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Evaluating the impact of agrometeorological advisory services on crop yields using propensity score matching method in Karnataka's rainfed regions

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सार – इस शोधपत्र में भारत के कर्नाटक राज्य के उत्तरी भाग के चार जिलों में कृषि उत्पादकता पर कृषि मौसम विज्ञान परामर्श सेवाओं (एएएस) के प्रभाव का आकलन किया गया है। हम विशेष रूप से 2024 में उनके बंद होने से पहले जिला कृषि मौसम विज्ञान इकाइयों (डीएएमयू) की भूमिका पर ध्यान केंद्रित करते हैं। अध्ययन में चार प्रमुख खरीफ फसलों, यानी अरहर, बाजरा, मक्का और ज्वार के लिए एएएस तक पहुंच और फसल पैदावार के बीच सहसंबंध की जांच की गई है, जिसमें प्रोपेंसिटी स्कोर मैचिंग (पीएसएम) पद्धति का उपयोग किया गया है।

हमारे परिणाम फसल पैदावार पर एएएस के महत्वपूर्ण सकारात्मक प्रभाव का संकेत देते हैं। अरहर, बाजरा, ज्वार और मक्का की पैदावार गैर-लाभार्थियों की तुलना में लाभार्थियों के लिए क्रमशः 24 किग्रा/एकड़, 41 किग्रा/एकड़, 52 किग्रा/एकड़ और 102 किग्रा/एकड़ अधिक है। इसका अर्थ है कि चारों जिलों में लगभग ₹962 ± 162 मिलियन का संभावित आर्थिक लाभ होगा, बशर्ते कि नमूने में पाए गए जिलों में गैर-लाभार्थियों का अनुपात समान हो। उल्लेखनीय रूप से, कृषि विज्ञान केंद्रों (केवीके) के परिसर में रणनीतिक रूप से रखे गए डीएएमयू ने इन सलाहों को प्रसारित करने में महत्वपूर्ण भूमिका निभाई है, खासकर कोप्पल और बल्लारी जिलों में, जहां 70% से अधिक किसानों ने प्रत्यक्ष या अप्रत्यक्ष रूप से एएएस तक पहुंच की सूचना दी है।

यह देखते हुए कि मौसम की परिवर्तनशीलता और कृषि पर इसके परिणामी प्रभावों में जलवायु परिवर्तन के साथ वृद्धि होने का अनुमान है, हमारे परिणाम कृषि पैदावार को बनाए रखने, यदि सुधार नहीं भी कर पाए तो, और छोटे किसानों को अनुकूलन में मदद करने के लिए डीएएमयू को फिर से स्थापित और मजबूत करके एएएस की सामग्री और प्रसार को बढ़ाने की आवश्यकता को इंगित करते हैं।

ABSTRACT. The impact of Agrometeorological Advisory Services (AAS) on agricultural productivity in four districts in the northern part of the state of Karnataka in India is assessed in this paper. We particularly focus on the role of District Agrometeorological Units (DAMUs) prior to their discontinuation in 2024. The study examines the correlation between access to AAS and crop yields for four major Kharif crops, *viz*., pigeon pea, pearl millet, maize, and jowar, using the Propensity Score Matching (PSM) method.

Our results indicate a significant positive impact of AAS on crop yields. Yields for pigeon pea, pearl millet, jowar, and maize are higher by 24kg/acre, 41 kg/acre, 52 kg/acre, and 102 kg/acre, respectively, for beneficiaries as compared to non-beneficiaries. This translates into potential economic gains of approximately 962 ± 162 million across the four districts, assuming a similar proportion of non-beneficiaries across the districts as encountered in the sample. Notably, DAMUs, strategically placed in the premises of the Krishi Vigyan Kendras (KVKs), have played a pivotal role in disseminating these advisories, especially in Koppal and Ballari districts, where over 70% of cultivators reported having accessed AAS either directly or indirectly.

Given that weather variability and its consequent impacts on agriculture are only projected to increase with climate change, our results indicate the need to enhance the content and dissemination of AAS by reestablishing and strengthening the DAMUs to maintain, if not improve, agricultural yields and help smallholder farmers adapt.

Key words – Agro-meteorological Advisory Services (AAS), Propensity Score Matching (PSM), District Agromet Units (DAMU), Crop Yields, Rainfed Agriculture.

1. Introduction

Weather and climaticvariability play a vital role in agricultural production, necessitating informed decision-making to maximize productivity and mitigate associated risks (Mangshatabam *et al*., 2023; Pham *et al*., 2021; Singh R *et al*., 2020). Weather variabilityaffects the crucial aspects of farming, such as crop growth and development, crop yields, pest infestation andthe prevalence ofcrop diseases (Skendzic *et al*., 2021; Doblas-Reyes*et al*., 2003). Moreover,itimpacts water availability and consequently, key agricultural operations such as irrigation scheduling, fertilizer and pesticide application, the timing of sowing and harvesting, and intermediate crop operations (Raj & Garlapati, 2020; Doblas-Reyes *et al*., 2003).

