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Utility and Triggers in Uptake of Agricultural Weather and Climate Information Services in Senegal, West Africa

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Abstract: Weather and climate information services (WCIS) are gaining recognition among scientists and governments as an essential adaptation tool for agriculture, especially in the drylands of Africa. In Senegal, the widespread production and dissemination of WCIS was initiated in 2015 to cover the agricultural, pastoral and fishing sectors. This paper analyzes the types of decisions made by WCIS users, their preferences and level of satisfaction, and explores the triggers of agricultural WCIS adoption. We collected data during the onset and cessation of the rainy seasons to understand the utility and reliability of WCIS by farmers across all stages of the growing season. Data were analyzed using descriptive statistics. A binary logistic regression was tested to understand the socio-economic triggers in uptake of WCIS. Results showed that rainfall forecast is the most preferred WCIS (49% of the respondents) followed by extreme wind forecast. At the beginning of the rainy season, nearly 80% of the respondents have chosen the sowing date and about 60% have chosen crop varieties based on disseminated WCIS. In the middle of the growing season, about 70% of the respondents used WCIS to decide on fertilizer application dates. Results also showed that age and level of education, being trained on WCIS use, membership to farmers' organizations, owning a radio have a significant effect on WCIS-based decision-making. These factors are essential for triggering the uptake of WCIS, and therefore are required to improve the implementation of existing weather climate services in Africa.

Keywords: weather and climate information services; climate risk management; adaptation; decision-making; West Africa; Senegal

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1. Introduction

Rain-fed agriculture is, in general, highly dependent on weather and climate variations. Studies report that globally, 33% of crop yield variation is linked to weather and climate variabilities [1] and in areas prone to important food production, about 60% of yield variation is due to climate variation [1–3]. In sub-Saharan Africa in particular, agriculture is highly exposed to weather and climate risks because agricultural land in this part of the world is disconnected from modern irrigation systems [4–6]. Meanwhile, agriculture in Africa plays a critical role in most African economies and supports the livelihoods of a large number of people [5,7,8].

Weather and climate information services (WCIS) are gaining recognition among scientists and governments as an essential adaptation tool for agriculture [9,10]. WCIS is referred to as the generation, translation, transfer and use of scientific information for decision-making [6]. It provides fundamental knowledge of the local weather and climate, informs the decisions of farmers and institutions and supports resilience-building interventions. As such, agricultural WCIS are expected to improve crop productivity in Africa by supporting the management of risks associated with climate variability and change, thus contributing to meeting the sustainable development goals [9]. Prior to the onset of the cropping season, farmers require seasonal weather forecasts for their farms and regions and need to know the likelihood that the forecasted weather will affect their activities. Within the growing season, weekly, daily and instant weather information are crucial for timely guiding farmers' management practices within their farm's operations. Toward the cessation of the growing season, weather information may be used to plan harvest operation and storage, thus avoiding post-harvest losses.

The delivery and use of WCIS for agriculture in Africa started very recently, as evidenced by studies such as Cane et al. [11], who reported that crop production in southern Africa was strongly correlated with the Pacific Sea Surface Temperature (SST). Based on these findings, several initiatives were started in East, South and West Africa through Regional Climate Outlook Forums (RCOF) to provide seasonal forecasting based on SST [6,12,13]. Recently, in many African countries, the National Meteorological Services (NMS), as well as private enterprises are providing weather and climate information at the national scale, although these have remained so far at the pilot stage [10]. Studies on access to WCIS in Africa indicate that the system is still limited and region-specific [6]. Farmers in Eastern African countries are better off in terms of access to WCIS [14,15] followed by Southern Africa [16,17]. In Central and Western Africa, however, only a few people have access to WCIS [18–21]. Studies have also looked at the quality of the information disseminated as well as the extent to which potential users are able to access and use the services [22–24]. These studies have concluded that the evaluation process is challenging due to: (i) the nonrival and non-exclusionary nature of WCIS that makes it difficult to find the counter-factual; (ii) the stochastic nature of the climate over time that makes the mechanism of the impact vary from year to year; and (iii) the change in management decisions that are influenced by other agricultural development interventions and by farmers' varying goals, skills and constraints [6]. However, studies that explore the feedback from the various WCIS end-users in terms of preferences (WCIS and dissemination platforms), types of decisions made following the reception of WCIS, the usability/suitability of the information they receive and the level of uptake in WCIS in relation to some socio-economic variables, are lacking.

The economy of Senegal heavily depends on agriculture, a sector that represents approximately 15.7% of the gross domestic product (GDP) and employs 70% of the population [25]. The increasing impact of climate variability and change is drastically affecting the productivity of this sector. Similar to the other African countries, climate change in Senegal is evident through shortened growing periods, more unreliable rainfall distribution in time and space, an increased frequency of dry spells, floods, coastal erosion, rising sea surface temperature, etc. [20,26]. These changes have contributed to decreased agricultural and livestock productivity, northbound fish migration and an increasing risk event for fisher folks [27,28]. The overall consequences of these events have translated into a countrywide emergence of food insecurity [20,29].

