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Integrated Approach to Understanding Perceived Importance and Changes in Watershed Ecosystem Services (WESs): Insights from Central Nepal

Nabin Dhungana [1,2,3,*], Chun-Hung Lee [1,*], Samjhana Adhikari [4], Bishal Kumar Rayamajhi [5], Udit Chandra Aryal [2,6] and Pramod Ghimire [7]

1 Department of Natural Resources and Environmental Studies, College of Environmental Studies and Oceanography, National Dong Hwa University, Hualien 97401, Taiwan
2 Natural Resources Conservation Nepal, Bharatpur 44200, Nepal
3 WWF Nepal, Kathmandu 44600, Nepal
4 Ministry of Forests and Environment, Hetauda 44107, Nepal; samjhanaad@gmail.com
5 Faculty of Science Health and Technology, Nepal Open University, Lalitpur 44700, Nepal
6 Nepal Applied Mathematics and Informatics Institute for Research, Lalitpur 44700, Nepal
7 Faculty of Forestry, Agriculture and Forestry University, Hetauda 44107, Nepal
* Correspondence: nabindhungana.2007@gmail.com or nabin.dhungana@wwfnepal.org (N.D.); chlee@gms.ndhu.edu.tw (C.-H.L.); Tel.: +977-9856033741 (N.D.); +886-3-8633343 (C.-H.L.)

Abstract: With environmental changes, sustaining watershed ecosystem services requires understanding community perceptions and preferences. Integrated approaches considering community perceptions, climate change, and land use cover change are crucial. We address a study gap by combining climate change and land use cover change data with an analysis of community perceptions to evaluate the watershed ecosystem services situation in Nepal's Khageri Khola Watershed. Data from in-depth stakeholder interviews (n = 16), household perception surveys (n = 440), and participant observations (n = 5) were supplemented by meteorological and land use cover change data. Descriptive analysis, index value calculation, Spearman's Rho correlation, and chi-square statistics were used to understand linkages between socio-demographics, climate change perceptions, watershed ecosystem services importance, and changes in watershed ecosystem services supply. The Mann–Kendall test, Sen's slope calculation, and land use cover change analysis considered temperature, precipitation, and land use. Among watershed ecosystem services, communities prioritized drinking water as the most important and biodiversity support as the least important. Watershed ecosystem services exhibited decreasing trends, with soil fertility and productivity notably high (89%) and natural hazard control low (41%). Significant alignment existed between community perceptions and local climate indicators, unlike the incongruity found with land use cover changes, especially regarding water bodies. Socio-demographic factors influenced community perceptions. Policy recommendations include analyzing watershed-level community demand and preferences, integrating community perceptions with climate change and land use cover change data in decision making, engaging communities, equitable sharing of the benefits generated by watershed ecosystem services, and considering socio-demographic and topographic diversity in tailoring management strategies.

Keywords: watershed; watershed ecosystem services; ecosystem services assessment; management strategies; social perceptions; Nepal

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Academic Editor: Subhasis Giri

Received: 18 November 2024
Revised: 14 December 2024
Accepted: 20 December 2024
Published: 26 December 2024

Citation: Dhungana, N.; Lee, C.-H.; Adhikari, S.; Rayamajhi, B.K.; Aryal, U.C.; Ghimire, P. Integrated Approach to Understanding Perceived Importance and Changes in Watershed Ecosystem Services (WESs): Insights from Central Nepal. *Sustainability* **2025**, *17*, 62. https://doi.org/10.3390/su17010062

1. Introduction

Watersheds, as areas drained by watercourses, are suitable socio-economic and political units for planning and implementing natural resource management [1]. Over time, management programs have evolved from structure-driven, fragmented strategies targeting soil conservation and rainwater harvesting to more holistic, integrated approaches aimed at ensuring continuous provisioning of ecosystem services while addressing land degradation and water scarcity [2,3]. Beyond food and livelihood security, this safeguards additional ecosystem services for community well-being [4,5]. However, environmental and social factors limit the supply of watershed ecosystem services (WESs), with resource degradation posing significant threats to food security, livelihoods, and sustainable development [5–9].

Bio-physical watershed components include ecological patches of water, land, and forest, while socio-economic components encompass people, institutions, agricultural practices, environmental interactions, socio-economic activities, and adaptation strategies [10]. Ecological patches provide diverse WESs for community well-being [4,11], especially in heavily agriculture-dependent communities. Forests regulate water flow, mitigate soil erosion, and provide goods ranging from timber to medicinal plants [12–14]. The land itself supports agriculture, which is essential for human nutrition [15]. Water supports biodiversity, hydropower, fisheries, tourism, and recreation [16–18]. Since ecosystems are intricately interconnected, integrated approaches to managing ecological patches and services contribute to sustainability [12,19]. Local community management currently has more than 4 billion hectares of forest and farm landscapes managed by family farmers, smallholders, forest communities, and indigenous peoples worldwide [20]. Understanding reciprocal human/nature interactions bolsters the sustainable management of ecosystem resources and the supply of services [21,22]. Despite ecosystem services' importance for community well-being and local management of resources, the social dimension remains under-explored in many developing regions [23,24]. Local perspectives on ecosystem dynamics remain downplayed despite their value [23,25,26], while watersheds undergo climate change and anthropogenic disturbances that alter the distribution and supply of ecosystem services [5,9,27]. Climate change impacts ecosystems, communities, and economies, with weather patterns escalating the frequency and intensity of extreme events and disrupting ecosystem services supply [4,7]. These impacts are expected to accelerate in the future [23].

Human-induced land use land cover change (LULC) also affects the distribution and supply of ecosystem services [9,28]. A study on Nepal's Koshi River Basin revealed declining crop production due to reduced agricultural land [29]. Similarly, research in China indicated that LULC changes caused decreases in water yield and soil retention [9]. Climate change and LULC impacts on ecosystem service supply are exacerbated by socio-economics and geography, including transitions from subsistence agrarianism to market economies, migration, labor shortages, and development activities, like road construction [30–32]. This highlights the need for understanding community priorities and perceptions in managing ecosystem services and designing community-preferred adaptation strategies. Tailoring strategies to local needs enhances their effectiveness and sustainability, and incorporating local insights and priorities helps management strategies be more relevant, impactful, and beneficial in the short and long term. Initiatives like the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Convention on Biological Diversity (CBD), Post-2020 Global Biodiversity Framework, and UN Decade on Ecosystem Restoration 2021–2030 tout community-centered approaches for landscape planning and management [4,5,17,22,33]. Gauging social perceptions goes beyond identifying essential ecosystem services, illuminating how communities prioritize services, potential stakeholder conflicts, and perceived trade-offs among various environmental management scenarios [5,34,35]. Previous studies exploring socio-economic dimensions of ecosystem services have assessed community preferences in a biodiversity hotspot in Chile [36], perceptions of climate change impacts on ecosystem service delivery in Mali [23], and community perspectives on forest Kenyan ecosystems [37]. However, our understanding of socio-demographic variables' complex influence on ecosystem services at the watershed scale encompasses multiple ecosystems and remains fragmented. Exploring the possible impacts of climate change and human disturbances on local environments and community well-being requires an evaluation of social perceptions of ecosystem services [35]. To address the aforementioned knowledge gap, we evaluate community perceptions of ecosystem services, their importance, and environmental trends in a complex, changing context. The aim is to identify the priority WESs of local communities and how socio-demographics affect these priorities, how local communities perceive changes in WES supply and how these perceptions vary with socio-demographics, and explore the congruity/disparity between community perceptions of WES supply and observed climate and land use land cover (LULC) change patterns. By answering these study questions, we offer valuable practical and policy-level insights for managing WESs in alignment with community needs.

