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Research article

Preference, perceived change, and professed relationship among ecosystem services in the Himalayas

Kishor Aryal[a,b], Tek Maraseni[a,c,*], Armando Apan[a,d]

[a] University of Southern Queensland, Toowoomba, 4350, Queensland, Australia
[b] Ministry of Industry, Tourism, Forests, and Environment, Sudoorpaschim Province, Dhangadhi, Nepal
[c] Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou, 730000, China
[d] Institute of Environmental Science and Meteorology, University of the Philippines Diliman, Quezon City, Philippines

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ABSTRACT

The demand side of ecosystem service (ES), especially preference and perception of supply and interactions among ES, is an important yet underexplored research area for landscape planning and management in human-dominated landscapes. Taking a case of multifunctional landscape in the Hindu-Kush Himalayan region, we carried out a social survey of ES, focusing on preference, perceived change, and observed relationship among six major ES from the local people's perspective. Using a semi-structured questionnaire, data collection was done from 300 households from 10 categories of human settlements, based on watershed and land cover types. Garrett mean score (GMS), ordinal logistic regression estimates, and Chi-square test were performed for quantitative data, while an inductive approach was adopted for qualitative data analysis. The results show that at the landscape level, local people preferred water yield (GMS = 70) and crop production (GMS = 66) as the most preferred ES, whereas habitat quality (GMS = 37) and carbon sequestration (GMS = 35) were among the least preferred ES. More than 70% of the respondents believed that the supply of crop production has decreased over the last two decades; however, the supply of other provisioning and non-provisioning ES has increased as observed by majority of the respondents. Among the 15 pairs of ES, local people believe that co-occurrence of ES is possible. Majority of the respondents said that there exist synergistic relationship among 13 pairs of ES, except crop production which is negatively related with timber production and carbon sequestration. Among the identified trade-offs in ES, majority of local people believed that direct trade-offs (i.e., linear inverse relationship) is dominant as observed in 8 pairs of ES, followed by concave and convex trade-offs. Based on our analysis, we argue that the preference and perceived change of ES is more dependent on spatial heterogeneity of communities (i.e., watershed type, municipal category, and land cover type of residence) than socio-economic determinants. Further, we have discussed and suggested few policy and management measures including place-based spatial assessment of the social demand and preference, embracing agroforestry practices in ecosystem management programs, mainstreaming non-local ES in local decision making by incentives, and optimizing the supply of desired ES though integrated biophysical and socio-economic assessment of the landscape.

1. Introduction

Sustainable ecosystem management is vital for human wellbeing and ecological integrity of the natural landscapes. Two-way relationship between nature and human is crucial in sustaining intact ecosystems without alteration or significant change in earth's biophysical functioning (Goymer, 2014; Lorel et al., 2019). Inherent dynamics, non-linear functional relationships, and limited predictability of the ecosystems, especially due to increasing human influences, have challenged the existence of critical ecosystems and attainment of many sustainable development goals (DeFries and Nagendra, 2017; Grêt-Regamey et al., 2014; Hasan et al., 2020). In turn, scientific communities and policy makers are getting worried about convincing people for ecosystem management; however, they have focused on conceiving monetary value of ecosystem services (ES) (Costanza et al., 1997; Daily and Ruckelshaus, 2022; de Groot et al., 2012), stochastic model based on precautionary principles (Felipe-Lucia, 2021; Meunier et al., 2022), and developing lavish (theoretical) blueprint framework of management

* Corresponding author. Block: Q 525, University of Southern Queensland, Toowoomba, 4350, Queensland, Australia.
E-mail address: Tek.Maraseni@usq.edu.au (T. Maraseni).

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(Cha et al., 2021; Schultz et al., 2015). Livelihood support value of ES, identical pattern of people-ecosystem interaction (i.e., demand and disturbances), and local communities' perspectives about ecosystem dynamics have rarely been recognized (Pascua et al., 2017; Wu, 2013).

Natural landscape, as a mosaic of ecosystem assets (i.e., forestland, cropland, wetlands, settlements, and others), exhibits various form of spatial association and relationship among ES. There has been a long-lasting discussion about the relationship among ES whether to have synergy, trade-offs, or indifference (Aryal et al., 2022; Lee and Lautenbach, 2016; Vallet et al., 2018). The relationship among ES is not only dependent on constituency and configuration of the ecosystem assets (Costanza et al., 2017), but also defined by socio-economic demand of ES (Khosravi Mashizi and Sharafatmandrad, 2021; Mouchet et al., 2014). Besides, the relationship can be assessed through socio-economic perspectives (i.e., human interference and demand), and explained in the form of supply-demand scenario (Cavender-Bares et al., 2015; King et al., 2015). Since the inception of Millennium Ecosystem Assessment (2005), a plethora of literature can be found about bio-physical assessment of ES supply and relationship; however, socio-economic aspect has largely been ignored (Bidegain et al., 2019; Cebrián-Piqueras et al., 2020). Such socio-economic analysis is important in understanding the demand of ES, such as differences in choice and priority, perception of interactions, and availability of ES. While a landscape cannot supply all the desired ES simultaneously (Turkelboom et al., 2018), divergence in demand of ES based on differing socio-economic context of different ecosystem beneficiaries is a crucial aspect of sustainability science in ecosystem management.

Human dominated landscapes in the Himalayan region are characterized by consistent anthropogenic disturbances, such as land use change, agricultural intensification, habitat alteration and biodiversity loss, migration and urbanization (Elsen et al., 2018; Xu et al., 2008). Further, emerging climate problems in the Himalayas (i.e., increasing incidence of floods and landslides, shifting snow line, irregular and intense rainfall, temperate variables, and glacial lake outburst floods), has rectified the need of better understanding of the relationship between demand perspective of local people and supply potentials of a particular landscape (Kattel, 2022; Sharma et al., 2022; Wei et al., 2017). Quantification and modelling of ES supply-demand scenarios from regional and global dataset might ease in understanding the relationship from the broader perspective; however, perception and observation of local people is a must consideration for in-depth understanding of socio-ecological interactive relationship and feedback mechanism (Fischer et al., 2021; Shen et al., 2021). Accordingly, various global goals and national objectives, including UN Sustainable Development Goal 2015–2030, Paris Agreement-2015, Post-2020 Global Biodiversity Framework, Convention on Biological Diversity, and UN Decade on Ecosystem Restoration 2021–2030, have embraced the need for a bottom-up approach in understanding of dynamics of ES putting local people at the centre of landscape planning and management (Aryal et al., 2023b; Costanza et al., 2016; Laudari et al., 2022).

Few studies in the past have considered social and economic aspects of ES, for example, socio-economic factors in urban ecosystem by postulating urban socioecological system (Wilkerson et al., 2018), social values of ES in agriculture dominated landscapes in Argentina (Cáceres et al., 2015), social preference in biodiversity hotspot in South America (Bidegain et al., 2019), individual's preference over ES in protected area in Nigeria (Adeyemi et al., 2022), choice experiment of ES in Mongolia (Khan et al., 2019), collective social preference over ES in the United States (Campbell, 2018), and provisioning of ES based on socio-economic changes in Europe (Dunford et al., 2015). Such studies are indicative of social interest over ES but are not sufficient to articulate the differences and dynamics of socio-demographic variables over environmental gradients in multifunctional landscape in the Himalayas. A study in China explored the priority conservation in mountain ecosystems but it was solely based on bio-physical indicators (Yu et al., 2021). Likewise, perception identification of ES was done in mountain foothills but it was site-based and only focused on forestry stakeholders (Acharya et al., 2019).

Understanding of ES without the engagement of local people has very limited practical applications (Klapwijk et al., 2014). In this backdrop, we see a knowledge gap of understanding and quantifying relationship among ES (i.e., synergy, trade-offs, and indifference) from local people's perspective, and operationalizing the trade-offs relationship in multifunctional landscapes in the Himalayas. This knowledge would ease policy makers not only by optimizing the balanced supply of ES in accordance with local people preferences but also to safeguard the sustainability of state interventions for ecosystem management. In this regards, taking a case of a multifunctional landscape at the centre of Hindu-Kush Himalaya region, this research aim to fulfill the knowledge gap by answering: (1) what is the choice and preference of local people over multiple ES and what socio-demographic variables are associated with the choice, (2) what is the perceived supply trend of major ES and what are the major reasons behind the observed changes in the supply, and (3) how do local people observe and interpret relationship among various ES, and if trade-offs is the concern, how do they operationalize the trade-offs relationship among competing ES. By answering these research questions, this paper aims to build a solid foundation for sustainable management of landscapes in accordance with the interest and demand of the local people in the Himalayan region and beyond.

