Developing ecotourism sustainability maximization (ESM) model: a safe minimum standard for climate change mitigation in the Indian Himalayas

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Abstract Recently, ecotourism has been identified as an adaptation strategy for mitigating climate change impacts, as it can optimize carbon sequestration, biodiversity recovery, and livelihood benefits and generate new opportunities for the sustenance of the economy, environment, and society of the area endowed with natural resources and cultural values. With the growing responsibility at the global level, ecotourism resource management (ERM) becomes inevitable for its sustainable requirements. The integration of ecological and socio-economic factors is vital for ERM, as has been demonstrated by developing an Ecotourism Sustainability Maximization Model for an area under study, that is the Yuksam-Dzongri corridor (also known as Kangchendzonga Base Camp Trek), in the Khangchendzonga Biosphere Reserve (KBR), Sikkim, India. This model is based on the earlier developed ecotourism sustainability assessment (ESA) framework by the authors, which is based on the hierarchical relationship among ecotourism principles, criteria, indicators, and verifiers. Employing such relationships, this paper attempts to maximize ecotourism sustainability (ES) as a function of its sustainability principles, criteria, indicators, and verifiers, subject to the constraints identified through the safe minimum standard (SMS) approach by employing linear programming. Using 58 indicators as decision variables and 114 constraints, the model resulted in a maximum level of achievable ES with a score of 84.6%, allowing the resultant optimum values of the indicators to be maintained at the operational level. A central tenet of the model is the collective responsibility and adoption of a holistic approach involving the government, tourists, tourism enterprises, and local people.

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Introduction

Biodiversity and conservation of cultural diversity through ecotourism is a viable tool to meet the objectives of the convention on biological diversity (CBD, 1992, 2018; UNDESA, 2021; UNEP, 2002). Ecotourism as a part of sustainable tourism is firmly positioned in the UN's 17 Sustainable Development Goals (SDGs). With the potential to contribute, directly or indirectly, to all the 17 SDGs, ecotourism has been included as a target in goals #8, #12, and #14 (WTO-UNDP, 2017). Ecotourism can be a prominent factor in achieving the targets of SDG 13–Take urgent action to combat climate change and its impact due to its ability to produce new opportunities for the economy, environment, and society of the area endowed with natural and cultural resources. This has been proved in some areas where ecotourism is accepted as an adaptation strategy for mitigating the impacts of climate change on local communities, such as around the protected areas in Ghana, the Dana Biosphere Reserve, Jordan, etc. (Jamaliah & Powell, 2018; Agyeman, 2019). Ecotourism holds a 7% share of the international tourism market of 903 million tourist arrivals and tourist receipts of US$856 billion suggests a 2007 estimate by the United Nations World Tourism Organization (UNWTO). "Tourism Towards 2030," UNWTO's (2011, 2015) long-term outlook and an assessment with quantitative projections estimate that with an average annual growth until 2030, international tourist arrivals worldwide are expected to grow to 1.8 billion, indicating the likely worth of ecotourism.

Ecotourism is a major income-generating ecosystem service which adds to both biomass accumulation and biodiversity recovery to mitigate the global climate change impact. Biomass accumulation results in a net increase in standing biomass in forest areas and attracts more ecotourists (Di Sacco et al., 2020). A study by The Economics of Ecosystems and Biodiversity–TEEB (2009) initiative estimated the value of tropical forest ecosystem services to be USD 6120/ha/year, based on data from 109 studies, where recreation and tourism contributed 6.2%. Through this role, ecotourism can provide alternative sources of livelihood opportunities and support the locals to meet the challenges posed by climate change. Thus, it is extremely effective for sustainable development, yet, over the years many adverse impacts of ecotourism have been observed in the form of trail proliferation and widening, vegetation-cover loss, exposed tree roots, soil erosion, littering at recreation sites, water contamination, unsightly, and dangerous construction, the occurrence of landslides, degradation of trekking routes, climate change-induced fires, etc. (Sirakaya et al., 2001; Newsome et al., 2002; Page & Dowling, 2002; Jiang, 2009; NITI Aayog, 2018).

To conserve the environmental resources, these red signals should be continually monitored to identify any negative environmental impact and corrective measures can be taken to restore the balance (Ashok et al., 2017; Eraqi, 2007; Popova, 2003). In this regard, ecotourism needs to be made sustainable itself through the Sustainability Monitoring Methodology, so that it can take care of environmental and cultural resources and contribute to reducing greenhouse gas emissions; educating communities, tourism stakeholders, and tourists on how to prepare for and adapt to climate change and protect the environment. We have identified–BellagioSTAMP-2009, developed by the International Institute for Sustainable Development (IISD) as a guide to the Societies' initiative toward measuring the progress of sustainable development based on its eight principles for sustainability assessment and measurement (IISD, 2009). Among its eight principles, the "Framework and Indicators of Sustainability Assessment" describes that for developing a sustainability assessment procedure, the following four steps are required–(i) a conceptual framework that identifies the domains within which core indicators to assess progress are to be identified, (ii) standardized measurement methods wherever possible, in the interest of comparability, (iii) step 3–the most recent and reliable data, projections, and models to infer trends and build scenarios, and (iv) step 4–comparison of indicator values with targets, as possible (IISD, 2009; Pinter et al., 2012).

Realizing the effectiveness of the BellagioSTAMP-2009 guidelines and being cognizant of the fact that there is no scientific method for ecotourism sustainability, the authors are in the process of developing a comprehensive methodology for the assessment of ecotourism's sustainability namely, "Ecotourism Sustainability Assessment Method–ESAM" through a series of studies, namely–Stage 1, Stage 2, Stage 3, and Stage 4. As duly discussed below, the first two stages have already been developed, while work is in progress for the last two. Stage 1 gave the "conceptual

framework," i.e., the development of the ecotourism sustainability assessment (ESA) framework–a set of principles, criteria, indicators, and verifiers to guide the measurement of the progress of the ecotourism sustainability (ES) (Ashok et al., 2017). Wherein, stage 2 offered a "standardized method" mentioned as–the development of the Ecotourism Sustainability Maximization (ESM) model, to set the target for achieving the maximum level of ES, which is the main objective of this paper.

The objectives are as follows: (a) to understand the impact of the global shutdown on tourists' arrivals during COVID-19, (b) to determine the decision variables (DVs) for operationalizing the ecotourism sustainability principles at the destination level, based on the identified linear relationship among the principles, criteria, and indicators–verifiers of the already developed ESA framework, (c) to maximize the sustainability of the ecotourism destinations, despite their ecological and social constraints impeding the achievement of ecotourism sustainability, (d) to estimate the optimum value of the decision variables, i.e., ESIs for defining the use level of the resources at the ecotourism destinations, and (e) to understand the application of the optimum value of the decision variables obtained through the ESM model for the sustainability of the ecotourism destination.

The study site chosen is "Yuksam-Dzongri Corridor of West District of Sikkim Himalaya, India" with the intent to validate each step of the ESAM methodology–to obtain the necessary data on verifiable evidence, obtained through scientific data collection and periodic observation methods. The development of the ESM model is not mere empirical research, it has a strong scientific, mathematical, and theoretical base in the form of the well-established safe minimum standard approach, ecological constraints, linear equations, C&I approach, and BellagioSTAMP, etc. (Ciriacy-Wantrup, 1952; Perring, 1991; Colfer et al., 1995; Wright et al., 2002; IISD, 2009; Pinter et al., 2012).

ESM model–concepts

Ecotourism resource management (ERM)

Ecotourism resource management (ERM) aims at the efficient management of ecotourism resources. It consists of natural (geographical position, microclimatic conditions, the existence of wildlife, vegetation, natural beauty, geo-morphologic structure, etc.) and cultural resources (local people, dress, food, dance/music events, festivals, architectural heritage, etc.) which collectively attract tourists from all over the world (Boley & Green, 2016; Eraqi, 2007; Kiper, 2013). Thus, it requires limiting the use–level of ecotourism resources, which can be managed through the safe minimum standard (SMS) approach, proposed by many scholars to help achieve the goal of sustainable ecotourism development (Perring, 1991; Pigram, 1990).

Safe minimum standard approach

The term "SMS" was first coined by Ciriacy-Wantrup (1952) for the conservation of renewable resources. This approach is defined as a collective choice process that prescribes protecting a minimum level or safe standard of a renewable natural resource unless the social costs of doing so are somehow excessive or intolerably high (Berrens et al., 1998). It is a "socially determined dividing line between moral imperatives to preserve and enhance natural resource systems and the free play of resource trade-off" (Toman, 1994; Munasinghe & Shearer, 1995). The SMS is a policy that eliminates the risk of catastrophic outcomes in the management of natural resources and can be used to develop the "Ecological Sustainability Constraints." These constraints can impose direct restrictions on resources–using economic activities by deciding the level of environmental resources' use within a limit, to achieve sustainability in the field of tourism development (Perring, 1991; Pigram, 1990).

Application of ERM and SMS through the ESA framework

The concepts of ERM and SMS can be applied to an ecotourism destination through some framework to help establish a symbiotic relationship among people, natural resources or biodiversity, and tourism activities and help to make it sustainable. In this regard, the "C&I approach"–which is used as an abbreviation for the entire hierarchy of principles, criteria, indicators, and verifiers (PCIV), has been applied. This offers a structured approach toward defining the means and

objectives of achieving sustainability of ecology, economy, and society and calculating the progress of sustainability at the destination level (Colfer et al., 1995; Wright et al., 2002). Here, the ESA framework can help implement the above goals, as it has been developed using the C&I approach, as discussed below.

