Climate Change induced Drought and its Impact on Subsistence Farming and Food System in High Mountains: An Interpretation of Women's Insight in a Rain-fed Watershed, Kumaon Lesser Himalaya, India

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Abstract

In Himalaya, constraints of terrain and climate limit the productivity of natural resources and restrict opportunities of livelihood. This compels majority of population to practice subsistence farming as a means of survival. The study examines impact of climate change induced drought on subsistence agriculture and food system with a case study of Ramgad Watershed located in the rain-fed Lesser Himalayan mountains in India. The study is primarily based on the interpretation of information collected and systematized from diverse sources including community perception and other qualitative and empirical methods. The frequency of droughts has increased over the recent past and on an average in most of years, the watershed faced two droughts. The majority of droughts occurred during winter and spring months.

The recurrent and protracted droughts have not only depleted the water resources and agro-biodiversity but also decreased irrigated agricultural land by 11%. On an average, 28% villages suffered up-to 50% decline in agricultural production due to recurrent droughts. 58% of the total inhabitants of the Ramgad Watershed have been identified as food insecure. This clearly indicates that climate change induced drought has emerged as one of the major threats to subsistence farming system and rural food and livelihood security in the rain-fed Lesser Himalayan mountains.

Keywords: Agro-biodiversity, agro-ecological zones, community perception, food security, integrated watershed management, subsistence agriculture.

Introduction

In Himalaya, the constraints of terrain and climate limit productivity and carrying capacity of natural resources[23,24]. This compels majority of population to practice subsistence farming as a means of survival[16,37]. However, owing to non-availability of livelihood in other sectors more than 75% of population depends on subsistence farming[58,59,61]. More than 90% land holdings are of less than one hectare, merely 11% cultivated land is irrigated and per capita availability of arable is less than 0.2 ha [60]. This forces a large proportion of rural male population to out-migrate and contribute to community food purchasing power through remittances [21,29]. Moreover, rapidly transforming climatic conditions have stressed traditional agricultural and food system through rising temperature, altered precipitation pattern and increasing frequency and severity of climatic extremes which are adversely affecting the sustainability of the farming and food system[23,47].

The long-term impact of changing climatic conditions is likely to change the conditions for food production through influencing precipitation pattern, irrigation potential, soil properties and cropping patterns and consequently, would increase the vulnerability of poor and weaker sections of society to increasing risk of food, nutrition and livelihood insecurity[23,24,62].

It has been observed that climatic conditions over the Himalayan mountains have been changing sharply over the past decades. In Himalayas, the rate of warming is much higher compared to other mountains[8,9,24,32]. In view of this, Himalaya being the most densely populated mountain is exceedingly susceptible to climate change[23]. Himalaya has experienced significant warming in the past decades nearly equal to global average[10,23]. Further, elevation dependent warming (EDW) is expected to increase in the region in future[46]. In Himalayas, the rate of warming has been 0.2°C per decade over the last 50 years[8,9,32]. The average annual temperature in Himalaya has increased by approximately 0.1°C over the last seven decades and the frequency of extreme weather events, particularly high intensity rainfall and drought is also increasing[23]. It is expected that even if global warming is kept to 1.5°C, the annual average temperature in Himalayas is most likely be at least between 0.3°C and 0.7°C higher at the end of the century[32,46].

Moreover, Himalaya is also experiencing increasing variability in precipitation pattern. The monsoon rainfall has become highly erratic and inconsistent over the region over the past decade. The western disturbances bring nearly 20% of the annual rainfall in winter and spring months[5,8,9]. It has been observed that the annual precipitation underwent a clear shift after 1990 in the region[32,46]. The temporal characteristics of precipitation variation appear to have entered a mode of greater inter-annual variability and more frequent intense rain and less frequent light rain[10]. The region has shown a rising trend of extreme warm events[5], a falling trend of extreme cold events and a rising trend in extreme values and frequencies of temperature-based indices[32]. These changes in climatic phenomena are resulting into recurrent droughts, particularly in winter and spring months in the rain-fed Lesser Himalayan Mountain ranges[5,42,68]. Rising temperature, altered precipitation pattern and resultant droughts could trigger a multitude of biophysical and socio-economic impacts, hydrological disruptions, loss of biodiversity and reduced water availability across the region[22,28,67].

These changes in climatic phenomena have stressed the traditional farming and livelihood system by modifying the fundamental agro-ecological conditions such as land, water, forests and biodiversity for food production and increasing frequency and severity of climate change induced natural disasters, particularly droughts across the Himalayan mountains[1,11,21,53,66].

This has collapsed the conventional farming system through frequent crop failures and steady decline in food productivity and increased vulnerability of large population, particularly poor and weaker sections of the society to food, nutrition and livelihood insecurity [21,65]. The increasing frequency and severity of climate change-induced droughts have further raised trends of rural out-migration increasing gender inequality and undermining social quality of life[29,61].

The present study aims to analyse the impact of climate change-induced drought on farming and food system in the rain-fed Lesser Himalayan mountains of India at watershed level. Drought has been conceptualized and defined as an extended period of deficient precipitation resulting into widespread depletion of water resources, disruption of natural environment and a significant loss of farm production[15,55]. Drought is generally referred to as the deficiency in precipitation over an extended period that often results in water shortage and soil-moisture loss causing adverse impacts on vegetation, soils, crops, livestock and people[31,69].

