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REVIEW ARTICLE

Weather based agro advisory services in promoting sustainable agriculture: A review

Jayashree V[1], Asokhan M[1*], Nirmala Devi M[1], Padma S R[2], Pragadeesh V[1], Anjugam M[3] & Kokilavani S[4]

[1]Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[2]The Controllerate of Examinations, Tamil Nadu Agricultural University Coimbatore 641 003, Tamil Nadu, India
[3]Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[4]Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - masokhan@tnau.ac.in

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Abstract

Agricultural production is closely linked with weather conditions, as fluctuations in temperature, rainfall, wind patterns and humidity significantly influence crop productivity. Adverse weather events often lead to considerable crop losses, emphasizing the need for timely and accurate weather information. Weather Based Agro Advisory Services (WBAAS) play a pivotal role in bridging this gap by providing farmers with real-time and forecasted weather information, enabling them to adopt strategic measures to mitigate risks and optimize agricultural outputs. WBAAS offers customized guidance based on weather predictions, including optimal sowing times, irrigation scheduling, pest and disease management and post-harvest strategies. By receiving accurate and timely advisories on parameters such as temperature, relative humidity, wind speed and rainfall, farmers can make informed decisions, reducing the likelihood of crop failure and improving yield quality and quantity. These services not only aid in minimizing production losses but also enhance economic returns by promoting resource efficiency and sustainable farming practices. The integration of technological innovations into weather based agro advisory services further strengthens their impact, facilitating the dissemination of precise weather data through mobile applications, SMS alerts and other digital platforms. Studies have demonstrated the transformative potential of these services in improving farmers' adaptive capacity and resilience against climate variability. This review analyses studies on how farmers utilize technological innovations combined with weather-based information to enhance agricultural productivity. It examines the impact of weather based agro advisory services on agriculture and explores their broader role in achieving sustainable farming practices and addressing challenges posed by climate change.

Keywords: adoption; climate change; crop productivity; perception; Weather Based Agro Advisory Services; weather forecast

Introduction

Weather is extremely important in agriculture and changes in weather patterns can have a significant impact on crop yields (1). Before and throughout the cropping season, the weather has a significant impact. Climate change has made weather management in agriculture an important issue (2). The productivity of crop production is highly dependent upon meteorological factors such as rainfall, temperature, wind direction, relative humidity and hail (3). The weather has an impact on both short-term (tactical) and long-term (strategic) decisions made to maximise the benefits of crop production in terms of both quantity and quality (4). As everyone knows, Indian agriculture is regarded as an attempt to gamble during the monsoon. Despite other technological advancements, the country's agricultural production is still largely determined by the climate and weather. As weather conditions affect every phase of crop growth, it is clear that they determine whether a crop will succeed or fail (5).

Weather forecasting's principal objective is to give recommendations to the farmers on both present and predicted weather and how it will affect their daily farming operations, such as sowing, weeding, time of application of pesticides, irrigation scheduling, fertilizer application etc. and overall crop management (6). Weather information used in agricultural operations should be made so that crop planning and management can use it efficiently. Farmers are able to make decisions and better manage agricultural risks can be enhanced by accurate weather information and advisory services (7). These services can aid in the creation of environmentally friendly and sustainable agricultural systems, enhance output and quality, lower production costs, significantly decrease losses and risks, boost labour, water and energy efficiency, preserve natural resources and reduce pollution from pesticides and other drivers that harm the environment (8, 9).

A systematic weather-based farm advisory provides recommendations for actions to be taken based on an interpretation of how current and future weather conditions will affect crops, livestock and farm operations (10). Weather-based crop advisory services can give farmers up-to-date information on crop health, weather patterns and appropriate measures, empowering them to make well-informed decisions about methods of crop management (11). By utilising the services, farmers can increase their crop yield and minimise weather-related losses by adhering to timely cultivation techniques and making informed decisions (12, 13). It is essential to address challenges such as limited Information Technology infrastructure, sustainability concerns and accessibility issues. By overcoming these hurdles through strategic investments and collaborative efforts, weather based agro advisory services can emerge as indispensable tools in fostering agricultural growth, resilience, improve yield, increase farmers income and sustainability in an ever-changing environment.

