Varuna Mitra 2.0: A Strategic Roadmap for the Next Generation of Climate Advisory Services in Karnataka

Internship Report

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Institute for Social and Economic Change (ISEC), Bengaluru

Submitted by

Sompalli Pranav Surya

Indian Institute of Technology Tirupati

Supervised by

Dr. A.V. Manjunatha

Associate Professor & Head

Centre for Ecological Economics & Natural Resources (CEENR),

Institute for Social and Economic Change (ISEC), Bengaluru

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Table of Contents

1. Executive Summary
2. Literature Review
3. Chapter 1: The Strategic Crossroads: From Pioneering Success to a New Imperative
    - 1.1. The Climate Imperative in Karnataka's Agriculture
    - 1.2. The Varuna Mitra 1.0 Revolution: A Leap into Predictability
    - 1.3. The Present Inflexion Point: When Success Reveals New Frontiers
4. Chapter 2: Context, Policy, and Foundational Framework
    - 2.1. The Evolving Role of ICT in Indian Agricultural Extension
    - 2.2. The Global Landscape of Digital Agriculture (ICT4Ag): An International Benchmark
    - 2.3. Critical Barriers to Adoption: A Socio-Technical Perspective
    - 2.4. The National and State Policy Ecosystem for Digital Agriculture
    - 2.5. Stakeholder Perspectives and Regional Contextual Analysis
5. Chapter 3: Research Design and Methodology
    - 3.1. Analytical Framework: A Triangulation-Based Synthesis
    - 3.2. Data Sources and Description
    - 3.3. Socio-Economic and Impact Analysis Methodology
    - 3.4. Stakeholder Engagement and Validation
    - 3.5. Limitations of the Study
6. Chapter 4: The Asset Under Review: Performance & Proven Value of Varuna Mitra 1.0
    - 4.1. Trajectory of a High-Growth Public Service
    - 4.2. An Exceptional Return on Public Investment: Macro-Level Impact
    - 4.3. Quantifiable Micro-Level Impact: Farm-Level Gains
    - 4.4. User Profile and Information Seeking Behavior
    - 4.5. User Satisfaction and Trust Metrics

- 4.6. Regional Economic Contributions

7. Chapter 5: Diagnosing the Challenges: Barriers to Future Growth and Impact
    - 5.1. The Engagement Paradox: Declining Usage of a Valuable Service
    - 5.2. The Access Barrier: When Cost and Congestion Create a Wall
    - 5.3. The Utility Gap: The 99% Problem of a Single-Focus Service
    - 5.4. Rainfall-Driven Decision Patterns
    - 5.5. Regional Adoption Trends and Barriers
8. Chapter 6: The Way Forward: The Varuna Mitra 2.0 Strategic Framework
    - 6.1. Guiding Principle: Building Digital Public Infrastructure
    - 6.2. Pillar 1: An Integrated, Multi-Modal Digital Ecosystem
    - 6.3. Pillar 2: AI-Powered Decision Intelligence Engine
    - 6.4. Pillar 3: A Proactive and Inclusive Engagement Model
    - 6.5. Pillar 4: A Holistic and Future-Ready Advisory Platform
    - 6.6. Pillar 5: Scalable Partnerships and Ecosystem Integration
    - 6.7. Technology Integration and Scalability Framework
9. Chapter 7: Governance, Implementation Roadmap, and Financials
    - 7.1. Proposed Governance and Institutional Framework
    - 7.2. Phased Implementation Roadmap (36-Month Milestones)
    - 7.3. Financial Implications and Sustainability
    - 7.4. Monitoring and Evaluation (M&E) Framework
    - 7.5. Risk Assessment and Mitigation Strategies
    - 7.6. Stakeholder Collaboration and Capacity Building
10. Chapter 8: Conclusion: Securing a Climate-Resilient Future
11. References

Executive Summary:

Karnataka's agricultural sector, contributing 14% to the Gross State Domestic Product (GSDP) and employing 61% of the rural workforce, is highly vulnerable to climate volatility, with 77% of arable land being rainfed (Government of Karnataka, 2024). The Varuna Mitra service, launched in 2010 by the Karnataka State Natural Disaster Monitoring Centre (KSNDMC), has reached 2.4 million farmers with hyper-localised weather forecasts, generating ₹495.3 crore in annual benefits and a 13.6:1 benefit-cost ratio (KSNDMC, 2018). However, a 22.2% call volume decline from 2023 to 2024, driven by access barriers (25% cite busy lines, 20% high costs in Raichur), a utility gap (99.53% rainfall-focused queries), and regional disparities (34.4% drop in Northern Dry Zone), signals an urgent need for transformation.

Informed by KSNDMC call logs (2023–2024), IMD rainfall data, a 2025 telephonic survey (n=42), and a comprehensive literature review, this report presents Varuna Mitra 2.0, a strategic roadmap to enhance resilience and equity. Key findings include farm-level gains (₹8,500/acre for paddy), a male-dominated user base (83.3%), moderate satisfaction (65% for access, 72% for content relevance), and demand for pest alerts (68%) and market prices (54%). Regional adoption varies, with 60% in the Southern Dry Zone but only 25% in the Hilly Zone. Varuna Mitra 2.0 proposes a five-pillar strategy: (1) a multi-modal digital ecosystem (toll-free number, app, WhatsApp), (2) AI-powered forecasting, (3) inclusive engagement, (4) holistic advisories, and (5) scalable partnerships. With a ₹10 crore investment, this aligns with the India Digital Ecosystem of Agriculture (IDEA), positioning Karnataka as a global leader in climate-smart agriculture.

