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Advancing Sustainable Crop Production Through Agro-Advisory Services: A Review

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ABSTRACT

Agro-advisory services play a pivotal role in enhancing sustainable crop production by delivering timely, location-specific, and actionable information to farmers. These services integrate advanced scientific tools, weather forecasts, and crop management techniques to address critical agricultural challenges. By bridging the gap between research institutions and farming communities, agro-advisories promote the adoption of sustainable practices that optimize resource use, improve productivity, and mitigate environmental impacts. Key components of agro-advisory services include weather-based forecasts, pest and disease alerts, crop and soil health assessments, irrigation scheduling, and market information. The integration of technologies such as remote sensing, Geographic Information Systems (GIS), mobile apps, and IoT devices has significantly improved the precision and accessibility of these services. Tailored advisories help farmers make informed decisions, reducing risks associated with climate variability and enhancing resilience to extreme weather events. Agro-advisories also contribute to sustainable agriculture by promoting climate-smart practices, such as efficient water use, organic farming, and integrated pest management, which reduce reliance on chemical inputs and conserve natural resources. Furthermore, these services empower farmers by improving their technical knowledge and decision-making capabilities, fostering economic and social benefits. However, challenges like limited access to technology, poor literacy, and inadequate infrastructure in rural areas hinder the widespread adoption of agro-advisories. Addressing these barriers through capacity-building programs, policy support, and enhanced digital inclusion is crucial to maximize their impact. Overall, agro-advisory services are indispensable for achieving sustainable crop production and ensuring food security in the face of global challenges.

Keywords: Climate Change, Agro-Advisory Services, Agro-meteorology and Weather forecasting.

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INTRODUCTION

Agriculture is distinct from other economic sectors in that its output is heavily reliant on weather conditions. The degree of success of agricultural production and economics is decided to a large extent by how well weather conditions corresponding to the crop's optimal requirements are best utilized to raise the crops. Also, how successfully adverse weather circumstances, such as moisture, thermal, wind, radiation, and biotic stress, are handled to minimize crop adversity. It is well understood that variability in weather elements (particularly rainfall and temperature) is the primary cause of inter-annual variability in crop output. The onset of weather extremes (dry spells, droughts, floods, heat waves, and hailstorms) harms agricultural yield, resulting in a low level of productivity (Parry et al., 2004; Aggarwal & Mall, 2002). Furthermore, weather can have an impact on agricultural output at multiple levels (vegetative stage, harvest, transportation, storage, etc.). Flooding, droughts, heat waves, cold spells, hailstorms, and other natural calamities pose significant risks to farms. Farmers often plant low-risk, low-return crops (such as early maturing varieties that are drought-resistant) to deal with erratic weather rather than investing in more profitable crops that are more sensitive to weather fluctuations and extremes. It is proposed that a Farmers' Friends program, similar to the Fishermen's friends program, be replicated on a pilot size to institutionalize the NGO intermediation process in disseminating weather information to the agricultural community (Sivakumar, 2007). Furthermore, farmers who are concerned about bad weather may be hesitant to make other agricultural investments, such as increasing fertilizer use. As a result, farmers may become

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trapped in a cycle of low productivity as a consequence of extreme weather events. Many risks connected with crop output are influenced by a region's climate and seasonal weather, which ultimately determines farm income. This necessitates an assessment of the vulnerability of any location or area. Climate change's effect on Indian agriculture and water resources is a major concern for policymakers and development experts. Agriculture in India is heavily reliant on the south-west monsoon. Because a significant portion of the net sown area is rainfed, the agricultural sector in India is extremely sensitive to changes in rainfall patterns (Aggarwal et al., 2002). Rice and wheat account for a large portion of the foodgrain crops produced in India, and any discernible positive or negative change in rice and wheat yields may have a significant impact on the country's food security (Singh et al., 2015). The productivity levels of these crops in the future decades will be primarily determined by changes in sensitive weather factors such as temperature, rainfall, and solar radiation. Because climate change affects the nation's food security, the magnitude of the shift and its consequences will be of concern to scientists, planners, and policymakers, particularly in terms of regulating the food supply and preserving reserves for the future.

