

Disparities in Digital Information Access in Indian Agriculture

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Abstract

Agricultural success hinges on the timely access to and application of precise information, which is critical for informed decision-making and sustainable outcomes. Traditional extension systems often struggle to meet the diverse and dynamic information needs of India's vast farming population. While digital technologies are increasingly recognized as transformative tools for agricultural extension, systematic state-level evidence on the enabling digital infrastructure remains limited, particularly from a supply-side perspective.

This study addresses this gap by developing a novel Digital Extension Service Preparedness Index (DESPI), a composite state-level index that captures the supply-side readiness of digital infrastructure for agricultural extension in India. The index is constructed by integrating multiple secondary datasets spanning household digital asset ownership, network connectivity, and electricity access from diverse national and industry sources that have not previously been combined for this purpose. Using Principal Component Analysis, these indicators are aggregated into a multidimensional measure of digital preparedness.

The analysis reveals substantial inter-state disparities, with network access emerging as the most uneven and constraining dimension of digital infrastructure. By explicitly focusing on infrastructure availability and access rather than actual usage or outcomes, the study provides a foundational assessment of the structural conditions necessary for scaling digital extension services. The findings highlight the uneven geography of digital infrastructure and offer indicative insights into the conditions that may influence the reach of digital agricultural extension. The study provides an evidence base to inform more context-specific and targeted policy considerations for strengthening digital infrastructure, while recognizing that infrastructure alone is insufficient to ensure effective adoption or outcomes.

Introduction

The Indian agricultural landscape is rich in diversity, characterized by unique production systems, influenced by various factors. Extension and advisory services play a key role in improving farm productivity and household income as evident from studies from various settings, including India (Cawley et al. 2018; Danso-Abbeam et al. 2018; Anikha and Shaijumon 2023). The country boasts 14.64 million operational holdings, with an average household landholding size of 1.08 hectares (Department of Agriculture & Farmers Welfare 2022). The country has a wide extension network, primarily led by the National Agricultural Research and Extension System (NARES) supported by private and community-based organizations. India has pioneered various models for transferring farm technologies and validating robust extension education approaches to address the information and service needs of its diverse farmer base (Singh et al. 2016). However, the effectiveness and scalability of these efforts in reaching the massive and geographically varied farmer population with domain-specific knowledge remains a key concern. The Committee on Doubling Farmers' Income (DFI) (2017) reported grossly inadequate manpower availability of the extension system (Government of India, Ministry of Agriculture & Farmers Welfare 2017). The report stated that the ratio of extension service provider (ESP) to operational farm holdings was 1: 1156. Besides, as per the recent NSSO survey (2021), only 48.7% of agricultural households reported accessing any kind of agricultural information and only 41.6% of them received information from government agencies. Besides, there is a growing need for real-time advisory support for the farmers, with the challenges arising from climate change becoming more apparent (Gulati et al. 2018). On the other hand, studies suggest that digital extension services can be effective in improving the agricultural performance of smallholder farmers (Rajkhowa 2021; Rajkhowa and Qaim 2021). In the Indian context, this claim is well-supported by the growing number of research studies (Kumar 2019; Rajkhowa and Qaim 2021; Steinke et al. 2021). The increasingly important role of digital extension is driven by the recent mobile revolution and an increase in tele-density, particularly in rural areas (Mittal et al. 2019). Hence there is a strong case for expanding the coverage of digital extension services (Suresh et al. 2022). With the use of digital applications, digital extension services help farmers to receive more effective agricultural advice (Amoussouhoui et al. 2023). In response to these needs, the Union Government has recently announced the launch of the Digital Agriculture Mission to build innovative agri-focused solutions

leveraging digital technologies (Ministry of Agriculture & Farmers Welfare 2022). However, the basic digital infrastructure to deliver digital extension services is a key concern. Coggins et al. (2022) underscores the common pitfalls related to infrastructure constraining the use of digital extension tools such as inaccessible device, mobile network and electricity among others. This study tries to evaluate the status of the digital infrastructure of Indian States in the context of expanding digital extension services for agriculture.

However, it is important to distinguish between mere access to digital infrastructure (Kermah and Birindwa 2021) and effective or meaningful access to digital extension services. While access refers to the availability of enabling infrastructure such as digital devices, internet connectivity, and electricity, meaningful access depends on users' ability to utilize these resources effectively, which is shaped by factors such as digital literacy, skills, affordability, and contextual relevance (Telecom Regulatory Authority of India 2024). These two dimensions, though related, are conceptually distinct. This study focuses specifically on infrastructure access as a supply-side condition, and does not directly capture the extent to which such access translates into actual usage or outcomes.

Farmers in India depend on a variety of sources to access information on aspects related to farming. Along with the formal and informal sources they also rely on various Information and Communication Technologies (ICTs). An overview of the NSSO 77th round report suggests that the major ICT-based sources include Kisan Call Centers (KCC), Television/Radio, and Smart phones (NSSO 2021). To get a better understanding of this usage pattern of ICTs for accessing technical information on agriculture, necessary data was drawn from the NSSO report and analyzed. The heat map represents the variation in usage of the ICTs by the growers in India (Fig. 1). The data corresponds to the number per 1000 households who accessed technical advice in various states. More reliance on Radio/TV for accessing information was observed in general and states like Kerala, Delhi and Himachal Pradesh were driving this usage, at all India level.