2. Materials and Methods

2.1. Study Watershed

The study focused on the Khageri Khola Watershed, spanning 133 sq km within Chitwan District, central Nepal (Figure 1). Situated in the Chitwan Annapurna Landscape's Barandabhar forest corridor, it spans the latitudes 27°35′45′′ to 27°47′04′′ and longitudes 84°27′37′′ to 84°35′06′′, with elevations ranging from 180 m to 1307 m from msl [11,38]. The watershed encompasses four local government areas: Bharatpur Metropolitan City, Kalika Municipality, Ichhakamana Municipality, and Ratnanagar Municipality, supporting 16,424 residents in 3686 households. Locals engage primarily in agriculture, livestock, business, foreign employment, and ecotourism, with major crops, including rice, maize, and mustard [11,38]. Residents are predominantly Janjati, with smaller Brahmin, Chhettri, Thakuri, and Dalit populations. The watershed supplies downstream ecosystems, including Chitwan National Park, the Beeshazari Tal Ramsar site, and the Khageri irrigation system [11].

The watershed experiences significant rainfall and temperature variability. Approximately 72% of the area is forest, while farmland comprises 23%. Flooding occurs regularly, particularly in flatter areas, where 46% of the land has a slope of less than 3%. Human activities and climate change degrade resources and threaten biodiversity through upstream deforestation, open grazing, and soil erosion, which are further exacerbated by the impacts of floods and droughts. The Khageri irrigation scheme, crucial for downstream agriculture and wildlife conservation, faces water scarcity due to upstream changes [11,39]. The Khageri Khola Watershed was selected for its ecological and societal significance, providing freshwater ecosystem services, including drinking water, irrigation, and flood regulation. Since management regimes vary between upstream and downstream areas, divergent stakeholder perspectives can be expected to shape preferences for sustainable watershed management policies. Water scarcity, reduced land productivity, and increasingly frequent and severe extreme weather events highlight the need for adaptive management strategies aimed at environmental resilience and tailored to community needs [11,38–40]. For further details, refer to [11].

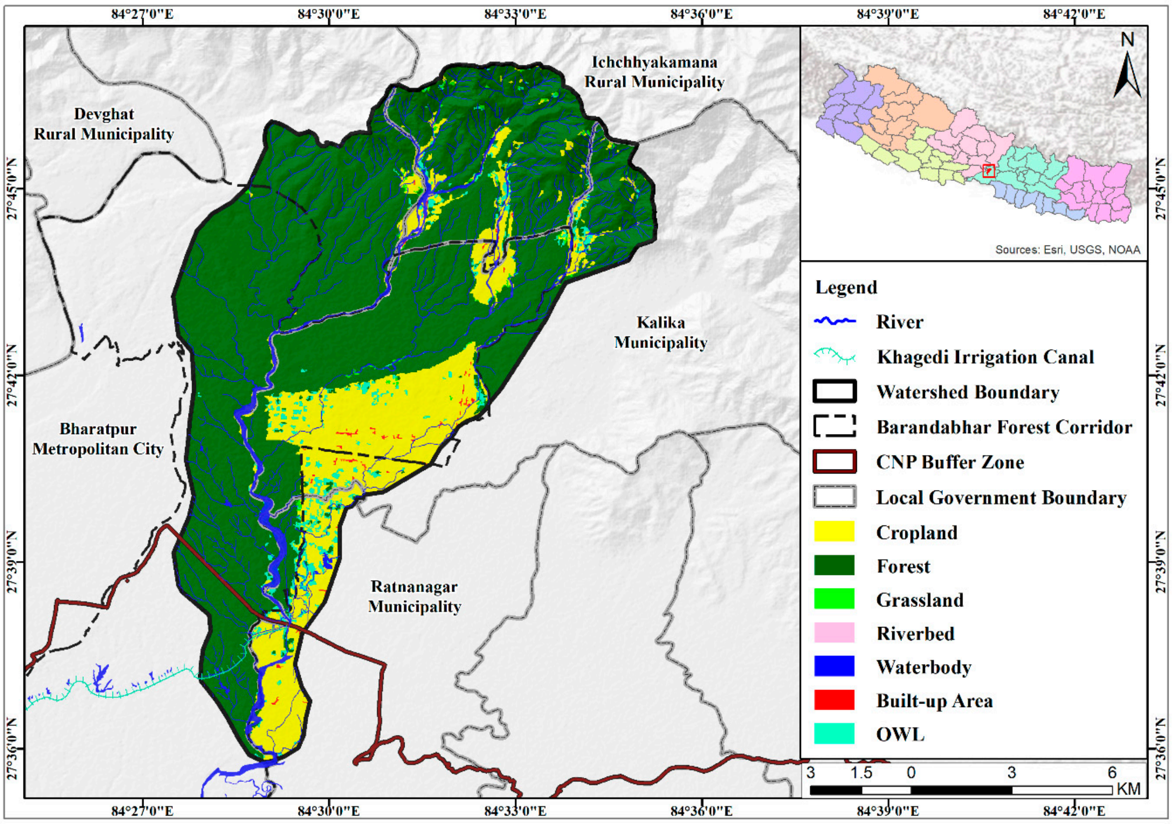


Figure 1. Study watershed in Chitwan District, Central Nepal, showing watershed boundaries, rivers, irrigation canals, forest corridors, buffer zone, local government areas, and land use. Note: OWL represent other wooded land.

2.2. Identification of WES

Ecosystem services were identified based on a literature review, including research into ecosystem services in tribal communities in India [17], river ecosystems in China [41], ecosystem service preferences in Indonesia [42], and how ecosystem services benefit small-scale farmers in Nepal [43]. Qualitative approaches such as in-depth interviews with stakeholders (n = 16) from government and private agencies, along with representatives from community-based organizations and community-level participant observations (n = 5) and pairwise ranking also informed our choice of six major WESs for study (Table 1).

Table 1. Identified WESs and community values.

Ecosystem Services	Descriptions as per Community	Community Values
Drinking water	Water specifically for human consumption/household needs (drinking, cooking, washing, livestock, etc.)	Human well-being, socio-economic development, and health
River/stream/lake water	Water sourced from rivers, streams, or lakes used for agricultural irrigation, supporting wildlife habitats, recreation, and maintaining wetlands	Human and wildlife well-being, socio-economic development, health, religious and cultural value, and environmental conservation
Forest products	Products like timber for house construction and maintenance, furniture and agricultural tools, firewood for cooking, and livestock fodder obtained from national forested areas and agro-forests	Human well-being and socio-economic development

Table 1. *Cont.*

Ecosystem Services	Descriptions as per Community	Community Values
Biodiversity support	Provision of habitats and food sources for diverse flora/fauna species, contributing to overall richness and variety	Environmental conservation and coexistence
Soil fertility and productivity	Soil's ability to support agriculture and enhance crop yields, providing essential nutrients, maintaining soil structure, and promoting plant growth	Human well-being, socio-economic development, and health
Natural hazard control	Regulation and mitigation of floods, landslides, riverbank and soil erosion, and detrimental effects on human settlements, agriculture, and infrastructure	Human well-being, socio-economic development, and environment conservation

2.3. Household Perception Survey

Qualitative and quantitative approaches informed data collection. The study utilized a stratified random sampling technique, considering topographic characteristics and demographic variables (age, gender, occupation, income, and household location). A total of 440 participants represented both upstream and downstream areas and were chosen through the item-to-response ratio, ensuring robust statistical analysis [44]. The upstream area spanned five locally governed wards, representing approximately 70% of the households. The downstream area comprised eight wards, constituting around 30% of the sample [11,38]. Data were collected via a structured questionnaire assessing climate change perceptions, ranked importance, and trends of six WESs through a five-point Likert scale. Pilot testing with 30 respondents ensured questionnaire clarity, relevance, and effectiveness. Trained enumerators conducted face-to-face interviews, administering a final questionnaire initially developed in English and translated into Nepali, ensuring cultural sensitivity and inclusivity. Only the respondents over 18 years old were included in the survey. The field study lasted from March to August 2023. Figure 2 shows the methodological framework.