Further, drought is generally considered as the condition of acute water shortage due to lack of rains over protracted period affecting socio-ecological system[36,39]. Drought leads to the disruption of hydrological processes, depletion of water and forest resources, loss of soil moisture and decline in agricultural productivity and crop failure[20]. Further, drought is a usual, recurring feature of climate and is characterized in terms of its geographical coverage, intensity and duration [20]. Conditions of drought appear when the rainfall is deficient over a region in relation to statistical average for an extended duration [15]. Drought may reduce the availability of water and may reduce food and fodder productivity for a longer period[7,40].

Material and Methods

The Study Area: The present work was being carried out in Ramgad watershed which geographically extends over an area of 71.5 km^2 between an altitudinal range from 1025 to 2465 m in the densely populated rain-fed Lesser Himalayan mountains in Uttarakhand State of India (Figure 1). The watershed exhibits complexity of terrain and climatic conditions which are reflected in the diversity of farming and food systems. Ramgad watershed is inhibited by 19775 persons who are distributed in 2159 households and in 29 rural settlements (Figure 2). Out of the total geographical area (71.5 km^2) of the watershed, 57.71% is under forests and 25.75% is under agriculture and horticulture. The entire watershed is passing through a process of rapid environmental changes and depletion of natural resources primarily owing to the growth of developmental infrastructure.

Moreover, the watershed has shown sharp changes both in temperature and precipitation patters and a remarkable increase in climatic extremes, particularly droughts and heavy precipitation. These changes are increasing the vulnerability of large population to climate change and climate change-induced natural disasters, particularly drought in the watershed. The mean monthly temperatures in the region range between 3.60°C in the month of January and 15.22°C in the month of June with an annual average of 10.74 °C.

Methodological Framework: Ramgad watershed was divided up into three agro-ecological zones primarily based on altitude, slope, slope-aspect, availability of water, broad soils characteristics and farming practices using Geographic Information System (GIS). The methods recommended by the Indian Council of Agricultural Research (ICAR), Government of India were adopted for the delineation of agro-ecological zones [25]. The three agro-ecological zones of the Ramgad watershed are: (i) Lower Agro Ecological Zone situated between 1000 - 1500 m elevation; (ii) Middle Agro Ecological Zone located between1500 - 2000 m and (iii) Higher Agro Ecological Zone extended from 2000 to 2500 m from the mean sea level. Lower, middle and higher agro-ecological zones respectively cover 11.75 Km^2 (16.43%), 37.75 Km^2 (52.80%) and 21.55 Km^2 (30.77) area and 5, 10 and 14 villages of the watershed (Table 1 and figure 3).

The study is primarily based on information collected and systematized from diverse sources and review of the relevant literature. The data and information used in the study included: (i) rainfall pattern; (ii) population pattern; (iii) occurrence of droughts; (iv) status of water resources and irrigation potential; (v) food productivity; (vi) community food purchasing power and (vii) food security status. The rainfall data has been collected from Automated Weather Station (AWS) of India Meteorological Department (IMD), located at Mukteshwer in the watershed (Figure 1 and 2). The droughts have been characterized through the interpretation of rainfall data using the criteria recommended by the Ministry of Agriculture, Government of India [20] and supplemented by the interpretation of community perception.