Hence it is clear that the usage of ICTs to access farming related information and services vary substantially among various states. Despite the growing emphasis on digital extension, a critical gap remains in the availability of comparable, state-level evidence on the underlying digital infrastructure that supports such services. Existing studies have largely focused on adoption, usage, or impact of digital technologies, with limited attention to systematically assessing the readiness of states in terms of enabling infrastructure. The absence of such comparative evidence constrains the ability to identify regional disparities and to design targeted interventions for strengthening digital extension systems. To bridge this critical knowledge gap, this study examines the enabling factors for successful digital extension services. Importantly, this study adopts a preparedness-oriented perspective rather than a performance-based one (Rajkhowa and Qaim 2021). While much of the existing literature evaluates the outcomes or impacts of digital technologies in agriculture (MacPherson et al. 2024; Yesigat et al. 2025), relatively limited attention has been given to assessing whether the foundational conditions required to support such outcomes are in place. By focusing on preparedness, the study shifts the analytical lens from realized benefits to underlying readiness, thereby providing a diagnostic understanding of structural constraints that may shape the effectiveness of digital extension services. This understanding is crucial for identifying weaknesses in digital infrastructure that hinder the reach and effectiveness of digital extension services, ultimately strengthening the digital extension ecosystem.

Theoretical Framework

This study adopts a supply side analytical perspective by focusing exclusively on the availability and quality of digital infrastructure as a foundational condition for DEAS. Accordingly, the analysis is intentionally limited to infrastructure related factors such as access to digital devices, network connectivity, and electricity supply, and does not directly account for demand side aspects such as digital literacy, user behaviour, or actual utilization of digital advisory services. Conceptually, the relationship between digital infrastructure and DEAS outcomes is not assumed to be direct or deterministic. Rather, digital infrastructure is treated as a necessary but not sufficient condition for the effective functioning of digital extension systems. Several studies are supporting this argument (Choruma et al. 2024; Fabregas et al. 2023; FAO 2021; Subramanian 2021). While the presence of adequate infrastructure enables the possibility of accessing digital

services, the realization of meaningful use and outcomes depends on additional enabling factors, including user capabilities, affordability, institutional support, and contextual relevance. With this conceptual understanding, the study identifies and organizes the key dimensions of digital infrastructure that function as foundational enabling conditions for access to DEAS.

In order to access the DEAS, digital assets are a basic prerequisite. It comprises of various digital tools from basic to advanced, to receive, share and disseminate agricultural information. Traditionally, the extension efforts in India were supplemented by the digital devices such as Television and Radio (Khan et al. 2024; Sharma 2025). The Government of India had given a special emphasis on the role of these mass media, which is evident from the initiation of a special programme, "Mass media support to Agricultural Extension" to leverage electronic media in agricultural knowledge dissemination, back in 2004 (Ministry of Agriculture & Farmers Welfare 2023). Recently, mobile phones, especially smart phones have emerged as a game changer in the Indian agricultural extension and technology dissemination landscape (Fu and Akter 2016; Fernando and Yaseen 2022). Coggins et al. (2022) identified them as digital extension tools for agricultural knowledge access. Smart phone with its basic (such as push and pull SMS, interactive voice response) and advanced applications (like mobile applications and access to social media platforms) are widely used for disseminating the agricultural content. Smart phones have also shown their usefulness in tackling information asymmetries, allowing farmers to request information (Ali and Kumar 2010). Computers are also reported to be used in various technology dissemination models like information kiosks and web portals, underscoring their importance as a key digital device in this context (Glendenning et al. 2010; Saravanan et al. 2015). Hence all these digital devices are considered to be critical for agro advisory dissemination. Progress of the coverage of digital devices and services in India in the recent past 2012–2022 is shown below (Fig. 2).

Some of the key enablers of access to digital extension services include mobile network, internet connectivity, internet penetration (Kansiime et al. 2022). Addom and Baumüller (2020) has already underscored the importance of these enablers in their digital agriculture framework. Farmers are increasingly and consistently using the Internet to find information and guidance (OECD 2015). Besides the quality parameters of the network such as speed of the internet (4G availability) are also relevant (Saravanan and Suchiradipta 2015). Mobile phones, data cards, dongles, and other wireless communication devices connected to telecom networks via cellular technologies like 2G, 3G, 4G, and 5G are also vital for DEAS, since a large wireless subscription base indicates greater access to mobile networks. Access to electricity is the other critical factor in deciding the access to DEAS. Besides, the issues with electricity supply in Asia are limiting the expansion of internet coverage (Vignare 2013).

Taken together, these dimensions constitute the foundational enabling conditions that shape the preparedness of regions to support DEAS. By isolating supply side conditions, this study provides a diagnostic understanding of infrastructural readiness, while recognizing that the translation of such readiness into effective service delivery and agricultural outcomes lies beyond the scope of the present study.

Methods

To assess the status of Indian states to a transition to digitally driven extension advisory services, we developed a composite index viz. The Digital Extension Service Preparedness Index (DESPI). The selection of indicators for DESPI was guided by the objective of capturing the supply-side preparedness of states to support DEAS. Unlike general digital infrastructure or digital development indices, which are typically designed to assess broader technological advancement or digital inclusion, DESPI specifically focuses on infrastructure conditions that directly influence the potential delivery and accessibility of agricultural extension services in digital mode. By contextualizing digital infrastructure within the domain of agricultural extension, the index provides a more targeted assessment of infrastructural readiness for digital advisory ecosystems. To reflect the multidimensional nature of the construct under consideration, various indicators were selected under each dimension. Also, we tried to incorporate the qualitative and quantitative indicators of digital infrastructure to the

extent possible. However, there were limitations to this such as data unavailability, pay wall restrictions to access state-level disaggregated data, etc. Hence the analysis was limited to 21 States in the country.