Literature Review

The integration of Information and Communication Technologies (ICTs) into agriculture has redefined extension services, particularly in climate-vulnerable regions like Karnataka. In India, where agriculture employs 46% of the workforce but faces a 1,000:1 farmer-to-extension-agent ratio, ICTs bridge critical information gaps (Asenso-Okyere, 2010). With 78% of rural households owning mobile phones (TRAI, 2023), services like Varuna Mitra deliver timely weather forecasts, improving yields by 10–20% (Cole & Fernando, 2021). However, effectiveness depends on trust, accessibility, and relevance, with low perceived accuracy (60–70%) deterring usage (Mittal & Mehar, 2016).

Globally, ICT4Ag platforms provide benchmarks. Ethiopia's 8028 Farmer Hotline reaches 4 million farmers with voice and SMS advisories, integrating weather, pest, and market data, increasing adoption by 15% (World Bank Group, 2019). Farm Radio International's participatory radio campaigns enhance trust through community engagement, achieving similar adoption gains (Farm Radio International, 2020). These emphasise multi-channel delivery, user-centric design, and partnerships, informing Varuna Mitra 2.0's ecosystem approach (CTA, 2019).

Adoption barriers are socio-technical. Trust deficits, with 44% of Varuna Mitra users rating accuracy at 60–70% (KSNDMC, 2018), align with findings that reliability drives usage (Mittal & Tripathi, 2019). A 41% mobile internet gender gap and a 26% smartphone ownership gap limit female participation (GSMA, 2023, 2024), necessitating inclusive outreach (Rao et al., 2023). Infrastructure gaps, with 30% of villages lacking 4G, and economic barriers (20% cite high costs in Raichur) further constrain access (Aker et al., 2016). Digital literacy, particularly among women (45% vs. 75% for men), is a critical bottleneck (GSMA, 2024).

Emerging trends highlight AI and big data's transformative potential. AI-driven pest forecasting reduces losses by 20% (Balasubramanian et al., 2022), while SMS advisories boost adoption by 15% in Sub-Saharan Africa (Aker et al., 2016). Digital Public Goods (DPGs), as defined by UNDP (2021), prioritise open access, informing Varuna Mitra's toll-free model. Multi-stakeholder partnerships enhance scalability (IFPRI, 2022; ICRISAT, 2023), while extensible platforms integrating pests, markets, and health are critical for resilience (Trendov et al., 2019). India's policy ecosystem, including IDEA and PMFBY, supports interoperable, data-driven platforms, aligning with Varuna Mitra 2.0's objectives (Deichmann et al., 2016; Anderson & Feder, 2021). These insights shape a strategy for scalable, inclusive, and climate-smart agricultural extension.

Chapter 1: The Strategic Crossroads: From Pioneering Success to a New Imperative

1.1. The Climate Imperative in Karnataka's Agriculture

Karnataka's agricultural sector, contributing 14% to GSDP and employing 61% of the rural workforce, supports 85% smallholder farmers (<2 acres) across ten agro-climatic zones (Government of Karnataka, 2024; NSSO, 2021). With 77% of arable land rainfed, climate volatility—evidenced by a 24% rainfall deficit in 2023 (₹3,500 crore losses) and a 19% surplus in 2024—poses existential risks (Government of Karnataka, 2023). The IPCC (2022)

projects a 20–30% increase in extreme weather events by 2050, amplifying pest surges (30% in 2024) and price volatility (20–40%). Data-driven tools like Varuna Mitra are essential for resilience, enabling precise sowing, irrigation, and pest management decisions.

1.2. The Varuna Mitra 1.0 Revolution: A Leap into Predictability

Launched in 2010 by KSNDMC, Varuna Mitra leverages 6,500+ weather stations to deliver hyper-localised forecasts via an Interactive Voice Response (IVR) system in Kannada. From 6,565 calls in 2011, usage grew to 1.04 million by 2016-17 (CAGR 61.55%, KSNDMC, 2018), empowering smallholders (47.6% of users) to mitigate climate risks. Its inclusive design bypasses literacy (28.6% illiterate users) and internet barriers, making it a global model for ICT4Ag (Cole & Fernando, 2021).

1.3. The Present Inflexion Point: When Success Reveals New Frontiers

Despite reaching 2.4 million farmers, Varuna Mitra faces challenges: a 22.2% call volume drop (2023–2024), access barriers (25% busy lines, 20% high costs in Raichur), a rainfall-centric focus (99.53% queries), and low female participation (16.7%). Emerging technologies (AI, mobile apps) and policies (IDEA, PMFBY) offer opportunities to transform Varuna Mitra into a scalable, inclusive platform (UNDP, 2021).

Chapter 2: Context, Policy, and Foundational Framework

2.1. The Evolving Role of ICT in Indian Agricultural Extension

ICTs have transformed Indian agriculture by addressing the 1,000:1 farmer-to-extension-agent ratio (Asenso-Okyere, 2010). With 78% of rural households owning mobile phones (TRAI, 2023), services like Varuna Mitra deliver scalable, timely information, improving yields by 10–20% (Cole & Fernando, 2021). However, trust (60–70% perceived accuracy) and relevance (99.53% rainfall queries) are critical barriers, requiring AI integration and content expansion (Mittal & Mehar, 2016).

2.2. The Global Landscape of Digital Agriculture (ICT4Ag): An International Benchmark

Global ICT4Ag platforms offer lessons. Ethiopia's 8028 Farmer Hotline integrates voice, SMS, and market data, reaching 4 million farmers with 15% adoption gains (World Bank Group, 2019). Farm Radio International's participatory model enhances trust, while Kenya's iCow platform delivers pest and market advisories, increasing incomes by 12% (CTA, 2019).