2. Methods

2.1. Study area

Himalayan landscape is a typical representation of high mountains, glaciers and large rivers, non-directional topographic features, multi-functional ecosystems, and rural livelihood practices. Among the major Himalayan landscapes, Hindu-Kush Himalaya is a home to about 2 billion people, enjoying multiple ES throughout the unique environmental gradient in South Asia (Hussain et al., 2019). This study was carried out in Chitwan Annapurna Landscape, that lies at the centre of Hindu-Kush Himalaya, located in the central region of Nepal (Fig. 1). Further details of the study area can be found in Aryal et al. (2023c, 2023a).

2.2. Data collection

Data collection was done through literature review, policy review, expert consultation, and household survey. Policy and literature about ES were reviewed to understand landscape and ecosystem functioning in the study area and also to understand the context of livelihood of people, development scenario in the study area, and the role of ES in supporting various biophysical and social functions and functionaries. Based on literature review, we finalized 6 major ES in the study area as: crop production– CP, timber production– TP, carbon sequestration– CS, water yield– WY, soil conservation– SC, and habitat quality– HQ. The reason behind the selection of those ES and its importance is further elaborated in Aryal et al. (2023c). Households survey was the main instrument to answer the research questions. The methodological framework of the survey is presented in Fig. 2.

The study area was divided into two broader categories, such as upstream and downstream watersheds based on flow accumulation methods in ArcGIS 10.8.1. Each type of watershed was further divided into various land cover classes based on Environmental Systems Research Institute - land cover map (ESRI, Microsoft & Impact Observatory, 2021). Considering the human settlements in and around various land cover types, we identified 10 settlement categories in the vicinity of five major land cover types, from both upstream and downstream areas. Those settlement categories were supposed to be homogenous within the category and heterogenous among the categories. We randomly selected 10 villages from each of those settlement categories. Within each village, we carried out 30 households survey, totalling 300

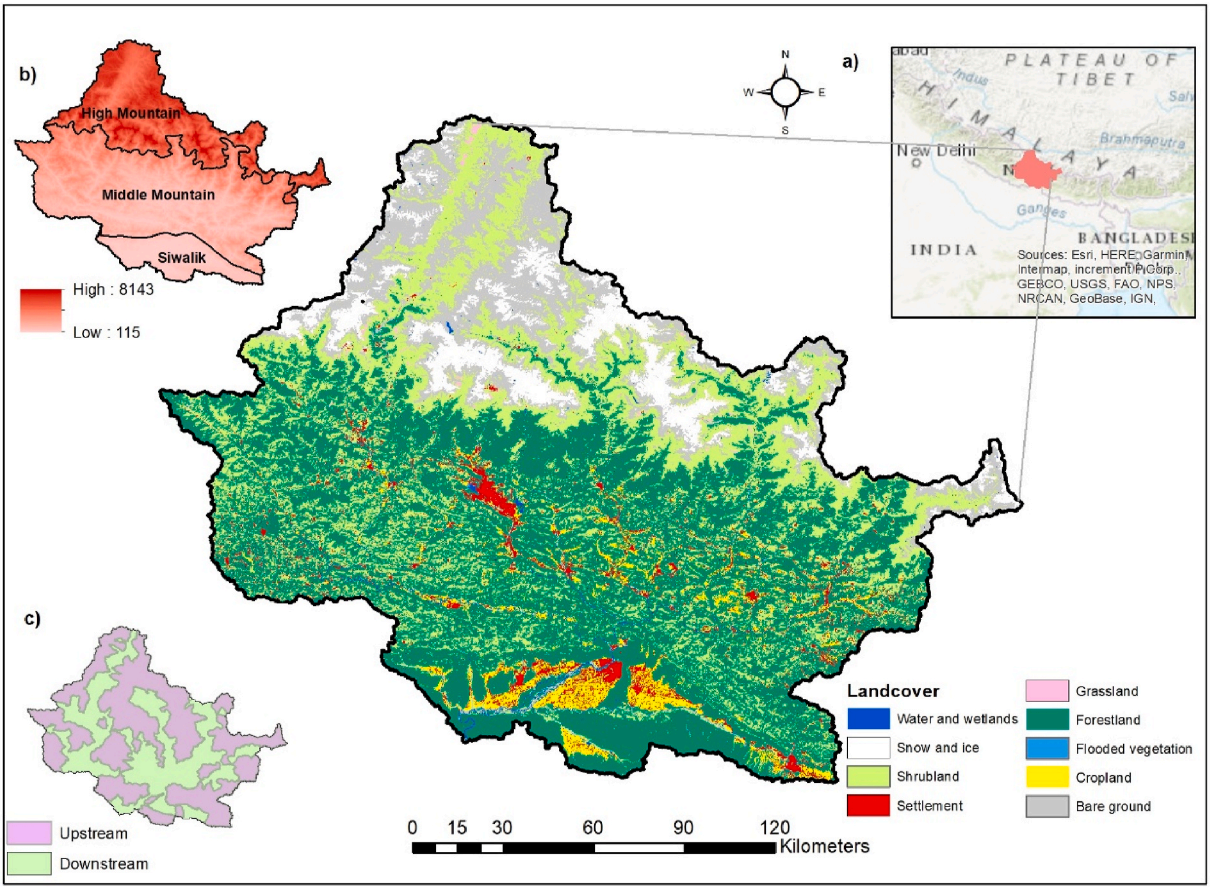

Fig. 1. Map of the study area showing land cover types. Land cover map was prepared from ESRI 10 m global land cover map. a) base map inbuilt in ArcGIS 10.8.1; b) topographic division of the study area into three classes (i.e., high mountains, middle mountains, and Siwalik lowlands) and elevation range (meter above mean sea level) extracted from SRTM digital elevation model; c) upstream and downstream watershed areas of the CHAL area.

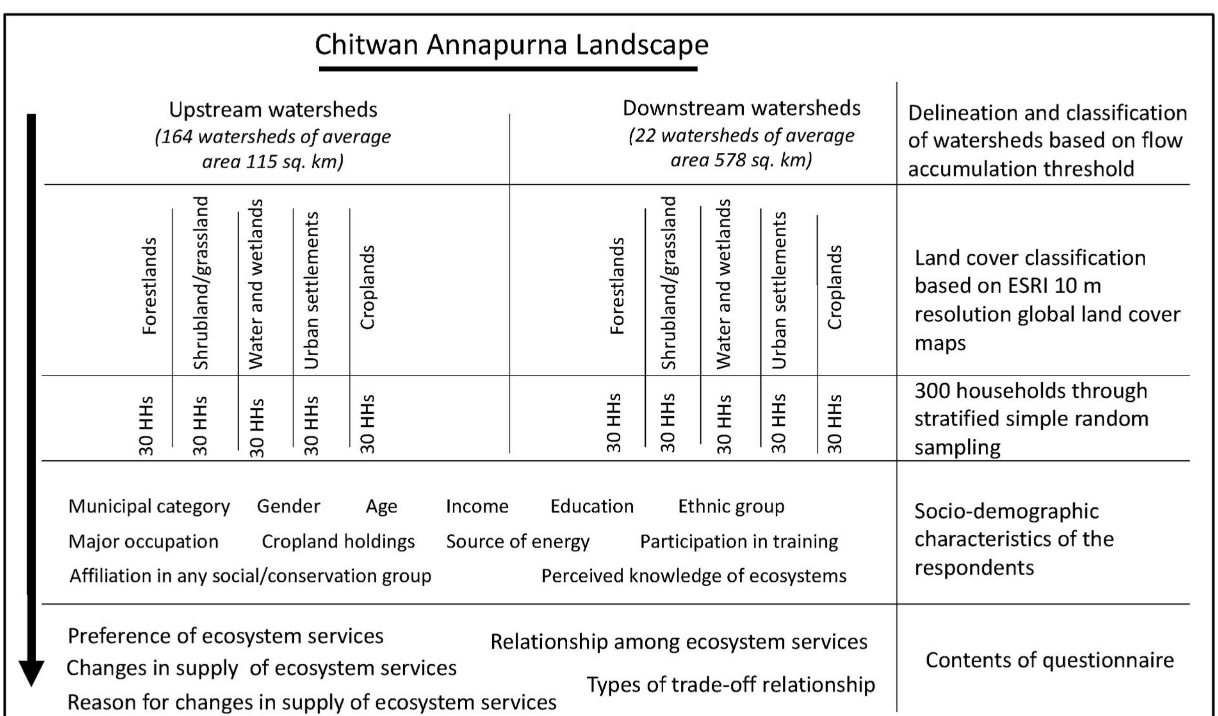

Fig. 2. Methodological framework of the household survey.

