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How locals' views on ecosystem (dis)services vary: Socio-demographic insights from a Himalayan protected area

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ABSTRACT

Understanding local perceptions of ecosystem services and disservices is essential for capturing human-nature interactions within protected areas. Although these perceptions are embedded in socio-economic contexts, their variation across socio-demographic groups remains underexplored. Thus, we investigate how socio-demographic factors shape local perceptions of ecosystem services and disservices in the buffer zone of Langtang National Park, a Himalayan protected area. Using data from 105 semi-structured interviews and three focus group discussions with residents, we employed a mixed-method approach to data analysis, integrating descriptive statistics, an econometric *probit* model, and thematic analysis. Our results reveal that geographical location is a consistent determinant across most ecosystem (dis)service categories. Positive perceptions of services are driven mainly by tangible livelihood and economic benefits, while concerns about environmental degradation and justice underpin negative perceptions. Gender, ethnicity, and religion are significantly associated with perceptions of ecosystem disservices, including human health impacts (e.g., allergies) and governance-related challenges (e.g., legal complications and development constraints). The intensity of disservice perceptions is mediated by local forest composition, traditional and indigenous knowledge, and everyday interactions with nature. Our findings underscore that advancing sustainability in protected areas requires transdisciplinary approaches that integrate ecological science, geography, and socio-cultural values to foster resilient and adaptive socio-ecological systems.

1. Introduction

Protected areas, geographically defined regions governed by specific regulations to minimize human disturbance, remain a cornerstone of global efforts to safeguard biodiversity and maintain ecosystem integrity (Xu et al., 2017; Zeng et al., 2022). Over time, they have become widely recognized for their role in conserving biodiversity and delivering a broad spectrum of ecosystem services (Ivanić et al., 2020; Pu et al., 2023). The ecosystem services are classified into provisioning (e.g., food, freshwater, and energy), regulating (e.g., climate regulation, air purification, and water circulation), cultural (e.g., recreation, spiritual values, and tourism), and supporting (e.g., soil formation and nutrient cycling) services, which represents the manifold benefits that people derive, both directly and indirectly, from ecosystems (Costanza et al., 1997; MEA, 2005).

The ecosystem services framework has catalyzed a paradigm shift in conservation thinking by placing human well-being at the centre of environmental governance (Paavola and Hubacek, 2013). Its most

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profound contribution lies in reframing the relationship between humans and nature not as separate entities, but as interdependent components of a shared system, highlighting humans as primary beneficiaries of ecosystem functions (Costanza et al., 2014; de Groot et al., 2017; Primmer et al., 2015). However, the underlying concept of ecosystem services has been criticized for its anthropocentric orientation, as it prioritizes human benefits over the intrinsic value of ecosystems and promotes the commodification of nature (Matulis, 2015; Schröter et al., 2014; Sullivan, 2009). Despite these critiques, the framework has influenced environmental research, governance, and management, promoting more inclusive and socially attuned strategies (Costanza and Liu, 2014).

Applying the ecosystem services framework to protected area management within this evolving paradigm offers a means of aligning conservation priorities with societal needs (Hummel et al., 2019). This does not imply that protected areas exist solely to provide human benefits. Instead, conserving the intrinsic value of nature remains fundamental. At the same time, the framework can complement this intrinsic-value rationale by fostering public support. In doing so, protected areas contribute to environmental goals and human development imperatives, including poverty reduction (Dudley et al., 2017; Naughton-Treves et al., 2005). This framework can also shift stakeholder perceptions from viewing protected areas as zones of restriction to recognizing them as sources of opportunities and benefits (Boćkowski et al., 2024). Such transformation is particularly evident when ecosystem services directly enhance livelihoods through opportunities such as employment, capacity-building, education, and revenue generation (Ivanić et al., 2020). Yet, despite these strengths, the current application of the framework remains incomplete.

Mainly, the ecosystem services framework often neglects ecosystem disservices. Their omission partly reflects the fact that disservices remain largely absent from influential assessments such as the Millennium Ecosystem Assessment (MEA), The Economics of Ecosystems and Biodiversity (TEEB), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and consequently have not been adequately incorporated into policy or planning (Veibiakkim et al., 2025). Integrating services and disservices within a unified framework provides a clearer understanding of nature's net contribution to human well-being (Blanco et al., 2019). It strengthens the economic rationale for biodiversity conservation, offering a more robust scientific basis for effective management and long-term sustainability in support of both conservation and societal goals (Ninan and Kontoleon, 2016; Gan et al., 2024).

Ecosystem disservices remain conceptually contested, with their identification shaped by context and the knowledge, values, and perceptions of the evaluator (Campagne et al., 2018; von Döhren and Haase, 2015). Consequently, conceptual ambiguity and catch-all terms characterize the empirical literature on ecosystem disservices (Saunders, 2020). Two dominant perspectives can be distinguished. The first defines ecosystem disservices as outcomes of natural ecological processes, excluding those induced by human actions (Martin and Doucet, 2022; Shackleton et al., 2016; Wu et al., 2021). Within this perspective, ecosystem disservices are ecosystem-generated functions, processes, or attributes that result in perceived or actual negative impacts on human well-being (Blanco et al., 2021; Shackleton et al., 2016).

The second perspective conceptualizes ecosystem disservices as arising not only from natural functions but also from human modifications and human-induced processes (Escobedo et al., 2011; Lyytimäki and Sipilä, 2009; Lyytimäki, 2014). Empirical studies adopting this perspective document a wide range of disservices linked to ecosystem modification and human-induced processes, including maintenance costs of green spaces (Barnes et al., 2020; Conway and Yip, 2016; Paudel and States, 2023); fear and stress associated with unsafe or contaminated sites, such as former military training areas or poorly lit environments (Gómez-Baggethun and Barton, 2013; Plieninger et al., 2013); criminal activities in urban parks (Escobedo et al., 2018; Stanis et al., 2025); restrictions imposed by conservation measures (Baumeister et al., 2022; Veibiakkim et al., 2025); inadequate forestry planning and management (Rodríguez-Morales et al., 2020); the use of urban green spaces for open defecation and waste disposal (Thapa et al., 2023); and legal or regulatory limitations (Teixeira et al., 2019). Given this conceptual divergence, our study integrates both perspectives by adopting a community-centered approach in which local communities identify and categorize ecosystem disservices based on their lived experiences.

Understanding local perceptions of ecosystem services within protected areas is crucial for identifying community needs, preferences, and expectations (Elwell et al., 2018; Evangelista et al., 2024). Likewise, considering ecosystem disservices alongside services provides a more comprehensive understanding of how communities experience both the benefits and the burdens of protected areas (Ninan and Kontoleon, 2016). Such perceptions offer valuable insights that can guide the development of contextually grounded policies, thereby enhancing the legitimacy, equity, and long-term success of conservation initiatives through strengthened social support (Cortés-Avizanda et al., 2021; Ke et al., 2024; Subedi et al., 2025). Importantly, perceptions are not a fixed or objective measure but a socially constructed process shaped by observation, interpretation, and evaluation, which are influenced by the heterogeneity embedded in the varied identities, values, and lived experiences of populations, communities, and societies (Bai et al., 2024; Lau et al., 2018; Thiemann et al., 2022).