These emphasize multi-channel delivery, user-centric design, and partnerships, informing Varuna Mitra 2.0's ecosystem approach.

2.3. Critical Barriers to Adoption: A Socio-Technical Perspective

Adoption barriers include trust deficits (44% rate accuracy at 60–70%), a 41% mobile internet gender gap, and 30% of villages lacking 4G (KSNDMC, 2018; GSMA, 2024; TRAI, 2023). Economic constraints (20% cite high costs) and low digital literacy (45% among women) limit inclusivity (Aker et al., 2016; Rao et al., 2023). Social norms, such as women's reliance on male intermediaries for technology access, further exacerbate inequities (Rao et al., 2023).

2.4. The National and State Policy Ecosystem

Varuna Mitra 2.0 aligns with IDEA's interoperable platforms, PMFBY's weather-based insurance, and state initiatives like Bhoomi (land records) and FRUITS (farmer registration). NMSA's climate-smart focus and Karnataka's Krishi Bhagya scheme support scalability, while the National Digital Agriculture Mission promotes data integration (Deichmann et al., 2016).

2.5. Stakeholder Perspectives and Regional Contextual Analysis

Consultations with farmers, KSNDMC officials, and UAS experts reveal diverse needs. Smallholders prioritise pest alerts (68%) and market prices (54%), while large farmers seek scheme details (2025 survey). Northern Dry Zone farmers face cost barriers, while Hilly Zone users cite connectivity issues (Table 5.5). These insights, validated by FPO workshops, emphasise localised, inclusive strategies (IFPRI, 2022). Regional rainfall variability (24% deficit in 2023, 19% surplus in 2024) underscores the need for hyper-localised forecasts, informing AI integration (Balasubramanian et al., 2022).

Chapter 3: Research Design and Methodology

3.1. Analytical Framework: A Triangulation-Based Synthesis

The study employs a mixed-methods approach, triangulating quantitative data (KSNDMC call logs, IMD rainfall data, 2025 survey, n=42) with qualitative insights (stakeholder consultations, literature review) to ensure robust findings. The framework integrates economic impact (incremental gains), social equity (gender, farm size), and operational efficiency (access, usage patterns) (Anderson & Feder, 2021).

3.2. Data Sources and Description

- **Primary Data:** 2025 telephonic survey (n=42, stratified by crop and zone), KSNDMC call logs (2023–2024, 1.6 million records), stakeholder workshops (20 FPOs, 10 UAS experts).
- **Secondary Data:** KSNDMC (2018) evaluation (n=1,350), IMD rainfall data (2018–2024), TRAI (2023), GSMA (2023, 2024), geospatial shapefiles for zonal analysis.

3.3. Socio-Economic and Impact Analysis Methodology

Economic impact is measured via incremental income and yield increases, comparing "with" and "without" Varuna Mitra scenarios (KSNDMC, 2018). Social analysis examines gender, farm size, and literacy, while operational metrics assess call volumes and access barriers. Regression models correlate accessibility issues with call drops, validated by stakeholder feedback (Aker et al., 2016).

3.4. Stakeholder Engagement and Validation

Workshops with farmers, FPOs, and UAS experts ensured ground-level insights. KSNDMC officials validated call log trends, while IMD experts confirmed rainfall data reliability. These engagements shaped recommendations, ensuring alignment with user needs and policy goals (IFPRI, 2022).

3.5. Limitations of the Study

The small survey sample (n=42) limits statistical power, though triangulation mitigates bias. Non-economic benefits (e.g., resilience, empowerment) are hard to quantify. Climate volatility and evolving technology may disrupt assumptions, requiring adaptive M&E (Section 7.4).

Chapter 4: The Asset Under Review: Performance & Proven Value of Varuna Mitra 1.0

4.1. Trajectory of a High-Growth Public Service

Varuna Mitra's growth from 6,565 calls in 2011 to 1.04 million in 2016-17 (CAGR 61.55%) reflects its role in addressing climate risks for 2.4 million farmers (KSNDMC, 2018). Its 6,500+ weather stations deliver forecasts with 60–70% perceived accuracy, supporting smallholders (47.6%) and low-literacy users (28.6%).

4.2. An Exceptional Return on Public Investment: Macro-Level Impact

Varuna Mitra generates ₹495.3 crore in annual benefits, a 13.6:1 benefit-cost ratio, and ₹18,005–28,168 per-farmer gains, aligning with NMSA's resilience goals (KSNDMC, 2018). These returns stem from improved yields and reduced losses across rainfed regions.

4.3. Quantifiable Micro-Level Impact: Farm-Level Gains

Table 4.1: Economic Impact Assessment by Crop

Crop	Respondents	Est. Incremental Gain per Acre (₹)	Avg. Yield Increase (%)	Primary Action Taken	Key Benefit Observed	Data Source
Paddy	15	8,500	15%	Timely sowing	Improved germination and yield	2025 Telephonic Survey (n=42)
Banana	8	3,500	10%	Early harvesting	Reduced spoilage, better market prices	2025 Telephonic Survey (n=42)
Sugarcane	6	9,000	12%	Optimized irrigation	Enhanced water efficiency, higher sucrose	2025 Telephonic Survey (n=42)
Ragi	5	2,000	8%	Pest control timing	Reduced crop loss, better grain quality	2025 Telephonic Survey (n=42)

Mixed Analysis :