2.1 Selection of the dimensions and indicators

Since the construct of digital extension service preparedness is multi-dimensional, a rigorous literature review was performed to find its dimensions and underlying indicators for a nuanced understanding. The DESPI has three overarching dimensions, Digital Asset Possession Sub index (DAPSi), Network Access Sub index (NASi), and Electricity Supply Sub index (ESSi). Under each of these dimensions, suitable indicators were identified and integrated. Under the DAPSi, indicators pertaining to present status of access to various digital devices were included. These include possession of commonly used digital devices to access extension services such as Radio, Television, Computer, Smart phone by households. To continue, network access indicator components make up NASi which includes household level access to both mobile network and internet and its quality. Finally, ESSi incorporates measures of electricity availability along with its qualitative aspects.

2.2 Data Sources and Definitions

The study draws on secondary data compiled from national and industry reports. Data on household access to computers and smart phones were obtained from the National Sample Survey Office (NSSO 2020) and Cyber Media Research India (2018). Information on television and radio penetration was taken from Statista (2021) and NSSO reports on mass media access, while internet availability and broadband connectivity were retrieved from NSSO (2020). Additional indicators of digital connectivity were drawn from the Internet and Mobile Association of India (IAMA 2019), Telecom Regulatory Authority of India (TRAI 2020), and Open Signal (2021). To account for enabling conditions, data on household electricity connectivity were obtained from the Agrawal et al. (2020) and the Ministry of Power (2021).

Definitions of the indicators were based on those provided in the original datasets. Computer access refers to the availability of a computer (desktop, laptop, notebook, tablet, or similar device) within the household premises, irrespective of ownership. Smartphone access is defined as the presence of at least one smart phone in the household, regardless of whether every member personally owns one. Internet access indicates the presence of broadband, Wi-Fi, or other fixed-line connections in the household. Television penetration refers to the share of households owning or having access to a television set, while radio access refers to the presence of at least one radio set in the household. 4G availability represents the proportion of households within a state that can access 4G networks, while internet penetration is defined as the percentage of the total population using the internet. Wireless subscriptions include all active mobile and fixed wireless connections. It should be noted that these datasets report state-level averages and do not distinguish between rural and urban households, which constrain the interpretation of intra-state disparities.

2.3 Composite index construction

Composite index refers to an overall measure of a subject by summarizing a group of measurements of different aspects of the subject (Rong Chen et al. 2021). Since various indicators were measured on different levels, normalization of the indicators was performed using the min-max method, to make the data comparable across the indicators to allow for aggregation. This rescaling transformed the entire range of values between 0 and 1.

$$y_{in} = [x_{in} - \min (x_{in})] \div [\max (x_{in}) - \min (x_{in})]..... \text{Eq. (1)}$$

Where y is the scaled value and x is the original value. To maximize the overall variation of the resulting composite index, the combination weights were obtained through Principal Component Analysis (PCA). Correlations analysis of the indicators under each dimension was performed prior to PCA and found that indicators under each dimension were strongly correlated. The communality values derived through the PCA explained the extent of variance contributed by

various indicators. The normalized values and PCA derived weightages of various indicators constituting DESPI for each state are presented in Table 1.

Table 1
Normalized values of indicators of digital extension service preparedness across states

Digital Extension Service Preparedness Index												
Sl no	States	Digital Asset Possession				Network Access				Electricity Supply		
		HHC	HHSP	HHR	HHT	HHI	HH4G	IP	WSB	HHGE	ADES	SHDE
1	Andhra Pradesh	0.016	0.711	0.958	0.911	0.144	0.315	0.136	0.238	0.833	0.975	0.690
2	Assam	0.105	0.000	0.380	0.162	0.153	0.248	0.295	0.089	0.250	0.000	0.000
3	Bihar	0.010	0.079	0.000	0.000	0.118	0.220	0.068	0.354	0.250	0.725	0.414
4	Chhattisgarh	0.085	0.053	0.465	0.938	0.114	0.803	0.114	0.063	0.500	0.725	0.621
5	Delhi	1.000	0.737	0.915	0.920	1.000	1.000	1.000	0.194	0.917	1.000	1.000
6	Gujarat	0.225	0.868	0.817	0.951	0.508	0.374	0.250	0.380	1.000	0.950	1.000
7	Haryana	0.340	0.474	0.817	0.933	0.742	0.293	0.545	0.154	0.250	0.725	1.000
8	Himachal Pradesh	0.281	0.684	0.817	0.969	0.908	0.614	0.545	0.000	0.833	0.900	0.931
9	Jharkhand	0.003	0.605	0.000	0.108	0.175	0.724	0.023	0.078	0.000	0.375	0.483
10	Karnataka	0.209	0.526	0.986	0.924	0.193	0.201	0.318	0.388	0.583	0.900	0.724
11	Kerala	0.627	1.000	0.944	1.000	0.904	0.070	0.659	0.227	1.000	0.850	1.000
12	Madhya Pradesh	0.059	0.447	0.465	0.902	0.138	0.329	0.114	0.305	0.667	0.325	0.724
13	Maharashtra	0.327	0.763	0.789	0.942	0.519	0.000	0.409	0.793	0.750	0.850	0.828
14	Odisha	0.000	0.579	0.408	0.897	0.000	0.047	0.000	0.154	0.583	0.900	0.931
15	Punjab	0.389	0.842	0.817	0.978	0.796	0.390	0.545	0.181	0.917	0.925	1.000
16	Rajasthan	0.242	0.526	0.380	0.938	0.365	0.233	0.182	0.372	0.667	0.600	0.931
17	Tamil Nadu	0.451	0.684	1.000	0.965	0.210	0.160	0.500	0.463	0.917	0.900	0.931
18	Telangana	0.157	0.105	0.958	0.906	0.326	0.460	0.136	0.212	0.833	0.850	0.759
19	Uttarakhand	0.327	0.211	0.183	0.960	0.733	0.100	0.136	0.015	0.667	0.700	1.000
20	Uttar Pradesh	0.127	0.526	0.183	0.884	0.184	0.101	0.136	1.000	0.083	0.450	0.931
21	West Bengal	0.167	0.474	0.437	0.915	0.142	0.077	0.091	0.475	0.667	0.850	0.966
PCA weightage values		1.18	1.20	1.34	1.250	1.67	0.34	1.72	0.01	1.29	1.37	1.28
HHC: % of households with access to computer; HHSP: % of households with access to smartphone; HHR: % of households with access to Radio; HHT: % of households with access to Television; HHI: % of households with access to internet; % of households with 4G availability (HH4G); Internet penetration % (IP); WSB: Wireless subscription base (in million); % of households connected to Grid electricity (HHGE); Average daily electricity supply (in hours) (ADES); Share of households dissatisfied with grid electricity(SHDE)												