Most research on ecosystem services remains heavily skewed towards monetary valuation and biophysical assessments (Larson et al., 2019; Subedi et al., 2026; Shi et al., 2022). In contrast, the socio-cultural dimensions, particularly how local stakeholders perceive, value, and interact with ecosystem services within their specific socio-economic contexts and lived experiences, remain comparatively underexplored (Quintas-Soriano et al., 2018; Thiemann et al., 2022; Zhang et al., 2020a). Similarly, ecosystem disservices have received limited attention in academic research, with most studies focusing on awareness-raising, definitions, and categorization (Blanco et al., 2019; Wu et al., 2021). This global imbalance is also evident in Nepal, where research within protected areas has largely focused on economic valuations of services, often overlooking nuanced socio-cultural dimensions and ecosystem disservices. For instance, studies have estimated the economic value of ecosystem services in Koshi Tappu Wildlife Reserve (Sharma et al., 2015), Shivapuri-Nagarjuna National Park (Peh et al., 2016), and across seven other protected areas across Nepal (DNPWC, 2017). Other studies have examined tourists' willingness to pay for entry fees in Chitwan and Langtang National Parks (Pandit et al., 2015; Thapa et al., 2024) and assessed the impacts of land-use change on ecosystem services in Koshi Tappu Wildlife Reserve (Chaudhary et al., 2016). Together, these trends highlight a persistent research gap regarding the socio-cultural dimensions of ecosystem (dis)services in Nepal. Addressing this gap is essential for fostering a more holistic understanding of the complex interactions between people and nature.

Against this backdrop, our study addresses two research questions: 1) How do socio-demographic factors shape local perceptions of ecosystem services and disservices? 2) What explains differences in how socio-demographic groups perceive the importance of ecosystem services and the severity of disservices? To answer these questions, we collected data from semi-structured interviews and focus group discussions with residents of the buffer zone surrounding Langtang National Park. The data were analyzed using descriptive statistics, an econometric *probit* model, and thematic analysis (see Fig. 2 for the methodological framework). Our study provides empirically grounded insights into social drivers underlying perceived benefits and costs of protected areas. Its main contribution lies in an integrated analysis of ecosystem services and disservices within protected areas, providing a more holistic understanding of how local communities interact with and interpret the protected area landscapes. In doing so, it establishes a robust empirical foundation for advancing research on the conceptualization and multiple dimensions of ecosystem disservices in Nepal. More broadly, the

findings contribute to the ecosystem (dis)service scholarship by illuminating the human dimensions of ecosystem (dis)services within the complex socio-ecological context of the Global South, as exemplified by Nepal.

2. Materials and methods

2.1. Study area

We selected Langtang National Park (henceforth, Langtang) as our study area (Fig. 1) for its pronounced geographical variation and ecological richness (Text S1). Moreover, its buffer zone, which also includes human settlements within the park's core area, fosters close human-nature interactions that sustain local livelihoods through ecosystem services such as agriculture, animal husbandry, cheese production, hydropower, transhumance, nature-based tourism, and water bottling (DNPWC and CODEFUND, 2024). Combined with accessible infrastructure, such as rural roads and basic accommodations, this dynamic socio-ecological setting provided an ideal context for engaging diverse communities in our study.

2.2. Data collection

We collected primary data through a workshop, interviews (n = 105) and focus group discussions (n = 3). Data collection was conducted from April 3 to May 6, 2024, in the buffer zones of Lantang, spanning nine rural municipalities. These rural municipalities included Gosaikunda, Kalika, and Naukunda in Rasuwa district; Helambu, Panchpokhari Thangpal, and Jugal in Sindhupalchowk district; and Dupcheshwor, Tadi, and Suryagadi in Nuwakot district. Permission to conduct our study was obtained from the Department of National Park and Wildlife Conservation, Nepal.

2.2.1. Interview

We conducted face-to-face, semi-structured interviews using questions refined through a rapid appraisal and pre-testing to ensure clarity and contextual relevance. The rapid appraisal included a half-day stakeholder workshop on March 26, 2024, in Gosainkunda Rural Municipality, Rasuwa, to refine the interview questions further. Fifteen participants were purposively selected for their direct or indirect involvement with Langtang, representing diverse backgrounds, including buffer zone user committees, conservation practitioners, entrepreneurs, farmers, hoteliers, journalists, local leaders, NGO workers, and mothers' groups.

The workshop included breakout sessions that divided participants into two groups for structured discussions. Insights from these sessions produced a list of 23 ecosystem services and six ecosystem disservices specific to Langtang (Table S1). Each group also identified one key service from the provisioning, regulating, and cultural categories considered most important for conservation and local livelihoods, highlighting hydropower, carbon sequestration, and nature-based tourism, respectively.

On March 27–28, 2024, we conducted pre-testing interviews in Gosainkunda rural municipality in Rasuwa district to assess the reliability and validity of the interview questions before the main data collection. We interviewed five respondents, including a farmer, a hotelier, a herder, a local political leader, and a member of the buffer zone user committee.

We selected 12 data collection sites in Rasuwa, 7 in Sindhupalchowk, and 5 in Nuwakot (Table S2) using convenience sampling, a

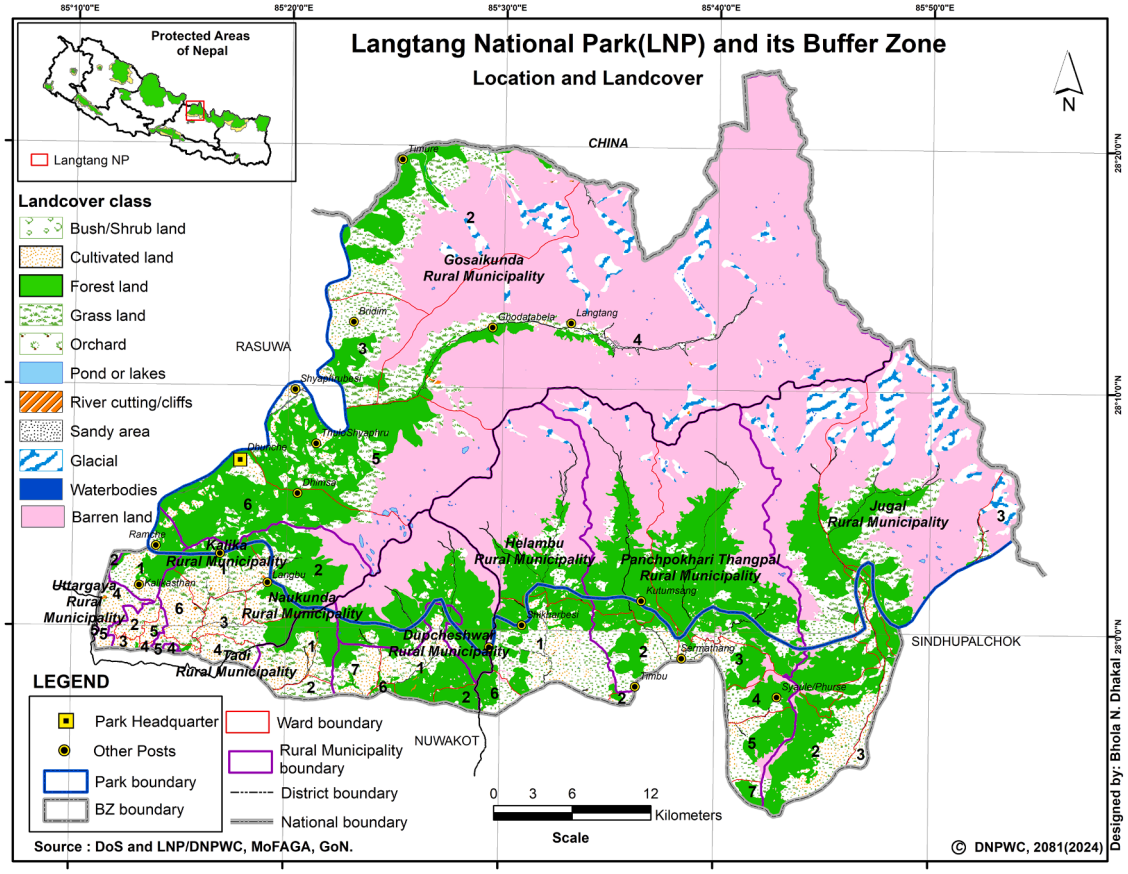

Fig. 1. Location map of the study area. The map highlights the rural municipalities where the study was conducted and shows land use types. Adapted from Lantang National Park (LNP) and buffer zone: location and land cover, published by the Government of Nepal, Ministry of Forests and Environment (MOFE), DNPWC (2024) (https://dnpwc.gov.np/media/others/Langtang_location_map_2081.jpg).