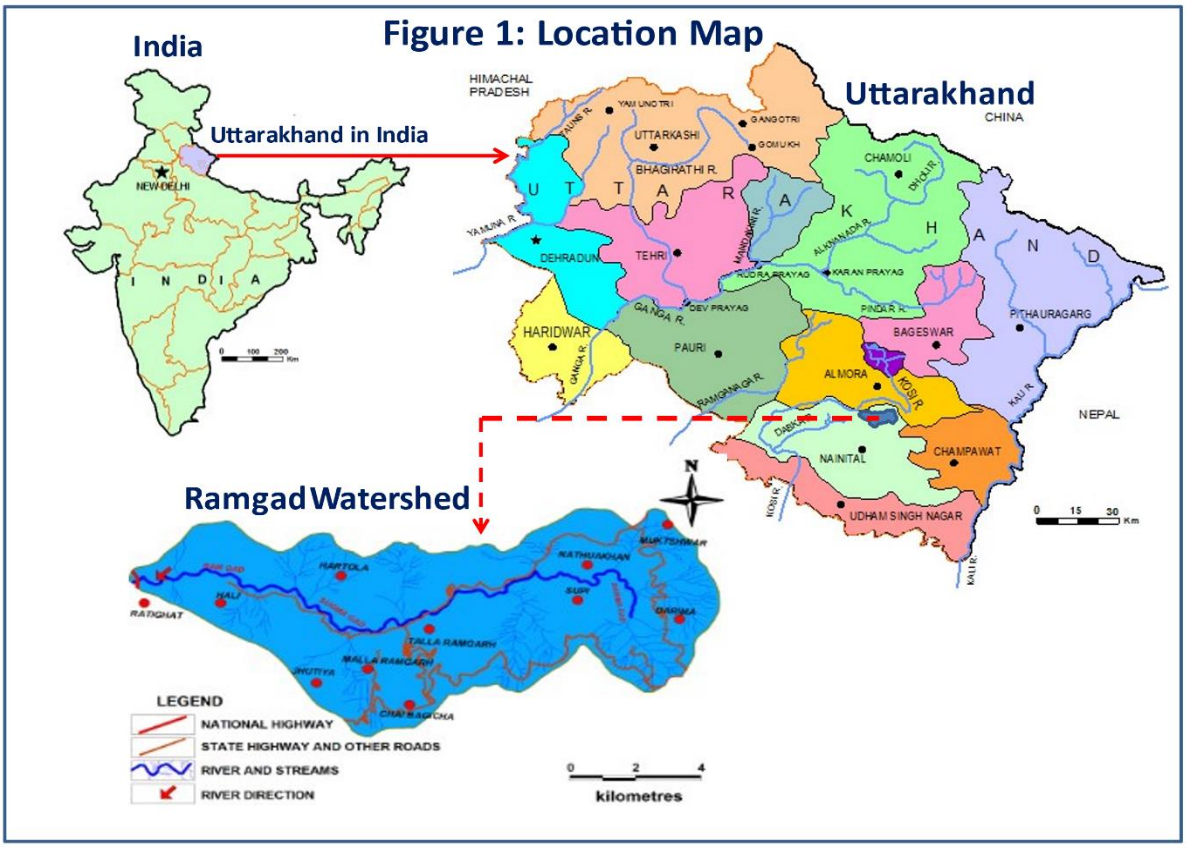

Fig. 1: Location Map of Ramgad Watershed

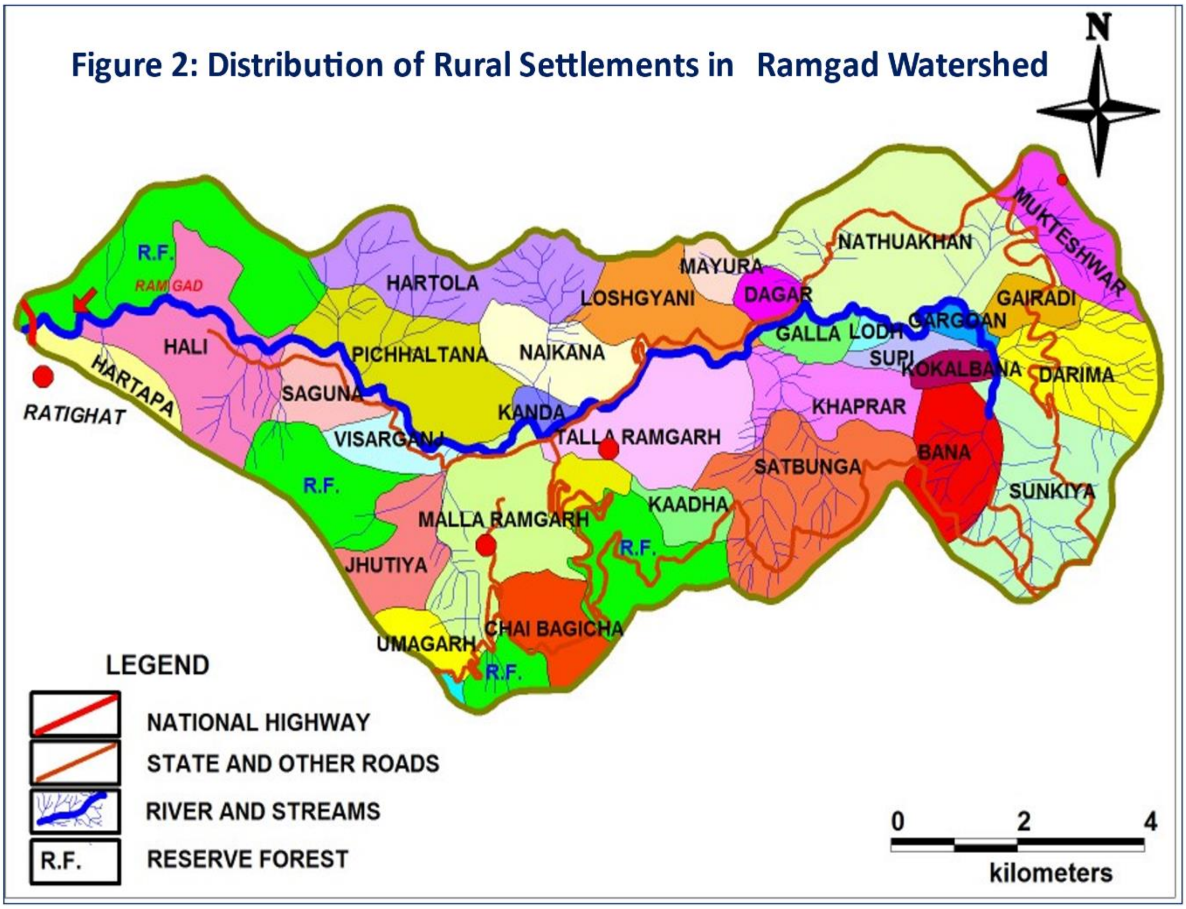

Fig. 2: Distribution of Rural Settlements in Ramgad Watershed

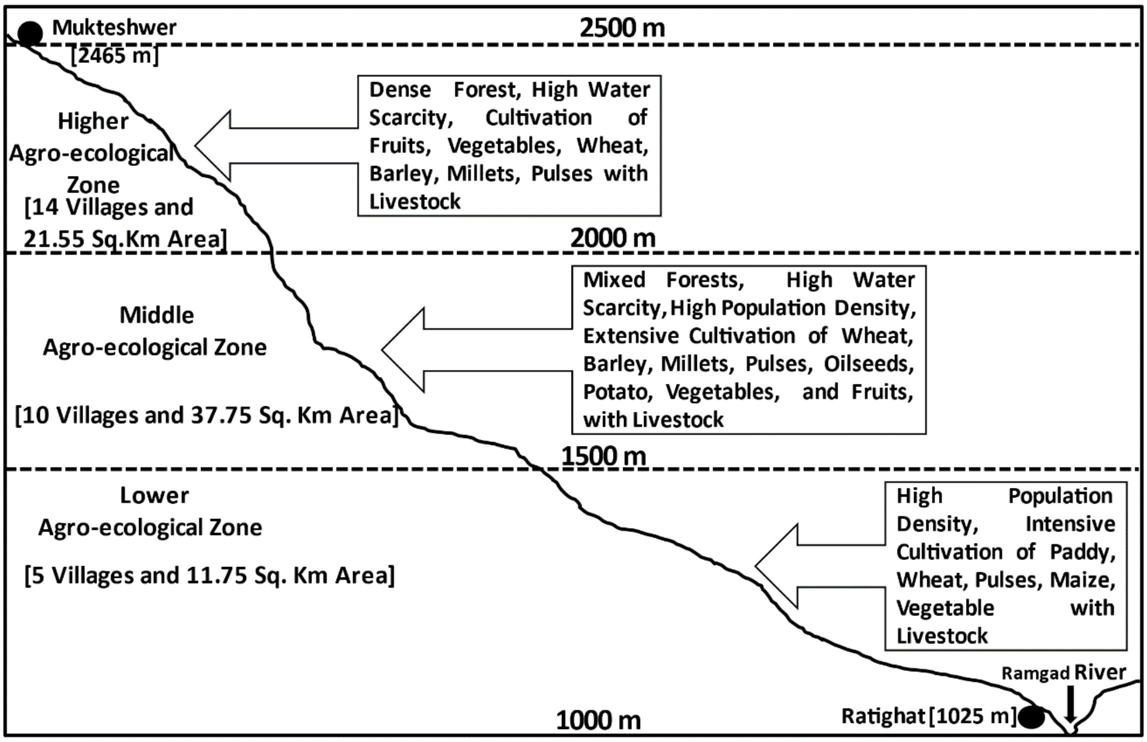

Fig. 3: Agro-ecological Zones of Ramgad Watershed

Table 1
Agro-ecological Zones of Ramgad Watershed

Agro-ecological Zone	Altitude [Meters]	Villages	Area [in Km^2]	% of Total Area	Major Agricultural Crops
Lower Agro-ecological Zone	1000-1500	05	11.75	16.43	Paddy, Wheat, Pulses, Oilseeds, Maize, Livestock, Fish
Middle Agro-ecological Zone	1500-2000	10	37.75	52.80	Wheat, Barley, Millets, Pulses, Oilseeds, Potato, Vegetables, Fruits, Livestock
Higher Agro-ecological Zone	2000-2500	14	21.55	30.77	Fruits, Wheat, Barley, Millets, Pulses, Livestock

The data pertaining to the status of water-flow in streams and natural springs (which constitute the only source of irrigation) and availability of water for irrigation have been collected both from local level Government offices and supplemented by extensive field observations, ground mapping using Global Positioning System (GPS) and social surveys including focused group discussions and Ket respondents' Interviews. The critical information pertaining to the community perception of climate change induced drought and its impact on agricultural resources, agro-biodiversity, farming system, food productivity, rural livelihood were generated through the comprehensive household-surveys in all the 29 rural settlements of the watershed using exclusively designed schedules and questionnaires.

The sample size for the study of community perception and household surveys consisted of 10% of families. The families included in survey comprised of women headed households (25%), family living below poverty line according to the categorization of the State Government (40%), families totally dependent on farming (15%) and households who depend both on agriculture and other means of livelihood (20%). In order to analyse the changes that occurred in the spatial and temporal patterns of droughts and their impact on farming and food system, the elderly members of families, particularly women who are considered as primary resource developers in the region due to increasing trends of male out-migration, were specifically included in the household survey and other information interactions. The food deficit situations were determined by estimating demand of food and its local production at village level using the dietary norms recommended by the National Institute of Nutrition, Government of India (NIN)[41].

