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Article

Sowing Innovation, Harvesting Change: A Study of Agricultural Technology Adoption Among Smallholders in Vidarbha, India

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Abstract: India's agricultural evolution is increasingly shaped by the integration of emerging technologies. Small farmers in vulnerable regions are not evenly distributed. A paradox is illustrated in the eastern part of Maharashtra, which continues to suffer from chronic rural distress. This study investigates the patterns, drivers, and barriers of agricultural technology adoption in such contexts. A mixed-method approach is used to capture both quantitative and qualitative dimensions of technology adoption. The Technology Adoption Index (TAI) is applied to assess the level of adoption. Qualitatively, the study incorporates field interviews and focus group discussions structured around the RANAS behavioral model, addressing risk perception, attitudes, social norms, ability, and self-regulation as key psychological factors influencing farmer behavior. A total of 200 small farmers were selected for the survey. Adoption patterns are linked to both capability and institutional capacity. Higher digital penetration, a robust extension network, and proximity to agricultural research institutions have led to elevated TAI scores in certain districts. In contrast, adoption in Yavatmal is constrained by several barriers—such as lack of control mechanisms, insufficient trust in digital systems, and continued reliance on traditional knowledge networks—which undermine farmers' willingness to adopt new technologies. The early successes of cluster-based farming models were also highlighted in the study. These clusters combine real-time environmental data with centralized decision-making and mobile phones to deliver improved input efficiency, crop health monitoring, and farmer advisory services. However, resource constraints and a lack of institutional support are limiting the scalability of such models. According to this study, technology alone cannot drive transformation in marginalized agricultural systems. Tools for embedded innovation must be supported by adaptive policy frameworks, targeted subsidies, and culturally resonant communication strategies. The survey recommends expanding AI-based cluster farming through public–private partnerships and developing a region-specific Digital Readiness Index. This work contributes to a more equitable and context-sensitive vision of agricultural modernization in India.

Keywords: Agricultural Technology Adoption; Smallholder Farmers; Vidarbha Region; Digital Agriculture; Technology Adoption Index (TAI); RANAS Model; AI Cluster Farming; Extension Services; Precision Farming; Inclusive Innovation.

INTRODUCTION

One-half of India's population depends on agriculture for their livelihood [1]. Significant productivity gaps and structural inefficiencies are reflected in the sector's contribution to national GDP [1]. The mismatch between demographic reliance on agriculture and its economic output is compounded by environmental vulnerability, weak market access, and low technological penetration—especially among small farmers operating on less than two hectares of land [2].

The most pronounced paradoxes are found in the Vidarbha region. Despite its natural endowments, it has become a symbol of India's agrarian distress. Some of the highest rates of farmer suicides in the country are reported in this region [3]. According to the National Crime Records Bureau, Yavatmal has the highest suicide rate in the country [3].

While the government and civil society have introduced a wide range of social welfare schemes, loan waivers, and awareness campaigns, these efforts have had limited long-term impact due to a lack of structural reforms and sustained support for innovation. The discourse around agricultural technology could be a game-changer. Agri-tech innovations can transform agriculture from a high-risk occupation into a more sustainable enterprise [4][5]. In low-input, rainfed agricultural systems, improved decision-making can reduce the risks associated with environmental shocks.

However, the adoption of agricultural technology among smallholders remains low. According to surveys, less than 20% of small farmers have adopted any precision agriculture tools. The barriers go beyond access. Farmers often distrust unfamiliar technology, especially when there is inadequate demonstration or lack of contextual adaptation. Social norms, intergenerational knowledge systems, and local governance mechanisms influence how new practices are evaluated and adopted at the grassroots level [6].

The region's internal diversity adds further complexity. There is a strong presence of Krishi Vigyan Kendras in the districts of Nagpur and Akola [6]. However, the digital divide is significant, with internet access ranging from 75% in Nagpur to less than 50% in tribal blocks of the region.

This study aims to address the following research questions:

- What is the level of technology adoption among small farmers?
- What are the key drivers of technology adoption?
- What are farmers' perceptions of agricultural technologies?
- What lessons can inform the design of inclusive and scalable agri-tech interventions?

The study employed a mixed-method approach to answer these questions. A sample of 200 farmers across four districts was assessed using the Technology Adoption Index (TAI), which captures Access, Frequency of Use, and Diversity of Technologies. The RANAS behavioral framework [7] was used to explain human behavior in resource-constrained settings.