Moreover, it is dependent on management elements to protect crops from extreme weather conditions. Ideally, agricultural technological development should decrease overall reliance on weather and climate. However, the relationship between output and weather/climate does not appear to weaken. Meteorological conditions impact high-yielding agricultural varieties that are more sensitive to environmental conditions, necessitating maximal optimization of water, air, thermal, and nutritional conditions. This causes significant fluctuations in annual crop yields that outweigh the rise in yields caused by agricultural growth. As a result, the importance of agro-meteorological knowledge is growing. Using educated information on the impact of weather and climatic factors on agricultural productivity can reduce damage and allow for additional yield without major financial outlay. As a result, weather forecast-based agro-advisories play a significant role in agriculture and the Dary sectors (Kumar et al., 2024). Weather forecasts in all temporal ranges are preferable for effective planning and administration of agricultural practices such as cultivar selection, sowing, need-based application of fertilizers, pesticides, insecticides, efficient irrigation, and harvest (Prakash et al., 2022). Weather forecasts in the short and medium ranges greatly assist in making short-term changes in daily agricultural operations that minimize losses caused by adverse weather conditions and improve agricultural production yield, quantity, and quality. Agromet Advisory Service (AAS) plays a pivotal role in shaping farmers' perceptions and encouraging the adoption of conservation agriculture practices in India (Kumar et al., 2017) by providing tailored, weather-based insights and guidance to enhance resource efficiency and resilience to climate change.

Impact of Climate Change on Indian Agriculture

India has one of the world's fastest-expanding economies, but it is vulnerable to climate change and its consequences. With approximately 30 percent of the Indian population living below the poverty line, the effects of climate change, particularly in agriculture, could worsen living conditions, as agriculture has been a primary source of livelihood for a significant portion of the poor. Climate change will disproportionately affect the poorest and most marginalized sections of the Indian populace. Previous research has shown that climate change may pose a threat to total food productivity. Despite the carbon fertilization effect, studies performed by the Indian Agricultural Research Institute (IARI) show that every 10 degrees Celsius increase in temperature may result in a loss of 4-5 million tons in annual wheat production (Aggarwal et al., 2009). Temperature increases may also have a minor impact on the nutritional content of cereals and pulses, according to research.

It should be noted that the impact of environmental changes is expected to be very high in India due to greater reliance on agriculture, limited natural resources, an alarming increase in human and livestock population, changing land use patterns, and socioeconomic factors that pose a significant threat to meeting food, fiber, fuel, and fodder requirements. Snow melt, irrigation availability, the frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic transformation matters, soil erosion, and energy availability are all likely to have a significant impact on agricultural land-use as a result of global warming, affecting agricultural production and thus the nation's food security. Climate change may have both positive and negative effects on crops. A warming climate and decreasing soil moisture can also result in an increasing need for timely and frequent irrigation.

The major types of climate information needed by farmers before and during crop production are as follows (FAO 2019):

- Before the cropping season begins, an agrometeorological crop-risk analysis is performed to determine the most appropriate crop(s) based on crop water requirements and forecasted seasonal rainfall.
- Determination of the best planting date for a particular region based on rainfall onset.
- Seasonal climate outlooks, which can be used to prepare farmers for a variety of scenarios that may emerge during the season as a result of uncertainty in long-term weather forecasts. Crop contingency plans can be developed for a variety of situations.
- Three-day weather forecasts throughout the growing season, with a focus on the likelihood of extreme weather events; 10-day crop management advisories based on the forecasted weather.

Agromet Advisory Service scheme in India:

The Agrometeorological Advisory Service (AAS) provided by the India Meteorological Department (IMD), Ministry of

Earth Sciences (MoES), is a step towards contributing to weather-based crop/livestock management strategies and operations aimed at increasing crop output and food security. The current AAS system's primary focus is to collect and organize climate/weather, soil, and crop information, and to combine it with weather forecast to help farmers in making management decisions. This has aided in the development and implementation of operational tools to handle weather-related uncertainties for efficient agriculture in rapidly changing environments via agro-meteorological applications.