To enhance agricultural productivity and yield, it is important to align crop selection and cultivation practices with weather conditions and forecasts. Agrometeorological Advisory Services (AAS) provide integrated weather information and agricultural advisories, which have become important tools for farmers (Rathore *et al*., 2016; Tyagi A., 2011; Sivakumar *et al*., 2000). These services deliver localized weather forecasts and are aimed at helping farmers manage their activities more effectively. Accurate weather forecasts allow for better planning of sowing, irrigation and harvesting, while extended-range forecasts help anticipate dry spells or heavy rains, enabling preventive measures (Mangshatabam *et al*., 2023; Aggarwal *et al.*, 2010). AAS also provides warnings about potential pest and disease outbreaks, allowing farmers to take timely actions to protect their crops (Chaubey *et al*., 2019). Studies have shown that AAS contributes to higher yields by optimizing planting schedules, irrigation practices, and pest control measures (Chattopadhyay & Chandras, 2018). In West Africa, improved weather forecasts and advisories have led to better crop management and increased yields in millet and sorghum (Bacci *et al*., 2023). However, the effectiveness of AAS depends on factors such as farmers' access to information, literacy levels, and local extension services (Cegnar *et al*., 2023). The success of AAS varies with local agricultural practices, climate conditions and crop types. Despite challenges in quantifying the costs and benefits of agrometeorology programsespecially in developing countries (World Bank Report, 2015), the positive impact of AAS on farm productivity and risk mitigation is well-documented (Ansalehto *et al*., 1985; Maini & Rathore, 2011; NCAER, 2020; Nannewar *et al*., 2023).

In India, the India Meteorological Department (IMD) provides AAS to farmers across India under the centrally sponsored scheme ‘Atmosphere & Climate Research Modelling Observing Systems & Services (ACROSS)’ of the Ministry of Earth Sciences (MoES) of the Government of India. This scheme isalso known as *Gramin Krishi Mausam Sewa* (GKMS). This scheme facilitates the generation of medium-range weather forecasts at the district and block levels every five days. Agricultural advisories are then generated based on these forecasts (Rathore *et al*., 2011; Singh *et al*., 2023). Currently, these advisories are being generated by 130 Agromet Field Units (AMFUs) located at various State Agricultural Universities (SAUs), institutes of the Indian Council of Agricultural Research (ICAR), Indian Institutes of Technology (IITs), and similar institutions.About 199 localised, block-level units known as District Agrometeorological Units (DAMUs) were set up in 2019. They were located in the Krishi Vigyan Kendras, theextension institutions under the ICAR. The AMFUs and the DAMUs provided agrometeorological advisories in about 700 districts and 3100 blocks (GOI 2023). However, in 2024, DAMUs were discontinued by the Government of India. This paper evaluates the impact of AAS on crop yields in areas where the DAMUs provided advisoriesbefore they were discontinued. The analysis is based on a field survey across four of the six districtsof the Kalyana Karnataka (K-K) region in north Karnataka.

2. Data and methods

2.1. *Study area*

The state of Karnataka in India has the second-largest area currently cultivated under rainfed agriculture (Wani S.P *et al*., 2012; Rajegowda *et al*., 2009). Rainfed agriculture accounts for 68% of the net sown area in the state, which is utilized for food production (Deshpande, 2022). The K-K region includes six districts -Bidar, Kalaburgi, Yadgir, Raichur, Koppal and Ballari lying in three agroclimatic zones: the north-eastern dry, northeast transition, and northern dry agroclimatic zones (ACZs) (E-Krishi, 2022).

In the past eight years, all districts in the region encountered at least two years of deficit rainfall (Table 1). Agriculture in this region predominantly depends on the south-west monsoon. The observed rainfall variations significantly affect the region's agricultural activities, water resource management, and overall socio-economic development (Shanabhoga M.B. *et al*., 2020; Rajegowda *et al*., 2009).