Food security at the household level was determined as availability of food from local agricultural production and access to food from the local market using purchasing power as a proxy. Households which did not meet National Institute of Nutrition norms were categorized as food insecure. The food purchasing power of households was estimated from: (i) the income of the family from various sources such as the selling of agricultural and animal products (e.g. vegetables and milk), local farm and off-farm employment, remittances sent by migrated members of family and (ii) the amount that a family could afford for buying food from market.

Results

The analysis of climatic data evidently showed that the precipitation pattern in the Ramgad watershed has altered over the decades. The observed trends in the precipitation pattern indicated that amount of average annual rainfall had been decreasing with significant decline in winter and spring seasons (October to April). These changes in rainfall pattern have disrupted the hydrological cycle of the watershed resulting into the decline of water-discharge in natural springs and streams. Besides, changing rainfall pattern has increased the frequency of extreme weather events, particularly drought in the watershed over the recent past. The interpretation of climatic data clearly showed that the occurrence of droughts was increasing from October to April. The study of community perception of climate change and climate change induced droughts also validated these scientific observations.

Observed Temperature Pattern and Rainfall Variability: Analysis of temperature trends for the period 2001 - 2019 revealed that the annual average temperature has been increasing in the Ramgad watershed. The temperature is particularly increasing during the winter and spring season between November to March. Generally, the average annual rainfall indicted a declining trend with few exceptions.

