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RESEARCH ARTICLE

Hyperlocal data documentation for farmer empowerment through phygital services

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Abstract

The study explores the documentation and utilisation of hyperlocal agricultural data through the mobile agri support services (MASS) initiative implemented in 2024 in 3 aspirational districts of Telangana viz., Kumuram Bheem Asifabad, Jayashankar Bhupalpally, Khumuram and Bhadradri Kothagudem. The initiative integrates physical and digital (phygital) approaches to enhance the accessibility, precision and timeliness of agricultural services for smallholder farmers. A total of 1000 farmers were surveyed using participatory rural appraisal (PRA) techniques, focus group discussions (FGDs) and structured interviews to assess socio-economic profiles, constraints and technology adoption patterns. This study analysed hyperlocal agricultural data from 6 villages in 3 aspirational districts of Telangana covering 1465 households and 1418 farmers cultivating 150.3–385.4 ha per village with limited irrigation (10.2–200.3 ha). Paddy, cotton and red gram were the major crops, with borewells as the main irrigation source and no marketing facilities. The FGDs revealed that 83–100 % of farmers faced high input costs, price fluctuations, weak extension services, limited technology access and allied sector constraints, while socio-economic data showed predominance of middle-aged, marginal, low-income farmers with high dependence on moneylenders and low access to agro-advisories, indicating significant structural and institutional gaps. The study concludes that hyperlocal data, when integrated within a phygital extension framework, enables need-based advisories, efficient resource utilisation and inclusive service delivery. The MASS model demonstrates a scalable approach to strengthening agricultural extension, fostering farmer empowerment, institutional innovation and profitability through real-time, localised data-driven interventions.

Keywords: constraints; focussed group discussion; farmer empowerment; mobile agri support services; participatory rural appraisal; phygital extension; Telangana

Introduction

In the era of digital transformation, agriculture increasingly depends on data-driven decision-making to enhance productivity, sustainability and profitability. While macro-level data provides general trends, it often fails to capture the localised realities faced by smallholder farmers. Hyperlocal data, being accurate, contextual and site-specific, bridges this gap by capturing and reflecting the real -time conditions of individual farms and villages. The present study recognises that empowering of farmers begins with understanding their local environment. By systematically collecting and analysing data on soil health, water availability, cropping patterns, pest presence and climate variability, hyperlocal datasets enable precise and timely interventions.

Through the mobile agri support services (MASS) platform a collaboration between Professor Jayashankar Telangana Agricultural University (PJTAU), EEI (Extension Education Institute) and EEEIPL (Evergreen Energy Enterprises (Ind) Private Limited), farmers will receive both physical (capacity buildings, soil testing, usage of drones, agri-inputs etc) and digital (apps, advisories, video conferencing etc) support. The MASS vehicle acts as a two-way "phygital" bridge that not only delivers services to farmers' doorsteps but also captures field-level data to inform future advisories and policies. According to Food and Agriculture Organization of the United Nations (FAO), the emerging paradigm focuses on linking farmers with dynamic datasets, weather, soil, remote sensing, pest alerts and translating those datasets into customised, operational recommendations. The FAO argues that such data-driven advisory models enhance decision accuracy, reduce information asymmetry and improve input optimisation especially in smallholder contexts (1)

The MASS intervention is a structured, hyperlocal and phygital (physical + digital) extension model designed to address technological, economic, environmental and institutional gaps identified in aspirational districts such as Kumuram Bheem Asifabad, Jayashankar Bhupalpally and Bhadradri Kothagudem. It integrates field-level facilitation with digital advisory systems to enhance farmers' productivity, resilience, income stability and aspirations. This model enhances farmers' access to personalised agro-advisories, promotes climate-resilient and precision practices and strengthens market linkages. By closing the loop between data

collection, analysis and service delivery, hyperlocal data facilitates informed decision-making, reduced input costs and improved profitability. Moreover, it serves as a scalable, replicable framework for inclusive rural development, demonstrating how data can empower farmers and transform agriculture from the ground up (2, 3).

Hypothesis

H_0: There is no significant difference in agricultural performance and access to extension services among farmers across the selected villages. H_1: Significant differences exist in agricultural performance and access to services among farmers across the selected villages due to variations in irrigation, institutional support and socio-economic factor

Materials and Methods

Research design

The project primarily aimed to evaluate the MASS interventions realised by the farmers. Experimental research approach was followed for carrying out the study. The experimental research approach is a systematic method used to establish cause-and-effect relationships between variables. In this approach, the researcher deliberately manipulates one independent variable (socio economic profile) and observes its effect on a dependent variable (MASS intervention) while controlling other influencing factors.