2.2. *Survey design*

The Census of India 2011 (GOI, 2011) was used as the sampling frame for the study. Two of the six districts, *viz*., Raichur and Bidar, each have an Agrometeorological

TABLE 1

Rainfall categorization in the K-K region

District	2016	2017	2018	2019	2020	2021	2022	2023
Annual rainfall category K-K region Annual rainfall category K-K region								
Ballari	Deficit[1]	Normal[2]	Deficit	Normal	Excess[3]	Normal	Normal	Deficit
Raichur	Deficit	Normal	Deficit	Deficit	Excess	Excess	Normal	Deficit
Koppal	Deficit	Normal	Deficit	Normal	Excess	Normal	Excess	Deficit
Kalagburgi	Normal	Normal	Deficit	Deficit	Excess	Normal	Excess	Normal
Bidar	Excess	Excess	Deficit	Deficit	Excess	Normal	Excess	Normal
Yadgir	Deficit	Deficit	Deficit	Deficit	Excess	Normal	Excess	Normal

(*Source*: KSNDMC 2023)

[1]Deficit: D*eparture from normal rainfall is between -20% to -59%*
[2]Normal: *Departure of actual rainfall is between -19% to +19%*
[3]Excess: *Departure from normal rainfall is +20% or more*

TABLE 2

Number of households surveyed by village and block

District Name	Block Name	VillageName	Number of households surveyed
Yadgiri	Shorapur (with KVK)	Kolihal	111
	Yadgiri (without KVK)	Karengi	89
Koppal	Gangavathi (with KVK)	Mukkumpi	117
	Yelbarga (without KVK)	Ryavanki	83
Ballari	Hagaribommanahalli (with KVK)	Alaburu	103
	Sandur (without KVK)	Seliyanpanahalli	97
Kalaburgi	Jevargi (with KVK)	Desangi	115
	Afzalpur (without KVK)	Madra (B)	84

Field Unit (AMFU). These districts were, therefore, studied separately, and results of the same have been published in Nannewar *et al*. (2023).For the districts of Ballari, Kalaburgi, Koppal and Yadgir, two blocks were chosen from each district – onewith a Krishi Vigyan Kendra (KVK) and one without.The KVK isintegral tothe National Agriculture Research System (NARS), serving as a knowledge and resource centre to enhance the district's agricultural economy (ICAR, 2023). One village from each block was then selected randomly from the full list of Census villages. Thelist of cultivators obtained from the village revenue officer and Gram Panchayat office (decentralised unit of governance at the village level in India) was used as the sampling frame for the selection of households for the survey. A stratified random sample was then selected from this list. The stratification was done based onagricultural land ownership acrossfive strata - marginal farmers (owning less than 1 hectare), small farmers (1 to 2 hectares), semi-medium farmers (2 to 4 hectares), medium farmers (4 to 10 hectares), and large farmers (owning more than 10 hectares). The number of households surveyed in each village was determined using equation (1).

$$H_{i,b,d} = \frac{\text{No. of HH to be surveyed in a district} \times \sum_i H_{i,b,d}}{\sum_d \sum_b \sum_i} \tag{1}$$

where, $H_{i,b,d}$ is the number of households to be surveyed in village *i* in block *b* and district *d*. A total of 799 households were surveyed across eight villages in the four districts (Table 2).

Close-ended questionnaires were utilized to collect responses. The questionnaires were designed to capture demographicdetails, crop production details (by crop and season), input utilization, market access,and information about access to agricultural extension services, including AAS.

2.3. *Assessing the Impact of AAS*

The surveyed households reported accessing agrometeorological information from a variety of sources. For the purpose of this study, these households were categorized into two distinct groups based on thesource of information. The beneficiaries (B) group includes households that accessed agrometeorological information, categorized by the source of access. Direct Access refers to households receiving weather forecasts and agricultural advisories through mobile applications, text messages from the India Meteorological Department (IMD) and publications in print and electronic media. Indirect Access includes those who obtained this information *via* interactions with agricultural extension workers, input dealers, KVK officials, cooperative societies, and social networks (including other farmers and friends). The non-beneficiaries (NB) group include households that reported not accessing agrometeorological information from any source, *i.e.*, utilizing neither direct nor indirect channels for weather or agricultural advisory information.

Weuse the Propensity Score Matching (PSM) method toassess the impact of AAS on crop yields for four major crops in the region - Pigeonpea, Maize, Pearl Millet and Jowar (Sorghum). PSM is a statistical technique typically used to estimate the impact of a treatment or intervention in observational studies.

The PSM method involves three steps - First, a propensity score is calculated for each cultivator household. The propensity score is the predicted probability of receiving the treatment given the observed covariates which is estimated using the logistic regression method in this study. Second, the treatment group units are matched with the control group units. Several matching algorithms are available for this step, such as nearest neighbor matching, cardinal matching, full matching, etc. We use the nearest-neighbor method, which is the most appropriate for our purposes, given the characteristics of our sample. In nearest-neighbor matching, each treated unit is paired with the control unit with the closest propensity score to ensure that similar cultivator households are compared across treatment and control groups. Third, the treatment effect is calculated by comparing the outcome between the treatment group units and their matched control group units. These steps, applied specifically to our problem of assessing the impact of AAS on crop yields in the KK region, are discussed in detail further.