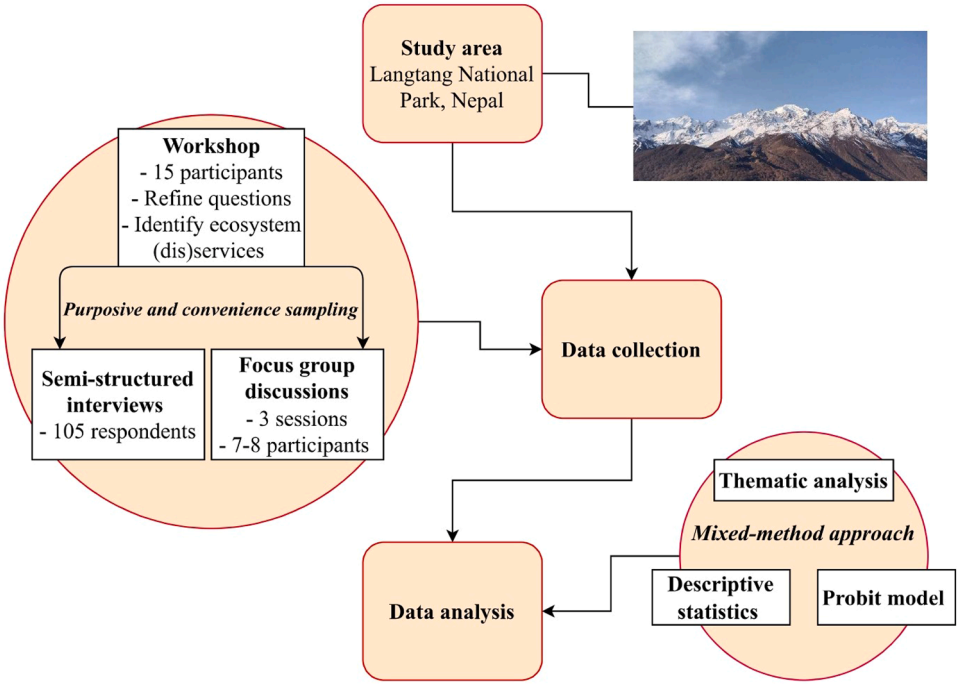

Fig. 2. Methodological Framework. The figure presents the data collection methods, sampling techniques, and analytical procedures applied in the study.

nonprobability sampling method. Consistent with the principles of convenience sampling (Etikan et al., 2016), we prioritized sites based on practical considerations, including accessibility, geographic proximity, and respondents' availability. Accordingly, we chose human settlements along trekking trails or accessible mountainous earthen roads as data collection sites.

At each site, we used purposive sampling to select respondents, based on the principle that individuals with specific backgrounds offer valuable insights aligned with our objectives (Campbell et al., 2020). We purposefully included participants from diverse professional backgrounds, such as farmers, local political leaders, school teachers, Langtang officials, and social workers, to capture a broad range of perspectives shaped by their roles and experiences. In total, we conducted 105 face-to-face interviews using a printed set of finalized questions (Text S2). The interviews followed a semi-structured and survey-oriented format and typically lasted between 30 and 90 min. Informed consent was obtained before each interview, and we documented responses by taking detailed notes directly on the printed question sets.

The interview questions were developed and administered in Nepali. To assess respondents' understanding of ecosystem services, we began with the literal translation, *paristhitika pranali sewa haru*, though this was often unfamiliar. We therefore used more accessible expressions, such as *prakriti ko sewa haru* (nature's services) or *watawaraniya sewa haru* (environmental services). As *sewa haru* (services) was not always intuitive, we adopted *faida haru* (benefits), with *watawaraniya faida haru* (environmental benefits) emerging as the most widely understood term. Similar challenges arose for ecosystem disservices (Nepali literal translation, *paristhitika pranali ko nakaratmak sewa haru*). Thus, we used alternatives such as *prakriti ko nakaratmak sewa haru* and *watawaraniya nakaratmak sewa haru,* with *watawaraniya befaida haru* (environmental disadvantages or disbenefits) being most widely understood.

We consistently began with the literal Nepali translation of key terms, introducing alternative expressions only when needed. The interview then included a brief overview of ecosystem services and disservices specific to Langtang (framed as *Langtang bata hune …* before each term), followed by Likert-scale questions. Literate respondents completed the scale independently, while researchers recorded responses for illiterate respondents with explicit consent based on their stated ratings. One particular challenge was explaining carbon sequestration (*karbon sanchiti*). This was addressed with a simple, relatable example of humans releasing carbon dioxide (CO_2) and trees absorbing it, which most respondents readily understood.

2.2.2. Focus group discussion

We conducted three focus group discussions, one in each district of Langtang, to collect qualitative data. The discussion sites were selected using convenience sampling. Each group comprised seven to eight participants, consistent with Guest et al. (2016), who recommend that three focus groups with six to twelve participants are sufficient to capture diverse perspectives. Participants were selected purposively to ensure representation across diverse social backgrounds, with particular attention to gender balance. They included national park-dependent communities, such as farmers, herders, forest-based entrepreneurs and hoteliers. Each discussion followed a structured checklist covering key topics: participants' understanding of Langtang, services important to local livelihoods, disservices of concern, and how these (dis)services relate to daily lives and livelihood activities. Each session lasted approximately 90 min, and we recorded the discussions through detailed note-taking.

2.3. Data analysis

The data analysis used descriptive statistics, an econometric *probit* model, and thematic analysis. Descriptive statistics summarized respondents' socio-demographic characteristics and their perceptions of ecosystem (dis)services in Langtang. The *probit* regression model was used to estimate the influence of socio-demographic factors on perceptions of ecosystem (dis)services in the study area. At the same time, thematic analysis was applied to qualitative data obtained from semi-structured interviews and focus group discussions. The qualitative findings complemented the probit model results, providing deeper insights into local perspectives.

2.3.1. Probit model

We conducted *probit* regression analysis using STATA 16. The *probit*

model is widely employed in studies examining perceptions and awareness levels (Adnan et al., 2023; Xie et al., 2022). It is particularly suitable for analyzing binary-dependent variables, in which the independent variables comprise both continuous and categorical data (Saqib et al., 2016; Ado et al., 2019).

The selection of three ecosystem services, including hydropower, carbon sequestration, and nature-based tourism as dependent variables, was guided by breakout group discussions with local stakeholders during the workshop described earlier. In addition, three ecosystem (dis) services, such as allergies, barriers to development and construction, and legal complications, were retained as dependent variables based on their statistical significance and overall model fit during preliminary analyses. Disservices that did not demonstrate sufficient explanatory power or adequate model performance were excluded from subsequent analyses.

