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Climate Change Impact and Adaptation Practices in Agriculture: A Case Study of Rautahat District, Nepal

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Abstract: This study identifies the impact of climate change and adaptation practices on agriculture in the Rautahat district of central Nepal by analyzing the atmospheric temperature, rainfall pattern, soil moisture, and direct field survey. The impact and status of crop production systems are emphasized. Primary data on crop production system were collected through household surveys and adaptation practices in crop production were collected through focus group discussions, key informants' interviews, and direct observations. Time series data on key climatic variables and productivity of major crops were collected from the government sources. Mann–Kendall trend analysis and Sen's Slope methods were used for the analysis and quantification of temperature and rainfall trends. Spearman's rank correlation analysis was performed to find the relation of seasonal rainfall with the crop yields. The study showed that the annual average rainfall was decreasing at the rate of 10.21 mm/year and the annual mean temperature had increased at a rate of 0.02 °C/year over the last 30 years, but their variations were found to be statistically insignificant. Seasonal rainfall also increased, except for the post-monsoon rain. Estimation of Soil Moisture Index through remote sensing technique indicates that it has been reduced considerably over the past 15 years at the beginning of the monsoon. It was observed that farmers have been using different adaptation measures like the use of high-yielding varieties of crops, enhanced irrigation system, switching to hybrid seed, and increased access to pesticides. As a result, the yields of major crops including rice, maize, wheat, sugarcane, potatoes, and pulses all showed increasing trends during 1999 to 2014. However, the total costs of production of all crops have increased many fold as a consequence of the cost associated with the arrangements for such adaptation measures and shifts towards market-based commodities.

Keywords: climate change; trend analysis; correlation; soil moisture; crop yield; adaptation

1. Introduction

The Himalayan region is believed to be a hotspot of climate change as the rates of warming in this region are significantly higher than the global average of 0.74 °C over the past 100 years [1]. Studies have shown that a major part of the Himalayan region is undergoing warming at rates higher than 0.01 °C per year [2]. At the end of the century the annual average temperature is projected to be warmer by 4–5 °C for western, central, and eastern Himalaya and rainfall may increase by 20–40% over the entire Hindu Kush Himalayan region based on general circulation models [3]. Nepal ranks fourth on a recently published list of country vulnerability that is based on the Climate Change Vulnerability Index [4], with poverty and adaptive capacity being some of the key determining factors in the ranking. Climate change is a pressing issue and a growing concern for Nepal as the mean temperature in Nepal since 1977 has risen at a rate between 0.03 °C·year^{-1} and 0.12 °C·year^{-1}, with an average of

0.06 °C·year $^{-1}$, whereas the rate of global average surface temperature rise within the last century was about 10 times smaller than this [1,5,6]. Nepal has been experiencing considerable changes in precipitation patterns as well, which has direct impact on overall agricultural productivity [7]. On the other hand, only 26.5% of cultivable agricultural land in Nepal is irrigated, of which less than 50% land has access to water supply all year round [8]. As a result, agricultural production depends on favorable weather conditions, mainly in the monsoon time. A late or erratic monsoon quickly translates into crop losses and subsequently into food insecurity. This is the most challenging issue for a country like Nepal where more than 80% of people are dependent solely on agriculture for their livelihood. Being aware of the status of climatic variability, its impact on agriculture production systems, and adaptation practices are all necessary to predict future scenarios and reduce vulnerability.

The impact of climate change on water resources within Lesser Himalaya and glacier retreat in the Higher Himalaya of Nepal has been identified [7,9,10]. However, there is a lack of published research on the impacts of climate change on farming systems and the adaptation practices in the southern region of Nepal, the Terai. The study in eastern Terai by Regmi [11] has shown that farmers faced a rain deficit in the years 2005 and 2006 because of an early monsoon, and crop production was reduced by 12.5% nationwide. Midwestern Terai also faced heavy rain with floods, which reduced production by 30% in these years [11]. Some review studies carried out by individuals and organizations in Nepal and elsewhere have reported that climate change offers both challenges and opportunities to farmers, depending upon the geographical regions and types of effects it has produced [12–14]. The National Adaptation Programs of Action of the Ministry of the Environment, a body of the Nepal government [7], identifies agricultural land in the entire southern plain region of the country as vulnerable to sedimentation due to floods and inundation. Similarly, drought is affecting crop production and animal husbandry. The winter drought assessment confirmed that production of the major winter crops, wheat and barley, decreased nationally in 2009 by 14.5% and 17.3%, respectively, compared to previous years [15]. The ability of Nepal's agriculture sector to adapt to such change is limited because of its low productivity and the high incidence of poverty, particularly among the rural population. However, it is expected that the local communities are utilizing certain adaptation measures to cope with the adverse impacts of climatic variability; these are not known currently because of the lack of proper studies focusing on agriculture production. This research therefore tries to identify the impact of climatic variability and climatic changes on the agriculture sector in one of the most fertile areas of Nepal, the Rautahat district. It also identifies the autonomous adaptation practices of the communities to cope with such variability.

2. Materials and Methods

2.1. General Approach

This research was conducted using a combination of qualitative and quantitative methods for collection of relevant data from both primary and secondary sources. The key climatic data, namely rainfall and temperature, were collected from the Department of Hydrology and Metrology (DHM) of the Nepal government and productivity data on major crops grown in the research district was collected from the Ministry of Agriculture Development (MOAD) of the Nepal government. As secondary sources of information, qualitative and quantitative information about farming systems, cropping patterns, production of major crops, and the adaptation measures used by the community to cope with the effects of climate change were collected through sample household surveys. In addition to this, qualitative information was collected using participatory rural appraisal tools and techniques such as key informants' interviews, focus group discussions, and direct observations during field survey. Moreover, the information collected through action research carried out with limited participant farmers for two crop seasons was also used for triangulation of the information collected from secondary and primary sources.

2.2. Primary Data

Relevant primary data were collected using a combination of qualitative and quantitative methods such as sample household survey and participatory rural appraisal tools and techniques, as discussed in Section 2.1. The survey methodology, including the sampling framework, data collection methods, and tools used in the study, is briefly described below.

2.2.1. Household Survey

Quantitative data with respect to the effects of climatic variables, community adaptation practices for agricultural systems, and the impacts on productivity of major crops and livelihoods of farmers in the study areas were collected through purposive random sample survey of households using a stratified-multi stage cluster sampling method. The outline of the questionnaire is given in Appendix A. For this purpose, 180 respondents altogether were selected randomly from four sample study Village Development Committees representing the study district. The sample was distributed equally (45 per VDC) to four VDCs selected to represent the study areas, gender, age groups, and population of the study area (Table 1).

Table 1. Distribution of respondents by caste/ethnicity, sex, and age groups.

Caste/Ethnicity	Frequency	%
Hills Bahuns/Kshetris/Thakuris	17	9.5
Hills Janajatis	6	3.3
Hills Dalits	5	2.8
Madhesis/Tharus	74	41.1
Muslim or other religious groups	33	18.4
Others (unspecified groups)	45	25.0
Total	180	100.0
Sex		
Male	172	95.6
Female	8	4.4
Total	180	100.0
Age groups (year)		
Less than 40	4	2.2
41–50	77	42.8
46–50	32	17.8
51–60	56	31.1
Above 60	43	23.9
Total	180	100.0

2.2.2. Interview Technique

The household survey was conducted vi a group interview technique where five respondents selected from each sample cluster were invited to assemble in one accessible place and the interview was conducted by an experienced field researcher. The interviewer asked a common question to all five respondents in the group but the individual responses were recorded separately in the questionnaire. The group interview technique was considered to be more effective for a survey in which the information has to be collected from the experience and memories of the respondents. Moreover, this type of group interview was helpful in extracting reliable information from respondents since responses were expected to be similar with respect to the effects of climatic variables on the farming system and livelihoods of people in the study clusters.

2.2.3. Key Informant Interviews (KII)

In addition to sample household surveys, some qualitative information was collected regarding key issues in farming and the associated impacts of climate change on major crop production systems and adaptation measures being applied by local communities. Key Informants' Interviews were conducted with selected individuals who were considered knowledgeable about the issues of climate change and its impacts on the agriculture production system in the community in general and adaptation practices of the farmers in the study district in particular. The responses and views expressed by the key informants were analyzed and used in cross checking the findings of the study.