Table 1: Key milestones in the evolution of agromet services

Year	Advancement in Agromet Services
1932	Agromet services
1945	Farmers Weather Bulletin
1976	Agromet Advisory Services (AAS) at State Level
1991	AAS at Agro-Climatic Zone Level (130 Zones
2008	AAS at District Level (636 Districts
2012	Gramin Krishi Mausam Sewa (GKMS)
2018	Experimental AAS at Block Level (200 Blocks in 24 States) and plans to extend to ~ 6500 blocks
2019	Expanded Block-Level AAS & Digital Integration
2020	Weather-Based Insurance Integration
2021	Customized Crop-Wise Advisories & Increased Automation
2022	Scaling to Block Levels Nationwide & Climate Change Adaptation
2023	Data Integration and Interoperability & Public-Private Partnerships

AAS provide very special inputs to farmers in the form of advisories that can make a huge difference in agriculture output by taking advantage of benevolent weather and minimizing the negative impact of malevolent weather. This can transform India's face in terms of food security and poverty alleviation. In India, IMD, MoES, is operating an operational AAS, Gramin Krishi Mausam Sewa (GKMS), at the district level, which represents a small step towards agricultural management that is in tune with weather and climate variability, leading to weatherproofing for farm output. AAS defines the demands of the farming community by determining the information requirements of various groups of end-users. The primary need of the farmer has evolved as location-specific weather forecasting in quantitative terms. As a result, it was created and made active in June of 2008. Following that, a mechanism was created to integrate weather forecast and climatic information with agro-meteorological information to produce district-level agromet advisories outlining farm management actions to capitalize on favourable weather and mitigate the effects of adverse weather. To improve information dissemination, a system for communicating and disseminating agro-meteorological advisories has been created.

Application of ICT to address climate change issues

There is much scope for technological developments to reduce GHG emissions in the agricultural and livestock sector. For example, increases in crop yields and animal productivity will reduce emissions per unit of production. Such increases in crop and animal productivity will be implemented through improved management and husbandry techniques, such as better management, genetically modified crops, improved cultivars, fertilizer recommendation systems, precision agriculture, improved animal breeds, shelter management, improved animal nutrition, dietary additives and growth promoters, improved animal fertility, bio-energy crops, anaerobic slurry digestion manure disposal mechanisms and methane capture systems. And also in these line ICT could deliver promptly

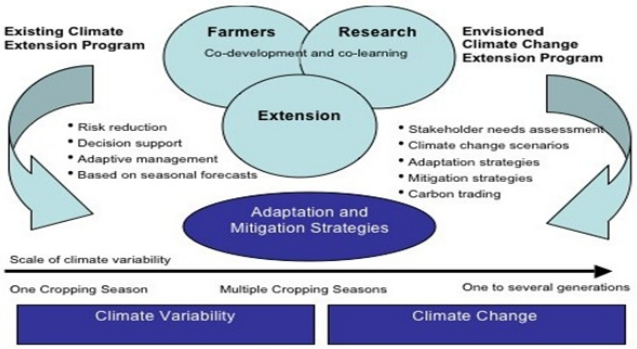
1. Awareness creation about climate resilient dairy husbandry practices.
2. Sensitization of line dept. officials and field functionaries about the adverse climate effect and adaptation practices.
3. Preparedness towards the external climate impact and implementation of appropriate measures.
4. Evolving the risk aversion strategies with multi-stakeholders.
5. Framing the cope-up methods for resilient practices and reduce the vulnerability.
6. Awareness on carbon trading and conservation agriculture.

