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Farmers' Perceptions of Climate Change and Agricultural Adaptation in Burkina Faso

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Abstract: The Sahel region is considered a hotspot for climate change hazards and vulnerability of weather reliant sectors, including agriculture. Farmers in Burkina Faso have a long history of adapting their farming activities to frequent changes in climate. Using 150 in-person surveys, this study assesses farmers' perceptions of climate change based on multiple climate variables, and reviews adaptation practices, including soil and water conservation strategies, in the Soudanian, Soudano-Sahelian, and Sahelian agroclimatic zones of Burkina Faso. In general, farmers are aware of changing climatic conditions, including increased temperatures, greater rainfall variability, heavier precipitation events, delayed onset, and premature offset of the rainy season. However, farmers perceive shifts in climate differently depending on their location and agroclimatic zone. As a result, different adaptation strategies are implemented by farmers according to the climatic, societal, and economic context. Survey results show that in the Sahel, climate adaptation strategies rely on traditional knowledge and experimental approaches; whereas in the Soudanian zone, where weather conditions are more favorable for agriculture, adaptation practices are market oriented. These regional differences are important for targeting advisory services, planning processes, and decision-making to support the effective provision of weather and climate information services to the last mile.

Keywords: Sahel; climatic trends; extreme weather events; climate services; climate resilience

1. Introduction

The Sahel region and Western Africa observed a warming of 0.5–0.8 °C over the period 1979 to 2010, with warmer day and nighttime temperatures. Warming in this region is more significant than the average over the rest of Africa [1–4]. In Burkina Faso, over the period of 1950 to 2013, a positive trend of the hottest day in the year and hot-day frequency across the country was observed [5]. Future temperature projections suggest a 1–2 °C, 2–4 °C, and 5–7 °C increase under representative concentration pathway (RCP) 2.5, 4.5 and 8.5, respectively, from June to August by the end of the century [6].

Since the late 1960s, the region has experienced increasing inter-annual rainfall variability [7]. Despite the decrease in annual rainfall totals, some studies suggest a greening of the Sahel in the last two decades, a likely result of consecutive years of rainfall recovery [8–11]. Other authors assert that dry-spells are now shorter but more frequent than the historical average, while some associate the shift in dry-spells (June–July) to the warming of the tropical-Atlantic Ocean [12,13]. Uncertainty remains for

precipitation projections, with a range of possible precipitation scenarios (varying between -30% and $+30\%$) depending on the model and scenario applied over West Africa [14,15].

Development challenges faced by Sub-Saharan countries include unsustainable population growth, endemic poverty, lack of governance, poor educational and healthcare systems, impoverished infrastructures, and increasing conflict, as well as degraded environments. All these factors reflect the relatively low adaptive capacity and high vulnerability of livelihoods to weather-related hazards [16–18] (Table 1.).

Table 1. Some of the observed agricultural adaptation strategies in Western Sahel.

Practice	Description	Reference
Livestock mobility	Promotes the optimal utilization of spatially heterogenous availability of forage and water resources	[19]
Climate resilient crops	Quinoa (<i>Chenopodium quinoa</i> Willd.) promotion in the Sahel	[20]
Vallerani systems	Water harvesting catchments using a tractor for sowing shrubs and trees	[21]
Planting trenches	Soil-stabilization technique through tree cover restoration	[22]
Contour ridges	Water micro-catchment technique using ridges spacing 1–2 m	[22]
Sand-dune stabilization	Combination of mechanical and biological measures (fences and grass)	[22]
Contour bunds	Water micro-catchment technique using stone bunds	[23]
Mulching	Reduce the evaporation of remaining moisture from the soil	[24]
Zai-pit system	Planting pits to rehabilitate barren land, improve infiltration and nutrient availability for plants	[24]
Vegetative strips	Vegetation establishment for soil erosion reduction	[25]
Agroforestry	Agricultural areas interspersed by self-generating and local tree species	[26]

The application of the abovementioned practices (Table 1) provide evidence of adaptation among local populations [27]. In Burkina Faso, several studies have examined the typology of farmers' adaptation, awareness of climate hazards, and past climatic trends [28–36].

While the aforementioned studies have outlined existing practices applied in the country, there is a lack of understanding of farmers' perceptions of climate and the available options for effective adaptation. Current literature does not provide a comprehensive assessment of farmers' perceptions of climate compared against climatic trends across the different agroclimatic zones and agrometeorological services as a way to build climate resilience. Therefore, there is a knowledge gap that hinders the effective adaptation of farmers to climate change. In the present study, farmers' awareness of climate change (for the past 10–20 years), adaptation measures, vulnerability, and provision of climate services are evaluated in order to inform a framework for climate change adaptation for farmers in Burkina Faso. Finally, the study analyzes meteorological data over a 45-year timeframe to examine observed climate trends compared to farmers' perceptions. This work builds upon previous studies by elucidating how farmers' perceptions mirror climatic trends and identifying gaps and needs for more effective adaptation at a farm level. Recommendations are provided to improve current agrometeorological decision-making by farmers and strengthen climate resilience amongst those most vulnerable to the future impacts of climate change.

2. Materials and Methods

2.1. Study Area and Farmer Surveys

Structured farmer surveys, conducted between February and April 2018, were randomly distributed in hard-copy to 150 smallholder farmers (cropping systems) located in 17 provinces along Burkina Faso's different agroclimatic zones defined by annual rainfall: Sahelian (400–600 mm year⁻¹; 38 surveys), Soudano-Sahelian (600–900 mm year⁻¹; 56 surveys) and Soudanian (more than 900 mm year⁻¹; 56 surveys) (Figure 1). Each survey was composed of 17 questions and were divided as follows: (a) farmers' perceptions on hydro-climatic events (1–8), (b) climate change impacts and vulnerability (9–12), (c) agricultural adaptation and climate services (13–17). To investigate whether farmers had observed changes in temperature, precipitation, and wind patterns, the time frame used in this study was 10 to 20 years. Semantic barriers were overcome by translating the survey to local languages (Mooré, Dyula, and Fula), otherwise the survey was carried out in French.