2.2.4. Soil Moisture Estimation Using Remote Sensing Technology

Surface soil moisture is one of the most important variables in hydrological processes and is also an important indicator for climate change monitoring. Surface soil moisture is the amount of water in the upper 10 cm of soil [16]. Estimating soil moisture is crucial for many water budgeting processes and for meteorological and agricultural applications. However, accurate measurement of in situ soil moisture is too expensive, time-consuming, and tedious, as it requires a repeated sampling process to analyze temporal changes. Direct measurements of soil moistures are limited to discrete point-based measurements at specific locations, which cannot represent the spatial and temporal distribution as soil moisture is highly variable both spatially and temporally. Advances in remote sensing have provided various methods to estimate the surface soil moisture spatially and temporally. Remote sensing has the ability to collect information from various samples over a wide area in a short duration of time, especially with recent developments in sensor functionality and both temporal and spatial image resolution. Many researchers have shown that near-surface soil moisture can be measured by optical and thermal infrared remote sensing techniques, as well as active and passive microwave remote sensing techniques [17]. Remote sensors do not measure the soil moisture content directly, so mathematical models are necessary to describe the connection between the measured signals and soil moisture content.

To estimate the soil moisture through remote sensing, the method described by [18–20] was followed. The method combines visible, infrared, and thermal datasets of Landsat-7 imagery and Landsat-8 imagery representing the multispectral image, data acquired by both Operational Land Imager and Thermal Infrared Sensor. The Landsat images were downloaded for free from the official website of the United States Geological Survey (USGS) and the standard method of image processing techniques is followed as described below. This method maps the soil moisture using land surface temperature (LST) and Normalized Vegetation Index (NDVI). Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) are combined to estimate the soil moisture in the form of Soil Moisture Index (SMI). Different corrections to the Landsat images are necessary to process them for the estimation of soil moisture index. Atmospheric correction was done to the Landsat image by converting it into Top of Atmosphere (TOA) or its Radiance and then to its Reflectance as given by Equations (1) and (2).

$$L_\lambda = M_L\, Q_{cal} + A_L. \quad (1)$$

where, L_λ is the Top of Atmosphere Spectral radiance, M_L is the band-specific multiplicative rescaling factor from the metadata, A_L is the band-specific additive rescaling factor from the metadata, and Q_{cal} is the quantized and calibrated standard product pixel values (DN). Equation (2) is used to convert the DN values to TOA reflectance:

$$\rho_\lambda = M_\rho\, Q_{cal} + A_\rho, \quad (2)$$

where ρ_λ is the TOA planetary reflectance without correction for solar angle (note that ρ_λ does not contain a correction for the sun angle), M_ρ is the band-specific multiplicative rescaling factor from the metadata, and A_ρ is the band-specific additive rescaling factor from the metadata. Sun angle correction was done using Equation (3):

$$Sun\ Angle\ Correction = TOA\ Reflectance/\sin\,(sun\ elevation). \quad (3)$$

Normalized Difference Vegetation Index (NDVI) was calculated using Equation (4):

$$NDVI = Float\ (NIR_{\ REF} - RED_{\ REF})/Float\ (NIR_{\ REF} + RED_{\ REF}), \tag{4}$$

where NIR_{REF} is near infrared reflectance and RED_{REF} is red band reflectance. Thermal Infrared Bands (bands 10 and 11 in Landsat 8 image) are converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata file (Equation (5)):

$$T = \frac{K_2}{ln\left(\frac{K_1}{L_A} + 1\right) - 272.15}, \tag{5}$$

where, T is At Satellite brightness temperature (in Kelvin), L_A is the TOA spectral radiance (watt per steradian per square meter), and K_1 and K_2 are band-specific thermal conversion constants from the metadata. Land surface temperature (L_{st}) is determined using Equation (6):

$$L_{st} = \frac{B_t}{1 + w\left(\frac{B_t}{p}\right)\ln(e)}, \tag{6}$$

where B_t is the satellite temperature, w is the wavelength of the emitted radiance, e is the Land Surface Emissivity, the value of e is obtained from Equation (7), and the value of p is 14,380.

$$e = 0.004\ P_v + 0.986, \tag{7}$$

where P_V is the proportion of vegetation obtained from Equation (8):

$$P_v = \left[\frac{NDVI - NDVI_{\ MIN}}{NDVI_{\ MAX} - NDVI_{\ MIN}}\right]^2. \tag{8}$$

Soil Moisture Index (SMI) is obtained by using Equation (9):

$$SMI = \frac{Float\ (T_{\max} - T_s)}{Float\ (T_{\max} - T_{\min})}, \tag{9}$$

where T_{max} and T_{min} are the maximum and minimum temperatures in the study area as obtained from Equation (5), and T_S is the raster value of L_{st} obtained from Equation (6).

2.3. Secondary Data

2.3.1. Meteorological Data and Analysis

Data on temperature and rainfall was collected from the Department of Hydrology and Meteorology of the Nepal government for the nearest station of Simara Airport. The data on key climatic variables such as rainfall were collected for 31 years (1984 to 2014), and mean maximum and minimum temperature for 28 years (1987 to 2014). Seasonal mean rainfalls for four prominent seasons, namely pre-monsoon, monsoon, post-monsoon, and winter, were calculated to establish the relationships with the productivity of major crops grown in the study area. Nonparametric Mann–Kendall statistical tests [21,22] were used to detect trends in temperature and rainfall during the last three decades. This test is the most common one used by researchers in studying hydro-meteorological time series trends [23] and can be used even if there is a seasonal component in the series. The null hypothesis (H0) for these tests is that there is no trend in the series. The alternative hypothesis (H1) is that there is a trend. Each test has its own parameters for accepting or rejecting HO. On rejecting the null hypothesis, the result is said to be statistically significant. This test is based on the calculation of Kendall's tau (τ) measure of association between two samples, which is itself based on the ranks with the samples. The trend was quantified using Sen's slope method, which is another index to quantify the trend using the nonparametric procedure developed by Sen [24].

2.3.2. Yield of Major Crops

Time series data on yield of crops grown in the study district were accessed from the website of the Ministry of Agriculture Development (MoAD) of the Nepal government for the past 15 years (1999 to 2014). The trends of the yields were determined using Mann–Kendall tests and they were quantified using Sen's slope method [24]. The same data were used for analysis of yields against seasonal and mean rainfalls of the corresponding years. Rice, maize, wheat, pulses, potatoes, and sugarcane are the dominant crop types in the working area and their yields have been analyzed. Spearman's rank correlation [25,26] was conducted to find the relationship between seasonal rainfall and the production of major crop types in the study area. The null hypothesis in this test is that as the ranks of one variable increase, the ranks of the other variable are not more likely to increase or decrease; the Spearman correlation coefficient, ϱ ("rho") is 0. If the dependent variable tends to increase when the independent variable increases, the Spearman correlation coefficient is positive. If the dependent variable tends to decrease when the independent variable increases, the Spearman correlation coefficient is negative. A Spearman correlation of zero indicates that there is no tendency for the dependent variable to either increase or decrease when the independent variable increases. When the independent and dependent variables are perfectly monotonically related, the Spearman correlation coefficient becomes 1.

2.4. Study Area

The study was conducted in four Village Development Committees (VDCs) of Rautahat district of Nepal purposely selected for the study to cover one of the potential areas of agriculture production, and also to represent different geology within the same district. This is ranked as one of the districts having the least adaptive capability by the Ministry of Environment [27]. This lies in central Nepal (Figure 1) and covers two physiographical zones, namely the Terai and the Churia.

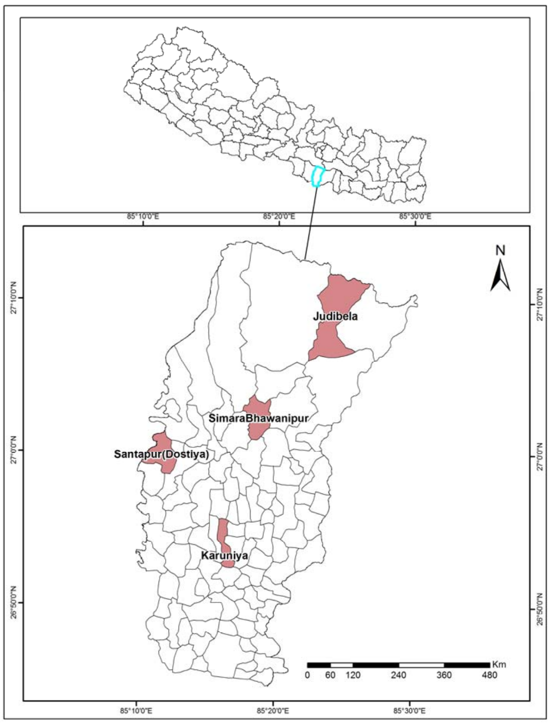


Figure 1. Location map of the study area within the map of Nepal.