Given these challenges for agricultural development in the country, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) has collaborated with the Senegalese Meteorological service since 2015 to pilot approaches for the production and use of WCIS. In this paper, we consider the questions of: (1) what feedback from WCIS users in Senegal could be used to inform widespread WCIS delivery in Africa to contribute to agricultural development and, (2) what socio-economic variables could be stimulated to improve the uptake of WCIS in the country. Lessons learnt from this Senegal case study could be used to improve the strategy for large-scale uptake of existing services and use of climate information.

2. Materials and Methods

2.1. Study Area

The study was conducted in Senegal, West Africa, where the adoption of WCIS is growing [20]. The country is divided into 15 administrative regions, of which 11 have been considered for this present study based on the criteria: the importance of agriculture, the vulnerability to climate change and the use and widespread adoption of WCIS [20,30] (Figure 1). Agriculture and livestock production constitute the mainstay of the country and employ 70% of the population [25]. Agricultural production is adversely impacted by a combination of poor soil and weather conditions and a lack of infrastructure and access to quality seeds and fertilizer, that have left the agricultural sector underdeveloped and unable to meet the food requirements of the nation's 15 million people [26]. As a result, the country relies heavily on food imports, especially rice, which accounts for 65% of the national consumption [31]. The sector, however, has the potential to grow and feed the population if the required agricultural input facilities such as fertilizers, improved crop varieties, credit, equipment, climate information services and relevant agro-meteorological advisories are met [28,30]. Rainfall is the key factor that determines agricultural production as less than 5% of cultivated land is under irrigation [26]. Senegal's climate is divided into three main zones according to the Köppen–Geiger climate classification methodology [32]: Hot Desert climate (BWh) in the northern zone of the country; Hot semi-arid climate (BSh) in the central part of the country, and Savanna; Dry winter (Aw) in the southern zone of the country. In general, the growing season in Senegal occurs from May to October (Figure 2) but in the northern zone, the duration of the rainy season is shorter (from July to September). The agricultural economy is characterized by the dominance of smallholder farmers cultivating millet, sorghum, groundnut, maize and rice for subsistence purposes. The use of WCIS to cope with climate variability and change was piloted in 2015 in a remote area (Kaffrine) of the country [33]. Following the success of this pilot phase, a widespread initiative took place starting in 2016, covering the agricultural, pastoral and fishing sectors. With the rapid spread of information and communication technologies (ICTs), notably mobile phones (SMS, voice calls, Unstructured Supplementary Service Data (USSD), Interactive Voice Response (IVR), social media (WhatsApp and Facebook), community radios and internet connectivity, the delivery breakthroughs of WCIS in various sectors and regions have been facilitated in the country.

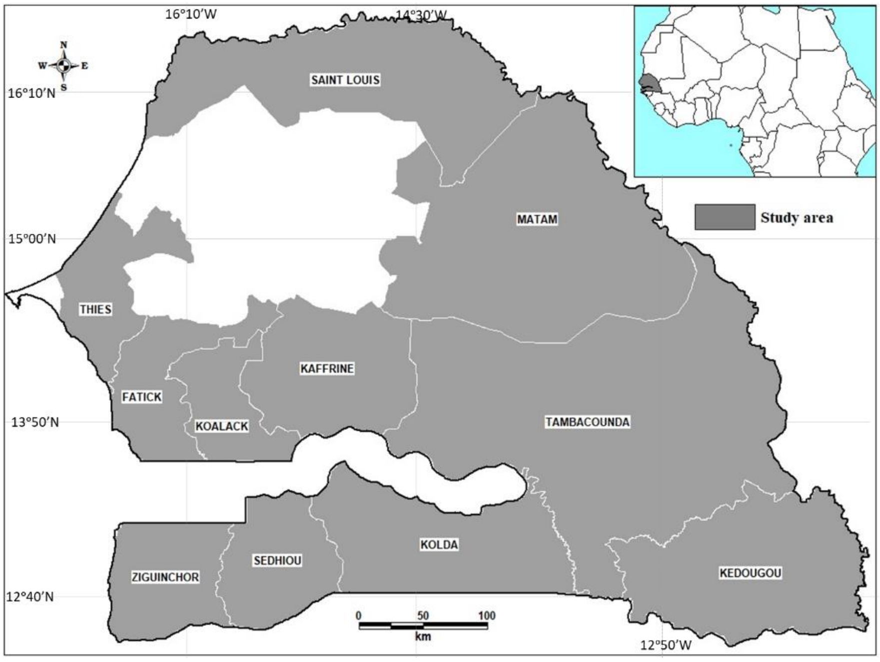

Figure 1. Location of the study area.

