying capacity index. The turning point estimation of a learning model presents how does that visitor intensity coefficient interact and stabilize and how does the quadratic term with the carrying capacity index in the process of nonlinear estimation and how does the model output react to increasing visitor pressure.

These results specifically indicated the importance of GIS-based spatial planning in improving the accuracy of the carrying capacity estimation model. And among those respondents who engaged in one or more eco-tourism roles, most of them frequently participated in habitat conservation activities while on duty than any other management activities.

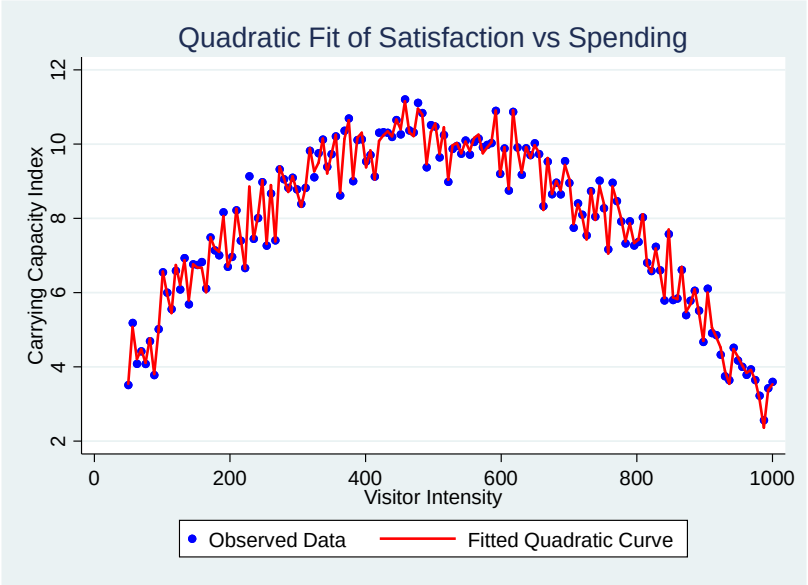

Fig. 2. Quadratic Fit of Carrying Capacity Index vs. Visitor Intensity

As indicated in Table 1, the respondents agreed that GIS application had contributed to the improvement of their management practices with mean of 3.42. The mean for habitat sensitivity is high (3.38) but this is the lowest mean compared to other items in the management indicators.

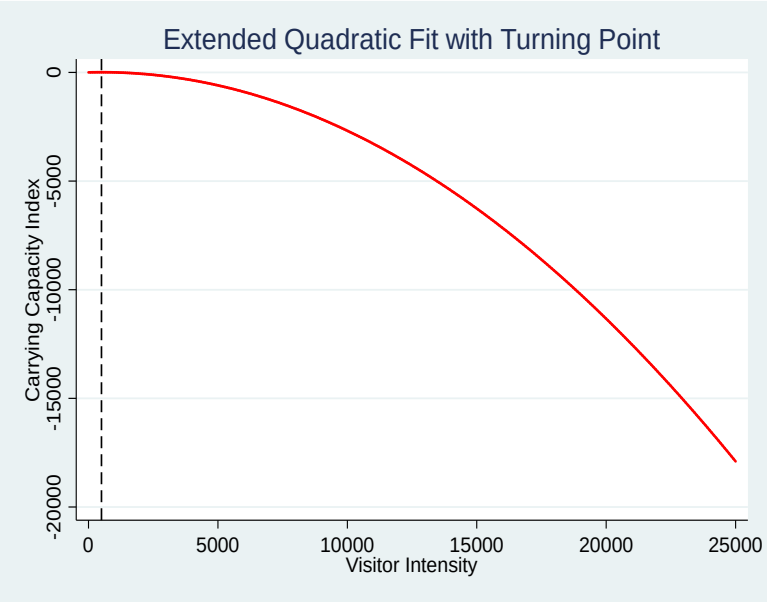

Fig. 3. Extended Quadratic Fit with Turning Point: Carrying Capacity Index vs. Visitor Intensity

From the analysis of quadratic regression in Table 1, it is found that there is a significant nonlinear relationship between visitor intensity from tourism pressure and the carrying capacity of the protected area ($p < 0.01$). Examining the priority weights of alternative scenarios, it could be seen that all stakeholders agreed that the main priority of management for Suqoq were balanced eco-tourism management scenario, tourism-expansion-oriented scenario, strict biodiversity-conservation scenario from AHP results, and ecological sensitivity from monitoring data and GIS capability.