For site specific weather forecast and Agromet Advisory Billetin Farmers can download and use some significant weather app

- "MAUSAM App" for location-specific forecast and warning: (https://play.google.com/store/apps/details?id=com.imd.masuam)
- "Meghdoot App" for Agromet advisory (https://play.google.com/store/apps/details?id=com.aas.meghdoot)
- "Damini App" for Lightning warning: Damini Lightning apps is developed by IITM-Pune and ESSO. The apps is monitoring all lightning activity which are happening in specifically for all india. This app provides alert, if lightning is happening near you by GPS notification. under 20 KM and 40 K. (https://play.google.com/store/apps/details?id=com.lightening.live.damini)

- Public Observation – IMD for Application provides weather information to users location wise. Users can also provide their feedback on this app. (https://play.google.com/store/apps/details?id=com.mausam.crowdsource)
- "Umang App" for UMANG (Unified Mobile Application for New-age Governance) is envisaged to make e-governance 'mobile first'. It is developed by Ministry of Electronics and Information Technology (MeitY) and National e-Governance Division (NeGD).
- (https://play.google.com/store/apps/details?id=in.gov.umang.negd.g2c)

The following Climate-Extension-Program framework will also depict the climate impact program at field level.



Fig,1: Framework of a Combined Climate Variability and Change Extension Program (Fraisse et al. 2009)

Disseminating information through extension in light of CSA

Agromet advisories are distributed to farmers via different multi-channel systems such as All India Radio and Doordarshan, private TV and radio channels, newspapers, the internet, and SMS. The National Bank for Agricultural and Rural Development, for example, sends out agromet warnings to farmers via SMS and IVR. In addition, in collaboration with the National Informatics Centre (NIC)/Agricultural Technology Management Agency (ATMA)/KVK/NABARD/Internet, several AMFUs have begun issuing agromet advisories via SMS. Agromet Advisories are also being disseminated in both regional and English languages via kisan SMS, a portal established by the Government of India's Ministry of Agriculture and Farmers Welfare. Currently, this service immediately benefits 21.69 million farmers. (Chattopadhyay and Chandras, 2018).

Extension approaches used in CSA

Addressing these global challenges necessitates generational adaptation and the application of new knowledge, which necessitates interaction and support from a diverse variety of organizations. Extension systems address a wide range of goals that include and extend far beyond the transmission of new technology. This includes responding effectively and responsively to domestic and foreign markets to reduce vulnerability and strengthen the voice of the rural poor. Extension systems can add to CSA in a variety of ways. The provision of agro meteorological services by the India Meteorological Department (IMD), Ministry of Earth Sciences, is a step towards contributing to weather-informed crop/livestock management strategies and operations aimed at increasing crop output and food security. IMD is running the Gramin Krishi Mausam Sewa (GKMS) project, which aims to service the farming community in various parts of the nation and has the potential to change any country's face regarding food security and poverty alleviation.

Innovative extension approaches for climate smart agriculture

Farmers registered mobile numbers received short text messages of 160-164 characters in the local tongue (Marathi). Based on weather warnings and contingency plans, farmers received no more than two SMS messages per week. To provide advisory services to farmers, one-page advisories in the shape of tables or posters related to weather prediction of agricultural operations required to be done were pasted on common display boards of villages. These advisors were dubbed Krishi Salah in the CCA initiative. Farmers were organized in groups because it is easier to connect and spread climate-related information to them in groups. Various committees were established in the village to oversee various components, such as the CCA project's village development committee (VDC). A committee had 10-15 members, and there was a 40-50% allocation for women in all committees (MANAGE, 2018).

Economic assessment of the AAS

According to a study conducted by the National Centre for Agricultural Economics and Policy Research in 1996 to evaluate the economic effect of weather forecast-based advisories in 1996, 2009, and 2015, farmers received a 10-25% economic benefit from the use of agromet advisory services. The National Council of Applied Economic Research estimated the economic benefit of these services in 2009 at Rs. 50,000 crores per year, which could be increased to Rs. 211,000 crores if the entire farming community in the nation used Agromet information in their agricultural activities. In 2015, the National Council of Applied Economic Research estimated the economic benefit of weather information use as a product of the proportion of farmers getting information. Crop-specific conversion factors were used to convert farmers' financial earnings to economic profits. At the moment, only 24 percent of farms are taking advantage of SMS services. When all farming households use Agromet Services, it can generate a net economic benefit of up to Rs. 3.3 lakh crores on the 22 major crops (Chattopadhyay and Chandras, 2018).

