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Climate and Land Use Change Pressures on Food Production in Social-Ecological Systems: Perceptions from Farmers in Village Tank Cascade Systems of Sri Lanka

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Abstract: Climate and land use change pressures are critical to food production in Social-Ecological Systems (SESs). This study assessed farmers' perceptions of the pressures of climate and land use changes alongside their impacts on food production in Mhahakanumulla Village Tank Cascade System (MVTCS), a SES maintained by traditional agricultural land use systems in the dry zone of Sri Lanka. This study used both rating and ranking scale questions to quantify farmers' perceptions. The tobit regression model was employed to evaluate how farmer perception was influenced by socio-economic factors. The results showed that most of the farmers had experienced that the climate of the MVTCS area had changed over time, and they perceived variability of rainfall patterns as the most prominent and influential climate change. The increased cost of production, wildlife damage, and land degradation were ranked by the farmers as the most impactful factors of food production due to climate change. The farmers rated deforestation and land clearing as the most influential and impactful changes in land use, while wildlife damage and land degradation ranked as the highest impacts on food production due to land use changes. Among the socio-economic determinants, training and income/profit positively influenced farmer perceptions of the severity of both climate and land use change. The level of farmer's adaptation to climate change had a negative association with their perception of the severity of climate change. Household size negatively influenced the perceptions of the severity of climate change while positively influencing perceptions of land use change impacts. Among the spatial determinants, farm size and downstream locations of MVTCS positively influenced perceptions of the severity of both climate and land use change. Thus, the effectiveness of adaptation strategies towards climate and land use change pressures depends on how well they are understood by the farmers. The study findings provide helpful insights for formulating localized land use policies and climate change adaptation strategies in these globally important landscapes with a combination of both top-down and bottom-up approaches.

Keywords: climate change; land use change; farmers' perceptions; perception determinants; Village Tank Cascade Systems

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1. Introduction

Global food systems are under increasing pressure from climate and land use change impacts [1,2]. Social-Ecological Systems (SESs) are critically dependent on traditional food systems for food production and have experienced various climatic and non-climatic pressures over time [3]. These external and internal pressures have impaired the capacity of ecosystems to produce ecosystem services and have increased food production challenges in SESs [4–7]. In Sri Lanka, the Village Tank Cascade System (VTCS) is a social-ecological system maintained by traditional smallholder agricultural systems, which have been recognized as a globally important agricultural heritage system [8]. The VTCS have withstood seasonal climate variability during the last 2000 years [9]. However, this rainwater harvesting-based agricultural system has faced challenges due to the changing climate and land use patterns, particularly over the last fifty years, making food production in this region vulnerable [10,11].

The adverse impacts of climate change can be observed in both natural ecosystems and social systems [3]. Regional climate change projections indicate that more climate variability and extreme events are likely to adversely impact agricultural production, particularly in most South Asian countries [12,13]. Due to limited adaptive capacities, these countries are less resilient to the harmful impacts of climate change and variability [14]. Being a country in the South Asian region, Sri Lanka is no exception when it comes to the impacts of climate change on food production [15,16]. Thus, climate change is likely to impact both the natural ecosystem and social system in the VTCSs. In particular, farming communities in the VTCS areas are likely to be vulnerable to crop failure, yield reductions, and limited livelihoods and incomes due to climate change characterized by variability in rainfall and temperature [10,17–19]. Land use changes have been observed in VTCS areas due to the expansion of agricultural land use and demographic changes during the last three decades [11,20,21]. Both structural and pattern changes in land use have occurred, especially in the natural land cover system, causing degradation of the hydro-socio-ecologically important land uses [9,22]. These changes lead to the impairment of ecosystem functions and ecosystem services impacting sustainable food production and livelihoods [23–27].

Other than the scientific observations and measurements, farmers' perceptions are an alternative and complementary approach to assessing climate and land use change impacts and adaptation needs [28]. This participatory research approach with inclusive methodologies can lead to an accurate and effective way of assessing farmers' perceptions that help identify and address the issues faced by farmers [29]. Participatory methodologies ensure effective participation, especially marginalized communities who are most likely to face vulnerabilities and also help better understand the local context [30]. Understanding farmers' perceptions of influential factors of changing climate and land use variables that impact food production is important because their adaptation decisions are shaped by their perceptions [10,28,31,32]. Farmers are the most important decision-makers in their farming operations [33]. Thus, the effectiveness of adaptation strategies depends on how well the impacts of climate and land use changes are perceived by farmers [34]. Despite this obvious need, no studies have evaluated farmers' perceptions, and the determinants of their perceptions regarding climate and land use change in VTCS areas has particularly focused on the impacts of farm-level food production [35].

Farmers' perceptions of assessing climate and land use changes may be influenced or confounded by many other socio-economic and environmental factors in addition to changing farm-level biophysical factors [36]. Thus, identifying potential indicators and relationships related to the above factors is vital for better understanding and recording of farmers' perceptions of climate and land use changes that impact food production. However, in past VTCS research, climate and land use change perception assessments and related indicators are potentially lacking [35]. This study adopted the general framework of analyzing SES characteristics proposed by Ostrom [37] and Berkes and Folke [38] to explore and identify such potential indicators and relationships. Accordingly, a VTCS is characterized by diverse multifunctional subsystems associated with climate, land use, water use, food production, ecological production, and socio-cultural production. Furthermore, various external (e.g., climate change) and internal (e.g., land use change) influential factors interact with these subsystems, which can affect the sustainability and productivity of VTCSs and could influence farmers' perceptions [6,39–42]. Understanding of such indicators and relationships (Figure 1) could also help scientists and planners to better understand the local context, taking account of farmers' perceptions (bottom-up approach) and combining them with the observed data (top-down approach) for precise decision-making for successful adaptation planning [10].