Preliminary findings highlighted the gendered dimensions of technology adoption. Women farmers are often overlooked. They reported lower participation in training programs, limited control over mobile phones, and exclusion from decision-making forums. This underscores the need for gender-sensitive technology deployment strategies.
District-level variations in technology adoption were the focus of the study. By combining behavioral science and agricultural economics, a more nuanced understanding of decision-making is developed. The study offers policy-relevant insights for government agencies, non-profits, and private agri-tech providers seeking to expand the reach and impact of digital agriculture in India.

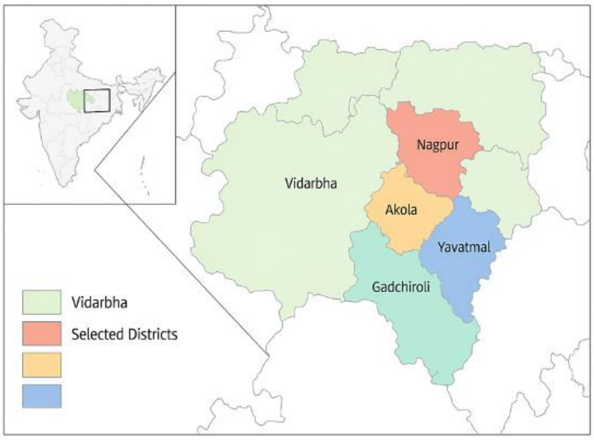

Figure 1: Overview of Vidarbha Region with Study Districts Highlighted

Table 1: Key Agricultural and Socio-Economic Indicators of the Selected Districts in Vidarbha *(Source: Compiled from NSSO [2], Census 2011 [8], NCRB [3], TRAI [9], and Government of Maharashtra Irrigation Reports [10])*

District	Avg. Landholding Size (ha)	Irrigation Coverage (%)	Literacy Rate (%)	Mobile Penetration (%)	Farmer Suicide Rate (per 100,000)
Nagpur	1.6	42	88.4	78	9.2
Akola	1.4	39	86.2	74	12.5
Yavatmal	1.2	27	80.3	62	34.1
Gadchiroli	1.0	21	74.8	54	18.7

The **introduction** lays the foundation for a deeper inquiry into the multidimensional nature of agricultural technology adoption. The conceptual model, empirical findings, and actionable policy recommendations necessary for catalyzing sustainable agricultural transformation in marginal farming systems are covered in the following section.

LITERATURE REVIEW

A variety of variables affect the adoption of agricultural technology. Over the past three decades, global and regional research has increasingly focused not only on the technological potential but also on the complex dynamics that govern its adoption among different agricultural populations. The study of agricultural technology adoption is both urgent and insightful due to the interplay of stressors and vulnerabilities.

Agricultural innovation systems should be viewed as socio-technical constructs. The traditional linear model of "lab-to-land" has been replaced by more interactive frameworks. Adoption patterns are influenced by access and affordability, as well as psychological readiness, social networks, and perceptions of utility [11].

Green Revolution technologies spread rapidly through canal irrigation systems and input subsidies in northern states. However, newer digital and AI-driven tools have struggled to gain traction beyond controlled pilots. This contrast underscores the importance of understanding how farmers evaluate and interact with innovation [12].

Adoption outcomes are shaped by structural systems. In regions with weak market linkages, adoption is perceived as a high-stakes gamble. These realities demand that agricultural technology studies move beyond narrow econometric models and embrace interdisciplinary approaches that incorporate behavior, culture, and power structures [13].

As the current study seeks to situate itself within this evolving body of knowledge, it is essential to explore the major theoretical paradigms that have influenced research on technology adoption. These models provide the analytical scaffolding for the present inquiry.

2.1 Theoretical Models of Technology Adoption

Economic, behavioral, and system-oriented perspectives have traditionally been used to study technology adoption. Each model offers unique insights into the mechanisms that drive or hinder adoption in rural and resource-constrained environments.

Rogers' *Diffusion of Innovations* (DOI) theory states that an innovation is communicated through certain channels over time among the members of a social system [11]. Rogers identifies five categories of adopters and argues that adoption depends on the perceived attributes of the innovation. However, this model has been criticized for its lack of attention to structural constraints.