Key benefits from weather forecasting to different sectors:

The availability of timely weather information allows farmers to organize their operations so that not only costs and crop

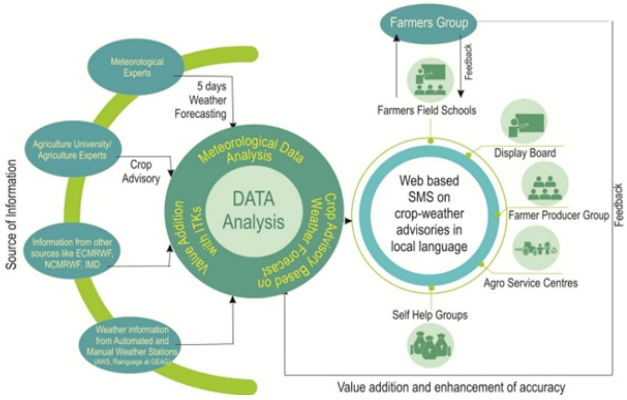
losses are minimized but yield gains are maximized. These weather forecasts aid in crop selection, crop variety, planting/harvesting dates, and investments in agricultural inputs such as irrigation, fertilizers, pesticides, herbicides, and so on. Small farmers with small cultivable land whose agricultural production is dependent on the monsoon are the largest beneficiaries. Unreliable monsoon knowledge could result in major losses for the farming community. Improved weather forecasts are being used by economic sectors all over the world to optimize their activities. According to the World Bank, the key sectors expected to benefit the most out of the 30 or so are:

Agriculture and Related Industries (Farm and Fisheries): The agriculture industry could benefit greatly for the following reasons:

- Accurate predictions would allow for timely agricultural sowing, ploughing, irrigation, and harvesting. Increased precision would help with fertilizers application timing, pest and disease management, and preventing over-applications that are washed or blown away.
- Forecasting could direct the cost-effective use of special preventive measures to mitigate the damage caused by wind and precipitation such as frost, hail, drought, and erosion.
- Forecasting could be used to optimize agricultural product storage and transportation, reducing post-harvest losses.
- Forecasting could improve pasture, animal, and fish production-rainfall impacts forage availability, and animal welfare is dependent on temperature and wind control.

Dissemination of Agro-meteorological Bulletins:

AAS's mission is to provide knowledge that will assist farmers in making the best use of weather and climate resources. It is assumed that farmers have pertinent knowledge and skills when disseminating information. Although concerted efforts are being made to establish two-way communications, the information flow is currently mainly one-way. Because agro-meteorologists at Agro-meteorological Field Units (AMFUs) interact with farmers less frequently, good communication and working relationships have been established with agricultural extension personnel such as Krishi Vigyan Kendras, Kisan Call Centres, and others to promote participatory methods for interactions with farmers. Due consideration is being given to the message's content, which must be pertinent to the farmer's upcoming weather-based decision making. This includes identifying weather and climate sensitive choices and interacting with weather forecasters from IMD Meteorological Centres and agriculture specialists from SAUs and ICAR. Under the Public Private Partnership mode, AMFUs disseminate supportive agromet advisories to farmers via various multi-channel systems such as All India Radio (AIR) and Doordarshan, Private TV and radio networks, Newspaper and Internet, SMS and IVRS. Agromet warnings are also distributed through the Ministry of Agriculture's Kisan Portal (http://farmer.gov.in).