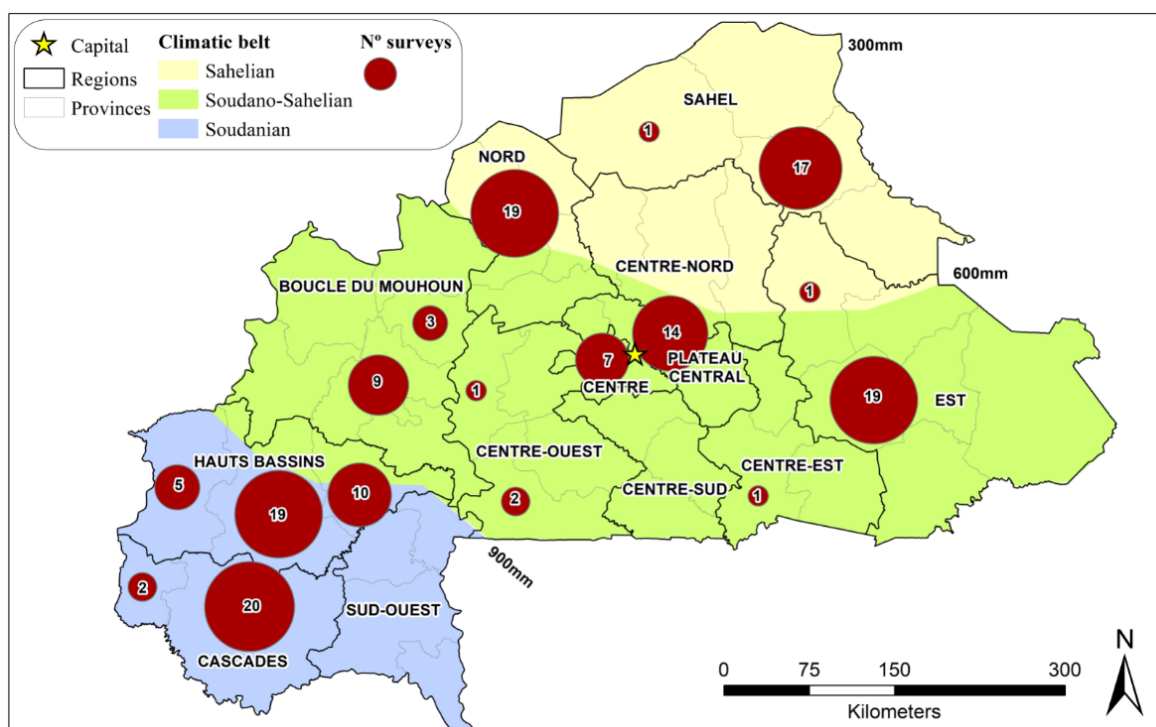


Figure 1. Spatial distribution of surveys along the different agroclimatic zones (Sahelian, Soudano-Sahelian, and Soudanian).

2.2. Socio-Economic Characteristics and Farm Typology

Women farmers in Burkina Faso have limited access to land and therefore the number of women surveyed was considerably lower (18%) than that of men (Table 2). Of the farmers surveyed, 42% knew how to read and write, while 62% were between 20 and 49 years old. The majority of the farmers (53%) had fields sizing between 1 and 5 ha, and 10% were recognized as having more than 20 ha. The crops grown in Burkina Faso vary according to the agroclimatic zone. The survey baseline responses showed that Soudanian farmers grow crops with higher water requirements and based their agricultural activities on a market-oriented economy (42% maize, 13% rice, and 9% cotton), while Soudano-Sahelian farmers had a more diversified income (28% maize, 16% millet, 13% black-eyed peas, 10% vegetables and cotton, 9% both for sesame and sorghum). Sahelian farmers based their farming systems on low water requirements and subsistence agriculture (34% millet, 29% sorghum, 11% both for vegetables and black-eyed peas).

Table 2. Socio-economic characteristics of farmers surveyed and farm typology (as % of respondents) across the different agroclimatic zones.

Agroclimatic Zone	Gender		Literacy Rate		Farmers Age (Years)				Farm Size (ha)				
	Male	Women	Yes	No	20–29	30–39	40–49	50+	<1	1–4	5–9	10–19	20+
Soudanian	86	14	61	39	10	30	28	32	14	38	14	20	14
Soudano-Sahelian	68	32	35	65	12	35	29	24	28	50	10	2	10
Sahelian	97	3	22	78	0	42	29	29	4	96	0	0	0
Total	82	18	42	58	10	34	28	28	18	53	10	9	10

Legend: the total number of surveys (156) were distributed as follows: Soudanian (56), Soudano-Sahelian (56), Sahelian (38).

2.3. Climate Data

Past daily precipitation (mm) and minimum/maximum temperature (hereafter, Tmax and Tmin in °C) data were retrieved from the National Oceanic and Atmospheric Administration (NOAA) [37] for the historical period 1973–2017 (45 years). Three synoptic automatic weather stations were selected for completeness over the time period (data coverage between 88%–95%), and were used to analyze changing climatic trends across the different agroclimatic zones: Sahel (Dori; 14°01' N 0°01' W; 280 m.a.s.l.), Soudano-Sahelian (Ouagadougou airport; 12°21' N 1°30' W; 310 m.a.s.l.), and Soudanian (Bobo Dioulasso airport; 11°09' 4°19' W; 450 m.a.s.l.). For the missing values, a rescaling of the neighbor series (pre-bias correction) was conducted using neighboring temporal data rather than neighboring spatial data (as the distance of closest weather stations and missing data was too large [38]). To reduce the error, the 45-year time series was divided in 10-year time periods (1973–1982, 1983–1992, 1993–2002, 2003–2012, 2013–2017) to later calculate the arithmetic mean for a specific time period. This technique minimized the under/overestimation of the observations.