For the *probit* regression analysis (Text S3), Likert-scale responses originally measured on a five-point scale were dichotomized to meet model assumptions. Responses of 4 and 5 were coded as "1″ (indicating high or important perception), whereas responses of 1, 2, and 3 were coded as "0" (indicating low or unimportant perception) (Table 1). Independent variables primarily consist of socio-demographic characteristics, including district, gender, marital status, ethnicity, age, religion, family size, education, occupation, and dependence on timber, with both continuous and categorical data types represented (Table 1).

2.3.2. Thematic analysis

We conducted a thematic analysis to systematically interpret qualitative data. The process began with transcribing and carefully examining insights from semi-structured interviews and focus group discussions to gain an in-depth understanding of the data. Next, we proceeded to code, identify patterns (themes), and interpret these themes to generate meaningful insights (Finlay, 2021; Graham and Clarke, 2021). Themes initially emerged inductively from the qualitative data. Following the quantitative analysis, results from the descriptive statistics and *probit* model informed the refinement and interpretation of the identified themes, thus shaping the subsequent phases of the thematic analysis. This iterative approach enabled us to explore contrasting narratives related to socio-demographic variables within the thematic content. Additionally, we established a clear connection between the thematic analysis findings and the *probit* model results, thereby strengthening the overall analysis.

3. Results

3.1. Socio-demographic characteristics of the respondents

Among the 105 respondents, the majority (52%) were from Rasuwa district, followed by 31% from Sindhupalchowk and 17% from Nuwakot district (Table 1 and Table S3). Most respondents were male (81%), while 19% were female. This gender imbalance reflects the socio-cultural and institutional context of the Langtang region, where males tend to dominate household decision-making and occupy community leadership roles, making them more accessible during data collection. The relatively low representation of women in local institutions, including government positions, political parties, and buffer zone user committees, further limited their inclusion in our study. The majority of the respondents (87%) reported being married. Regarding ethnicity, 64% of respondents identified as Tamang/Hyolmo, while the remaining 36% belonged to other ethnic groups, including Brahmin/Chhetri, Ghale, Newar, and Sherpa. The age distribution showed that 60% were between 41 and 60 years old, while the remaining 40% were between 18 and 40 years old. Religious affiliation was predominantly Buddhist (88%), while 12% identified as Hindu. The respondents' educational backgrounds varied: 61% had received formal education, while 39% had none. Overall, 40% of respondents were farmers. In comparison, 60% were engaged in non-farming occupations, such as elected government representatives, hoteliers, local political leaders, Langtang National Park employees, members of buffer zone user committees, schoolteachers, and social workers. Overall, the socio-demographic profile reflects the regional context of the Langtang area, characterized by the predominance of Tamang/Hyolmo communities, Buddhist traditions, male-headed households, and livelihoods based on agriculture and nature-based tourism.

Table 1
Descriptive statistics of the variables used in the *probit* regression model. We present the mean and standard deviation (SD) of the dependent and independent variables, including the descriptions of dummy variables for district, gender, marital status, ethnicity, age, religion, family size, education, occupation, and dependence on timber.

Variable	Description	Mean	SD
Dependent variables			
Hydropower	Dummy = 1 if the respondent considers hydropower important (4–5), and 0 if unimportant (1–3).	0.64	0.48
Carbon sequestration	Dummy = 1 if the respondent considers carbon sequestration important (4–5), and 0 if unimportant (1–3).	0.80	0.40
Nature-based tourism	Dummy = 1 if the respondent considers nature-based tourism important (4–5), and 0 if unimportant (1–3).	0.60	0.49
Allergies	Dummy = 1 if the respondent considers allergies to be high (4–5), and 0 if low (1–3).	0.58	0.49
Barriers to development and construction	Dummy = 1 if the respondent considers barriers to development and construction to be high, and 0 if low (1–3).	0.47	0.50
Legal complications	Dummy = 1 if the respondent considers legal complications to be high (4–5), and 0 if low (1–3).	0.38	0.48
Independent variables			
District	Rasuwa is the reference group (coded as 0 for the dummy variable).	0.52	0.50
Sindhupalchowk	Dummy = 1 if the respondent is from Sindhupalchowk, and 0 otherwise	0.31	0.46
Nuwakot	Dummy = 1 if the respondent is from Nuwakot, and 0 otherwise	0.17	0.37
Gender	Dummy = 1 if the respondent is male, and 0 otherwise	0.81	0.39
Marital status	Dummy = 1 if the respondent is married, and 0 otherwise	0.87	0.33
Ethnicity	Dummy = 1 if the respondent belongs to the Tamang/Hyalmo group, and 0 otherwise	0.64	0.48
Age	Dummy = 1 if the respondent belongs to 41–60 years age group, and 0 otherwise	0.60	0.49
Religion	Buddhist is the reference group (coded as 0 for the dummy variable)	0.88	0.32
Hindu	Dummy = 1 if the respondent belongs to Hindu, and 0 otherwise	0.12	0.32
Family size	Continuous, number of family members	1.53	0.50
Education	Dummy = 1 if the respondent attended formal education, and 0 otherwise	0.61	0.49
Occupation	Dummy = 1 if the respondent is a farmer, and 0 otherwise	0.40	0.49
Timber	Dummy = 1 if the respondent considers timber as important, and 0 otherwise	0.57	0.49

3.2. Determinants of perception of ecosystem services

Our *probit* regression and thematic analyses show significant differences in perceptions of ecosystem services, particularly hydropower, carbon sequestration, and nature-based tourism, shaped by socio-demographic factors.

3.2.1. Hydropower

Local perceptions of hydropower as an ecosystem service provided

by Langtang are mixed: 64% of respondents consider it important, while 36% perceive it as unimportant (Table 1). Our *probit* regression analysis indicates that determinants such as geographical location, marital status, and occupation are significantly associated with these perceptions (Table 2; Table S4). In particular, respondents from Sindhupalchowk and Nuwakot are significantly less likely than those from Rasuwa to perceive hydropower as important, with marginal effects indicating reductions of 40% and 26%, respectively (Table 2; Table S5).

These district-level differences are further corroborated by qualitative findings, which reveal contrasting benefits and concerns across sites. Respondents in Rasuwa (MQ10, MQ42, and MQ47) highlighted tangible economic benefits from hydropower, including equity shares, improved road infrastructure, installation of drinking water supply systems, and improved healthcare facilities. A closer look at equity ownership shows notable contrasts: while 70% of respondents in Rasuwa reported holding equity shares in hydropower projects, only 27% in Nuwakot and 10% in Sindhupalchowk did so (Table S6). Conversely, focus group participants in Melamchighyang, Sindhupalchowk, expressed concerns about adverse environmental impacts, including soil erosion, landslides, and reduced irrigation water.

Marital status is significantly associated with perceptions of hydropower: married respondents are more likely than unmarried respondents to consider it an important ecosystem service (Table 2). Marginal effects indicate that being married increases this probability by 29% (Fig. 3). Farmers are significantly less likely than non-farmers to view hydropower as important, with a 20% reduction in likelihood. Qualitative insights help explain these associations. Married respondents and non-farmers during interviews (MQ13, MQ21, MQ34, MQ40, and MQ60) generally emphasized hydropower's benefits, such as reliable household energy, improved infrastructure, and investment and employment opportunities. In contrast, unmarried respondents and farmers during interviews (MQ25, MQ36, MQ68, MQ90, and MQ105) highlighted environmental concerns, including deforestation, soil erosion, landslides, construction-related disturbances, pollution, and perceived threats to biodiversity. One respondent explained:

> "*Hydropower brings many environmental problems. Vibration scare wildlife and change their behavior. High tension lines cut through the forest, and nothing grows under them. Construction spreads dust and waste. Dams and water storage harm rivers and fish and water life disappearing" (MQ25).*

3.2.2. Carbon sequestration

Perceptions of carbon sequestration are largely positive: 80% of respondents consider it important, and 20% perceive it as unimportant (Table 1). The results from *probit* regression analysis show that geographical location and education level are significantly associated with these perceptions (Table 2; Table S7).