In our study, the propensity score denotes the conditional probability of an individual cultivator accessing the AAS, given a set of observed socio-economic and input utilization covariates. The MatchIt Package in the R version 4.3.3 is used for the PSM. A binary 'group' variable was constructed to differentiate the beneficiaries of AAS, who constitute the treatment group, and the non-beneficiaries, who form the control group. Individual cultivators in the beneficiary category were assigned a value of 1, and those in the non-beneficiary category were assigned a value of 0. The covariates used are social category (Soc), gender (Gen), literacy level (Lit), availability of irrigation facilities (Irr), extent of chemical fertilizer use (Chem), extent of land for a particular crop (Land), manure use (Man), seed rate (SR), and plant protection value (PPV). Equation (2) isused to estimate the propensity score.

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 * Soc + \beta_2 * Gen + \beta_3 * Lit + \beta_4 * Irr + \beta_5 * Chem + \beta_6 * Land + \beta_7 * Man + \beta_8 * SR + \beta_9 * PPV \quad (2)$$

where,

ln [p/ (1- p)] represents the natural logarithm of the odds ratio.

β_0, (Intercept) : Baseline log-odds of a cultivator being a beneficiary when all the other covariates are zero.

β_1, $to\, \beta_9$: These coefficients represent each covariate's effect on the outcome's log odds. Each βvalue adjusts the log-odds ratio depending on the value of its corresponding covariate.

The logistic regression model assumes that the likelihood of someone benefiting from AAS is unrelated to their potential crop yields. We assume the ignorability/unconfoundedness assumption, which suggests that no unobserved confounding variable significantly influencesthe treatment assignment (access to AAS) and outcome (crop yields) after controlling for the observed covariates. The covariates have been selected based on our understanding, from the field surveys, of the factors influencing treatment assignment and outcomes. In addition, avariance inflation factor (VIF) of greater than or equal to 5 was used to check for multicollinearity among the covariates.

TABLE 3

Distribution of households by extent of landholding

	Marginal	Small	Semi-medium	Medium	Large
	Distribution of households by extent of landholding [All values in percentages]				
Koppal	39	27	21	11	0.5
Ballari	27	29	30	11	3
Kalaburgi	29	30	29	12	0
Yadgir	26	37	22	14	0.5

TABLE 4

Distribution of households by literacy levels of the head of the household

	Can read and write	Can read but cannot write	Can sign name	Can not read and write
Ballari	47	3	21	30
Kalaburgi	52	3	10	36
Koppal	39	2	15	45
Yadgir	29	2	11	58

The next step is to matchthe propensity score, which was done using the 'nearest neighbormethod'. The use of the nearest neighbor method allows the creation of a well-matched control group for comparison based on the propensity score, particularly as there is an imbalance in the number of cultivators who accessed AAS, *i.e.*, beneficiaries (treated), and those who did not access AAS, *i.e.*, non-beneficiaries (control) in the study area. A caliper of 0.1 was used in our study. The use of a caliper enhances the quality of matching by restricting the maximum allowable difference in the propensity scores between the beneficiary and non-beneficiaries of AAS. Additionally, the ratio of the control (AAS non-beneficiaries) to treatment (AAS beneficiaries) groups used in the PSM method is set to 2:1, ensuring improved balance and reduced bias in treatment effects estimates.

After the matching process, it is important to assess the quality of the matches *via* model diagnostics. The balance of covariates between the treated and control groups was examined using the '*standard mean difference*'. This measure compares the means of each covariate between the treated and control groups, normalized by their respective standard deviations. A standard mean difference close to zeroindicates negligible differences between groups, suggesting successful balancing of covariates. In this study, we have checked for the improvement in the imbalance of the covariates using both SMD ≤ 0.1 and ≤ 0.2.

The next step is to estimate the Average Treatment Effect (ATE) to quantify the yield difference between the beneficiaries and non-beneficiaries of the AAS. The result reflects the average impact of the treatment on crop yields, *i.e.*, the difference in yieldsfor particular crops between beneficiaries and non-beneficiaries.

3. Results and discussion

3.1. *Demographic Details of the Study Area*

Tables 3 and 4 show the distribution of surveyed households by landholding size and literacy levels of the head of the household, respectively. Marginal and small landholders constitute the majority in all four districts. 72% of the surveyed households belong to Other Backward Classes (OBCs), while the remaining 16% and 12% of the households belong to the Scheduled Castes (SC) and Scheduled Tribes (ST), respectively. Forty-two per cent of the surveyed heads of households (HoH) could not read and write.