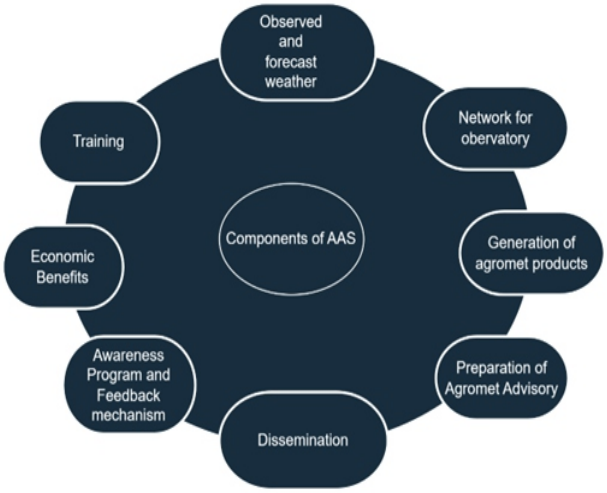


Fig,2: Framework for flow diagram for data generation in web-based advisories like

Agro-DSS portal

Essential components of agrometeorological advisory are:

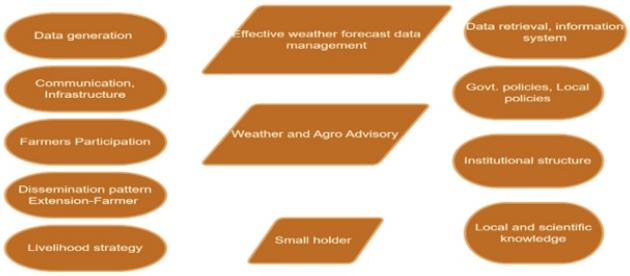
- Weather forecast.
- Warning of extreme weather events.
- Information related to location-specific normal sowing practices of crops.
- Farm management details, such as irrigation scheduling, insect and disease control spraying, nutrient (e.g., N, P, K) application, and so on.
- Suggested means for forecasted weather for farmers to take proper action based on their situation.
- Special alert for pest and disease outbreaks, as well as suitable control measures.
- Advice on livestock administration and animal husbandry.



Fig,3: Flow chart of a combined component of Agro-Advisory Services for better utility of AAS

Role of AAS in Improving Crop Production and Ensuring Food Security

Crop yield sensitivity to seasonal variations in climate is a significant cause for inter-year crop production. Drought, flood, unseasonal rain before harvest, hailstorm, and other natural disasters have reduced food grain output in India over the years. Climate variability has increased in the nation, both spatially and temporally. The number of days with no rain (dry spells) and heavy rain is rising (Singh et al. 2014), and a well-distributed monsoon season has become increasingly uncommon in recent years. New research in India on the sensitivity of grain yield to historical climate variability found that rice is more sensitive to climate variation than other grains such as maize, sorghum, finger millet, and pearl millet (Davis et al. 2019). A timely agromet advisory can help to minimize crop loss. For example, an advisory to harvest crops that have reached physiological maturity due to predicted rainfall can save the entire yield. Similarly, farmers can make crop selection decisions based on the general monsoon forecast for a given season. Choosing hardy crops with low crop water requirements may help to prevent crop loss in the case of agricultural drought. Another element is the dissemination of scientific cultivation practices by weather forecasts to farmers via AAS. This will ensure that farmers complete all agronomic and crop protection activities on time, resulting in increased crop output. Correct AAS can also reduce input material waste (fertilizers, plant protection chemicals, and planting material) and labour costs in the case of heavy rain.



Fig,4: Flow chart of a combined component of AAS and various stakeholders for better utility of AAS

Agro-Meteorological Support for Farm Management

After characterization of the agro-climate, including length of crop growing period, moisture availability period, distribution of rainfall and evaporative demand of the regions, weather requirements of cultivars, and weather sensitivity of farm input applications, weather-based farm advisories have been organized as a support system. This is all just background knowledge. The following are the components of a normal Agromet Advisory Bulletin for reaping the benefits of favourable weather and minimizing or mitigating the effects of adverse weather.