Rautahat district is one of the areas of fertile land, and agriculture has been the major mode of livelihood of the people. It is considered that this district is representative of many other districts of central and eastern Terai of Nepal in terms of climate change impact, agriculture production, and autonomous adaptation initiatives. The study area includes Judibela, Simara Bhawanipur, Santpur (Dostiya), and Karuniya VDCs within the district (Figure 1). Judibela VDC is in the northern part of the district and Karuniya VDC is in the southern part. Simara Bhawanipur and Shantapur VDCs are in the central part of the district. These working VDCs were selected mainly to cover different geographical areas extending from north to south within the same district, so that the portions of upper, middle, and lower Terai are represented.

3. Results

3.1. Climate Change Indicators

Temperature, rainfall, and soil moisture are considered major climate change indicators in this study. The analysis of variation of rainfall and temperature within the last 30 years, and the distribution of soil moisture content within the study area between the years 2000 and 2015, are presented in this section.

3.1.1. Temperature

The monthly climatic data for nearly the last three decades, given in Table 2, show that the average annual maximum and minimum temperatures in the past 28 years were 30.45 °C and 18.09 °C, respectively. The mean annual temperature for the same period was 24.27 °C. The variation of annual temperature for the last 28 years in the study area is shown in Figure 2, which shows that the temperature follows a linear trend of increase.

The result of the Mann–Kendall test and Sen's slope for the variation of annual average maximum and minimum temperature is shown in Table 3, which shows that the trends of both of these temperatures are increasing, as indicated by the positive Tau (τ) values, but statistically insignificant at 95% confidence level, as indicated by the p-values greater than 0.05. Table 3 also shows that the maximum, minimum, and annual mean temperatures increased by 0.01 °C/year, 0.019 °C/year, and 0.015 °C/year, respectively, over the last 28 years.

Table 2. Monthly temperature and rainfall data for nearly the past three decades.

Month	Monthly Temperature (°C) (1987 to 2014)			Monthly Rainfall (mm) (1984 to 2014)
	Max	**Min**	**Mean**	**Average**
January	21.26	7.69	14.48	12.04
February	25.65	9.78	17.71	16.17
March	30.83	13.59	22.21	14.99
April	35.13	18.96	27.04	44.06
May	35.18	23.12	29.15	136.83
June	34.37	25.30	29.84	279.70
July	32.65	25.56	29.11	564.92
August	32.76	25.43	29.09	438.52
September	32.59	24.31	28.45	289.72
October	31.67	19.93	25.80	74.05
November	28.89	13.86	21.38	4.28
December	24.38	9.50	16.94	10.19
Average	30.45	18.09	24.27	1885.47

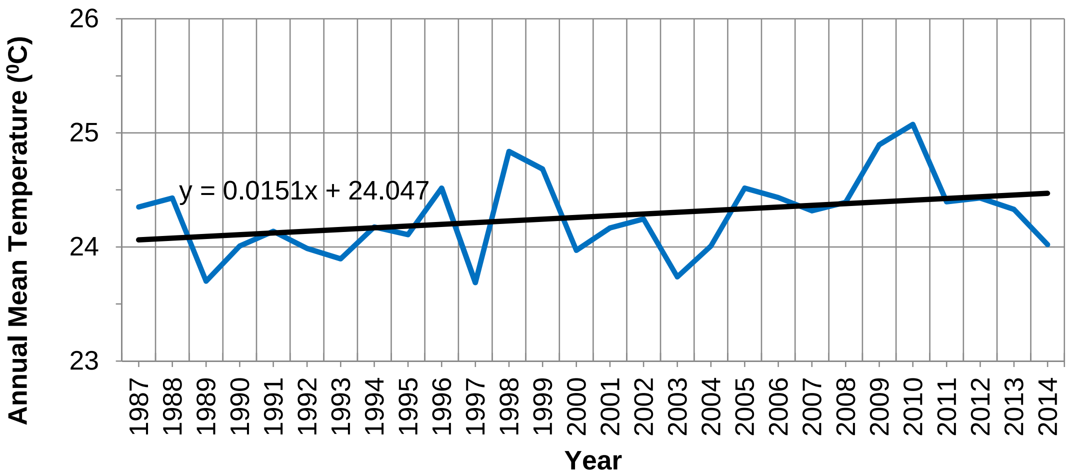


Figure 2. Annual mean temperature in the study area for the last 28 years.

Table 3. Mann–Kendall test and Sen's slope results of mean annual, maximum, and minimum temperatures for 1987 to 2014.

Temperature	*p*-Value	τ-Value	Sen's Slope (°C/year)	Trend	Significance	Alpha Value
Tmax	0.286	0.146	0.010	Increasing	Insignificant	0.05
Tmin	0.082	0.236	0.019	Increasing	Insignificant	0.05
Average	0.075	0.242	0.015	Increasing	Insignificant	0.05

3.1.2. Rainfall

Monthly rainfall data for the last 31 years are given in Table 2, which shows that the months of May, June, July, August, and September get most of the rainfall. The annual average and seasonal rainfall for the last 31 years is plotted in Figure 3, which shows that the seasonal and average annual rainfall pattern is periodically changing, as felt by a majority of the respondents.

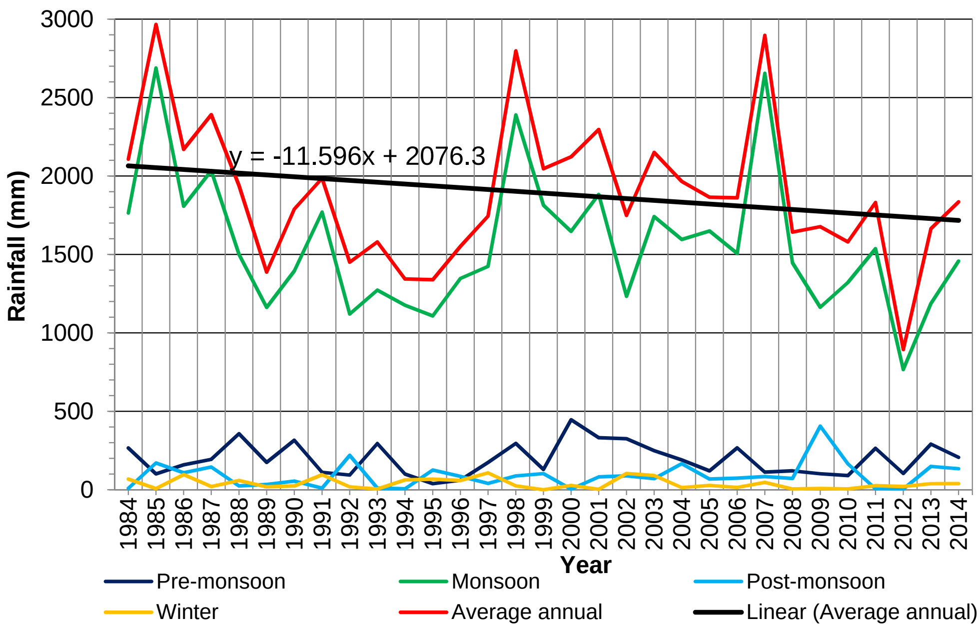


Figure 3. Variation of seasonal and average annual rainfall in the study area for the last 31 years.

The results of the Mann–Kendall test and the Sen's slope for the variation of annual average and seasonal rainfall from 1984 to 2014 are shown in Table 4. It is evident from Table 4 that the annual average, pre-monsoon, monsoon, and winter rainfalls have a decreasing trend, as indicated by the negative Tau (τ) values, but the post-monsoon rainfall is on an increasing trend, as indicated by the positive Tau (τ) value. However, they are all statistically insignificant at the 95% confidence level, as indicated by the *p*-values greater than 0.05 in all cases. Sen's slope method quantified that the pre-monsoon, monsoon, winter, and average annual rainfalls are all decreasing at a rate of 0.52 mm/year, 11.75 mm/year, 0.59 mm/year, and 10.21 mm/year, respectively; however, the post-monsoon rainfall has been increasing at the rate of 1 mm/year since 1984.

Table 4. Mann–Kendall test and Sen's slope results for variation in rainfall between 1984 and 2014.