There is a significant disparity in access to irrigation across the four districts, with the highest proportion of

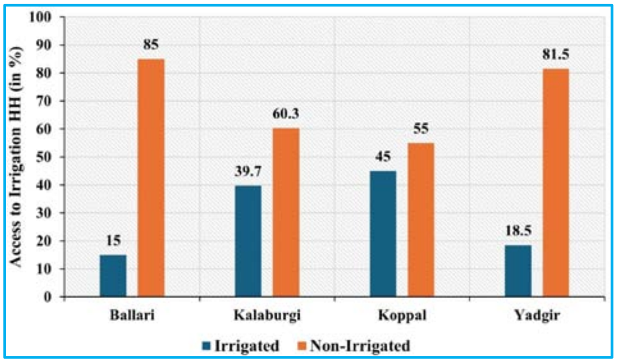

Fig. 1. Access to irrigation across surveyed households in the four districts of Kalaburgi, Koppal, Ballari and Yadgir

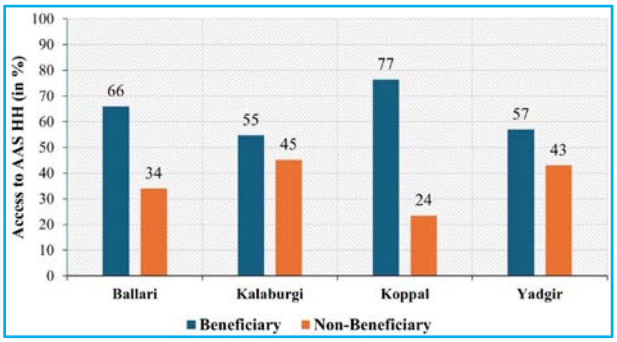

Fig. 2. Access to AAS of HH in the study area

households with access to irrigation in Kalaburgi, followed by Koppal, Yadgir, and Ballari (Fig. 1). Overall, about 70 per cent of the surveyed cultivators reported having no access to irrigation.

There is a higher proportion of beneficiaries (*i.e.*, those who access AAS either directly or indirectly) in regions where District Agrometeorological Field Units (DAMU) had been instituted in Krishi Vigyan Kendras (66% in Ballari, 77% in Koppal and 57% in Yadgir). Among the four districts, Kalaburgi is the only one in which the AAS is prepared and distributed by AMFU Raichur, *i.e.*, there is no DAMU in this district. It was observed thatthe presence of DAMUs has improved access to AAS in the study area (as compared to those reported in Nannewar *et al.*, 2023). This is also evident from the fact that 69% of the cultivators in the threedistricts with operational DAMUs are direct beneficiaries who receive either agricultural advice or meteorological forecasts through mobile apps, text messages, or other media.

3.2. *Impact of access to AAS on crop yields*

The impact of AAS on crop yields has been studied for four major *kharif* crops grown in the study area, *viz.*, pigeon pea, pearl millet, maize and jowar. Table5 shows the number of beneficiaries and non-beneficiaries for these crops.

TABLE 5

Number of beneficiaries and non-beneficiaries of AAS for selected crops

	Beneficiaries	Non-Beneficiaries	Total
Pigeon pea	176	122	298
Maize	171	66	237
Pearl Millet	89	29	118
Jowar	57	22	79

TABLE 6

Categorical Variablesused in the Logistic Regression Model

Variables	Levels	Values	Reference level
Social Category	3	OBC SC ST	OBC
Access to AAS	2	Beneficiaries (B) Non-Beneficiaries (NB)	NB
Literacy levels	4	Can read and write Can read but cannot write Can sign name Cannot read and write	Can read and write
Gender	2	Female Male	Female
Access to Irrigation	2	Irrigated Non-Irrigated	Irrigated
Ownership of mobile phones	2	Yes No	Yes

The covariates used in PSM analysis to assess the impact of AAS on crop yields include categorical and continuous variables (Table 6).However, the variable for land quality was not included due to significant difficulties in obtaining precise data for each cultivator's plot. This is a limitation of this study as variations in land quality can influence agricultural outcomes. Therefore, we used one - and two-way ANOVAto understand the relationship between the covariates used in the PSM analysis.Here, we demonstrate the detailed results for the

TABLE 7

Results of the One-way ANOVA test for Pigeonpea

Variables	Access to AAS		ANOVA results		
Mean	Beneficiaries	Non-beneficiaries	F-value	Df	p-value
Chemical fertilizers (kg/acre)	101	99.8	0.01	273	0.91
Manure application rate (kg/acre)	185	242	0.57	250	0.45
Seed application rate (kg/acre)	7.8	7.3	0.34	292	0.54
Plant protection value (Rs./acre)	2392	3217	8.6	274	0.004**
Extent of land (acre)	4	3.6	1.45	296	0.229

TABLE 8

Summary of Two-Way ANOVA results for Pigeon pea cropDependent Variable: Crop Yield