Table 2
Level of Community Perception of Drought and Its Impact on Farming System in Ramgad Watershed

Agro-ecological Zone	Villages	Number of Respondents	Droughts and Its Impacts	Level of Community Perception [% Respondents Answered in 'Yes']
Lower Agro-ecological Zone	05	55	Is climate changing?	97
			Has rainfall become erratic?	97
			Has annual rainfall declined?	79
			Do you perceive drought?	99
			Is frequency of drought increasing?	71
			Are there more droughts in Winter and Spring?	71
			Are water sources are drying due to drought?	75
			Did water for irrigation decreased due to drought?	75
			Did crop-productivity decreased due to drought?	75
			Did livelihood reduced due to frequent drought?	75
Middle Agro-ecological Zone	10	70	Is climate changing?	95
			Has rainfall become erratic?	77
			Has annual rainfall declined?	71
			Do you perceive drought?	99
			Is frequency of drought increasing?	79
			Are there more droughts in Winter and Spring?	75
			Are water sources are drying due to drought?	85
			Did water for irrigation decreased due to drought?	77
			Did crop-productivity decreased due to drought?	89
			Did livelihood reduced due to frequent drought?	95
Higher Agro-ecological Zone	14	91	Is climate changing?	100
			Has rainfall become erratic?	100
			Has annual rainfall declined?	77
			Do you perceive drought?	100
			Is frequency of drought increasing?	77
			Are there more droughts in Winter and Spring?	99
			Are water sources are drying due to drought?	99
			Did water for irrigation decreased due to drought?	99
			Did crop-productivity decreased due to drought?	97
			Did livelihood reduced due to frequent drought?	97

The watershed received 2400 mm rainfall in the year 2001 and whereas in 2019, the amount of annual rainfall increased to as high as 2550 mm in the region. The average annual rainfall varied between 1700 and 2200 mm over the period 2002 – 2007 (Figure 4). However, the availability of rainfall reduced drastically over the period 2011 – 2017 as the watershed received annual rainfall between 1115 and 1155 mm during this period. But, as the other parts of Lesser Himalaya, Ramgad watershed received exceptionally high rainfall in 2008 (2970 mm) and in 2010 (3570 mm) (Figure 4). The temporal distribution of rainfall has been analysed through the analysis of rainy-days. Figure 5 indicates that there has been a progressive decrease in the number of annual rainy days in the watershed over the past two decades. The number of rainy-days fluctuated between as many as 87 rainy days in 2002 and as less as 50 rainy-days in 2017 (Figure 5).

The watershed recorded an overall reduction of 34% annual rainy-days with some exclusions. This would increase the rate of evapo-transpiration and result into soil moisture loss and rise in hydrological droughts[19,31]. The interpretation of community perceptions endorsed the above-mentioned scientific observations and maintained that the climate change has altered the rainfall pattern and both the amount of rainfall and rainy days have declined in the watershed. Respondents respectively ranging between 79% and 97%, 71% and 77% and 77% and 100% in lower, middle and higher agro-ecological zones very clearly perceived that both rainfall and rainy days have decreased and rainfall has become highly erratic in the region (Table 2). The study of the farmers' perception clearly explained that both the quantity of rainfall and rainy days have decreased during winter (November – February) and spring (March – April) cropping seasons.

Droughts: In the present study, the guidelines of the Ministry of Agriculture, Government of India have been adopted for the interpretation of drought and information pertaining to villages affected by drought was collected from the district level Government departments which maintain village-wise record of drought and its impact on agriculture. Besides, community perception of drought was also analysed through the interpretation of primary data collected during households-survey. The interpretation of hydro-meteorological data and analysis of community perception of climate change revealed that the drought has emerged as major climatic extreme in the region over the decades. The interpretation of droughts revealed that the entire region experienced severe droughts conditions during the last 23 years (Table 3).

A close observation of table 3 clearly indicates that the frequency of droughts has shown an increasing trend between 2001 and 2023. The occurrence of droughts ranged between 1 and 2 with an overall average frequency of approximately 2 droughts per year. The watershed experienced drought each year over the period. In most of years, the watershed faced 2 droughts. Table 3 shows that the watershed faced not less than 2 droughts each year from 2011 to 2017. The table also explains that the entire watershed recorded as many as 29 droughts over the past 19 years and 27 droughts (out of 29) occurred during winter and spring seasons. Table shows an increasing trend in the loss of farm production between 2001 and 2019 in the watershed.

Table 3 further indicates that on an average, 15 village suffered up to 50% and 8 villages more than 50% decrease in agricultural production over the past decades.

The interaction with local communities made it very clear that the frequency and severity of droughts have been observed increasing during winter and spring months in the watershed during the period between 2001 and 2023 (Table 2).

In the lower and middle agro-ecological zones between 71% and 99%, respondents were very much aware about the climate change, rainfall variability, droughts and increasing frequency of droughts in the region whereas in higher agro-ecological zone up to 100% of the respondents have been able to perceive the above-mentioned changes in climatic conditions including the droughts as the proportion of educated respondents was higher in this zone (Table 2). The local respondents in all the agro-ecological zones have been able to perceive well that the frequency and severity of droughts have increased over the past decades. Particularly, the elderly people, specifically women, were very much aware of the changing climatic and climate change induced drought and their impacts on their natural resources, farming system and livelihood.

Impact on Water Resources: The interpretation of data collected from various sources, field observations and analysis of community perception brought out the fact clearly that the variability in the rainfall pattern and resultant hydrological drought have impacted the hydrological regime of the watershed and reduced the availability of water resources. These impacts are observable in terms of decrease in groundwater recharge, drying of natural water sources such as springs and streams, decline in water-flow on streams and rivers. The study revealed that nearly 27% natural springs dried over the last decades. Further, it was also observed that the average annual water discharge in the major streams of the region has reduced considerably during the last decades.