households throughout the study area. The selection of 30 households in the urban settlement was through simple random sampling. However, for the other four types of land cover categories, we randomly selected 30 households within one 1 km periphery of the land cover types to represent local people in the vicinity of the respective land cover category. In order to avoid the non-response incidents, if the selected respondent did not respond, we replaced them with the other random household member but within the periphery of the corresponding land cover types. In this regard, the collected samples were believed to be representative of the population within the place categories, which collectively represent the socio-economic preference and perception of local people for the study area.

Household survey was carried out in April–August 2022, based on a set of semi-structured questionnaire (Supplementary file A). The questionnaire was reviewed by a panel of experts (n = 3) and ethical approval was taken from the first authors' academic institution. The questionnaire was accompanied by an information sheet that contained basic information to help the respondents about basic idea and understanding of ES. The questionnaire was administered and facilitated by the personnel studying and working in the relevant field. To help the respondents to understand comparative value of ES, the questionnaire was translated into local language and supplemented by the information sheet before starting the survey of each household. First, we collected socio-demographic characteristics of the respondents which included municipal category of residence based on political classification by the Government of Nepal (n = 3; metropolitan city or municipality or rural municipality), type of housing (n = 3; house made up of mud-stone, use of brick/blocks with stainless steel roofs, or reinforced cement concrete), gender (n = 2; male or female), age group (n = 3; young age $<$35 years, mature 35–59 years, or old $\geq$60 years), family size (n = 2; single family of $\leq$4 members or joint family of $>$4 members), cropland holdings (n = 2; $<$0.5 ha or $\geq$ 0.5 ha), annual income (n = 2; below poverty line of annual income $<$1000 US$ or above poverty line), main source of energy (n = 3; biogas, fuelwood, or liquefied petroleum gas), education level (n = 4; illiterate, informal education/training, school, or university), membership in any social and/or conservation groups (n = 2; yes or no), involvement in training about natural resource and ecosystem management (n = 2; yes or no), and perceived level of knowledge about ES (n = 3; high, little, or no). Socio-demographic characteristics of the respondents is presented in Supplementary file B.

Secondly, preference ranking of ES was carried out for six major ES in the study area in the measure of 1–6 (1 implying most preferred and 6 denotes the least preferred ES). Third, perceived trends of ES were identified as increasing, decreasing or no change for each of the six ES as compared to their state of supply before 20 years. In addition to indicating the perceived trends, the questionnaire was designed to collect reasons behind the perceived trends. Fourth, the questionnaire was developed also to collect the perceived relationship among 15 pairs of the six ES. The relationship was characterized as either synergistic (i.e., both ES follow the same direction of increase/decrease), trade-offs (when one ES increases the other decreases or vice versa) or indifference (one ES is independent of increase or decreases of the other ES). If the respondents indicate trade-offs for any pair of ES, they were asked to select a type of trade-offs from among five different expressions of trade-offs in ES (Lester et al., 2013) as illustrated in Fig. 3.

2.3. Data analysis

Quantitative data analysis was done is R (R Core team, 2021). Socio-demographic characteristics of the respondents were computed through descriptive statistics. Preference ranking of the ES was done through the method of Garrett's ranking techniques (Dhanavandan, 2016). In this technique, rank-wise frequency, percent position of the rank, and Garrett Ranking Conversion Table are needed to calculate Garrett mean score. For this, rank-wise frequency (i.e., frequency for rank 1 to rank 6) was obtained for each ES. Percent position of the (rank 1 to rank 6 in our case) is calculated as:

$$Percent\ position = 100 * \frac{(Rij - 0.5)}{Nj}$$

where,

Rij = Rank given for the ith variable by the jth respondent (i.e., 1–6)

Nj = Number of variables ranked by the jth respondent (i.e., 6)

After calculation of the percent position, Garrett value of the corresponding percent position was extracted from the Garrett Ranking Conversion Table. Garrett mean score was then calculated as:

$$Garrett\ mean\ score = \frac{\sum Gpp * Rf}{N}$$

where,

Gpp = Garrett score corresponding to percent position.

Rf = Rank wise frequency.

N = Number of respondents.

This ranking was done for relevant grouping variables, as well as for the whole landscape level.

Further, ordinal logistic regression model (i.e., 'polr' function in R) was employed to understand the socio-demographic characteristics that are associated with the prioritization of ES. Ordinal ranking of ES (i.e., an ordered factor of priority 1 > 2>3 > 4>5 > 6) was response variable, while predictors for the model were municipal category, watershed types, land cover category, type of housing, gender, age group, family size, cropland holdings, income level, main source of energy, education level, membership in any social and/or conservation groups, and

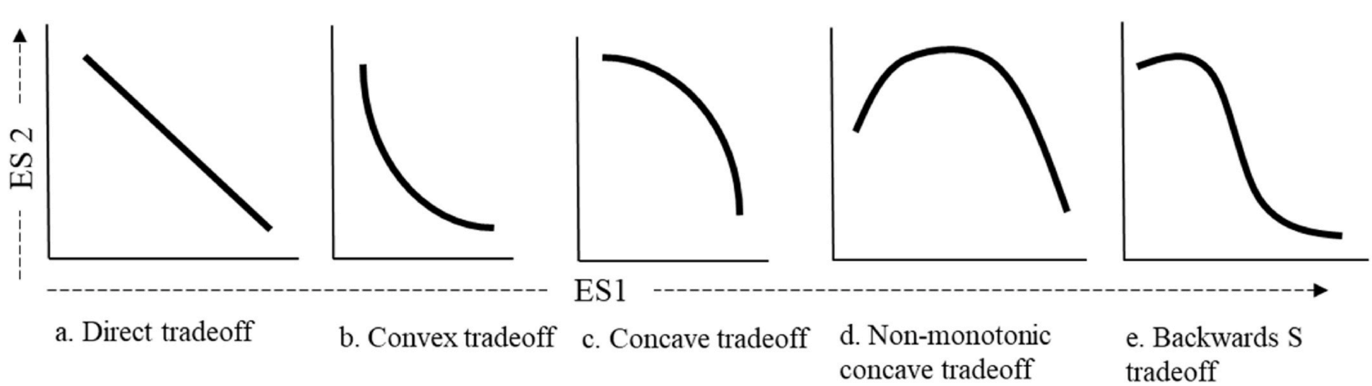

Fig. 3. Types of trade-offs in ES. With an increase in one ES, the other ES in: a) direct trade-offs = uniformly decreases; b) convex trade-offs = first highly decreases then the rate of decreases reduces; c) concave trade-offs = first slowly decreases then highly decreases; d) non-monotonic trade-offs = first increases but then highly decreases; e) backward S trade-offs = first become indifferent, after some amount it highly decreases and in the extreme level, it again become indifferent.
Source: adapted from (Lester et al., 2013)

involvement in training about natural resource and ecosystem management. The model for ordinal logistic regression was:

$$logit(P(Y \leq j)) = \beta_{j0} + \beta_1 x_1 + \cdots + \beta_n x_n$$

where, $P(Y \leq J) = 1$. Y is the ordinal outcome with the j categories. β_0 is the intercept, and β_n is the coefficient associated with X_n.

Moreover, perceived trends of ES were analysed through the use of descriptive statistics (i.e., frequency distribution). However, we conducted Pearson's Chi-square test (i.e., 'chisq.test' function in R) to understand any significant relationship of socio-demographic variables with the perceived trends of ES.

$$X^2 = \sum (Oi - Ej)^2 \Big/ Ej$$

where, X^2 = chi-square value, Oi is observed value and Ej is the expected value.