Structure of the ESA framework

The ESA framework has been developed using the C&I (PCIV) approach, which provides the theoretical basis for the development of the present ESM model. It states that ES depends upon its four fundamental principles–Sp_I to Sp_{IV}. These ecotourism sustainability principles are dependent on 8 ecotourism sustainability criteria–C_1 to C_8, which further have a dependence upon 58 ecotourism sustainability indicators (ESIs)–X_{11} to X_{58} and their corresponding 58–verifies. The 58–verifiers can provide the status of their corresponding ESIs by collecting field-level information (as mentioned in Table 1) (Ashok et al., 2017; Kumari, 2008; Kumari et al., 2005). This framework can be a powerful tool for sustainable ecotourism development and management, provided it computes the optimum values of ESIs using a "Resource Optimization Model."

Resource optimization model through stakeholders' participation and application of linear programming

ERM necessitates the decision of the optimal management of environmental and socio-cultural resources to restrict their use level and guide ecotourism on the path of sustainability. Ecologically constrained optimization models have been developed by Walter and Schofield (1977) and Bertuglia et al. (1980) for the optimal management of wilderness recreation resources. However, these optimization models have not used any serious moral and social discourse while deciding on the use of environmental resources within a limit, which can provide the solution to the issue of "where to stop?" in ecotourism development.

To fulfill this, the stakeholders' participation approach was adopted to define the use level of ecotourism resources in the study area, in the form of acceptable and desirable values of indicators for ES. The "acceptable

value" of indicators refers to the acceptable levels of use of resources, which are primarily a matter of judgment (scientific or societal) based on reproductive rates, habitat conditions, market demand, and so forth (Munasinghe & Shearer, 1995). While the essence of "desirable value" refers to maintaining desirable conditions over time to attain intergenerational equity, which should be reflected in the system's long To fulfill this, the stakeholders' participation approach was adopted to define the use level of ecotourism resources in the study area, in the form of acceptable and desirable values of indicators for ES. The "acceptable value" of indicators refers to the acceptable levels of use of resources, which are primarily a matter of judgment (scientific or societal) based on reproductive rates, habitat conditions, market demand, and so forth (Munasinghe & Shearer, 1995). While the essence of "desirable value" refers to maintaining desirable conditions over time to attain intergenerational equity, which should be reflected in the system's long-term stability (Prabhu et al., 1999). These location-specific inputs (which may also differ at different time intervals) can be used as lower and upper limit values of decision variables while formulating the linear equation. As linear programming can provide an optimal solution for a real-life problem with given constraints. It facilitates optimal allocation of resources by minimizing (e.g,. maybe overall cost of production, the adverse impact on environment, etc.) or maximizing (e.g., maybe level of sustainability of environment, customer satisfaction) its overall goal to find the solution to a problem. Thus, it can provide a simultaneous solution to three basic problems of the economy, i.e., (a) optimum allocation of productive resources, (b) efficient utilization of these resources, and (c) realizing a balance between the different sectors of the economy to generate maximum benefit (Bertuglia et al., 1980; Overton, 1997; Walter & Schofield, 1977). Here, this method has been applied to maximize "ecotourism-sustainability" to defining the "use level of ecotourism resources" at the optimum level under several practical constraints.

Study area description

The study area is the Yuksam-Dzongri Corridor, KBR, near the Rathong Glacier (4380 m) of the Himalayan mountain region in India (Fig. 1). The tourists data showed a rise in ecotourism over 5 times, from 1964 tourists in 1990–1991 to 10490

Table 1 Nomenclature used for the Principles, Criteria, Indicators, and Verifiers, developed under the Ecotourism Sustainability Assessment (ESA) Framework, and calculated weights and Ecotourism sustainability constraints for ESIs (DV-Decision Variable)

	Indicators	Physical meaning of indicators	Impact of indicators on ecotourism sustainability	ARW*	AAV**	ADV***	Verifiers	Physical meaning of verifiers
C_1	Criteria 1 Maintenance of ecosystem health							
	X_{11}	Sightings of wildlife and avifauna	+	22.29	22.00	40.50	V_{11}	Percent of Visitors
	X_{12}	Rate of forest regeneration	+	22.29	60.50	86.50	V_{12}	Percent of forest area
	X_{13}	Availability of fresh water (rivers, streams, lakes)	+	19.50	70.50	98.00	V_{13}	No. of rivers, streams, lakes having fresh water
	X_{14}	Presence of religious and heritage sites	+	16.93	0.57	1.08	V_{14}	No of religious and heritage sites available
	X_{15}	Unique ecosystem features (endemic species: floral and faunal)	+	26.29	81.50	96.50	V_{15}	Percentage of Ecosystem Specific Plants
	X_{16}	Presence of exotic species (floral and faunal) -	−	−12.14	9.80	4.90	V_{16}	Percent of area
	X_{17}	Growth in livestock population	−	−15.07	4.80	1.40	V_{17}	Annual growth rate
	X_{18}	Occurrence of endangered/ threatened species	−	26.29	81.50	96.50	V_{18}	Percent of area under of endangered species
	X_{19}	Use of RCC in development of tourism infrastructure	−	−13.86	15.00	5.20	V_{19}	Percent of Tourist facilities
	X_{110}	Status of civic amenities	+	22.14	76.00	98.00	V_{110}	Percentage of household
	X_{111}	Occurrence of natural hazards	−	−14.64	10.00	4.50	V_{111}	Incidence of hazard in a year
				100				
C_2	Criteria 2 Maintenance of local culture							
	X_{21}	Impact of alien culture on local community	−	−12.5	8.50	3.00	V_{21}	Level of Impact
	X_{22}	Tourists interest socio-cultural and religious activities	+	37.50	48.00	70.50	V_{22}	Percent of tourists
	X_{23}	Involvement of locals in religious-cultural activities	+	30.50	55.50	81.50	V_{23}	Level of Significance
	X_{24}	Availability of local food and handicrafts	+	34.29	63.00	86.00	V_{24}	Availability at destination
	X_{25}	Significance of traditional dresses, languages, games, and use of local construction materials	+	−10.86	41.00	16.50	V_{25}	Availability and consumption
	X_{26}	Dependence of locals on foreign materials/ product	−	36.29	64.00	91.50	V_{26}	Percent of local population

Table 1 (continued)

	Indicators	Physical meaning of indicators	Impact of indicators on ecotourism sustainability	ARW*	AAV**	ADV***	Verifiers	Physical meaning of verifiers
	X_{27}	Involvement of non-locals in tourism activities	−	−15.21	16.00	5.50	V_{27}	Percent of outsider
				100				
C_3	Criteria 3 Livelihood generation							
	X_{31}	Annual tourist inflow	−	−12.37	120.00	100.00	V_{31}	Ratio of tourist and local population
	X_{32}	Participation of locals as Ecotourism Service Providers (ESPs)	+	27.50	72.50	94.00	V_{32}	Percent of local population working as service providers
	X_{33}	Tourists availing local facilities	+	27.36	68.00	93.50	V_{33}	Percent of tourists
	X_{34}	Level of out-migration	+	20.93	11.00	6.00	V_{34}	Annual out flow of the Local People
	X_{35}	Level of institutional support to micro-enterprises	+	29.00	38.00	94.00	V_{35}	Percent of Panchayat fund
	X_{36}	Economic activities compatible to ecotourism	+	23.64	52.00	94.50	V_{36}	Level of govt. support
	X_{37}	Economic activities incompatible to ecotourism	−	−16.00	2.50	1.00	V_{37}	Degree of restriction
				100				
C_4	Criteria 4 Enabling environment and environmental awareness generation							
	X_{41}	Ecotourism policy and development regulation	+	14.79	64.00	100.00	V_{41}	Degree of effective functioning
	X_{42}	Capacity building facilities	+	13.64	67.50	93.50	V_{42}	Availability of training facilities
	X_{43}	Inter-departmental co-ordination towards ecotourism development	+	10.29	71.50	95.00	V_{43}	Level /degree of co-ordination
	X_{44}	Level of environmental awareness among officials/administrators	+	13.93	72.00	99.00	V_{44}	Level of environmental awareness
	X_{45}	Role of institutions (Panchayats/ CBOs/ NGOs/ international donor agencies) in promoting ecotourism	+	13.93	66.00	98.00	V_{45}	Level of support
	X_{46}	Nature Interpretation Centre (NIC) and visitor management facilities	+	11.14	65.50	93.50	V_{46}	level of efficiency

Table 1 (continued)