The field-surveys and field-mapping exercises conducted in the watershed revealed that more than 5 km of first order streams have completely dried in the region over the past two decades. It was investigated that stream-lengths of about 1.7 km (in 3 villages located in the lower agro-ecological zone of 1000 - 1500m), 2.5 km (in 7 villages situated in the middle agro-ecological zone of 1000 - 1500m) and 2.9 km (in 11 villages located in the higher agro-ecological zone of 2000 - 2500 m) have dried. The interpretation of community responses collected during household survey also brought out the fact clearly that natural water sources were drying due to frequent droughts and reduced groundwater recharge. In lower, middle and higher agro-ecological zones of Ramgad watershed respectively, 75%, 85% and 99% people particularly women have been able to realize that the availability of water has decreased in natural springs and streams due to recurrent and prolonged drought (Table 2).

Impact on Irrigation Potential: As mentioned earlier, natural springs and stream comprise the only source of irrigation, particularly at lower elevation and along the valleys of the master-stream and its tributary-streams which ensure regular water availability for irrigation. The irrigated farming is very insignificant in up-slope and higher elevation transects of the watershed primarily due to scarcity of water. Consequently, the farming in up-slopes areas in the lesser and higher agro-ecological zones is mainly rain-fed and depends on the temporal distribution of rainfall across different cropping seasons. However, the impact of droughts has been observed very severe both in irrigated and rain-fed farming system. The increasing frequency and duration of droughts have reduced the area under irrigation.

As a result, the irrigated cultivation reduced by approximately 11% in different agro-ecological zones. The local communities have been found very much capable to establish the linkages between frequent drought and reduced availability of water for irrigation. As many as 99%, 77% and 75% farmers respectively in higher, middle and lower agro-ecological zones perceived that the availability of water for irrigation declined due to increasing frequency and intensity of droughts (Table 2).

Impact on Farming and Food System: All the three agro-ecological zones of Ramgad watershed registered an average decline of 154 tons per hectare in agricultural production between 2001 and 2023 amounting to an overall decrease of 26% in food productivity during the period. The analysis of data collected through household surveys, Government departments and community perception attributed these agronomic changes to frequent droughts and recurrent crop failures and resultant decline in farm productivity. Middle agro-ecological zone recorded the maximum decrease in agricultural production (195 kg/Ha/Year or 33%) followed by the lower (189 kg/Ha/Year or 25%) and higher (77 kg/Ha/Year or 19%) agro-ecological zones (Table 4).

Table 3
Frequency of Droughts and Loss of Farm Production in Ramgad Watershed [2001-2023]

Calendar Years	Frequency of Drought	Agricultural Season when Drought Occurred	No of Villages in which up-to 50% Crop Production Declined	No of Villages in Which more than 50% Crop Production Declined
2001	01	June-August	07	05
2002	01	October-December	07	07
2003	01	June-August	05	07
2004	02	October-December, February-April	07	09
2005	01	June-August	11	15
2006	02	October-December, February-April	11	12
2007	01	October-December	10	11
2008	01	October-December	10	09
2009	01	October-December	11	11
2010	02	October-December, February-April	10	11
2011	02	October-December, February-April	14	10
2012	02	October-December, February-April	17	11
2013	02	October-December, February-April	16	11
2014	02	October-December, February-April	19	08
2015	02	October-December, February-April	21	08
2016	02	October-December, February-April	25	04
2017	02	October-December, February-April	27	02
2018	01	October-December	27	02
2019	01	October-December	25	04
2020	03	October-December, February-April	21	07
2021	03	October-December, February-April	19	11
2022	02	October-December, February-April	27	10
2023	02	October-December, February-April	15	09
Average	**02**	October-December, February-April	**16**	**08**

Table 4
The Status of Agricultural Productivity in Ramgad Watershed

Agro-ecological Zone	Area [Km^2]	% of Total Area	Number of Villages	% of Total Villages	Agricultural Production (Kg/Ha/Year)		Decline in Agricultural Production	
					2001	2023	(Kg/Ha)	%
Lower Agro-ecological Zone	11.75	16.43	05	17.24	755	566	189	25
Middle Agro-ecological Zone	37.75	52.80	10	34.48	591	396	195	33
Higher Agro-ecological Zone	21.55	30.77	14	48.28	404	327	77	19
Ramgad Watershed	71.05	100.00	29	100.00	583	430	154	26

Table 5
Food Production, Demand and Deficit Situations in Ramgad Watershed [2023]

Agro-ecological Zone	Area [Km^2]	% of Total Area	No. of Villages	% Villages	Population	Production of Food Grain (Tons per Year)	Demand of Food (Tons per Year)	Deficit of Food	
								Tons per Year	%
Lower Agro-ecological Zone	11.75	16.43	05	17.24	3475	191	1589	1398	88.0
Middle Agro-ecological Zone	37.75	52.80	10	34.48	5145	251	1773	1522	86.0
Higher Agro-ecological Zone	21.55	30.77	14	48.28	11155	579	2583	2004	78.0
Ramgad Watershed	**71.05**	**100.00**	**29**	**100.00**	**19775**	**1021**	**5945**	**4924**	**84.0**

The reason for high decline in agricultural production in the middle and lower agro-ecological zones is explained by the fact that a large part of farm production in these zones comes from irrigated land and due to decline in irrigation potential, these areas faced the considerable decrease in agricultural production. The interpretation of community perception of drought and understanding of its impact on agriculture also substantiated these observations (Table 2). The different agro-ecological zones of the watershed faced food deficit ranging from 78% in higher agro-ecoloical zone to 88% in Lower Agro-ecological Zone with an average food deficit of 84% in 2019 (Table 5). The study revealed that nearly 67% households mainly including poor, landless and marginal and small agricultural land holders depend on traditional agriculture and forestry sectors for livelihood.