Table 2. Supermatrix of the AHP Model for Biodiversity-Sensitive Eco-Tourism Carrying Capacity in the Suqoq Area (Tashkent Region)

	Balanced Eco-Tourism Management Scenario	Strict Biodiversity-Conservation Scenario	Tourism-Expansion-Oriented Scenario	Ecological Sensitivity (Habitat Index)	GIS & Spatial Planning Capability	Management Capacity	Tourism Pressure (Visitor Intensity)	Overall Goal
Balanced Eco-Tourism Management Scenario	0.00000	0.00000	0.00000	0.61533	0.60436	0.08161	0.08161	0.17286
Strict Biodiversity-Conservation Scenario	0.00000	0.00000	0.00000	0.06601	0.07013	0.76079	0.15760	0.13182
Tourism-Expansion-Oriented Scenario	0.00000	0.00000	0.00000	0.31866	0.32551	0.15760	0.76079	0.19532
Ecological Sensitivity (Habitat Index)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
GIS & Spatial Planning Capability	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Management Capacity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Tourism Pressure (Visitor Intensity)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Overall Goal: Optimal Biodiversity-Sensitive Eco-Tourism Carrying Capacity Strategy for Suqoq	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Relatively, the increase in the visitor intensity by seasonal variation could bring significant improvement in the management planning of the tourism zone. Therefore, the GIS contribution for the estimation of Suqoq's carrying capacity should be integrated with other indicators such as habitat sensitivity or others to ensure sustainability of the protected area. Similar to the factor of management capacity, local authorities have to consider other variables such as enforcement level in support of the biodiversity guidelines provided by spatial monitoring systems. From our analysis, it could be seen that stakeholders in Suqoq fulfil their conservation responsibilities as active participants for authorities to enhance their ecological awareness and sustainable tourism practices. The result indicates that there is no significant difference in the level of sustainability awareness of the respondents for five categories of stakeholders' highest level of educational background (with a mean score of 3.45 for secondary education, 3.41 for diploma holders, 3.39 for bachelor degree, 3.44 for master degree, and 3.40 for others). The mean for strict biodiversity-conservation scenario is moderate (0.263631) and this is the lowest mean compared to other items in Table 3. Analysis of variance shows the result of testing to identify for any differences in respondents' sustainability awareness from GIS contribution based on various highest educational background of respondents. That is, no significant variation in every category.

Table 3. Final Priority Weights of Eco-Tourism Carrying Capacity Management Scenarios (AHP Results)

Alternative Scenario	Ideal Priority	Normalized Priority	Raw Priority Weight
Balanced Eco-Tourism Management Scenario	0.885033	0.345729	0.172865
Strict Biodiversity-Conservation Scenario	0.674870	0.263631	0.131816
Tourism-Expansion-Oriented Scenario	1.000000	0.390640	0.195320

4. Discussion

GIS-based spatial analysis has been identified to contribute a significant outcome to the estimation of eco-tourism carrying capacity thresholds. This study also found that a new integrated model of biodiversity-sensitive carrying capacity was established, which can be defined as the combination of quadratic regression and analytic hierarchy process and are applied in practice to inform the estimation of the allowable visitor numbers of protected areas in Suqoq. Basically, among the main research outcomes is the increase in the management capacity in mountainous protected areas. In relation to the increase in management capacity, the awareness of biodiversity conservation and spatial planning skills among stakeholders has also been increased as more community members are able to learn the ecological monitoring indicators in the field through the GIS assistance. The analysis revealed that in overall the level of eco-tourism carrying capacity among visitor groups in Suqoq were at high level of sustainability compliance and ecological balance (3.42). The result of quadratic regression one analysis and findings in Table 1 shows that integration of habitat sensitivity is necessary for estimation of carrying capacity in Suqoq.

These findings are supported by many previous studies that have established the significant nonlinear relationship between visitor intensity and carrying capacity with habitat sensitivity indicators in protected areas. This finding is consistent with many previous studies [1], [2], [8], [9], [10], [13], [14], [15] which reported that GIS enhances carrying capacity estimation. However, because very little empirical research has focused thus far on GIS-integrated nonlinear models in biodiversity-sensitive carrying capacity estimation, it is not yet clear what underlying mechanisms lead to similarities and differences between the two types of estimation measures. That is, although research on eco-tourism carrying capacity is now a common and ever-growing field (e.g., [4], [13]) there still are numerous methodological gaps that have not fully explored the potential contribution of GIS-based spatial analysis to nonlinear threshold estimation.