	Indicators	Physical meaning of indicators	Impact of indicators on ecotourism sustainability	ARW*	AAV**	ADV***	Verifiers	Physical meaning of verifiers
	X_{47}	Enforcement of code of conduct for tourists and service providers	+	10.07	74.50	100.00	V_{47}	Compliance by tourists and service provider (in percent)
	X_{48}	Allocation of funds for conservation of nature in Panchayat planning process	+	12.21	21.50	38.00	V_{48}	Degree of fund diversion
				100				
C_5	Criteria 5 Tourists' satisfaction							
	X_{51}	Growth rate in tourists inflow	−	-17.43	4.10	1.70	V_{51}	Percentage of increase in a year
	X_{52}	Environmental awareness among the tourists	+	23.64	71.50	97.00	V_{52}	Degree of Awareness
	X_{53}	Tourist feedback towards ecotourism support	+	21.00	70.00	96.00	V_{53}	Degree of support
	X_{54}	Tourists, response on host community	+	22.14	49.00	71.50	V_{54}	Behavior of the local people
	X_{55}	Duration of tourists' stay	+	21.43	14.5	22.90	V_{55}	Days of Tourists' stay
	X_{56}	Tourists' displeasure	−	21.00	3.00	92.00	V_{56}	Percentage of tourists register complain
	X_{57}	Tourists willingness to revisit/recommend	+	−14.21	17.40	13.80	V_{57}	Percent of tourists
	X_{58}	Overall satisfaction level of the tourists	+	22.43	31.00	53.00	V_{58}	Percentage of tourists
				100				
C_6	Criteria 6 Carrying capacity (CC)							
	X_{61}	Support facilities along prime tourist zone	+	34.36	X_{81}	10.14	V_{61}	Level of tourist facilities
	X_{62}	Existence of carrying capacity norms (CC norms)	+	34.21	X_{82}	14.00	V_{62}	Degree of implementation of CC norms
	X_{63}	Compliance of CC norms by tour operators	+	30.07	X_{83}	20.50	V_{63}	Percentage of tour Operator
	X_{64}	Compliance of CC norms by the permit authority	+	29.21	X_{84}	20.64	V_{64}	Percentage of tour Operator
	X_{65}	Crowding at destination	−	−27.86	X_{85}	17.43	V_{65}	Level of crowding
				100				
C_7	Criteria 7 People's participation							
	X_{71}	Environmental awareness among local people	+	14.14	68.00	90.50	V_{71}	Level of environmental awareness

Table 1 (continued)

	Indicators	Physical meaning of indicators	Impact of indicators on ecotourism sustainability	ARW*	AAV**	ADV***	Verifiers	Physical meaning of verifiers
	X_{72}	Use of non-conventional sources of energy by households/ service providers	+	22.00	62.50	82.00	V_{72}	Percentage of House Hold/ Tour Operator
	X_{73}	Home-stay/ paying guest facilities	+	18.00	26.00	47.00	V_{73}	Percentage of household
	X_{74}	Community stakeholders workshops for environmental awareness	+	14.00	11.90	21.20	V_{74}	Number of community stakeholder meeting, workshop in a year
	X_{75}	Community-level funds for conservation activities	+	18.14	31.00	63.00	V_{75}	Frequency of local-level funds Generation
	X_{76}	Gender participation in community development activities	+	13.71	33.00	50.00	V_{76}	Percentage of women involved in JFMc, EDC, SHG, etc
				100				
C_8	Criteria 8 Conservation management using traditional/indigenous knowledge system							
	X_{81}	Empowerment of locals in decision-making	+	10.14	58.50	82.50	V_{81}	Degree of empowerment
	X_{82}	Use of traditional knowledge at institutional level	+	14.00	56.50	77.00	V_{82}	Level of acceptance and use
	X_{83}	Documentation of indigenous knowledge	+	20.50	58.00	73.50	V_{83}	Percentage of traditional knowledge
	X_{84}	Practice of environment-friendly economic activities	+	20.64	53.00	76.00	V_{84}	Percentage of people
	X_{85}	Inheritance of indigenous knowledge by younger generation	+	17.43	69.50	87.50	V_{85}	Percentage of younger population
	X_{86}	Involvement of younger generation in conservation	+	17.29	64.50	94.00	V_{86}	Percentage of younger population
				100				

ARW average relative weight (average relative weight calculated for Indicators, obtained from the subject (Ecotourism) experts and ecotourism key stakeholders), *AAV* average acceptable value (acceptable value of indicators obtained from ecotourism key stakeholders), *ADV* average desirable value (desirable value of indicators obtained from ecotourism key stakeholders)

visitors in 2009–2010. It also showed a decline in tourist arrivals during 2011–2013 due to the earthquake in the KBR in September 2011 (Bhardwaj, 2011; HMI, 2018). Tourist arrivals further increased to 9951 during 2019 before dropping to an almost negligible level due to the COVID-19 pandemic (Fig. 2).

Methodology

Influence of COVID-19 on ecotourism

To assess the influence of COVID-19 on ecotourism at the destination and forecast the possible recovery
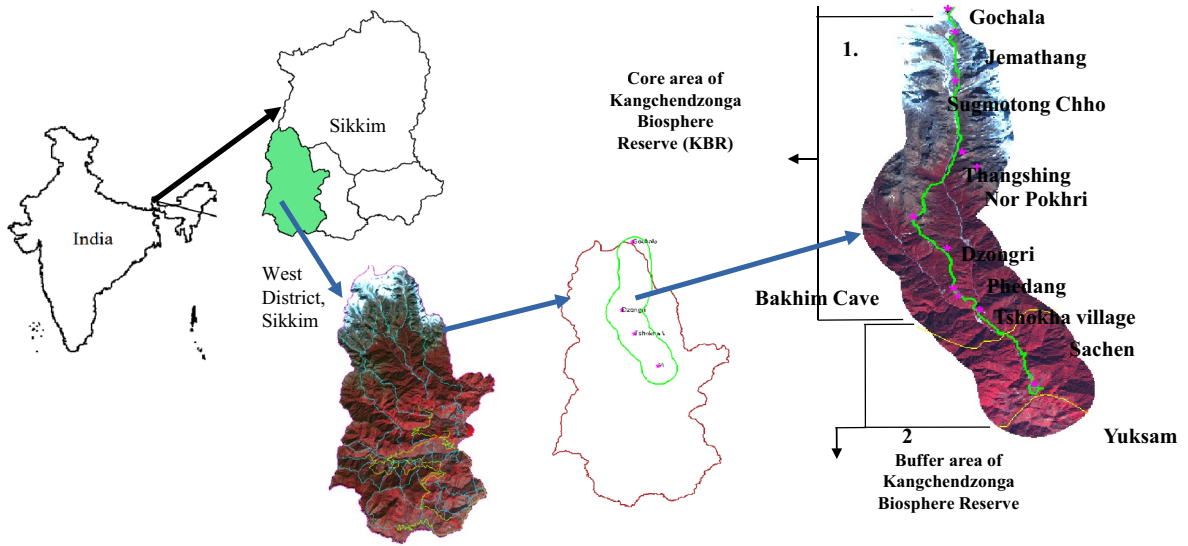
Fig. 1 Location map of the study area showing West District of Sikkim. Some points of tourist attractions along the trekking route are overlaid on satellite image of Kangchendzonga Biosphere Reserve

from the terrible situation, the trend equation using the regression method was applied to the tourists' arrival data up to 2019 and to the pandemic-impacted data of 2020. Depending on various other factors, the number of tourists is expected to rise by 2024–2026 (S1; Fig. 2). The projection was done in two stages.
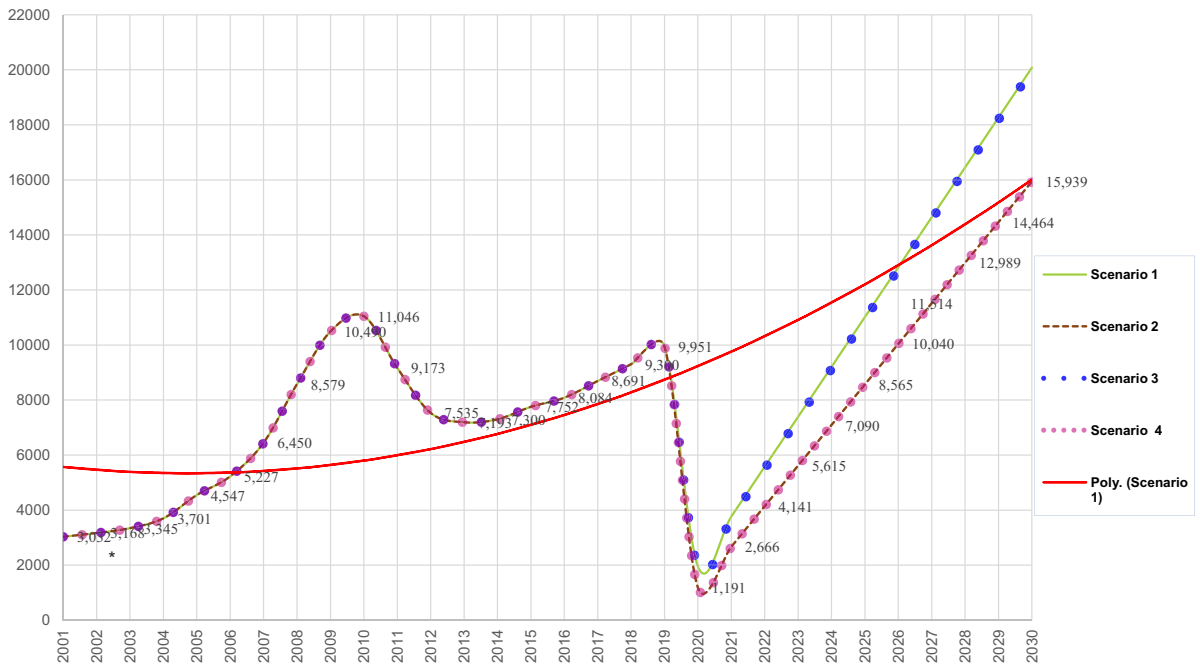
Fig. 2 Sharp decline in Tourists Arrival can be seen in 2020, coinciding with Covid-19. However, Regression based extrapolation up to 2030 predicts a fast reversal–trend and forecast after COVID-19. Data Source: 1990–2006 (Tambe et al., 2011), 2008–2019 (KNP-RO (Kangchendzonga National Park, Range Office), 2019), Yuksam, West District, Sikkim

Estimation of tourists' arrival

This stage derived inspiration from two studies: (1) a global survey by the UNWTO's panel of tourism experts on international tourist arrivals in different geographies across the globe (UNWTO, 2021), and (2) a comprehensive study conducted by the National Council of Applied Economic Research (NCAER), India upon the impact of COVID-19 on Indian household income and tourism recovery (NCAER, 2021). We devised two scenarios for the estimation of recovery of tourism using the Delphi method. It is an iterative and consensus-building approach to soliciting opinion and judgment by a group of experts on a particular topic and a much-used method in multiple studies related to tourism recovery forecasts (Zhang et al., 2021).