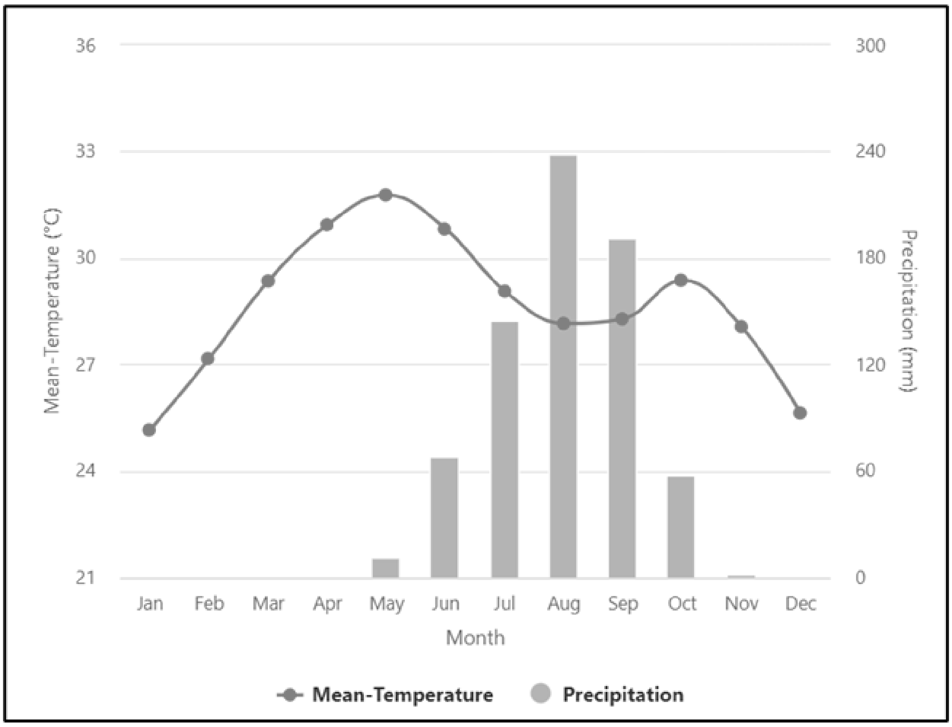

Figure 2. Monthly climatology of mean-temperature and precipitation in Senegal from 1991 to 2020.

2.2. Data Collection

Data were collected between 2018 and 2019 in three phases using three different structured and stratified questionnaires. The first phase took place in July 2018, during the onset of the growing season, and the second phase covered September and October 2018, during the cessation of the rainy season. The purpose of using two data collection periods is to cover all decisions made and the various appreciations of the utility and reliability of WCIS by farmers (crop producers) during all stages of the growing season, during which relevant agricultural WCIS are disseminated. In total, 391 farmers were randomly selected out of 945 recorded in the SMS and voice messaging platform database. The sample frame is made of farmers who directly receive WCIS. Stratified sampling is used with proportional allocation with region considered a stratification variable. Each of the 11 selected regions for the study is considered as a stratum, and from each of these strata, a given number of producers was sampled, representing 41% of the total number in the region with 95% confidence interval. The samples are representative of the study regions. During the two periods, we interviewed the same farmers. During the onset of the rainy season, the main questions that were asked were related to the relevance, preference, types and accuracy of the WCIS that the respondents received and the decisions they have made to guide their activities. At the cessation of the rainy season, the questions were also related to the relevance, preference, types and accuracy of the WCIS that respondents received and the decisions made to guide their activities during the growing season and at the end of the rainy season. In addition to the WCIS that the farmers received through mobile platforms, they were also accessing WCIS through community radios. WCIS disseminated during the onset of the growing season covered seasonal weather forecasts, rain and extreme wind events, wet and dry spells. From the middle to the end of the rainy season, disseminated WCIS covered dry and wet spells, flood event forecasts, rain and wind events and off-season rainfall.

To understand the factors influencing the adoption of WCIS, we carried out an additional survey in 2019 with 1500 randomly selected farmers who were exposed to WCIS. Five out of the 11 regions were considered in this third phase survey: Ziguinchor, Sedhiou, Kolda, Kaffrine and Kaolack. These regions were selected because there was a solid

WCIS users database created and managed by the consolidation networks (producers' organizations). The 1500 respondents were randomly selected using a stratified two-stage sampling method where the producer organization represents the primary unit and farmers represent the secondary unit. The sex and area of residence were considered as interest variables for the sampling. A sampling frame of 12,484 member farmers of the farmers' organizations was used. These 12,484 producers are grouped into 50 producers' organizations, including 9562 beneficiaries and 2922 non-beneficiaries. The beneficiaries are those who receive weather and climate services from the National Meteorological Service and through community Mobile Network Operators (MNO), radios and social networks. Non-beneficiaries are those who do not receive WCIS at all. Prior to the surveys, the objectives of the study were presented to each respondent (head of household, mainly). Respondents were informed that all answers will stay private and only the study team will have access to personal information such as their name. All respondents accepted to be part of the study.

2.3. Data Analysis

A descriptive statistic (relative frequency of the variables) was used to understand the type and magnitude of WCIS disseminated during each of the stages of the growing season, the preference in terms of channels, the reliability of the WCIS, the decisions made on the basis of the WCIS disseminated, the level of satisfaction regarding the decisions they have made and the actions that require specific WCIS products.