Aggregate scores were obtained for each dimension by taking the average of sum of weighted scores under each indicator. A non-compensatory method was followed for the construction of the composite index as suggested by De Muro et al. (2010) and Mazziotta and Pareto (2013), and followed by Vishnu et al. (2024). While the arithmetic mean was used within the dimension to aggregate the scores, geometric mean was used across the dimensions. The DESPI values reflect the relative status of Indian states on their preparedness to deploy digital extension services.

Results and Discussion

Indian agriculture is increasingly embracing digital tools and technologies to supplement its advisory services in the recent years. The rise of digital tools and technologies has digitally transformed traditional agricultural extension (Rasheed 2012). The recent developments in the mobile, computing and networking technologies offered novel ways of technology transfer (MANAGE 2017). Besides, various social media platforms are increasingly relied for communication, collaboration and improved service delivery (Klerkx 2021). However, the successful implementation of these services is contingent upon a robust digital infrastructure. Various studies point to the underlying IT infrastructure such as high speed internet, mobile connectivity and access to digital devices can accelerate pace of digitalization in agriculture (Varshney and Singh 2019; Department of Telecommunications 2020). The status of various States on these various aspects of digital infrastructure was analyzed. At first, the States were evaluated with regard to their status of digital infrastructure. Their scores on the three dimensions and overall DESPI score was calculated and scrutinized (Table 2). Network access allows farmers to connect to the services, digital devices provide the platform for interaction, and electricity ensures constant use.

Our analysis revealed significant variations in DESPI scores across Indian states. The Coefficient of Variation (CV) values were worked out with regard to the scores of DAPSi, NASi, and ESSi to check variability among the states concerning dimensions of DESPI. It was found that the variability was highest with regard to NASi (74.37%) followed by DAPSi (42.33%) and ESSi (32.37%). Thus it is clear that connectivity is far from uniform across the regions where the disparity is evident in the infrastructure. The less variability with regard to DAPSi and ESSi might be due to better access to digital devices and electricity supply by the States than network access parameters. Digital devices such as Television and Radio are owned by a sizable portion of the Indian households. Prasar Bharati, India's autonomous public service broadcaster reaches 92 per cent of the area and 99.1 per cent of the total population and the overall tele-density stands at 84.8 per cent (Ministry of Finance 2022-23). Further, about two third of the households in the country own a television, while 93.3 per cent of the households own a mobile telephone (BARC India 2020; International Institute for Population Sciences and ICF 2021). With regard to electricity access, 96.7 per cent of Indian households are connected to the grid, with another 0.33 per cent relying on off-grid electricity sources (Agrawal et al. 2020). Results were corroborated by the NSSO (2021–2022) survey, which revealed that while 77.5 per cent of households had access to mass media such as TV, Radio and Internet, just 41.8 per cent of households reported having broadband access on their home premises. 69 per cent of Indian farm households lack internet access, highlighting a significant digital divide in agricultural areas with regard to internet access (Ferguson et al. 2024).

Table 2
Performance of Indian states on various dimensions of Digital Infrastructure

Sl.No.	State	DAPSi	NASi	ESSi	DESPI	Rank	Category
1	Delhi	0.723	0.376	0.983	0.954	i	Digital Pioneers
2	Kerala	0.675	0.252	0.739	0.847	ii	
3	Punjab	0.502	0.113	0.827	0.774	iii	
4	Himachal Pradesh	0.711	0.422	0.810	0.761	iv	
5	Gujarat	0.650	0.610	0.659	0.644	v	
6	Haryana	0.784	0.340	0.916	0.639	vi	
7	Tamil Nadu	0.474	0.144	0.566	0.625	vii	
8	Maharashtra	0.523	0.269	0.729	0.624	viii	Digital Progressors
9	Uttarakhand	0.174	0.154	0.287	0.509	ix	
10	Karnataka	0.419	0.399	0.786	0.501	x	
11	Telangana	0.429	0.156	0.486	0.482	xi	
12	Rajasthan	0.394	0.176	0.617	0.468	xii	Digital Enthusiasts
13	Andhra Pradesh	0.893	0.998	0.973	0.442	xiii	
14	West Bengal	0.476	0.005	0.806	0.361	xiv	
15	Chhattisgarh	0.696	0.713	0.888	0.350	xv	
16	Madhya Pradesh	0.549	0.250	0.815	0.338	xvi	Digital Aspirants
17	Uttar Pradesh	0.168	0.227	0.082	0.319	xvii	
18	Jharkhand	0.174	0.287	0.154	0.197	xviii	
19	Assam	0.896	0.714	0.948	0.146	xix	
20	Odisha	0.663	0.156	0.836	0.120	xx	
21	Bihar	0.762	0.643	0.947	0.102	xxi	