The *Technology Acceptance Model* (TAM) was developed to address these limitations [12]. It suggests that two beliefs—perceived usefulness and perceived ease of use—influence an individual's attitude toward technology, which in turn shapes their intention and actual usage. This model has been applied in studies involving mobile apps, decision-support tools, and market information systems. However, TAM is often critiqued for being overly individualistic and not adequately considering social and environmental contexts.

The *RANAS* model—Risk, Attitude, Norms, Ability, and Self-regulation—is better suited for analyzing behavior change in low-resource settings [7]. It has been adapted to rural contexts in recent studies. The model breaks down behavioral drivers into five components:

- **Risk**: Perceived risk or exposure if the behavior is not adopted.
- **Attitudes**: Cost-benefit perceptions, including emotional reactions.
- **Norms**: Perceptions about what others do and approve of.

- **Ability**: Skills, time, and resources required.
- **Self-regulation**: Planning, commitment, and resilience in the face of setbacks.

The RANAS model provides a useful framework for understanding why certain technologies are adopted, rejected, or only partially integrated into agricultural systems. It is particularly relevant for farmers in high-risk environments with low institutional support.

Scholars are increasingly advocating for hybrid models that combine components from multiple frameworks. The *Technology Adoption Index* (TAI) is an operational tool that captures various indicators such as awareness, frequency of use, diversity of technologies adopted, and willingness to recommend [13]. Behavioral insights help to develop a more comprehensive understanding of empirical trends and underlying motivations.
In this study, we combine qualitative inquiry with quantitative scoring. This allows us to capture both observable trends in technology use and the deeper psychological and social dynamics that influence adoption among smallholder farmers.

2.2 Empirical Studies on Agricultural Technology Adoption in India
India's diverse agricultural technology landscape varies significantly across states. Some regions experience higher levels of mechanization and insurance coverage for irrigation, while others lag behind due to weak infrastructure and limited extension outreach [14].

A study by *Birthal et al.* found that access to extension services—particularly those offered through Krishi Vigyan Kendras has a greater influence on technology adoption than education or income levels [4]. This highlights the importance of institutional intermediation. Similarly, *Joshi et al.* found that peer influence plays a significant role in encouraging modern practices such as integrated pest management, hybrid seeds, and zero-tillage farming [15].

In recent years, mobile-based digital interventions have attracted considerable attention. According to an analysis by *Mittal and Mehar*, the effectiveness of mobile advisories depends on network availability, information credibility, and household literacy levels [16]. Their findings suggest that trust and last-mile connectivity are key constraints to digital tool adoption.

Gender continues to be a critical axis of exclusion. *Ragasa et al.* report that women farmers face systemic exclusion from agri-tech services due to limited access to mobile phones, reduced decision-making power, and underrepresentation in training programs [17]. Targeted training initiatives for women have shown promise when delivered through community-based platforms [18].

Key predictors of adoption include disparities in infrastructure—such as access to electricity, road connectivity, and proximity to markets. *Singh et al.* argue that the lack of basic infrastructure severely limits the effectiveness of technology diffusion [19].

These studies underscore the complex interactions between behavioral intent, institutional frameworks, and infrastructural readiness. They provide a strong justification for the use of a mixed-method approach in understanding agricultural technology adoption.

2.3 Technology Adoption in Vidarbha: Status and Gaps
India's more agriculturally challenged regions, such as Vidarbha, are underrepresented in the technology adoption literature. Micro-level studies offer critical insights into the region's challenges and opportunities in integrating agricultural technologies.

A landmark study by *Domingues et al.* focused on the impact of digital technologies on labor productivity and input efficiency [5]. Despite generally positive perceptions of tools such as soil sensors, automated irrigation, and mobile advisories, the adoption rate was below 30% due to low affordability and inadequate technical support. The lack of adaptation to specific crop patterns and soil profiles in the region further widened the gap between awareness and implementation.

In a study on citrus growers, *Kulkarni et al.* used multiple production stages to assess the Technology Adoption Index (TAI) [20]. The study found low scores in post-harvest management technologies. The findings suggest that primary input-related technologies are more widely accepted than knowledge-intensive and precision-dependent solutions.