Rainfall	*p*-Value	Tau (τ) Value	Sen's Slope (mm/Year)	Trend	Significance
Pre-monsoon	0.760	−0.041	−0.520	Decreasing	Insignificant
Monsoon	0.208	−0.161	−11.750	Decreasing	Insignificant
Post-monsoon	0.622	0.065	1.000	Increasing	Insignificant
Winter	0.324	−0.127	−0.595	Decreasing	Insignificant
Annual Average	0.208	−0.161	−10.210	Decreasing	Insignificant

3.1.3. Soil Moisture

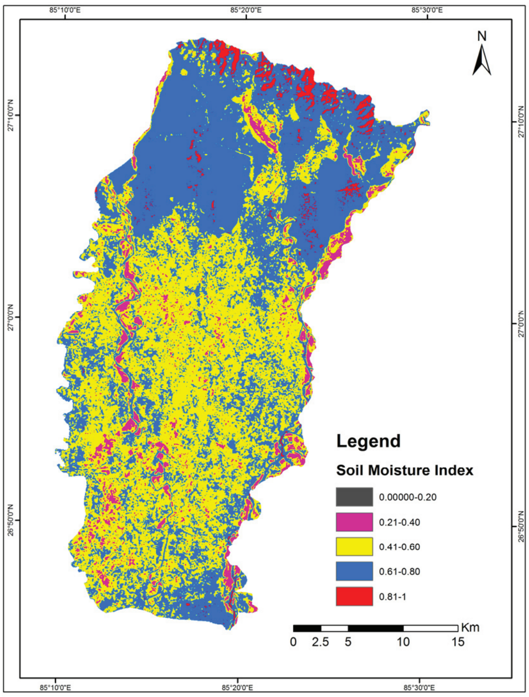
Soil moisture in the month of June was estimated first for the whole Rautahat district and then for the working VDCs within the district. The spatial distribution of soil moisture index was analyzed in the value range; the highest range is 0.81 to 1 and the lowest range is −0.027 to 0.18. The highest soil moisture index in the study area was 0.92 and the lowest index was −0.015. The results of soil moisture indexes of the whole district for the years 2000, 2014, and 2015 are given in Table 5 and Figure 4. It can be seen that the soil moisture decreased progressively from the year 2000 to 2015, but the decrease was more prominent in 2015.

In general, only part of the northernmost portion of the district had high soil moisture, and in limited, isolated patches. Such areas progressively decreased from 2000 to 2015 (Table 5). Nearly 47% of the area within the district had a high soil moisture index of 0.60 to 0.80 in the year 2000, but by 2014 this range of moisture was only available in about 20% of the area. In 2015, the area declined rapidly and only about 1% of the area had this range of soil moisture. This indicates that the surface soil of the whole district is becoming dryer. The soil moisture in all the working VDCs decreased progressively from 2000 to 2015, which is evident from Figures 5–8 and Tables 6–9.

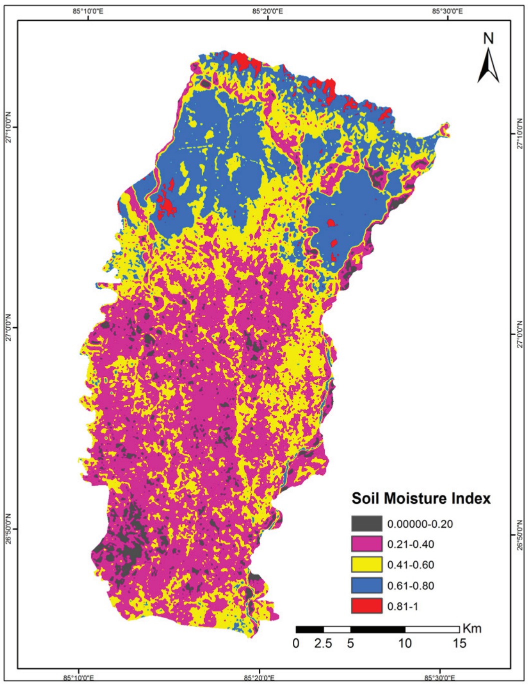
For example, a high soil moisture index range of 0.61–0.80 covered 73.03% of the area of Judibela VDC in 2000 but only 54.57% of the total area in 2014. Instead, 83.96% of the total area had a lower soil moisture index range of 0.38–0.57 in 2015. A similar pattern can be seen for all the other study VDCs, as shown in Tables 6–9.

Table 5. Area (in %) covered by different SMI values in Rautahat district.

	Year				
	SMI Class	2000	2014	SMI Class	2015
		Area (%)	Area (%)		Area (%)
Rautahat District	0.000001–0.20	0.00	3.84	−0.027–0.18	21.10
	0.21–0.40	5.01	44.28	0.19–0.37	45.09
	0.41–0.60	46.06	30.63	0.38–0.57	32.72
	0.61–0.80	46.81	20.08	0.58–0.77	0.94
	0.81–1	2.11	1.17	0.78–0.97	0.15



(**a**)



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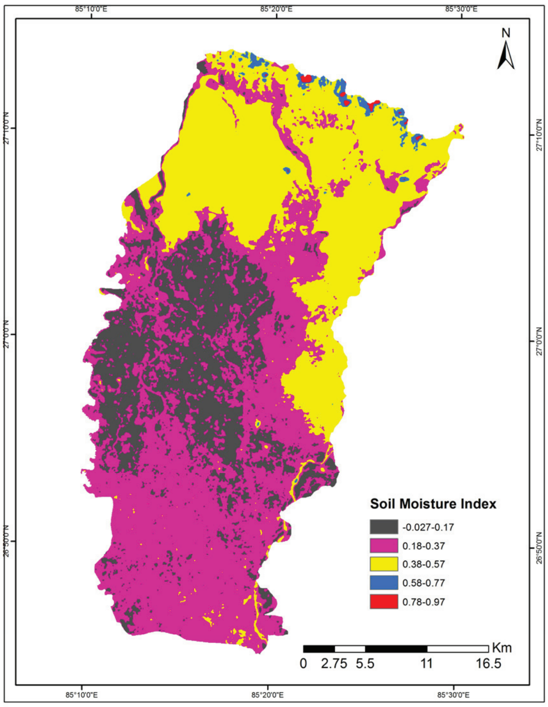
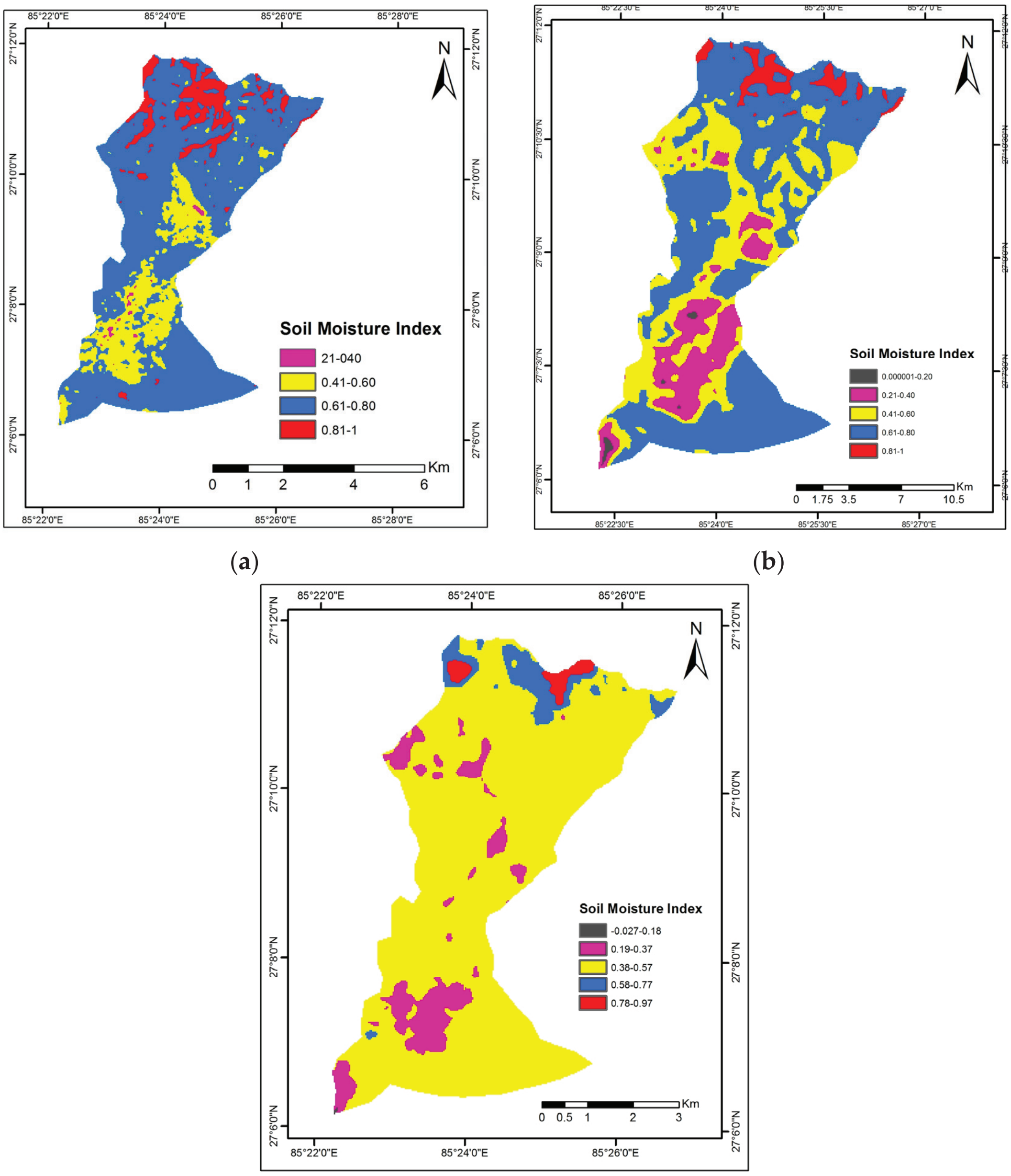


(**c**)

Figure 4. Soil moisture index of Rautahat district in different years: (**a**) 2000; (**b**) 2014; and (**c**) 2015.