Importantly, the disparities identified in this study should be interpreted as differences in supply-side infrastructural readiness rather than differences in actual usage or effectiveness of digital extension services. The DESPI framework evaluates the extent to which states possess the foundational infrastructure conditions necessary to support digital advisory systems. Accordingly, higher preparedness scores indicate greater infrastructural capacity to enable digital extension delivery, but do not necessarily imply higher levels of adoption, engagement, or agricultural outcomes. The persistence of infrastructure disparities across states may be reflecting broader structural inequalities in digital development, investment capacity, and network expansion (Arora and Sapre 2026; Timilsina et al. 2025). While access to basic digital devices and electricity has improved considerably across much of India, advanced digital connectivity infrastructure such as broadband access, internet penetration, and network quality continue to exhibit uneven spatial distribution. These disparities are likely shaped by differences in telecom infrastructure investment, geographical constraints, levels of urbanization, market incentives for private service providers, and historical patterns of regional development (Barman et al. 2018; Timilsina et al. 2025; Tufail 2014). Consequently, despite overall progress in digitalization, the enabling conditions required for digital extension remain unevenly distributed across states.

An important observation emerging from the analysis is that disparities are considerably sharper in network-related indicators than in basic infrastructure components such as electricity access or ownership of digital devices. This suggests that the digital divide in DEAS is increasingly shaped not by the mere access to devices, but by the quality and reach of connectivity infrastructure (Mittal et al. 2019; Sen et al. 2025). The finding is significant because it indicates a transition from first-level access inequalities toward more complex disparities in digital readiness associated with network quality and integration.

Further, to make the inference more meaningful, we categorized the States into 4 categories, viz. Digital Pioneers, Digital Progressors, Digital Enthusiasts, and Digital Aspirants based on the quartile scores (Table 2). Digital Pioneers are the leaders in terms of digital infrastructure who performed consistently across the three dimensions of DESPI. Digital Progressors are also better performers with the scope of some level of improvement with regard to digital infrastructure. Digital Enthusiasts category mainly comprise of States who are not well performers and have more scope for improvement. Finally, the category Digital Aspirants represents relatively poor performers with a huge scope for improvement in terms of digital infrastructure for the delivery of extension services in digital mode. Interestingly, the CV values indicated variation of the DESPI scores of states coming under different categories viz. Digital Pioneers (16.4), Digital Progressors (12.2), Digital Enthusiasts (14.5), and Digital Aspirants (48.8). A substantially high CV among the Digital Aspirant category was observed compared to the other three categories. Besides, it can be seen that the findings are confirmed by the observed trend of ICT usage patterns in the Indian states from the NSSO survey report (NSSO 2021). The leading states with better usage of ICTs were featured in the category of Digital Pioneers. The performance of various states with regard to various indicators under each dimension of DESPI is scrutinized further (Fig. 3a, Fig. 3b, and Fig. 3c). It can be seen that the performance of the leading states such as Delhi and Kerala were high and consistent across the dimensions. Similar is the case of poor performing State like Bihar. Performance of the States with regard to some of the indicators such as access to radio and grid electricity connection was found to be satisfactory across most of the states.

The variation in state-level preparedness observed in this study carries significant implications for the future of agricultural information interventions. For farmers, uneven digital infrastructure risks heighten the existing inequities by creating asymmetries in access to timely information, markets, and advisory services (Oklikah et al. 2025; Ullah et al. 2020). Further, gaps in digital infrastructure do not operate in isolation but intersect with the socio-economic differences that already shape agricultural opportunities (Duggi et al. 2025). It may tend to reinforce existing inequalities in productivity, market participation, and livelihood security rather than reducing them (Laskar 2023). For policymakers, the findings highlight that infrastructure provisioning, while necessary, is insufficient on its own. Even in situations where access to digital infrastructure is better, a sizable segment of the rural population is unable to do fundamental ICT tasks or use it for productive purposes (Kotu et al. 2026). Without parallel efforts to strengthen the demand side enablers the benefits of infrastructure risk reinforcing exclusion rather than fostering inclusive access (Cheruku and Katekar n.d.; Sindakis and Showkat 2024). For digital interventions to be effective, users must be capacitated to actively engage with and benefit from them, rather than being treated merely as passive recipients of information (Confederation of Indian Industry 2021).

It would be pertinent to discuss the findings in light of the Agricultural Extension Density in India as propounded by the Committee on Doubling Farmers' Income (DFI) (2017). A wide gap in extension manpower requirements was reported from the majority of the Indian states. The findings of this study assume more significance in such a context. Expanding the reach of digital extension services can supplement the already strained public extension machinery. Digital services have the potential to revolutionize smallholder agriculture by addressing information irregularities that hinder value chain activities (Evans 2018). However, to harness the potential of digital extension services, the basic digital infrastructure needs to be upgraded (Rajkhowa 2021). This includes expanding broadband coverage, creating community information centers and leveraging mobile networks for better reach (Awad 2021; Baffoe-Bonnie et al. 2021). Besides, individual ownership of digital devices as well as access and affordability of network services were also found to be key enablers of access to digital extension services (Kansiime et al. 2022). A study by the World Bank (2020) contended that countries with better basic digital infrastructure had higher levels of agricultural extension service provision. Further, digital infrastructure

can contribute to rural rejuvenation by strengthening rural networks and enhancing the viability and competitiveness of small agricultural enterprises (Botos and Cseh 2011; Zhang 2024). To improve the digital infrastructure, some of the potential pathways include agreements on policy between businesses and government, industry collaborations for offsetting costs and to create common standards (Ken Hu 2014). Additionally, significant financial investments are needed to close the digital divide between rural and urban IT infrastructure (Bajpai et al. 2021). This would transform the digital extension service by increasing the reach of extension in remote areas, provision of timely, accurate information, enabling better interaction, and reducing the cost of extension services (FAO 2019). Nevertheless, evidence suggests that purely digital approaches are unlikely to replace traditional extension approaches in most contexts. Rather, blended models that strategically integrate digital platforms with trusted face-to-face interactions appear more viable, both in fostering inclusivity and in building trust on which effective advisory services ultimately depend.