Experiments with *Cluster Farming Models*, supported by the Ministry of Agriculture, have shown promising results [21]. These models use AI services and real-time environmental data to generate advisories for farmer clusters. Farmers reported increased yields, more timely input access, and reduced wastage. However, scalability is limited by high upfront costs, poor 4G/5G penetration in tribal blocks, and the lack of reliable maintenance services.

A separate survey assessed digital preparedness across four districts [22]. Proximity to agricultural research institutions, stable electricity, and better market access made **Akola** and **Nagpur** more equipped for digital interventions. In contrast, **Yavatmal** and **Gadchiroli** lag due to poor road connectivity, intermittent electricity, weak mobile networks, and low institutional trust.

Additionally, interviews and assessments conducted by NGOs such as **PRADAN** highlight social barriers such as caste hierarchies, language constraints, and exclusion of women and tenant farmers from formal agricultural services [23]. These social dimensions present significant barriers to widespread technology adoption.

Table 2: Summary of Studies on Agricultural Technology Adoption in Vidarbha Region

Study	District(s)	Technology Focus	Key Metrics / TAI Scores	Key Findings
Domingues et al. (2023) [5]	Vidarbha-wide	Digital tools (soil, drip, apps)	<30% adoption	High awareness, poor implementation due to affordability and training
Kulkarni et al. (2021) [20]	Akola, Amravati	Citrus farming TAI	TAI: 12.99–19.88	Post-harvest and pest control technologies least adopted
ToI (2024) [21]	Gadchiroli, Chandrapur	AI Cluster Farming	+10–15% yield increase (pilot)	Real-time advice effective, but limited reach and infra barriers
CCR (2025) [22]	Nagpur, Akola, Yavatmal, Gadchiroli	Digital readiness	High (Nagpur, Akola); Low (Gadchiroli)	Readiness index matches infra and signal disparities
PRADAN & MSSRF (2023) [23]	Yavatmal, Gadchiroli	Extension & Inclusion	Qualitative assessments	Women, tribals excluded from tech and training loops

The current survey uses a dual model to generate a detailed understanding of adoption behavior. The **heterogeneity** of the region requires a differentiated approach.

METHODOLOGY

A mixed-method research model is used to investigate the adoption of technology by small farmers. This approach integrates quantitative assessment through the **Technology Adoption Index (TAI)** with qualitative behavioral insights to capture the region's complex socio-economic, agro-ecological, and institutional landscape. The dual-pronged design makes it suitable for high-impact empirical research.

3.1 Study Area and Sampling Design

The region is experiencing a **developmental slowdown.** The survey was conducted in four districts, each representing a diverse socio-political spectrum. The regions of **Akola** and **Nagpur** have higher penetration of agri-tech solutions, while **Yavatmal** reflects underdeveloped infrastructure, tribal demographics, and heightened farmer vulnerability.

The survey focused on smallholder farmers. A total of 200 farmers from each district were selected. **Location, caste group, gender**, and **proximity to market and infrastructure** were used as sampling variables. Lists were obtained from the local agricultural offices.

3.2 Quantitative Framework: Technology Adoption Index (TAI)

The study used a structured index to measure technology adoption. The adoption of technology across five key domains was evaluated. These domains were selected based on a synthesis of the literature and consultations with local extension officers and subject matter experts [13].

Table 3: Domain Structure of the Technology Adoption Index (TAI)

TAI Domain	Description	Example Technologies
Irrigation and Water Use	Water conservation, precision irrigation	Drip, sprinklers, tensiometers
Soil Health and Nutrient Mgmt	Soil treatment, balanced input application	Neem urea, micronutrients, soil cards
Pest and Disease Management	Non-chemical, timely response strategies	Traps, SMS alerts, bio-pesticides
Post-Harvest Handling	Storage and spoilage reduction	Solar dryers, hermetic bags, cold storage
ICT and Advisory Access	Mobile/online access to weather, price, and crop info	mKisan, WhatsApp groups, AI chatbots

The engineering use **frequency, synchrony,** and **diversity** were used to score each domain. The combined score of the normalized domain values is 100. The data was analyzed using two different methods.

3.3 Qualitative Framework: Behavioral Inquiry via RANAS

The study broke down technology adoption into five components: **risk perception, attitude, norms, ability,** and **self-regulation.** The model was originally developed for health and sanitation studies.