The findings of the analysis were then presented in figures and tables as appropriate.

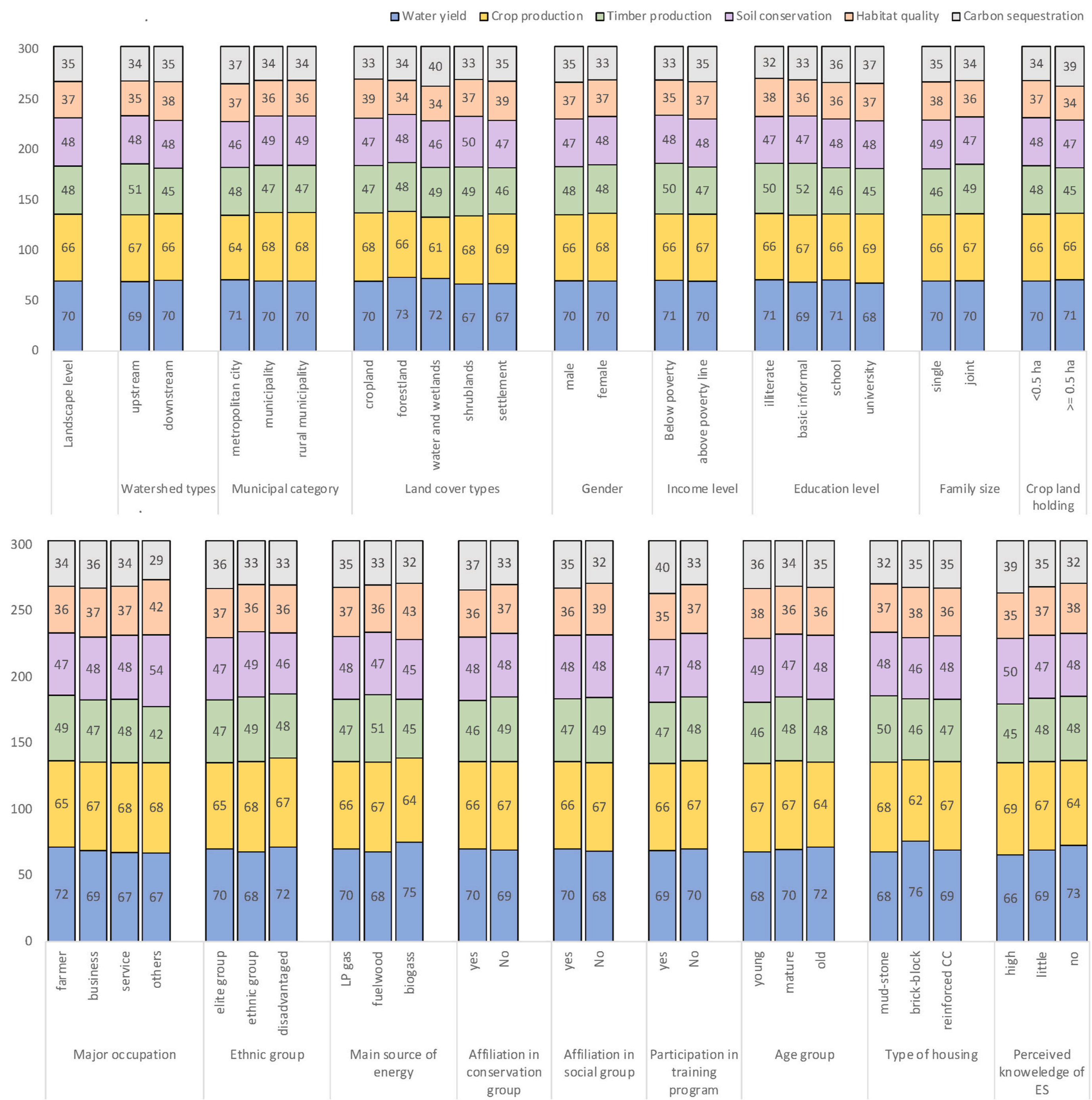

Fig. 4. Stacked bar chart showing the Garret mean score of ecosystem services based on various socio-demographic group of the respondents (i.e., highest value means 1st priority and lowest value means least priority).

3. Results

3.1. Preference ranking of ecosystem services

Among the six ES, we found three main clusters of preferences. Highest priority was given to either WY or CP; medium priority was given to either TP or SC; and least priority was given to either HQ or CS. The priority ranking of ES, with mean value of Garrett ranking for each ES, for each socio-demographic group is presented in Fig. 4.

At the landscape level, we observed WY as the 1st priority ES, followed by CP (2nd), TP (3rd), SC (4th), HQ (5th), and CS (6th). There was no difference in preference ranking of ES based on watershed types, except for TP and SC. Respondents from upstream areas prioritized TP (3rd) over SC (4th), which was reverse in case of respondents from downstream areas. Based on the proximity to land use types, respondents residing near shrublands, and urban settlements preferred CP rather than WY as the 1st priority, and similarly, they preferred SC over TP as the 3rd priority. People residing near water and wetlands prioritized CS (5th) than HQ (6th) as their preferred ES.

People above the poverty line preferred SC (3rd) than TP (4th), which was not the case for people below the poverty line. People having university degree prioritized CP (1st) than WY (2nd). Garrett mean score of CP and TP is higher for people with mud-stone house type as compared to those of the other house types. People who have acquired at least school level education preferred SC (3rd) than TP (4th). Respondents who are affiliated with a conservation group or those who have attended at least a natural resource related training program prioritized SC (3rd) than TP (4th), and CS (5th) than HQ (6th). Age groups had no effect in ranking differences except TP and SC, for which the respondents with young age found to prioritize SC(3rd) over TP (4th). Respondents who claimed to have high knowledge on ES prioritize CP (1st) over WY (2nd), SC (3rd) over TP (4th), and CS (5th) over HQ (6th).

To visualize the association of various socio-demographic variables with preference ranking of the ES, the summary of the regression coefficient of the ordinal logistic regression is presented in Table 1.

Reference variables: metropolitan city (municipal category), downstream (watershed types), croplands (proximity to land cover), female (gender), old (age group), joint family (family size), <0.05 ha (cropland holdings), above poverty (income group), biogas (main source of energy), illiterate (education level), brick and block (type of housing), no (membership in conservation group), no (membership in social group), and no (involvement in training about ecosystem services)

Various socio-demographic variables were found to be influential in differences in priority ranking of ES. For instance, preference of CP was significantly negatively associated ($r = -1.452$) with respondents from the municipality category as compared to those from respondents from metropolitan city. Similarly, preference of CP was significantly positively associated with upstream respondents ($r = 1.043$) as compared to those from downstream. TP was positively associated with municipality respondents ($r = 2.196$), crop land holding of$\geq$0.5 ha ($r = 0.916$), and participation in training program ($r = 0.625$), while it was negatively associated with upstream respondents ($r = -2.517$) as compared to their respective reference categories. Likewise, CS is negatively associated with respondents living near to water and wetlands ($r = -1.276$), crop land holding of$\geq$0.5 ha ($r = -1.061$), affiliation in conservation group ($r = -0.683$), and participation in training program ($r = -0.855$). Preference of WY is positively associated with urban settlements, people of young age, respondents with house type of mud-stone and reinforced cement concrete, but negatively associated with respondents living near to forestland. SC is positively associated with upstream people but negatively associated with municipal residents, respondents near to forestlands and shrublands. HQ was found to be significantly and positively associated with people living near to forestland and shrublands.

3.2. Perceived changes in supply of ES and associated causes of changes

Regarding the perceived supply trends of ES, majority of the respondents indicated that crop production has decreased but all the other ES have increased in the last two decades (Fig. 5). For instance, 71% respondents believed that CP has decreased, while TP, CS, WY, SC, and HQ have been increased as indicated by 71%, 63%, 67%, 43%, and 73%

Table 1
Association of socio-demographic features with the preference of ecosystem services based on ordinal logistic regression.