Materials and Methods

The reviewed literature was compiled from peer-reviewed publications, reports and newspaper articles sourced from a large database. The search primarily focused on previously cited incidents, reports, case studies, research and review publications to ensure comprehensive coverage. Web-based search engines such as Scopus and Google Scholar were used to gather literature on technological advancements, their effects on utilization, farmer perception and the adoption of WBAAS. To ensure empirical evidence from both past and present studies, the review prioritized publications from 2003 to 2023, covering the last 20 years. Relevant keywords such as "WBAAS" and "Agriculture," "WBAAS" and "Climate change," "WBAAS" and "Agromet services," "WBAAS" and "Farmer perception," and "WBAAS" and "Weather parameters" were used to refine the search. These keywords were employed to systematically identify and categorize relevant articles for this study. The majority of studies analyzed were limited to South India, ensuring a region specific focus. During the first phase of screening, the emphasis was placed on review papers related to WBAAS to establish a strong foundation for the analysis. A total of 621 articles were identified, of which 175 were peer-reviewed journal publications. For this review, 104 papers from 51 peer-reviewed journals, reports, newspaper articles and websites were selected. The acquired literature was precisely analyzed to identify key technological innovations, climatic changes influenced by weather parameters and measures for mitigating adverse effects. Special attention was given to studies assessing farmers' adoption behavior, constraints in utilizing agro-advisory services and their impact on agricultural productivity. The study primarily focused on WBAAS associated with farming, highlighting their role in supporting decision-making, risk management and climate resilience among farmers. By synthesizing findings from multiple sources, the review provided valuable insights into the effectiveness of such advisory services in improving agricultural sustainability and productivity. As part of the analysis, NVIVO software was used to generate a word cloud visualization.

Results and Discussion

Technological innovations in WBAAS

Agricultural sector is adopting new technologies and solutions to optimize the collection and processing of information, thereby enhancing agricultural productivity (14, 15). When the farming community is informed about upcoming weather conditions in advance, they can make necessary adjustments to their agricultural operations at the farm level. This proactive approach allows them to mitigate the impacts of unfavourable weather conditions effectively (16). Sharing knowledge through advisories as effective tools for understanding user priorities requires collaboration with meteorological services. This partnership aims to promote environmentally friendly and sustainable development in Indian agriculture, particularly in a country like India with rich biodiversity and extreme weather variability, including crop failures and cloudbursts (17). The dissemination of climate data and agricultural information can be efficiently facilitated through applications enabled by Information Technology (IT). Current dissemination methods include mobile phones, radio, television, face-to-face interactions and electronic mail (18). Additionally, a web-based system has been developed and utilized for sharing agricultural information (19) (Fig. 1).

With the anticipated substantial increase in mobile and internet penetration, the growth of vernacular content, the rising use of smartphones and the rapid development of convergent application technologies, digital platforms present an unparalleled opportunity to provide meteorological, climatological and hydrological information to farmers affordably and in near real-time (20). Smallholder farmers in developing countries, who largely rely on rainfed agriculture, are the most affected due to their high sensitivity to climate variability and change (21).

The Indian Council of Agricultural Research (ICAR) seeks to provide crucial information to farmers through a simple and user-friendly mobile application. Once installed, the app presents targeted weather parameters such as temperature and precipitation, along with details on major crops like cereals, vegetables, fruit crops and livestock relevant to specific locations (22). Mobile phones are increasingly utilized to deliver agricultural and related information to smallholder farmers. There is significant interest in their potential to disseminate climate and weather data, as farmers consistently express a strong need for weather information (23). The Short Message Service (SMS) is a way of storing and forwarding transmitting short messages to and from mobile phones. SMS is a cost-effective, robust and reliable technology that aids small-scale farmers in enhancing their agricultural businesses. Effective use of SMS communication among all agricultural stakeholders can boost the agriculture sector, thereby improving the living standards of farmers (24).