Trends in climate variables were examined by means of linear regression as well as by trends at a decadal temporal scale. The trends of climate extremes, maximum temperature above 40 °C (hereafter T40max), was calculated using daily data for the 1973–2017 period. The coefficient of variation (cv), expressed as a percentage, was used to estimate the variation on interannual precipitation Equation (1). Heavy rainfall events were defined as days with precipitation higher than 20 mm day⁻¹. The shifts in onset and offset of the rainy season were evaluated on a 10-day basis; while the start and the end of the rainy season was determined once 5% and 95%, respectively, of the total annual precipitation was attained [39]. Changes in dry-spell frequency (7 or more consecutive days with no precipitation during the rainy season) were evaluated accordingly to the length of the rainy season in each agroclimatic zone: Soudanian (1 May–1 October), Soudano-Sahelian (20 May–20 September), and Dori (1 June–1 September).

$$CV = \frac{\sigma}{\mu} \quad (1)$$

where σ and μ corresponded to the standard deviation and precipitation mean for the period of interest.

Furthermore, farmers appraisals from surveys were compared with empirical ground-based information from weather stations to evaluate the consistency between these two datasets. The emerging findings from the surveys was examined as the ratio between the number of answers and total number of respondents per agroclimatic zone, as a percentage. In addition, the analysis of variance (ANOVA) as well as the Tukey HSD post-hoc tests were used to determine which specific groups (possible answers) were significantly different ($p < 0.05$) from each other. The ANOVA and Tukey HSD test were conducted using the statistical software Minitab 19 (version 2.0).

3. Results

3.1. Past Climatic Trends

The period 1973–2017 was the basis for the analysis of all climatic information (air temperature and precipitation) across the country’s three agroclimatic zones. Annual maximum and minimum air temperatures increased in all three stations, but the rate of increase was greater for Tmin than for Tmax (Figures 2 and 3). The increasing trends in Tmax were more significant for the Soudanian and Soudano-Sahelian zone ($p < 0.001$; 0.29 and 0.27 °C decade⁻¹, respectively) than for the Sahelian zone ($p > 0.05$; 0.04 °C decade⁻¹). From 1973 to 2017, Tmax increased by 1.26 °C in southern and central parts of the country and by 0.18 °C in northern parts. The increase in Tmax (Table 3) was reflected in the number of hot days per year with temperatures exceeding 40 °C (T40max). Even though the Sahel region did not experience an increase in T40max during this period, T40max was recorded on average 100 days year⁻¹. However, the greatest increase was observed in the capital, Ouagadougou (from 30 to 60 days year⁻¹), and in the second largest city, Bobo Dioulasso (from 1 to 6 days year⁻¹), when comparing the 1973–1982 with the 2013–2017 period. T40max increase was exacerbated by the coupled effect of urban expansion and changes in vegetation cover. In addition, Tmin increase was significant at all three stations ($p < 0.001$), particularly in the Sahel (0.41 °C decade⁻¹) and, to a lesser extent, in the Soudanian and Soudano-Sahelian zone (0.22 and 0.17 °C decade⁻¹, respectively).

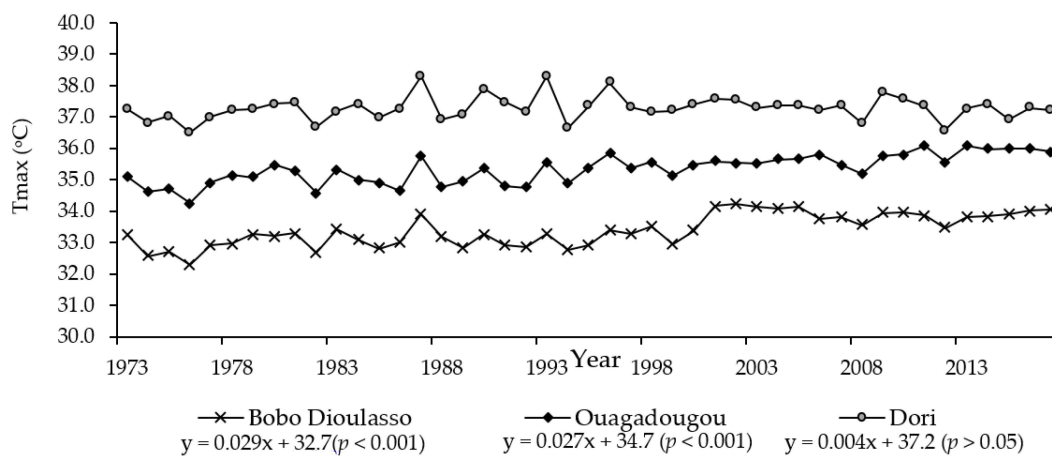


Figure 2. Mean annual maximum temperature (Tmax), lineal regression, and statistical significance along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2017.

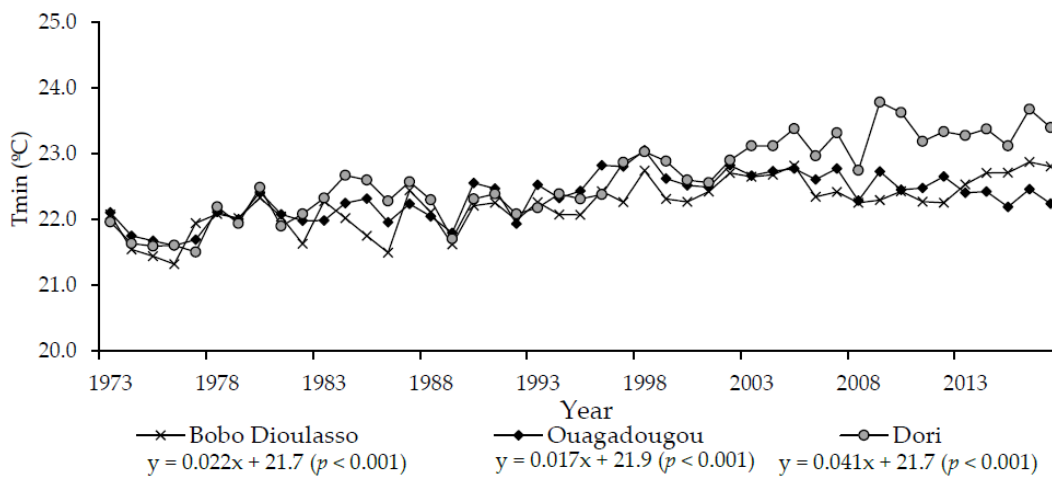


Figure 3. Mean annual minimum temperature (Tmin), lineal regression, and statistical significance along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2017.

Table 3. Changes in the number of days per year with temperatures above 40 °C along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2017.