#1. Scenario 1–recovery "up to 2024"
#2. Scenario 2–recovery "later than 2024"

After completing the first and second rounds of the Delphi survey, 5-point scores were given by the experts for calculating the final values. The second estimation was based on a mix of the experts' viewpoints (UNWTO, 2021) followed by the experts' opinion pooling in two Delphi rounds.

Forecasting of the tourist arrival based on trend equation using regression

Based on the above estimation of tourist arrivals from 2020 to 2026, further 4 scenarios (S-1, S-2, S-3, and S-4) of forecasting tourist arrivals have been done by applying trend equation using regression analysis in IBM SPSS (statistical package for social scientists), 20.0. Scenarios S-1 and S-2 are based on estimated tourist data, and scenarios S-3 and S-4 are based on the percentage of estimated tourist data (Figs. 2; S1).

Development of the ESM model

Considering a linear relationship among the principles, criteria, and indicators, the linear programming (LP) model was applied to develop a decision-making structure to maximize the ES as a function of ecotourism principles, criteria, indicators, and corresponding verifiers. To model a linear problem, first, the decision

variables were established. Here, the DVs have been determined from the ESA framework. ecotourism sustainability (ES) depends on 58 ecotourism sustainability indicators (ESIs) and their corresponding verifiers at the operational level. These 58 ESIs are considered DVs of the model (Ashok et al., 2017). The relative weights for the ESIs (decision variables) were obtained by implying both the Top-Down and Bottom-up approaches through the participation of subject matter (Ecotourism) experts and local key stakeholders in two stages.

Relative weight using top-down and bottom-up approach

The top-down approach refers to the application of the Delphi technique, where 19 subject matter experts ($n = 14$ for 2003–2004; $n = 5$ for 2013) of multi-disciplinary backgrounds participated in allotting relative weights (between 0 and 100) to the sustainability principles of ecotourism (Sp_I to Sp_{IV}). These values were calculated and their mean values were accepted. Further, all the criteria related to each principle received a pro-rated weight of that particular principle based on the priority ranking given to them by the experts. Then, their mean values were accepted as relative weight factors for criteria (Fig. 3).

The bottom-up approach refers to the participation of local key stakeholders ($n = 10$ for 2003–2004; $n = 4$ for 2018–2019) in allotting the priority ranking to the indicators (ESIs-X_{11} to X_{86}) to operationalize their receptive criteria. Secondly, the weight for each criterion obtained in Stage I is assumed as 100 and then is distributed among the related indicators depending upon their priority ranking given by the local experts. Subsequently, the weights calculated for individual indicators are multiplied by the final weight factor of their respective criterion to obtain the relative efficacy of a particular indicator (S 2). Finally, the relative weights for indicators (ESIs) are calculated and mean values are accepted for the model (Table 1; Fig. 4).

Developing linear equations for the model

The ESA framework entails that ES is based on its four key principles, i.e., (i) protection of natural and cultural resources (Sp_I), (ii) generation of socio-economic
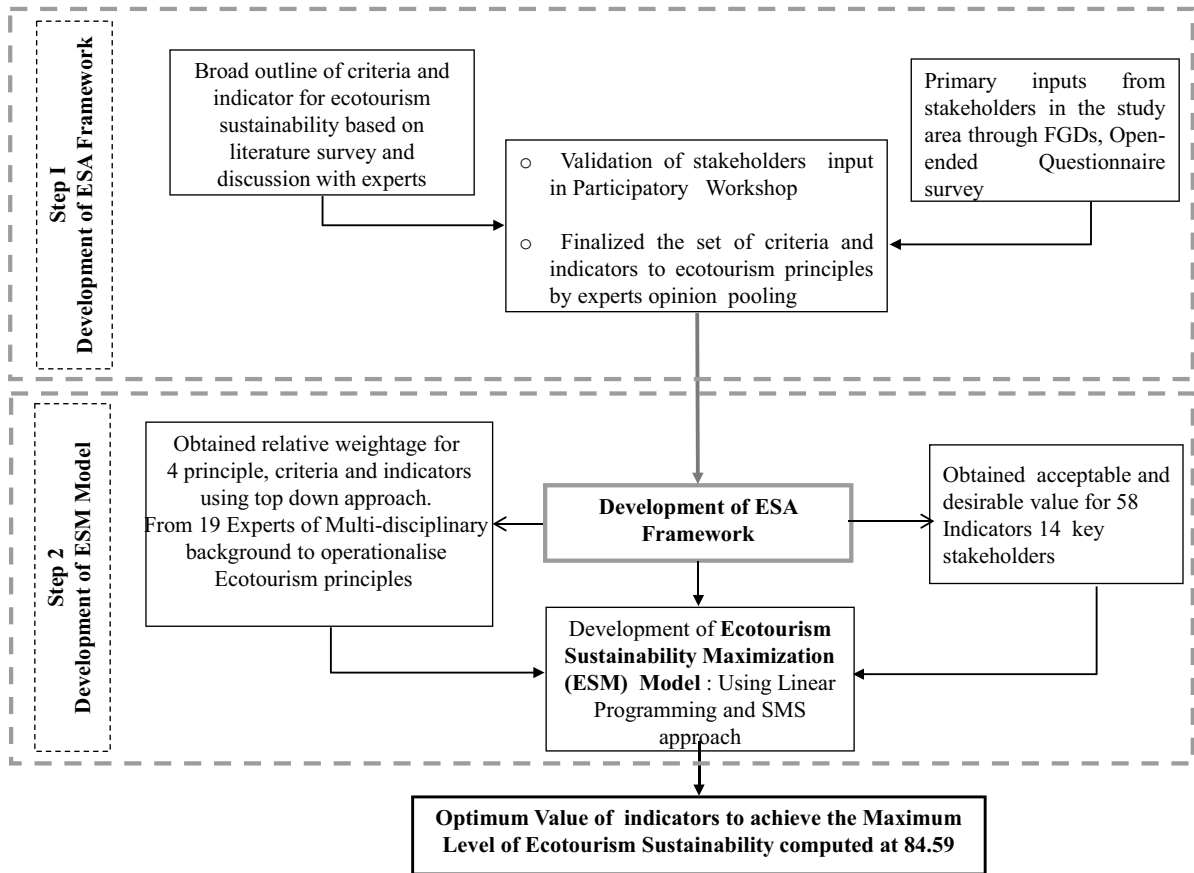
Fig. 3 Broad outline for development of ecotourism sustainability assessment (ESA) Framework and Ecotourism Sustainability Maximization (ESM) Model

benefits to the local community (Sp_{II}), (iii) generation of environmental awareness (Sp_{III}), and (iv) optimum satisfaction of touristic aspirations (Sp_{IV}). These four principles have been operationalized through the different combinations of criteria like Sp_I by C_1, C_2, C_4, C_6, and C_8; Sp_{II} by C_1 and C_4; Sp_{III} through C_4 and C_7; and Sp_{IV} through C_1, C_5, C_7, and C_8. These criteria can be operationalized through their respective indicators (Ashok et al., 2017; Kumari et al., 2005). Based on the relationship between the components of the ESA framework, the equation was formulated to define the objective function of the model. Ecotourism Sustainability (ES) is dependent upon 4 principles, which can be formulated as:

$$ES = W_1 Sp_I + W_2 Sp_{II} + W_3 Sp_{III} + W_4 Sp_{IV} \qquad (1)$$

where

W_i = Weight for the ith principle of ecotourism sustainability

Sp_i = Ecotourism principles

Subsequently, the 4-principles (Sp_I, Sp_{IV}) depend upon the 8-criterion (C_1, C_8) occurring in different combinations for each of the principles. This is formulated as:

$$Sp_I = w_{11}C_1 + w_{12}C_2 + w_{13}C_3 + w_{16}C_6 + w_{17}C_7 + w_{18}C_8 \qquad (2)$$