Socio-demographic variables		Ecosystem services					
Group	Categories	Crop production (CP)	Timber production (TP)	Carbon sequestration (CS)	Water yield (WY)	Soil conservation (SC)	Habitat quality (HQ)
Municipal category	Municipality	−1.452*	2.196**	0.098	0.316	−1.189*	−0.666
	Rural municipality	−1.687	−0.683	1.003	1.761	1.491	−1.607
Watershed types	Upstream	1.043*	−2.517**	0.695	−0.337	0.874*	0.334
Proximity to land cover	Forestland	1.100	0.284	−0.583	−1.554*	−1.376*	1.525**
	Settlements	−0.788	−0.077	−0.519	1.347**	−0.094	0.412
	Shrublands	0.667	1.717	−1.005	−0.208	−3.597**	1.828*
	Water and wetlands	0.605	0.269	−1.276*	−0.116	−0.510	0.730
Gender	Male	0.318	−0.256	−0.035	0.110	0.314	−0.328
Age group	Mature	−0.554	−0.195	0.347	0.537	0.369	−0.370
	Young age	−0.904	0.107	0.195	1.397**	0.474	−0.464
Family size	Single	0.434	0.515*	−0.169	−0.185	−0.147	−0.339
Crop land holdings	≥ 0.5 ha	0.297	0.916**	−1.061**	−0.311	−0.205	0.402
Income group	Below poverty	0.032	−0.390	0.068	−0.081	0.053	0.284
Main source of energy	Fuelwood	−0.263	−0.049	−1.771	1.501	0.975	0.913
	LP gas	0.411	−0.057	−1.315	0.656	1.060	0.623
Education level	Basic education	0.088	−0.427	0.151	0.231	−0.297	0.478
	School	0.301	0.092	−0.094	−0.392	−0.774	0.682
	University	−0.050	0.482	−0.595	0.061	−0.764	0.526
Type of housing	Mudstone	−0.552	0.372	0.290	2.137*	−0.623	−0.127
	RCC	−0.480	0.437	0.016	2.040*	−0.843	0.098
Affiliation in conservation group	yes	0.038	0.392	−0.683*	0.490	0.154	0.064
Affiliation in social group	yes	0.021	−0.016	−0.129	0.006	−0.047	0.418
Participation in training	yes	−0.300	0.625*	−0.855**	0.586	0.486	0.031

Note: Significance level * denotes $P < 0.05$, and ** denotes $P < 0.01$.

Fig. 5. Perceived supply trends of each ecosystem service in percentage, n = 300.

Table 2
Chi-square value of perceived change in supply of ES based on various socio-demographic variables.

Socio-demographic variables	Chi-square values					
	Crop production (CP)	Timber production (TP)	Carbon sequestration (CS)	Water yield (WY)	Soil conservation (SC)	Habitat quality (HQ)
Municipal category	19.107**	21.688**	22.097**	14.747**	9.913**	*42.275***
Watershed type	0.409	9.418**	9.445**	0.998	1.391	15.652 **
Land cover category	25.979**	*25.574***	*24.102***	*31.600***	23.354**	*39.481***
Gender	0.000	0.009	0.051	0.040	0.757	0.025
Age group	0.173	0.190	1.506	2.496	1.959	1.995
Family size	0.210	0.814	0.056	0.383	0.420	0.131
Crop land holding	0.024	0.031	0.001	4.711	0.001	*3.399*
Income group	16.212**	0.017	0.325	0.054	0.000	5.628*
Education level	9.385*	9.101*	4.311	*4.571*	9.101*	5.409
Type of housing	*13.783***	38.258**	33.241**	6.816*	0.562	21.379**
Affiliation in conservation group	2.643	20.522**	17.523**	7.680**	1.259	0.526
Affiliation in social group	0.323	0.531	1.190	0.947	7.133**	0.009
Participation in training	0.004	2.795	1.952	0.000	1.326	0.000
Knowledge about ES	1.880	4.736	2.333	0.926	0.164	0.026

Significance level * denotes P < 0.05, and ** denotes P < 0.01.

of the respondents, respectively. Fig. 5 shows that supply of almost all ES have changed (i.e., either increasing or decreasing); however, substantial proportion of the respondents (i.e., 23%) indicated the supply of SC has not been changed so far.

Amongst others, watershed type, municipal category, land cover type, type of housing, education level, and membership in conservation group were found to have statistically significant effect in perceived trends of ES (Table 2). For example, proximity to land cover type and municipal category found to have significant difference in understanding of the supply of all six ES, followed by type of housing (i.e., for 5 ES except SC), watershed type (i.e., for 3 ES including TP, CS, and HQ), education level (i.e., for 3 ES including, CP, TP, and SC), and membership in conservation group (i.e., for 3 ES including TP, CS, and WY).

The perceived supply trend of CP was significantly different according to land cover type. For instance, respondents near to forestland perceived increasing trends while the respondents from all the other land cover categories indicated decreasing trends of CP. Similarly, 84% of metropolitan respondents believed decreasing CP while only 54% of rural municipality respondents believed in decreasing trend. The difference in perceived supply of CP was also attributed to income level (i.e., 77% of respondents above poverty line indicated decreasing while that of only 53% respondents below poverty line indicated decreasing trend), education level (76% of the respondents with school level education believed it is decreasing while only 55% of illiterate group believe in decreasing trends), and type of housing (more proportion of respondents with brick-block housing said it to have decreasing trend than respondents with mud-stone housing).

The group of socio-demographic classes with higher proportion who rated increase in TP were 78% of upstream respondents (watershed type), 93% of respondents near to shrublands (land cover category), 88% of respondents from rural municipality (municipal category), 80% of illiterate respondents (education level), 87% of respondents with mud-stone housing (type of housing), and 81% of the respondents having no membership in any conservation group. The trends of CS also followed similar trends as of the TP, except for education level which had no significant difference in perceived supply trend. Socio-demographic groups that rated high increasing trend of WY were respondents living near the shrublands (85%), in rural municipality (87%), having mud-stone types of housing (76%), and with no involvement in conservation group (76%). In case of SC, increasing trends was perceived by the substantial proportion of respondents living in rural municipality (49%), near shrublands (65%), illiterate group (54%), and having no membership in conservation group (45%). Likewise, 82% of upstream respondents, 89% of rural municipality, 95% of the people living near to shrublands, 82% of the people below poverty line, and 92% of the people with mud-stone housing type perceived increase in supply of HQ.

Based on the local people's knowledge and experience, several reasons were identified for the increase and/or decrease of the major ES. Local people have identified numerous reasons for the perceived change in supply of ES in the last two decades, out of which top five reasons are illustrated in Table 3.

Among the respondents who believed CP is decreasing, almost half of them indicated conversion of cropland into settlement and built-up areas as the main reason. The shortage of farm labour was the second most important reason for decreasing crop production. On the other hand, increased access to irrigation and improved agronomic practices were believed to be the reason for increasing CP as observed by one-third of the respondents who believed CP is increasing. Similarly, deforestation and illegal logging were observed as the major reasons for decreasing the supply of TP. Conversely, substantial proportion of the respondents who believed TP is increasing claimed that use of alternatives to timber for energy and housing as well as restrictive law enforcement have contributed to increase in TP. In addition to deforestation, reduced trends of plantation and unmanaged plantation practices are claimed to decrease the supply of CS. On the other side, the

Table 3
Top five perceived reasons for increasing or decreasing supply of ecosystem services, with the percentage of respondents[a].