Variables	Degrees of Freedom	F-Value	p-Value	Significance
Social Category	2	4.005	0.0192*	*
AAS	1	0.436	0.5096	ns
Social Category:AAS	2	0.179	0.836	ns
Literacy Level of HoH	3	1.22	0.303	ns
AAS	1	0.618	0.433	ns
Literacy Level of HoH:AAS	3	0.43	0.732	Ns
Gender of HoH	1	1.325	0.251	ns
AAS	1	0.53	0.467	ns
Gender of HoH:AAS	1	0.133	0.716	ns
Ownership of Phone	1	2.761	0.0977.	ns
AAS	1	0.428	0.5137	ns
Ownership of Phone:AAS	1	4.075	0.0444*	*
Access to Irrigation	1	19.984	1.12e-5***	***
AAS	1	0.292	0.5894	ns
Access to Irrigation:AAS	1	4.612	0.0326*	*

pigeon pea crop and then present the overall results for all four crops. The results of the one-way ANOVA test are shown in Table 7. Plant protection value differs significantly between beneficiaries and non-beneficiaries and can be a confounding variable that could bias the estimation of the impact of AAS on the pigeon pea yields.

The relationship between pigeon pea yields, the categorical variables used, and their interaction with access to AAS is analysed using the two-way ANOVA test (Table 8). The results show a significant effect of social category on yields. This is likely due to the higher access to various inputs and extension sources among cultivators belonging to the OBC category compared to those from the SC and ST categories. This observation has also been highlighted in other studies (*e.g.*, Kaur, Srinivas, and Bazaz, 2021). However, the interaction between social category and access to AAS was insignificant, suggesting that the impact of social category on pigeon pea yields does not vary across AAS beneficiaries and

TABLE 9

Summary of balance measures before and after matching- Illustrated for Pigeon Pea

	Means Treated	**Means Control**
	Before Match	
Propensity score	0.622	0.545
Extent of crop	4.066	3.625
Chemical Fertilizers	101.360	99.809
Manure application rate	185.149	242.388
Seed application rate	7.748	7.385
Plant Protection Value	2392.180	3217.069
Social Category		
OBC	0.773	0.730
SC	0.222	0.246
ST	0.006	0.025
Literacy Level of HoH		
Can read and write	0.415	0.418
Can read but cannot write	0.028	0.016
Can sign name	0.091	0.139
Illiterate	0.466	0.426
Gender of HoH		
Female	0.114	0.131
Male	0.886	0.869
Availability of Phone		
No	0.074	0.041
Yes	0.935	0.941
Access to Irrigation		
Irrigated	0.260	0.269
Non-irrigated	0.740	0.731
	After Match	
Propensity score	0.61807	0.61760
Extent of crop	4.012	3.741
Chemical Fertilizers	90.928	96.694
Manure application rate	191.146	163.345
Seed application rate	7.598	7.645
Plant Protection Value	2329.588	2319.093
Social Category		
OBC	0.763	0.805
SC	0.231	0.195
ST	0.006	0.000
Literacy Level of HoH		
Can read and write	0.420	0.488
Can read but cannot write	0.018	0.012
Can sign name	0.089	0.092
Illiterate	0.473	0.408
Gender of HoH		
Female	0.118	0.095
Male	0.882	0.905
Availability of Phone		
No	0.065	0.059
Yes	0.935	0.941
Access to Irrigation		
Irrigated	0.260	0.269
Non-irrigated	0.740	0.731

TABLE 10

Summary of the Standard Mean differences before and after PSM – Illustrated forPigeon Pea

	SMD (Before Match)	**SMD (After Match)**
Propensity score	0.6222	0.0038
Extent of crop (acres)	0.1251	0.0771
Chemical Fertilizers (CF)	0.0124	-0.0460
Manure	-0.0913	0.0444
Seed application rate	0.0630	-0.0081
Plant Protection Value (Rs. /acre)	-0.3337	0.0042
Social Category		
OBC	0.1031	-0.0988
SC	-0.0585	0.0855
ST	-0.2516	0.0787
Literacy Level of HoH		
Can read and write	-0.0066	-0.1381
Can read but cannot write	0.0723	0.0356
Can sign name	-0.1685	-0.0103
Illiterate	0.0795	0.1305
Gender of HoH		
Female	-0.0552	0.0746
Male	0.0552	-0.0746
Availability of Phone		
No	0.1257	0.0226
Yes	-0.1257	-0.0226
Access to Irrigation		
Irrigated	0.1098	-0.0202
Non-Irrigated	-0.1098	0.0202
Proportion of imbalance in SMD >=0.2	**5%**	**0%**
Proportion of imbalance in SMD >=0.1	**26%**	**5%**

non-beneficiaries. While owning a phone did not significantly affect crop yields on its own ($p = 0.0977$), the interaction between phone ownership and access to AAS was significant ($p = 0.0444$). This implies that AAS beneficiaries who own a phone might receive agrometeorological advice more efficiently or consistently, potentially impacting their yields differently as compared to beneficiaries who do not own a phone. Similarly, access to irrigation significantly impacts pigeon pea yields ($p = 1.12e-05$), influenced by AAS access