$$Sp_{II} = w_{21}C_1 + w_{22}C_2 + w_{23}C_3 + w_{24}C_4 \qquad (3)$$

$$Sp_{III} = w_{34}C_4 + w_{37}C_7 \qquad (4)$$

$$Sp_{IV} = w_{41}C_1 + w_{45}C_5 + w_{47}C_7 + w_{48}C_8 \qquad (5)$$

where W_{ij} = Weight of jth criteria for i^{th} principle.
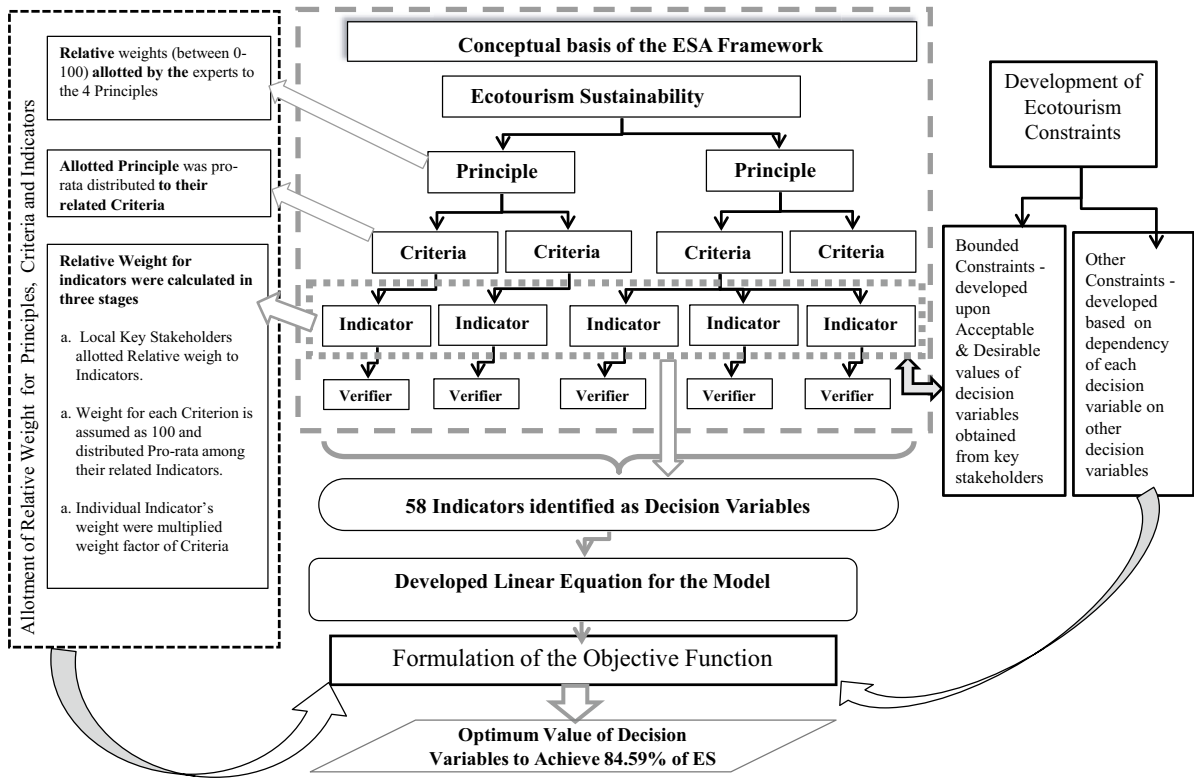
Fig. 4 Methodology adopted for the development of the Ecotourism Sustainability Maximization Model

Using Eqs. (2), (3), (4), and (5) in Eq. (1) where weight allocated for C_1 to C_8 can be combined (S2), it can be presented as:

$$ES = \overline{w_1}c_1 + \overline{w_2}c_2 + \overline{w_3}c_3 + \overline{w_4}c_4 \\ + \overline{w_5}c_5 + \overline{w_6}c_6 + \overline{w_7}c_7 + \overline{w_8}c_8 \qquad (6)$$

where

$$\overline{w_1} = W_1 w_{11} + W_2 w_{21} + W_4 w_{41}$$

$$\overline{w_2} = W_1 w_{12} + W_2 w_{22}$$

$$\overline{w_3} = W_3 w_{13} + W_2 w_{23}$$

$$\overline{w_4} = W_2 w_{24} + W_3 w_{34}$$

$$\overline{w_5} = W_4 w_{45}$$

$$\overline{w_6} = W_1 w_{16}$$

$$\overline{w_7} = W_1 w_{17} + W_3 w_{37} + W_4 w_{47}$$

$$\overline{w_8} = W_1 w_{18} + W_4 w_{48}$$

The 8 criteria (C_1, C_8) depend upon their respective indicators (X_{11}, X_{86}) (ESA framework; Ashok et al., 2017). This can be formulated as:

$$C_1 = w'_{11}X_{11} + w'_{12}X_{12} + w'_{13}X_{13} + w'_{14}X_{14} \\ + w'_{15}X_{15} + w'_{16}X_{16} + w'_{17}X_{17} \\ + w'_{18}X_{18} + w'_{19}X_{19} \\ + w'_{110}X_{110} + w'_{111}X_{111} \qquad (7)$$

$$C_2 = w'_{21}X_{21} + w'_{22}X_{22} + w'_{23}X_{23} \\ + w'_{24}X_{24} + w'_{25}X_{25} + w'_{26}X_{26} \\ + w'_{27}X_{27} + w'_{28}X_{28} \qquad (8)$$

$$C_3 = w'_{31}X_{31} + w'_{32}X_{32} + w'_{33}X_{33} \\ + w'_{34}X_{34} + w'_{35}X_{35} + w'_{36}X_{36} \\ + w'_{37}X_{37} + w'_{38}X_{38} \qquad (9)$$

$$C_4 = w'_{41}X_{41} + w'_{42}X_{42} + w'_{43}X_{43}$$
$$+ w'_{44}X_{44} + w'_{45}X_{45} + w'_{46}X_{46} \qquad (10)$$
$$+ w'_{47}X_{47} + w'_{48}X_{48}$$

$$C_5 = w'_{51}X_{51} + w'_{52}X_{52} + w'_{53}X_{53}$$
$$+ w'_{54}X_{54} + w'_{55}X_{55} + w'_{56}X_{56} \qquad (11)$$
$$+ w'_{57}X_{57} + w'_{58}X_{58}$$

$$C_6 = w'_{61}X_{61} + w'_{62}X_{62} + w'_{63}X_{63}$$
$$+ w'_{64}X_{64} + w'_{65}X_{65} \qquad (12)$$

$$C_7 = w'_{71}X_{71} + w'_{72}X_{72} + w'_{73}X_{73}$$
$$+ w'_{74}X_{74} + w'_{75}X_{75} + w'_{76}X_{76} \qquad (13)$$

$$C_8 = w'_{81}X_{81} + w'_{82}X_{82} + w'_{83}X_{83}$$
$$+ w'_{84}X_{84} + w'_{85}X_{85} + w'_{86}X_{86} \qquad (14)$$

where

X_{ij} means j^{th} indicator for i^{th} criteria
w'_{ij} means weight for X_{ij}

Formulation of the objective function

In the present model, the maximization of ecotourism sustainability has been defined as the objective function. ES depends upon four principles, namely, Sp_I and Sp_{IV} (Eq. (1)). These four principles depend upon many criteria (Eqs. (2), (3), (4), and (5)). Further, these criteria depend upon several indicators (Eqs. (7), (8), (9), (10), (11), (12), (13), and (14)). Finally, ES depends upon 58 indicators, considered as the DVs for the model. Among the 58-DVs, 13 have a negative impact on the sustainability of ecotourism but the remaining ones have a positive impact. As maximization of ecotourism sustainability is the objective of the model, the following equation was formulated to obtain the OV of indicators (Eq. (15)).

$$ES = \overline{W_1}\sum_{j=1}^{11}(W'_{1j}, X_{1j}) + \overline{W_2}\sum_{j=1}^{7}(W'_{2j}, X_{2j})$$
$$+ \overline{W_3}\sum_{j=1}^{7}(W'_{3j}, X_{3j}) + \overline{W_4}\sum_{j=1}^{8}(W'_{4j}, X_{4j})$$
$$+ \overline{W_5}\sum_{j=1}^{8}(W'_{5j}, X_{5j}) + \overline{W_6}\sum_{j=1}^{5}(W'_{6j}, X_{6j})$$
$$+ \overline{W_7}\sum_{j=1}^{6}(W'_{7j}, X_{7j}) + \overline{W_8}\sum_{j=1}^{6}(W'_{8j}, X_{8j})$$
$$(15)$$

Development of ecotourism constraints and sustainability indicators

58 bounded constraints were based on the desirable and acceptable values of the DVs (Table 1), while 56 others were identified based on the dependence of each variable on others (Table 2). The acceptable and desirable values obtained by consulting local experts were used as bounded constraints (Table 1). These values were used as lower and upper bounds in the model, respectively.

In the case of decision variables having a positive impact

$$m_{ij} \leq X_{ij} \leq M_{ij}$$

where m_{ij} = the minimum value of the decision variable required for ecotourism sustainability, X_{ij} = decision variable, and M_{ij} = maximum value of decision variable are desirable for ecotourism sustainability.

For example, for the indicator $X_{11} = 22\% \leq X_{11} \leq 40.5\%$.

In the case of decision variables having a negative impact.

The negative impact of DVs indicates that when these DVs increase, the ecotourism sustainability will decrease, therefore,

$$m_{ij} \leq X_{ij} \leq M_{ij}$$

where m_{ij} = the minimum value of decision variable desirable for ecotourism sustainability, X_{ij} = decision variable, and M_{ij} = maximum value of decision variable acceptable for ecotourism sustainability.

For example, for indicator X_{16} the acceptable and desirable values may be presented as $9.80\% \leq X_{16} \leq 4.90\%$. The growth of exotic plants is very harmful to the indigenous plant communities because the alien plants compete with them for space, light, nutrients, and water (Newsome et al., 2002). So, less than 4.90% growth of weeds is desirable for the ES, while up to 9.80% of the growth of weeds (from the base year of 1995) is acceptable for the study area. The key stakeholders have allotted acceptable and desirable values for each DV. Their mean values were calculated and have been accepted for the model as constraints (lower and upper bounds for decision variables) in the model (Table 1).