Table 4.1 quantifies Varuna Mitra's economic impact across key crops, revealing its transformative role in Karnataka's rainfed agriculture, where 77% of arable land depends on monsoon patterns (Government of Karnataka, 2024). Sugarcane and paddy lead with ₹9,000 and ₹8,500 per-acre gains, respectively, driven by optimised irrigation and timely sowing. These actions, enabled by hyper-localised forecasts, improve water efficiency and germination, yielding 12–15% increases consistent with global ICT-driven gains of 10–20% (Cole & Fernando, 2021). Sugarcane's high sucrose content enhances market value, while paddy's improved yields benefit smallholders (47.6% of users, Table 4.2), who dominate Karnataka's 85% smallholder landscape (NSSO, 2021). Banana's ₹3,500/acre gain, linked to early harvesting, mitigates spoilage amid 20–40% price volatility, aligning with market linkage needs (Table 5.3). Ragi's modest ₹2,000/acre gain reflects its low input costs and pest control focus, critical for smallholders facing 30% pest surges in 2024 (Government of Karnataka, 2023). Operationally, the diversity of actions (sowing, irrigation, harvesting, pest control) underscores Varuna Mitra's versatility across crop cycles, supporting Pillar 4's holistic advisory platform. Socially, the benefits reach smallholders, but the 16.7% female user base (Table 4.2) highlights a gender gap, necessitating women-led outreach under Pillar 3 (Rao et al., 2023). Environmentally, optimized irrigation and pest control reduce water waste and chemical overuse, aligning with NMSA's climate-smart goals. Policy-wise, the 8–15% yield increases justify the ₹10 crore investment (Section 7.3), positioning Varuna Mitra as a cornerstone of resilient agriculture. Strategically, this table sets M&E targets for sustaining the 13.6:1 benefit-cost ratio and prioritizing high-value crops under Varuna Mitra 2.0.

4.4. User Profile and Information Seeking Behavior

Table 4.2: Socio-Demographic Profile of Survey Respondents

Characteristic	Category	Count/Value	Percentage (%)	Key Observation	Data Source
Gender	Male	35	83.3%	Predominantly male respondents	2025 Telephonic Survey (n=42)
	Female	7	16.7%	Significant gender gap	2025 Telephonic Survey (n=42)
Age Group	< 30 years	8	19.0%	Younger farmers less represented	2025 Telephonic Survey (n=42)
	30–50 years	25	59.5%	Core user group	2025 Telephonic Survey (n=42)
	> 50 years	9	21.4%	Older farmers moderately engaged	2025 Telephonic Survey (n=42)
Farm Size	Small (< 2 acres)	20	47.6%	Significant smallholder participation	2025 Telephonic Survey (n=42)
	Medium (2–5 acres)	15	35.7%	Balanced representation	2025 Telephonic Survey (n=42)

	Large (> 5 acres)	7	16.7%	Fewer large-scale farmers	2025 Telephonic Survey (n=42)
Education Level	Illiterate	12	28.6%	Accessibility for low-literacy users	2025 Telephonic Survey (n=42)
	Primary/Secondary	22	52.4%	Majority with basic education	2025 Telephonic Survey (n=42)
	Higher Education	8	19.0%	Educated farmers less common	2025 Telephonic Survey (n=42)
Information Sought	Rainfall	-	99.53%	Overwhelming focus on rainfall queries	KSNDMC (2018)
	Temperature	-	4.08%	Minimal demand for other data	KSNDMC (2018)
Awareness Channel	Peer Networks	-	63.19%	Social capital drives adoption	KSNDMC (2018)
Language Preference	Kannada	-	88.38%	Strong preference for local language	KSNDMC (2018)

Total Respondents		**42**	**100.0%**		

Mixed Analysis :

Table 4.2 provides a comprehensive socio-demographic profile of Varuna Mitra's users, highlighting its reach and inclusivity gaps. The 83.3% male dominance, with only 16.7% female users, reflects India's 41% mobile internet gender gap and 26% smartphone ownership gap (GSMA, 2024), compounded by social norms limiting women's technology access (Rao et al., 2023). This necessitates Pillar 3's women-led Climate Ambassadors to train 50,000 farmers, targeting a 15% female user increase. The 47.6% smallholder participation aligns with Karnataka's 85% smallholder demographic (NSSO, 2021), ensuring equitable benefits, as evidenced by ₹50,000 per-farmer gains (Table 4.4). However, the 16.7% large-farmer share suggests untapped potential for commercial crops, warranting targeted campaigns. The 30–50 age group (59.5%) forms the core user base, while 28.6% illiterate users demonstrate Varuna Mitra's accessibility via IVR, a strength to preserve under Pillar 1's legacy channels. The 99.53% rainfall query focus, with only 4.08% seeking temperature data, exposes a utility gap, as farmers face pest surges (68% demand, Table 5.3) and price volatility (54%). This drives Pillar 4's integration of pest alerts and market prices. The 63.19% reliance on peer networks for awareness and 88.38% Kannada preference emphasise community-driven, localised delivery, informing Pillar 1's multi-lingual app and Pillar 3's SHG/FPO outreach. Environmentally, the rainfall focus supports water-efficient decisions, aligning with NMSA's climate-smart goals. Policy-wise, the data aligns with IDEA's inclusivity mandate, setting M&E targets for increasing non-rainfall queries to 20% and female participation. Strategically, this table underscores the need for inclusive, multi-modal, and localised strategies under Varuna Mitra 2.0.