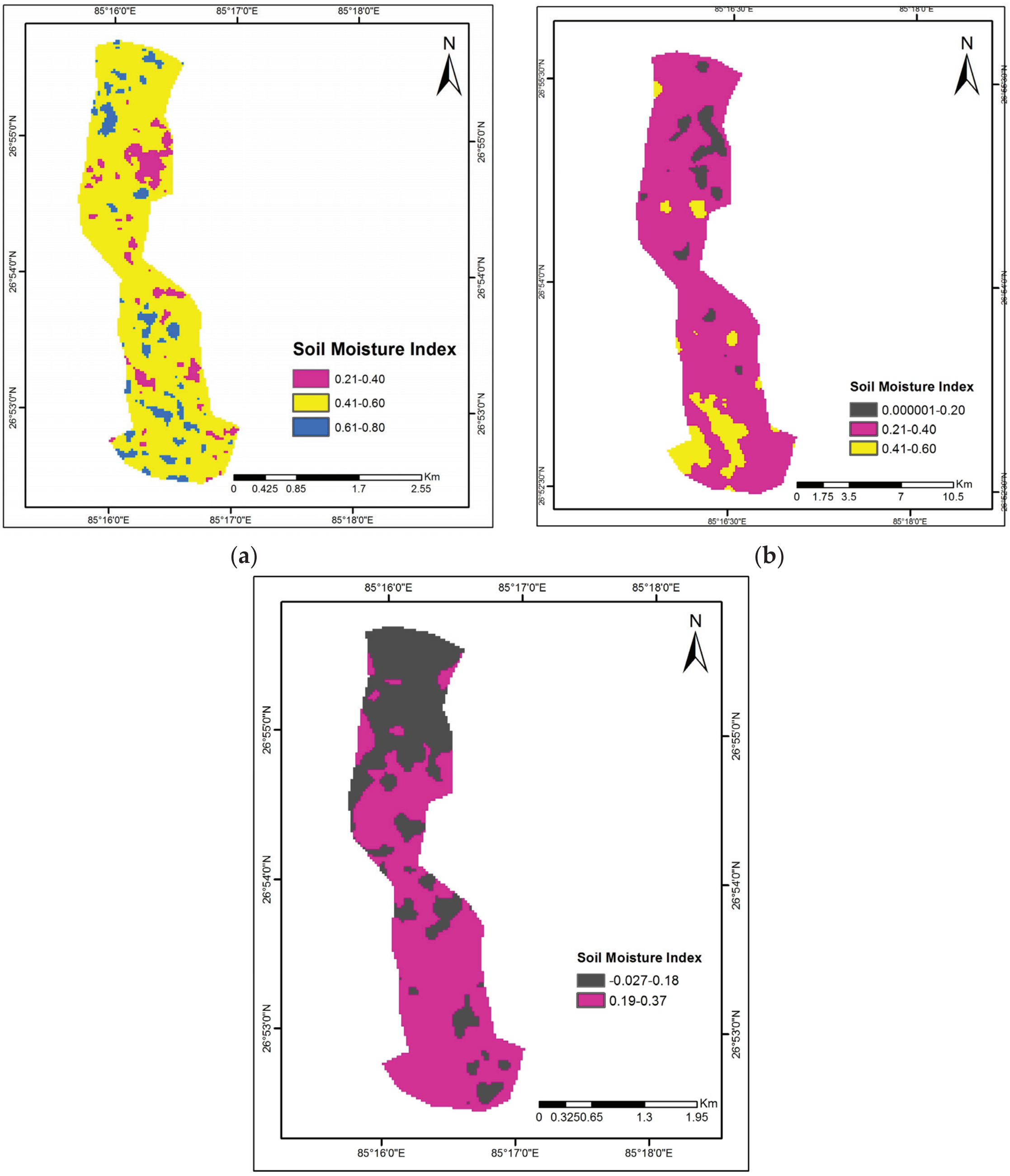


(**a**) (**b**) (**c**)

Figure 5. Soil moisture index of Judibela VDC for different years: (**a**) 2000; (**b**) 2014; and (**c**) 2015.

Table 6. Soil moisture index (SMI) for the different years in Judibela VDC.

Working VDC	Year				
	Class	2000	2014	Class	2015
		%	%		%
Judibela	0.000001–0.20	-	0.37	−0.027–0.18	0.02
	0.21–0.40	0.44	11.97	0.19–0.37	9.4
	0.41–0.6	17.99	29.14	0.38–0.57	83.96
	0.61–0.80	73.03	54.57	0.58–0.77	4.99
	0.81–1	8.54	3.94	0.78–0.97	1.63

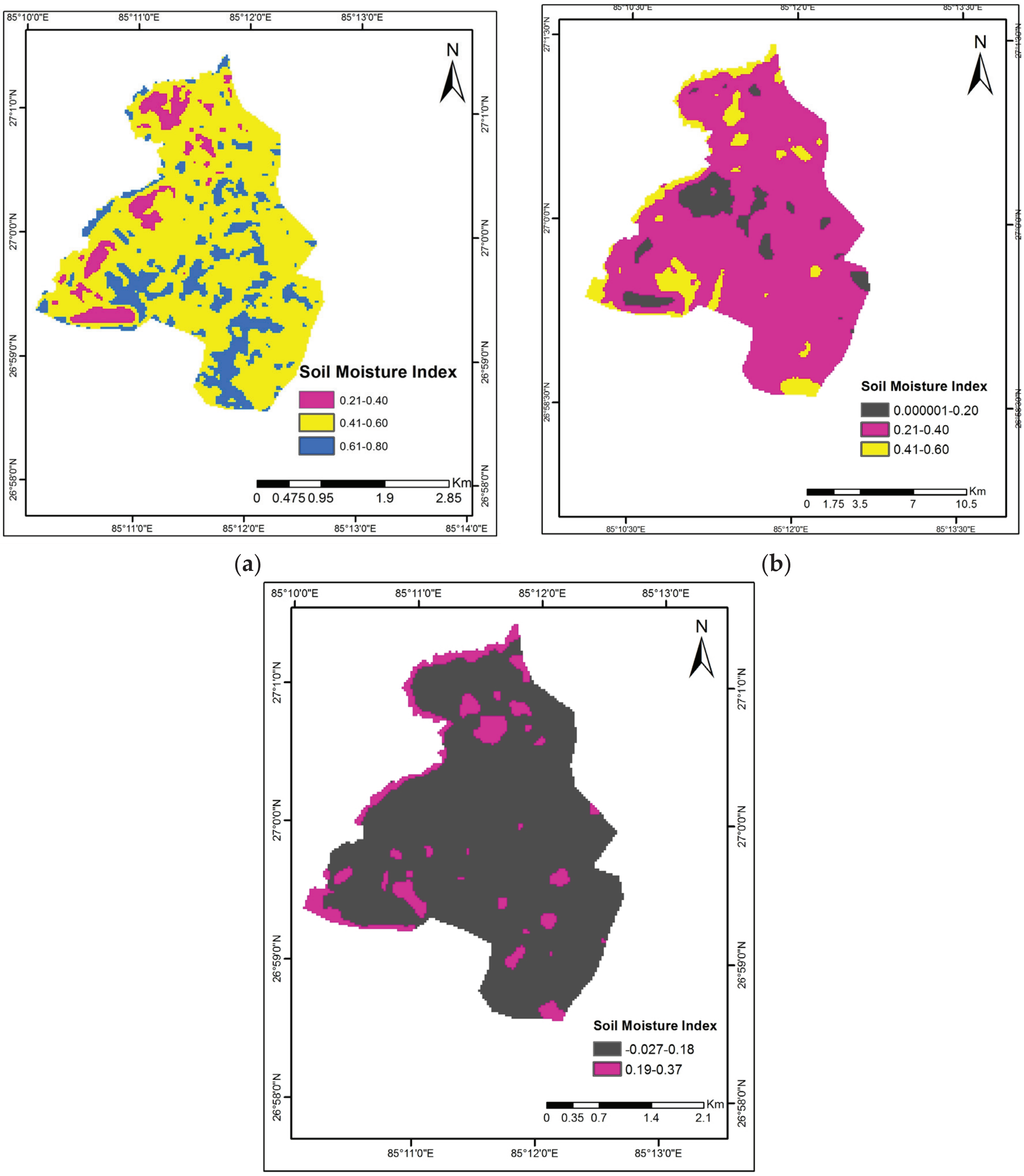


(**a**) (**b**) (**c**)

Figure 6. Soil moisture index of Karuniya VDC for different years: (**a**) 2000; (**b**) 2014; and (**c**) 2015.