To understand the triggers in the uptake of WCIS, we have related the use (or nonuse) of WCIS with socio-economic variables such as age, region, education, networking, membership to farmers' organizations, ownership of radio and agricultural equipment. A binary logistic regression was used to weigh the influence of the socio-cultural variables on the likelihood for a farmer to make a decision after he/she has received a WCIS. The goodness of fit of the statistical model was evaluated as follows:

Let y_i be a binary random variable which takes the value 1 if the individual i makes a decision after receiving weather information and 0 otherwise. Let y^* be an unobservable latent variable directly related to the observable binary variable y and linearly related to the explanatory variables:

$$y_i^* = x_i\beta + \varepsilon_i$$

Let δ be a constant such that:

$$y_i = \begin{cases} 1 & si\ y_i^* > \delta \\ 0 & si\ y_i^* < \delta \end{cases}$$

Assuming that $\delta = 0$. We have:

$$y_i = \begin{cases} 1 & si\ y_i^* > 0 \\ 0 & si\ y_i^* < 0 \end{cases} \quad P(y = 1|x) = P(y^* > 0|x)P(y = 1|x) = F(x\beta)$$

where F is the distribution function of ε which is supposed to follow a logistic law of mean 0 and variance 1.

So:

$$P(y = 1|x) = \frac{1}{1 + e^{-x\beta}}$$

This last relation defines the logit model. The estimation method used is the maximum likelihood. The estimated β coefficients are consistent, asymptotically normal and asymptotically effective.

The results are interpreted in terms of percentage change in odds ratio following a unitary variation of an explanatory variable x_k, all other explanatory variables remaining constant.

$$\frac{\varnothing(x,\ x_k + \alpha) - \varnothing(x,\ x_k)}{\varnothing(x,\ x_k)} * 100 = 100\left(e^{\beta_k \alpha} - 1\right)$$

where $\varnothing(x) = \frac{P(y=1|x)}{P(y=0|x)} = \frac{P(y=1|x)}{1-P(y=1|x)}$ is the odds.

The systematic selection technique was used to select the best model to minimize the Akaike Information Criterion (AIC). The AIC is an estimator of out-of-sample prediction error and thereby, the relative quality of statistical models for the used data [34].

3. Results

The majority of the respondents are practicing agriculture as a primary income generation activity. The types of crops grown vary according to location. In the southern regions of the country, the major crops grown are maize and rice. In the central zone, groundnut, millet and sorghum predominate. In total, 87% of the respondents are men while 13% are women. Respondents whose age is between 35 and 50 years represent 46% of the total respondents. Respondents aged above 50 years represent 31% while 23% of the respondents are below 35 years old. Regarding marital status, 91% are married, 7% are single and 2% are widowers.

3.1. Frequency, Accuracy and Preference of the Disseminated WCIS

During the growing period, several WCIS were disseminated in the country. The seasonal forecast was communicated prior to the onset of the rainy season. Following this, a range of other forecasts were disseminated with varying frequencies (Figure 3). Rainfall forecast (50%) was the most communicated WCIS followed by wind (39%) and flood (8%) events. Dry and wet spells and temperature forecasts were the least represented. Regarding the accuracy of WCIS disseminated, 89% of the respondents declared that the WCIS they have received were accurate because the events forecasted actually happened. However, 11% of the respondents declared that the information they received was not accurate because the expected weather events did not occur in their localities.

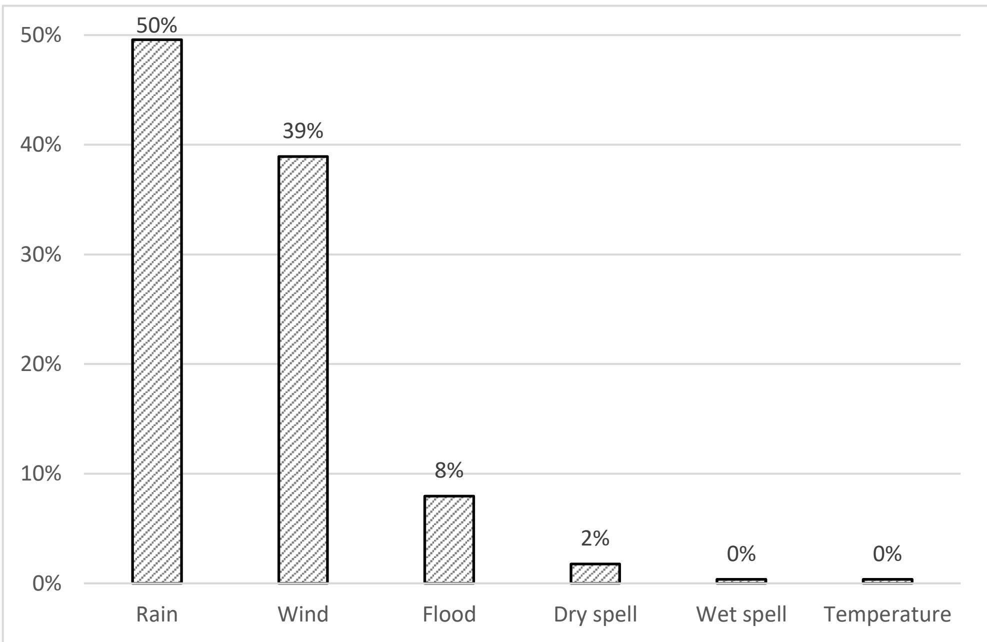

Figure 3. Types and frequency of WCIS disseminated.

The most important WCIS that farmers need to guide their day-to-day decision-making are shown in Figure 4. In general, all respondents stated that the rain forecast is the most important weather information for them. The wind forecast comes in the second position in the order of importance (46%) followed by the dry-spell forecast (18%). The seasonal and wet-spell forecasts come together in the fourth position with 14% each.