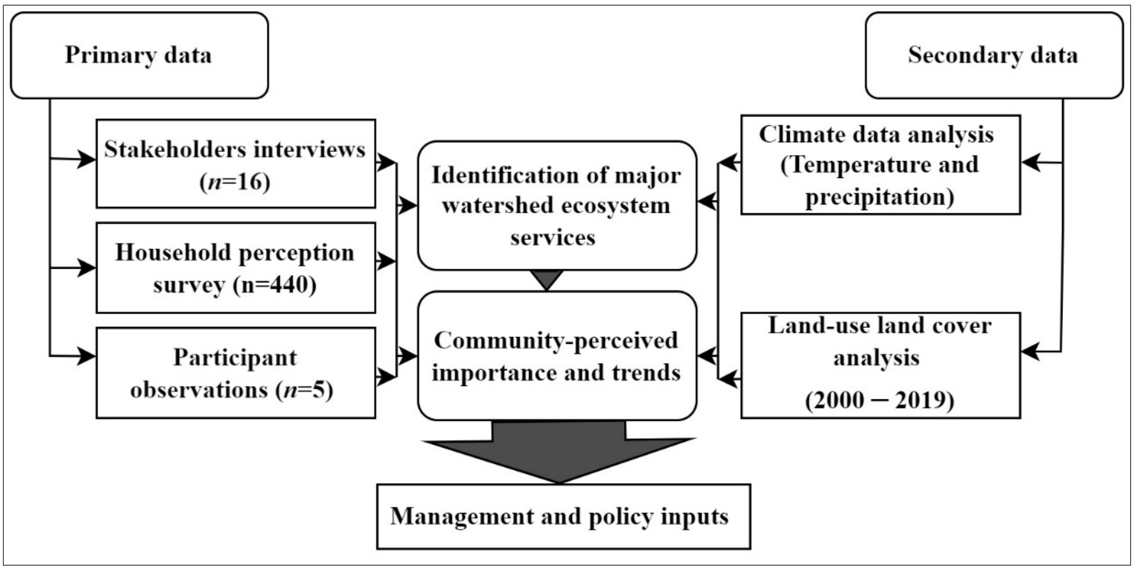


Figure 2. Methodological framework for identifying key WESs, importance, and trends for management and policy inputs.

2.4. Data Analysis

Cronbach's alpha coefficient was employed to assess questionnaire reliability and the internal consistency of the selected ecosystem services. Quantitative data was analyzed using IBM SPSS Statistics 26. Respondents' socio-demographic characteristics were examined using descriptive statistics. The ranking technique employed to rank WES importance followed previous work [45], using the following Equation (1):

$$I = \sum_{i=1}^{N} Xi{\cdot}Wi/N \quad (1)$$

where I represents the perceived index of the WESs; Xi represents each WES; and Wi represents the respective weight of each WES, based on perceived importance. The weights were: not important = 0, very low importance = 0.25, low importance = 0.5, high importance = 0.75, and very high importance = 1. N = total number of responses. Pearson's chi-square was used to test associations among socio-demographic variables and indicators of local climate change. Spearman's Rho correlation measured relationship strength between independent and dependent variables, with significant associating indicated if the *p*-value was below 0.05. The *p*-values presented are derived from all data within each perception category. Qualitative data from stakeholder interviews, participant observations, and secondary sources were thoroughly analyzed using description, categorization, and linking methods commonly employed in qualitative data analysis [11,46].

2.5. Climate Data Analysis

Monthly precipitation and mean temperature data spanning 1981 to 2023 were collected from the nearest meteorological station to the watershed (Rampur Station Index 0902), as no meteorological station exists within the watershed. Those data were sourced from the Department of Hydrology and Meteorology (DHM). Through the Mann–Kendall test and Sen's slope method, we analyzed the type, magnitude, and significance of trends in climate time-series data. A non-parametric method, the Mann–Kendall test, detects the presence of monotonic positive or negative trends in a time series and determines whether they are significant. Sen's slope method estimates the magnitude of linear trends (slope) [47]. The MS Excel program XLSTAT was utilized to calculate the magnitude, trend significance, and Sen's slope of meteorological data [48]. Respondents' perceptions of climate change and observed climate trends were compared to determine alignment/incongruity between perceptions and actual data.

2.6. Land Use Land Cover Analysis

Land use land cover (LULC) analysis used data compiled between 2000 and 2019 by the Forest Research and Training Centre (FRTC), Government of Nepal, with support from the International Centre for Integrated Mountain Development (ICIMOD) [49]. The data had a spatial resolution of 30 m, encompassing seven land-use categories: Cropland, Forest, Grassland, Riverbed, Water body, Built-up area, and Other Wooded Land (OWL). Data processing, analysis, and mapping were conducted in ArcGIS (Version 10.3). A cross-tabulation module in ArcGIS was utilized to detect LULC changes and develop an LULC change matrix identifying longitudinal transitions in LULC categories and their respective areas. Subsequently, a thematic layer was generated to depict various 'from–to' change classes to identify gains and losses over time [50]. Gains for each category were determined by subtracting the persistence from the column total, while losses were calculated by subtracting the persistence from the row total [51]. The annual rate of change for each LULC class was computed using the following formula [52].

$$r = \left(\frac{1}{t2 - t1}\right) \times \ln\left(\frac{A2}{A1}\right)$$

where r represents the annual change rate for each LULC category. A2 and A1 denote the LULC category areas at the analysis period's end and beginning, respectively, while t2 − t1 indicates the number of years in the analysis period.

3. Results

3.1. Respondents' Characteristics

The household survey comprised 440 participants (70.45% from the watershed's upstream and 29.55% from the downstream region), with 53.86% male and 46.14% female (Table 2). Ages ranged from 18 to 66, with most falling between 29 and 39 (39.55%). The majority were Janajati (76.36%). Most had completed primary education (24.54%). Respondents had diverse occupations, with 53.18% being farmers, followed by remittances, private services, government services, day laborers, and non-governmental organizations (NGOs).

Table 2. Respondent socio-demographic characteristics.

Characteristics	Respondents	
	Number	Percentage (%)
Topographic location *		
Upstream	310	70.45
Downstream	130	29.55
Gender		
Male	237	53.86
Female	203	46.14
Age group		
18–28	76	17.27
29–39	174	39.55
40–50	101	22.95
51–61	65	14.77
>61	24	5.45
Ethnic group		
Brahmin/Chhetri	89	20.23
Janajati	336	76.36
Dalit	15	3.41
Education level		
Illiterate	81	18.41
Primary	108	24.55
Lower Secondary	69	15.68
Secondary	93	21.14
Higher Secondary	47	10.68
Undergraduate	42	9.55
Occupation		
Agriculture	234	53.18
Private services	56	12.73
Government	42	9.55
NGOs	12	2.73
Remittance	66	15.00
Daily labor	30	6.82
Monthly household income (NPR)		
<20,000	88	20.00

Table 2. *Cont.*

Characteristics	Respondents	
	Number	Percentage (%)
20,000–40,000	197	44.77
40,001–60,000	99	22.50
60,001–80,000	50	11.36
>80,001	6	1.36

Notes: * Household topographic location; NGOs: non-governmental organizations; NPR: Nepalese Rupees; USD 1 = NPR 133.56 on 5 May 2024 (Nepal Rastra Bank).

3.2. Perceived WES Importance

The WES importance ranking (Table 3) is influenced by knowledge, perception, and community values. Drinking water ranked most important, followed in descending order by soil fertility/productivity, river/stream/lake water, natural hazard control, forest products, and biodiversity support.

Table 3. Importance ranking of six major WESs, their frequency of perceived importance, sum of index, and rank.

Watershed Ecosystem Services	Perceived Importance				Sum of Index	Rank
	Very Low	Low	High	Very High		
Drinking water	0	2	14	424	0.990	I
River/stream/lake water	9	20	102	309	0.904	III
Forest products	23	18	104	295	0.881	V
Biodiversity support	34	58	142	206	0.795	VI
Soil fertility/productivity	4	11	21	404	0.969	II
Natural hazard control	12	16	106	306	0.901	IV

Figure 3 shows the importance rankings for ecosystem services across socio-demographic groups. Rankings were consistent across topographic locations, except for biodiversity support and natural hazard control. Upstream respondents assigned fourth and fifth priority to natural hazard control and biodiversity support, respectively. Downstream respondents ranked biodiversity support as third in importance and natural hazard control as sixth. Male and female respondents generally attached similar importance to ecosystem services, with exceptions being river/stream/lake water and natural hazard control. Males ranked natural hazard control and river/stream/lake water as third and fourth in importance, respectively, while females ranked them as vice versa.