To enhance the effective dissemination of agromet advisory bulletins, a Web-based agromet advisory system, known as Web-based Agro-Advisory Services, has been designed, developed and implemented. To ensure effective

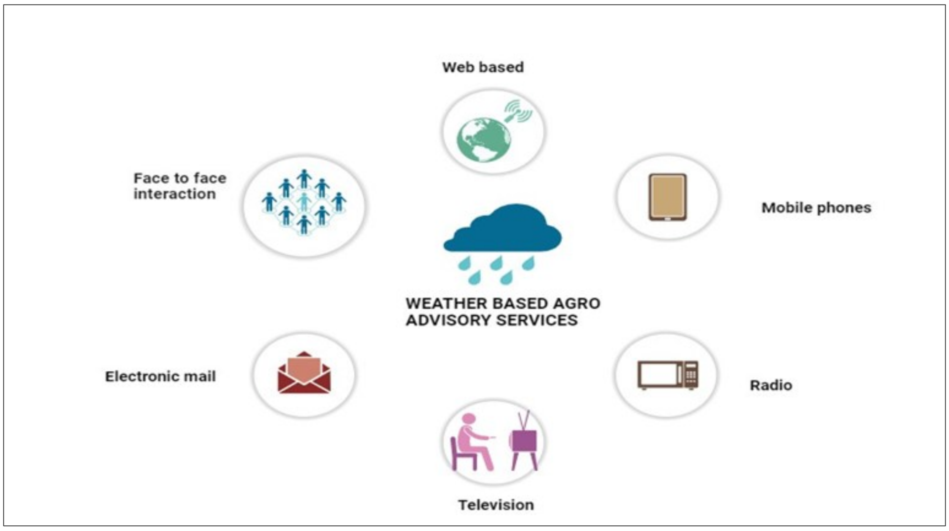

Fig. 1. Technological innovations in WBAAS.

dissemination, these bulletins are uploaded on the WBAAS website (www.drmr.res.in/Web-AAS) in both Hindi and English (25).

Farmer perception and adoption on WBAAS

Farmers current views on weather forecasting show that those who have utilized the agromet advisories services have seen significant profits (26). Due to climate change and its increasing variability over time, farmers experience crop losses because the farmers are unaware of unusual weather events (27). Perception is shaped by how we interpret information and it varies from person to person (28). Different individuals perceive the same situation differently and assign various meanings to their perceptions (29). The majority of farmers over 90 per cent agreed on the necessity of Agro-Advisory Services (AAS), finding rainfall prediction advisories extremely useful for their farming activities, followed by temperature-based advisories (30). About 80 % of farmers believe that weather advisories help reduce the costs and expenses of farming. Additionally, nearly 68 % of the farmers think that these advisories help lower irrigation charges by allowing them to plan their farm activities in advance (31). Approximately 85 % of farmers agreed on the necessity of AAS, finding advisories based on predicted rainfall events to be highly beneficial for their farming activities, with temperature-based advisories being the next most useful. Most farmers (88 %) felt the need for agro-meteorological advisory services (32).

Technology adoption is the process of accepting, integrating and utilising new technology in society (33). Majority of respondents (77.78 %) adopt weather-based farm advisories to schedule sowing times, indicating widespread acceptance of this method for optimising agricultural activities (34). The majority of AAS farmers used herbicides in their crops, with 87 % using paddy, 60 % using maize and 55 % using bajra (35).