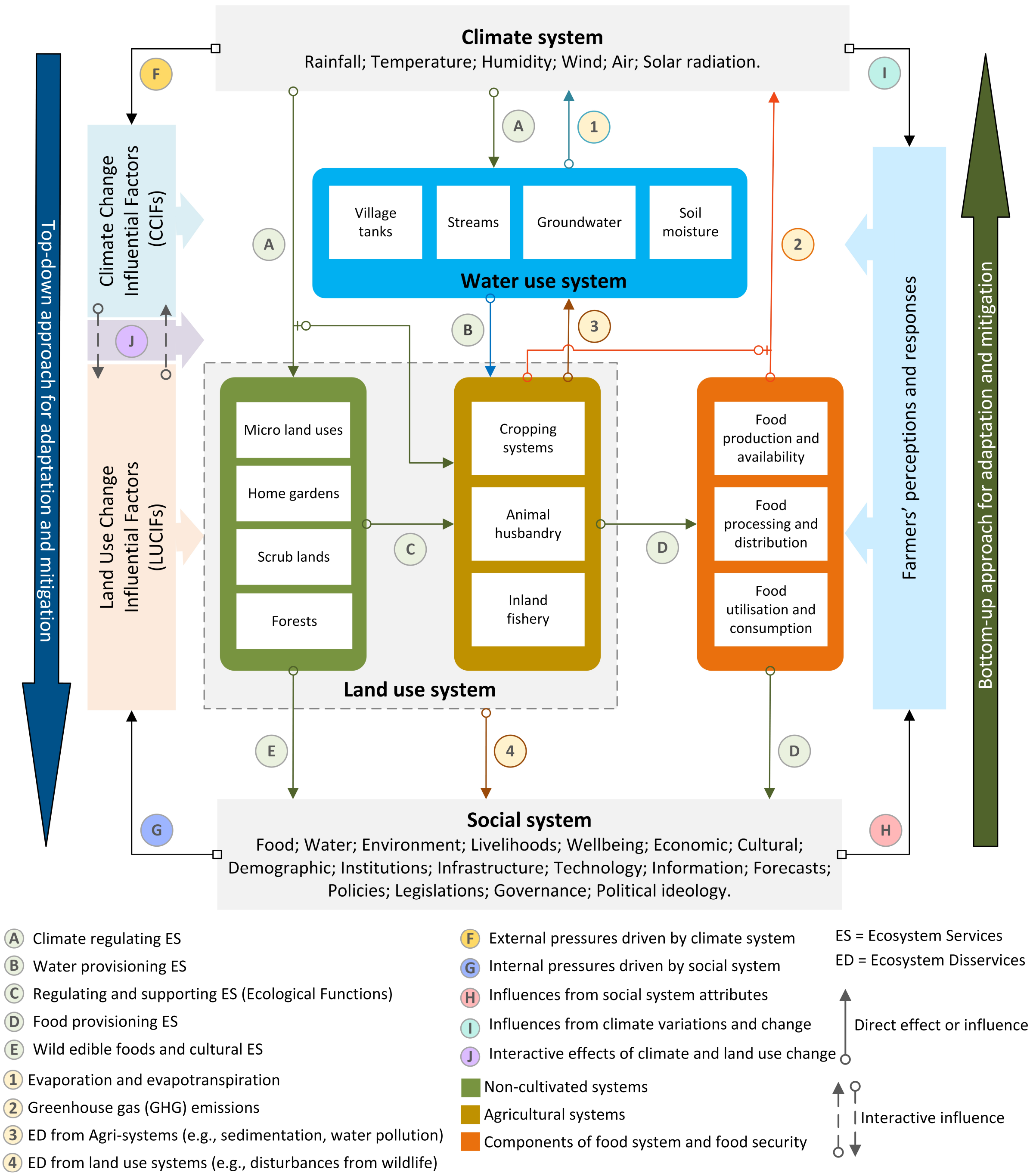

Figure 1. Potential indicators and relationships for understanding farmers' perceptions and responses to climate and land use change impacts on food production in Village Tank Cascade Systems of Sri Lanka. Source: the authors.

This study aimed to investigate farmers' perceptions of climate change and land use change pressures that affect food production systems in the Mahakanumulla Village Tank Cascade System (MVTCS), an agriculture-dominant rural SES located in the dry zone of Sri Lanka. The specific objectives were: (i) to examine the socio-economic characteristics of farmers; (ii) to evaluate the challenges that farmers consider critical for sustainable food production; (iii) to assess the farmers' perceptions of the behavior of influential factors of climate change and their impacts on food production; (iv) to assess the farmers' perceptions of the behavior of influential factors of land use change and their impacts on food production; and (v) to analyze the determinants of farmers' perceived risks of climate and land use change.

2. Materials and Methods

2.1. Study Area, Population, and Sampling

This study was conducted in MVTCS, located in the upper Nachchaduwa cascade complex in the Anuradhapura district of Sri Lanka (8°5′–8°15′ N and 80°20′–80°35′ E) (Figure 2). The MVTCS is a branch-type cascade system, consisting of 12 villages and 28 small tanks, which occupy approximately 4000 ha of land, with ten major land-use types: dense forests, open forests, scrub lands, seasonal crops, chena lands, home gardens, paddies, water bodies/streams, rocky areas and built-up areas [43]. The MVTCS has an undulating landscape, which is characterized by slopes and valleys that support water movement through a network of cascade tanks drained into the Nachchaduwa reservoir. The population of the study area was 3432 (47.8% male and 52.2% female). Of the 1193 households, 364 families were practicing full-time professional farming [43]. Considering a 10% margin of error and 90% confidence interval [44], a sample of 81 household heads from the full-time professional farming households of the MVTCS was randomly selected for face-to-face interviews. A government Agriculture Instructor from the Department of Agriculture of the north-central province who was responsible for the study area assisted in identifying the full-time farming households in the study area.

This study area is characterized by a tropical monsoonal climate with a well-defined bi-modal rainfall pattern. The annual average rainfall of the study area is 1320 mm (with intra-annual variation of 798 to 2483 mm), and the average daily temperature is 28 °C (ranging from 27 to 29 °C) according to the weather data of the last fifty-year period (1971–2020) of the Anuradhapura meteorological station [45]. The average monthly rainfall of the area varied from 24.1 mm to 261.5 mm between 1870 and 1970 (non-global warming period) and from 13.7 mm to 258.4 mm between 1971 and 2020 (global warming period) according to the weather data recorded at this station [46,47] (Figure 3). Evaporation varies from 3.5 mm/day to 7.5 mm/day (highest from May to September), and evapotranspiration varies from 1000 mm/year to 1400 mm/year [48]. The variations in annual rainfall patterns enable farmers to adapt to two cultivation seasons: (i) Yala (March to August), a low rainfall dry season with approximately 482 mm/season; and (ii) Maha (September to February), a high rainfall wet season with an approximately 839 mm/season average according to the 1971–2020 rainfall data. Unpredictable seasonal variability in the temporal distribution of rainfall and extreme events such as droughts, especially during the Yala season, have affected food production and livelihoods in the study area [10]. A recent study indicated that observed climate variability during the past three decades and projected climate change impacts on paddy production in the study area will make sustainable food production more challenging in the future [45].

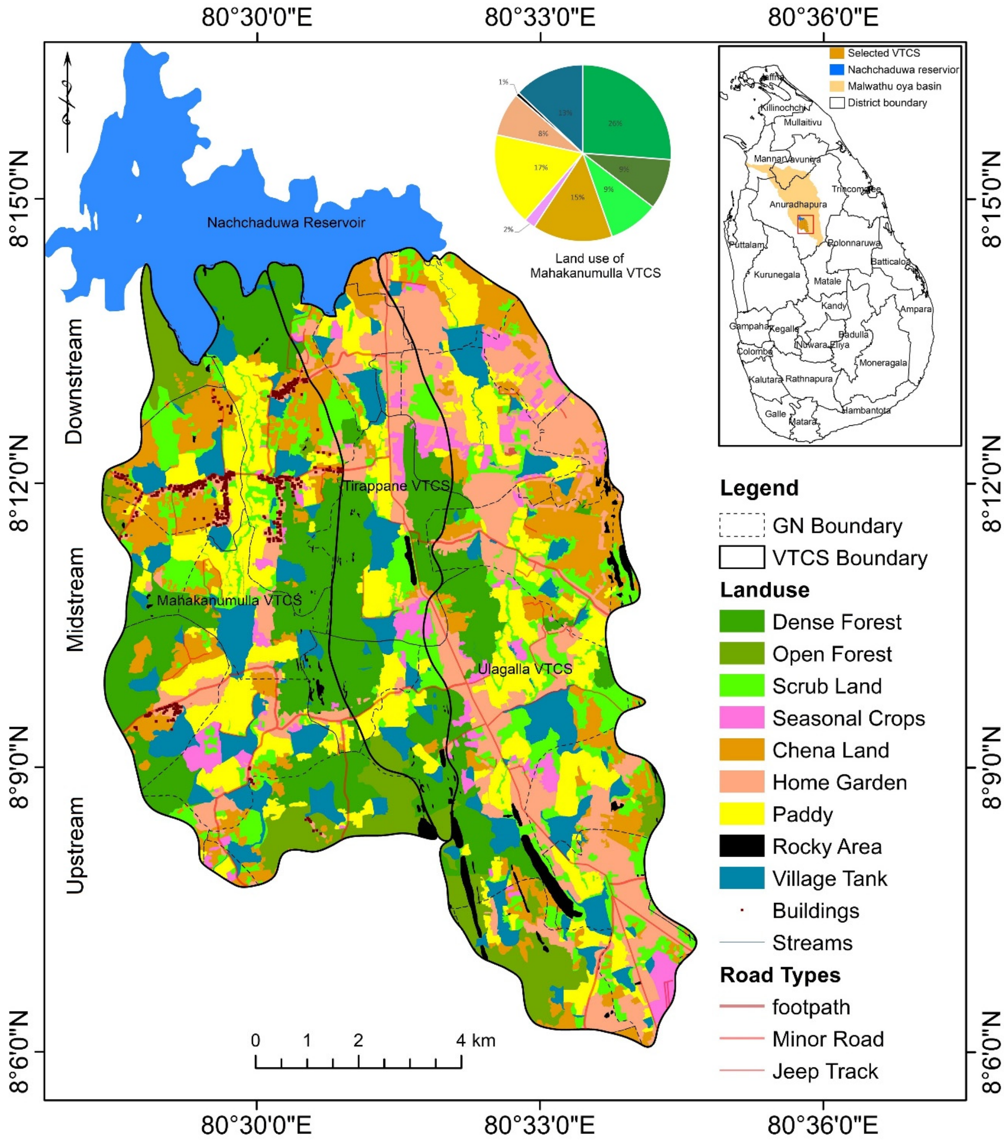

Figure 2. Location and land use system of the study area (Mahakanumulla VTCS) in the upper Nachchaduwa cascade complex. Land use data source: HLP-BLA [43].