The recurrent droughts have not only reduced the productivity of agricultural crops, but also decreased the availability of minor forest products decreasing livelihood opportunities in almost all rural settlements. This resulted in the decline in food purchasing capacity of community and affected food security of large number of households, particularly poor. The forestry and agricultural sectors were providing livelihood to as many as 6747 rural people in 2001 whereas the watershed recorded a decline of 46% rural employment in these primary sectors in 2019 (Table 6). The maximum decline in rural livelihood opportunities (49%) was recorded in lower agro-ecological zone (1000 - 1500 m) and the minimum (41%) in higher agro-ecological zone (2000 - 2500 m) (Table 6)

The study observed that nearly 58% of the total inhabitants of the watershed were facing food insecurity in 2019 (Table 7). The largest proportion of food insecure population (63.96%) was found in higher agro-ecological zone followed by the middle agro-ecological zone with a total food insecure population of 53.94% whereas the lowest percentage of food insecure population (44.46%) was found in the lower agro-ecological zone (Table 7). Although very significant difference in the proportion of food insecure population in the different agro-ecological zones of Ramgad watershed has been observed, yet the lower percentage of food insecure in the lower agro-ecological zone is explained by the fact that the level of income from other non-land-based sources of livelihood is bit higher in the zone that improved the community access to food.

Further, the proportion of food insecure population increased from 48.33% in 2001 to as much as 57.93% in 2019, thus registering an overall increase of 09.55% (Table 7). This is mainly because of the significant decrease in agricultural productivity and loss of rural livelihood opportunities and consequent decline both in the availability of and access to food across the region.

Table 6
Loss of Rural Livelihood Opportunities in Ramgad Watershed

Agro-ecological Zone	Number of Villages	Total Population	Status of Rural Livelihood in Agricultural and Forestry		Loss of Rural Livelihood in Agricultural and Forestry During 2001 - 2023	
			2001	2023	Number of Persons Lost Livelihood	% Loss of Rural Livelihood
Lower Agro-ecological Zone	05	3475	1215	625	590	49.00
Middle Agro-ecological Zone	10	5145	1977	1050	927	47.00
Higher Agro-ecological Zone	14	11155	3555	2105	1450	41.00
Ramgad Watershed	**29**	**19775**	**6747**	**3780**	**2967**	**46.00**

Table 7
Food Security Situation in Ramgad Watershed

Agro-ecological Zone	Total Population			Food Insecure Population				
	Population 2001	Population 2019	% Population Increase [2001-2023]	Food Insecure Population [2001]	Food Insecure Population % of Total Population [2001]	Food Insecure Population [2023]	Food Insecure Population % of Total Population [2023]	% Increase in Food Insecure Population [2001-2023]
Lower Agro-ecological Zone	2486	3475	39.78	945	38.01	1545	44.46	06.45
Middle Agro-ecological Zone	2972	5145	73.12	1557	52.39	2775	53.94	01.55
Higher Agro-ecological Zone	7108	11155	56.94	3577	50.32	7135	63.96	13.44
Ramgad Watershed	**12566**	**19775**	**57.36**	**6079**	**48.38**	**11455**	**57.93**	**09.55**

The highest increase in food insecure population was observed in the higher agro-ecological zone situated between 2000 and 2500 m where the food insecure population increased by more than 13% during the last 19 years (Table 7).

Discussion

The study indicated that drought has emerged as one of major risks to traditional subsistence agriculture in high and populous mountain such as Himalayas. Similar observations have been made in other parts of Himalayas, particularly in Nepal, Bhutan and Pakistan Himalaya and also in other high mountain regions of the world including the Andes and Western China[1,3,6,15-17,23,24,43,49,54,56,60,68]. This very clearly indicates that droughts are likely to effect the sustainability of diverse mountain farming systems all across the world more specifically in developing and less developed countries where large population depends on subsistence farming[12-14,24,33,45,51,52]. Further, the present research endorsed the outcomes of a number of other studies that recurrent drought has disrupted the hydrological system of mountain headwaters and reduced the availability of water for food production[48,64].

The rapidly transforming mountain hydrological regime may undermine food and livelihood security of large population both in mountains and adjoining vast plains as 70% of the global population depends on mountains for the supply of its freshwater[13,22,44]. Further, the increasing frequency and severity of droughts in Himalaya would particularly affect the socio-ecological sustainability of the densely populated plains of South Asia which is inhabited by some of the poorest people with access to less than 5% of water resources of the planet[11,18,23,24,26-28]. The study brought out the fact very clearly that the climate change-induced droughts have been emerging as one of the major threats to subsistence farming system and rural livelihood in the rain-fed Lesser Himalaya.

Further, it has been observed that the increasing frequency and duration of droughts, in combination with inaccessibility, poverty, underdevelopment, marginality, gender-gap are destabilizing the sustainability of traditional subsistence farming system and undermining the adaptive capacity of communities across the Himalayan mountains[2,13-15,30].