Period	Soudanian		Soudano-Sahelian		Sahelian	
	Number	Difference (%)	Number	Difference (%)	Number	Difference (%)
1973–1982	1	-	30	-	99	-
1983–1992	2	+100.0	29	-3.3	98	-1.0
1993–2002	2	+100.0	38	+26.7	102	+3.0
2003–2012	6	+500.0	44	+46.7	94	-5.1
2013–2017	6	+500.0	60	+100.0	98	-1.0

All three sites showed decreasing trends in annual precipitation (Figure 4), which were significantly different in the Soudano-Sahelian and Sahelian zone ($p < 0.001$ and $p < 0.05$, respectively), but not in the Soudanian zone ($p > 0.05$). The decreasing trends in yearly precipitation ranged from 55.8 mm decade⁻¹ (Ouagadougou) to 3.4 mm decade⁻¹ (Bobo Dioulasso). However, decreasing precipitation trends were not consistent throughout the study period (1973–2017), with a precipitation recovery over most recent years (2013–2017) when compared to the previous study period (2003–2012). The sharpest precipitation decrease was noted in the 80s, 90s and early 00s in the Sahel and Soudano-Sahelian region, whereas precipitation remained constant in the Soudanian zone. In addition, the coefficient of variation (cv) showed a significant increase in interannual rainfall variability throughout the 1972–2017 period (Table 4). For instance, the cv in 1972–1983 was of 5.6, 9.2, and 12.0; while in 2003–2012, the cv was of 10.0, 18.6, 20.2 in Bobo Dioulasso, Ouagadougou, and Dori, respectively. These values suggest that rainfall variability was largest in northern parts of the country (Sahel zone) when compared to the southernmost parts (Soudanian zone). The dry-spell frequency (more than seven days without any precipitation during the rainy season) increased in all agroclimatic zones throughout the study period: Soudanian (from 2.9 to 4.5 dry spells year⁻¹), Soudano-Sahelian (from 2.4 to 5.2 dry spells year⁻¹), and Sahelian (from 2.8 to 4.0 dry spells year⁻¹) (Table 5). A similar pattern was observed for rainfall intensity (prec. >20mm day⁻¹) with an increase over time (e.g., from 5.4 to 7.0 days⁻¹ year⁻¹ when comparing 1973–1982 with 2013–2017 in the Sahelian zone) (Table 5).

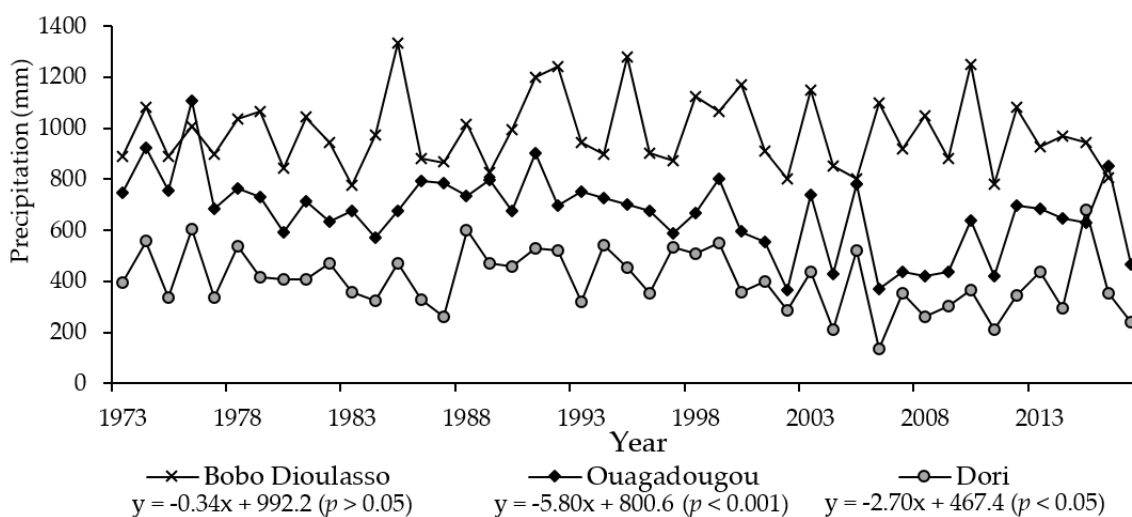


Figure 4. Total annual precipitation (mm), lineal regression, and statistical significance along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2017.

Table 4. Changes in annual precipitation (μ) and interannual rainfall variability (cv) along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2017.

Period	Soudanian		Soudano-Sahelian		Sahelian	
	μ (mm)	cv (%)	μ (mm)	cv (%)	μ (mm)	cv (%)
1973–1982	970	5.6	765	9.2	447	12.0
1983–1992	1010	10.4	731	6.9	432	15.0
1993–2002	996	9.3	642	10.4	430	14.4
2003–2012	986	10.0	537	18.6	314	20.2
2013–2017	910	4.1	656	9.7	401	22.2

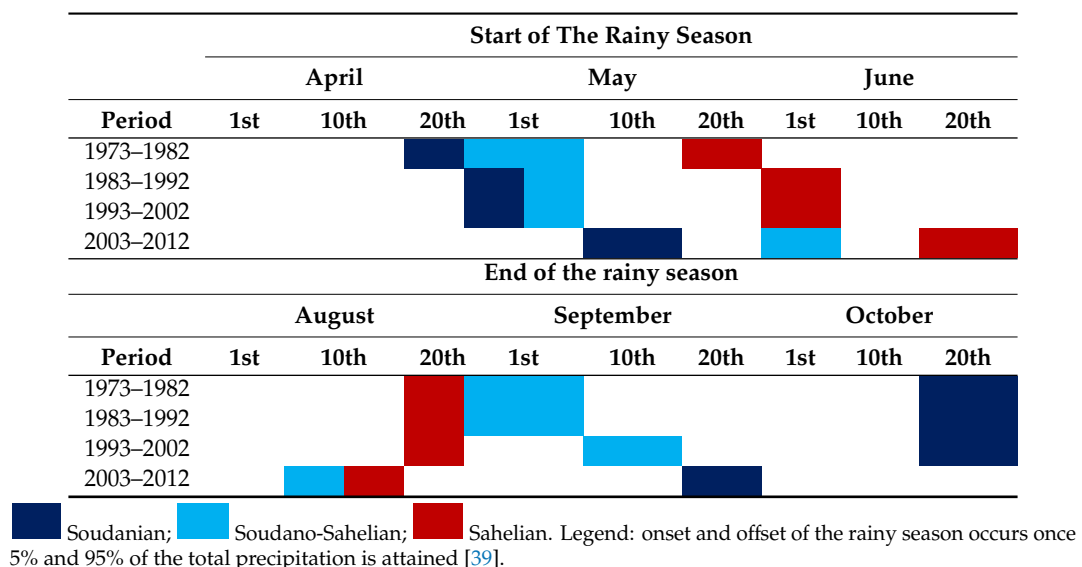
Legend: average precipitation for Bobo Dioulasso (983 mm), Ouagadougou (667 mm), and Dori (405 mm) for the period 1973–2017.