Sampling procedure

A multi-stage purposive and random sampling technique was used for the selection of state, districts, mandals, villages and respondents:

Telangana was selected purposively as the site of MASS implementation as depicted in Fig. 1. Three aspirational districts Kumuram Bheem Asifabad, Jayashankar Bhupalapally and Bhadradri Kothagudem were chosen based on their backwardness index and depicted in Fig. 2. Two mandals per district were randomly selected. One representative village from each mandal was chosen, totaling 6 sample village. The 600 farmers were selected randomly from intervention villages to form the experimental group and 400 farmers were selected from nearby non-intervention villages to serve as the control group. The final sample comprised 1000 respondents, ensuring adequate power for statistical analysis. Data was collected from the 600 respondents using Participatory Rural Appraisal (PRA) techniques, focussed group discussion (FGDs) and well-structured interview schedule. Socio economic profile included farmer demographics and behavioural factors: age, gender, education, landholding, farming experience, income, risk-taking ability, mass media exposure, extension participation, decision-making behaviour and use of agro-advisories.

Tools for data collection

A structured interview schedule was developed in English, translated into Telugu and validated through expert review.

Data analysis techniques

The collected data was coded, tabulated and analysed using appropriate statistical tools to assess the impact of the MASS intervention on farmers' aspirations and related variables. The following statistical techniques were employed:

Frequency distribution and percentages were used to analyse categorical variables, socio-economic characteristics (age group, education level, landholding category) and constraints identified. This facilitated understanding of the distributional patterns of respondents across treatment and control groups. Class interval is used to categorised respondents into low, medium and high categories and arithmetic means to determine the central

Fig. 1. Map of India showing Telangana state (Source: www.alamy.com).

Sl. No	District	District Map	Number of Villages
1	Kumrum Bheem Asifabad		434
2	Badadri Kothagudem		479
3	Jayashankar Bhupalpally		223

Fig. 2. Selected aspirational districts (Proof of concept) (Source: NITI Aayog PoC).

tendency of respondent scores. The Z-test was employed to determine whether there was a statistically significant difference between the mean aspiration scores of treatment and control groups and pre and post intervention measurements. The test was applied under the assumption of large sample size and known/ estimated population variance.

Results

Hyperlocal data through participatory rural appraisal

Participatory rural appraisal (PRA) techniques were employed to generate hyperlocal data across the selected villages of the 3 aspirational districts Kumuram Bheem Asifabad, Jayashankar Bhupalpally and Bhadradri Kothagudem. The data revealed that paddy, cotton and red gram were the predominant crops cultivated by farmers under rainfed conditions, with limited irrigation sources such as canals and bore wells.

Results from Table 1 indicated that pertaining to the data generated in PRA through the techniques of resource map, Venn diagram and pie diagram reveals that, selected villages comprised 1465 households with a total population exceeding 8000 and 1418 farmers. Total cultivable land across villages ranged from 150.3 ha to 385.4 ha, of which irrigation coverage varied between 10.2 ha and 200.3 ha, indicating strong dependence on rainfed agriculture. Paddy (40–200 ha), cotton (40–150 ha) and red gram (2–45 ha) were the dominant crops. Borewells (4–60 per village) constituted the primary irrigation source, while marketing facilities were absent in all villages. Old and local less yielding varieties are grown by the farmers of selected villages of 3 aspirational districts in paddy, cotton and redgram, less sources of irrigation, rainfed farming is predominant, poor availability of agriculture labour, less area under irrigation, mono cropping is followed, no social institutions in the villages and the support offered by the outside institutions is not encouraging, in few villages good number of live stock is available giving scope for establishment of livestock based enterprises by linking with the institute NRC-Meat and other dairy firms, transport and market facility are not available, which is leading to storage and post harvest losses and driving towards distressed sales. The offices of agriculture and allied sectors were not located in the villages, there by the farmers are deprived of access to latest agro advisories due to poor contact of these officers.

Constraints identified through focus group discussions (FGDs)

Focus group discussions conducted in each village helped identify and classify farmers' constraints under economic, social, technological, environmental, institutional and policy dimensions.