Sn	Reasons for decreasing supply	%	Reasons for increasing supply	%
Crop production				
1	Land use conversion from farmland to settlements	45	Increased access to irrigation	39
2	Lack of labour (including urban migration and labour migration abroad)	30	Improved agronomic practices, and agricultural modernization, including modern tools and technologies	31
3	Increased invasion by problem animals	19	Increased accessibility of fertilizers, including chemical fertilizers	28
4	Lack of fertilizer and high cost of fertilization	17	Incentives for farming practices	24
5	Low interest of farmers (i.e., buying foods rather than growing)	16	Easy access to good quality seeds, crop variety and hybrids	19
Timber production				
1	Deforestation and decrease in forest area	47	Use of alternatives for energy and housing	48
2	Illegal logging and misuse of forest products	23	Restrictive law enforcement and decreasing illegal logging	33
3	Decreasing trends of plantation, unmanaged plantation and lack of monitoring and protection of plantation sites	22	Reduced dependency and less extraction of forest resources	16
4	Lack of forest protection measures	18	Increase in forest area and decreasing trend of deforestation	15
5	Population increase, urbanization, and forest encroachment	18	Protection and conservation of forests	14
Carbon sequestration				
1	Deforestation and decrease in forest area	43	Increase in forest area and decreasing trend of deforestation	42
2	Decreasing trends of plantation, unmanaged plantation and lack of monitoring and protection of plantation sites	23	Plantation and afforestation programs	34
3	Forest quality degradation	19	Reduced dependency and less extraction of forest resources	16
4	Population increase, urbanization, and forest encroachment	11	Protection and conservation of forests	12
5	Illegal logging and misuse of forest products	9	Restrictive law enforcement and decreasing illegal logging	8
Water yield				
1	Drying up and disappearance of springs and water sources	48	Improved technology for water resource extraction, storage, and supply	72
2	Incomplete and weak implementation of water related projects	21	Proximity to water resources (lakes, rivers, snow-capped mountains)	28
3	Soil erosion, flood, and landslide	16	Spring-shed and water source protection	12
4	Negative effect of climate change	15	Appearance of water springs	10
5	Population increase, urbanization, and excessive use of water resources	15	Regular and adequate rainfall	8
Soil Conservation				
1	Unmanaged infrastructure development activities, including haphazard rural road construction	37	Plantation and increase in forest area	38
2	Riverbank cutting and sedimentation	32	Soil conservation programs (check dams and gabion walls)	30
3	Increasing incidence of flood and landslide	25	Embankment and river training works	23
4	Population increase, urbanization, and land use conversion	21	Public awareness and low disturbance by people	21

(*continued on next page*)

Table 3 (*continued*)

Sn	Reasons for decreasing supply	%	Reasons for increasing supply	%
5	Lack of soil conservation and watershed management program	18	Restrictive law enforcement on forest resource extraction	9
Habitat quality				
1	Deforestation and habitat fragmentation	50	Restrictive law enforcement and decrease in forest and wildlife crime	44
2	Settlement, land plotting and habitat encroachment	41	Afforestation and increase in forest area	39
3	Illegal extraction of forest resources and poaching	14	Conservation and management of forest resources	16
4	Lack of proper conservation efforts	10	Public awareness and capacity building	15
5	Degradation of natural forests and loss of species	9	Compounding and fencing of wildlife habitat	9

[a] Note: percentage of respondents was estimated within the category of respondents who indicated either increase or decrease of ES.

increase in forest area and afforestation program have been claimed to support in increasing CS in the study area.

Half of the respondents who believed WY is decreasing claimed that drying up and disappearance of the springs is the main reason. Nevertheless, 72% of the respondents who claimed WY is increasing believed that improved technology for water resource extraction, storage, and supply is the major reason behind increasing WY. One-third of the respondents believed that SC is diminishing due to the reason of unmanaged infrastructure development, including improper rural road construction. However, plantation and increase in forest area, as well as the implementation of various soil conservation measures, have been reported as the reason for increasing supply of SC. Deforestation, habitat fragmentation and encroachment are reported for the decline in HQ; however, restrictive law enforcement, afforestation and increase in forest area were identified as the reasons for increase in HQ.

3.3. Relationship among major ecosystem services from the local people's perspective

According to the percentage of responses, we found that trade-offs relationship occurred only between two pairs of ES, and the remaining 13 pairs were found to have synergistic relationship (Fig. 6). Trade-offs relationship between CP and TP was reported by the highest number of respondents (i.e., 75%), followed by the pair of CP and CS (i.e., 61%). Based on the percentage of respondents, highest synergistic relationship was observed between SC and HQ (94%), followed by WY and HQ (92%), and TP and CS (79%). CS and WY, CS and HQ, and CS and SC were found to have highest frequency of indifferent relationship as observed by 38%, 34%, and 29% of the respondents, respectively.

Among the respondents who have indicated trade-offs in the various pairs of ES, we have observed four different types of trade-offs such as, direct trade-offs, convex trade-offs, concave trade-offs, and non-monotonic concave trade-offs. Direct trade-off is dominant among eight pairs of ES, including the relationship of CP with WY, SC and HQ. Concave trade-off is dominant between the pairs of CP and TP, TP and SC, and CS and SC. Similarly, convex trade-off is observed between CP and CS, TP and HQ, and WY and HQ.

4. Discussion

Sustainable ecosystem management framework requires the assessment of socio-economic perspective in addition to the biophysical production possibilities of a landscape to supply various provisioning, regulating, cultural, and supporting ES. Knowledge level and education, as well as traditional practices and experience, play a crucial role in understanding socio-ecological interaction among people and nature, and in prioritizing for conservation and management interventions (Fletcher et al., 2021; Hosen et al., 2020). In our research, WY and CP are the two highly prioritized ES, followed by TP and SC. Non-provisioning ES, such as HQ and CS are among the least preferred

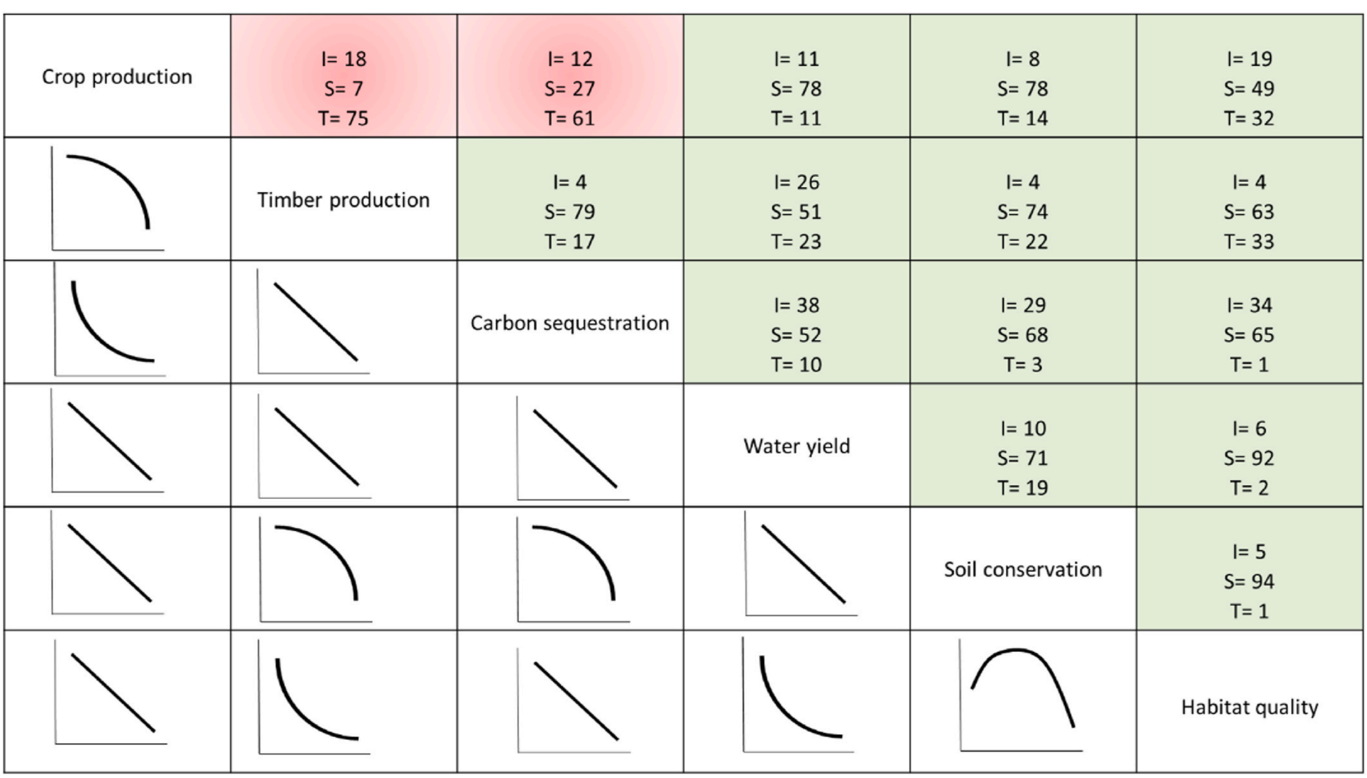

Fig. 6. Relationship matrix of ecosystem services from socio-economic perspective (percentage of respondents in the diagonal upwards and dominant types of trade-offs in the diagonal downwards). I = indifference, S = synergy, and T = trade-offs.