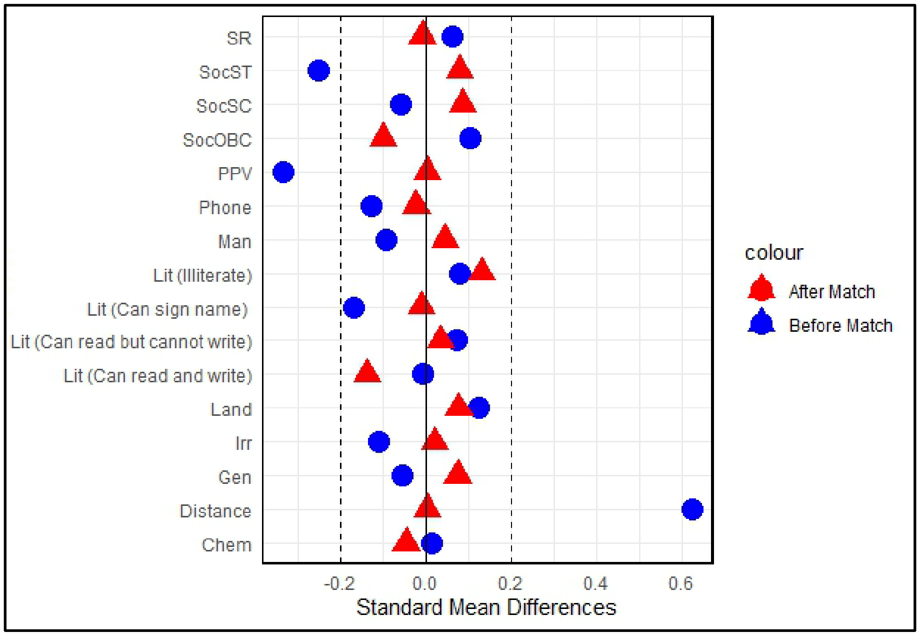

Fig. 3. Covariate balance measure by SMD threshold ≥ 0.2

TABLE 11

Yield difference between beneficiaries and non-beneficiaries of AAS

Crops	Beneficiaries (kg/ acre)	Non-beneficiaries (kg/ acre)	Yield difference (kg/acre)	95% CI
Pigeon pea	291	267	24	(22.1 – 26.4)
Peral millet	489	447	41	(35.8 – 47.5)
Maize	908	806	102	(79.3 – 125.3)
Jowar	492	440	52	(41 – 62.7)

(p = 0.0326). This indicates that farmers benefit from AAS advice on irrigation methods and scheduling of crop operations, which impacts their yields.

3.3. *Propensity Score Matching : Illustrative example of Pigeonpea Crop Analysis*

Before propensity score matching, there were 122 pigeon pea cultivators in the control group (non-beneficiaries) and 176 cultivators in the treated group (beneficiaries). Notable imbalances in the standard mean difference (SMD) were observed between the treated and control groups for some covariates, *viz*., the extent of area under cultivation, amount of chemical fertilizer used, social category, ownership of phone, and access to irrigation. These imbalances indicate a significant level of disparity and highlight the need for matching to ensure unbiased comparison.As shown in Table 9, the groups were significantly more balanced after matching. The effective sample size for pigeon pea cultivators after matchingwas 97 and 169 cultivators in the control and treatment groups, respectively. The summary of the standard mean difference (SMD) for all the covariates used in the logit model is given in Table 10. The SMD of the propensity score, an important indicator of the overall balance achieved through matching, shows a value of 0.622 and 0.0038 before and after matching, respectively, indicating that the matching procedure has successfully minimized the differences between the two groups. Similarly, the SMDs for both categorical and continuous variables are predominantly close to zero, reflecting a well-balanced matching as shown in Fig. 3.

Following the successful matching and balance verification process, the ATE for pigeon pea is estimated. Pigeon pea cultivators in the beneficiaries group have yields that are 24.3 ± 2.2 kg/acre higher than the non-beneficiaries group. This yield difference between

TABLE 12

Impact of AAS on Yields and Farm Incomes for Four Crops

Crop	No of cultivators surveyed	Yield Difference between B & NB		Extent of crop (acres/ household)	Market price (₹ /kg)	Value gap between Beneficiaries and Non-Beneficiaries (₹/acre)	Potential Income Difference	
		(kg/acre)	%				(₹/household)	%
Pigeon pea	298	24	9	3.8 ± 0.35	48.5 ± 1.6	1178 ± 113	4478 ± 595	9
Pearl Millet	118	42	9	1.8 ± 0.23	35.8 ± 3	1492 ± 243	2687 ± 556	9
Maize	237	102	13	3.2 ± 0.38	13 ± 0.5	1329 ± 167	4255 ± 736	12
Jowar	79	52	12	2.6 ± 0.55	26 ± 6.6	1349 ± 444	3508 ± 1373	13