Table 2 specified that FGDs (n = 30 farmers per village) revealed that 100 % of respondents reported high input costs, unstable market prices, lack of soil testing facilities, inadequate access to crop insurance, labor shortages, weak cooperative systems, inefficient subsidies and poor infrastructure. Between 83–100 % reported limited access to modern technologies, poor extension services, lack of climate-resilient knowledge and dominance of middlemen. Allied sector constraints such as poor breed quality, inadequate veterinary services and rising feed costs were reported by 100 % of respondents.

Socio-economic profile of farmers

From the Table 3 it is evident that the socio-economic analysis of the sample revealed that a socio-economic profiling (n = 600) indicated predominance of middle-aged farmers (70–92 %), males (87–95 %), marginal landholders (30–70 %) and low annual income groups (60–83 %). A majority depended on moneylenders (50–71 %), exhibited low mass media exposure (43–75 %) and had low access to weather-based agro-advisories (45–89 %). These findings highlight structural, technological and institutional bottlenecks and underscore the necessity of hyperlocal, phygital extension systems to enhance productivity, resilience and farmer empowerment.

Discussion

Most farmers relied on traditional and locally adapted varieties; often low yielding compared to improved or hybrid varieties. This indicates a need for variety replacement programs and access to quality seed systems (2, 3). The absence of strong agricultural institutions within villages restricted farmers' exposure to scientific practices and formal support systems (4, 5). Livestock populations were relatively high in some areas, presenting opportunities to diversify income through dairy, goatery and poultry enterprises. However, linkages with veterinary and allied services were found to be weak (6). The PRA findings clearly demonstrate that while natural resources such as land and livestock are available, their productivity is constrained by poor institutional connectivity, low technological penetration and limited access to extension services (7).

Due to chronic shortage of agriculture labor, information service providers, poor capacity building facilities, poor market, post -harvest management and other infrastructural facilities, the farmers of these aspirational districts may be connected to the external markets, networked with the phygital services for offering timely and quality agro advisories through digital farmer-scientist interactions and promotion of entrepreneurial skills of these farmers on drones and other income generation activities like seed production, vermin compost preparation, organic farming, value addition etc. Soil testing facility has to be created to test the soils of these farmers regularly to apply soil test-based fertilisers to minimise the cost of cultivation and reduce the natural resources pollution. Especially the sustainable practices like direct seeded rice, alternate wetting and drying in paddy, integrated pest and disease management must be encouraged to practice in a big area to realise more carbon credits. Farmers felt imperative about drone technology; hence this must be promoted by the startups and other players to serve the needs of the farmers.

Hence, linking farmers with external markets, input suppliers and digital service providers through platforms like MASS become essential. By integrating these villages into the phygital ecosystem, farmers can receive timely and need-based agro-advisories, enhancing both their productivity and profitability (8, 9). Information and Communication Technology (ICT) deployments historically struggled with adoption not because of lack of information availability, but because of mismatch between message relevance, message timing, user capability and local institutional context. They argue that ICTs succeed when they shift from "broadcasting information" to "co-creating solutions" involving farmer participation, iterative problem-solving and locally relevant framing (8).

Economic constraints were dominated by high input costs (especially seeds, fertilisers and pesticides), inadequate access to formal credit and unstable market prices that resulted in unpredictable incomes (2). Many farmers depended on informal moneylenders at high interest rates, which increased financial stress (10, 11).

Technological constraints included limited access to modern tools, low levels of mechanisation and poor awareness of integrated pest management (IPM) and integrated nutrient management (INM). Most farmers lacked soil testing facilities and knowledge of climate-resilient practices, making their production systems highly vulnerable to climatic fluctuations.

Institutional and infrastructural issues such as the absence of Farmer Producer Organizations (FPOs), poor road connectivity, limited post-harvest facilities and dominance of middlemen in marketing were major barriers to achieving fair prices (10, 11). In addition, policy-level inefficiencies delay in subsidy distribution, complex procedures for availing schemes and inconsistent support programs further weakened the farmers' capacity to adopt innovations.