Across age groups, drinking water, soil fertility/productivity, and biodiversity support received identical importance rankings. Differences appeared in the perceived importance of river/stream/lake water, forest products, and natural hazard control. Notably, the 29–39 age group attached higher importance to all WESs compared to other age groups. Ethnicity appeared to influence perceptions, with Indigenous people (*Janajati*) in particular attaching higher importance to all WESs, indicating their greater dependency on them for subsistence. Perceived importance also varied with education level and occupation. Respondents with education above undergraduate prioritized soil fertility and productivity over drinking water. Government workers prioritized natural hazard control, while other groups prioritized drinking water. Agricultural workers attached higher importance to all WESs than did other groups. As for monthly household income, importance rankings for drinking water and soil fertility/productivity were consistent with those of other groups, but other WES ranks showed divergence with income level.

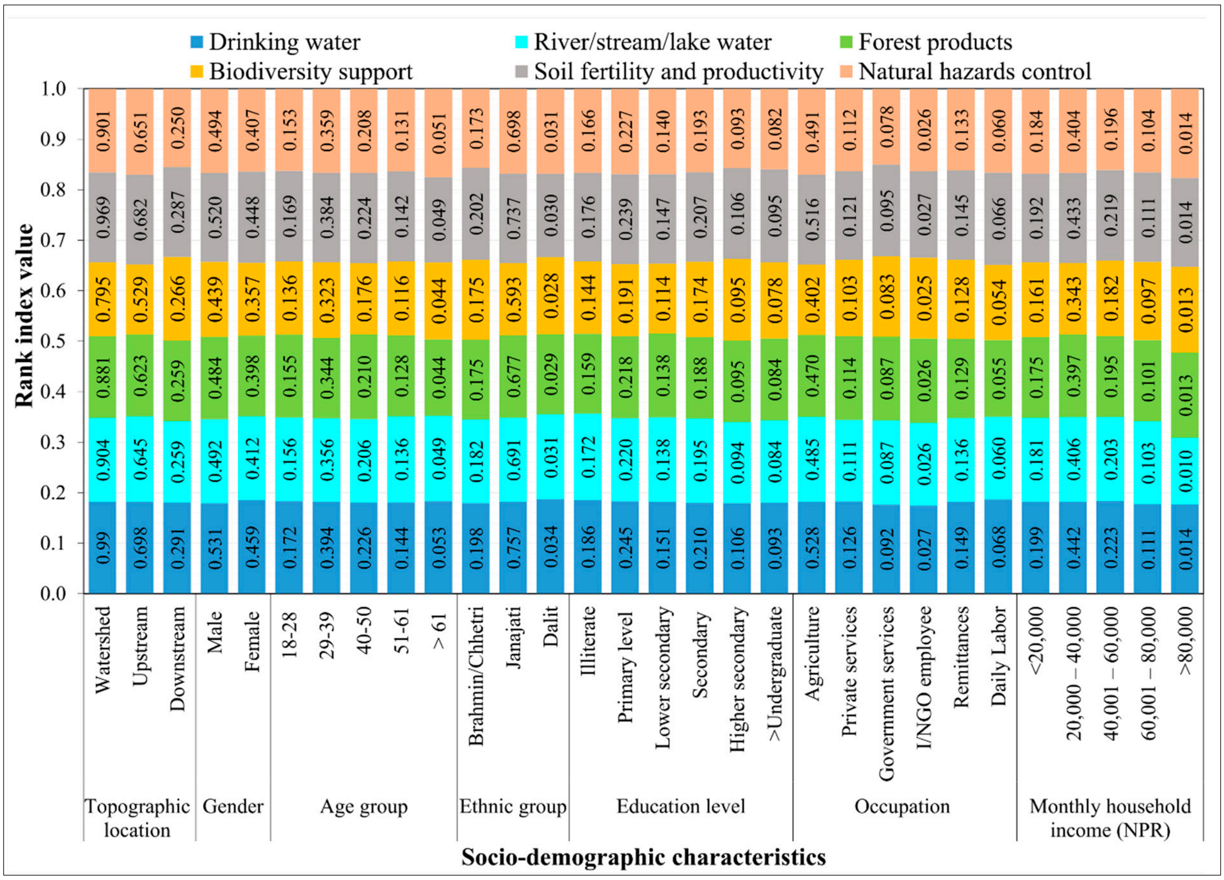


Figure 3. Stacked bar chart showing the rank index values of WESs across socio-demographic groups, with higher values indicating greater importance. The figure idea is adopted from [22].

3.3. Perceptions of Climate Change and Impacts

Nearly all respondents (99.32%) perceived local temperatures increasing, while the majority (95.68%) perceived winters becoming warmer (Figure 4). These anecdotal perceptions correspond with official DHM data documenting notable increasing trends in mean temperature in the watershed (Figure 4 and Table S1). Despite mean annual temperatures increasing by 0.005 °C, winter and pre-monsoon temperatures have actually decreased by 0.002° and 0.004 °C, respectively, indicating cooling trends during these seasons (Table S1). Figures 4 and 5 summarize respondents' perceptions of rainfall variability. Nepal's monsoon season typically lasts from early June until September. Over 96% of respondents reported late starts to monsoons and a prolonged dry season. Similar percentages also noted decreases in rainfall quantity (96.14%) and rainy days (97.05%), while 87.27% perceived an increase in rainfall intensity.

Contrasting the respondents' perceptions, data showed consistent declining precipitation at a rate of 0.1821 mm/year, albeit with seasonal and annual variations (Figure 5 and Table S1). A large percentage of respondents (over 88%) reported understanding climate change and watershed management, with 93% considering climate change as a key factor in degrading the watershed and WESs over the past decade with 90.68% reporting a noticeable increase in degradation. Only 5.45% observed no change. Despite relying heavily on WESs for their daily livelihood (96.59%), respondents perceived a declining trend in that dependency (69.09%). Only 2.50% observed no change. Respondents attributed decreasing dependency on watershed resources, specifically in forest products and farming and agricultural practices, changes in socio-economic conditions, diversified income sources, and better access to markets and facilities to result in a shift of their needs and interests.

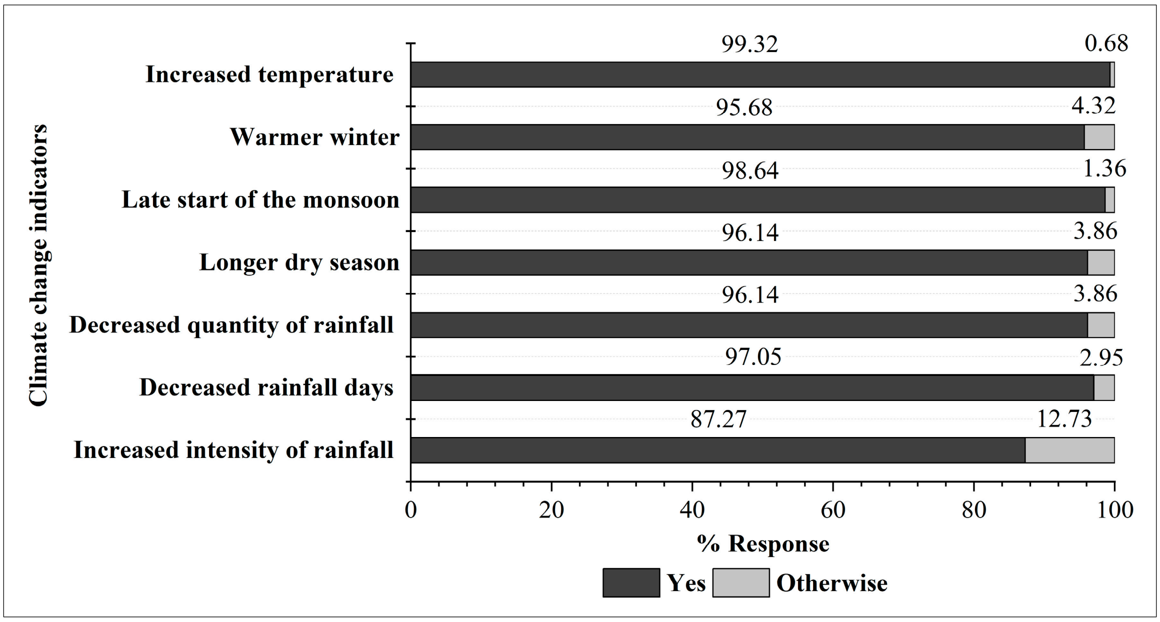


Figure 4. Respondents' perceptions of local climate change indicators.