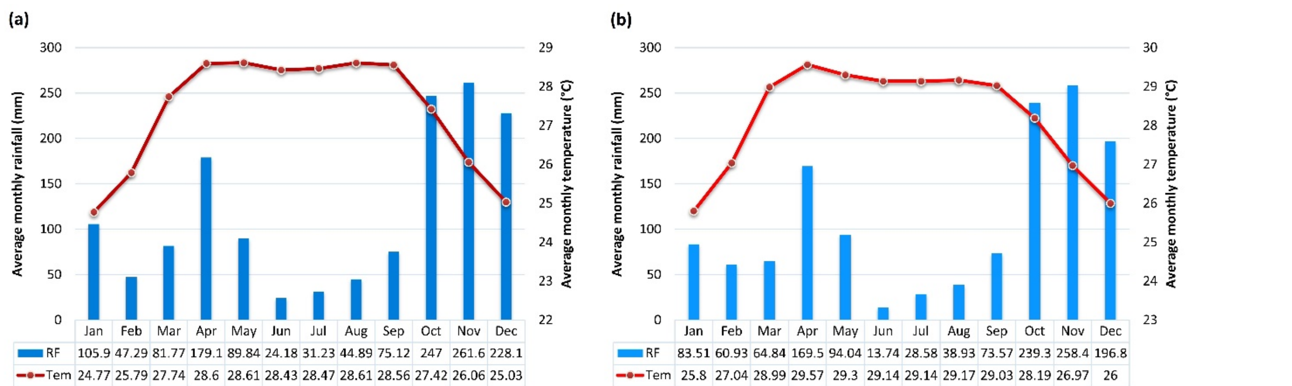

Figure 3. The average monthly rainfall and temperature of the study area. (**a**) Non-global warming period (1870–1970); (**b**) global warming period (1971–2020). Source: Authors developed based on weather data (1870–2020) of the Anuradhapura meteorological station.

Three traditional farming systems (lowland paddy, rainfed upland crops, and homestead farming) are mostly practiced in the MVTCS. Lowland paddy cultivation (approximately 20% of the land area) is the predominant agricultural activity in the study area [11]. The agricultural lands of the MVTCS are highly fragmented, and many farms are less than 2 ha [23]. Farming in the MVTCS has relied on relationships with rich biodiversity, traditional knowledge, and culture of the area since ancient times for food production and wellbeing. However, land use and land cover changes and landscape pattern changes during the past three decades in VTCSs have impacted the ecological functions and supply of ecosystem services in the study area, making sustainable food production more challenging [11,49]. Studies indicate that over the last century (1910 to 2019), there has been a 27-fold increase in population a 7-fold expansion in home gardens, as well as 79% and 49% declines in the areas of forest and scrub lands, respectively, in the MVTCS [50]. These trends indicate increasing threats to ecosystem health of the MVTCS landscape due to the impacts of human activities [11,43].

2.2. Data Collection and Analysis

Data on farmers' perceptions were collected using structured interviews undertaken between December 2022 and February 2023. Ethical approval for this participatory survey was granted by the Human Research Ethics Committee of the University of New England, Australia (Approval No: HE22-030). The interview schedule was created using ArcGIS Survey123 (version 3.17) software (ESRI, Redlands, CA, USA), and data collection was performed through the ArcGIS Survey123 field app on mobile smartphones. The interview schedule (Supplementary File S1) covered five thematic sections (A–E) to assess the climate and land use change pressures on food production, including (A) socio-economic and farming characteristics; (B) challenges in farming; (C) land use change influential factors and pressures affecting farming; (D) climate change influential factors and impacts on farming; and (E) farmers' perceptions of adaptation to climate change. Both open-ended and closed-ended questions were included to collect qualitative and quantitative perception data for the above thematic areas. The survey questionnaire was pre-tested and improved before the survey. We selected fifteen explanatory (predictor) variables related to socio-economic, knowledge, and spatial factors used in previous studies [51–56], which are shown in Section A of the interview schedule, that were assumed to influence the farmers' perceptions about land use and climatic change pressures in the VTCSs areas (Table 1). Further, challenges experienced by farmers on food production in the study area were evaluated using the eighteen indicators identified in Section B. The farmers rated the challenges using a five-point rating scale, where each variable was weighted as 5 = extremely challenging, 4 = highly challenging, 3 = moderately challenging, 2 = less challenging, and 1 = least challenging, representing the extents to be very high, medium, low, and not at all based on the farmers' experiences.

Table 1. Description of predictor variables used to measure farmers' perceptions of climate change and land use change impacts.

No	Variable	Rationale of Selection of the Variables	Measurement	Sources
1	Age	Age influences the understanding of long-term climate and land use change trends and climate variability changes in the area based on long-term observations and knowledge. Thus, age may influence farmers' decisions on climate and land use change impacts.	Age of respondents in years	[14,57]
2	Gender	Gender is involved in different scales of operations in smallholder farming systems. Thus, perceptions of climate change and adaptation may be varied according to gender.	Gender of respondents: 1 = male; 0 = female	[14,51,55,57]

Table 1. *Cont.*

No	Variable	Rationale of Selection of the Variables	Measurement	Sources
3	Marital status	Marital status is likely to influence perception score because it may influence the performance of farming activities, productivity, and household food security status.	Marital status of respondents: 1 = married; 2 = single; 0 = widowed	[14,57]
4	Education level	Education level enhances access to information and quantitively understanding climate and land use changes and their impacts more accurately. Thus, farmers' perceptions may be influenced by their educational level.	Level of education of respondents: 0 = no education; 1 = primary; 2 = secondary; 3 = higher	[14,55,57]
5	Farming experience	Similar to age, long-term farming experience may influence understanding of the impact of climate and land use changes, successes and failures, and challenges facing food production.	Number of years of farming (1–50)	[57,58]
6	Number of generations	A farmer living with a greater number of generations in the area stimulates knowledge enhancement and sharing and thus may influence farmers' perceptions.	Number of generations in the area (1–5)	[52]
7	Household size	The number of family members in a farming household is assumed to be a proxy for labor availability for farming and an increased family burden for the household head; thus, this may influence the perceptions related to changing climate and land use change issues.	Total number of family members (2–6)	[14,55,57,58]
8	Employed household members	Employed household members are likely to access to farm inputs and, improved technology for higher food production, thus, may influence perceptions of farming challenges and impacts of climate and land use changes.	Number of household members employed (0–4)	[52]
9	Membership in farmers' organization	An advantage of belonging to a farmers' organisation is well-informed farming decisions based on formal evidence-based discussions supported by extension services. Thus, the perceptions of a member may differ from a non-member.	Membership in a farmers' organization: 1 = Yes; 0 = No	[58]
10	Cost of farming	Impacts of land use and climate change (e.g., loss of soil fertility, land degradation and scarcity of water for farming) may influence increasing food production costs and it may affect the capacity to adapt to these changes. Thus, farmers' perceptions are sensitive to the cost of production.	Changes of expenses for farming last 20 years: 0 = constant; 1 = increased; 2 = decreased	[55]
11	Level of income/profit from farming	Increased level of income (profit) from farming are likely to influence the implementation of more adaptation options and remedial measures to mitigate the impacts of climate and land use change. Thus, changes in profit may influence farmers' perception scores.	Changes of profit from farming last 20 years: 0 = constant; 1 = increased; 2 = decreased	[14,52,55,57]
12	Training received	Training and awareness increase farmers' capacity to understand the behaviour of influential factors of climate and land use change, and skills to mitigate the impacts. Thus, training and awareness may influence perception scores related to the impacts.	Training and awareness received: 1 = yes; 0 = no	[14,57]
13	Farmers' adaptation	Level of adaptation influenced farmers' perceptions of severity of climate and land use change impacts. Socio-economic and spatial factors influence farmers' adaptation decisions.	0 = Non; 1 = Low; 2 = Moderate; 3 = High	[53,54]
14	Size of the farm	Farm size is linked to level of exposure and adaptive capacity to climate change impacts. Thus, it may influence farmers' perceptions of climate change impacts.	Size of land under crop (1–16 acres)	[52]