ES. Local people believe that the supply of CP is decreasing mainly because of land use conversion from farmlands to settlements and lack of labour due to urban and abroad migration. While all the other ES are believed to be increasing because of reduced dependency on forests, use of alternatives for housing and energy, increase in forest area, restrictive law enforcement, plantation and afforestation, and use of improved technology in management and supply of ES. Local people observed synergistic relationship among most pair of ES, and believe that co-existence of ES is possible.

4.1. Examining the preference of ES and socio-demographic determinants

The priority for WY implies that water resource conservation and protection program might be rewarded by local communities. Concomitantly, being a developing country, a priority for CP (as the 2nd priority) seems not a surprising result; however, various ES related programs often ignore agricultural domain of the landscape. For example, the Forest Act (2019) of Nepal does not recognize crop production as an ES while MEA (2005) put crops as the provisioning ES in its priority (GON, 2019; MEA, 2005). Likewise, some of the United Nations and Global Environment Facility supported programs on ES have focused on rehabilitation of forest and rangelands (GEF, 2019) but largely ignored the management of agricultural components. Not only the policy perspective, agricultural domain of ES is poorly articulated in academic as well (Bommarco et al., 2018; Vignola et al., 2015). Our assessment of people's priority over CP signifies the importance of incorporating the agricultural aspects in various ecosystem management programs in agricultural landscapes in the Himalayas.

Medium priority for TP (3rd priority) indicates that local people in the Himalayan region are still dependent on forest resources for their livelihood (Aryal et al., 2020b; Khadka et al., 2021; Laudari et al., 2019). Priority for SC in the Himalayas might be attributed to the issue of water and climate induced disasters, and land productivity (Pandey and Bardsley, 2015; Sil et al., 2016; Thapa et al., 2020). Integrated soil conservation and watershed management programs can be a priority action to address the need of SC as observed by the local people. CS was among the least preferred ES in the Himalayas, which pinpoint a general environmental issue that local people might not be interested in non-local ES (Chen et al., 2021; Lu et al., 2021). Alternatively, a lack of adequate CS related policies and programs might be one of the reasons for least priority because CS related program has been relatively new agenda as compared to other environmental domain (Maraseni et al., 2020; Suwarno et al., 2016). Further, numerous research and policy agenda overrated CS as an isolated domain of the forestry sector, but CS is closely linked with other aspects of the landscape such as cropping practices, wetland management, soil, and habitat function.

Upstream-downstream difference in choice of TP and SC (i.e., upstream preferred TP while downstream preferred SC) corroborates the issue of low availability of quality timber in the upstream as compared to lowland downstream areas (Poudyal et al., 2019; Subedi et al., 2014). It is because good quality tropical hardwood species (i.e., *Shorea robusta* and *Tectona grandis*) are abundant in lowland downstream areas whereas upstream areas are mostly occupied by conifers and softwood timber species (Aryal et al., 2016; Bhatta et al., 2021). Alternatively, people in the downstream might have suffered more from soil erosion problem (i.e., flood, sedimentation, and river cutting) which is reflected in their priority ranking (Deshar et al., 2021; Thapa et al., 2022). People below poverty line preferred TP than SC which might indicate that people with low financial capacity still depend on forest resources than financially capable ones (Bijaya et al., 2019; Nerfa et al., 2020). In this regard, we found livelihood support from ES is crucial; and as Przewoźna et al. (2022) suggested, specific objective prioritization of various ES is critical in prioritizing and decision making for ES management. As opposed to a finding by Mahlalela et al. (2022) in Southern Africa where urban people preferred WY, we found people living in urban settlements preferred CP than WY. But this was not the case for people living in rural settings in the Himalayas, probably due to two main reasons. First, WY is not the concern of urban people because their livelihood is not dependent on water resources (i.e., cropping and irrigation). Second, numerous drinking water related projects are operated in urban areas to satisfy their water demand (Pandey, 2021; Phuyal et al., 2020). Likewise, least priority for HQ and CS indicate that local people are still unaware of the importance of non-local ES (Lu et al., 2021), and there is a poor linkage between livelihood and biodiversity conservation, which should be strengthened for sustainable management of ES. In this regard, we support the claim of exploring economic potentials of non-local ES (Aryal et al., 2019a; Garbach et al., 2012) and argue that local people's preference for global ES must be moderated with supportive financial instruments (i.e., carbon markets or payment for ES) and livelihood support (i.e., employment and income generating activities).

Regarding the ranking approach, we believe that preference of ES is better understood at differentiated socio-demographic group rather than that of individuals (Campbell, 2018). In accordance with our findings, a study by Ali et al. (2020) found that spatial heterogeneity of people affect the choice of ES and willingness to manage ES accordingly. As opposed to our findings, Adeyemi et al. (2022) claimed that gender, age group, education, income level and household type have significant role in ES prioritization. The reason behind the difference in findings can be attributed to difference in research area because our assessment is based on the Himalayan landscape, where Adhikari et al. (2018) also identified spatial heterogeneity as the major factor in differing choices of ES. Although education, economy and demographic characteristics are important in understanding and prioritizing ES, our findings stressed on the need of analysing spatial heterogeneity and community mosaics in Himalayan landscapes in ascertaining people's preference and executing sustainable ES management practices.

4.2. Perception of the supply dynamics of ecosystem services

In contrast to our findings of decreasing WY, Adhikari et al. (2018) reported that majority of respondents claimed WY was decreasing in some parts of Central Nepal. The difference in findings can be attributed to the fundamental understanding of the ES. For example, scientists and policy makers might understand WY based on its gross availability within a defined geographic boundary, but for the local people it might be about water availability for their domestic purposes (i.e., drinking water supply or irrigation or local hydropower generation) (Adhikari et al., 2020; Chakma et al., 2020; Uprety et al., 2019). Our findings corroborate with the study of Paudyal et al. (2015) who found decreasing trends in food production and increasing for forest products, carbon and freshwater availability in Central Nepal. Notably, respondents living near to forestland said CP is increasing which might be because they have witnessed the problem of forest encroachment for farming. In contrast to our findings in the Himalayas, Adeyemi et al. (2022) reported that higher proportion of people believed in increase in CP but decrease in TP in Africa. The difference in understanding might be attributed to the difference in geographic region; however, such variations in understanding urge policy makers to assess the place-based divergence in understanding of availability of ES before taking actions for optimizing the supply of ES.

We observed significant difference in understanding of the supply trends of ES based on land cover types and municipal category (Table 2). It indicates that ES trends cannot be generalized for the whole landscape but be observed and scrutinized at the site specific and local level for better planning and management of ES. For instance, majority of respondents living near forestlands indicated CP is increasing which might indicate that although CP is decreasing at the landscape level, people living near the forestland might have still witnessed forestland conversion into croplands. Our findings of the difference in perceived supply trends of TP might be because people away from forestlands (i.e., having brick-block and reinforced cement concrete housing) face high price rise of timber which is related with perceived (relatively) low availability of

TP (Aryal et al., 2016; Subedi et al., 2014). Alternatively, because of the reduced dependency of people in forest resources (Shrestha and Fisher, 2017), respondents with mud-stone housing might have witnessed more increase in TP. Overall, we found that community mosaics throughout the landscape as explained through the spatial heterogeneity of respondents is major determinants of preference and perceived changes in supply of various ES, demanding more place-based site specific ecosystem management program throughout the landscape.