Impact on utilization of WBAAS in agriculture

Extreme weather events are significant components of the climate, typically happening at the synoptic scale and lasting for a shorter period compared to global climate change. Implementing weather-based crop management practices enhances profitability. Climate change has led to more frequent extreme weather events, impacting agriculture (36, 2). Dependable weather forecasts and tailored agrometeorological advisories are crucial (37). The generation of forecast information across different time scales (from short-term to seasonal) and spatial resolutions has consistently increased, becoming more accurate, reliable and timely (38). Weather information services can enhance farmers management of their activities and farm outcomes by providing relevant and usable data to support decision-making and address the potential impacts of anticipated climate changes (39-41). Understanding weather patterns and their variability is critical for understanding the overall impact of various factors on agricultural production and critical for implementing effective cropping systems, as well as soil and water management practices.

Agricultural production is frequently unstable due to external factors like weather, insects and pests, diseases and fluctuating input/output prices (42, 43). Services based on climate information are crucial for managing agricultural systems efficiently, profitably and with minimized risk (43). Agro-meteorological data, including weather forecasts, soil condition information and agro-advisories, are essential for effective farm management (44). The majority of farmers followed the weather advisories provided by the Krishi Vigyan Kendra (KVK) for their day-to-day farming operations (45). The creation of climate information services using forecast visualization and communication has enhanced the adoption of forecasts for climate-sensitive decisions among smallholder farmers (46). These practices encompass timely land preparation, appropriate sowing times, recommended seed rates, selecting suitable crop varieties, effective weeding, moisture conservation techniques, pesticide application, irrigation and harvesting (47, 48). Expenditure incurred by farmers from land preparation to harvest has been estimated at each stage and crop growth and yields were monitored on a regular basis in both groups' farmer fields. The absence of timely and reliable agrometeorological information significantly hinders effective farm planning and operations.

The five livelihood capital resources affecting Weather Information Services adoption (WIS)

In the various studies, it was interesting to see how the various capital assets that smallholder farmers possessed influenced their awareness, access, use, value and finally uptake of WIS within the different studies. Table 1 provides the farmer attributes covered under the five capitals, along with the various WIS types offered for each study.

Constraints of farmers on adoption of WBAAS

Despite the swift expansion and significant potential of ICT applications in the agricultural sector, their usage remains limited. This is due to several challenges, including inadequate IT infrastructure in rural areas, concerns about sustainability and affordability, ease of use, accessibility, scalability and the availability of relevant and localized content in appropriate languages (65). The majority (96.66 %) of respondents indicated that there is inconsistency in the delivery of weather advisory services (66). Nearly three - fourth (70.73 %) of farmers reported that WBAAS are difficult to understand, particularly when they need clarification on certain messages (67). 78.18 % of respondents indicated that if they have any doubts after receiving a message, there is no mechanism to clarify these doubts. Their only option is to call back to the KVK, which incurs a cost (68). Most respondents (84.50 %) reported that they have not received any information relevant to local crops (69). About 69.17 % of the farmers expressed that there is a lack of clarity on

Table 1. Characteristics of the five capital resources and how they influence the adoption of WIS