The temperature, flood and off-season forecasts are the least important WCIS according to farmers.

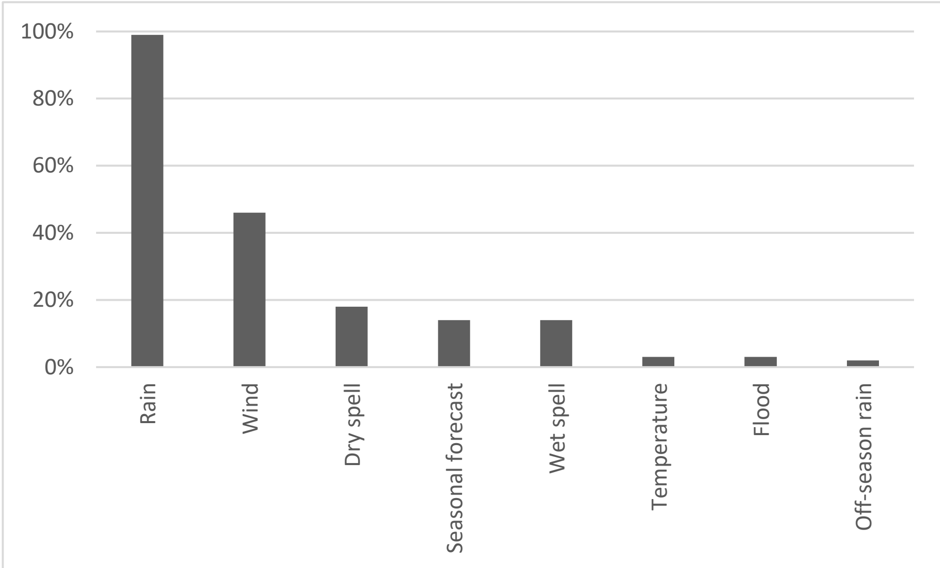

Figure 4. Distribution of WCIS as per users' preference (sample size: 391).

3.2. Types of Decision Made and Level of Satisfaction of the Decisions Made by Farmers

After receiving WCIS, the decisions that farmers make to cope with weather variability are multiple and vary according to the growing stage of the crops. Figure 5a,b shows the types and magnitude of the decisions made at the onset of the season, the peak and during the offset of the growing season. At the onset of the rainy season, farmers use WCIS to make decisions on crop choice and sowing date (Figure 5a). These WCIS also guide the farmers to identify crop varieties that are suitable for the length and quality of the season. The type of croplands (topography and soil type) as well as the cropland size are decided based on the WCIS disseminated during the period.

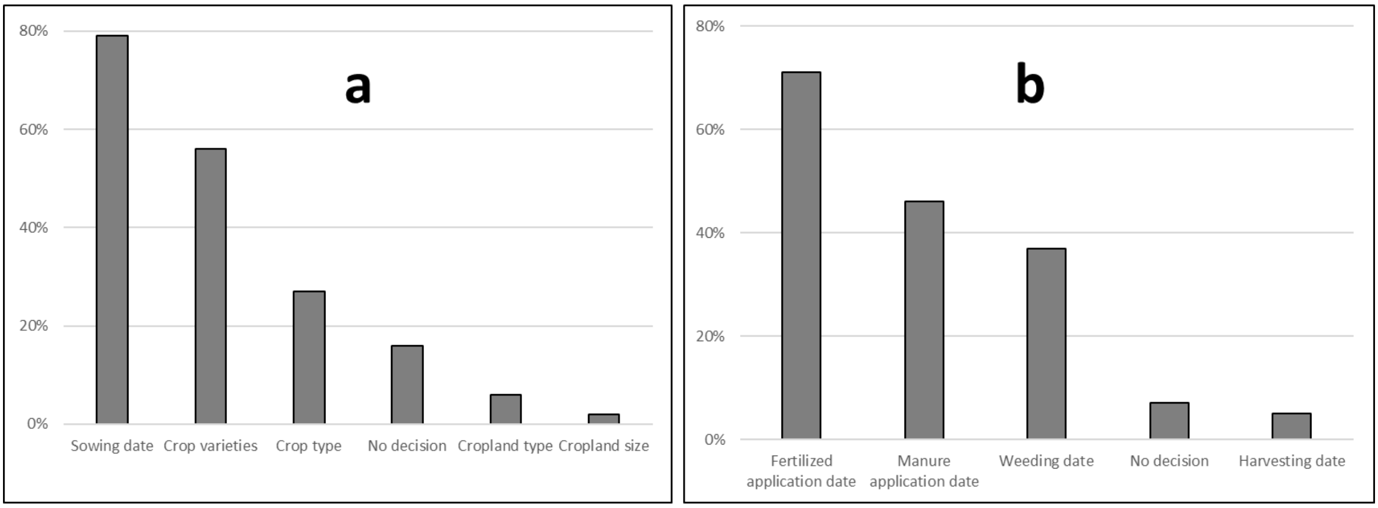

Figure 5. (**a**) Decisions made at the beginning of the growing season; (**b**) decisions made during the pic of the rainy season and at the end the growing season (sample size: 391).