A **sub-sample** of 80 farmers was selected for interviews to ensure representation of early adopters, non-adopters, and late adopters. The interview schedule was translated into Hindi and Marathi for use in non-English-speaking areas. Questions explored how farmers viewed the risks and benefits of agri-tech, the influence of peers and family, and their consistency in following through with planned practices.

Interviews were transcribed and translated for analysis. **Open and axial coding** were used to identify dominant themes and variations. Field observations were used to triangulate the codes.

3.4 Data Collection and Field Procedures

Primary data collection was conducted by a team of trained **enumerators.** In Hindi and Marathi, enumerators were trained on digital data collection tools, research ethics, behaviorally sensitive interviewing, and mock role-play sessions. Mobile-based tools were used.

The purpose of the survey was explained to all participants. Informed consent was sought and documented. Confidentiality protocols were strictly followed. Daily briefing sessions were held to resolve any discrepancies.

3.5 Integrated Research Design

The two models were combined at both the design and analysis stages. Quantifiable indicators of adoption behavior were provided by the TAI, while the RANAS model gave insight into the psychological and social mechanisms behind those behaviors. Triangulation enhanced the **policy relevance** of the findings.

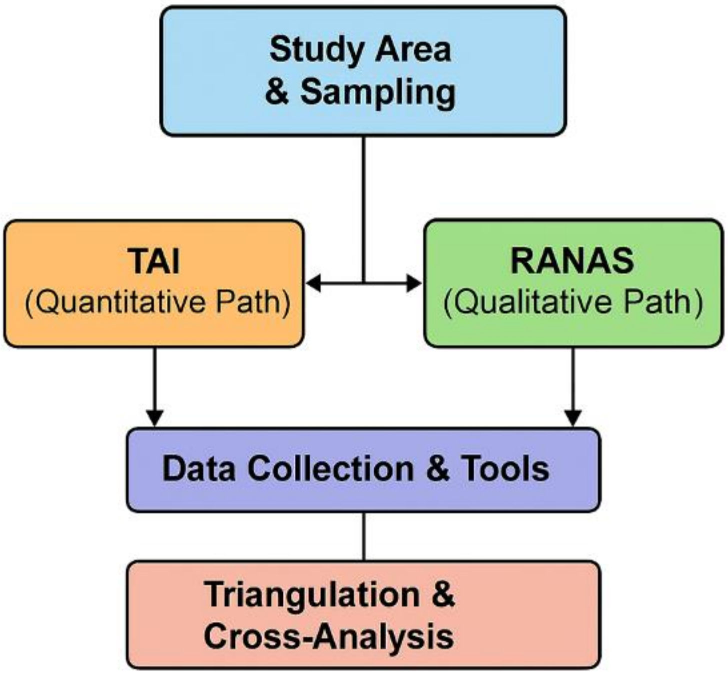

Figure 2: Integrated Research Framework for Agri-Tech Adoption Study

There is a **multi-dimensional lens** to study agricultural innovation in India. This enables the measurement of gaps and exploration of the structural and behavioral roots of agricultural technology adoption.

RESULTS AND DISCUSSION

The empirical findings from the study are presented in this section. The results are interpreted in the context of existing literature.

4.1 Demographic and Socio-Economic Profile

The demographic snapshot highlights the **heterogeneity** of smallholder farmers. Table 4 summarizes key characteristics:

Table 4: Socio-Demographic Profile of Respondents (N=200)

Characteristic	**Category**	**Percentage (%)**
Gender	Male	78.5
	Female	21.5
Age	< 35 years	23.0
	35–55 years	52.5
	> 55 years	24.5
Education Level	No formal schooling	19.5
	Primary	28.0
	Secondary	32.5
	Post-secondary and above	20.0
Landholding	Marginal (<1 ha)	38.5
	Small (1–2 ha)	61.5
Access to Irrigation	Yes	56.0
	No	44.0
Access to Government Schemes	Yes	33.5
	No	66.5

A large number of **female farmers** are active. Education levels remain modest, although secondary schooling is relatively common. **One-third** of the study highlighted **gaps in extension outreach.**

4.2 TAI-Based Adoption Scores

There was considerable **variation** in the Technology Adoption Index (TAI) scores.