Table 1. Details of selected villages collected through participatory rural appraisal techniques

Sl.No.	Particulars	Nayakapuguda	Gunturpally	Aggubudem	Nuzrulnagar	Polaram	Sayanapalli
1	Crop acreage (paddy, cotton, redgram)	Paddy – 40.0 ha Cotton – 150.0 ha Red gram – 25.0 ha	Paddy – 60.0 ha Cotton – 125 ha Red gram – 2 ha	Paddy – 200.0 ha Cotton – 120.0 ha Red gram – 15.0 ha Mango – 50.0 ha	Paddy – 70.0 ha Cotton – 40.0 ha Red gram – 45.0 ha Chilly- 25.0 ha	Paddy – 70.0 ha Cotton – 80.0 ha Red gram – 5.0 ha	Paddy -90.0 ha Cotton – 40.5 ha Red gram – 5.0 ha Maize – 80.6 ha
2	Varieties grown in paddy, cotton and Redgram	Paddy: Jai shri ram, Chintlu, Telanganasona Cotton: US 7067, Rasi NED, Sadan	Paddy: Amani, Telangana sona Cotton:USA7061, Kabaddi, saketh, US-51	Paddy: MTU-1064, MTU-1262, MTU-1264 and JGL-27356 Cotton: Meraka and Srirama Redgram: Telangana Kandi-1 (WRGE-93), Asha (ICPL-87119), Laxmi (ICPL-85063) and LRG-52	Paddy: MTU-1261, Jai shri ram, Telangana sona and BPT 5204 Cotton: NCS 1134, NCS 207, RCH 659 and US 4708 Redgram:WRGE-121, WRGE-97, Telangana Kandi-1 (WRGE-93) and Rudreswara (WRG-65)	Paddy: Swarna, Telangana sona and MTU-1064 Cotton: RC 22, 659, Tulasi and NCS 929 Redgram: WRGE-121, WRGE-97, Telangana Kandi-1(WRGE-93) and Rudreswara (WRG-65)	Paddy: Telangana sona, BPT 5204 and MTU-1064 Cotton: ofto, Shivanandi and RCH 659 Telangana Kandi-1 (WRGE-93), Asha (ICPL-87119), Laxmi (ICPL-85063) and LRG-52
3	Number of house holds	135.0	105.0	600.0	250.0	110.0	270.0
4	Number of population	350.0 male and 417.0 female	250.0 male and 180.0 female	2000.0 male and 2100.0 female	600.0 male and 350.0 female	400.0 male and 450.0 female	800.0 male and 915.0 female
5	Number of farmers	100.0	118.0	550.0	265.0	125.0	260.0
6	Total arable/ Cultivable land	222.6 ha	190.2 ha	385.4 ha	175.3 ha	150.3 ha	225.5 ha
7	Land under irrigation	80.9 ha	60.5 ha	200.3 ha	50.5 ha	10.2 ha	50.2 ha
8	Rain-fed area	141.6 ha	130.3 ha	185.2 ha	125.3 ha	140.3 ha	175.1 ha
9	Sources of irrigation						
	1.Canals (number)	1.0	1.0	2.0	0	1.0	1.0
	2.Borewells (number)	10.0	4.0	50.0	60.0	20.0	50.0
	3. Tanks (number)	0	0	0	0	1.0	0
10	Number of Agriculture Laborers	30.0	1.0	200.0	100.0	40.0	100.0
11	Area under black soils	400.2 ha	120.1 ha	150.5 ha	20.4 ha	120.3 ha	150.5 ha
12	Area under red soils	150.2 ha	70.3 ha	200.3 ha	100.4 ha	30.2 ha	75.3 ha
13	**Livestock**						
	Drought animals	20.0	3.0	70.0	10.0	20.0	40.0
	Sheep and goat	200.0	100.0	500.0	120.0	50.0	150.0
	Milch animals	110.0	30.0	300.0	80.0	100.0	90.0
	Poultry	400.0	100.0	500.0	150.0	200.0	250.0
14	**Institutions**						
	1. School	1	1	1	1	1	1
	2. Bank	No	No	1	No	No	No
	3.Health centre	No	1	1	No	No	No
	4.Agriculture department	No	No	1	No	No	No
	5.Verterniary department	No	No	1	No	No	No
	6.Horticulture department	No	No	No	No	No	No
	7. Gram panchayat	1	1	1	1	1	1
15	Transport facility	Available	Available	Available	Available	No	No
16	Marketing facility	No	No	No	No	No	No

Table 2. Constraints expressed by the sample farmers during the focus group discussion conducted in the selected villages of the project