Respondents from Sindhupalchowk are significantly more likely than those from Rasuwa to view carbon sequestration as an important ecosystem service, with marginal effects indicating a 19% higher likelihood (Table 2; Table S8). Qualitative insights reinforce this pattern, as focus group participants in Malamchighyang of Sindhupalchowk highlighted the cultural and spiritual significance of forests in Buddhist traditions, noting their role in supplying oxygen and protecting communities, particularly those at the base of steep hills, from landslides. As one participant from the discussion explained:

> "*You can see dense forests on the hills. We, the people of Melamchighyang, worship the forest as a god, a belief rooted in our Buddhist traditions. We value it for two main reasons. First, it provides us with fresh air (oxygen); when I travel to urban areas, I often feel breathless. Second, it protects our village from landslides, as our settlement lies at the foot of the hills" (Focus group participant, Melamchighyang, Sindhupalchowk).*

Respondents with formal education are more likely than those without to consider carbon sequestration an important ecosystem service, with marginal effects indicating a 29% increase in likelihood (Fig. 3). Supporting qualitative insights illustrate how educational exposure promotes environmental awareness. For instance, schoolteachers interviewed (MQ1 and MQ9) noted the establishment of eco-clubs in schools that promote conservation values, and the carbon cycle is included in the school curriculum from the primary level.

3.2.3. Nature-based tourism

Perceptions of nature-based tourism as an ecosystem service varied among respondents: 60% considered nature-based tourism important, while 40% did not (Table 1). *Probit* regression analysis shows that geographical location, age, and perceived importance of timber are

Table 2

Determinants of local perceptions of ecosystem services. The table presents the results of a probit regression analysis examining factors influencing local perceptions of hydropower, carbon sequestration, and nature-based tourism. We include ten categories of independent variables, with coefficients (β), standard errors (SE), and marginal effects (dy/dx) reported. Coefficients represent estimated effects, with SE in parentheses. Blank cells denote unavailable data. Significance levels: $p < 0.10$ (*), $p < 0.05$ (**), and $p < 0.01$ (***) indicate significance at the 90%, 95%, and 99% confidence levels, respectively. Marginal effects (dy/dx) for factor levels are the discrete change from the base level. Model fit statistics include the chi-square, Prob > chi2, and Pseudo R-squared.

Variable	Hydropower		Carbon Sequestration		Nature-based tourism	
	β (SE)	dy/dx	β (SE)	dy/dx	β (SE)	dy/dx
District						
Rasuwa (reference)						
Sindhupalchowk	-1.24*** (0.32)	-0.40	1.06** (0.43)	0.19	-0.80** (0.31)	-0.26
Nuwakot	-0.84** (0.40)	-0.26	-0.01 (0.50)	-0.003	-0.84** (0.39)	-0.27
Gender	-0.44 (0.38)	-0.13	-0.14 (0.41)	-0.03	0.20 (0.34)	0.06
Marital status	1.01** (0.48)	0.29	0.45 (0.59)	0.092	-0.78 (0.50)	-0.25
Ethnicity	0.12 (0.34)	0.03	-0.13 (0.44)	-0.02	-0.20 (0.33)	-0.06
Age	-0.23 (0.32)	-0.068	0.16 (0.41)	0.03	0.80** (0.33)	0.25
Religion						
Buddhist (reference)						
Hindu	-0.46 (0.52)	-0.13	-0.28 (0.76)	-0.05	-0.21 (0.51)	-0.06
Family size	-0.39 (0.28)	-0.01	-0.54 (0.36)	-0.11	-0.38 (0.28)	-0.12
Education	-0.23 (0.34)	-0.07	1.43*** (0.41)	0.29	0.08 (0.33)	0.02
Occupation	-0.69** (0.33)	-0.20	-0.43 (0.37)	-0.08	-0.50 (0.32)	-0.16
Timber	0.31 (0.29)	0.091	-0.36 (0.34)	-0.07	0.53* (0.28)	0.17
No. of observations (n)	105		105		105	
Chi-square	27.30		27.79		22.83	
Prob > chi2	0.004		0.003		0.019	
Pseudo R-squared	0.20		0.26		0.16	

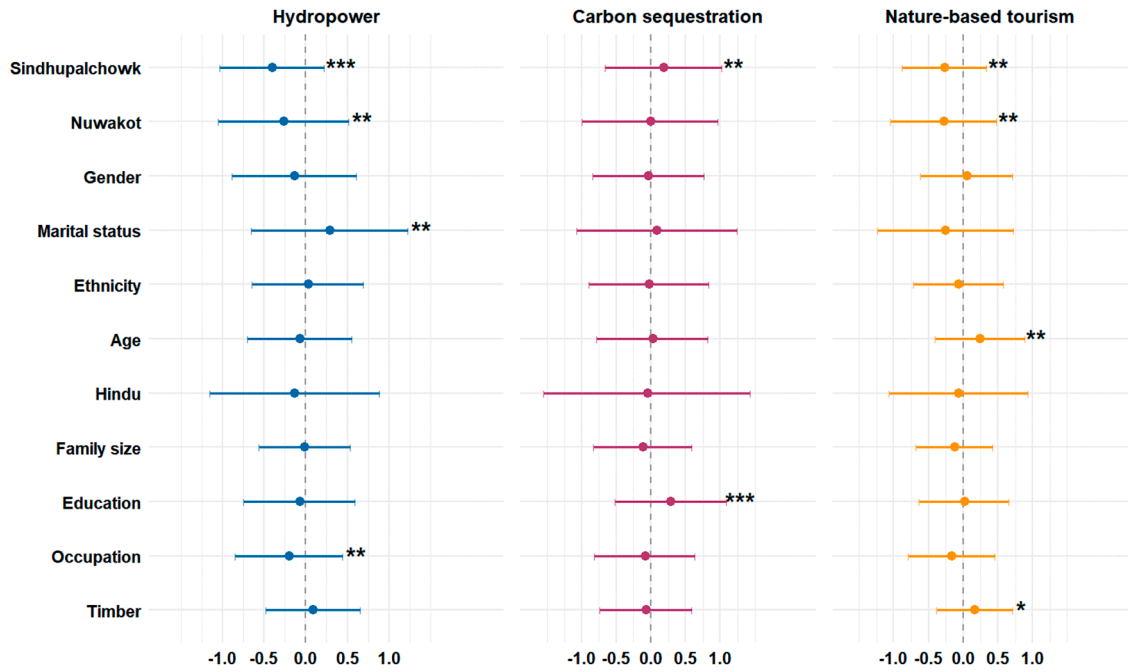

Fig. 3. Marginal effects from *probit* regression model examining the influence of socio-demographic factors on local perceptions of ecosystem services: hydropower, carbon sequestration, and nature-based tourism. Dots indicate estimated marginal effects (dy/dx) and horizontal lines represent 95% confidence intervals. Asterisks denote significance levels (*p < 0.10, **p < 0.05, ***p < 0.01). The Y-axis lists the independent variables, and the X-axis represents the range of marginal effects.

significantly associated with these perceptions (Table 2; Table S9).