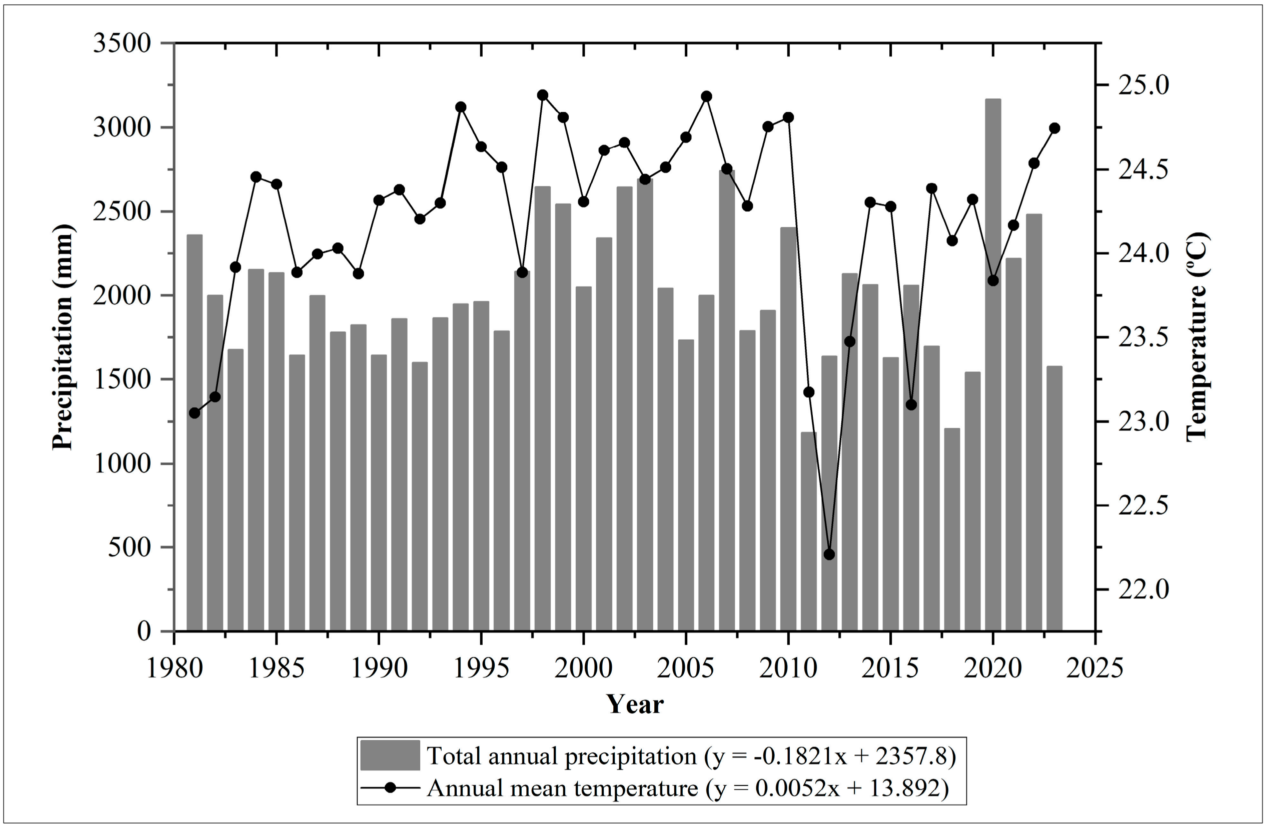


Figure 5. Bar chart showing total annual precipitation (in mm), and trend line showing mean temperature (in °C) at stations near the watershed from 1980 to 2023, along with Sen's slope equation.

3.4. Factors Affecting Climate Change Perception

Spearman's Rho correlation assessed factors affecting climate change perceptions (Table S2). Demographic characteristics were found to be statistically significant for all indicators. Education level showed a negative association with increased temperature. Monthly household income and topographic location both positively correlated with decreased rainfall quantity. Ethnicity showed a negative correlation with increased rainfall intensity, whereas education level, monthly household income, occupation, and topographic location were positively correlated. Topographic location and ethnicity were positively correlated with a longer dry season and a late-starting monsoon, respectively. Monthly household income, occupation, and topographic location all positively correlated with warmer winters. While significant bivariate relationships existed between socio-demographic characteristics and perceptions of climate change, no robust correlations were found between independent and dependent variables, with few exceptions.

3.5. Perception of WES Supply Trends

Generally, respondents perceived decreasing trends in WES supply over the last decade. More than 60% experienced diminishing availability of water for drinking and quantity of observable water in rivers/streams/lakes (Figure 6), attributable to pressures, including climate variability, encroachment, land use conversion, sedimentation, landslides, excessive sand/gravel extraction, and increased demand. For example, the Khageri Irrigation scheme, aimed at irrigating 39,000 hectares of farmland, was hampered due to climate-related factors and land use conversion (Table S1, Figures 5 and 7), resulting in insufficient water supply, even during the monsoon. Interviews with community members and Divisional Forest Office personnel highlighted concerns about urbanization, road expansion, and local governments designating riversides as dumping sites, harming freshwater ecosystems and downstream protected areas. A majority (53.64%) perceived a decrease in forest product availability, citing overuse and community encroachment as a key factor in reducing timber and fodder availability and hindering their collection. LULC data confirm decreased forest cover over the past two decades (Table 4, Figures 7 and 8), although 26.37% of respondents perceived an increase, and 20% perceived no change in the supply of forest products. Similarly, perceptions of biodiversity support were mixed, with 49.09% reporting a decrease, 33.41% an increase, and 17.50% no change. Experiences varied between upstream and downstream areas, with their different management regimes. Downstream areas, with protected forests and limited access, had richer biodiversity compared to upstream regions under community-based management. Major biodiversity threats included illegal hunting, habitat encroachment, drying water sources, and invasive species. Downstream stakeholders indicated that excessive water during monsoons caused flooding, forcing wildlife to seek shelter upstream and reflecting them as climate refugees.

Most respondents (88.40%) reported a decline in soil fertility/productivity, attributing it to various factors (Figure 6). Soil erosion and reduced soil fertility emerged as major concerns, particularly affecting agricultural land and its surroundings. Soil erosion disproportionately impacted upstream areas due to unsustainable cultivation practices, steep topography, erratic rainfall patterns, overgrazing, deforestation, sub-optimal farming techniques, and inadequate terrace management. Respondents also cited sedimentation of agricultural land, damage to irrigation channels, and prolonged dry spells as factors in declining soil fertility. Additionally, they mentioned flash floods, insufficient conservation measures adhered to during cultivation on steep slopes, and open grazing as factors exacerbating soil and agricultural land degradation, specifically in diminishing soil fertility and decreasing agricultural production. Perceptions of natural hazard control were mixed, with the majority (41.37%) experiencing decreased trends, while 24.09% reported no change. Some respondents (28.2%) noted an increase in the frequency and impact of various natural hazards, including floods, riverbank erosion, and soil erosion, compared to previous decades. However, 34.54% of respondents reported no impact on their agricultural land, infrastructure, and settlements from natural hazards.