Sl.No	Problem	Villages											
		Polaram		Sayanapally		Abbugudem		Gunturpally		Nyakapuguda		Nazrulnagar	
		F	%	F	%	F	%	F	%	F	%	F	%
	Economic constraints:												
1	High costs for inputs like seeds, fertilisers, pesticides and machinery.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
2	Limited access to formal credit, forcing them to rely on informal.	15.0	50.0	30.0	100.0	30.0	100.0	20.0	66.6	30.0	100.0	30.0	100.0
3	High-interest loans.	20.0	66.6	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0.	100.0
4	Unstable market prices for crops leading to unpredictable incomes.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
5	Insufficient storage facilities and transportation, leads to post-harvest losses and reduces farmers' bargaining power.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
	Social constraints:												
6	Limited access to education and training on modern farming techniques and sustainable practices.	20.0	66.6	30.0	100.0	30.0	100.0	30.0	100.0	27.0	90.0	28	93.3
7	Women farmers often face discrimination and have less access to resources and decision-making opportunities.	15.0	50.0	30.0	100.0	15.0	50.0	30.0	100.0	25.0	83.3	30.0	100.0
8	Subdivision of land due to inheritance laws leads to smaller, less viable farming units.	20.6	66.6	30.0	100.0	15.0	50.0	15.0	50.0	30.0	100.0	30.0	100.0
	Technological constraints												
9	Limited access to modern technology: Small and marginal farmers often lack access to advanced agricultural technologies, including precision farming tools and high-yield seed varieties.	25.0	83.3	27.0	90.0	28.0	93.3	30.0	100.0	20.0	66.6	15.0	50.0
10	Poor extension services: Inadequate agricultural extension services limit the dissemination of modern farming practices and technologies.	20.0	66.6	25.0	83.3	27.0	90.0	28.0	93.3	30.0	100.0	27.0	90.0
11	Lack of mechanisation: Many farms are not mechanised, leading to lower productivity and higher labor costs.	27.0	90.0	27.0	90.0	30.0	100.0	15.0	50.0	30.0	100.0	28.0	93.3
12	Poor knowledge on IPM	20.0	66.6	27.0	90.0	28.0	93.3	20.0	66.6	28.0	93.3	15.0	50.0
13	Low awareness on INM	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
14	Lack of knowledge on IFSs	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	10.00	15.0	50.0
15	Lack of Soil testing facilities	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
16	Non availability of quality seed of major cops	25.0	83.3	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
17	Poor knowledge on climate resilient practices in major crops	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
18	Lack of information on innovative water management techniques.	30.0	100.0	30.0	100.0	30.0.	100.0	30.0	100.0	30.0	100.0	28.0	93.3

Environmental constraints													
19	Climate change: Changing weather patterns, increased frequency of extreme weather events and rising temperatures adversely affect crop yields.	20.0	66.6	30.0	100.0	30.0	100.0	30.0	100.0	27.0	90.0	28.0	93.0
20	Water scarcity: Over-reliance on groundwater and inefficient irrigation practices lead to water scarcity and depletion of water tables.	15.0	50.0	30.0	100.0	15.0	50.0	30.0	1000	25.0	83.3	30.0	100.0
21	Soil degradation: Overuse of chemical fertilisers and pesticides, along with poor land management practices, degrade soil health.	20.0	66.6	30.0	100.0	30.0	100.0	30.0	1000	27.0	90.0	28.0	93.3
22	Pest and disease outbreaks: Increased vulnerability to pests and diseases due to monocropping and lack of crop diversification.	15.0	50.0	30.0	100.0	15.0	50.0	30.0	100.0	25.0	83.3	30.0	100.0
23	Lack of knowledge on sustainable practices to improve the carbon credits	20.0	66.6	30.0.	100.0	15.0	50.0	15.0	50.0	30.0	100.0	30.0	100.0
Situational constraints													
24	Poor irrigation facilities	20.0	66.6	27.0	90.0	28.0	93,3	20,0	66.6	28,0	93,3	15,0	50,0
25	Soil fertility depletion	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
26	Inadequate access to crop insurance	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.-	100.	15.0	50.0
27	Labor shortages	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
28	Poor knowledge on compliance with regulations	25.0	83.3	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
29	Facing difficulty in managing weeds	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
30	Lack of knowledge on value addition	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	28.0	93.3
31	Poor post-harvest management facilities	20.0	66.6	27.0	90.0	28.0	93.3	20.0	66.6	28.0	93.3	15.0	50.0
32	Lack of FPOs	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
33	Lack of knowledge on processing techniques in major crops	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	15.0	50.0
Policy-related constraints													
34	Inefficient subsidies and support programs: Subsidies and support programs often do not reach the intended beneficiaries or are not implemented effectively.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
35	Complex regulatory Environment: Complicated and often unclear regulations can hinder farmers' ability to innovate and adopt new practices.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	28.0	93.0
36	Limited implementation of reforms: Slow and inconsistent implementation of agricultural reforms affects farmers' ability to benefit from policy changes.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
Institutional constraints													
37	Weak cooperative movement: Inadequate functioning of cooperative societies affects collective bargaining power and access to resources.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
38	Poor infrastructure development: Lack of rural infrastructure, including roads, electricity and telecommunications, hampers agricultural productivity and access to markets.	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	28.0	93.3