Table 1. *Cont.*

No	Variable	Rationale of Selection of the Variables	Measurement	Sources
15	Location of the farm	Variations in spatial and socio-economic factors from upstream to downstream of the VTCS meso-catchment can be observed. Accordingly, variations in farming characteristics and productivity potentials may influence farmers' perceptions of climate and land use change impacts.	1 = upstream; 2 = midstream; 3 = downstream	[56]

The climate and land use change pressures were measured using closed-ended questions in sections C and D of the interview schedule. These questions were aimed at quantifying farmers' perceptions of Climate Change Influential Factors (CCIFs) and Land Use Change Influential Factors (LUCIFs) and their impacts on farm productivity based on the selected indicators. The farmers may not have knowledge and awareness about the reasons for climate and land use change vulnerabilities. Still, they can understand and realize the consequences of climate and land use change impact on food production. In this regard, we developed five CCIFs and five LUCIFs describing the consequences of climate and land use change vulnerabilities to measure farmers' perceptions. This study adopted the measurement tools for the assessment of farmers' perceptions of climate change vulnerability suggested by Shrivasatava [59], Raghuvanshi [60], and the assessment of land use change impacts suggested by FAO-LADA-Tool [61].

This study used both rating and ranking scale questions to quantify the farmers' perceptions. The CCIFs and LUCIFs were evaluated through farmers' perceptions, measuring the severity of each influential factor rated on a five-point Likert scale: 1 = very low or no severity (0–9%); 2 = low (10–25%); 3 = medium (26–50%); 4 = high (51–75%); and 5 = very high severity (76–100%). Similarly, the impacts on food production caused by these CCIFs and LUCIFs experienced by the farmers were evaluated based on twelve climate change impact indicators and ten land use change impact indicators [3,13,23,61,62]. The impacts were rated on a five-point Likert scale: 1 = least or no impacts (0%); 2 = less impacts (0–25%); 3 = moderate impacts (26–50%); 4 = high impacts (51–75%); and 5 = severe impacts (76–100%) based on the farmers' experience in the past 10 years. The rated weights were analyzed to calculate the weighted mean score of each impact factor, and these were ranked accordingly (Table 2). Often, the farmers were uncertain of how to convert their perception of the consequences of climate and land use change influential factors (CCIFs and LUCIFs) into a Likert scale score. Therefore, during the interview, an agricultural instructor assisted in transforming their perceptions to a numerical scale of zero to five, where the higher the value, the higher the influence or impact on food production.

Furthermore, the farmers' views on climate change characteristics (trends, variability, frequency, intensity, and extreme events) in the area during the past 10 years were prioritized based on their perceptions, using rank order scale close-ended questions. Similarly, the farmers' agreements on land use change trends from present to future based on their experience were rated on a five-point Likert scale from 1 = strongly agree to 5 = strongly disagree. The weighted mean was calculated using the following formula: $\sum(\text{Score} \times \text{Frequency})/\sum(\text{Frequency})$ [63]. The farmers' perceptions attributed to the adaptation measures being practiced were evaluated in Section E to rate their effectiveness using four-point rating scales, where each variable was coded as 1, 2, 3, and 4, representing not effective, low, medium, and high, respectively.

Table 2. Description of influential factors of climate and land use change used to measure farmers' perceptions.

Influential Factor	Description of the Consequence of the Influence	Scale of Measurement of Farmer's Perception
Climate Change Influential Factors (CCIFs)		
Changes in average rainfall amount	Changes in long-term rainfall trends are associated with unpredictable rainfall variability, resulting in decreased availability of irrigation and groundwater [13,45,64].	The severity of CCIFs is rated based on a 5-point Likert scale in terms of percentages (severity score): 1 = very low or no severity (0–9%); 2 = low (10–25%); 3 = medium (26–50%); 4 = high (51–75%); and 5 = very high severity (76–100%).
Increase in average temperature	Warming trends with increased hot days and heat stress affect yield quality and quantity and some ecosystem services. Increased evapotranspiration leads to shortages of irrigation water. The emergence of new insects, diseases, and invasive aquatic plant infestation affects human health and capacity [13,45,64].	
Changes in rainfall pattern	Inter-annual monsoonal and seasonal changes (variations/shifts) in rainfall patterns such as changes in the timing of rainfall, including untimely rain, and early and delayed onset of rainy season/monsoons, lead to water stress and reduced food production [10,45].	
Occurrence of wet hydrological extremes	The less frequent but heavy intensity of rainfall within a short period results in high runoff, flash floods, and landslides, leading to crop loss, soil erosion, and sedimentation [65].	
Occurrences of dry hydrological extremes	Long dry spells and prolonged droughts lead to reduced water quantity and quality, affecting food production and human health [65].	
Land Use Change Influential Factors (LUCIFs)		
Deforestation	Clearing of natural forests in catchment areas for agriculture, settlements, and critical infrastructure. This would create a mosaic of patches in undisturbed forest, leading to land degradation, reduced soil moisture, groundwater recharge, and reduction of ecosystem service supply from natural forests [21,43].	The severity of LUCIFs is rated based on a 5-point Likert scale in terms of percentages (severity score): 1 = very low or no severity (0–9%); 2 = low (10–25%); 3 = medium (26–50%); 4 = high (51–75%); and 5 = very high severity (76–100%).
Encroachment	Encroachment into natural forest and semi-natural scrub lands due to agricultural and urban expansion and intensification, leading to the destruction of ecologically sensitive habitats important for maintaining ecological functions essential for food production sustainability [21].	
Structural change	Refers to changes in spatial composition—changes in presence and amount (richness/diversity) of land use patches in a particular land use category. This would change the habitat variability and landscape heterogeneity and affect changes in biodiversity values [23,49].	
Pattern change	Refers to changes in spatial configuration—the physical arrangement (position or orientation) of land use patches within the land use category or in the landscape and their spatial characteristics. This would lead to the destruction of ecological functions and the reduction of biodiversity values and ecosystem services. Additionally, changes in wild animal movements increase wild animal damage to crops and livelihoods [23,49].	
Fragmentation	When the natural and human-managed landscape is altered, its composition and configuration are called landscape fragmentation. It could be explained as a subdivision of land use types due to human choices. This would lead to effects on biodiversity and weaken the ecological processes and functions of the landscape that are essential elements of maintaining the sustainability and productivity of tank cascade systems [49].	

Both descriptive and inferential statistics were used to obtain information within the data. The mean, standard deviation, percentage distributions, and weighted mean were used to explore the data, while the tobit regression model was used to determine the impacts of socio-economic variables on the perceptions. Thus, the influential factors (determinants) of farmers' perceptions of climate change and land use change pressures were scrutinized using the tobit regression model. This regression model was used for censored dependent variables that restrict or censor the predicted values within the range of observed values [66]. The dependent variables in this study were censored within a range of 12–60 for climate change perceptions and 10–50 for land use change perceptions because these two variables had a total of 12 and 10 statements, respectively, scored as 1 to 5 on a 5-point rating scale. We used the VGAM package of the R statistical program (version 3.6.1) to perform the tobit analysis [67].