From the middle toward the end of the rainy season, the WCIS communicated were used to guide decisions on the dates to spread fertilizers and manure, weeding and harvesting dates (Figure 5b). Results show that 16% of the respondents did not make any decision at the beginning of the rainy season and 7% of them did not make decision at the end of the rainy season even though they received the same WCIS.

The respondents who did not make decision after receiving WCIS gave reasons they do not trust the WCIS being disseminated (13% of respondents). About 31% of this category of respondents mentioned they did not understand the meaning of the WCIS. More than 6% of this category of respondents said they received the WCIS very late and therefore they did not have time to make adequate decisions.

Among those who have made a decision (about 85% of the respondents), 95% certified they are satisfied with the decision they have made. For them, the decisions made (dependent to the WCIS received) have overall contributed to a saving in time, energy and food stock, and improvement in their productivity and resilience. About 5% of the respondents made decisions but felt unsatisfied with the decisions they made because, for them, the use of WCIS decreased their crop productivity.

3.3. Preference for WCIS Dissemination Channels

In terms of access to WCIS, 99% of the respondents have received weather information via voice message system and more than 95% have received weather information through SMS. Few respondents have received WCIS over the radio (less than 5% of respondents). In addition, some respondents mentioned they got access to WCIS via social media such as WhatsApp and Facebook, and from people at their local mosques or during social events.

Regarding preference, 63% of the respondents preferred the SMS channel while 35% favored voice messaging and only 2% chose the radio. As far as education is concerned, illiterate respondents tended to prefer voice messages while educated people preferred SMS (Figure 6). In general, all the respondents who received the WCIS have shared it with family members, neighbors, friends and members of their producers' organizations.

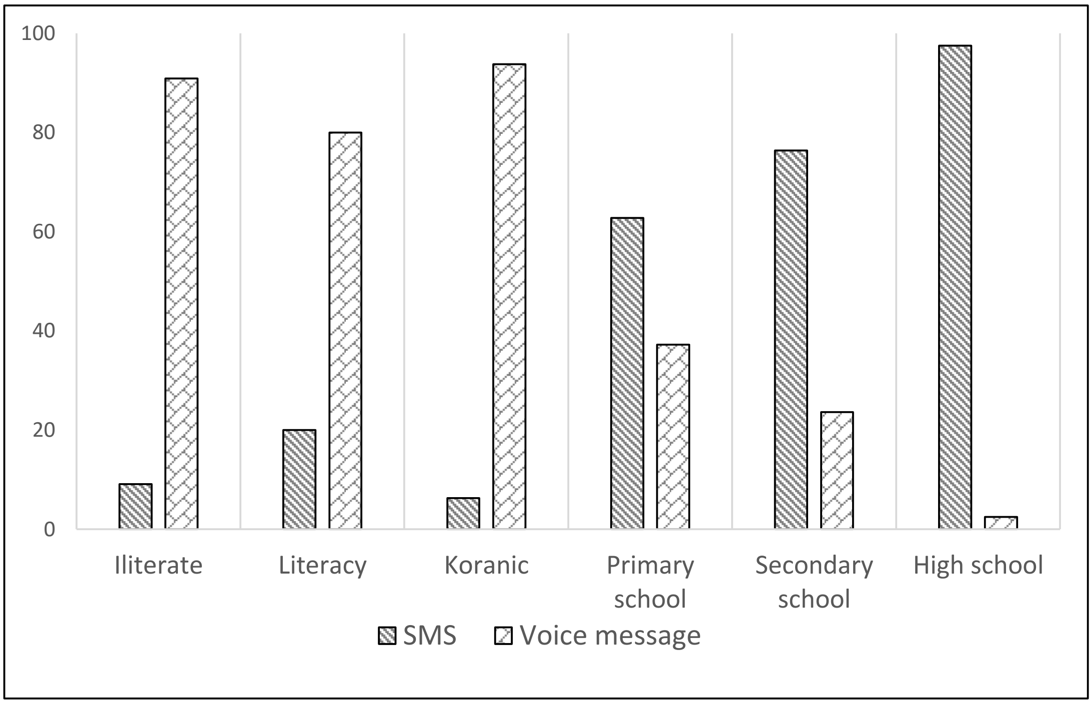

Figure 6. Preference (in %) of communication channels according to level of education (sample size: 391).

In order to check whether the relationship between the reception channel preference and the level of education is significant, we performed the exact Fisher Independence Test instead of the Chi-square independence test due to the small numbers (lower numbers at 5). This test displayed a p-value equal to 0, attesting that there is a relationship between the preference of the reception channel and the level of education.