Specifically, respondents from Sindhupalchowk and Nuwakot are less likely than those from Rasuwa to view nature-based tourism as important, with marginal effects indicating reductions of 26% and 27%, respectively (Table 2; Table S10). Thematic insights provide context for these differences, as respondents (HE17 and MQ76) highlighted that district-level disparities in tourist attractions, tourist volume, and local tourism infrastructure significantly contribute to this negative association. Focus group participants in Kadeni, Nuwakot, also attributed lower tourist numbers to inadequate tourism promotion. As one respondent from Sindhupalchowk noted:

> "*Our district has good places like Panchpokhari and the Amayangri trek. It's tourist season now. You came from Rasuwa; you must have seen many international tourists there. But here, have you seen any? Not even one. That's the problem, no proper promotion and no facilities. We just don't have what Rasuwa has" (MQ78).*

Age is also significantly associated with perceptions of nature-based tourism: respondents aged 41–60 years are more likely than those aged 18–40 years to consider it important, with marginal effects indicating a 25% higher probability (Fig. 3). Qualitative evidence from focus group discussions in Bhrittim, Rasuwa, suggests that younger individuals increasingly pursue alternative careers due to tourism's seasonal income and its vulnerability to external shocks, including the COVID-19 pandemic and the 2015 earthquake. Moreover, many young people migrate to urban centers or abroad in search of better employment and education opportunities.

Recognizing timber's importance increases the probability of perceiving nature-based tourism as important by 17% (Fig. 3). Thematic analysis underscores this linkage: respondents interviewed (MQ35, MQ51, MQ71, and MQ91) highlighted that forest conservation supports nature-based tourism by ensuring a reliable supply of timber for the development of essential tourism facilities, including shelters, trekking trails, rest areas, and footbridges, within sustainable forest management practices.

3.3. Determinants of perceptions of ecosystem disservices

The following sections present results demonstrating significant variation in perceptions of ecosystem disservices, particularly allergies, barriers to development and construction, and legal complications, shaped by socio-demographic factors.

3.3.1. Allergies

Perceptions of allergies differed among respondents: 58% considered allergies as highly prevalent, while 42% did not (Table 1). Probit regression analysis shows that ethnicity, gender, geographical location, occupation, and religion are significantly associated with these perceptions (Table 3; Table S11).

Respondents from Sindhupalchowk and Nuwakot are significantly more likely than those from Rasuwa to consider allergies very common, with marginal effects indicating increases of 44% and 32%, respectively (Table 3; Table S12). Qualitative insights align with these results. Focus group participants in Melamchighyang of Sindhupalchowk noted a higher prevalence of allergies due to reliance on agriculture, animal husbandry, and forest resources, which increase exposure to allergenic plants and insects. A respondent (MQ95) explained that allergies vary with local plant species. For example, the bark of Chilaune (*Schima wallichii*) can cause skin irritation in Nuwakot. These geographical differences also align with the significant association between ethnicity and perceptions of allergy prevalence, with Tamang/Hyalmo respondents 20% less likely than non-Tamang respondents to consider allergies highly prevalent (Fig. 4).

Farmers are significantly more likely than non-farmers to perceive allergies as highly prevalent, with a 24% increase in likelihood (Fig. 4). Male respondents are less likely than female respondents to report allergies as common, with a 36% reduction in likelihood. These associations are further supported by qualitative insights: female respondents and farmers (MQ28, MQ31, MQ32, MQ35, MQ39, MQ55, and MQ88) described extensive knowledge of allergy sources linked to forest use and gendered roles, citing examples such as larvae on *Utis* (*Alnus nepalensis*) causing seasonal allergies, pollen-induced irritation, butterfly-related infections, and skin reactions caused by Chilaune, and

Table 3
Determinants of local perceptions on allergies, barriers to development and construction, and legal complications. The table presents the results of a probit regression analysis. Ten independent variable categories are included, with coefficients (β), standard errors (SE), and marginal effects (dy/dx) reported. Coefficients represent estimated effects, with SE in parentheses. Blank cells denote unavailable data. Significance levels: $p < 0.10$ (*), $p < 0.05$ (**), and $p < 0.01$ (***) indicate significance at the 90%, 95%, and 99% confidence levels, respectively. Marginal effects (dy/dx) for factor levels are the discrete change from the base level. Model fit statistics include the chi-square, Prob > chi2, and Pseudo R-squared.

Variable	Allergies		Barriers to development and construction		Legal complications	
	β (SE)	dy/dx	β (SE)	dy/dx	β (SE)	dy/dx
District						
Rasuwa (reference)						
Sindhupalchowk	1.69*** (0.41)	0.44	−0.25 (0.31)	−0.08	−0.31 (0.32)	−0.09
Nuwakot	1.13*** (0.43)	0.32	0.49 (0.39)	0.17	0.48 (0.39)	0.16
Gender	−1.43*** (0.49)	−0.36	0.47 (0.34)	0.16	−0.62* (0.34)	−0.20
Marital status	0.72 (0.53)	0.18	−0.38 (0.45)	−0.13	0.06 (0.48)	0.02
Ethnicity	−0.79* (0.41)	−0.20	0.04 (0.32)	0.01	0.57* (0.34)	0.18
Age	0.20 (0.33)	0.05	0.53* (0.30)	0.18	0.35 (0.31)	0.11
Religion						
Buddhist (reference)						
Hindu	−1.34** (0.61)	−0.34	−1.04** (0.52)	−0.35	−0.27 (0.56)	−0.08
Family size	0.15 (0.32)	0.04	−0.16 (0.27)	−0.05	0.10 (0.28)	0.03
Education	0.29 (0.37)	0.07	0.44 (0.31)	0.15	0.76** (0.33)	0.24
Occupation	0.94** (0.38)	0.24	−0.35 (0.30)	−0.12	0.38 (0.31)	0.12
Timber	−0.03 (0.14)	−0.008	0.17 (0.13)	0.05	0.06 (0.13)	0.02
No. of observations (n)	105		105		105	
Chi-square	46.95		20.33		19.88	
Prob > chi2	0.00		0.041		0.04	
Pseudo R-squared	0.32		0.14		0.14	

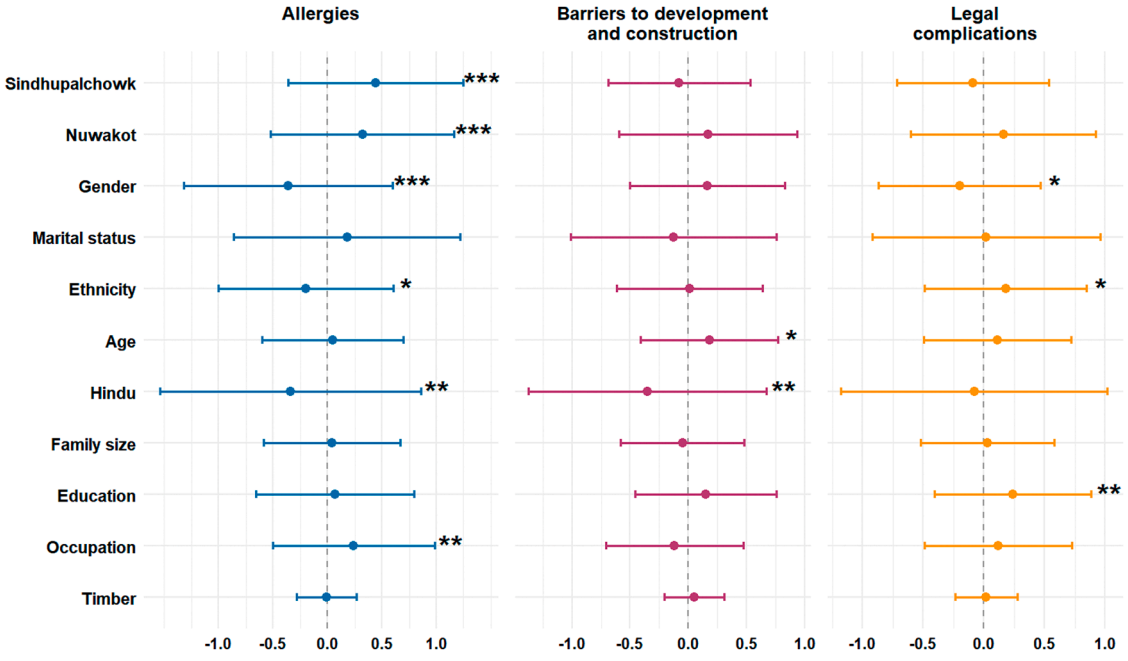

Fig. 4. Marginal effects from *probit* regression model examining the influence of socio-demographic factors on local perceptions of ecosystem disservices: allergies, barriers to development and construction, and legal complications. Dots indicate estimated marginal effects (dy/dx) and horizontal lines represent 95% confidence intervals. Asterisks denote significance levels (*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$). The Y-axis lists the independent variables, and the X-axis represents the range of marginal effects.