Table 5: Mean TAI Scores by Domain and District

Domain	Nagpur	Akola	Yavatmal	Gadchiroli	Overall Mean
Irrigation	68.4	59.6	45.3	33.2	51.6
Soil Health Management	63.2	60.1	48.9	36.4	52.2
Pest and Disease Control	70.5	63.4	50.6	39.8	56.1
Post-Harvest Handling	52.1	48.7	40.3	26.7	41.9
ICT and Advisory Services	76.3	65.9	55.2	42.3	59.9

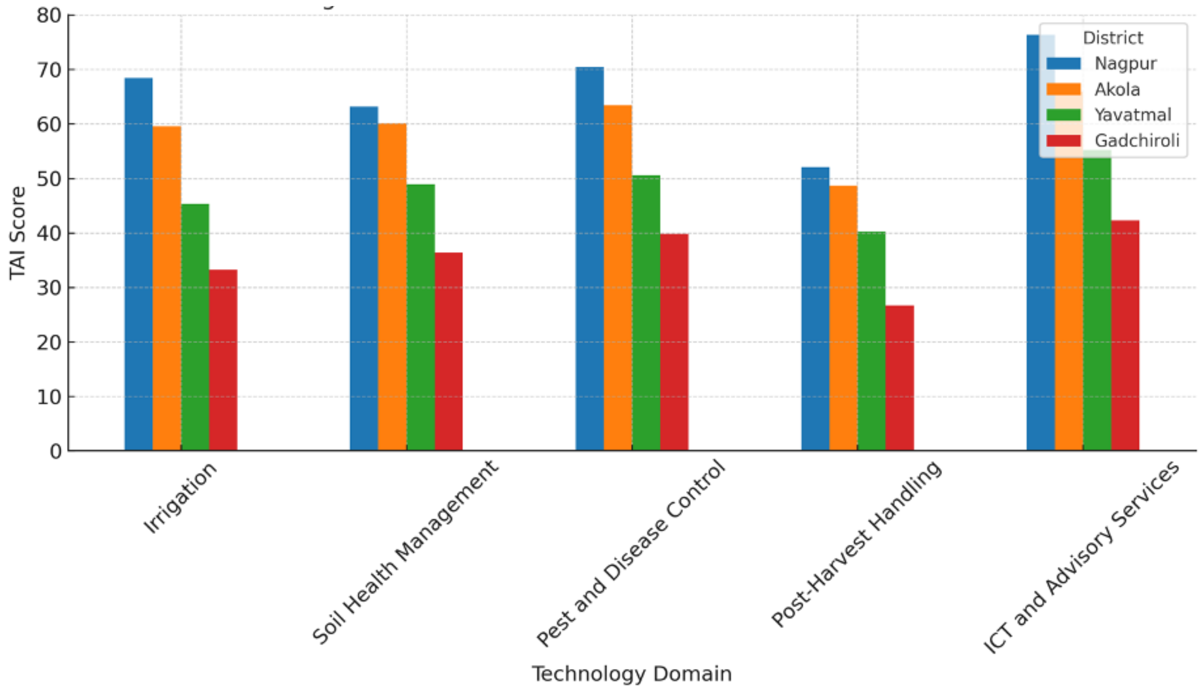

Figure 3: TAI Domain-wise Performance across Districts

The more developed parts of the province outperformed the distressed areas. In semi-remote regions, the highest mean adoption was attributed to **mobile penetration.**

4.3 Regression Analysis of TAI Determinants

Multivariate regression analysis identified the following predictors as statistically significant ($p < 0.05$) in influencing TAI scores:

- **Education level (β = 0.31):** Positively correlated, indicating higher adoption among literate farmers.
- **Access to irrigation (β = 0.27):** Suggests that water security encourages investment in modern inputs.
- **Digital literacy (β = 0.24):** Mobile usage—especially WhatsApp—enhances exposure to innovations.
- **Proximity to Krishi Seva Kendra (KSK) (β = 0.18):** Physical access to extension services remains crucial.

Gender and **landholding size** were not statistically significant at the 95% confidence interval, although trends indicated marginal advantages for **men** and **larger landholders.**

The more developed districts outperformed the distressed ones. In semi-remote regions, higher mean adoption was attributed to stronger mobile penetration and better infrastructure.