Characteristics of the five capital resources	Awareness	Access	Use	Value	Uptake
Age	The age group that is most aware of online WIS is the 30-39 year old, followed by the 20 -29 year old.	Using multiple WIS was less common among farmers over age 50. The household head's age is correlated with a reduced likelihood of gaining access to WIS.	Inversely and negatively correlated with ICT proficiency	Willingness to pay and age had a negative correlation, but the age effect can be offset by participatory training	Uptake varies depending on other variables. ICT literacy gaps between generations affect adoption.
Study	(49)	(50, 51)	(52)	(53)	(49)
Education	A farmer who has a higher education is probably going to be more knowledgeable about scientific weather information.	Education level increased the likelihood of accessing forecasts.	The people who used WIS through modern media were educated to a secondary level Higher education levels led to an increase in WIS use.	Education has a positive impact on willingness to pay.	Illiteracy and informal education decreased uptake.
Study	(54)	(51)	(49, 55)	(53)	(55)
Gender	According to certain studies, there are no significant gender differences in WIS awareness. suggests, however, that it is dependent upon the social structures within a community.	Weather forecasts were more readily accessible men than to women. Men prefer to obtain information through newspapers, SMS, WhatsApp, or the internet, whereas women prefer to obtain information through community leaders, SMS, out-grower management and extensionists.	In general, women were more likely than men to use multiple sources. WIS use was low among females household who was female were more likely to use WIS. The use of WIS varying between men and women.	The value of WIS does not significantly differ by gender.	The adoption of WIS differed by gender (based on access and literacy levels).
Study	(49)	(51, 56)	(49, 50, 55, 56)	(53)	(55)
Household size	Increasing household size raises WIS awareness.	The chance of accessing WIS increased with household size and In East Africa, however, the opposite was noted.	Due to the presence of labour, bigger households are more likely to adopt WIS.		Due to the presence of labour, larger households are more likely to adopt WIS.
Study	(50)	(50, 51)	(50)		(50)
Community/ Institution Membership/ NGOs	Increased awareness.	Increases the availability of online resources, greater accessibility. The accessibility of several information sources, such as early warnings. Using social networks to access indigenous knowledge is crucial.	Use of WIS is influenced by an institution's membership	The value of WIS to a farmer is increased by membership in a group or organisation.	Institutional membership has a positive impact on WIS uptake.
Study	(57)	(49, 50, 54, 58)	(59)	(53, 59)	(50, 59)
Farming experience	It has a positive correlation with increased knowledge of local knowledge.	Inversely and negatively correlated with ability to use ICT.	With increased farming experience, the use of WIS might decrease.		The more farming experience one has, the lower the likelihood of WIS adoption.
Study	(54)	(52)	(50, 51)		(50)

Farm Size	Farm sizes that were larger had a greater likelihood to be aware.	Access was more likely to be available to farmers with larger farms. Access to climate information services increased by (2.30 %) for every unit increase in farm size.	Size increases reduce the likelihood of adoption.	Favourable impact on willingness to pay.	Smaller farms are more likely to use WIS to mitigate climate variability.
Study	(49)	(50)	(60)	(60)	(60)
Crop	Farmers who grow vegetables are more likely to be aware of about WIS.	WIS is more accessible to vegetable farmers.	Crop variety influences when and how particular information is used.	Higher-value crop producers typically place a higher value on WIS.	Farmers use indigenous forecasting to manage their crops when scientific forecasts are inaccurate.
Study	(49)	(49)	(61, 62)	(62)	(62)
Access to financial capital and land ownership	Increase the probability that people will be aware of WIS.	Access to funding improved WIS use.	When WIS is available, use it more often, constraint to use when unavailable.	Having access to credit considerably increases Willingness to pay (WTP).	Sharecropping could reduce WIS adoption. Land ownership increases uptake of WIS.
Study	(51)	(51, 55)	(50, 63)	(60)	(62, 63)
Extension services	Extension services improves WIS awareness.	Increases access	Increases Use	Increases Willingness to pay	Increase uptake
Study	(49)	(49, 60, 64)	(49, 60, 64)	(60)	(59)

how prices are determined in the markets (70). Farmers reported a significant lack of ICT knowledge and skills, which was reflected in the highest mean score of 1.63 (71).

Suggestions to improve the adoption of WBAAS

NVivo's text analysis tools, such as word frequency and word cloud visualizations, are used to analyse the suggestions for improving the adoption of WBAAS. These tools provide meaningful insights into the significance and occurrence of key terms or concepts, thereby facilitating better data interpretation and comprehension.

From (Fig. 2), the word cloud highlights the key suggestions for enhancing the adoption of WBAAS. To enhance the adoption and effectiveness of WBAAS, several key measures need to be implemented. Providing accurate and timely weather advisories is crucial for enabling farmers to make informed decisions regarding their agricultural practices. Improving network infrastructure and connectivity in villages will ensure seamless dissemination of weather advisory messages (65). Access to timely credit is essential to support smooth agricultural operations, allowing farmers to respond effectively to weather-based recommendations (66). The regular visits of extension personnel will further strengthen the advisory system by facilitating direct farmer engagement and personalized guidance.