Table 7. Soil moisture index (SMI) for the different years in Karuniya VDC.

Working VDC	Year				
	Class	2000	2014	Class	2015
		%	%		%
Karuniya	0.000001–0.20	-	5.62	−0.027–0.18	88.93
	0.21–0.40	8.25	84.04	0.19–0.37	11.07
	0.41–0.60	83.21	10.34	0.38–0.57	-
	0.61–0.80	8.54	-	0.58–0.77	-



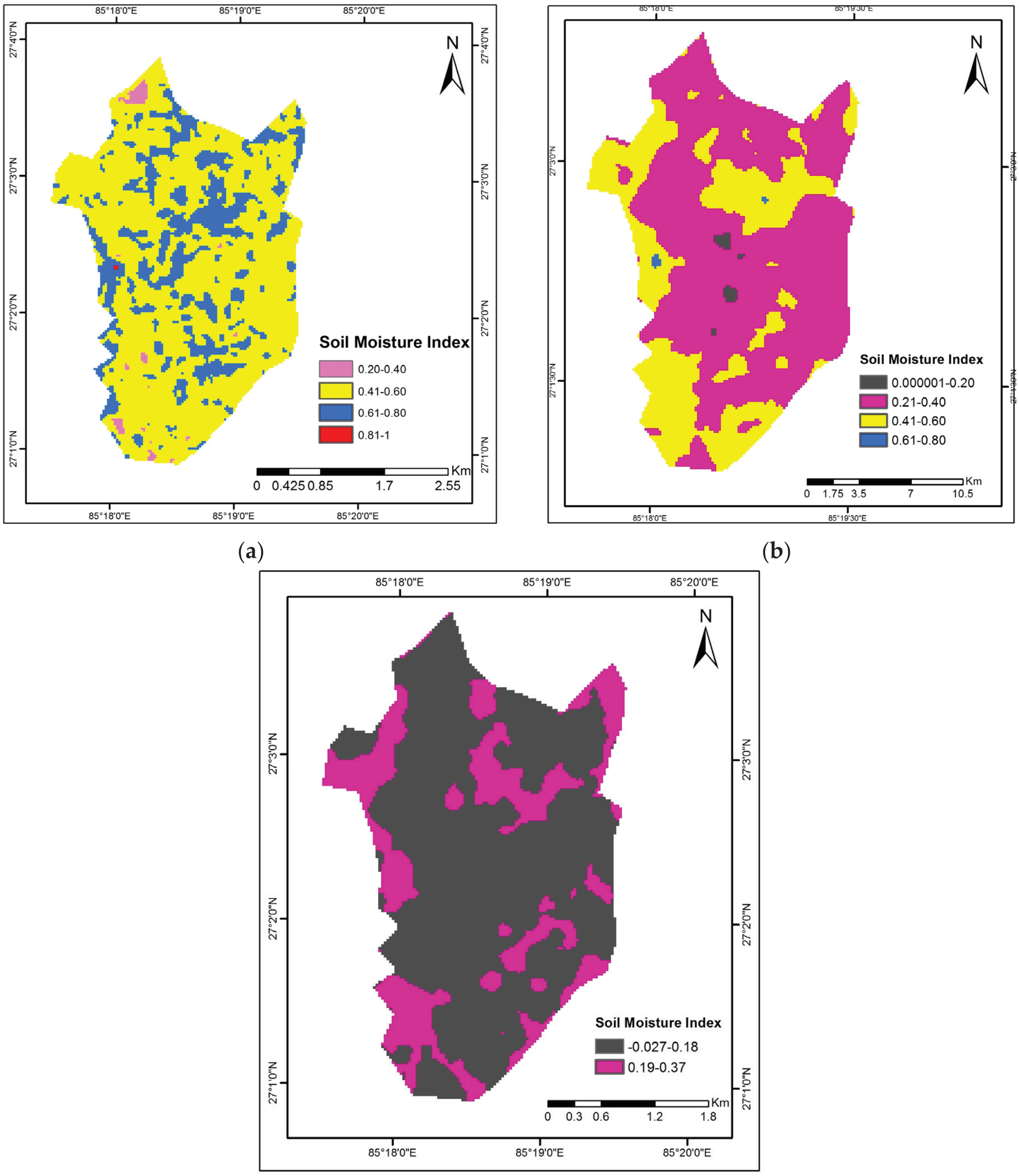
(**a**) (**b**)

(**c**)

Figure 7. Soil moisture index of Santapur VDC for different years: (**a**) 2000; (**b**) 2014; and (**c**) 2015.

Table 8. Soil moisture index (SMI) for the different years in Santapur VDC.

Working VDC	**Year**				
	Class	**2000**	**2014**	**Class**	**2015**
		%	**%**		**%**
Santapur	0.00001–0.20	-	7.36	−0.027–0.18	86.96
	0.21–0.40	7.84	82.52	0.19–0.37	13.04
	0.41–0.60	73.19	10.12	0.38–0.57	-
	0.61–0.80	18.97	-	0.58–0.77	-



(**c**)

Figure 8. Soil moisture index of Simara Bhawanipur VDC for different years: (**a**) 2000; (**b**) 2014; and (**c**) 2015.

Table 9. Soil moisture index (SMI) for the different years in Simara Bhawanipur VDC.

Working VDCs	**Year**				
	Class	**2000**	**2014**	**Class**	**2015**
		%	**%**		**%**
Simara Bhawanipur	0.000001–0.20	-	0.64	−0.027–0.18	74.4
	0.21–0.40	1.17	67.22	0.19–0.37	25.6
	0.41–0.60	75.19	31.95	0.38–0.57	-
	0.61–0.80	23.61	0.19	0.58–0.77	-
	0.81–1	0.03	-	0.78–0.97	-

3.2. Agricultural Production

The data on production of major crop types in the study area were collected from the database of the Ministry of Agriculture Development, Nepal government [28]. Unfortunately, the data were available only from 1999 to 2014; an attempt was made to find the data before 1999 as well, but authentic data were not available by any means. Paddy, maize, wheat, sugarcane, potatoes, pulses, and oil seeds are the major crop types in the study area. The yearly yields of these crops per year from 1999 to 2014 are given in Table 10. Mann–Kendall trend analysis and Sen's slope method were applied to find the trend of the yields of major crops from 1999 to 2014, and the results are presented in Table 11. Table 11 shows that the yields of all crops except oil seeds had an increasing trend. However, only the increasing trends of maize, wheat, potatoes, and sugarcane were statistically significant at the 95% confidence level. Sen's slope method quantified that the yields of maize, wheat, potatoes, and sugarcane increased at a rate of 68.67 Kg/Ha per year, 80.8 Kg/Ha per year, 290.5 Kg/Ha per year, and 477.3 Kg/Ha per year between 1999 and 2014. The pulses yield increased at a rate of 12.86 Kg/Ha per year, but the yield of oil seed decreased at a rate of 2.25 Kg/Ha per year (Table 11).

Table 10. Yearly yield of major crops grown in the study area (data generated from [27]).

Year	Yield (Kg/Hectare)						
	Paddy	Maize	Wheat	Oil Seeds	Potato	Sugarcane	Pulses
1999	2500	1800	2000	812	10,349	30,000	1000
2000	2785	1600	1720	818	13,455	30,000	988
2001	2660	1780	1950	797	13,455	36,000	963
2002	2800	1700	2100	950	14,057	36,000	700
2003	2800	1700	2100	950	14,057	36,000	700
2004	2534	1906	1749	887	14,896	36,042	700
2005	2326	1906	1749	887	14,896	36,042	789
2006	2230	1967	2300	803	14,896	36,042	789
2007	2433	1800	2504	837	16,500	35,091	829
2008	2660	1875	2238	837	16,833	39,129	796
2009	2472	1747	2420	669	16,058	45,754	802
2010	2651	3200	2420	828	16,058	35,250	790
2011	3350	3150	2677	828	18,300	40,000	868
2012	2243	3300	3100	815	16,089	41,180	1205
2013	3135	3235	3107	828	16,089	32,000	1205

Table 11. Mann–Kendall test and Sen's slope results for yields of major crops (1999 to 2014).