Market constraints													
39	Middlemen dominance: The presence of middlemen in the supply chain often leads to reduced profits for farmers.	27.0	90.0	27.0	90.0	30.0	100.0	28.0	93.3	30.0	100.0	28.0	93.3
40	Export barriers: Regulatory barriers and lack of information on international markets limit farmers' ability to export their produce.	20,0	66.6	27.0	90.0	28.0	93.0	20.0	66.6	28.0	93.3	15.0	50.0
41	Poor marketing infrastructure.	27.0	90.0	27.0	90.0	30.0	100.0	28.0	93.3	30.0	100.0	28.0	93.3
Allied activities constraints													
***Dairy farming*:**													
42	Poor breed quality	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
43	Inadequate veterinary services	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
44	Lack of cold storage facilities	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
Poultry farming:													
45	Poor knowledge on disease management	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0
46	Lack of proper marketing channels.	20.0	66.6	27.0	90.0	28.0	93.3	20.0	66.6	28.0	93.3	15.0	50.0
47	Rising feed costs	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0	30.0	100.0

Table 3. Distribution of sampled farmers according to their age

Sl.No.	Variable	Category	Polaram n = 100	Nayakapuguda n = 100	Sayanapalli n = 100	Nazrulnagar n = 100	Abbugudem n = 100	Gunturupally n = 100
1	Age	Young age (0-33)	10 (10 %)	15 (15 %)	24 (24 %)	18 (18 %)	12 (12 %)	7 (7 %)
		Middle age(33–64)	89 (89 %)	80 (80 %)	70 (70 %)	75 (75 %)	86 (86 %)	92 (92 %)
		Old age (>64)	1 (1 %)	5 (5 %)	6 (6 %)	7 (7 %)	2 (2 %)	1 (1 %)
2	Gender	Male	89 (89 %)	92 (92 %)	95 (95 %)	87 (87 %)	90 (90 %)	91 (91 %)
		Female	11 (11%)	8 (8 %)	5 (5 %)	13 (13 %)	10 (10 %)	9 (9 %)
3	Education	Illiterates	24 (24 %)	40 (40 %)	25 (25 %)	38 (38 %)	10 (10 %)	27 (27 %)
		Primary schooling (up to 5th class)	62 (62 %)	52 (52 %)	40 (40 %)	51 (51 %)	80 (80 %)	60 (60 %)
		Upper primary schooling (up to 8th class)	-	-	-	-	-	
		Secondary school (up to 10th class)	14 (14 %)	8 (8 %)	35 (35 %)	11 (11 %)	10 (10 %)	13 (13%)
4	Farming Experience	Low Farming experience	10 (10 %)	15 (15 %)	24 (24 %)	18 (18 %)	12 (12 %)	7 (7 %)
		Medium Farming experience	50 (50 %)	60 (60 %)	60 (60 %)	55 (55 %)	56 (56 %)	72 (72 %)
		High Farming experience	40(40 %)	25 (25%)	16 (16 %)	27 (27 %)	32 (32 %)	21 (21 %)
5	Land holdings	Marginal farmers (<2 acres)	30 (30 %)	42 (42 %)	40 (40 %)	70 (70 %)	55 (55 %)	60 (60 %)
		Small farmers	30 (30 %)	29 (29 %)	25 (25 %)	20 (20 %)	20 (20 %)	25 (25 %)
		Semi medium farmers	26 (26 %)	19(19 %)	20 (20 %)	10 (10 %)	15 (15 %)	15 (15 %)
		Medium farmers	14 (14 %)	10 (10 %)	15 (15 %)	-	10 (10 %)	-
6	Annual income	Low annual income (<70069/-).	60 (60 %)	80 (80 %)	75 (75 %)	83 (83 %)	67 (67 %)	70 (70 %)
		Lower-middle(70070 – 273099)	40 (40 %)	20 (20 %)	25 (25 %)	17 (17 %)	33 (33 %)	30 (30 %)
7	Financial source	Bank loans	21 (21 %)	68(68 %)	26(26 %)	38(38 %)	35(35 %)	41(41 %)
		Relatives	8(8 %)	12(12 %)	12(12 %)	12(12 %)	4(4 %)	8(8 %)
		Money lenders	71(71 %)	20(20 %)	62(62%)	50(50 %)	53(53 %)	51(51%)
		Societies	-	-	-	-	8(8 %)	-
8	Crop grown	Paddy	30 (30 %)	25 (25 %)	20 (20 %)	40 (40 %)	80 (80 %)	10 (10 %)
		Cotton	50(50 %)	40 (40 %)	60 (60 %)	35 (35 %)	5 (5 %)	70 (70 %)
		Red gram	10 (10 %)	8 (8 %)	20 (20 %)	20 (20 %)	10 (10 %)	15 (15 %)
		More than 1 crop (paddy and cotton)	4 (4 %)	25 (25 %)	--	5 (5 %)	5 (5 %)	4 (4 %)
		More than 1 crop (paddy and red gram)	-	2 (2 %)	--	--	--	--
		More than 1 crop (cotton and redgram)	6 (6 %)	--	--	--	--	1 (1 %)
9	Usage of natural resources	Low usage of	55 (55 %)	63 (63 %)	68 (68 %)	60 (60 %)	74 (74 %)	58 (58 %)
		Medium	45 (45 %)	37 (37 %)	32 (32 %)	40 (40 %)	26 (26 %)	42 (42 %)
10	Information seeking behaviour	Low	40 (40 %)	25 (25 %)	45 (45 %)	37 (37 %)	14 (14 %)	58 (58 %)
		Medium	60 (60 %)	75 (75 %)	55 (55 %)-	63 (63 %)	86 (86 %)	42 (42 %)