Bhalaayo (*Semecarpus anacardium*).

3.3.2. *Barriers to development and construction*

Perceptions of barriers to development and construction were mixed: 53% considered them low-prevalence, and 47% considered them highly prevalent. Age and religion are significantly associated with these perceptions (Table 3; Table S13). Hindu respondents were 35% less likely than Buddhist respondents to view barriers arising from national park regulations as highly prevalent (Table 3; Fig. 4). Older respondents (41–60 years) were more likely than younger respondents (18–40 years) to perceive such barriers as substantial, with an 18% increase in the likelihood (Table S14).

Qualitative insights further elucidate these contrasting perspectives. The divergence largely stems from differing stakeholder priorities, with conservationist authorities emphasizing environmental protection, while local people prioritize development needs, a tension compounded by limited mutual awareness and political incentives to demonstrate progress through visible infrastructure projects, particularly road construction (MQ105). Older respondents (MQ1, MQ17, and MQ91) aged 41–60 years frequently described Langtang as a constraint on road

construction, noting that using local materials (e.g., stones and timber) or initiating construction requires permissions and lengthy, complex environmental impact assessments. In contrast, younger respondents (MQ33) cautioned that road expansion could negatively affect tourism-related businesses by reducing opportunities for local enterprises. To illustrate these challenges in practice, one respondent explained:

> *"Our village road in the hills only works during the dry season. After the rains, we must clear mud, stones, and fallen trees to use the road again. But the national park requires permission. Do we really need permission just to open the road to take crops to market or sick people to the hospital? Every season, we face this problem" (MQ59).*

3.3.3. Legal complications

Perceptions of legal complications were lower: 38% of respondents considered them highly prevalent, while 62% viewed them as low (Table 1). Gender, ethnicity, and education are significantly associated with these perceptions (Table 3; Table S15).

Male respondents were less likely than female respondents to perceive legal complications as highly prevalent, with a 20% reduction in the likelihood (Table 3; Table S16). In contrast, Tamang respondents were 18% more likely than non-Tamang respondents to report high prevalence (Fig. 4). Qualitative insights indicate that female and Tamang respondents (MQ37, MQ43, and MQ44) often described park regulations as cumbersome, emphasizing the multiple procedural steps and royalties required to access resources that have been collected for generations. One respondent explained these legal complications:

> *"The forest has been our lifeline since our ancestors. We get firewood, food, fodder, grazing for our animals, and even shelter from it. But now the national park laws say we need permission and have to pay fees for all of this. It makes it difficult for us to make a living" (MQ43).*

Respondents with formal education are more likely than those without to consider legal complications highly prevalent, with marginal effects indicating a 24% increase in the likelihood of this view (Fig. 4). Thematic insights suggest that educated respondents (MQ87 and MQ92) tend to compare national park regulations with other regulatory frameworks, perceiving them as more complex and difficult for the general public to interpret.

4. Discussion

We systematically examine how socio-demographic factors influence perceptions of ecosystem services, particularly hydropower, carbon sequestration, and nature-based tourism, and disservices, including allergies, development and construction barriers, and legal restrictions, in the buffer zone of Langtang. Our study provides four novel insights into the socio-demographic determinants of perceptions of ecosystem (dis) service in protected areas.

First, our analysis reveals that geographical location, specifically district-level differences, significantly shapes respondent perceptions of ecosystem services. This finding is consistent with Adhikari et al. (2025), Bai et al. (2024), and Zhao et al. (2024), who similarly argue that local environmental interactions strongly condition how communities value ecosystem services. In our case, the distinct perceptions observed across Rasuwa, Sindhupalchowk, and Nuwakot likely reflect the uneven distribution of nature-based livelihoods, with hydropower development and nature-based tourism being especially prominent in Rasuwa. This spatially contingent pattern mirrors trends documented in China's mountainous regions (Wang et al., 2024), Bhutan's eastern Himalayas (Kandel et al., 2018), and India's Himalayan landscapes (Sanyal and Dasgupta, 2025), where dependence on natural resources and terrain-specific opportunities produce differentiated perceptions of ecosystem services. A similar geographic structuring is evident in perceptions of ecosystem disservices, particularly those related to allergies, where differences appear linked to the type, and abundance of tree species. This is consistent with findings from urban forest studies by Nowak and Ogren (2021), who highlight the influence of native species composition on allergy potential. Parallel evidence from cities such as Barcelona, Montreal, New York, Paris, and Vancouver further shows that pollen allergy risks vary with dominant canopy species, underscoring that allergenicity is fundamentally shaped by species-level traits and broader forest composition (Sousa-Silva et al., 2021).

Second, our results indicate that formal education and cultural-spiritual values positively influence perceptions of ecosystem services, particularly regulating services like carbon sequestration. This aligns with findings by Dehghani Pour et al. (2023); Kandel et al. (2024); Wangchuk et al. (2021), and Zhang et al. (2020b), who underscore that higher educational attainment is associated with increased awareness and appreciation of regulating services. These observations suggest that education can cultivate environmental consciousness and foster pro-conservation attitudes, likely due to the integration of environmental topics into both curricular and extracurricular programs in contexts such as Langtang. However, this relationship is not universal. Studies from the United Kingdom (Collins et al., 2019) and Nigeria (Zhang et al., 2016) found that formal education did not significantly influence perceptions of ecosystem services. This discrepancy may stem from the limited integration of ecological content in school curricula and the stronger influence of informal, experience-based learning in shaping environmental awareness (Zhang et al., 2016). Cultural and spiritual values shaping perceptions of regulating services align with the findings of Maheshwari et al. (2024), who highlight the deep historical connection between cultural ethos, religious belief systems, and nature conservation. Religious convictions can motivate conservation-oriented behavior at both individual and community levels, reinforcing norms of care and stewardship toward the natural world (Bhagwat et al., 2011). Moreover, many faiths ascribe sacred value to particular landscapes, species, or ecological processes, cultivating a sense of responsibility that supports protection (Dudley et al., 2009).