- District-specific weather prediction in quantitative terms for the next 5 days for rainfall, cloud, maximum/minimum temperature, wind speed/direction, and relative humidity, including forewarning of potentially damaging weather events and recommendations for crop protection.
- Weather forecast-based information on soil moisture state and recommendations for irrigation, fertilizers, and herbicide application, among other things.
- Advisories on sowing/planting dates and the suitability of carrying out intercultural operations covering the full crop spectrum from pre-sowing to post-harvest to assist farmers in their day-to-day cultural operations.
- A weather forecast-based warning system for key pests and diseases of important crops, as well as advice on plant protection measures.
- Spreading methods for manipulating crop microclimates, such as shading, mulching, other
- surface modification, shelter belts, frost protection, and so on, in order to protect crops under stressed conditions.
- Reducing agricultural production system's contribution to global warming and
- environmental degradation through prudent management of land, water, and farm inputs, especially pesticides, herbicides, and fertilizers.
- Animal health, shelter, and dietary advice.

Fig,5: Flow chart of a region-specific generation of Agro-Advisory Services at micro-level.

Constraints Involved with AAS

The primary bottleneck in the dissemination of AAS is the lack of linkage between institutional players due to deficiencies in quality weather data availability, data sharing, coordination, and communication. The accuracy of the medium-term forecast (lead time of 5 days) is the main determinant of AAS success, as the accuracy of seasonal forecasts (lead time of 1 month) is presently doubtful, and is intended for policymakers rather than farmers. Another cause is the availability of dedicated human resources for advisory preparation and dissemination. This is why weather and agriculture advisories are always effectively combined. There has also been no attempt to engage farmers in improving the content of AAS. This results in the development of AAS without regard for the needs and goals of farmers. Other causes include ineffective research programmes and insufficient use of information and communication technologies (ICTs), which leads to a low rate of AAS adoption (Singh et al. 2019). AAS content should be very location specific, focusing on specific crops produced, livestock, market facilities, and so on. Remote regions suffer from a lack of timely information due to inadequate communication infrastructure and services. The twenty-first century has seen a massive leap in information and communication

technologies (ICTs), and information dissemination is becoming less expensive by the day, with providing AAS as text messages becoming the most effective method of reaching a large number of farmers across the country. However, many extremely poor and marginalized farmers in India cannot buy a mobile phone. As a result, AAS providers should devise methods to include them in the information dissemination cycle as well.

Future Challenges

Extreme weather events such as heavy rain, cloud bursts, and hailstorms are causing extensive crop damage in many parts of India. Even though IMD issues 'nowcast bulletins' and 'special weather bulletins,' forecast accuracy needs to be better. With the advent of ICTs for AAS dissemination, the agency has been able to provide agencies to serve large numbers of farmers. However, many rural farms still lack access to mobile phones and the Internet. It has been observed that the same farmer receives different AAS for the same period from different AAS providing organizations, which confuses. Although the IMD issues block-level weather forecasts, AAS based on those forecasts is not upscaled to the national level. The final goal of AAS will be customized advisories for farmers. This will necessitate weather forecasts with farm-level spatial precision, farmer-level crop and soil intelligence, and massive computing power for AAS automation.

CONCLUSION

In this age of climate change, the significance of agromet advisory services is growing. Extreme weather events are becoming more common, presenting a significant threat to global crop production sustainability. This chapter has gone into great detail about weather-related risks in agriculture, what type of information farmers require, the current system of AAS creation and dissemination in India, their economic effect, constraints, and future challenges. The twenty-first century has seen a significant increase in computing capacity, and thus in the dissemination of AAS via ICTs. Despite these advances, if we view the country as a saw hole, the dissemination of accurate AAS at the right moment to farmers is lacking. The spatial resolution of the weather forecast has improved significantly, which has yet to be exploited in the shape of block-level AAS. Climate variability and change pose new threats and challenges to the current structure of AAS development and dissemination. Automation of AAS, further exploration of extension agrometeorology, and other opportunities are suggested for the immediate future.

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