3. Results

3.1. Socio-Economic and Farming Characteristics of Respondents

Descriptive statistics for the responses are presented in Table 3. The socio-economic and farming characteristics of the respondents were assumed to influence their perceptions of climatic and land use change pressures in the MVTCS, linked with food production. Concerning gender, the majority of the respondents were male farmers (74%). The age range of the farmers was 26–81 years, of which 60.5% were 45–65 years, while 30.9% were more than 65 years of age. The mean number of years of farming experience for the household heads was 32.88 years. Farming across generations can be seen in MVTCS. About half of the farmers interviewed were fifth-generation farmers, while 45% were second-generation. Information collected on marital status indicated that 97% of the respondents were married and 3% of them were single. The average household size was 3.69, which is similar to the average size of 3.7 persons per household in Sri Lanka [68]. Among the respondents, 50% achieved primary education (equivalent up to grade 10), 46.4% up to secondary education (equivalent to high school education), and 3.6% completed diploma or degree-level education. The average farm size of the MVTCS was 1.85 ha, ranging from 0.4 ha to 6.484 ha. More than half of the farmers interviewed were not aware of adaptation measures, and nearly half of the respondents had not received any training and awareness on mitigating climate and land use change impacts from relevant agencies. Farming location is another important factor that determines the perception [56]. Nearly half of the interviewed farmers were from the midstream area of the MVTCS meso-catchment.

Table 3. Descriptive statistics of the farmers interviewed.

No	Variable	Categories or Unit	Minimum; Maximum; Mean	Standard Deviation or Percentage
1	Age	Years	26; 81; 58.6	11.48
2	Gender	Male	-	74%
		Female	-	26%
3	Marital status	Married	-	97.5%
		Single	-	2.5%
4	Education level	Primary	-	50%
		Secondary	-	46.4%
		University/diploma	-	3.6%
5	Farming experience	Years	8; 55; 32.8	11.79
6	Number of generations	Number	2; $\geq$5; 4.88	0.57
7	Household size	Number	2; 6; 3.69	1.14
8	Employed household members	Number	1; 5; 2.15	0.67
9	Membership in farmers' organization	Yes	-	100%
		No	-	0%
10	Cost of farming production	Increased	-	100%
		Decreased	-	0%
		Constant	-	0%

Table 3. *Cont.*

No	Variable	Categories or Unit	Minimum; Maximum; Mean	Standard Deviation or Percentage
11	Level of income/profit from farming	Increased	-	9%
		Decreased	-	84%
		Constant	-	7%
12	Level of training and awareness received	Non	-	49.38%
		Low/simple	-	35.80%
		Moderate	-	12.34%
		High	-	2.46%
13	Framers' adaptation	Non	-	53.33%
		Low	-	28.46%
		Moderate	-	16.91%
		High	-	1.30%
14	Size of the farm	Hectares	0.4; 6.48; 1.85	0.96
15	Location of the farm	Upstream	-	21%
		Midstream	-	52%
		Downstream	-	27%

The farmers in the MVTCS were cultivating more than one food group in different types of farming systems based on water availability. Tank water was the major water source for irrigation for farming paddies. In addition, the farmers used agro-wells (91%) and domestic wells (7%) for their seasonal and home gardens' horticultural crops. Only 7% of the farmers depended on direct rainwater (rainfed) for their shifting cultivation in upland areas of the MVTCS. About 98% of the farmers were practicing paddy cultivation; hence, rice was the major food crop produced. In addition, the community consumed substantial amounts of wild edible foods collected from non-farming areas of MVTCS (Figure 4).

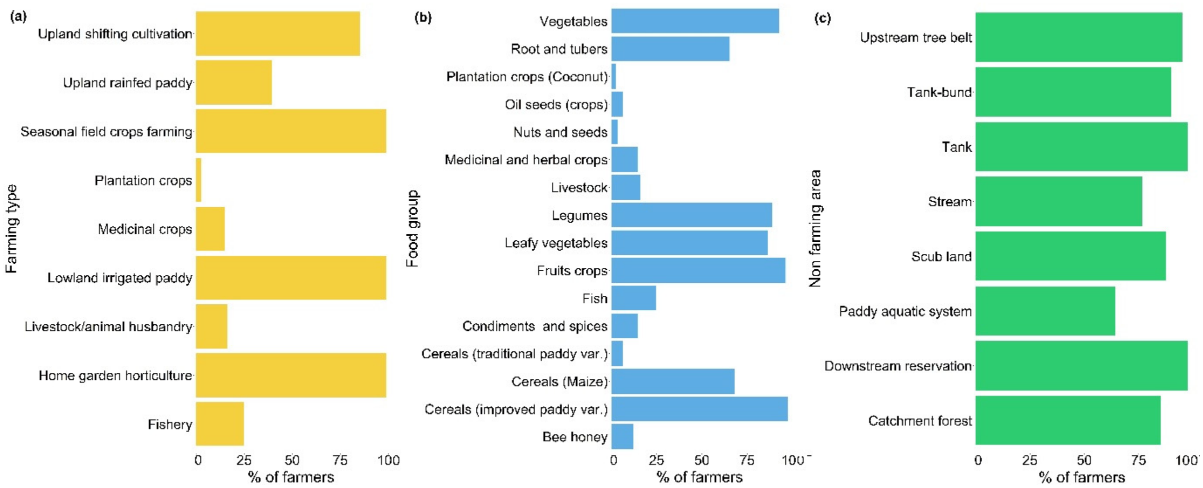

Figure 4. Farmers' engagement in food production. (**a**) Farming types; (**b**) food groups; (**c**) wild food foraging from non-farming areas.

3.2. Challenges in Farming

The respondent farmers identified and rated eighteen major challenges that affected farming and food production in the MVTCS. Crop damage by elephants and deteriorating farmers' health were ranked as the top challenges that influenced food productivity in the area. The majority of the farmers weighed these challenges as being on the 'high' and 'extreme' scales, thus justifying their consideration in food production. Other major challenges, such as pests and diseases, reduced soil fertility, and dependence on agrochemicals and subsidized fertilizers, were also highlighted and seemed to be influenced by the farmers' decision-making regarding food production (Figure 5).

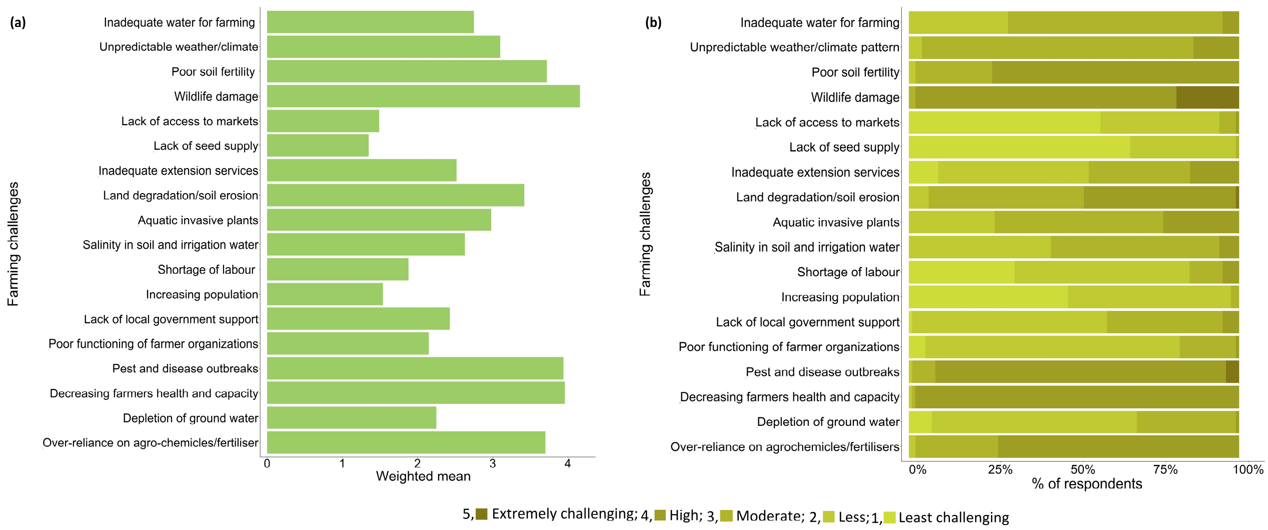

Figure 5. Farmers' perceptions of major challenges affecting farming. (**a**) Ranking, (**b**) rating.