Table 5. Changes in dry-spell frequency (seven days or more without rain) and precipitation intensity (>20 mm day⁻¹) along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2017.

Period	Soudanian		Soudano-Sahelian		Sahelian	
	Dry Spells (year ⁻¹)	Prec20 (mm)	Dry Spells (year ⁻¹)	Prec20 (mm)	Dry Spells (year ⁻¹)	Prec20 (mm)
1973–1982	2.9	18.0	2.4	9.5	2.8	5.4
1983–1992	2.9	15.1	2.4	10.7	2.9	5.9
1993–2002	3.1	14.7	3.3	9.4	2.6	6.2
2003–2012	4.3	13.8	3.6	9.6	4.0	5.1
2013–2017	4.5	16.8	5.2	11.8	4.0	7.0

The long time series showed a shortening of the rainy season in all agroclimatic zones: from 180 to 150 days in the Soudanian, from 140 to 100 days in the Soudano-Sahelian, and from 90 to 70 days in the Sahelian zone for the period 1973–2017 (Table 6). A delayed start of the rainy season was observed in all agroclimatic zones, from 20 April to 10 May in the Soudanian zone, from 1 May to 1 June in the Soudano-Sahelian zone, and from 20 May to 20 June in the Sahelian zone when comparing the 1973–1982 and 2003–2012 periods. In addition, the Soudanian zone experienced a notable advancing of the offset of the rainy season from 20 October to 20 September, respectively, when comparing the 1973–2002 and 2003–2012 periods. A similar pattern was observed for the Soudano-Sahelian and Sahelian zone, with a rainy season offset advancing from 1 September to 10 August and from 20 August to 10 August, respectively, when comparing the 1973–2002 and 2003–2012 periods.

Table 6. Changes to average onset and offset of the rainy season along the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian) for the period 1973–2012.



3.2. Farmers' Awareness of Extreme Weather Events

On average, most of the farmers surveyed perceived a temperature increase in the last 10–20 years ($p < 0.05$, 92%), with a higher number of positive responses towards Sahel (95%) (Table 7). A similar pattern was reported for dry-spell duration, with almost 92% ($p < 0.05$) of the farmers across the country perceiving longer dry spells during the rainy season. In contrast, the perceptions on precipitation intensity differed between agroclimatic zones. While Soudanian farmers perceived a decrease in precipitation intensity (60%), Soudano-Sahelian and Sahelian farmers were aware of increasing precipitation intensity (60% on average) over the last 10–20 years. Even though most of the farmers perceived an increase in rainfall variability, there were some discrepancies among Sahelian and Soudano-Sahelian farmers (with almost half of the farmers perceiving both an increase and a decrease) when compared to those living in the Soudanian zone (71% perceived an increase). In addition, there were significant differences ($p < 0.05$) between farmers observing a delayed and premature onset and offset of the rainy season (68% and 85%, respectively) with those acknowledging the opposite. Finally, farmers perceived similar changes in harmattan winds and dust storms along the different agroclimatic regions. Almost two-thirds (65%) of the farmers perceived an increase in the previous ($p < 0.05$), while the rest asserted a decrease or no changes both in frequency and intensity.

Table 7. Farmers' awareness of changes on weather-related hazards in the different agroclimatic zones (Soudanian, Soudano-Sahelian, and Sahelian).

Agroclimatic Zone	Temp. Change	Dry Spells Duration	Precip. Intensity	Rainfall Variability	Start Rainy Season	End Rainy Season	Harmattan Winds	Dust Storms
Soudanian								
(+)	89.1	85.5	37.7	71.4	66.0	5.5	61.8	61.8
(−)	5.5	5.4	60.4	16.1	28.3	94.5	29.1	29.1
(=)	5.5	9.1	1.9	12.5	5.7	0.0	9.1	9.1
Soudano-Sahelian								
(+)	92.4	94.6	61.8	46.3	58.0	3.8	54.7	53.7
(−)	3.8	3.6	32.7	50.0	32.0	67.3	26.4	22.2
(=)	3.8	1.8	5.5	3.7	10.0	28.8	18.9	24.1
Sahelian								
(+)	94.6	94.3	58.3	51.4	78.4	2.6	75.7	78.4
(−)	0.0	0.0	33.3	45.7	16.2	92.1	2.7	0.0
(=)	5.4	5.7	8.3	2.9	5.4	5.3	21.6	21.6
Average								
(+)	92.1 a	91.5 a	52.6 a	56.4 a	67.5 a	84.6 a	64.1 a	64.6 a
(−)	3.1 b	3.0 b	42.2 a	37.3 a,b	25.5 b	11.4 b	19.4 b	18.3 b
(=)	4.8 b	5.5 b	5.2 b	6.3 b	7.0 b	4.0 b	16.5 b	17.1 b

Legend: means that did not share a letter (a, b) were significantly different ($p < 0.05$) using the Tukey HSD test. Legend: (+), (−) and (=) refers to an increase/decrease/no change in temperature, dry-spell duration, precipitation intensity, rainfall variability; as well as delayed/advanced/no change on the start/end of the rainy season, just like stronger/weaker/no change on harmattan winds and dust storms.