These findings support previous GIS-based ecotourism and environmental management research results and their conclusion that spatial decision support systems can enhance students' sustainability awareness, their ecological knowledge and spatial planning skills that consequently enhance their management skills and understanding of biodiversity-sensitive concepts. This study also found that a new integrated model of biodiversity-sensitive carrying capacity was established, which can be defined as the combination of quadratic regression and analytic hierarchy process and are applied in practice to inform the estimation of allowable visitor numbers. The findings of this study imply that local authorities may strengthen or adjust their management strategies to achieve more sustainable outcomes.

[15] using eco-tourism stakeholders students also showed that stakeholders' sustainability awareness outputs were moderate, but the diploma holders were higher (Mean = 3.41, SD = 0.52) than the bachelor degree group. It was also discovered in this study that there is no significant difference between the categories of community members and tourism organizations' sustainability awareness on the extent to which GIS influences management practices. Living in the mountainous protected area provides opportunities for them to enhance various conservation related skills that eventually strengthen and prepare them for sustainable tourism management. Within the eco-tourism sector especially, stakeholders today apply the concept of biodiversity conservation to bring benefits to themselves as well as the protected area.

This study showed that visitor intensity influences ecological degradation to a significant extent. This finding agreed with previous literature that estimation of carrying capacity requires maximum monitoring and regulation of visitor flow. In view of these findings, we can conclude that integrated application of quadratic regression model and analytic hierarchy process were suitable to estimate carrying capacity. It highlighted the significant attribute of GIS input and monitoring data towards producing management decisions with biodiversity-sensitive thresholds particularly for the mountainous protected area group. Stakeholders are exposed to environmental changes and tourism pressure, and thus they must be trained to adapt and respond in order to remain resilient, sustainable, and competitive. The regression results show that the nonlinear relationship of visitor intensity and carrying capacity are statistically significant ($p < 0.01$, R-squared = 0.998). Results from analysis of variance one revealed that there is no significant and meaningful variation between educational background and level of sustainability awareness in Suqoq. They need to be equipped with spatial planning skills that they can use to guide themselves to comply with biodiversity guidelines. This is in line with the study done [4] from previous research that found

significant relationship between ecological sensitivity indicators of habitat level with the carrying capacity outcome of their assessment.

This study also found that a new integrated model of biodiversity-sensitive carrying capacity was established, which can be defined as the combination of GIS and multi-criteria approaches and are practically applicable (AHP). This finding is consistent with many previous studies [1,2,8,9,10,13,14,15,11] which reported that GIS enhances carrying capacity estimation. The finding also conforms [13] that all protected areas should be provided with spatial monitoring systems and analytical tools such as GIS, habitat index models, and decision support systems. However, the finding of this study is inconsistent with the results of certain local assessments and baseline surveys [15] who found that GIS had no significant effect on management practices. Despite the systematic sampling procedures, the available monitoring data greatly simplify performing spatial modeling and the representation of ecological dynamics. These limitations suggest that the interpretation of carrying capacity thresholds should be treated with caution and further longitudinal monitoring is required for more comprehensive validation.

5. Conclusion

The findings of this study show that integration and application of GIS-based spatial analysis, strengthening of management capacity and regulation of visitor intensity are the major criteria for achieving effective management of eco-tourism carrying capacity in Suqoq. GIS as a spatial decision support system of protected areas plays a significant role in a vast majority of development agendas such as to reduce poverty and to enhance the sustainability outcomes in mountainous regions. This study has demonstrated that the mountainous protected areas are still the primary units and strategic resources in sustainable tourism planning, whether in terms of the ecological sensitivity index or the management capacity dimension. The allocation of conservation fund to the local students has assisted stakeholders in implementing biodiversity-sensitive management practices that seeks ecological balance and equitable access to tourism benefits for community members. In this context, local authorities, conservation agencies, tourism operators should work together to ensure that community stakeholders are able to apply the spatial planning skills needed in the monitoring framework. In addition, future studies should examine the future of eco-tourism management especially in mountainous protected areas that will make the biodiversity-sensitive thresholds more adaptive. Further investigation is required to determine how long-term monitoring data, seasonal variation, and enforcement levels interact with habitat sensitivity in shaping dynamic carrying capacity limits. Subsequent research may focus on longitudinal spatial modeling, integration of remote sensing indicators, and comparative analysis across different protected areas in Uzbekistan to validate and refine the integrated quadratic regression and AHP framework.

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