It is important to note that the IT infrastructure required to implement digital extension services is expanding in a number of ways in India (CGIAR 2024; Ministry of Agriculture & Farmers Welfare 2023). Ninety-seven percent of households have access to electricity and an average Indian household receives 20.6 hours of power supply in a day (Agrawal et al. 2020). About 55 per cent of Indians become active internet users accessing the internet at least once a month with 93 per cent of them spending around 1.5 hours on internet (IAMAI and Kantar 2023). The saturation of 4G service in the country is 93 per cent of the villages (Ministry of Communications 2022). Further, the recent policy initiatives of the Government also underscore actions in this direction. For instance, Prime Minister's WiFi Access Network Interface (PM-WANI), aims to increase internet connectivity, especially in rural areas, by creating a robust digital communications infrastructure (Department of Telecommunications 2020).

While this study has focused on disparities in digital infrastructure across states, it is important to recognize that infrastructure alone does not guarantee inclusive digital outcomes (Alvarado et al. 2024; Shenglin et al. 2017). The extent to which infrastructure translates into effective digital extension service delivery and its use and socio-economic benefits depends critically on demand-side factors such as digital literacy, skills, affordability, and actual usage. Recognizing this duality is crucial for interpreting disparities in infrastructure and how they translate into results. FAO (2019) offers a more nuanced understanding of the prerequisites for digital transformation, by categorizing them into basic and enabling conditions. Basic conditions represent the minimum requirements for technology use, including availability, affordability, connectivity and supportive policies. Enabling conditions, on the other hand, refer to factors that facilitate the adoption and effective utilization of digital technologies, such as digital skills, active use of technologies, and a culture of digital innovation. This distinction is important because it highlights additional prerequisites that are necessary for deriving meaningful outcomes from digitalization in agriculture, thereby offering a more comprehensive understanding of the barriers and opportunities involved. While infrastructural preparedness creates the foundational conditions necessary for digital extension systems to function, the realization of meaningful outcomes depends on several additional demand-side, institutional, and contextual factors that extend beyond infrastructure availability alone (Purandare 2024).

Additionally, several challenges arise in accounting for and contextualizing demand-side factors. Even in regions with relatively advanced digital infrastructure, access to agricultural information may remain constrained if populations lack the capacity to effectively engage with digital technologies. However, assessment of that capacity remains challenging due to the absence of systematic and disaggregated data. Available indicators, such as e-literacy levels, often exist only at the national scale, with little differentiation between rural and urban contexts (FAO 2019). This gap not only restricts the ability to evaluate demand-side readiness but also obscures critical inequalities that shape how infrastructure translates into meaningful outcomes. Similarly, affordability is not a static variable since it fluctuates with income, seasonal expenditure patterns, and market dynamics, making it challenging to establish consistent, comparable measures across rural contexts. Likewise, data on actual usage of digital technologies are scarce and uneven. Existing data often focus on general internet or mobile phone use without distinguishing between agricultural, educational, or recreational purposes (Ahmad et al. 2024; Steinke et al. 2020). While the lack of disaggregated usage data remains a fundamental challenge, where such evidence does exist, it highlights a different concern. That is strong digital infrastructure does not necessarily translate into

agricultural ICT adoption. For instance, although Kerala is relatively well-positioned in terms of digital infrastructure as evident from this study, secondary evidence from the Government of Kerala (2017) indicates that the adoption of ICT applications for agricultural purposes remains strikingly low, at just 15 percent in the state. The disconnect is further evidenced in Punjab, considered a digital pioneer state, where a study finding indicate that although 63 percent of farmers reported knowing how to use the internet, only 38 percent made use of it for agricultural information (Jain et al. 2014). Hence the real challenge would be identifying and critically examining the key enablers of digital information access, particularly in light of such mismatches.

The analysis of this study is intentionally limited to supply-side infrastructural conditions and therefore does not directly evaluate how farmers engage with, utilize, or benefit from digital advisory systems. The policy implications should therefore be interpreted primarily in terms of infrastructure prioritization rather than extension effectiveness. The findings provide an evidence base for identifying regions where foundational digital infrastructure remains inadequate for supporting the expansion of digital extension systems. In this regard, the index can assist policymakers in targeting investments related to connectivity, digital access, and supporting infrastructure necessary for strengthening digital readiness across states. Future research is needed to systematically examine how both supply-side and demand-side factors interact to shape access to digital agricultural information and advisory services. In particular, further studies should incorporate additional dimensions such as gender, social inequalities, and other forms of marginalization, alongside regional disparities in digital infrastructure, to develop a more comprehensive understanding of digital inclusion in agriculture (Cariappa et al. 2024).