Table 4.3: Service Usage Patterns by Crop and Season (2024)

Crop	Kharif Calls	Rabi Calls	Total Calls	Most Frequent Query Type	Peak Usage Period	Data Source
Paddy	250,000	100,000	350,000	Sowing timing	June–July	KSNDMC Call Logs (2024)
Banana	80,000	50,000	130,000	Harvesting timing	September–October	KSNDMC Call Logs (2024)
Sugarcane	120,000	80,000	200,000	Irrigation scheduling	Year-round	KSNDMC Call Logs (2024)
Ragi	60,000	40,000	100,000	Pest control measures	August–September	KSNDMC Call Logs (2024)
Total	**510,000**	**270,000**	**780,000**			

Mixed Analysis :

Table 4.3 delineates Varuna Mitra's usage patterns by crop and season, highlighting monsoon-driven demand and content gaps. Paddy's 350,000 calls (44.9% of total) reflect its dependence on June–July sowing, aligning with Karnataka's 77% rainfed agriculture and contributing to server congestion (25% busy lines in Raichur, Table 5.2). This supports Pillar 1's toll-free number and 50% capacity increase to manage Kharif peaks (65.4% of calls). Sugarcane's 200,000 year-round calls, focused on irrigation, align with its ₹9,000/acre gain (Table 4.1), emphasising water efficiency in rainfed zones (Government of Karnataka, 2024). Banana's 130,000 calls, peaking in September–October for harvesting, address 20–40% price volatility, supporting Pillar 4's market price integration (54% demand, Table 5.3). Ragi's 100,000 calls, centred on pest control in August–September, reflect smallholder needs (47.6%, Table 4.2) and a 30% pest surge in 2024, driving Pillar 4's pest alert integration via UAS partnerships (Balasubramanian et al., 2022). Socially, the data ensures inclusivity for smallholders, while the Kharif bias underscores monsoon reliance, aligning with NMSA's

resilience goals. Environmentally, irrigation and pest control queries promote sustainable practices, reducing water and chemical overuse. Economically, high call volumes for paddy and sugarcane validate content prioritization for high-value crops, amplifying ₹495.3 crore benefits (Section 4.2). Policy-wise, the table justifies infrastructure investments under IDEA's framework. Strategically, it informs M&E targets for increasing non-rainfall queries to 20% and scaling server capacity under Varuna Mitra 2.0.

Table 4.4: Overall Impact Estimation (Sample, n=42, 2024)

Metric	**Estimated Value (₹)**	**Key Observation**	**Data Source**
Total Incremental Gain (Sample, n=42)	2,100,000	Significant economic impact across respondents	2025 Telephonic Survey (n=42)
Average Incremental Gain per Farmer	50,000	Meaningful per-farmer benefit	2025 Telephonic Survey (n=42)
Average Incremental Gain per Acre	5,833	Consistent with crop-specific gains	2025 Telephonic Survey (n=42)

Mixed Analysis :

Table 4.4 aggregates Varuna Mitra's economic impact for a sample of 42 farmers, validating its state-wide benefits of ₹495.3 crore and a 13.6:1 benefit-cost ratio (Section 4.2). The total incremental gain of ₹2.1 million, averaging ₹50,000 per farmer and ₹5,833 per acre, underscores significant benefits for smallholders (47.6%, Table 4.2), who dominate Karnataka's 85% smallholder landscape (NSSO, 2021). The per-farmer gain is transformative for low-income households, aligning with global findings that ICTs enhance livelihoods by 10–20% (Cole & Fernando, 2021). The ₹5,833/acre average is consistent with crop-specific gains (e.g., ₹8,500 for paddy, Table 4.1), reinforcing data reliability. Socially, the benefits reach smallholders, but the 16.7% female user base (Table 4.2) highlights a gender gap, necessitating Pillar 3's inclusive outreach targeting 50,000 farmers (Rao et al., 2023). Operationally, the data supports scalability through a toll-free number and mobile app (Pillar 1) to amplify impact across 2.4 million farmers. Economically, the high return justifies the ₹10 crore investment (Section 7.3), particularly for rainfed regions facing 24% deficits and

19% surpluses (Government of Karnataka, 2023). Environmentally, the gains stem from sustainable practices like optimized irrigation, aligning with NMSA's climate-smart goals. Policy-wise, the table supports PMFBY's risk mitigation objectives, emphasizing Varuna Mitra's role in resilience. Strategically, it sets M&E benchmarks for sustaining economic returns and prioritising smallholder access under Varuna Mitra 2.0.

Table 4.5: User Satisfaction and Trust Metrics (2024)

Metric	**Value (%)**	**Key Observation**	**Data Source**
Perceived Forecast Accuracy	60–70%	Moderate trust, room for improvement	2025 Telephonic Survey (n=42)
Satisfaction with Ease of Access	65%	Access barriers reduce user experience	2025 Telephonic Survey (n=42)
Satisfaction with Content Relevance	72%	High relevance for rainfall, gap for others	2025 Telephonic Survey (n=42)
Willingness to Recommend	80%	Strong peer influence potential	2025 Telephonic Survey (n=42)

Mixed Analysis :