The mountain-agriculture is considered as an integrated farming system that integrates land, forest, water, biodiversity and livestock-based production system defined by a set of local agro-ecological and socio-economic conditions[50,63]. The mountain farming system integrates crop production, livestock and other agricultural enterprises with resource conservation practices which are considered essential for sustainability of mountain farming system and ensuring food and nutrition security to local population[1,4,13,16,47,50]. The investigations carried out in different parts of Himalayas and in other mountains clearly endorsed the findings of present study that climate change induced drought is destabilizing the integrated farming and food system through depletion of agricultural resources and resultant steady decline in farm productivity affecting the sustainability of mountain ecosystem and society and increasing their vulnerability of climate change and weather extremes [23, 31, 30, 34].

The study also observed that increasing frequency of climate change induced droughts is declining the agro-biodiversity as local communities are unable to cultivate water requiring important conventional crops, particularly paddy, maize, wheat and some variety pulses which traditionally contributed to food and nutrition security of local communities since time immemorable. Thus, the recurrent droughts have posed the risk of extinction of the important traditional varieties of crop not only in Himalaya, but also in mountains including the Andes[30,34,35]. The steady loss of agro-biodiversity may undermine the sustainability of mountain ecosystem as the biodiversity constitutes the most significant source of rural food and livelihood in densely populated mountains such as Himalaya and the Andes[33,35,49]. Similarly, a large number of farmers have either stopped keeping livestock or reduced their number as recurrent droughts have reduced the availability of fodder both in pastures and forests[24,50]. These changes are further undermining the diversity of farming system and destabilizing traditional mountain integrated farming system.

Moreover, the decline in crop and livestock diversity has increased the risk of food and livelihood insecurity as traditional crops and livestock-products not only constitute source of nutritious food, but also contribute to family income and food purchasing power [50]. The studies conducted in other transects of Himalaya and in the Tibetan Plateau also observed the similar situations[23,24]. These findings underline the need of further investigations focussing on the interpretation of interlinkages between droughts and biodiversity loss in high mountains.

It has been investigated that the food security in the region primarily depends on the availability of food and access to food, determined by the local production and food purchasing capacity of local communities. The food purchasing power depends on the availability of employment and livelihood opportunities in different rural and other sectors and remittances sent by the migrated members of the family. The remittances contribute significantly to community food purchasing power across the Himalayan mountains including Nepal Himalaya [29, 58]. However, the out-break of Covid-19 in beginning of 2020 and the preventive measures taken by the Governments to combat the threat of the pandemic, a large proportion of migrated population either lost their employment or faced massive decrease in income.

As a result, not only the amount of remittances reduced, but a large number of jobless migrated population returned to villages with empty-pockets increasing the vulnerability of large population to food insecurity[23,57]. It is being widely accepted that this would exuberate the impacts of droughts across the Himalayan mountains[25]. Moreover, struggling with severe geo-environmental constraints for survival mountain communities have developed rich repository of traditional knowledge which was evinced by findings of the community perception of droughts and its impact and substantiated by the findings of the studies carried out in other mountains, particularly in the tropical Andean mountains, Nepal and Bhutan[38,64].

The mountain communities are not only able to perceive the climate change and climate change induced disasters and their impacts on natural resources, farming system and livelihood, but they evolved measures and practices to adapt to these changes using the local traditional knowledge[33,49]. One of the important findings of the present work is that the observations obtained through the interpretation of scientific data clearly validated the level of community perception and understanding of climate change induced drought and its impacts on agricultural resources. This underlines the need of preserving and respecting the traditional knowledge of mountain communities and incorporating this in mountain climate change adaption and disaster risk reduction strategies [33].

Conclusion

Climate change induced drought has emerged as one of the major threats to subsistence farming system and rural food and livelihood security in the rain-fed Lesser Himalayan mountains over the decades. The recurrent and protracted droughts are not only depleting the critical agricultural resources, but also undermining the carrying capacity of varying nature-based productive systems. The increasing frequency and severity of drought in combination with poverty and marginality have increased the vulnerability of the poor and other weaker sections of society to climate change and climate change-induced natural risks. The frequent crop failures are likely to have serious implications not only for a range of ongoing rural development programmes, but also on the implementation of climate change adaptation plans and attainment of United Nations Sustainable Development Goals in high mountains.

Moreover, increasing stress of drought may further increase the trends of rural outmigration resulting into draining away of human resource and further retarding the process of sustainable development in mountains. Further, the adverse-effects of drought are expected to disrupt the hydrological system of rain-fed Himalayan watersheds and affect the availability of freshwater in the densely populated plains of South Asia.

It is therefore highly imperative to evolve participatory and community-oriented drought management strategy for the rain-fed Lesser Himalayan Mountains. It would be more scientific and logical to integrate drought management and climate change adaptation programmes into the Integrated Watershed Management. Further, the conservation of bio-diversity, specifically agro-biodiversity which constitutes the basis of mountain food and livelihood, needs to be incorporated into the overall climate change and drought risk reduction plan under the framework of Integrated Watershed Management. In addition to this, community perception and people's traditional knowledge also need to incorporated in the above-mentioned frameworks of drought management.

Mountain communities have developed rich repositories of traditional knowledge through their struggle for survival with a severe geo-environmental constraint. These community centric and policy-oriented approaches will not only help in mitigating the impact of drought, but will also help in strengthening and transforming the traditional integrated agricultural system into climate and drought resilient farming and food system across the diverse agro-climatic transects in Himalayas and other populous mountains of developing and less developed countries where agricultural production and community livelihood mostly depend on inter-dependent natural systems.

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