3.3. Adaptive Capacity and Climate Services

Almost all farmers affirmed adopting agroecological practices to absorb climate impacts and risks across the country (Figures 5 and 6). The role of indigenous and traditional knowledge on ecosystem-based adaptation was reflected in farmers' responses. The most frequently applied strategies across the country included the application of organic matter (91%), followed by minimum tillage (75%), crop rotation (62%), agroforestry, and the use of furrows (both with 58%). Such strategies had in common the conservation of soil carbon, reduction of losses from direct evaporation, and preservation of soil nutrients. However, the number of farmers embracing environment conservation strategies differed between regions. For example, Sahelian smallholder farmers widely used, when compared to the Soudanian zone, traditional farming systems to adapt to climate shocks and reduce agrochemical impacts over the environment. This was estimated based on the number of respondents in the Sahel applying organic matter (92%), zero or minimum tilling (89%), adopting agroforestry systems (66%), associating crops (63%), or using zaï pit systems (29%).

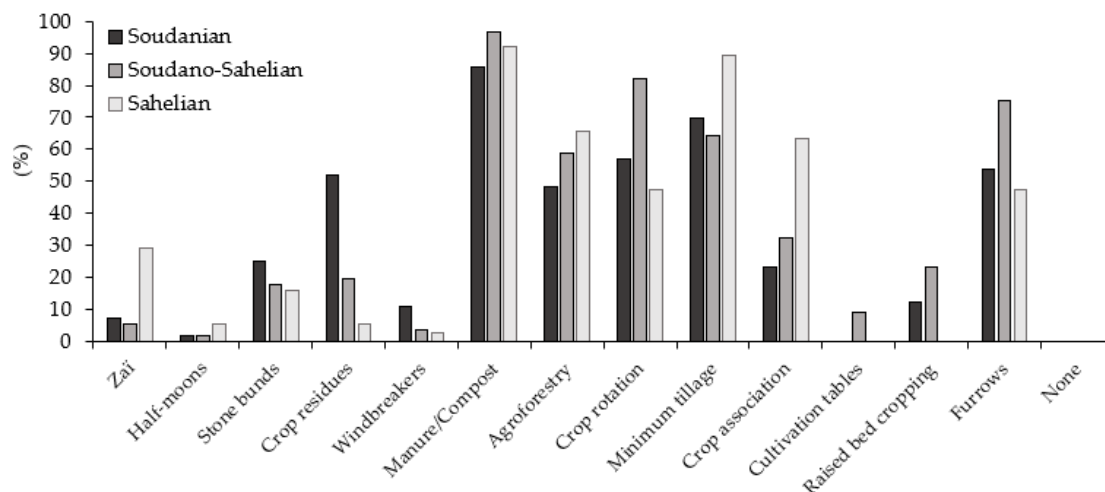


Figure 5. Soil and land management strategies in the different agroclimatic zones (Soudanian, Soudano-Sahelian, Sahelian).

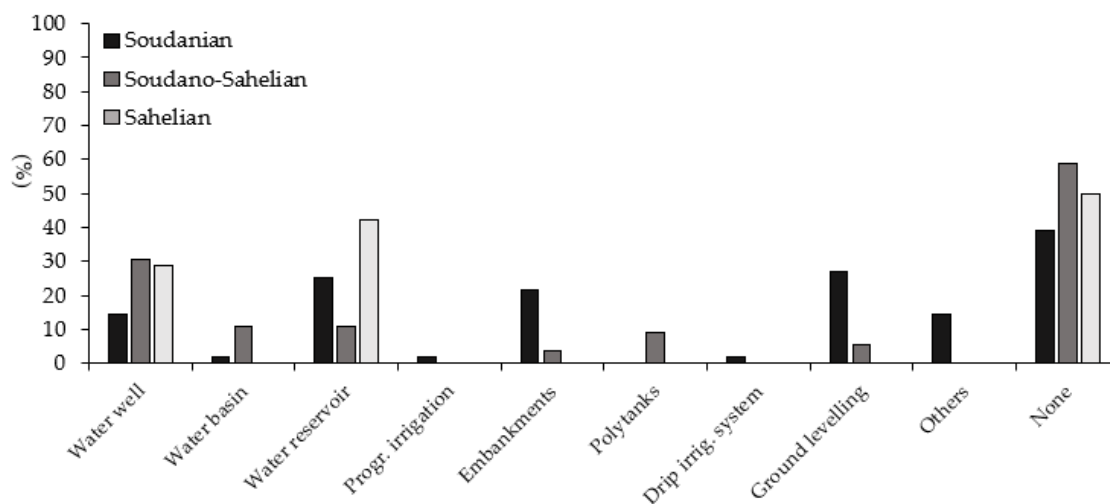


Figure 6. Water management techniques in the different agroclimatic zones (Soudanian, Soudano-Sahelian, Sahelian).

Furthermore, the use of water conservation strategies, including infrastructures for storing water, was relatively low due to the low purchasing power of farmers across the country, particularly of smallholder farmers in the Sahel (Figure 6). In fact, 49% of the farmers across the country acknowledged having no means to procure water conservation and/or irrigation infrastructures in their fields. The most prevalent strategy noted was shared water resources from reservoirs and water wells (26% and 24%, respectively). The use of technological solutions, such as ground levelling and embankments, were generally embraced by large-scale rice and maize farmers located in the Soudanian zone (27% and 21%, respectively). In addition, the use and type of plant growth regulators (e.g., herbicides) and growth promoters (e.g., fertilizers) were adopted differently across the country (Figure 7). Soudanian farmers widely used agrochemical herbicides (93%, e.g., Glyphader), synthetic fertilizers (82%, e.g., urea-CO(NH₂), N, P, K, and phosphate-PO₄³⁻), as well as pesticides and insecticides (41% and 73%, respectively, e.g., Cypercal and Caiman Rouge); whereas Soudanian and Sahelian farmers, particularly the latter, used the previous products to a lesser extent (58% insecticides, 55% synthetic fertilizers, 39% herbicides, and 9% pesticides, on average). In addition, animal draught tillage was mainly afforded by large-scale farmers in the Soudanian and Soudano-Sahelian zones (74% on average), but fewer in the Sahel (53%). A similar pattern was observed for the use of performant

seeds (e.g., drought tolerant maize genotypes), with 45% of the farmers having access to seeds in the Soudanian and Soudano-Sahelian zone, but very few in the Sahel (8%).