In contrast to our findings of local people's perception of changes in supply of ES, various estimates can be found at the national scale. Although Regmi (2020) estimated an increase in production of cash crop at the national scale of Nepal in the last decade of 2009–2019 and The World Bank (2022) estimated a sharp increase in food production index from 62.5 to 112.6 between the period of 2000–2019, an estimate by Sapkota (2019) is in line with our findings that production of cereal crop is decreasing. Perceived changes in the supply of ES are attributed to land use conversion, followed by lack of labour, and increased invasion by problem animals in farmlands which was also supported by previous studies (Paudel and Shrestha, 2018; Sharma and Acharya, 2017). Although some previous studies (Maharjan et al., 2020; Subedi et al., 2021) have identified agricultural land abandonment as a primary reason for decrease in CP, this was not among the major reasons for the decrease in supply of CP in our research. On the other hand, increased access to irrigation and improved agronomic practices were reported to be the major inputs for perceived increase in supply of CP; however, some of the previous studies (Aryal et al., 2019; Lamsal et al., 2018; Rai et al., 2019) blamed poor irrigation and traditional farming as the major problems in agricultural sector in Nepal. In this regard, averaging and generalization of increase or decrease might not be applicable for site specific intervention but be understood as a broader policy framework.

In line with the findings of Aryal et al. (2016), we found that increasing use of alternatives for energy and housing (i.e., iron and aluminium, solar and electric power) has contributed to increasing TP, along with restrictive law enforcement, as mentioned by previous studies (Aryal et al., 2020a; Parajuli et al., 2022; Paudel et al., 2020). Some studies affirm that plantation has been instrumental in increase in forest area and timber availability (Aryal et al., 2019b; Laudari et al., 2022) while the others (Aryal et al., 2020b; Shah, 2019) blame unmanaged plantation, low quality seedling, and reduced monitoring of plantation sites have contributed in decreased availability of timber. Top rated reason for decrease in TP and CS was deforestation and decrease in forest area throughout the landscape as mentioned in various policy documents of Nepal (Chapagain and Aase, 2020; REDD IC, 2018). As opposed to a previous study estimates of decreasing trends of CS in eastern part of Nepal by (Rimal et al., 2019), our study showed an increase in CS which corroborates with the national statistics of increasing forest area (DFRS, 2015), and accordingly CS potentials. Drying up and disappearance of water springs contributed to decrease in WY, whereas majority of respondents believed improved technology for water resource extraction, storage and supply were considered main reason for the increase in WY. Besides, we urge on the consideration of spatio-temporal variability of water yield which is attributed to various factors such as climate patterns, vegetation, local edaphic factors and evapotranspiration potentials.

4.3. Can we have all ES simultaneously?

Our finding shows that synergistic relationship among major ES is possible, except CP, for which over half of the respondents said to have trade-off relationship with TP and CS. Alternatively, any management intervention that focuses on increasing TP and CS might be counterproductive for the supply of CP. Our findings are supported by previous studies (Aryal et al., 2022; Illukpitiya and Yanagida, 2010; Li et al., 2020; Macchi et al., 2020; Sida et al., 2018; Vaast and Somarriba, 2014) that CP exhibit trade-offs with forest product and services, especially due to conflicting management objectives and policy interventions (Dade et al., 2019), land use change (Zheng et al., 2019), excessive human intervention (Li et al., 2020), and environmental variability of the landscape (Dade et al., 2019). Because CP is associated with intensive anthropogenic interventions, it might knowingly or unknowingly create some forms of trade-offs, be it in quantitative or qualitative form. This situation of trade-offs could be reversed by improved farming practices (Sida et al., 2018; Zhong et al., 2020), application of agroforestry practices (Aryal et al., 2019), landscape restoration practices (Laudari et al., 2022; Li et al., 2021), and informed management feedback in socio-ecological systems (Lu et al., 2021).

Regarding the local people's understanding of types of trade-offs, our finding contradicts with various previous estimates and empirical observation (Aryal et al., 2022; Li and Wang, 2018; Wang and Dai, 2020) which claimed to have non-linear relationship among ES because of dynamic socio-demographic structure, diverse demand of ES, climate uncertainties, and changing human-nature relationship. Knowledge level and education of the respondents might be crucial in understanding and perceiving the types of trade-offs because only 12% of the respondents have attended university and less than 10% of the respondents believed that they have good knowledge about ES. Although the reporting may vary according to the level of understanding, it might complement biophysical assessment of the relationship, and ease participatory planning and management for ES optimization.

Our findings indicate that simultaneous production of SC and WY is much easy if the landscape management program focus on improvement of HQ. At least 50% of the respondents reported a synergistic relationship between 12 out of the 15 pairs of ES, which indicate that local people believe in co-existence and co-occurrence of multiple ES. We acknowledge that various empirical observations and estimates that are published in the past have clearly explained about the biophysical constraints of landscape and trade-offs in ES (Aryal et al., 2022; Lee and Lautenbach, 2016; Mengist et al., 2020; Obiang Ndong et al., 2020). However, we cannot ignore the perception of local people, who have genealogical ties and generational experience and interaction with ecosystem assets (Pascua et al., 2017), that synergy among ES is possible. The multifunctionality of Himalayan landscape might be one aspect but a number of literature (Chen et al., 2022; Lin et al., 2018; Morán-Ordóñez et al., 2020) have reported synergy among TP, CS, SC, WY, and HQ. Moreover, the synergy can be explained through the logic of relationship. For example, forest product and productivity support both TP and CS (Badshah et al., 2020; Charmakar et al., 2021; Pandey et al., 2014). Similarly, enhanced revegetation in degraded and barren land would most likely support water retention and biodiversity as well as minimize soil erosion. In this regard, we argue that essential ES in the Himalayas are not mutually exclusive but can be optimized through consideration of socio-economic context and accordingly, participatory planning and management, integrated conservation and development action, sustainable forest management practices, use of technology and improved agronomic practices, and integrated watershed management.

We acknowledge that understanding of the relationship among ES only from the socio-demographic perspective is not adequate for landscape planning and management. Sustainable development initiatives require comprehensive understanding from both biophysical supply constraints and socio-economic demand perspectives. And our finding is novel in assessing socio-economic demand of ES, perceived supply trends, and relationship among the major ES in the Himalayas. The findings could further be improved by increasing the number of samples for the household survey, incorporation of hierarchical assessment of social values, and follow-up research because the priorities might change over time (Acharya et al., 2019). In addition, we further recommend future research on depicting utility functions of local people for each pair of ES. Also, we need to combine both social and biophysical research to assess any discrepancy and to make more concrete conclusions. Nevertheless, our findings enlightened the understanding of preference ranking of local people for ES, observed changes in ES supply, and perceived relationship which are crucial for optimal allocation and sustainable management of ES in the Himalayas.

5. Conclusions

We conducted socio-economic household survey to understand the demand and preferences of ES, along with the perceived supply trends and interactions among major ecosystem services (ES) in the Himalayas. Our assessment shows the need of integrating agricultural components in overall ecosystem management which has been ignored in global policy discourse and national program implementation. Further, mainstreaming of non-local ES in local decision-making can be made through the endorsement of financial incentives or payment schemes, linkages between livelihood and biodiversity, and by designing a local benefit of global services (i.e., climate finance). Moreover, understanding of non-provisioning ES should not be the sectoral agenda of forestry sector but be blend with the agricultural land, wetland, and others for ensured landscape productivity, livelihood support, and improved agronomic practices.

We argue that understanding of place-based differences in choice and demand of ES is crucial in landscape planning and management. Although landscape level approach provides broader outlook of ecosystem containment and socio-economic context, differing perceptions and multiple reasons for perceived change in supply of ES, as observed in our case, justify the need of site specific place-based intervention for sustainable ecosystem management. Co-existence and synergy among major ES are possible; however, trade-off relationship of crop production with timber production and carbon sequestration can be managed through the integration of agroforestry and improved agronomic practices in landscape restoration programs. Based on our findings, we recommend that human dominated landscape in the Himalayas and other parts of the world should consider immediate need of the local people (i.e., crop and water) while designing and implementing broader ecosystem management programs. Outcomes of policy and program interventions can be counted at the landscape level, but specific ecosystem-based intervention should be based on site-specific supply dynamics of ES and socio-economic context. Synergistic relationship among major ES is possible even in human dominated landscape by the consideration of land sharing approach (i.e., agroforestry) and integration of improved agronomic practices while endorsing sustainable landscape restoration and management programs.

Author contribution statement

Kishor Aryal: Conceptualization, Visualization, Data curation, Formal analysis; Methodology; Validation; Writing – original draft preparation, Writing – review & editing. **Tek Maraseni**: Writing – review & editing, Supervision. **Armando Apan**: Writing – review & editing, Supervision.

Declaration of competing interest

Authors declare no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.118522.

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