Moreover, ensuring the accuracy and timeliness of market information will help farmers optimize their marketing strategies and reduce post-harvest losses (67). To maintain the effectiveness of weather advisory services, it is essential to avoid repetition of the same advisory and instead focus on delivering context-specific, actionable recommendations. Organizing awareness programs will help improve farmers' understanding and adoption of WBAAS, while strengthening the credibility of the information provided will enhance their trust in the service (68).

In addition, weather advisory messages should be delivered exclusively in the local language to ensure clarity and accessibility for all farmers. The frequency of Short Message Service (SMS) based advisories should be

Fig. 2. (Word Cloud) Depiction of suggestions to improve the adoption of WBAAS.

increased to provide real-time updates on changing weather conditions (69). A continuous assessment of farmers' information needs at the village level will allow for adaptive improvements in the advisory services. Finally, implementing these measures will significantly reduce the risk of crop failure associated with climate-dependent farming, thereby promoting sustainable agricultural development and resilience among farming communities (71).

Future prospects and recommendations

WBAAS have significant potential to enhance agricultural productivity, but their current effectiveness is hindered by several challenges. The key issues include inadequate Information Technology infrastructure in rural areas, sustainability and affordability concerns, user-friendliness, scalability and the availability of relevant and localized content. Many farmers report irregularities in service delivery, difficulties in understanding messages, lack of efficient mechanisms to clarify doubts and irrelevant information regarding local crops. Additionally, confusion about market price fixation affects decision-making. Addressing these challenges through improved Information Technology infrastructure, sustainable financial models, user-friendly platforms, expanded reach and content, effective communication channels and integration with market information is crucial for maximizing the impact of these services on agricultural productivity.

For enhancing WBAAS in agricultural productivity include investing in rural IT infrastructure for improved accessibility, developing sustainable financial models, designing user-friendly platforms and providing training, expanding service reach and localized content, establishing efficient communication channels, integrating market information, fostering collaboration, continuous evaluation, conducting awareness programs and advocating for supportive policies. These efforts aim to empower farmers with timely and accurate weather information and market insights, enabling them to make informed decisions and enhance agricultural productivity sustainable.

Conclusion

WBAAS serve as important tool in the promotion of sustainable agriculture, particularly in the face of challenges such as climate variability, resource scarcity and increasing global food demand. This review highlights the transformative potential of WBAAS in enabling farmers to make informed decisions, optimize resource utilization and enhance productivity while maintaining environmental integrity. The integration of accurate weather forecasting, advisories and real-time updates empowers farmers to adopt adaptive practices such as precision farming, efficient water management and timely pest control measures. These services not only mitigate risks associated with weather uncertainties but also foster resilience against climate change, ensuring long-term agricultural sustainability. However, despite their proven benefits, the adoption of WBAAS faces several challenges, including limited access to technology, insufficient awareness and socio-economic barriers among smallholder farmers. Addressing these issues requires a multi-pronged approach involving policy support, capacity-building initiatives and investments in ICT infrastructure. Additionally, the role of stakeholders, including government agencies, research institutions and private players, is crucial in scaling up the accessibility and effectiveness of WBAAS. Future strategies should focus on integrating WBAAS with other sustainable agricultural practices, promoting community-centric models and leveraging advancements in data analytics and machine learning for more precise and localized advisories. By fostering inclusivity and enhancing user-friendliness, WBAAS can be instrumental in achieving sustainable agricultural development, ensuring food security and improving the livelihoods of farming communities worldwide. In conclusion, WBAAS are not merely tools for weather prediction but catalysts for a transformative shift towards sustainable agricultural practices. Their successful implementation and adoption have the potential to redefine the future of farming, making it more sustainable.

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Authors' contributions

JV was responsible for the conceptualization and formation of the original manuscript. AM contributed through conceptualization and supervision. NDM focused on idea development and reviewing. PSR and PV were involved in the collection of the review data. AM and KS provided handled writing and editing tasks.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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