Crops	*p*-Value	Tau (τ) Value	Sen's Slope (Kg/Ha/Year)	Trend	Significance	Alpha Value
Paddy	1	−0.010	0.00	Increasing	Insignificant	0.05
Maize	0.003	0.580	68.67	Increasing	Significant	0.05
Wheat	0.0005	0.715	80.80	Increasing	Significant	0.05
Oilseeds	0.485	−0.147	−2.25	Decreasing	Insignificant	0.05
Potato	0.0001	0.769	290.50	Increasing	Significant	0.05
Sugarcane	0.040	0.414	477.30	Increasing	Significant	0.05
Pulses	0.251	0.234	12.86	Increasing	Insignificant	0.05

As discussed in Section 3.1.2, rainfall generally had a decreasing trend in the study area over the last 30 years or so. To find the relationship between seasonal rainfall and the yield of major crops in the study area, a Spearman's rank correlation was conducted. The correlation results are given in Table 12, which shows that the yields of most of the crops are negatively correlated with the seasonal rainfall but their relationship is statistically insignificant at the 95% confidence level, as indicated by *p*-values greater than 0.05. The positive correlation of the wheat yield is found with post-monsoon and winter rainfall; however, this is also statistically insignificant (Table 12). Similarly, potato yield is positively correlated with winter rainfall but it is also statistically insignificant at 95% confidence level, as indicated by the *p*-value greater than 0.05.

Table 12. Spearman's rank correlation test results for the yield of major crops with seasonal rainfall.

Crops	Seasonal Rainfall	Rho Coefficient	*p*-Value
Paddy	Monsoon	−0.018	0.847
Maize	Pre-monsoon	−0.365	0.474
	Monsoon	−0.419	0.053
Wheat	Post-monsoon	0.109	0.896
	Winter	0.136	0.988
Potato	Post-monsoon	−0.0396	0.837
	Winter	0.128	0.918
Sugarcane	Pre	−0.374	0.104
	Mon	−0.473	0.141
	Post	−0.108	0.126
Pulses	Post-monsoon	−0.199	0.423
	Winter	−0.255	0.289

3.3. Adaptation Practices

The majority of respondents we interacted with during the field study informed us that they are aware about climate change and have been experiencing its adverse impacts in the past decade. As a consequence, their overall farming system has been affected. Nearly 47% of the respondent households have stated that they are using improved varieties of crops and improved production technology (Table 13), and they have also shifted the crop types. This is because the rainfall pattern has changed and they faced water scarcity at the usual time of paddy cultivation. Field survey shows that the choice of crop type is primarily determined by the availability of artificial irrigation or the external support for this, along with access to the market and the market trends. For instance, cash crops like sugarcane have been chosen by farmers to replace maize and pulses in the northern part of the study area. Similarly, farmers near the access road are producing vegetables, replacing their usual crops. Field survey shows that a number of farmers of Madeshi community in the southern part of Terai district have started growing hybrid maize on irrigated land with application of improved production technology (Table 14), though maize was not something they usually cultivated. By this shifting of crop types, farmers are earning significant income.

Table 13. Field survey data on use of improved variety of cereals in the study area.

Improved Crop Variety	Households Using Improved Crop Variety	(%) Households	Area Planted with Improved Crop Variety (Hectare/Household)	Average Production (kg/Hectare)
Rice	103	60.59	0.54	5505
Maize	23	51.11	0.53	8817
Wheat	41	28.67	0.28	2464

Similarly, in the northern part of the district, farmers who used to grow maize during the summer and pulses in the winter have shifted to cultivation of sugarcane. Some of the farmers around the accessible road heads have been growing vegetables year-round. Some farmers with medium and larger farms have shifted to perennial fruit plantations in the uplands and low productive low land. Capabilities of the farmers have also been enhanced from different sources and new technologies, as shown in Table 14. It was observed that some of the farmers have switched to hybrid maize cultivation in irrigated low land in the winter season as a cash crop replacing wheat. The majority of the farmers in the study area were looking for more profitable crops and adopting improved practices of crop farming. Even small farmers were moving towards specialized production of one or two crops only without keeping any livestock, which is against their tradition. All these adaptation measures supported agricultural production and the overall yield of the major crops showed an increasing trend despite the decrease in rainfall, but the cost of production of these crops has gone up many fold in the past two decades (Table 15). The data in Table 15 were generated from various reports of the Market Research and Statistics Management Program, Agribusiness Promotion and Market Development Directorate of Ministry of Agriculture Development, Government of Nepal between 1993 and 2015 [29]. The field survey shows that such an increase in cost of production is primarily due to the arrangements for the adaptation measures for the unusual crop types in terms of improved crop production technologies like alternative irrigation wells, improved seeds, fertilizers, pesticides, etc. This is evident from the many-fold increase in the variable cost, as shown in Table 15.

Table 14. Field survey data on access to external inputs and services for crop production in the study area.

SN	Category of Essential Agricultural Production Inputs and Services	Frequency	(%)	Average Distance (Km)	Average Travel Time (Minute)
A.	Crop production				
1	Access to improved seeds	136	75.6	7.20	70.70
2	Access to chemical fertilizer	134	74.4	7.03	77.87
3	Access to pesticide	133	73.9	6.89	73.40
4	Access to technical/extension services	47	26.1	1.80	15.50
	Average			5.73	59.37
B.	Livestock and poultry				
1	Access to basic veterinary services	60	33.30	3.30	34.80
2	Access to technical know-how in livestock and poultry farming	18	10.00	2.10	27.30
3	Access to productive inputs (feeds, medicines, vaccines, etc.)	52	28.90	2.80	29.40
4	Access to improved breeds (animal and poultry)	10	5.60	1.50	15.10
5	Access to fodder/forage seeds/saplings	43	23.90	1.70	14.60
	Average			2.03	21.60
C	Access to marketing services				
1	Cereal grains	33	18.5	2.00	27.90
2	Fresh vegetables and fruits	29	16.1	2.60	17.60
3	Livestock and poultry	2	1.1	1.50	10.00
4	Milk and milk products	33	18.3	1.30	11.40
5	Honey	1	0.6	1.00	10.00
	Average			1.60	12.25

Table 15. Data on average production cost of major crops for the last 20 years, generated from [29].

Fiscal Year	Paddy			Maize			Wheat		
	Fixed Cost (Rs)	Variable Cost (Rs)	Total Cost (Rs)	Fixed Cost (Rs)	Variable Cost (Rs)	Total Cost (Rs)	Fixed Cost (Rs)	Variable Cost (Rs)	Total Cost (Rs)
1993/94	256.08	12,731.23	12,987.32	205.2	7949.22	8154.42	215.96	9357.47	9573.44
1994/95	211.17	10,471.84	10,683.01	178.77	8703.13	8881.9	178.77	8703.13	8881.9
1996/97	224.06	16,666.43	16,890.48	224.14	13,584.72	13,808.86	224.14	13,584.72	13,808.86
1997/98	224.56	17,196.17	17,420.73	231.64	13,297.56	13,529.2	231.64	13,297.56	13529.2
1998/99	172.58	18,443.15	18,615.72	309.53	12,560.8	12,870.33	309.53	12,560.8	12,870.33
1999/00	180.76	21,356.34	21,537.1	180.28	15,618.17	15,798.45	180.28	15,618.17	15,798.45
2000/01	182.5	24,357.69	24,540.19	174.79	16,412.06	16,586.85	174.79	16,412.06	16,586.85
2001/02	181.75	20,291.79	20,473.54	174.75	16,198.53	16,373.28	174.75	16,198.53	16,373.28
2002/03	181.47	25,491.93	25,673.4	172.81	22,297.23	22,470.04	172.81	22,297.23	22,470.04
2006/07	405.98	22,304.57	22,710.54	280.29	21,221.9	21,502.2	280.29	21,221.9	21,502.2
2008/09	355.82	26,197.47	26,553.29	273.72	22,666.84	22,940.56	273.72	22,666.84	22,940.56
2009/10	361.00	29,695.89	30,056.89	273.72	28,776.55	29,050.27	273.72	28,776.55	29,050.27
2010/11	250.60	36,689.23	36,939.83	273.72	26,928.2	27,201.92	273.72	26,928.2	27,201.92
2011/12	245.57	48,834.04	49,079.61	257.75	43,713.03	43,970.78	257.75	43,713.03	43,970.78
2012/13	237.17	59,917.27	60,154.44	235.86	51,598.69	51,834.54	235.86	51,598.69	51,834.54
2013/14	269.09	70,863.25	71,132.34	262.8	62,805.29	63,068.09	262.8	62,805.29	63,068.09

4. Discussion

The magnitude and consequences of climate change on agriculture are currently highly uncertain in Nepal because of the extreme complexities of downscaling global climate models and projecting climate variables for high elevations and in monsoonal geographies. Nevertheless, the evidence suggests that the observed changes in temperatures and soil moisture are negatively affecting agriculture in many parts of Nepal. The effects of a changing climate on agriculture are already leaving poor people with even fewer assets, which they need to protect themselves from the shocks and stresses of change [30]. The climate change indicators, autonomous adaptations, and their impact on agriculture production are discussed in the following sections.