Third, our findings show that socio-demographic variables such as gender and caste/ethnicity did not significantly influence respondents' perceptions of ecosystem services, consistent with Ahononga et al. (2020) and Lima and Bastos (2019). This contrasts with studies that report strong effects of gender (Purwestri et al., 2023; Theimann et al., 2022) and caste/ethnicity (Cuni-Sanchez et al., 2016; Kandel et al., 2023; Koju et al., 2023; Zhao et al., 2024). A likely explanation is that the categories of ecosystem services examined in our study have limited gendered or ethnic dimensions, thereby reducing the salience of these factors in shaping perceptions. However, our findings reveal a different pattern for ecosystem disservices, where gender and ethnicity emerge as stronger predictors, particularly for disservices related to allergies and legal complications. This heightened sensitivity may stem from the extensive traditional ethno-botanical knowledge held by women and ethnic communities such as the Tamang. Ota et al. (2024) similarly note that women often possess deeper knowledge of indigenous biodiversity and greater traditional ecological expertise. Evidence from Ethiopia also shows that ethnicity plays a crucial role, as cultural heritage and access to natural resources shape the retention of traditional knowledge on plant uses (Gitima et al., 2025). Comparable findings have been documented among the Magar and Majhi (Malla et al., 2015), Yakkha (Subba et al., 2016), and Kumal (Thapa et al., 2025) communities in Nepal, who possess extensive ethno-medical knowledge owing to their reliance on medicinal plants for primary health care. Another plausible explanation is that greater engagement of women and ethnic communities in forest-dependent activities, which increases their exposure to potential ecosystem disservices; for example, women frequently collect and use forest resources such as fuelwood and fodder for household subsistence (Bitzer et al., 2024; Ota et al., 2024). Likewise, the significant positive association between marital status and perceptions of ecosystem services likely stems from married individuals having families to care for and households to manage, leading them to place greater value on services that support household energy needs and livelihood activities.

Fourth, our analysis reveals important synergies and trade-offs within Langtang's socio-ecological system, highlighting how respondents simultaneously perceive multiple benefits and burdens arising from ecosystem services and disservices. A notable synergy emerges between timber and nature-based tourism, whereby those who value timber are also more likely to view nature-based tourism as important. This synergy reflects the multifunctionality of forest ecosystems, which provide carbon sequestration, nature-based livelihood opportunities, recreational services, air and water regulation, protection against landslides and erosion, and nutrient cycling, and is consistent with the findings of Morgan et al. (2022), Ihemezie et al. (2022), and Taye et al. (2021). At the same time, respondents' perceptions underscore clear trade-offs between hydropower-driven economic gains and the associated environmental costs, mirroring patterns reported in Bhutan (Rai et al., 2024), Brazil (Mayer et al., 2021), China (Wang et al., 2023), India (Pandit et al., 2023), Pakistan (Sibtain et al., 2021), and Spain (Bejarano et al., 2019). The economic benefits of hydropower include income generation, investment opportunities, employment, enhanced energy access, and local development, which align with the observations of Mayeda and Boyd (2020) and Venus et al. (2022). Conversely, adverse environmental impacts such as reduced water flow, pollution, deforestation, disturbances to wildlife, and increased risks of floods and mudslides correspond with the findings of Abuhay et al. (2023) and Zhang et al. (2023).

We acknowledge some limitations in our study. First, a larger sample size, involving more respondents, could have improved the generalizability of the findings. We followed the principle of data saturation and concluded data collection when no new themes or insights emerged. To deepen our analysis, we also conducted focus group discussions to complement the interviews. Second, there is a possibility of response bias, particularly in the Likert-scale responses. To minimize this, we asked respondents to review their markings to confirm accuracy. Third, we could have included more socio-economic factors as independent variables and conducted multivariate regression analysis. Nonetheless, we ensured representation of respondents from diverse socio-demographic backgrounds by conducting interviews across different locations within Langtang, accounting for geographical variation. Fourth, the gender imbalance in our sample may limit the robustness and generalizability of gender-disaggregated findings, especially in quantitative analyses, where smaller subgroup sizes reduce statistical power. To address this, we triangulated quantitative results with qualitative findings to enhance overall robustness. Despite these constraints, our approach provides a robust foundation for understanding the socio-demographic determinants of perceptions of ecosystem (dis)service. We recommend that future research apply multivariate regression analysis and include a broader range of socio-economic factors to better capture the complex relationships that influence perceptions of ecosystem services and disservices. Additionally, future research should ensure more balanced gender representation to strengthen the generalizability of the gender-disaggregated findings.

Building on empirical insights from Langtang, we propose four policy directions to integrate ecosystem (dis)services into protected area governance, with broader relevance for similar socio-ecological contexts across the Global South. First, management plans and practices should be spatially responsive, explicitly accounting for geographical heterogeneity in ecosystem services and disservices. In Lantang, this entails strengthening institutional presence in Nuwakot and Sindhupalchowk by expanding range posts with adequate human resources, forming buffer zone user committees, and activating buffer zone community forest user groups. These structures can implement, prioritize, and design context-specific programs, such as livelihood support, equitable relief distribution, and robust compensation mechanisms. Second, governance interventions should recognize and address social diversity by drawing on indigenous and traditional knowledge and incorporating inclusive decision-making processes. In Langtang, this implies institutionalizing indigenous knowledge systems within formal governance frameworks. For instance, the traditional ecological knowledge of ethnic communities such as the Tamang/Hyolmo can be strategically leveraged to strengthen national park governance. A targeted policy action is to systematically document, validate, and promote the ethno-botanical knowledge of women and Tamang/Hyolmo community members, which can help mitigate ecosystem disservices while sustaining culturally embedded practices such as Ayurvedic treatments.

Third, investing in environmental education through formal curricula, extracurricular programs, and culturally rooted conservation initiatives can cultivate environmental stewardship and foster the long-term sustainability of biodiversity conservation. This could take several compelling forms, such as ecology-focused curricula delivered in local vernaculars, dynamic awareness-raising and training programs run by school-based eco-clubs, and conservation and educational initiatives led by monasteries in Langtang. Finally, policies should promote environmentally sustainable livelihood options that leverage synergies and mitigate trade-offs between economic development and ecological integrity, thereby enhancing conservation outcomes and community well-being. These options may include income- and employment-generating activities, such as the expansion and diversification of nature-based tourism, the promotion of water-based and non-timber forest product enterprises, the implementation of climate-resilient dairy programs, and the advancement of environmentally friendly and socially inclusive hydropower development projects.

5. Conclusions

Local perceptions of ecosystem (dis)services reveal a dynamic interplay between socio-demographic attributes and the spatial variability of Langtang's landscapes. Geographical location emerges as a consistent determinant across most ecosystem (dis)service categories, while attributes such as age, education, marital status, and occupation shape how services, including hydropower, carbon sequestration, and nature-based tourism, are valued. Similarly, socio-demographic factors, including age, education, ethnicity, gender, religion, and occupation, influence perceptions of disservices such as allergies, legal complications, and development constraints. Ecosystem services that directly support livelihoods and well-being are generally viewed positively, whereas those associated with environmental or economic trade-offs are often regarded negatively. At the same time, the intensity of disservice perceptions appears to be mediated by local forest composition, traditional and indigenous knowledge, and everyday interactions with nature. These findings underscore the need for protected area policies that respond to the spatial and socio-demographic diversity of local communities, ensuring inclusive participation and equitable distribution of benefits and burdens. Advancing sustainability in protected areas, therefore, requires trans-disciplinary approaches that integrate ecological science, geography, and socio-cultural values to build resilient and adaptive socio-ecological systems.

CRediT authorship contribution statement

Daya Raj Subedi: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Giri Prasad Kandel:** Writing – review & editing, Visualization, Methodology, Formal analysis. **Qijing Liu:** Writing – review & editing, Supervision, Conceptualization. **Dinesh Raj Bhuju:** Writing – review & editing, Methodology, Conceptualization. **Rajendra Prasad Shrestha:** Writing – review & editing. **Prajal Pradhan:** Writing – review & editing, Supervision, Methodology, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dr. Prajal Pradhan, one of the co-authors, is a member of the editorial

board of Sustainable Horizons, but was not involved in any editorial process of this submission. Other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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