3.3. Farmers' Perceptions of Climate Change and Its Impacts on Food Production

All of the interviewed farmers responded that the climate of the MVTCS area has changed over the past two decades. The farmers prioritized past climate change events based on their perceptions using rank order scale close-ended questions in the interview schedule. Among the past climate change events in the study area, 69% of the interviewed farmers had rated short-term changes in rainfall variability and patterns as the most prominent (Rank 1) climate change event during the past 10 years. However, 28.4% of the respondents rated long-term changes in average rainfall (decreasing trend) as the most prominent climate change in the area. Among the respondents, 93.8% rated the occurrence of extreme climate events (hazards) as the least prominent climate event in the area. In contrast, the trend of increasing average temperature was rated as a less prominent climate event in the area (Figure 6). In the case of the severity of CCIFs, 47 (58%) and 33 (41%) rated the influence of changes in rainfall patterns as being of amoderate and high severity, respectively. Likewise, 57 (70%) of the respondents rated the influence of dry hydrological extremes as being of a moderate severity in the study area. Overall, changes in rainfall patterns were rated as the most severe factor affecting food production (Table 4; Figure S1a). In terms of the weighted impacts, the respondents ranked the top five impacts on food production due to climate change as follows: (i) increased cost of production; (ii) increased wildlife damage; (iii) impact on human health (human stress); (iv) emergence of pests, diseases, and invasive aquatic plants; and (v) decreased biodiversity and ecosystem functions. Among the respondents, 75 (93%) weighed wildlife damage as having a high impact on food production, followed by an impact on human health (73; 90%) (Table 5; Figure S1b).

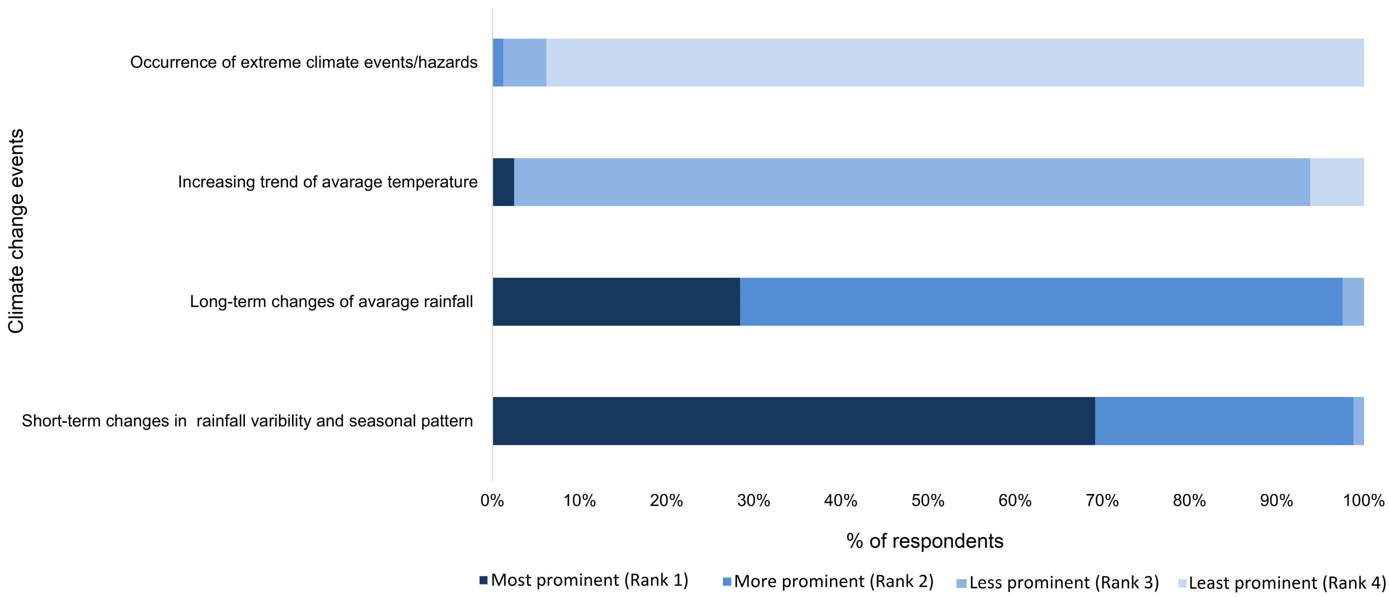

Figure 6. Farmers' perceptions of past climate change events.

Table 4. Farmers' perceptions of the severity of climate change influential factors (CCIFs).

Rank	Climate Change Influential Factors (CCIFs)	Frequency under Weighted Score					Weighted Mean
		1	2	3	4	5	
1	Changes in rainfall patterns	0	1	47	33	0	3.40
2	Changes in average rainfall amount	1	7	71	2	0	2.91
3	Occurrences of dry hydrological extremes	2	21	57	1	0	2.70
4	Increase in mean temperature	1	45	35	0	0	2.42
5	Occurrence of wet hydrological extremes	16	61	1	0	3	1.93

Weighted scale: 1 = very low severity; 2 = low; 3 = moderate; 4 = high; 5 = very high severity.

Table 5. Farmers' perceptions of climate change impacts on food production.

Rank	Impact	Frequency under Weighted Score					Weighted Mean
		1	2	3	4	5	
1	Increased cost of food production	0	0	7	46	28	4.26
2	Increased wildlife damage to crops	0	0	1	75	5	4.05
3	Impact on farmers' health and capacity	0	0	7	73	1	3.93
4	Emergence of pests, diseases, and invasive aquatic plants	0	1	7	72	1	3.90
5	Decreased biodiversity/ecosystem health	0	4	49	28	0	3.30
6	Shortage of water for farming/irrigation	0	3	77	0	1	2.99
7	Effects of household dietary requirements and food patterns	0	21	58	2	0	2.77
8	Increased sedimentation/eutrophication	1	44	24	12	0	2.58
9	Decreased livelihood options and income	0	42	38	1	0	2.49
10	Increased fallowing of lands	0	51	29	1	0	2.38

Table 5. *Cont.*

Rank	Impact	Frequency under Weighted Score					Weighted Mean
		1	2	3	4	5	
11	Increased soil erosion	9	64	8	0	0	1.99
12	Occurrence of stormwater and flash floods	20	59	2	0	0	1.78

Weighted scale: 1 = very low impacts; 2 = low; 3 = moderate; 4 = high; 5 = very high impacts.

3.4. Farmers' Perceptions of Land Use Changes and Their Impacts on Food Production

Among the respondents, 77 (95%) and 76 (93.8%) rated the influence of deforestation and encroachment due to land use change as the highest severity factors, respectively. Likewise, 66 (81.48%) and 14 (17.28%) of the respondents stated the influence of structural changes on land uses as being of a moderate and high severity in the study area, respectively. The influence of fragmentation on food production was perceived as similar to the influence of structural changes. The influence of changes in land use patterns was marked as being of the lowest severity in affecting food production (Table 6; Figure S2a). In terms of the weighted impacts, the respondents ranked the following as the top five impacts on food production due to the influence of land use change: (i) increased wildlife damage; (ii) increased land degradation; (iii) reduction of soil moisture/groundwater; (iv) loss of biodiversity and ecosystem services; and (v) decreased water quality (Table 7; Figure S2b).

Table 6. Farmers' perceptions of the severity of land use change influential factors (CCIFs).