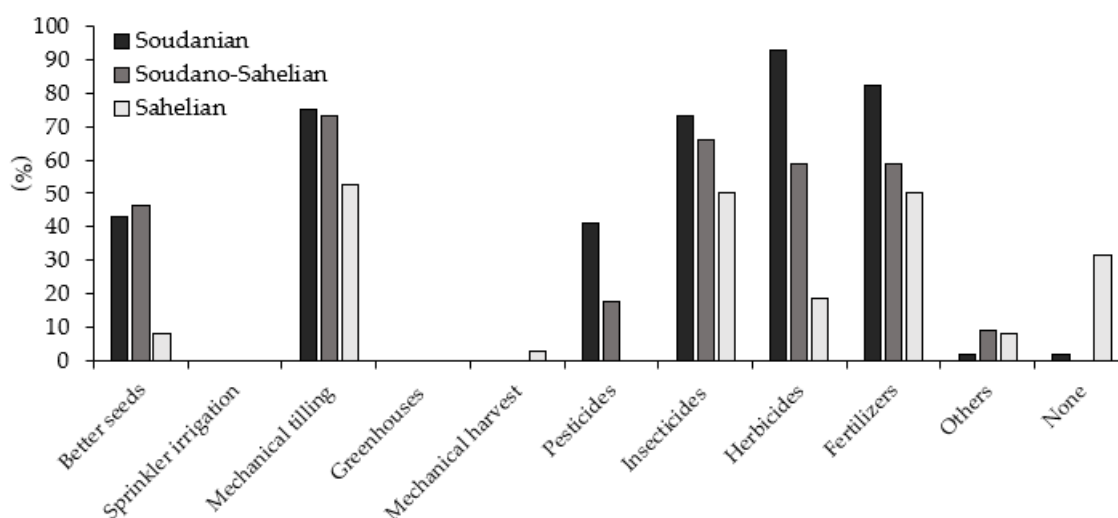


Figure 7. Use of plant growth regulators and agriculture mechanization methods in the different agroclimatic zones (Soudanian, Soudano-Sahelian, Sahelian).

The number of available climate services in Burkina Faso was low, probably because of the lack of generation, provision, and contextualization of information derived from climate databases, research, and modelling. The most effective communication means for delivering climate and weather information to farmers were the radio (39%), followed by television (TV) (27%), word of mouth (26%), and mobile phone (SMS) (3%). While the radio and word of mouth were the main communication means for delivering climate information in the Sahel (43% and 29%, respectively), in the Soudano-Sahelian and Soudanian, farmers accessed climate information through the radio and TV (38% and 29% on average, respectively). Finally, enhanced climate services (e.g., weather alerts on mobile phone-SMS) mainstreamed by the National Meteorological Agency (ANAM) were slowly being introduced but remain far from being distributed at a national scale.

3.4. Climate Change Impacts and Vulnerability

As reported in Sections 3.1–3.3, farmers' perceptions on natural hazards had a significant relationship to observed climate change. The evaluation of farmers' perceptions and adoption of soil and water conservation strategies was necessary to better understand the farmers' capability to cope with, respond to, and recover from climate change negative impacts. The combination of low adaptive capacity and lack of institutional support to cope with the adverse impacts of climate change leaves climate sensitive sectors vulnerable to the losses from extreme weather events. Overall, a third (34%) of the farmers surveyed had migrated in the last 10 to 20 years, with numbers as high as 50% in the Soudano-Sahelian zone. Among those having migrated, a small number of farmers (22%) had to flee their homes due to climate-related stressors (drought, flooding, heat-stress, land degradation etc.). However, a large number of respondents (56%) did not give a reason behind migration and were displaced because of the lack of job opportunities, which could be indirectly driven by climate change and land degradation. Finally, 10% of the farmers had to flee their homes due to marriage or conflict in the nearby Ivory Coast.

Greater concern or perceived vulnerability was acknowledged among farmers living in the Sahelian zone, with a decreasing number towards the southernmost parts of the country. On a scale from 0 to 4 (none, low, moderate, high, and very high), almost all farmers (>90%) in all agroclimatic zones perceived their agricultural activities at a moderate to very high vulnerability to climate change and weather-related hazards. For example, Sahelian farmers considered themselves at a very

high vulnerability to climate change impacts (92%), while a decreasing number affirmed this in the Soudano-Sahelian and Soudanian agroclimatic zones (73% and 33%, respectively).

4. Discussion

Survey results on selected farmers' perceptions on past climatic trends reflect climate observations from ground-based weather data from Dori, Ouagadougou, and Bobo Dioulasso (Table 8). Temperature increase was accepted by the majority (92%) of farmers in all agroclimatic zones, and climate records showed a consistent increase over time both for Tmax (0.04–0.29 °C decade⁻¹) and Tmin (0.17–0.41 °C decade⁻¹) over the period 1973–2017. The magnitude temperature of increase differed across the country, with the largest changes in the Soudanian and Soudano-Sahelian zones where temperature increase was slightly above values reported in the literature: 0.5–0.8 °C for the period 1979–2010 for the Sahel region and Western Africa [1–3,5]. Heatwave conditions were reflected in all agroclimatic zones, with a particular increase over the Soudanian and Soudano-Sahelian zone (T40max of six and 60 days year⁻¹ between 2013 and 2017, respectively), with persistent extreme warm conditions over the Sahel (T40max around 100 days year⁻¹). The current T40max (2013–2017) matched the National Centers for Environmental Prediction (NCEP) reanalysis trends for Western Sahel (1989–2009), observing the largest increase in heatwave duration (from 80 to 120 days year⁻¹ with Tmax >41 °C) at latitudes ranging between 12–18° N [40]. Although heat-stress conditions were not examined independently, farmer surveys showed a consensus on increasing temperatures across the country.

Table 8. Summary of similarities (S) and differences (D) between farmers' perceptions and climate observations along the different agroclimatic zones.