TABLE 13

Potential increase in annual income with access to AAS for all four districts

	Pigeon pea	Pearl millet	Maize	Jowar
Potential increase in income with access to AAS [₹/household]	4478 ± 595	2687 ± 556	4255 ± 736	3508 ± 1373
Potential increase in income with access to AAS for all Non-Beneficiaries in the Sample ['000 ₹]	546 ± 72	77 ± 16	280 ± 48	77 ± 30
Potential increase in income with access to AAS for All Likely Non-Beneficiaries in Study Districts [₹ Million]	536 ± 71	76 ± 15	275 ± 47	75 ± 29

beneficiaries and non-beneficiaries signifies a significant positive effect of AAS on pigeon pea yields. The yield difference between the beneficiary and non-beneficiary groups forall four crops considered in this analysis is shown in Table 11. The highest yield difference of 102 kg/acre was observed for maize.

3.4. *Impact of AAS on farm incomes*

In this study, we employed a population multiplier approach to extrapolate the economic impact of AAS from a sampled population to the entire cultivator population across the districts of Koppal, Ballari, Kalaburgi and Yadgir (Table 12). The total number of cultivators in these four districts was 784,879 (E-Krishi, 2022).First, we calculated the proportion of non-beneficiaries within the sample who were growing the selected crop. We then determined the percentage of all sampled cultivators involved in growing this selected crop to assess the relevance of AAS within the sample. This was followed by calculating the proportion of cultivators in the four study districts who grow the selected crop, providing a basis for broader extrapolation. By applying the proportion of non-beneficiaries from the sample to this district-level cultivators population, we estimated the number of cultivators who could benefit from receiving AAS. Finally, we calculated the potential increase in revenue for these non-beneficiaries by multiplying the identified revenue gap per household with the proportion of non-beneficiaries across the four districts. Applying this approach across the four districts results in potential increases of:₹536 million ± 71 million for pigeon pea, ₹76 million ± 15 million for pearl millet, ₹275 million ± 47 million for maize, and ₹75 million ± 29 million for jowar (Table 13). This shows the economic gains achievable through extending AAS to non-beneficiaries across four major crops in four districts.

This methodology allows us to quantify the potential economic benefits of extending AAS to non-beneficiaries, thereby supporting targeted interventions to enhance agricultural productivity across these districts. It also highlights the potential per-household income increases and the substantial economic benefits at the district level. The substantial district-wide economic benefits calculated for selectedcrops reveal the underutilized potential of AAS, particularly for non-beneficiaries who currently do not access these services. This underscores the need to expand AAS coverage to improve individual farmer incomes in the studied regions.

4. Conclusions

This study analyzed the role of AAS in improving agricultural productivity in four districts of North Karnataka in India. Our findings underscore the pivotal role of Agrometeorological Services (AAS), disseminated through various extension networks. The integration of

District Agrometeorological Field Units (DAMUs) in the dissemination process played a key role in enhancing AAS access through public and technical extension channels before their discontinuation in March 2024. The strategic approach of situating the DAMUS in the Krishi Vigyan Kendras was particularly effective in districts like Koppal and Ballari, where 81% and 71% of the surveyed cultivators in the district reported having accessed AAS through direct extension sources.

Our analysis shows thataccess to AAS has a significant and positive correlation with crop yields, especially for Kharif crops such as pigeon pea, pearl millet, maize, and jowar in predominantly rainfed districts. Beneficiaries of AAS show yields that are higher than those of non-beneficiaries by 24 kg/acre (9%), 41 kg/acre (9%), 52 kg/acre (12%), and 102 kg/acre (13%) for pigeon pea, pearl millet, jowar and maize, respectively. If translated into potential economic benefit, this yield difference can lead to enhanced annual incomes amounting to about Rs.962 million (±162 million) across all four crops and districts. This is assuming a similar proportion of non-beneficiaries across districts as in the sample.

These results underscore the direct economic benefits realized by access to AAS and highlight the potential gains that could be achieved if AAS were more broadly available. Extending AAS coverage is thus recommended not only to boost agricultural yields but also to secure the livelihoods of smallholder farmers in regions that are vulnerable to climate variability. This strategic expansion could have significant implications, even for designing programs for climate change adaptation in rainfed areas.

The results of this study also highlight the critical need for continued support to theDistrict Agrometeorological Field Units instead of their discontinuation. This would be important forsustaining the gains in agricultural productivity facilitated by AAS. Further strengthening and improvements in the functioning of the DAMUs can be considered to ensure that they also play an important role in ensuring strong adaptation measures for the most vulnerable section of farmers across the country.

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