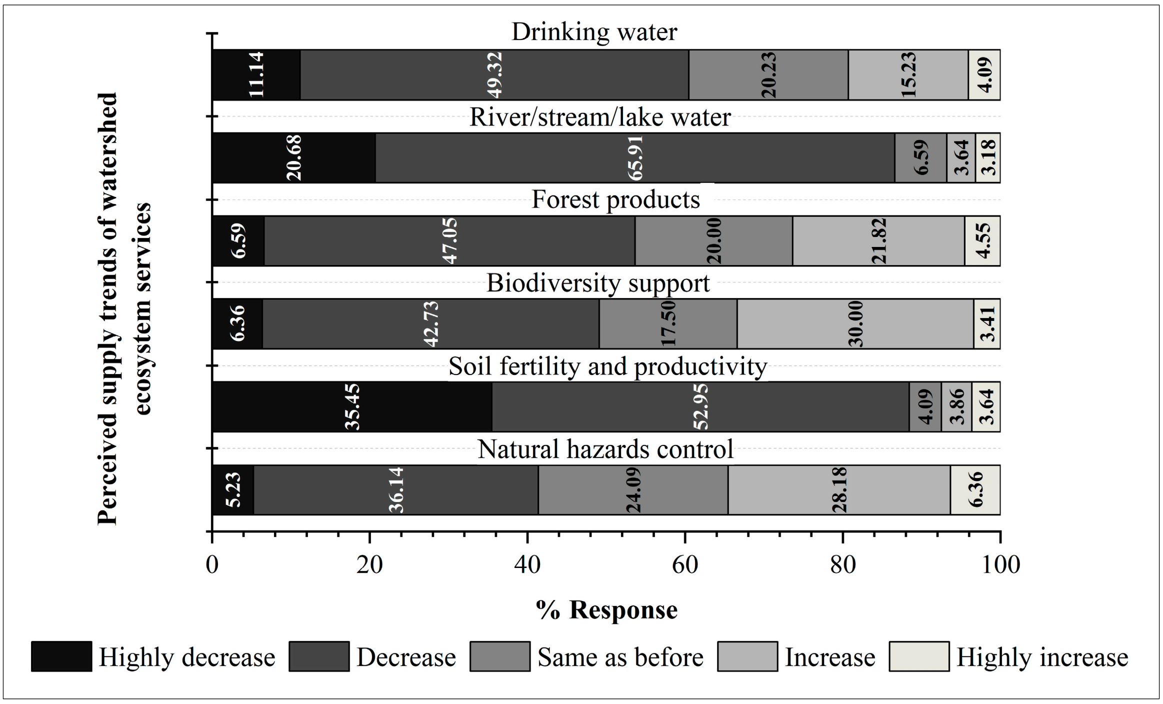


Figure 6. Respondents' perceptions of WES supply trends over the past decade.

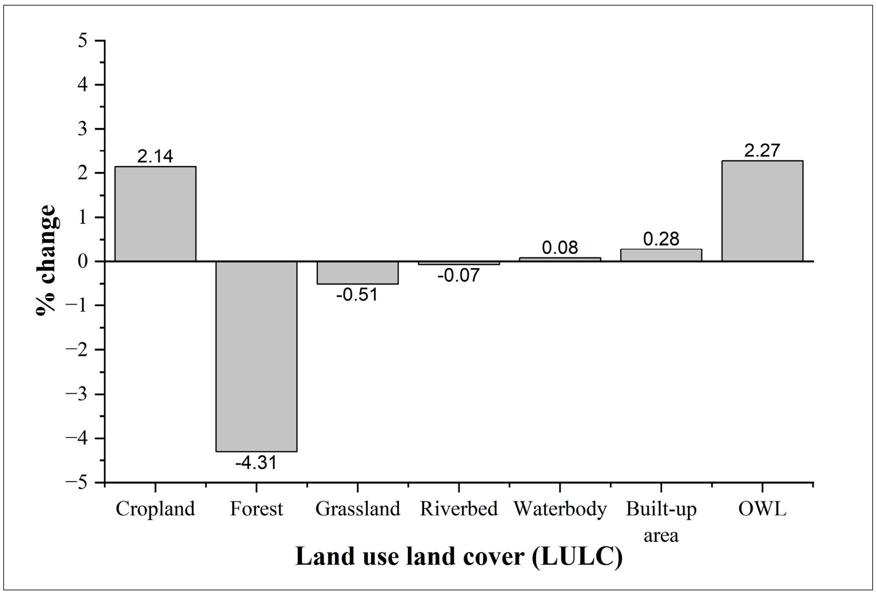


Figure 7. Percentage change in watershed land use/land cover per category from 2000 to 2019.

Table 4. LULC changes (in hectares and percentage) across different land use categories from 2000 to 2019, along with the annual rate of change for each category.

Land Use Land Cover	2000		2019		Change (2000–2019)		Annual Rate of Change (2000–2019)
	Hectares	%	Hectares	%	Hectares	%	%
Cropland	2476.00	18.66	2758.63	20.80	+282.62	+2.14	+0.57
Forest	10,565.56	79.61	9999.55	75.30	−566.01	−4.31	−0.29
Grassland	120.23	0.91	55.44	0.40	−64.79	−0.51	−4.07
Riverbed	36.01	0.27	30.12	0.20	−5.89	−0.07	−0.94

Table 4. *Cont.*

Land Use Land Cover	2000		2019		Change (2000–2019)		Annual Rate of Change (2000–2019)
	Hectares	%	Hectares	%	Hectares	%	%
Water body	2.52	0.02	17.22	0.10	+14.70	+0.08	+10.11
Built-up area	2.19	0.02	40.96	0.3	+38.77	+0.28	+15.42
OWL	69.90	0.53	370.50	2.80	+300.60	+2.27	+8.78
Total	13,272.42	100	13,272.42	100			

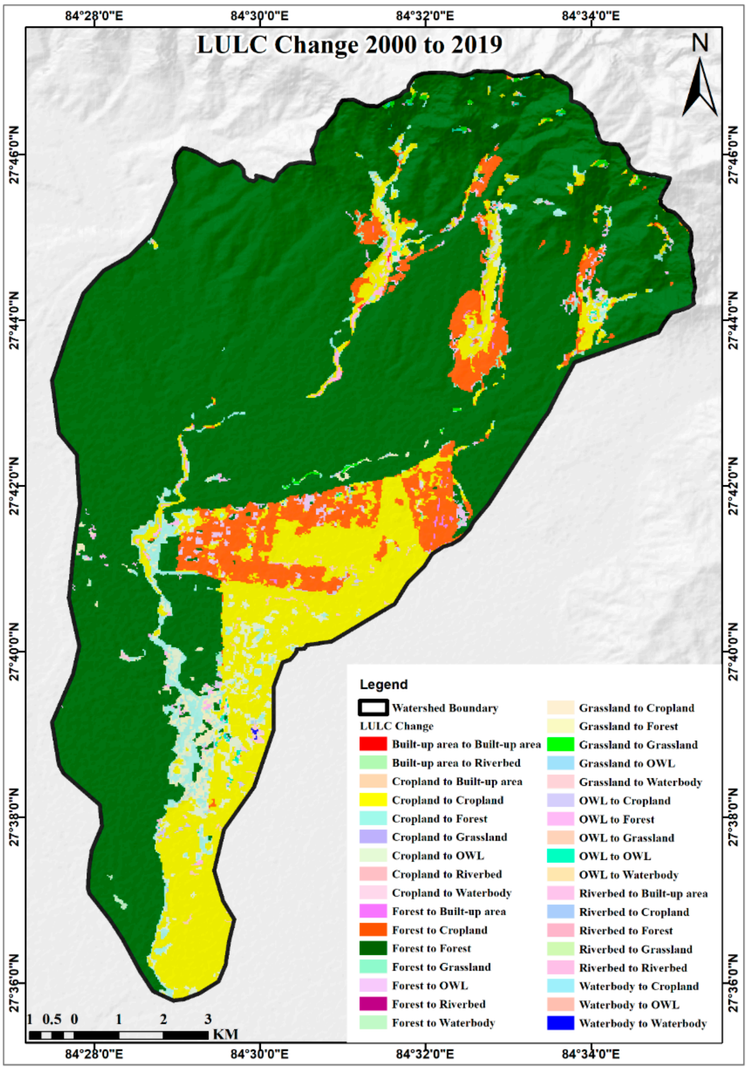


Figure 8. Map showing watershed land use/land cover changes (gain or loss) across seven categories from 2000 to 2019.