3.4. Triggers of Uptake in WCIS

The Hosmer Lemeshow test of the model exhibited a strong validity ($p > 0.99$). Table 1 shows the results of the logistic regression. The table shows that several socio-economic variables are significant triggers in the uptake of WCIS as risk management practices in the farming system. Indeed, it appears that age significantly influences the use of WCIS. The older a farmer is, the less likely he/she is to make decisions based on the WCIS received. Two other explanatory socio-demographic variables, region and level of education were also found to be significant. As far as region is concerned, farmers from Kaolack have a 58% less chance of considering WCIS in agricultural decision-making compared to those from Kolda. On the one hand, having a Koranic education reduces the chances of adopting WCIS compared to farmers who have no level of education (33% less likely). On the other hand, having an average level of education (secondary school) increases the probability for a farmer to adopt WCIS compared to a farmer who has no level of education. Some other characteristics of the farmers that significantly boosted the adoption of WCIS are: membership of farmers' organization and having attended training on WCIS use. A farmer who was a member of a farmers' organization was more likely to use WCIS compared to a farmer who did not belong to an organization (189% more likely). Farmers who have been capacitated to understand and effectively use WCIS were 115% more likely to make agricultural decisions based on WCIS compared to farmers who did not have a chance to attend a training on WCIS use.

Table 1. Triggers of WCIS adoption (sample size 1500).

Variable	Modalities	Odds Ratios	Confidence Interval	
			Lower Bound	Upper Bound
Age	Age	0.98 **	0.96	0.99
Region	Kolda			
	Kaffrine	1.50	0.87	2.59
	Kaolack	0.42 **	0.21	0.85
	Sedhiou	1.15	0.70	1.87
	Ziguinchor	0.99	0.57	1.74
Level of education	No education			
	Arabic	0.67 *	0.43	1.04
	Literate	1.24	0.62	2.49
	Primary school	0.81	0.49	1.35
	Middle school	2.20 *	0.99	5.09
	Secondary	1.05	0.42	2.59
	High school	3.86	0.63	33.19
# of years of experience in farming	Number of year of experience	1.03 ***	1.01	1.05
Having supports from an advisory service	No			
	Yes	0.67	0.39	1.15
Being trained on WCIS use	No			
	Yes	2.15 ***	1.44	3.24
Own a radio	No			
	Yes	1.53 *	0.96	2.46
Own a plow	Non			
	Yes	1.60 **	1.02	2.52
Use a tractor	No			
	Yes	0.31 ***	0.17	0.55
Level of confidence in weather forecast	Not confident			
	Less confident	0.39 **	0.16	0.96
	Just confident	0.73	0.32	1.69
	Very confident	2.09 *	0.91	4.84
Membership of farmers' organization	No			
	Yes	2.89 ***	2.01	4.19
Have access to seasonal forecast	No			
	Yes	1.63 ***	1.13	2.35

* significant at 10%, ** significant at 5% and *** significant at 1%, "#" stands for "number".

The regression shows that some economic variables such as ownership of a radio, plow or tractor significantly influence the level of adoption of WCIS. Farmers who own radios were more inclined to receive and use WCIS than those who did not. Farmers who own a plow as agricultural equipment were more likely (60% more) to use WCIS than those who do not have one, whereas farmers using a tractor in their activities are less likely (69% less) to adopt WCIS compared to those who do not use one. It is also observed that the adoption of instant WCIS deeply depends on access to the seasonal forecast. Farmers have access to seasonal forecasts are 63% more likely to use in-seasonal weather alerts compared to those who do not get access to the seasonal forecast.

4. Discussion

There are many steps involved in producing weather and climate information [35]. It begins with a snapshot of the atmosphere at a given time, then maps onto a three-dimensional grid of points. A supercomputer and a sophisticated model are then used to describe the behavior of the atmosphere with physics equations and finally, it falls to human forecasters to interpret the data and turn them into a meaningful forecast that is broadcast to the public. These steps point out the credibility challenge entailed within the accuracy of the forecasts. As stressed by Tall et al. [24], weather and climate information is inherently associated with some degree of uncertainty. In this present study, the level of trust of weather information by farmers is high (89%). This indicates that there has been significant improvements in rainfall forecasting design and production in Africa as noted by Singh et al. [5]. Respondent farmers in our study showed a high preference for rainfall and wind forecasts. In general, for smallholder farmers, the most important variable that affects crop productivity is rainfall variability. Therefore, they are more inclined to receive information on onset occurrence, distribution and offset of rainfall as well as the length of the growing season. Similar studies in Kenya [36], Malawi [16] and Mali [37] have also reported this preference for rainfall forecasts among farming communities.