4.1. Key Climate Change Indicators

The linear trends of increase in annual mean temperature, maximum temperature, and minimum temperature of the last 28 years in the study area is in accordance with the findings of other researchers in Nepal Himalaya [6,9,10]. The annual average, pre-monsoon, monsoon, and winter rainfall has also decreased in a linear fashion over the last 31 years, but the post-monsoon rainfall has increased over the same period. It should be understood that the trends of climatic variables are highly dependent on the periods of time examined and the presence or absence of extreme events during those periods.

The analysis showed that interannual variations in rainfall vary widely, the number of dry days during the monsoon and winter had increased, and more rainfall was concentrated in a shorter duration of monsoon in the study area. This implies that rainfall patterns were erratic, although there was little change in the total precipitation received in a year. The rainfall patterns clearly show that within every three years, average rainfalls during monsoon was more than average in one year and for two consecutive years the rainfall received in all seasons in the year was below average. The study result is in accordance with the results of [31], in which the authors have shown that a more erratic pattern (unusually high intensity; fewer rainy days) of rainfall has prevailed in the country in recent years.

The soil moisture in the Rautahat district was progressively decreasing at different years from 2000 to 2015. In general, only part of the northernmost portion of the district had high soil moisture, and even that was in the form of isolated patches. Such areas also progressively decreased from 2000 to 2015. This indicates that the surface soil of the whole district is becoming dryer and dryer. A similar trend of decreasing soil moisture content was found in all the working VDCs of the Rautahat district, implying that the area was influenced by climatic variability during the last 16 years. Therefore, adaptation to the traditional agriculture practices is imperative to cope with this trend. Although some research on soil moisture estimation using satellite images was done in a few places in the Lesser Himalayas of Nepal [10,31], it is lacking in the Terai area. This made it impossible to compare the results of the present study with others. Nevertheless, the study in Lesser Himalaya [10,32] indicated that the soil moisture progressively declined over the last couple of decades, as was found in this study.

4.2. Agricultural Production

Despite decreasing trends of precipitation and soil moisture content, there was a higher yield of major crop types in the study area, and the trend was increasing. Similarly, the yields of major crop types in the study area were negatively correlated with seasonal rainfall. Such an increased trend of yield of major crops and a negative correlation of crop yields with seasonal rainfall should have been contributed by a wider use of improved variety, chemical fertilizers, alternate irrigation to crops by deep boring, shifting to these crops, and other adaptation capabilities as well as the better crop management practices adopted by the majority of farmers, as shown in Table 14. This result is similar to the results of Poudel and Shaw [33], where they found that paddy, maize, and wheat yields were negatively correlated in Lamjung district of Nepal. It has to be noted that there can be some influence of data trends while performing correlation, which was not considered in this analysis.

It was the view of the majority of respondents that most of the rice- and maize-growing farmers were using hybrid seeds in irrigated fields and getting much higher production compared to the open-pollinated varieties used in the past. The trends of major crop yields found in the present study are similar to the findings for the whole country [34,35].

4.3. Adaptation Practices

The majority of respondent households we interacted with during field study were applying certain adaptation measures to cope with climate change. It is evident that most of the farmers have not only changed the varieties of crops they produce but also their cropping system in the past decade (Table 14), and therefore the yield of major crops has increased. Nearly 47% of the respondent households were using improved varieties of crops and improved production technology. They have also shifted the crop types to cope with these adverse conditions. For instance, a number of farmers have now started growing hybrid maize in irrigated land with the application of improved production technology, which was not their practice in the past. By this new practice, they are earning significant income from maize production. Similarly, in the northern part of the district, farmers who used to grow maize during the summer and pulses in the winter have shifted to cultivation of sugarcane. Some of the smallholders around the accessible road heads have been growing vegetables year-round. Some medium and larger farms in the study area have shifted to perennial fruit tree plantations in the uplands and low productive low land. Other enhanced adaptation capabilities, as shown in Table 14, should have a positive impact on the productivity of the land and the production of crops. Adaptation strategies surveyed in the study area were also observed in Lamjung district of Nepal [33], where the authors have stated that better crop management systems, better seeds, the use of fertilizers, and the introduction of new agro-technology contributed to the changes in crop yields, in addition to the climatic variables.

The majority of the farmers in the study area were looking for more profitable crops and had been adopting improved practices of crop farming. However, even small farmers were moving towards specialized production of one or two crops, and the majority of them were not keeping any livestock. Such a shift would make farming a more risky enterprise for the majority of small farmers as their dependency would be on limited crops, which are always at risk due to uncertainties in climatic variables.

5. Conclusions

This study showed that temperature and rainfall patterns changed in the central part of southern Terai of Nepal over the last 30 years. The study showed that the annual average rainfall decreased at a rate of 10.21 mm/year and the annual mean temperature increased at a rate of 0.02 °C/year over the last 30 years. The maximum and minimum temperatures increased at the rate of 0.01 °C/year and 0.019 °C/year, respectively, during the same period. However, these variations were found to be statistically insignificant. The pre-monsoon, monsoon, and winter rainfalls all decreased at a rate of 0.52 mm/year, 11.75 mm/year, and 0.59 mm/year, respectively; however, the post-monsoon rainfall increased at a rate of 1 mm/year between 1984 and 2014. People in the four VDCs of Rautahat district have also experienced climate change over the last 10–15 years and they felt that it had adversely affected their livelihood. Soil moisture has decreased considerably during the same period, forcing farmers in the study area to take adaptation measures to cope with changing conditions. The choices of adaptation measures have been determined by the availability or unavailability of improved production technology, irrigation systems, access to the market, and market trends. As a result, rainfall and crop yields were negatively correlated for most of the crop types, including paddy. The yield of maize, wheat, sugarcane, and potatoes all showed increasing trends, and these trends were all statistically significant. The yield of paddy and pulses also had an increasing trend, but it was statistically insignificant. However, the yield of oil seeds was found to have a decreasing trend. The increased yield of major crops was primarily due to adaptation measures, mainly the use of high-yield varieties of crops, enhanced irrigation systems, switching to hybrid seed, and increased access to fertilizers and pesticides. However, the cost of production of all these crops has been increasing due to the high costs of seeds, chemical fertilizers, pesticides, and irrigation water. Farmers had to face the penalty of increased production cost as a consequence of their shifts towards market-based commodities.

The rate of change in climatic variables and the production of major crops, quantified in this paper, can be a good reference for future research and short-term policy-making, especially for reducing climate change vulnerabilities in the Terai region of Nepal. A longer period of data on crop production covering a wider geographical area would have provided a better understanding of climate change impact and supported the formulation of future strategies for adaptation measures in agriculture. The updated and easy-to-access data-keeping systems of the concerned government line agencies can provide an opportunity to overcome such shortcomings in the future.

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Author Contributions: Subodh Dhakal and Subas Chandra Dhakal designed the research. Gopi Krishna Sedhain and Subas Chandra Dhakal conducted the field study and collected the secondary data. They also analyzed the agriculture production data. Subodh Dhakal worked on the soil moisture, analyzed the climate data, structured the manuscript, and wrote it.

Conflicts of Interest: The authors declare no conflict of interest. The decision to publish was made by the authors.

Appendix

Outline of household survey questionnaire

A. General information: location, name of household head, name of respondent, and caste/ethnic group
B. Demographic information: family size, sex ratio, education, and main occupation
C. Socioeconomic status: land ownership status, tenancy, and means of livelihood
D. Food production and security status: cropping pattern, sources and means of irrigation, crop types and area of cultivable land, annual crop production and sales by households, livestock/poultry holdings and sales within the last 12 months, food sufficiency status during the last 12 months, major staple food grains, food sufficiency period, reasons for insufficiency, and changes in cropping pattern during the last 10 years
E. Perception and knowhow about climate change
F. Perceived changes in rainfall patterns and associated effects during the last 10 years
G. Perceived effects of climate change in cropping patterns and productivity of major crops
H. Trend of incidences of insect pests of crops and diseases of livestock during the past 10 years
I. Adaptation measures used by community for reducing the effects of climate change
J. Access to basic productive inputs, services, and technologies to the community
K. Application of improved technology in farming
L. Cost of production of major crops
M. Access to financial services of household, including involvement in savings, credit, or microfinance
N. Access to credit of households
O. Social participation and institutional affiliation of the household
P. Access to vocational/skills development training in agriculture
Q. Perceived food scarcity situation in the community
R. Factors affecting the productivity of crops and livestock
S. Name of interviewer and date of survey

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