Rank	Land Use Change Influential Factors (LUCIFs)	Frequency under Weighted Score					Weighted Mean
		1	2	3	4	5	
1	Deforestation	0	0	4	70	7	4.04
2	Encroachment	0	0	5	73	3	3.98
3	Structural change	0	1	66	14	0	3.16
4	Fragmentation	0	6	58	17	0	3.14
5	Pattern change	0	36	30	13	2	2.77

Weighted scale: 1 = very low severity; 2 = low; 3 = moderate; 4 = high; 5 = very high severity.

Table 7. Farmers' perceptions of the land use change impacts on food production.

Rank	Impact	Frequency under Weighted Score					Weighted Mean
		1	2	3	4	5	
1	Increased wildlife damage	0	0	4	68	9	4.06
2	Increased cost of production due to land/soil degradation and decreased soil fertility	0	0	25	55	1	3.70
3	Reduction of soil moisture and groundwater	0	0	34	45	2	3.60
4	Decreased biodiversity/ecosystem health	0	2	55	23	1	3.28
5	Decreased water quality	0	5	48	28	0	3.28
6	Impact on farmers' health and capacity	0	0	61	18	2	3.27
7	Increased fallowing of lands	0	12	62	7	0	2.94
8	Soil erosion leading to sedimentation/eutrophication	0	23	45	13	0	2.88
9	Effects of household dietary requirements and food patterns	0	21	54	6	0	2.81
10	Decreased livelihood options and income	0	37	39	5	0	2.60

Weighted scale: 1 = very low impacts; 2 = low; 3 = moderate; 4 = high; 5 = very high impacts.

3.5. Determinants of Farmers' Perceptions of Climatic and Land Use Change Pressures

The tobit regression model on the perceptions of climate and land use change pressures presented in Table 8 shows that these two dependent variables were differently affected by different sets of socio-economic characteristics of the respondents. Compared to the respondents in upstream locations of the MVTCS, when other predictors were held constant in the respective models, the respondents from downstream locations graded the effects of both climate and land use change as more severe on average. The respondents from the midstream zone considered land use change pressure as being more severe than the respondents from upstream locations (2.490 higher average score; intercept 1 = 27.616), but they had similar perceptions to the upstream respondents with regard to climate change pressures. Larger households considered climate change to exert less severe impacts and land use change to exert more severe impacts than smaller households. Farmers with decreased profits considered climate change impacts as more severe than farmers with constant profits. Farm size was positively related to perceptions of the severity of both climate and land use change. The number of generations was negatively related to perception of the severity of both climate and land use change, and the level of training was positively related.

Table 8. Impacts of the predictors on the perceptions of climate change and land use change pressures.

	Perceived Climate Change				**Perceived Land Use Change**			
Predictors	**Estimate**	**Std. Error**	**z-Value**	***p*-Value**	**Estimate**	**Std. Error**	**z-Value**	***p*-Value**
Intercept: 1	43.660	3.833	11.391	0.000 ***	27.616	4.741	5.825	0.000 ***
Intercept: 2	0.468	0.079	5.959	0.000 ***	0.681	0.079	8.664	0.000 ***
Location (midstream)	0.394	0.582	0.676	0.499	2.490	0.720	3.458	0.001 ***
Location (downstream)	2.346	0.780	3.007	0.003 ***	2.625	0.965	2.721	0.007 ***
Household size	−0.347	0.177	−1.96	0.050 *	0.360	0.219	1.647	0.100 *
Generations	−0.589	0.347	−1.695	0.090 *	−0.095	0.430	−0.221	0.825
Farm size	0.089	0.078	1.145	0.252	0.016	0.096	0.167	0.867
Income/profit (decreased)	1.571	0.733	2.143	0.032 **	0.616	0.906	0.679	0.497
Income/profit (increased)	1.164	0.955	1.219	0.223	2.160	1.181	1.829	0.067 *
Trainings (low/simple)	0.859	0.586	1.466	0.143	1.973	0.724	2.724	0.006 ***
Trainings (moderate)	3.670	0.953	3.852	0.000 ***	3.078	1.178	2.612	0.009 ***
Trainings (high)	6.884	2.302	2.991	0.003 ***	4.675	2.847	1.642	0.101
Framers' adaptation	−0.201	0.100	−2.008	0.045 **	−0.001	0.124	−0.005	0.996
	Chi-square = 305.717 *** with 149 d.f R^2 = 0.296 Intercept 2 = 0.468 and $e^{0.468}$ = 1.597 (analogous to model SE)				Chi-square = 340.147 *** with 149 d.f. R^2 = 0.383 Intercept 2 = 0.681 and $e^{0.681}$ = 1.975 (analogous to model SE)			

Notes: '***' for 0.01, '**' for 0.05, and '*' for 0.10 levels of significance.

The levels of the farmers' adaptation to climate change were negatively related to the farmers' perceptions of climate change. The tobit models of the perceptions of climate change impacts and land use change pressure explained 29.6 and 38.3% of the variance in the dependent variables, respectively. A large proportion of the variance is still unexplained, which could arise from one or more extraneous variables that could not be included in the present study because of its fundamental nature.

4. Discussion

4.1. Farmers' Perceptions of Climate Change

In this study, farmers' perceptions of climate change were examined using indicators of climate change such as the occurrence of climate events and severity of CCIFs and their impacts on food production. The farmers' perceptions demonstrated that they considered several specific types of climate change over the past decade as challenges (ranging in severity) threatening food production. Moreover, a perception analysis revealed that the majority of the farmers recognized the temporal variations of climate change events in the study area, such as changes in seasonal rainfall patterns, rainfall intensity and extreme events, and long-term increasing trends in temperature. About 99% of the farmers perceived short-term changes in rainfall variability and changes in seasonal rainfall patterns as the most prominent climate change events in the study area and rated their severity as high to moderate. Similarly, more than 70% of the farmers perceived dry (droughts) and wet (floods) hydrological extremes and rated their influence as moderate to low severity, respectively. The increasing trends in temperature and variability of rainfall pattern are comparable with the findings of several empirical studies conducted based on observed meteorological data in the study area [11,64,65,69].

About 80% of the farmers perceived a trend of decreasing long-term average annual rainfall with a high to moderate severity. However, decreasing long-term average annual rainfall is contrary to the findings of several studies conducted using meteorological data of the study region, which show an increasing trend [10,65,69]. Mismatches between perceived and observed data could be related to the temporal variation of rainfall patterns [45]. Although the amount of long-term average annual rainfall is increasing, the trend of decrease in the number of rainy days, delay in the onset of seasonal rainfall, and the shorter rainy season (short duration/early cessation) in the study region may be influencing farmers' perceptions of rainfall [10]. This outcome possibly indicates that the respondents did not have a clear understanding of the impact of long-term climate change. This could be the reason why short-term weather variability was prominent in their perceptions. Thus, climate change communication strategies need to be reshaped among communities for better understanding [70].

Although the farmers perceived a decreasing trend of annual rainfall, it was not reflected in the ranking of farming challenges they perceived, as shown in Figure 5. The farmers put the statement 'inadequate water for farming' into a moderate priority, and 95% of the farmers perceived it as have a less to moderately effect on food production. This could be due to their recent experience of decreased rainfall. It was difficult for the farmers to perceive the long-term trend based only on their experience without any sophisticated tools. Thus, the availability heuristic could have influenced their perception of the trend [71,72].

Even though the observed temperature in the study area had increased by approximately 1 °C between 1971 and 2020 (Figure 3) with an increasing trend [45], the farmers' perceptions did not reflect this. More than 90% of the interviewed farmers categorized the increasing temperature as a less prominent climate change event with low to moderate severity, as shown in Table 4. The reason for the difference might be due to the effects of rising temperatures being less visible in a short period of time and indirectly impacting food production by limiting irrigation water availability. An increase in temperature could aggravate water stress in VTCSs (e.g., transpiration/evapotranspiration), a phenomenon that the farmers may not have been aware of [73].