Conclusion

The agricultural sector is increasingly becoming knowledge-intensive. Traditional modes of extension have so many limitations to cater the knowledge demands of the stakeholders including farmers. Extension service provisions steered by digital technologies are touted as the best options to meet the knowledge needs, given the time and cost concerns. This study contributes to the literature on digital agricultural extension by developing the Digital Extension Service Preparedness Index (DESPI), a novel state-level composite index designed to assess the supply-side readiness of digital infrastructure for agricultural extension in India. By integrating multiple secondary datasets relating to digital asset access, network connectivity, and electricity supply, the study provides a systematic and comparable assessment of infrastructural preparedness across states. Though the states vary with regard to various parameters of digital infrastructure, it was substantial in some aspects like network (mobile and internet) access. Further, profiling of States based on DESPI score helped to get a better understanding of leading and lagging States with regard to digital infrastructure. Given the present policy focus and emphasis of the country in digitizing extension and advisory services such as the Digital Agriculture Mission (2022) and Digital Public Infrastructure for Agriculture, this study is an important contribution (Ministry of Agriculture & Farmers Welfare 2026). By identifying disparities in digital infrastructure and offering a framework to assess preparedness, this study provides critical insights for policymakers to bridge the digital divide, enhance information access for farmers, and accelerate inclusive rural development in India. The findings provide an evidence base for identifying infrastructural gaps and prioritizing investments necessary to strengthen the enabling conditions for digital extension systems.

However, this study has some limitations and findings should be taken with caution since the DESPI was formulated with the available data sources for the Indian states. Besides, the state level measures were taken for computing the DESPI, without considering the rural urban difference in such parameters. Besides, the study majorly focused on the supply side factors of digital extension services. However, it provides an essential baseline for assessing how enabling conditions interact with infrastructure to shape digital transformation in the farm sector. By shedding light on the issues of digital infrastructure status and its variation across Indian states, the study discusses implications of digital information intervention for farmers and offers valuable insights for agricultural policymakers. Future research should integrate indicators of digital literacy, skills, and usage to better capture the demand-side dynamics.

Declarations

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Declaration

This study did not involve any human participants or animals. The research was based entirely on secondary data and publicly available information. Therefore, ethical approval and informed consent were not required.

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Author Contribution

Sreeram Vishnu: Conceptualization; Methodology; Formal analysis; Investigation; Data curation; Writing – original draft; Writing – review and editing; Visualization; Project administration. Sendhil Ramadas: Conceptualization; Methodology; Validation; Formal analysis; Writing – review and editing; Supervision. Mahesh B Tengli: Data curation; Formal analysis; Validation; Writing – review and editing. Denny Franco: Data curation; Investigation; Visualization; Writing – review and editing. Archana Bhatt: Methodology; Validation; Writing – review and editing. Alaka S Balan: Data curation; Investigation; Writing – review and editing. Navitha Raj: Data curation; Investigation; Writing – review and editing.

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Figures

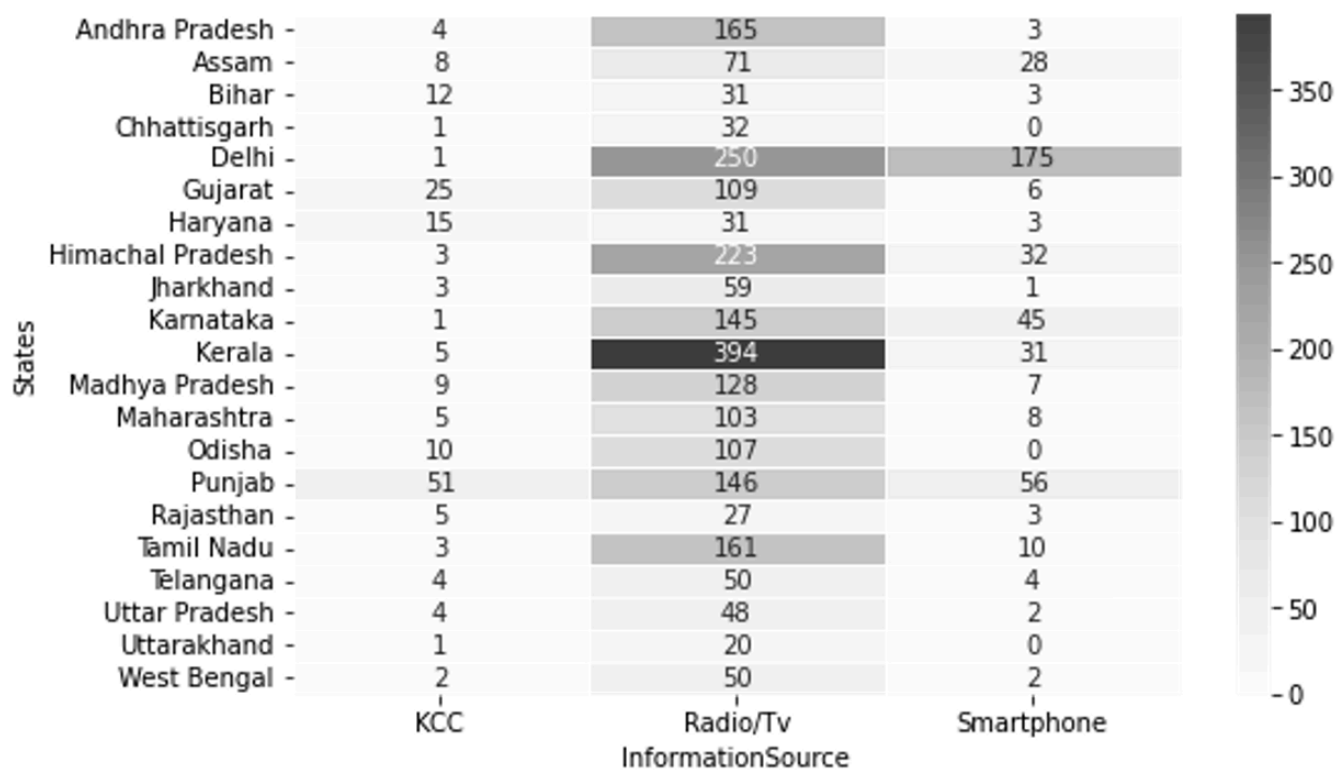


Figure 1

Usage of ICTs by farmers in different states

The brightness level of a cell indicates the number per 1000 agricultural households that accessed technical advice.