Table 2 Other constraints developed by identifying the dependency of each Ecotourism Sustainability Indicator (Decision Variables)

Sl. no	Other constraints
1	$X_{11} \leq 0.09\,X_{13} + 0.09\,X_{14} + 0.14\,X_{41} + 0.18\,X_{71} + 0.16\,X_{81} + 0.22\,X_{85} + 0.12\,X_{86}$
2	$X_{12} \leq 0.11\,X_{13} + 0.11\,X_{14} + 0.16\,X_{41} + 0.20\,X_{71} + 0.18\,X_{81} + 0.24\,X_{85} + 0.12\,X_{86}$
3	$X_{13} \geq 0.20\,X_{110} + 0.18\,X_{53} + 0.16\,X_{71} + 0.16\,X_{74} + 0.15\,X_{81} + 0.15\,X_{85}$
4	$X_{14} \geq 0.14\,X_{22} + 0.18\,X_{23} + 0.2\,X_{41} + 0.24\,X_{71} + 0.24\,X_{81}$
5	$X_{15} \geq 0.14\,X_{16} + 0.14\,X_{17} + 0.35\,X_{47} + 0.35\,X_{53} + 0.30\,X_{71} + 0.28\,X_{86}$
6	$X_{16} \geq 0.56\,X_{17} + 0.50\,X_{19} + 0.54\,X_{31} - 0.20\,X_{47} - 0.22\,X_{61} - 0.18\,X_{63}$
7	$X_{17} \geq 0.31\,X_{26} + 0.32\,X_{31} + 0.30\,X_{56} - 0.20\,X_{82} - 0.27\,X_{84}$
8	$X_{18} \geq 0.18\,X_{45} + 0.20\,X_{53} + 0.22\,X_{71} + 0.24\,X_{74} + 0.16\,X_{81}$
9	$X_{19} \geq 1.54\,X_{27} - 0.14\,X_{41} - 0.10\,X_{53} - 0.12\,X_{71} - 0.8\,X_{73} - 0.8\,X_{81}$
10	$X_{110} \leq 0.24\,X_{41} + 0.16\,X_{43} + 0.18\,X_{53} + 0.23\,X_{71} + 0.20\,X_{72}$
11	$X_{111} \geq 1.42\,X_{19} - 0.16\,X_{41} - 0.12\,X_{53} - 0.14\,X_{71}$
12	$X_{21} \leq -0.12\,X_{22} + 0.82\,X_{31} - 0.12\,X_{45} + 0.76\,X_{57} - 0.10\,X_{71} - 0.14\,X_{81} - 0.10\,X_{86}$
13	$X_{22} \leq 1200$
14	$X_{23} \geq 0.30\,X_{21} + 0.62\,X_{22} + 0.68\,X_{86}$
15	$X_{24} \leq 0.2\,X_{22} + 0.16\,X_{33} + 0.22\,X_{45} + 0.22\,X_{74} + 0.20\,X_{86}$
16	$X_{25} \leq 0.17\,X_{22} + 0.14\,X_{33} + 0.2\,X_{45} + 0.k2\,X_{74} + 0.17\,X_{86}$
17	$X_{27} \leq 0.24\,X_{41} + 0.20\,X_{45} + 0.20\,X_{71} + 0.22\,X_{81} + 0.14\,X_{86}$
18	$X_{32} \geq 0.46\,X_{41} + 0.48\,X_{42} + 0.44\,X_{44} + 0.50\,X_{45}$
19	$X_{33} \leq 0.22_{27} + 0.20\,X_{32} + 0.18\,X_{41} + 0.24\,X_{47} + 0.16\,X_{53}$
20	$X_{34} \leq 0.3\,X_{82} + 0.32\,X_{84} + 0.38\,X_{86}$
21	$X_{35} \geq 0.26\,X_{26} + 0.44\,X_{31} + 0.42\,X_{33} + 0.40\,X_{81}$
22	$X_{41} \leq 0.23\,X_{82} + 0.20\,X_{43} + 0.16\,X_{86} + 0.25\,X_{82} + 0.86\,X_{86}$
23	$X_{42} \geq -0.18\,X_{27} + 0.20\,X_{31} + 0.20\,X_{33} + 0.16\,X_{41} + 0.16\,X_{43} + 0.14\,X_{45} + 0.14\,X_{71}$
24	$X_{44} \geq 0.24\,X_{41} + 0.24\,X_{43} + 0.26\,X_{45} + 0.26\,X_{74}$
25	$X_{45} \geq 0.30\,X_{43} + 0.38\,X_{71} + 0.32\,X_{82}$
26	$X_{46} \leq 0.31\,X_{44} + 0.27\,X_{45} + 0.29\,X_{71} + 0.27\,X_{81}$
27	$X_{47} \leq 0.3\,X_{41} + 0.38\,X_{44} + 0.22\,X_{45} + 0.2\,X_{71}$
28	$X_{51} \leq 0.4\,X_{52} + 0.32\,X_{61} + 0.28\,X_{82}$
29	$X_{52} \leq 0.16\,X_{41} + 0.16\,X_{43} + 0.13\,X_{46} + 0.13\,X_{47} + 0.22\,X_{53} + 0.20\,X_{82}$
30	$X_{53} \leq 0.32\,X_{45} + 0.4\,X_{46} + 0.28\,X_{47}$
31	$X_{54} \leq 0.70\,X_{52} + 0.64\,X_{56}$
32	$X_{55} \leq 0.44\,X_{53} + 0.56\,X_{42}$
33	$X_{56} \leq 0.42\,X_{52} + 0.58\,X_{53}$
34	$X_{57} \leq 0.46\,X_{52} + 0.54\,X_{53}$
35	$X_{61} \leq 0.28\,X_{41} + 0.24\,X_{43} + 0.22\,X_{63} + 0.26\,X_{71}$
36	$X_{62} \leq 0.3\,X_{41} + 0.24\,X_{43} + 0.24\,X_{44} + 0.22\,X_{71}$
37	$X_{63} \geq 0.52\,X_{44} + 0.48\,X_{81}$
38	$X_{64} \geq 0.23\,X_{41} + 0.23\,X_{43} + 0.28\,X_{47} + 0.26\,X_{71}$
39	$X_{65} \leq 0.75\,X_{31} - 0.22\,X_{41} + 0.65\,X_{57} - 0.18\,X_{63}$
40	$X_{71} \geq 0.28\,X_{41} + 0.26\,X_{43} + 0.26\,X_{44} + 0.20\,X_{74}$
41	$X_{72} \geq 0.3\,X_{54} + 0.36\,X_{71} + 0.34\,X_{81}$
42	$X_{73} \leq 0.28\,X_{22} + 0.23\,X_{53} + 0.26\,X_{71} + 0.23\,X_{74}$
43	$X_{74} \leq 0.3\,X_{47} + 0.36\,X_{45} + 0.34\,X_{71}$
44	$X_{75} \leq 0.22\,X_{45} + 0.18\,X_{54} + 0.28\,X_{71} + 0.22\,X_{74} + 0.26\,X_{74}$
45	$X_{76} \geq 0.2\,X_{41} + 0.24\,X_{71} + 0.18\,X_{81} + 0.24\,X_{82} + 0.14\,X_{86}$
46	$X_{81} \leq 0.34\,X_{31} + 0.36\,X_{71} + 0.3\,X_{74}$
47	$X_{82} \leq 0.22\,X_{74} + 0.3\,X_{81} + 0.22\,X_{84} + 0.26\,X_{86}$

Table 2 (continued)

Sl. no	Other constraints
48	$X_{83} \geq 0.26\,X_{45} + 0.28\,X_{71} + 0.22\,X_{81} + 0.24\,X_{86}$
49	$X_{84} \leq 0.16\,X_{34} + 0.23\,X_{45} + 0.27\,X_{74} + 0.18\,X_{81} + 0.20\,X_{86}$
50	$X_{85} \geq 0.28\,X_{41} + 0.23\,X_{45} + 0.26\,X_{71} + 0.23\,X_{74}$
51	$X_{86} \geq 0.30\,X_{45} + 0.36\,X_{71} + 0.34\,X_{74}$
52	$X_{45} \leq 0.30\,X_{43} + 0.38\,X_{71} + 0.32\,X_{82}$
53	$X_{42} \leq 150$
54	$X_{17} + X_{42} \leq 990$
55	$X_{15} - 10\,X_{16} \geq 0$
56	$X_{32} - 10\,X_{27} \geq 0$

Other constraints

The dependency of each indicator was identified on other indicators, and respective weights were assigned. For example, wildlife sighting depends on the availability of clean water (X_{13}) and the abundance of forest resources (X_{14}). The abundance of these resources depends upon the involvement of the younger generation in the conservation of natural resources (X_{86}), which requires the transfer of traditional resource conservation knowledge to the younger generation (X_{85}). This is only possible when the local population is aware (X_{71}) and empowered (X_{81}) to protect resources. Along with this, it also requires government regulatory policy regarding the protection of natural resources (X_{41}). Such dependency has been taken as the basis of the following equation.

$$X_{11} \leq 0.09X_{13} + 0.09X_{14} + 0.14X_{41} + 0.18X_{71} \\ + 0.16X_{81} + 0.22X_{85} + 0.12X_{86}$$

The above equation indicates the dependency of decision variable X_{11} on the other variables, namely, X_{13}, X_{14}, X_{41}, X_{71}, X_{81}, X_{85}, and X_{86}. It also means that the value of X_{11} should be less than the sum of individual weights of the above 7 which are 0.09, 0.09, 0.14, 0.18, 0.16, 0.22, and 0.12, respectively. Similarly, the dependency of each indicator was identified and assigned their respective weights. These equations were used as constraints in the model (Table 2).