3.6. Socio-Demographic Characteristics Association with Perceived Supply Trends of WESs

Topographic location, age group, ethnic group, education level, occupation, and monthly household income significantly influenced respondents' perceptions of changes in WES supply, whereas gender had no significant impact (Table 5). Notably, respondents' age showed a significant association with perceptions of changes in forest products and soil fertility and productivity. Additionally, occupation was significantly less related to perceptions of biodiversity support. Forest products and natural hazard control had a significantly weaker relationship with monthly household income.

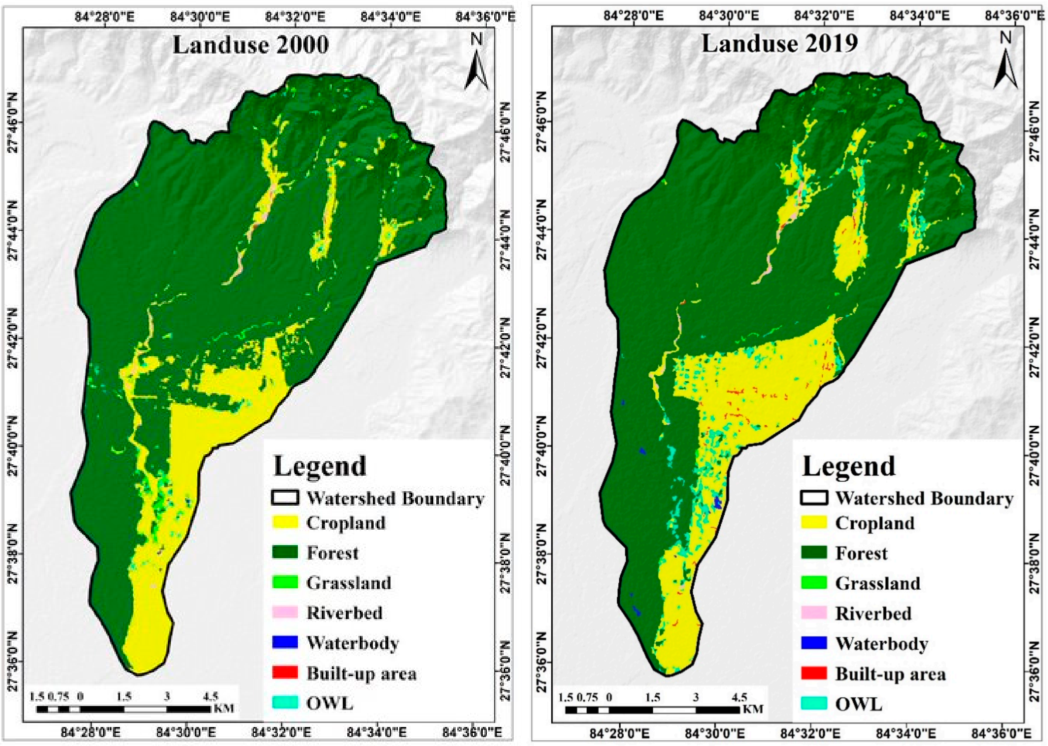
Table 5. Associations between seven socio-demographic characteristics groups and six perceived WES supply trends at 1%, 5%, and 10% significant levels.

Socio-Demographic Characteristics	Watershed Ecosystem Services					
	Drinking Water	River/Stream/ Lake Water	Forest Products	Biodiversity Support	Soil Fertility and Productivity	Natural Hazard Control
Topographic location	69.28 ***	69.28 ***	53.52 ***	87.59 ***	93.78 ***	45.85 ***
Gender	2.87	2.62	2.60	2.58	4.28	2.19
Age group	48.74 ***	26.85 *	17.71	31.65 *	25.76	34.64 **
Ethnic group	46.90 ***	50.98 ***	28.82 ***	35.04 ***	47.18 ***	24.93 ***
Education level	83.26 ***	45.14 ***	40.68 **	40.75 **	48.72 ***	37.13 *
Occupation	72.33 ***	41.38 **	55.25 ***	30.70	62.21 ***	24.48
Monthly household income (NPR)	54.87 ***	48.57 ***	24.94	30.40 *	53.62 ***	23.14

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; NPR: Nepalese Rupees; USD 1 = NPR 133.56 on 5 May 2024 (Nepal Rastra Bank).

3.7. Land Use Land Cover Change (LULC)

Figure 9 illustrates the land use category distribution in 2000 and 2019, while Table 4 shows LULC between those years. In 2000, the watershed comprised 18.66% cropland, 79.61% forest, 0.91% grassland, 0.027% riverbed, 0.02% water body, 0.02% built-up area, and 0.53% other wooded land (OWL).



(**a**) (**b**)

Figure 9. Watershed land use maps from 2000 (**a**) and 2019 (**b**).

Over the 19-year period, forests decreased by 4.316%, grassland decreased by 0.51%, riverbeds decreased by 0.07%, cropland increased by 2.14%, water bodies increased by 0.08%, built-up area increased by 0.28%, and OWL increased by 2.27% (Table 4). Over this 19-year period, significant conversions occurred, including forest to cropland (6.14%), cropland to forest (2.14%), and grassland to forest (0.66%) of the total area of the study watershed.

Table 4 and Figure 7 present the percentage change in the land use categories, with the highest decrease observed in forest area (−4.31%) and the lowest in riverbed (−0.07%). The overall annual rates of change indicate a decrease in forest, grassland, and riverbed areas at rates of 0.29, 4.07, and 0.94, respectively. Conversely, the remaining LULCs underwent spatial expansion (Table 4).

4. Discussion

Changing climate and socio-economic contexts require holistic and sustainable watershed management that considers both bio-physical characteristics and local community socio-economic dynamics [10,53]. Socio-economic factors like education, occupation, community perceptions, and perceived importance of ecosystem services, coupled with insights from time series data on land use changes and climate patterns, comprehensively depict the interplay between communities and their environment [22,45,54]. Integrating diverse sources of information allows prioritization of areas for conservation and management through sustainable practices benefitting communities and ecosystems [4,54].

4.1. Perceived WES Prioritization

Variations in perceptions of the relative importance of various WESs reflect divergent experiences, knowledge, and community priorities [35]. Respondents ranked drinking water as the most important and biodiversity support as the least, which complements previous research findings [5]. Soil fertility/productivity, river/stream/lake water, and natural hazard control ranked second, third, and fourth in importance, respectively, with only slight score variations between them, compared to drinking water. While all WESs are vital for livelihoods and daily community sustenance [5,55], forest products and biodiversity support were perceived as comparatively less important than others. Our findings here support earlier research indicating a decreasing trend in forest product dependency [56]. During the 1990s, agriculture and animal husbandry were primary livelihood activities in Nepal. Since 2015, significant socio-economic transformation has shifted a traditional rural economy relying heavily on forest resources to a monetized one. Increasing per capita income and facility access reduce reliance on forest products, with modern energy sources like biogas, liquefied petroleum gas (LPG), and electricity replacing firewood [56–58]. Biodiversity, ranking lowest among the six WESs, reflects locals prioritizing primary services crucial for local livelihoods over secondary services with perceived lesser benefits. This disparity highlights the disconnect between biodiversity conservation and community livelihoods [22]. Enhancing WES awareness and understanding could alter local perceptions regarding conservation and management [5]. Economic instruments, including payment for ecosystem services (PESs), offer 'win–win' solutions for biodiversity conservation and human livelihoods [59], as discovered in Guatemala, Cambodia, and Tanzania [60], where PES initiatives contribute to mutually beneficial outcomes [22].

4.2. WES Supply and Socio-Demographic Factors

Perceptions of WES supply differ with landscape scale, environmental conditions, community needs, and socio-economic factors [61]. Understanding local perspectives informs effective management and conservation of watersheds as holistic socio-ecological units [53]. Respondents perceived significant decreases in soil fertility and productivity, followed by river/stream/lake water, drinking water, and availability of forest products, aligning with studies on ecosystem services showing perceived decreasing trends in water availability [35,62] and agricultural productivity [22]. Contrasting our findings of a perceived decline in forest products, ref. [62] documented an increasing trend in forest products in areas of Central Nepal. The discrepancy reflects differing viewpoints on ecosystem services.