Source: Heat map developed from the NSSO (2021) report by authors

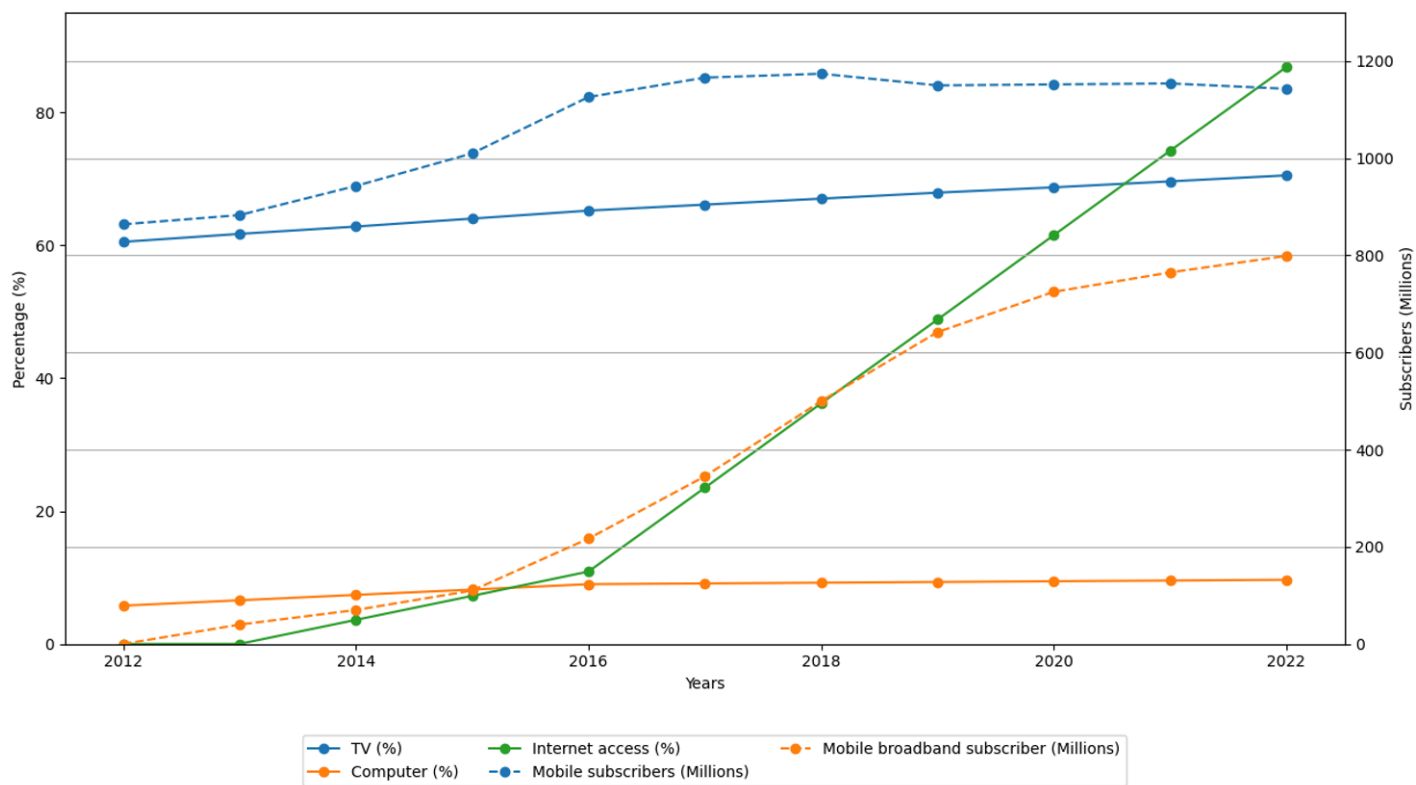


Figure 2

Progress of the coverage of digital devices and services in India (2012- 2022)

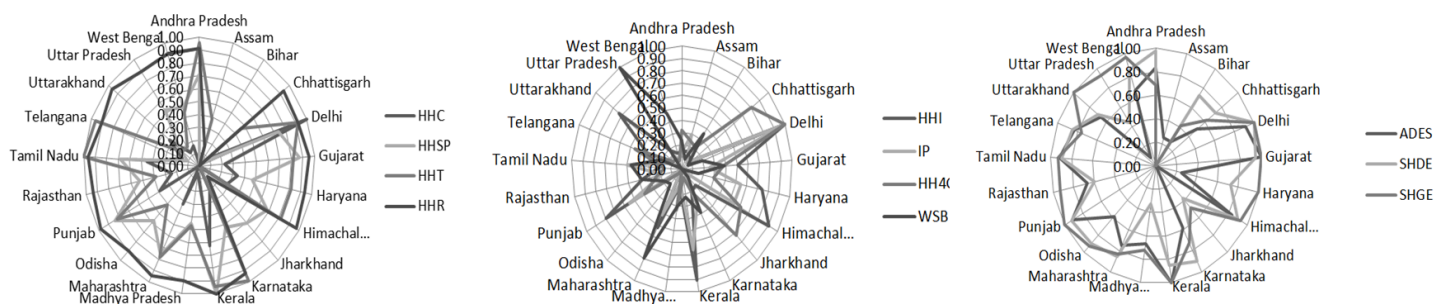


Figure 3

3a. Performance on DAPSi indicators

3b. Performance on NASi indicators

3c. Performance on ESSi indicators