A weather service by definition provides tailored, salient and usable agro-advisories for policy-makers and vulnerable communities, based on available weather information [24]. The results of the present study show that the decisions made from weather and climate information are location-specific and depend on the stage of the growing season and the type of crops grown. Farmers are well aware from experience that at the onset of the growing season, decisions on sowing date, crop type and varieties are fundamental for achieving a good yield. In the middle of the growing season, the choice of appropriate dates of spreading chemical and organic fertilizers in order to avoid the fertilizers being washed out by runoff [20,29] is essential. Similarly, the timing for weeding is important because a rain that immediately follows this farming operation will result in a weed outbreak. Whilst acknowledging the role of local knowledge in shaping these decisions, it is worth noting that the scientific weather and climate information, which refer to processed data, products and evidence-based knowledge about the atmosphere-ocean system across short and long-term scales, provides the most accurate basis for a decision-making [5,38]. Although the level of adoption of WCIS seems to be high in this present case, there are still farmers (about 7%) who do not trust weather and climate information. This reluctance can be explained by three factors: (i) lack of understanding climate information, (ii) the belief of indigenous knowledge and (iii) the lack of downscaled WCIS [24]. In most cases in Senegal, only weather information is communicated to farmers and it is up to end-users to make their own decisions. To help farmers understand and effectively use the weather and climate information, several training events were initiated and led by the Senegalese meteorological service [20,27]. However, the number of beneficiaries who attended the training remains well below the number of potential users in the country. In particular, the utility of weather and climate information is not always immediately apparent and thus, requires substantial interaction between WCIS providers and smallholder farmers to demonstrate relevance and applicability. Many farmers, although exposed to WCIS, still rely on their traditional knowledge and personal experience, which they perceive as more relevant to local decision-making [6,10,16,28]. Traditional knowledge refers to practices that are acquired by local people over a period of time through society–nature relationships and community practices [5]. Because weather information produced in Senegal has a very coarse resolution (at a regional scale), predicted weather events do not always occur in all localities within the targeted regions, leaving room for mistrust among users. The decisions made at multiple levels, in general, depend on climatic, agronomic, economic and social factors [5]. Different authors [13,39–41] have identified the most important characteristics for successful uptake of WCIS. These include: (i) decision-makers receive, trust and understand the information; (ii) information is locally relevant, fit-for-purpose and timely; (iii) appropriate governance and institutional structures are set for the provision of weather and climate information; and (iv) focus is made on the socio-economic values of the uptake of weather information.

Contrary to studies [42] that have found radio as the most widely trusted channel for communicating weather information among rural population across sub-Saharan Africa, our study shows that the mobile network operator platforms are the prominent WCIS dissemination channels. Senegal has more than 100 community radio stations that have been capacitated to translate weather and climate information into local language and disseminate it to farmers, pastoralists and fishing communities [20,27]. However, with the rapid spread of mobile phones and internet connectivity, WCIS users have shown preference for SMS, USSD and voice messages as the most adapted WCIS dissemination channels. With the radio, farmers must manage to conform to the timing set by the radio stations for WCIS broadcasting. The timing set by radio stations are not always compatible with the daily agenda of farmers. With mobile platforms, farmers can receive WCIS anytime, anywhere. Moreover, they can store the information and share it with other people via SMS or through social media such as Facebook, WhatsApp, Tweeter, etc.

The level of uptake of WCIS is intrinsically associated with some socio-economic characteristics among which the most important are, age and education, being a member of a farmers' organization and being capacitated to use WCIS, owning a radio. Young and educated farmers have a high propensity to adopt innovation when it comes to WCIS, which requires a minimal use of a basic cell phone and the ability to read text messages. Alternatively, older people are reluctant to change and entrust their ancestral beliefs [20]. Further, low literacy levels remain a challenge in some rural contexts in Senegal and limits the utility and impact of mobile-based agricultural information and services for some segments of the population, particularly female household heads and the elderly [43,44].

In the context of Senegal, the likelihood of a farmer to being trained to understand and effectively use WCIS is strongly associated with being a member of a farmers' organizations [44]. The training sessions target farmers' organization and in most cases, the leaders of the organizations identify the members to attend the trainings. Trained farmers become ambassadors and are mandated to train the rest of the members of their organization [20]. A study in Nepal by Jones & Boyd [45] highlighted that cognitive, normative and institutional factors influence adaptation actions toward climate risk management. This justifies the statement from Singh et al. [5] that barriers in climate information utility and uptake stem from inadequate understandings around how and why users make decisions.

Although the mobile phone appears to be the most preferred WCIS receiver in Senegal, in many rural areas, mobile networks are poor or nonexistent. Farmers from these areas rely on radio to receive needed WCIS. Radio coverage is much better in rural areas because 120 radios, members of the Union of the Senegalese Community Radios (URAC), timely broadcast WCIS in local languages throughout Senegal.

5. Conclusions

The paper has revealed the utility of weather and climate information services (WCIS) in guiding farmers' day-to-day decision-making at all stages of the growing season. Farmer's preferences, in terms of salient WCIS (rain and wind forecasts) as well as WCIS communication channels (SMS and voice messages) have been identified. Socio-economic triggers in uptake of WCIS such as age, education, being trained to use WCIS, being a member of farmers' organization and possessing a radio have been demonstrated. Findings from this research are essential for improving Africa's efforts to adapt to climate variability and climate change related risks in agriculture and to meet the sustainable development goals, including those that pertain to climate action, poverty and hunger. One of the important lessons that can be derived from this study is that weather forecasts alone are not sufficient to enable improved decision-making for climate-risk management. Rather, it is the suitable weather agro-advisories retrieved from WCIS that determine the value that WCIS can affect. Therefore, in addition to building the capacity of WCIS users to understand and effectively use the WCIS they receive, the direct provision of weather-related agro-advisories remains paramount. The importance of mobile network operators (MNO) in delivering WCIS to smallholders' farmers in a timely fashion is well acknowledged in this paper. However, the evidence of the effectiveness of the MNO in achieving impact at scale on technology uptake and on improved food and nutrition security amongst smallholder farmers needs to be explored. Finally, some priority learning areas that can strengthen the evidence of impact of WCIS and enable the sustainability of WCIS delivery are urgently needed to improve the design and target weather information services in Africa, in general.

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