While researchers may expect forest products to increase with expanding forest coverage, local communities may prioritize these services based on their abundance and easy access to timber, firewood, and fodder [63]. Our findings align with [62]'s observations of declining trends in biodiversity conservation, attributable to forest fires, increase in invasive species, and reduced water availability, as perceived by respondents [39,62]. Similar to our findings, earlier studies reveal increasing trends in occurrences of natural hazards, such as landslides and drought [64,65]. Consistent with previous research [5,22], we found that socio-demographic factors significantly influenced changes in WES perceptions. Topographic location, age, ethnicity, education, occupation, and monthly household income were all key predictors. Upstream community perceptions differed from downstream community ones due to having comparatively higher reliance on watershed resources and services, including water sources and forest products [11]. Age played a role, with older individuals being comparatively more positive compared to younger respondents in their experience-based perspectives, aligning with earlier findings [5]. Perceptions of ecosystem service importance and trends differed between educated and illiterate respondents, echoing previous findings that respondent knowledge and education level are crucial in understanding and perceiving ecosystem services [5,22]. Respondents with higher monthly household income reported less dependency on ecosystem services for their livelihoods compared to their lower-income counterparts. Understanding these differences in perception assists in targeting diverse needs and perspectives through community management strategies [5,22].

4.3. Nexus of Climate Change, LULC Changes, and Perceived WES Supply

Grasping the nexus between climate change, LULC changes, socio-economic demographics, and local perceptions of WESs bolsters long-term sustainability [5,9,22]. Our study echoes research confirming changes in ecosystem service supply in China's mountains [9], where climate change decreased water yield but increased soil retention, while LULC change decreased both water yield and soil retention. Residents' perceptions of variability in local climate change indicators in our study area align with data collected from nearby meteorological stations, supporting earlier findings [66]. Communities observed declining annual precipitation, rising temperatures, and prolonged dry spells, with reduced water availability for drinking, irrigation, and household use. This supports [39], who reported decreased water availability and drying springs.

While rising temperatures can reduce water yield through increased evapotranspiration [67], LULC data from 2000 to 2019 show an increase in water bodies in the study watershed, contrary to local perceptions. Ref. [39] supported these perceptions, noting a decline in water sources due to climate change. The discrepancy may stem from government and community forest programs that prioritize wetland rehabilitation, lake and pond conservation, and fish farming. These initiatives are likely known only to the few individuals involved, influencing their perception of the increase in water bodies. A study in central Nepal found that increasing forest cover reduced surface runoff and facilitated percolation, thereby recharging the aquifer water supply [63]. Our study revealed increased rainfall variability, characterized by intense rainfall events within shorter intervals, causing extreme events like floods, landslides, and soil erosion, which disrupt WES supplies. This is consistent with previous research indicating that mountain soil retention is highly influenced by precipitation intensity, altitude, and slope [68]. Conversely, decreased precipitation can reduce slope erosion and soil scouring by altering runoff dynamics [69,70], potentially affecting agricultural productivity [11]. LULC analysis revealed decreasing forest area, consistent with community perceptions of reduced forest product availability. This contradicts earlier reports of opposite trends [63]; however, discrepancies may be related to the scale and intensity of forest management efforts [71]. Study participants perceived invasive species to be increasing with climate change, reducing forest product availability and causing habitat degradation. LULC data showed that forest, riverbed, and grassland areas decreased, consistent with previous wildlife habitat research [72,73].

5. Conclusions

This study examined community perceptions of WESs across socio-demographic groups in relation to observed climate and LULC change patterns. Among the six WESs, drinking water was most important to communities, while biodiversity support was least important. Importance rankings varied with respondents' socio-demographic characteristics. Findings confirmed that decreasing trends in WES supply with environmental change and socio-demographic characteristics significantly shaped respondents' perceptions of those changes. Significant alignment existed between community perceptions of local climate change indicators, like temperature and precipitation, and the actual situation. However, the disparity between community perceptions and LULC changes, particularly regarding the actual documented increase in water bodies, suggests perceptions may be more closely aligned with observable climate patterns than with LULC changes. Our results underscore how integrating community perceptions with climate change and LULC change analyses can inform decision-making processes affecting WESs. Decreasing trends in WES supply reflect that conservation measures prioritizing sustainable resource management are critical. Besides fostering community engagement through education, awareness initiatives, and participatory decision-making, integrating climate change indicators and LULC change patterns with community perception assessments can reveal complex interactions shaping ecosystem dynamics and community livelihoods. Holistic approaches can target adaptation and mitigation strategies to overcome multifaceted environmental and socio-economic challenges. Aligning conservation efforts with observed climate and LULC change patterns enhances ecosystem and community resilience. Understanding socio-economic and topographical variability allows for tailoring conservation strategies to address communities' diverse needs and priorities. Programs incentivizing ecosystem stewardship, including user-pay schemes for ecosystem services, can enhance community motivation and promote active involvement in conservation and management. Establishing ownership and responsibility among local communities can safeguard ecosystem services for the future. Based on the findings of this study, we recommend (1) policies should integrate local perceptions of WESs, especially related to urgent priorities such as drinking water, to ensure long-term sustainability; (2) watershed management decisions must be informed by up-to-date data and integrate climate change and LULC in a manner accessible to communities; (3) better community information about the impact of land use changes on WESs, especially water bodies, can improve the alignment of local perceptions and strategies; (4) management strategies should be adapted to take into account the different needs of social and economic groups, as well as the topographical variations of the watershed; (5) programs should promote equitable sharing of the benefits generated by WESs, thus increasing community involvement and could lead to more efficient and sustainable watershed management, beneficial to both people and ecosystems. Integrated approaches that incorporate community perceptions, climate data, and land use analysis can provide a clearer understanding of ecosystem dynamics, enabling targeted interventions that support global environmental conservation goals.

This study emphasizes the importance of integrating community needs, socio-demographic relevance, and perceptions into ecosystem management in human-dominated watersheds worldwide. It provides guidance on prioritizing local needs and ecosystem services and capturing the complexity of the relationship between humans and ecosystems, especially in resource-constrained contexts like South Asia. Its integrated approach, focusing on local priorities and using a rigorous methodology, can serve as a model for other regions facing similar challenges. By aligning with global frameworks such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Convention on Biological Diversity (CBD), Post-2020 Global Biodiversity Framework, and UN Decade on Ecosystem Restoration, the study contributes valuable insights on addressing local needs while supporting global environmental goals.

Supplementary Materials: The following supporting information can be found at: https://www.mdpi.com/article/10.3390/su17010062/s1, Table S1: Seasonal and annual mean temperatures; Table S2. Correlation of socio-demographic characteristics and perceptions of climate change.

Author Contributions: Conceptualization, data collection, data curation, methodology, and writing, N.D.; land use land cover data analysis and writing, B.K.R.; writing—review and editing, C.-H.L., S.A., P.G. and U.C.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science and Technology Council (NSTC), Taiwan, under grant number 113-2621-M-259-005.

Institutional Review Board Statement: Not applicable. However, the research protocol conformed to the British Sociological Association's Statement of Ethical Practice guidelines. Study permission was obtained from the Department of National Parks and Wildlife Conservation, Nepal (Letter no. 079/80,133) and the Department of Forest and Soil Conservation, Nepal (Letter no. 079/80). All respondents remain anonymous to protect confidentiality.

Informed Consent Statement: Informed consent and approval to report the collected data from the interviews were obtained from all respondents.

Data Availability Statement: The data presented in this study are available on request from the first author.

Acknowledgments: We sincerely thank the local communities, especially the Khageri Khola Sub-watershed Conservation Committee (KKSWCC), for their invaluable support during the field investigation. We also appreciate the assistance from government and non-governmental organizations and extend special thanks to the reviewers for their insightful feedback and to the respondents for their time and valuable input in this study.

Conflicts of Interest: Author Nabin Dhungana was employed by the WWF Nepal. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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