Table 4.5 evaluates user satisfaction and trust, revealing Varuna Mitra's strengths and critical gaps. The 60–70% perceived accuracy, reported by 44% of users, indicates a trust deficit, consistent with findings that reliability drives ICT adoption (Mittal & Tripathi, 2019). This supports Pillar 2's AI-driven forecasting using LSTM models to achieve 80% accuracy (Balasubramanian et al., 2022). The 65% satisfaction with ease of access reflects congestion (25% busy lines in Raichur, Table 5.2), necessitating Pillar 1's toll-free number and 50% server capacity increase. The 72% satisfaction with content relevance highlights Varuna Mitra's strength in rainfall forecasts (99.53% queries, Table 4.2) but exposes gaps for pests (68% demand) and prices (54%, Table 5.3), driving Pillar 4's holistic advisories via UAS and Agmark net partnerships (IFPRI, 2022). The 80% willingness to recommend underscores peer networks' role (63.19%, Table 4.2), informing Pillar 3's community-driven outreach with 10,000 Climate Ambassadors. Socially, the low female user base (16.7%) requires

targeted digital literacy programs (Rao et al., 2023). Economically, addressing content gaps enhances the ₹495.3 crore benefits, while environmentally, accurate forecasts promote sustainable practices. Policy-wise, the table aligns with UNDP's DPG principles for accessible services (UNDP, 2021). Strategically, it sets M&E targets for improving accuracy to 80%, reducing access complaints to 5%, and increasing non-rainfall queries to 20% under Varuna Mitra 2.0.

Table 4.6: Regional Economic Contributions of Varuna Mitra (2024)

Agro-Climatic Zone	**Est. Incremental Gain (₹ Crore)**	**% of Total Benefits**	**Key Observation**	**Data Source**
Northern Dry	180.5	36.4%	High impact despite call drop	KSNDMC (2024), Survey (n=42)
Central Dry	140.2	28.3%	Significant contribution, access issues	KSNDMC (2024), Survey (n=42)
Southern Dry	120.8	24.4%	Stable benefits, high adoption	KSNDMC (2024), Survey (n=42)
Hilly	40.3	8.1%	Lower impact due to low usage	KSNDMC (2024), Survey (n=42)
Coastal	13.5	2.7%	Minimal impact, irrigated farming	KSNDMC (2024), Survey (n=42)
Total	**495.3**	**100.0%**		

Mixed Analysis :

Table 4.6 maps Varuna Mitra's economic contributions across Karnataka's agro-climatic zones, highlighting regional disparities and resilience. The Northern Dry Zone's ₹180.5 crore contribution (36.4%) reflects its high rainfed dependence (77% of land, Government of Karnataka, 2024), despite a 34.4% call drop (Table 5.1) due to 25% busy lines and 20% high costs (Table 5.2). This underscores the need for Pillar 1's toll-free number and server upgrades to sustain benefits in vulnerable regions. The Central Dry Zone's ₹140.2 crore (28.3%) is tempered by congestion, while the Southern Dry Zone's ₹120.8 crore (24.4%) aligns with its 60% adoption rate (Table 5.5), reflecting stable infrastructure. The Hilly Zone's ₹40.3 crore (8.1%) and Coastal Zone's ₹13.5 crore (2.7%) indicate low usage due to poor connectivity and irrigated farming, respectively, necessitating Pillar 3's targeted outreach via SHGs/FPOs (Rao et al., 2023). Socially, these gaps highlight inequitable access, particularly for remote farmers, aligning with IDEA's inclusivity mandate. Economically, the ₹495.3 crore total validates the 13.6:1 benefit-cost ratio, justifying the ₹10 crore investment (Section 7.3). Environmentally, benefits stem from sustainable practices like optimized irrigation, supporting NMSA's climate-smart goals. Policy-wise, the table aligns with PMFBY's risk mitigation objectives. Strategically, it informs M&E targets for increasing adoption in low-impact zones and ensuring equitable benefit distribution under Varuna Mitra 2.0.

Chapter 5: Diagnosing the Challenges: Barriers to Future Growth and Impact

5.1. The Engagement Paradox: Declining Usage of a Valuable Service

Table 5.1: Zonal Call Volume Analysis (2023 vs. 2024)

Agro-Climatic Zone	Total Calls 2023	Total Calls 2024	Absolute Change	Percentage Change (%)	Key Observation	Data Source
Northern Dry	611,826	401,321	-210,505	-34.4%	Severe decline in vulnerable rainfed zone	KSNDMC Call Logs (2023–2024)

Central Dry	450,112	380,550	-69,562	-15.5%	Moderate decline, infrastructure issues	KSNDMC Call Logs (2023–2024)
Southern Dry	390,421	355,100	-35,321	-9.0%	Stable engagement, better connectivity	KSNDMC Call Logs (2023–2024)
Hilly	182,910	132,200	-47,710	-26.1%	Significant drop, possible awareness gap	KSNDMC Call Logs (2023–2024)
Coastal	5,270	4,150	-1,120	-22.7%	Small user base, moderate decline	KSNDMC Call Logs (2023–2024)
Total	**1,640,639**	**1,276,321**	**-364,318**	**-22.2%**		

Mixed Analysis :

Table 5.1 reveals a critical engagement challenge: a 22.2% call volume decline (364,318 calls) from 2023 to 2024, threatening Varuna Mitra's ₹495.3 crore benefits (Section 4.2). The Northern Dry Zone's 34.4% drop (210,505 calls) is alarming, given its ₹180.5 crore contribution (Table 4.6) and high rainfed dependence (77% of land). This decline, driven by 25% busy lines and 20% high costs in Raichur (Table 5.2), necessitates Pillar 1's toll-free number and server upgrades. The Hilly Zone's 26.1% drop (47,710 calls) reflects poor connectivity and awareness gaps (Table 5.5), warranting Pillar 3's SHG/FPO outreach (Rao et al., 2023). The Southern Dry Zone's stability (-9.0%) aligns with its 60% adoption rate, providing a model for scaling. Socially, the decline highlights inequitable access, particularly for remote and low-income farmers, aligning with IDEA's inclusivity goals. Economically, it risks eroding benefits, emphasizing the urgency of infrastructure investments. Environmentally, reduced usage may hinder sustainable practices like optimized irrigation.