4.4 Behavioral Insights from RANAS Interviews

The **RANAS model** illuminated nuanced behavioral dynamics influencing technology adoption:

- **Risk Perception**: Many non-adopters perceived traditional methods as safer. In Yavatmal, fears of crop failure with new technologies were common.

- **Attitudes**: Early adopters viewed agri-tech as labor-saving and prestige-enhancing. Bio-fertilizers and mobile advisories received wide appreciation.
- **Norms**: Social proof strongly influenced decisions. A recurring sentiment was, *"If my neighbor uses it successfully, I will try it."*
- **Ability**: Women farmers—especially in Gadchiroli—reported lack of training and confidence in operating agricultural technology.
- **Self-Regulation**: Among low adopters, planning, savings, and follow-up were weak. In contrast, early adopters maintained records, experimented with trial plots, and had greater clarity of goals.

Farmer Yavatmal quote: *"My uncle tried drip irrigation and had to stop because the pipes cracked. So we all went back to flood. Why take the risk?"*

4.5 Triangulated Analysis

Combining quantitative insights from **TAI** and qualitative findings from **RANAS** reveals that **access to technology** is a necessary but insufficient condition for adoption. Behavior plays a decisive role. Even resource-accessible farmers are often held back by **socio-cognitive barriers.**

Effective extension strategies must blend **digital exposure** with **behaviorally informed nudges. It** includes peer demonstrations, small-scale trial programs, and identification of local champions. These approaches are more likely to **shift the adoption curve** than technology access alone.
This integrated understanding lays the groundwork for **targeted, inclusive, and scalable agri-tech interventions** in future policy designs.

CONCLUSION AND POLICY IMPLICATIONS

The objective of the study was to investigate the patterns, determinants, and behavioral underpinnings of agricultural technology adoption among small farmers. The study employed an integrated model that combined the **Technology Adoption Index (TAI)** for quantitative assessment with the **RANAS behavioral framework** for qualitative exploration, revealing a landscape of adoption shaped by socio-economic realities, infrastructural gaps, cognitive filters, and social dynamics.

Physical access to agri-tech solutions was widespread in some districts. However, lack of exposure, lack of trust in new methods, and the absence of social modeling emerged as prominent constraints. On the other hand, **positive peer norms, hands-on demonstrations,** and **perceived self-efficacy** served as strong enablers. Technology availability alone does not guarantee impact—it must be supported by behavioral engagement and tailored communication.

Education, digital literacy, and proximity to extension services significantly influenced TAI scores. The triangulated findings highlight the need to move beyond infrastructure- or subsidy-heavy interventions. **Policy effectiveness depends on deep contextual understanding.**

Policy Recommendations

The following interventions are recommended:

1. **Behavioral Extension Models:** Promote a behavior-centered approach by introducing **peer-led demo plots, tech champions,** and **storytelling-based farmer training** programs. These models foster trust and encourage community-driven adoption.
2. **Localized Advisory Systems:** Use **mobile-based platforms** to deliver **weather and crop-specific advisories.** Last-mile delivery can be managed by Krishi Vigyan Kendras (KVKs) and local NGOs to ensure timely, personalized, and culturally relevant information reaches the right people.
3. **Gender-Inclusive Agri-Tech Literacy Programs:** Launch training programs focused on **hands-on skills** and **confidence-building** to empower women farmers. Enabling women could create powerful ripple effects in household- and community-level innovation adoption.
4. **Incentivized Micro-Adoption:** Provide **smart subsidies** for **trial-scale adoption** of new technologies. These behavioral nudges can serve as tipping points to shift attitudes and practices at scale.
5. **Monitor Tech Uptake via TAI Dashboard:** Institutionalize the **Technology Adoption Index** within district- and state-level monitoring systems. A **data-driven feedback loop** will improve intervention transparency and allow course correction based on real-world insights.

Future Research Directions

This study paves the way for deeper inquiry into **sectoral adoption patterns, longitudinal tracking of behavioral shifts,** and **decision-support systems.** Comparative studies can help evaluate and refine behavioral intervention strategies. Further exploration of **real-time behavioral feedback loops** and **farmer-to-farmer influence networks** can advance our understanding of scalable adoption pathways.

Ultimately, sowing innovation requires more than technological inputs. For India's smallholder sector to transform, it needs a shift **in mindsets, structures, and support systems**. An **integrated and inclusive approach** is the foundation for building a resilient agricultural future.

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