The objective function was solved for 58 DVs in total, subject to a set of 114 constraints, by using the traditional simplex method for single objective linear programming with the help of the QSB software (Jana et al., 2004) through the Eq. (15).

Results and discussions

Trend equation regression analysis generated four scenarios for the recovery of tourist arrivals, namely, S-1, S-2, S-3, and S-4, in the study area. These scenarios estimated the recovery period (for tourists' arrival) of 4 years, 4–5 years, 6 years, and 5–6 years, respectively to reach the level of 2019. Among these four scenarios, the best forecasting has been shown in scenario 2, where the mean square error is minimal, i.e., 234.82 and estimates the recovery by 2026, increasing the tourists' number up to 10,040 by then and eventually to 15,940 by 2030 (Fig. 2; S1). The prediction curve shows a sharp decline in tourist arrivals in 2020 due to the situation created by COVID-19. However, regression-based extrapolation has shown a fast recovery in tourist arrivals by 2026, as the prediction is based on the actual tourists' data from 2001 to 2019. This is reflected in the linear trend from "2001 to 2010" and "2012 to 2019" (Fig. 2). The sharp decline in tourist arrival in 2011 and 2020 due to the occurrence of the 2011 earthquake in the area and the COVID-19 pandemic (2020) proved that any kind of excessive use or abuse of "ecotourism resources" or a "dreadful pandemic" like situation may not only limit the potential tourism earnings in this area but also in the entire state of Sikkim in future (Singh & Bhutia, 2020). Moreover, the Yuksam-Dzongri trekking corridor falls under the alpine and sub-alpine vegetation zone of the Indian Himalayas, which needs utmost care to protect its sensitive biodiversity and possibly mitigate any probable adverse impact of climate change. In such a situation, the optimum value of decision variables (ESIs) obtained by the ESM model can act as a protective cover for controlling the use levels of ecotourism

Table 3 Ecotourism sustainability performance scale

Band	Scale	According to Prescott-Allen (1997) and Pandey (2000)	Response scale	Level of sustainability
Good	5 (80–100)	Sustainable	Desired mark (desirable Sustainability performance)	Highly sustainable
Ok	4 (60–80)	Potentially sustainable	Acceptable performance	Sustainable in most aspects
Medium	3 (40–60)	Medium	Neutral or transitional performance	Potentially sustainable
Poor	2 (20–40)	Potentially Unsustainable	Undesirable performance	Approaching towards unsustainability
Bad	1 (< 20)	Unsustainable	Unacceptable performance	Unsustainable in all respect

resources, thus maximizing the site's sustainability afterward, if adopted.

With 58 indicators and 114 constraints (Eq. (15)), the ESM model revealed the maximum level of ecotourism sustainability at a score of 84.6%. This value was further cross-checked on the barometer of sustainability/measure of success (BoS/MoS) scale (Table 3). Based on the BOS scale, it can be construed that if an ecotourism destination achieves 80–100% (level 5) sustainability, it can be deemed to be a sustainable ecotourism destination. Further, the model derived the optimum value of the ecotourism sustainability indicators–ESIs (Table 4), which means that the above level of ecotourism sustainability (84.6%) can only be achieved if the destination restricts the utility level of the environmental resources up to its optima.

Now the question occurs that how the model derived "optimum values" of ecotourism sustainability indicators

can help achieve sustainable ecotourism development? How it can manage the ecotourism resources so that specific types of natural and cultural attractions of the ecotourism destinations are maintained? In this regard, the authors identified three ways that can be useful for the authorities or ecotourism-site managers (i.e., in the case of Study Area the Forests and Environment Department; Tourism Department; Police Check-Post, Yuksam, as well as the CBO namely–Kangchendzonga Conservation Committee) can maintain the destination's ecological sensitivity while sustainably managing ecotourism, as discussed below.

Relative contributions of criteria to achieve ecotourism sustainability

While scrutinizing the relative contributions of criteria in achieving 84.6% of ES, the contributions

Table 4 Optimum values of Decision Variable (ESIs) achieved from modeling using linear programming; 84.6% level of eco-tourism sustainability was achieved through the model

Criteria-1		Criteria-2		Criteria-3		Criteria-4		Criteria-5		Criteria-6		Criteria-7		Criteria-8	
DV	OV (%)	DV	OV (%)	DV	OV (%)	DV	OV (%)	DV	OV (%)	DV	OV (%)	DV	OV (%)	DV	OV (%)
X_{11}	40.5	X_{21}	10.0	X_{31}	75.0	X_{41}	50.44	X_{51}	1.7	X_{61}	79.42	X_{71}	75.91	X_{81}	30.0
X_{12}	78.8	X_{22}	65.05	X_{32}	94.0	X_{42}	93.0	X_{52}	68.07	X_{62}	79.59	X_{72}	83.0	X_{82}	30.0
X_{13}	98.0	X_{23}	81.5	X_{33}	61.3	X_{43}	100.0	X_{53}	76.85	X_{63}	98.0	X_{73}	47.0	X_{83}	73.5
X_{14}	100.0	X_{24}	61.92	X_{34}	54.13	X_{44}	99.0	X_{54}	50.03	X_{64}	100.0	X_{74}	50.24	X_{84}	63.91
X_{15}	96.5	X_{25}	54.42	X_{35}	100.0	X_{45}	68.44	X_{55}	22.9	X_{65}	27.0	X_{75}	63.0	X_{85}	85.87
X_{16}	4.9	X_{26}	16.5	X_{36}	94.0	X_{46}	79.28	X_{56}	3.7			X_{76}	50.0	X_{86}	64.59
X_{17}	7.0	X_{27}	5.5	X_{37}	1.0	X_{47}	82.99	X_{57}	13.0						
X_{18}	96.5					X_{48}	38.0	X_{58}	53.0						
X_{19}	5.2														
X_{110}	76.0														
X_{111}	4.5														

DV represents decision variables, *OV* represents optimum, *ESIs* represent ecotourism sustainability indicators

of "C_1"– "maintenance of ecosystem health," "C_4"– "enabling environment and environmental awareness generation" and "C_7"– "people's participation" are a prerequisite for sustainable management and were found to be the maximum. This suggests that other criteria must support the fulfillment of the above criteria, but it does not undermine the importance of others. The next–highest contributions are of "C_2" and "C_8" which refer to preserving cultural diversity through the maintenance of the local culture and the use of indigenous ecological knowledge for ecotourism development and management. If the above-mentioned five criteria are supported by the adoption of carrying capacity "C_6" norms, then it can provide an excellent base for the last two criteria, "C_3"– "livelihood generation" and "C_5"– "visitor satisfaction" (S3).

Operationalisation of ecotourism sustainability principles through criteria and indicators

The first principle of ecotourism– "protection of natural and cultural resources," Sp_I, offers a challenge to ecotourism to develop its tourism capacity and the quality of its products without affecting the very environment that maintains and nurtures it. This requires the adoption of resource conservation values during the decision-making, which is possible by adopting the OV of indicators as guidelines. The contribution of "C_1" "maintenance of ecosystem health," towards achieving a sustainability score on the BoS/MoS scale was found the highest so it should be accorded the highest priority during any ecotourism development and management decision-making. This criterion is followed by "C_2"– "maintenance of local culture," "C_6"– "carrying capacity," "C_4"– "enabling environment and environmental awareness generation," "C_7"– "people's participation" and "C_8"– "conservation management using traditional knowledge" (S3).

While assessing the OV of ESIs (Table 4; Fig. 5a–h), it can be construed that the optimum value of some indicators, viz. X_{13}, X_{14}, X_{15}, X_{16}, X_{17}, X_{18}, X_{19}, X_{111}, X_{21}, X_{23}, X_{26}, X_{27}, X_{42}, X_{43}, X_{44}, X_{63}, X_{64}, X_{72}, and X_{85} are falling under the range of 80–100%. Next to these, are some indicators, viz. X_{12}, X_{110}, X_{22}, X_{24}, X_{45}, X_{46}, X_{61}, X_{62}, X_{65}, X_{71}, X_{75}, X_{84}, and X_{86} have OV between 60–80%. These are followed by indicators X_{11}, X_{25}, X_{41}, X_{73}, X_{74}, and X_{76} having 40 to 60%. Lastly, values of a few indicators viz. X_{48}, X_{81}, and X_{82} fall between 20–40%. In line with the guideline provided by the Quebec declaration on ecotourism (QDE, 2002) the OV of indicators emphasizes prioritizing critical components, as these are vital for maintaining the flow of ecosystem services. The relative contribution of criteria as per the ESA Framework and the relative contribution of ESIs as per the optimum value achieved by the ESM model can guide the ecotourism management authority.

Likewise, principle I, the relative contribution of criteria as per the ESA framework and the relative contribution of ESIs as per Optimum Value achieved by the ESM model, has been analyzed for principles II, III, and IV for operationalizing the ecotourism sustainability principle in the study area mentioned in the supplementary document (S 4). This can guide the ecotourism management authority to implement the optimum value of ESIs to restrict the use level of ecotourism resources in the area.