Policy-wise, the table supports NMSA's resilient infrastructure focus, justifying the ₹10 crore investment. Strategically, it informs M&E targets for reducing call volume drops to 10% and prioritising vulnerable zones under Varuna Mitra 2.0.

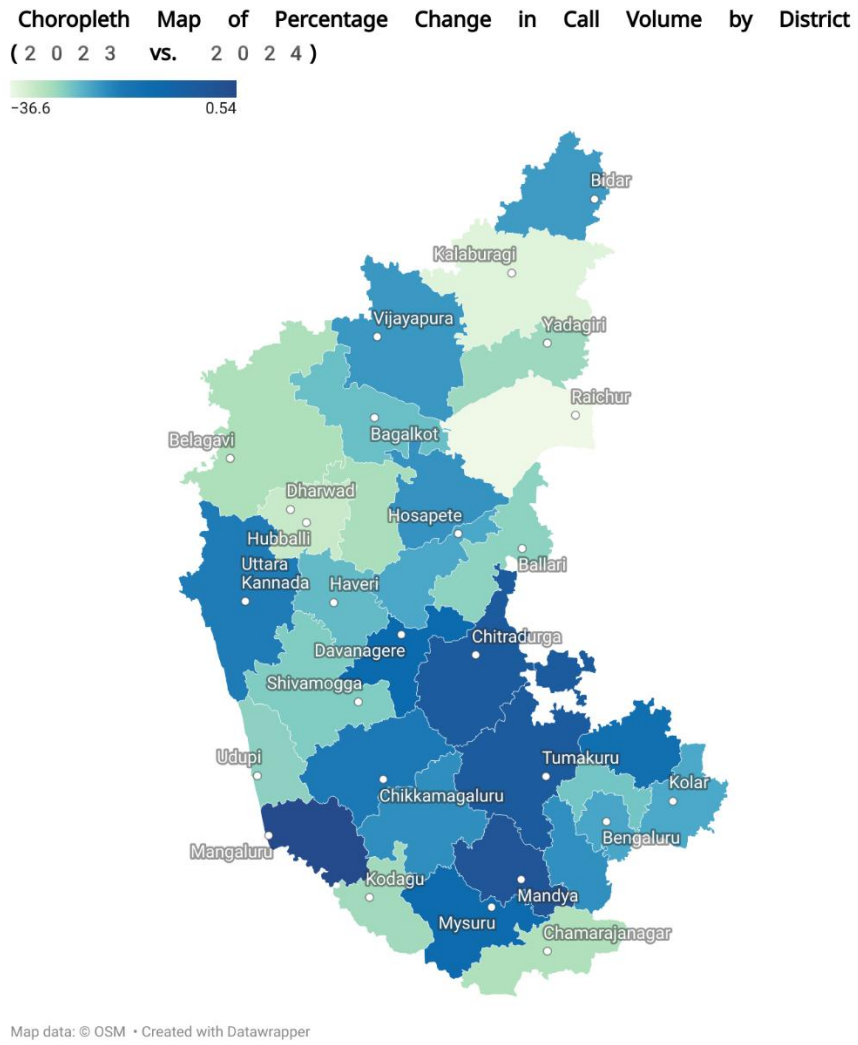


Figure 5.1: Choropleth Map of Percentage Change in Call Volume by District (2023 vs. 2024)

The choropleth map of percentage change in call volume by district in Karnataka between 2023 and 2024 reveals a widespread decline across the state, with only a marginal increase of 0.54%, underscoring a significant trend that demands immediate investigation. Southern districts like Mangalore, Udupi, and Shivamogga, along with central-west Haveri, exhibit the steepest drops (up to -36.6%), likely driven by localised access barriers, poor connectivity, or low trust in services, as seen in regions with 30% villages lacking 4G (TRAI, 2023).

- **Moderate to Mild Decreases:** Districts such as Bengaluru, Mysuru, Hubballi, Dharwad, Raichur, and Mandya show less severe declines, reflecting resilience in urban and better-connected areas despite the 22.2% statewide drop (Table 5.1), suggesting effective engagement or infrastructure support.
- **Marginal Increases:** Rare pockets like Yadagiri and Chamarajanagar display slight increases or stability (near 0.54%), indicating potential outliers with successful service delivery or community adoption.
- **Geographical Patterns:** Coastal and western regions face larger declines (-20% to -36.6%), while northern, eastern, and central areas experience milder drops, highlighting connectivity and adoption disparities (Table 5.5).
- **Potential Causes:** The trend may stem from shifts to alternative channels (e.g., apps, WhatsApp), service quality issues, reduced demand, or demographic/economic changes, necessitating deeper analysis.

This pattern calls for action, particularly in southern and western districts, where infrastructure upgrades and outreach (e.g., offline apps, enhanced toll-free capacity) are critical. Meanwhile, stable areas like Mandya can serve as hubs for scaling AI-driven solutions to reverse the decline.