11	Mass media exposure	Low mass	43 (43 %)	71 (71 %)	75 (75 %)	65 (65 %)	70 (70 %)	57 (57 %)
		Medium	30 (30 %)	21 (21 %)	15 (15 %)	20 (20 %)	18 (18 %)	25 (25 %)
		High	27(27 %)	8(8 %)	10(10 %)	20(20 %)	12 (12 %)	18 (18 %)
12	Risk taking ability	Low	65(65 %)	58 (58 %)	13 (13 %)	5 (5 %)	18 (18 %)	14 (14 %)
		Medium	12 (12 %)	18 (18 %)	70 (70 %)	72 (72 %)	13 (13 %)	6 (6 %)
		High	23 (23 %)	24 (24 %)	17 (17 %)	23 (23 %)	69 (69 %)	80 (80 %)
13	Decisioin making behaviour	Low	8 (8 %)	80 (80 %)	18 (18 %)	20 (20 %)	12 (12 %)	15 (15 %)
		Medium	31 (31 %)	11 (11 %)	72 (72 %)	55 (55 %)	21 (21 %)	75 (75 %)
		High	61 (61 %)	9 (9 %)	10 (10 %)	25 (25 %)	67 (67 %)	10 (10 %)
14	Weather based agro advisory services	Low	69 (69 %)	89 (89 %)	72 (72 %)	45 (45 %)	79 (79 %)	75 (75 %)
		Medium	31 (31 %)	11 (11 %)	28 (28 %)	55 (55 %)	21 (21 %)	25 (25 %)
		High	-	-	-	-	-	-
15	Extension participation	Low	65 (65 %)	25 (25 %)	70 (70 %)	8 (8 %)	80 (80 %)	28 (28 %)
		Medium	34 (34 %)	58 (58 %)	18 (18 %)	74 (74 %)	15 (15 %)	62 (62%)
		High	1 (1 %)	17 (17 %)	12 (12 %)	18 (18 %)	5 (5 %)	10 (10 %)

The profits of the farmers can be improved through group formation, connecting to markets, empowering them on post-harvest management and value addition. This kind of initiative of group formation may facilitate improving resource use efficiency and resilience towards climate change.

The requirements of two extreme categories of farmers in any given society like innovators and laggards can be addressed though developing farmer to farmer extension networks and creating a robust ecosystem to provide information through digital platforms. The artificial intelligence based technologies like drone based spray fluid application, sensor based irrigation etc have to be encouraged with proper supportive mechanisms and passing the advisories over digital platforms.