Application of optimum value of ESIs to restrict the utility level of ecotourism resources

The ecotourism management authority or site-managers can manage their destination's valuable and sensitive resources for ecotourism based on the optimum value achieved by the model.

Supporting indicators for criterion C_1 (maintenance of healthy ecosystems)

Ecotourism management authorities or site managers need to restrict the use level of resources depending on the positive and negative impact of ESIs on the ES. Criterion, C_1 was objectively measured by examining its related indicators based on its OV resulting from the model (Fig. 5a; Table 4). In the case of "availability of fresh water (rivers, streams, lakes)" (X_{13}), the OV obtained was 96.5%. Hence the mountain ecosystem can be designated as healthy if pure water is abundantly available throughout the year. If 100% of the "religious and heritage sites" (X_{14}), then it is presumed that the rich biodiversity and culture of the mountain ecosystem could be preserved. As the presence of ecosystem-specific plants, which represent the "unique ecosystem features (endemic species: floral and faunal)" (X_{15}), are critical for the maintenance of the mountain ecosystem, their extent of occurrence should optimally be 98%. In the case of the "occurrence of the endangered/threatened species" (X_{18}),
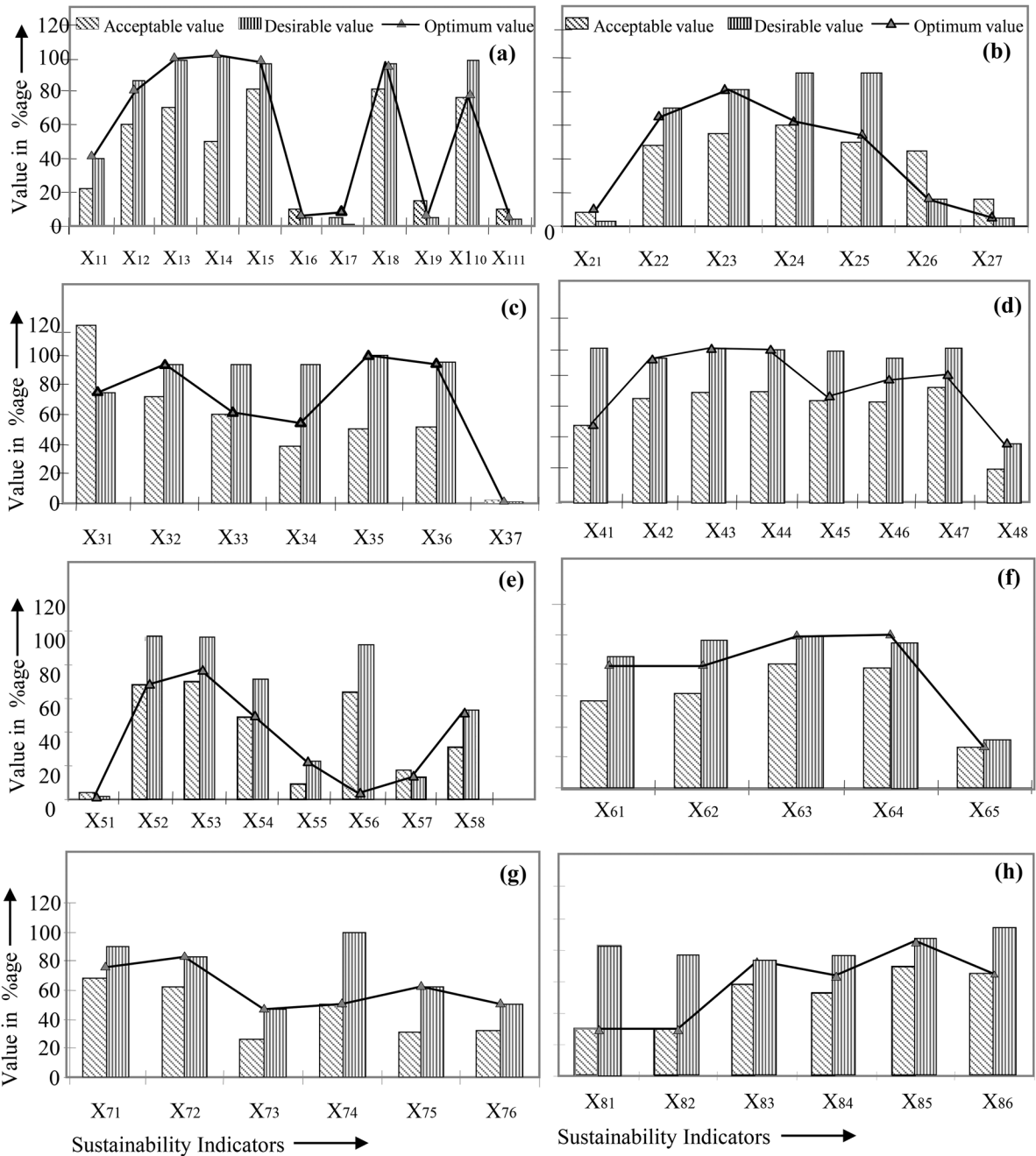
Fig. 5 a–h Optimum value achieved for 58 indicators with eight criteria; a. Maintenance of ecosystem health. **b** Maintenance of local culture. **c** Livelihood generation. **d** Enabling environment and environmental condition. **e** Tourists' satisfaction. **f** Carrying capacity. **g** People's participation. **h** Conservation management through indigenous knowledge

the OV arrived was 96.5%, which calls for more conservation efforts from the part of forest department without which many species might become extinct and disturb the balance of the ecosystem. In the case

of the composite indicator "status of civic amenities" (X_{110}), the OV was 76%, which implies that even if only 76% of the population has access to safe drinking water and sanitation facilities and 76% of solid

waste generated is disposed of, then the destination can also be considered sustainable (Table 4; Fig. 4).

In the case of negative indicators, i.e., "presence of exotic species (flora and fauna)" (X_{16}), the OV derived was 4.9%, while for "growth in livestock population" (X_{17}), the value obtained was 7%. This entails that beyond this level, any growth in weeds and livestock population may prove devastating for the region (Chettri et al., 2002). The OV for "RCC use in tourism infrastructure development" (X_{19}) was derived as 5.2%, which depicts that beyond this level, RCC construction can have harmful effects on ecological health. This has been experienced in many destinations (Hunter & Green, 1995). "Occurrence of natural hazards" (X_{111}), creates great imbalances in the functioning of the ecosystem and destructs the human life support system as well. Its value has also come close to the minimum desirable of 4.5% (Table 4; Fig. 5a). The optimal values of indicators obtained by the model are of great importance.

Likewise, the optimal values of indicators obtained by the model are of great importance and are presented in Table 4 and Fig. 5b, c, d, e, f, g, and h. If applied, they can help in achieving the maximum level of ecotourism sustainability at the operational level.

Conclusion

Under complex situations, having a multitude of interests among the stakeholders, i.e., tourists, locals, NGOs, tour operators, etc., the ESM model can prove to be an ideal solution as it adopts the SMS approach to define the acceptable and desirable values of indicators, referred to as, DVs by involving all stakeholders. Here, the ESM model can be considered an executable decision-making tool as it calculates the optimum value of 58 DVs to achieve 84.6% of ES, which falls under the Sustainable Category (80–100%) on the MoS Scale defined by Prescott-Allen (2001). If adopted, the ESM model can control the uses of ecotourism resources at the operational level and can also support the local community to sustain their livelihood even in the case of climate change in Himalayan regions as predicted by IPCC (2022).

Extended use of the results of the ESM Model can only be useful when (a) it is substantially validated,

and (b) its applicability (in terms of the performance of the ESIs at the operational level) is assessed on a temporal level. Based on the availability of the field data, the authors will be duly validating and assessing the applicability of the ESM model which may logically be developed as the 3rd and 4th study series in the process of developing an ESAM as per the guidelines given by the BellagioSTAMP 2009. In addition to this, the authors also want to integrate their 4 stage study series of the ESAM with a web-based geospatial platform, to make it a more comprehensive tool for ecotourism sustainability assessment and monitoring. This tool would be assessing the level of ecotourism sustainability based on the spatial information collected for 58 ESIs. Among the 58 ESIs, spatial data for 11 indicators, related to the first criterion, "C1–maintenance of ecosystem health," can be generated through satellite imagery and its derived products. The spatial data for the rest of the 47 indicators related to seven criteria ranging from "C2–maintenance of local culture" to "C8–conservation management using traditional/indigenous knowledge system" can be generated through crowdsourcing involving ecotourism stakeholders, i.e., tourists, local people (ecotourism service providers, CBOs, tour operators, etc.), government Tourism departments. Thus, it can fulfill the target of SDG 12. b, which mentions "developing and implementing tools to monitor sustainable development impacts for sustainable tourism" by fulfilling SDGs 8.9 (ensuring jobs, promotion of local culture and tourism products) and 15 (Protecting, restoring, and managing biodiversity in the terrestrial ecosystem) identified by the report of working group II sustainable tourism in the Indian Himalayan region (NITI Aayog, 2018). Through the application of the above "monitoring tool," deforestation can be controlled, carbon stock can be maintained and the biodiversity-rich areas will be undisturbed so they will regenerate. In turn, it will help optimize biodiversity recovery and livelihood benefits and can play an important role in taking urgent action to mitigate climate change for achieving the targets of SDG 13 in the Indian Himalayan regions.

Declarations

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