Changes in rainfall patterns (variability), which were perceived by the farmers, could have a significant impact on food production by limiting the water availability for farming in the study area. However, the farmers did not rate the shortage of water as being within the top five factors that affected food production (Table 5). In contrast, the farmers rated the increasing cost of production and crop damage by wild elephants as the top two challenges for farming. Thus, we observed potential synergistic effects between rainfall changes and the cost of food production and wildlife impacts. This is likely to occur in a situation where water becomes a limiting factor, putting farmers at risk of increasing costs of production and crop damage by wild elephants [23,56].

The farmers ranked the effects on human health as the third most impact factor due to climate change. This is because human health is indirectly affected by a combination of climate change stresses such as heat stress, drought, and impairment of critical ecosystem services that ensure human health and wellbeing such as air and water quality regulation [42]. Therefore, in some cases, the impact of climate change on food production could be the result of combined or interactive effects of more than one impact factor [40,74]. Thus, further research is needed to examine such combined or interactive effects.

4.2. Farmers' Perceptions of Land Use Change

Almost all the farmers interviewed reported a range of land use changes in the MVTCS landscape that impacted food production. In terms of the severity of LUCIFs, the farmers reported that deforestation in catchment areas and clearing of natural ecosystems (encroachments) had the highest influence on food production in the area. The farmers also perceived an impact of landscape fragmentation and structural/pattern changes on food production, and they reported their influence mostly as being moderately severe (Table 6). However, hardly any empirical studies were found on landscape pattern change analysis and its significance on food production and ecosystem services in the VTCSs. The farmers ranked crop damaged by wild animals and land degradation as the most impactful on food production due to land use change. Land degradation could have the most impact on food production in the study area because it can indirectly contribute to other land use change impacts perceived by farmers such as wildlife damage, decreased water quality, increased fallowing of lands, impact on human health, and increased cost of production [43,75]. Most of the farming challenges perceived by farmers are directly or indirectly related to climate and land use change consequences or/and their combined effects [40]. Thus, land use change impacts could be aggravated due to the interactive or combined effects of climate and land use change [41,74], and further studies are needed to investigate how such interactive effects impact food production in VTCSs.

4.3. Determinants of Farmers' Perceptions

We found that several variables influenced the farmers' perceptions of climatic and land use change and their pressures on food production. Among the socio-economic variables, household size negatively influenced the perceptions of the severity of climate change impacts. This is in agreement with the findings of Mekonnen, et al. [76], who found that family size had a negative effect on farmers' adaptation to climate change. However, household size positively influenced the perceptions of the severity of land use change impacts. Increasing family size may result in family members spending more time on their farms, facilitating greater awareness of local land issues (soil erosion, soil fertility, land degradation, biodiversity loss, etc.) [70,77–80]. Furthermore, in larger families, family members (especially women and children) are more likely to be involved in the collection of wild foods from the forest and scrub lands (Figure 4); thus, are likely to be exposed to evidence of degradation of their surrounding natural environment [81].

The number of generations of households was negatively correlated with both climate and land use change perceptions, which may suggest that more experienced farmers in the study area were more skeptical and uncertain about climate and land use change issues compared to younger generations. A further reason for this could be that some senior farmers may prefer adopting traditional farming practices that they are familiar with and which have evolved with time based on their traditional ecological knowledge, and they may not be knowledgeable regarding these issues affecting food production [79,82]. However, the results of similar studies suggest that an increased number of generations is likely to positively influence the perceptions of climatic risks because more senior farmers in the area tend to have a better awareness of the long-term trends of a changing climate due to greater experience, living across several generations [78].

All the categories of training received by the farmers were positively correlated with perceptions of the severity of both climate and land use change. This implies that training resulted in enhanced knowledge and awareness, influencing the farmers' perceptions of climate change and land use change, which could be taken as a significant predictor of adaptation to climate and land use change risks [80]. Adaptation negatively influenced perceptions of severity of both climate change and land use change. This implies that farmers with a better understanding of adaptation measures are less likely to rate threats from climate and land use as severe because they know how to manage these threats. The survey revealed that the farmers had been adopting different autonomous traditional agricultural practices (e.g., traditional soil management practices, cultivation of traditional crop varieties, applications of fertilizers of organic origin, traditional pest and weed management by maintaining biodiversity and bio-pesticides, etc.) shaped by their traditional knowledge and socio-cultural and cosmo-spiritual dimensions as a result of long-term system adaptation to cope with climate change (Figure S3) [12,43]. However, this study did not carry out an in-depth perception analysis related to the effectiveness of adaptation measures practiced by the farmers.

Both increasing and decreasing income/profit positively influenced perceptions of the severity of climate and land use change. Thus, the farmer's income/profit may influence how they perceived climate and land issues risks [83]. However, the farmers who experienced decreasing income/profit perceived a higher severity of climate change impacts than that of land use change. This implies that the farmers with low incomes/profits from their farms were more vulnerable to climate change impacts. The reason for this is that the low-income/profit farmers were likely to divert most of their profit to meet the essential costs of farm production and household needs; therefore, this may decrease their ability to undertake adaptation practices to withstand climate change impacts on farm production [14].

Among the spatial variables, farm size positively influenced perceptions of severity of both climate and land use change. However, this relationship was stronger for climate change impacts than land use change. This implies that farmers of large farms are more likely pick up on the overarching changes in climate than farmers of small farms that pick up more local changes that might dominate their smaller holdings [57,77–79,84]. Downstream areas of the study meso-catchment located adjacent to the Nachchaduwa reservoir forest area account for a larger extent of the command area, with larger sizes of individual farms [43,56]. Thus, compared to the respondents in the upstream locations of the study area, the downstream respondents perceived climate change threats as being more severe. Though the larger command area positively impacted productivity due to its large extent of intensive agricultural land uses, it could be subjected to negative consequences of climate change and wild elephant damage, resulting in crop production losses. Downstream areas of MVTCS are dominated by irrigated paddy cultivation rather than rainfed crop framing. Furthermore, more elephant habitat encroachments were recorded in downstream areas of MVTCS [56,85]. This could be the reason for the downstream farmers having shown a higher positive correlation than the upstream farmers with their perceived climate and land use change risks. However, the midstream areas of MVTCS regarded a higher average threat than the upstream with respect only to the land use change. This could be the reason that upstream farming is mostly restricted to small-size rainfed shifting cultivation and the midstream areas reporting larger farm sizes with high agricultural land use intensities [43].

5. Conclusions

This study investigated the perceptions of farmers towards climate and land use change and their impacts on food production in the VTCSs of Sri Lanka. The results revealed that short-term seasonal rainfall variability, deforestation and encroachment of natural ecosystems were perceived as the most prominent influencers on food production in the area. Among the socio-economic determinants, household size negatively influenced the perceptions of the severity of climate change and positively influencing perception of land use change impacts. The level of the farmers' adaptation to climate change had a negative association with their perception of the severity of climate change. Training and profit positively influenced the perceptions of the severity of both climate and land use change. Among the spatial determinants, farm size and downstream locations positively influenced the perceptions of the severity of both climate and land use change.

From the findings, it can be argued that adverse impacts of climate and land use changes on food production could be mitigated by improving farmers' knowledge and awareness. Improved farmers' perceptions could also help to minimize the gaps between observed and perceived data. Furthermore, an integrated assessment of farmers' perceptions and observed meteorological data is crucial to the design of optimal mitigation and adaptation strategies. This is an important policy suggestion for planning effective adaptation strategies in VTCSs. Therefore, local agricultural extension services should be equipped with updated climate information and sustainable land/farm management techniques to communicate effective adaptation strategies. This should be addressed among key actors at various scales (land users, land managers, policy makers, local authorities, regulatory agencies, etc.). The combination of both the top-down and the bottom-up approaches does provide better insight into formulating localized land use policies and adaptation strategies in the VTCS landscapes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16198603/s1, File S1: Questionnaire used for participatory interviews; Figure S1: Farmers' perception of climate change impacts on food production. (a) severity of climate change influential factors (CCIFs); and (b) impacts on food production; Figure S2: Farmers' perception of land use change impacts on food production. (a) the severity of land use change influential factors (LUCIFs), and (b) impacts on food production; Figure S3: Farmers' perception of adaptation practices [86].

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