Climatic Indicator	Soudanian	Soudano-Sahelian	Sahel
Temperature increase	S	S	S
Dry spell duration	S	S	S
Precipitation intensity	S	S	S
Rainfall variability	S	D	S
Start rainy season	S	S	S
End rainy season	S	S	S
Harmattan winds	-	-	-
Dust storms	-	-	-

Regarding long-term changes in precipitation patterns, increasing inter-annual rainfall variability was perceived by farmers in the Soudanian and Sahelian zone, while statistical indicators (coefficient of variation) corroborated the previous, with a doubling of cv in Bobo Dioulasso and Dori when comparing the 1973–1982 and 2003–2012 periods. These values were in line with studies providing longer datasets (1950–2013), showing a precipitation reduction (25%) and higher variability in southernmost parts of the country [5]. In addition, the 20th century reanalysis exhibited a clear multidecadal rainfall variability within the Sahel region [41]; while increasing interannual rainfall variability was reported since the 1960s, due to changes in rainfall patterns and decreases in total annual rainfall [7]. Our study showed a strong decline in annual rainfall between 1973–1982 and 2003–2012 periods in central and northernmost parts of the country, but with a rainfall recovery since 2006. Similar studies conclude that a rainfall recovery in northern parts of the country (Dori and Ouahigouya) has occurred over the past two decades [5]. Therefore, the recent rainfall recovery could be the reason behind discrepancies among farmers across the different agroclimatic zones in terms of rainfall variability and precipitation intensity.

In regard to the characteristics of the rainy season, the present findings from surveys and climatic records were in line with studies reporting a shortening of the rainy season in West Africa and its adverse implications for rainfed agriculture [42–45]. For instance, Diaconescu et al. [45] have observed an onset retreat over the 12–20 °N latitude and 15° W–15° E longitude bands. Some authors suggest that rainfall anomalies during the rainy season were negative (delayed onset) and positive (delayed offset),

indicating a shift and or displacement of the rainy season [43]. However, the previous findings were discrepant with our study, where most of the farmers (85%) across the country acknowledged an earlier offset of the rainy season. Trends in climate data presented in this study corroborates farmers' appraisals, displaying a shortening of the rainy season by at least one month in all parts of the country. Regarding heavy precipitation events, approximately two thirds of the farmers in central and northern parts of Burkina Faso reported an intensification of rainfall events. The previous was verified by long-term climatic observations and was reflected during the rainy season of 2009, with downpours exceeding 250 mm in 24 h [46]. In this line, Bichet & Diehiou [13] acknowledged that precipitation had intensified over the 1981–2014 period, with rainfall events exceeding 240 mm day⁻¹ within the region.

Furthermore, the lack of generation of weather information and scarce means for providing agrometeorological services in Burkina Faso further diminishes the adaptive capacity of farmers to climate change. In order to effectively implement targeted adaptation measures, tailored agrometeorological services that support the whole set of farmers' tactical and strategic decisions becomes fundamental. Providing farmers with advice on seasonal forecasts (e.g., date for land preparation to reduce weeding), crop calendars (e.g., crop variety choice and crop cycle fitted to seasonal forecasts), rainfall monitoring using rain gauges and relation to seasonal forecasts (to avoid sowing failure and re-sowing) can bolster farmers' ability to prepare for and respond to future climate change [47]. The results of the present study provide insight into observed and perceived impacts of climate change, both important for informing climate services and adaptation measures at all levels. Major findings that should be considered in the future development of climate services and adaptation frameworks in Burkina Faso include the identified drivers of cropping systems and adaptation measures, which are primarily market based for Soudanian farmers while Sahelian farmers based their farming systems on low water requirements and subsistence agriculture. The provision of climate services in the country can incorporate these insights into further targeting services most relevant to each region. In addition, adaptation measures should be tailored to the observed and perceived climate context as well as available means of farmers to access necessary resources to implement adaptation measures. Overall, the information presented in our study provides a stronger baseline from which policymakers can inform subnational adaptation planning and providers of climate services can further tailor their products in the future.

In addition, survey results from this study highlight that radio and TV were the main means through which farmers currently receive weather information. As a result, scaling-up of agrometeorological services through the radio and TV will likely be the most effective method for building climate resilience. However, given the increasing access to phones and sustainable improvement in the network throughout the country, other digital services (SMS and phone applications) for mainstreaming agrometeorological information to farmers should be further explored. In fact, the use of these Information and Communication Technologies (ICTs) has been shown to close the gaps between climate information producers and end users, in addition to being effective for building climate resilience among African farmers [48–50].

Future work should consider existing knowledge of communication networks and identified needs of farmers in order to propose measures for strengthening information flows to farm communities. The provision of services and advisories to farmers and end users is multifaceted and requires constant feedback. The present study highlights the need to develop tailored climate services by agroclimatic region and farming systems, as well as to consider the means by which farmers receive information.

5. Conclusions

As a result of increasing rainfall variability, shifts in rainy season onset/offset, increased dry-spell duration, intensified precipitation events, and increased heatwave duration, farmers across Burkina Faso have traditionally adjusted their agricultural activities to absorb climatic shocks. For that reason, the most widespread practices are related to soil and water conservation practices that can reduce soil erosion besides enhancing water infiltration rates. However, given the rate of change and

intensification of natural hazards, these practices seem to be insufficient in the long term. For that reason, decision makers have to develop a roadmap for improving agrometeorological services in Burkina Faso. This includes the identification of challenges, goals, and benefits of providing end users with agrometeorological information for tactical farming decision-making. The national framework on climate services needs to consider the provision of tailored services to end-user needs. Hence, these agrometeorological services have to be tailored to each agroclimatic region and type of agricultural activity (crop or livestock). The provision of climate information needs to be mainstreamed by the Meteorological Agency (ANAM) and canalized, together with extension services, through existing and densely coverage communication means (radio, TV, and mobile phone). Climate services have to include feedback mechanisms where end users can contribute to its strengthening. The engagement of end users along the climate services value chain and, to some extent, on the decision-making process will assure its viability, besides scaling-up the number of potential beneficiaries. The present study provides a steppingstone for building a climate services roadmap in Burkina Faso, with a focus on the perceptions and needs of end-users. The results of the present study can inform future stages of the development of effective climate services and farm advisories in Burkina Faso.

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