These findings underscore the importance of developing a comprehensive, digitally enabled and inclusive extension system that addresses not only technological gaps but also the economic and institutional bottlenecks faced by smallholders. Integrated digital platforms that combine advisory services, market intelligence, credit facilitation and institutional linkages are increasingly recognised as critical instruments for improving smallholder resilience and innovation uptake.

A substantial number of respondents depended on moneylenders rather than formal banking institutions for credit. This highlights the need for expanding financial literacy, credit access and fintech-based solutions within rural areas (12–14).

In terms of information and communication behaviour, farmers demonstrated low to medium levels of risk-taking, decision-making and mass media exposure. Their awareness about weather-based agro-advisory services, climate-resilient practices and market information systems was poor. Similarly, participation in extension activities such as demonstrations, training programs, or field visits remained limited.

This pattern reveals significant information asymmetry and outreach challenges, emphasising the necessity of phygital extension systems like MASS, which combine physical presence with digital communication tools to reach even the most remote farming communities. The farmer response rates and advisory follow-through were significantly higher when the digital recommendations were backed by in-field experiential proof. The PJTSAU thus underscores the practical significance of hyperlocal validation and field-based reinforcement (15).

Comparative insights between sample and non-sample farmers

A comparative analysis between sample (intervention) and non-sample (control) farmers illustrated a largely similar socio-economic and resource-use pattern, confirming that structural challenges such as small farm size, poor irrigation access and limited market connectivity are systemic across regions.

However, farmers who were exposed to the MASS intervention showed notable improvements in their access to information, digital advisories and awareness about climate-smart and precision agriculture practices. The exposure to mobile soil testing, drone demonstrations and digital video conferencing sessions improved their understanding of resource efficiency and modern technologies.

These early outcomes demonstrate that MASS has begun to influence farmers' behavioral, informational and attitudinal shifts. Farmers increasingly expressed interest in adopting technologies like direct-seeded rice, alternate wetting and drying irrigation, integrated pest management and drone-based input application, reflecting the positive diffusion of innovations through the phygital model. The innovative extension models in India increasingly rely on hybrid digital–physical mechanisms to overcome last-mile constraints and highlights that trust, contextualisation and social reinforcement are essential preconditions for adoption and these are difficult to achieve through digital-only approaches (16, 17)

Implications for phygital extension

The findings from PRA, FGDs and farmer profiling collectively highlight the transformative potential of phygital models like MASS in bridging information gaps and democratising agricultural knowledge. The MASS effectively integrates physical infrastructure (soil testing labs, drones, agri-input samples, training modules) with digital interfaces (apps, helplines, expert video sessions and data analytics dashboards). This combination creates a real-time, two-way communication system between farmers and experts.

By leveraging hyperlocal data, the system can generate customised advisories tailored to specific crops, soil and weather conditions. Such personalisation enhances the precision and relevance of extension messages, thereby improving farmers' decision -making capacity, resource-use efficiency and overall productivity.

In the long term, scaling this model can lead to:

- Establishment of digital farmer networks for peer learning.
- Promotion of drone-based service entrepreneurship among rural youth.
- Enhanced data-driven governance and planning at the village level.
- Integration of value-chain actors through shared data platforms.

Hence, the phygital model not only supports technological adoption but also fosters institutional innovation, financial inclusion and empowerment within rural communities, positioning hyperlocal data as the cornerstone of sustainable agricultural transformation.

Conclusion

The study highlights that farmers in the selected aspirational districts face structural constraints such as rainfed farming, small landholdings, low-yielding varieties, weak institutional support, limited market access and dependence on informal credit. However, significant opportunities exist in livestock resources and farmers' willingness to adopt improved and climate-smart practices.

Findings show that the MASS phygital model enhanced farmers' access to timely, need-based advisories and increased awareness of precision and sustainable technologies. A key insight is that hyperlocal data, when integrated with both digital tools and field-level support, improves the relevance, trust and effectiveness of extension services.

Overall, phygital extension systems anchored in hyperlocal data can strengthen decision-making, improve resource-use efficiency and promote sustainable farmer empowerment. Hence null hypothesis is rejected and research hypothesis is accepted.

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Authors' contributions

SD carried out conceptualisation of the study. SD and JMRM conducted study design, methodology, data collection and field survey. SD performed data analysis and interpretation, visualisation (Tables, figures, diagrams) and writing of the original draft. SD and JMRM contributed to writing, review and editing. JMRM and PP provided supervision, project administration and funding acquisition. All authors read and approved the final manuscript.

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