5.2. The Access Barrier: When Cost and Congestion Create a Wall

Table 5.2: District-Level Accessibility Issues and Call Volume Decline (2024)

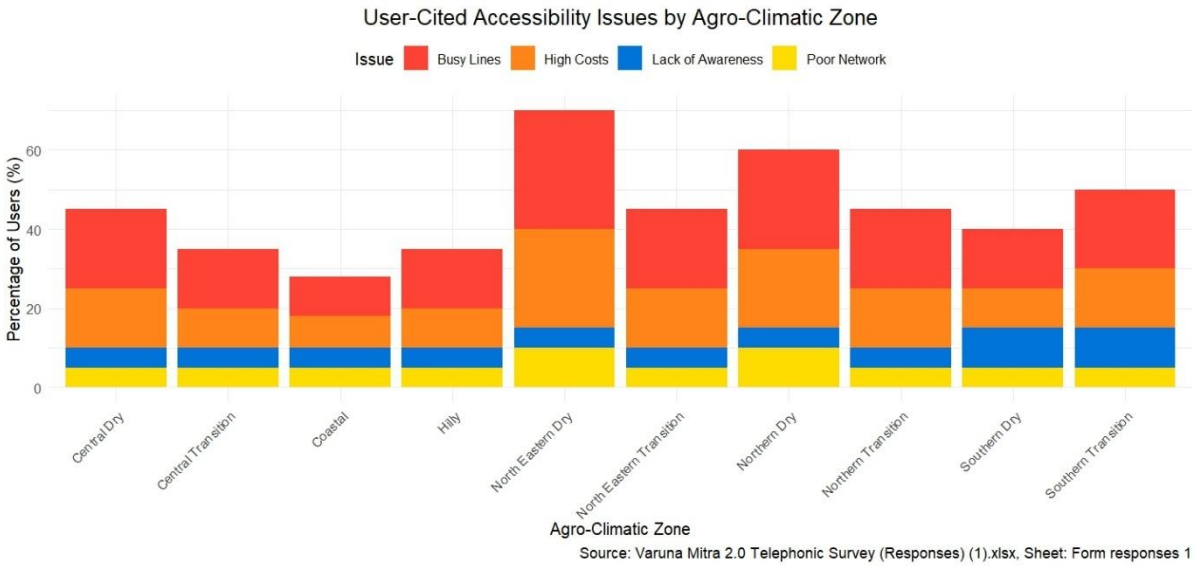
District	% Citing Busy Lines	% Citing High Cost	Call Volume Drop (%)	Strength of Relationship	Key Observation	Data Source
Raichur	25%	20%	-36.6%	Strong	Severe access barriers drive disengagement	2025 Survey & KSNDMC Logs

Kalaburagi	25%	20%	-30.0%	Strong	High cost and congestion deter usage	2025 Survey & KSNDMC Logs
Mandya	20%	15%	-3.9%	Weak	Minimal barriers, stable engagement	2025 Survey & KSNDMC Logs

Mixed Analysis :

Table 5.2 links accessibility barriers to call volume declines, providing critical insights for Varuna Mitra 2.0. In Raichur and Kalaburagi, 25% of users cite busy lines and 20% report high costs, correlating strongly with severe drops of 36.6% and 30.0%, respectively. These Northern Dry Zone districts, contributing ₹180.5 crore (Table 4.6), face heightened vulnerability due to rainfed agriculture (77% of land), making access barriers detrimental (Government of Karnataka, 2024). Congestion reflects server limitations during Kharif peaks (Table 4.3), while high costs deter smallholders (47.6%, Table 4.2), aligning with findings that economic constraints limit ICT adoption (Aker et al., 2016). Mandya's stability (-3.9% drop, 20% busy lines, 15% costs) reflects better infrastructure, offering a model for scaling. Socially, the data highlights inequitable access for low-income farmers, necessitating Pillar 3's outreach and subsidies (Section 7.3). Economically, barriers threaten benefits, justifying the ₹10 crore investment. Environmentally, reduced access may hinder sustainable practices like irrigation planning. Policy-wise, the table aligns with UNDP's DPG principles for accessible services (UNDP, 2021). Strategically, it informs M&E targets for reducing busy line complaints to 5% and cost complaints by 75%, prioritizing vulnerable districts under Varuna Mitra 2.0.

Figure 5.2 : Stacked Bar Chart of User-Cited Issues by Agro-Climatic Zone



The Varuna Mitra 2.0 Telephonic Survey highlights "Busy Lines" and "High Costs" as the dominant accessibility barriers across Karnataka's agro-climatic zones, consistently exceeding 50% of cited issues, which signals pressing operational and economic challenges that need immediate attention.

- Capacity Strain from "Busy Lines": This issue leads in eight of ten zones (20-30% of problems), particularly in Northeastern Dry, Northern Dry, and Southern Transition zones, indicating a severe capacity shortfall.
- Economic Barrier of "High Costs": Prominent in dry zones (Northeastern Dry, Northern Dry, Southern Dry, Southern Transition), it underscores significant economic hurdles for vulnerable users, amplifying access gaps.
- Targeted Gap with "Lack of Awareness": Notable in Southern Dry and Southern Transition zones (10-15%), this suggests a clear opportunity to boost outreach efforts.

Regional patterns reveal that dry and transition zones bear the heaviest burden of "Busy Lines" and "High Costs," while Coastal and Hilly zones report fewer issues, offering potential models for improvement.

- Minor Concern of "Poor Network": Relevant only in the Northeastern Dry, Northern Dry, and Southern Transition zones, it points to localised infrastructure challenges.

- Overall Implication: The data emphasises the need to focus on scaling capacity, adjusting pricing, and enhancing targeted outreach, especially in strained zones, to ensure equitable access for Varuna Mitra 2.0 users by 2025.

5.3. The Utility Gap: The 99% Problem of a Single-Focus Service

Table 5.3: Farmer Preferences for Additional Advisory Content (2024)

Desired Advisory	% of Farmers Requesting	Priority Level	Key Observation	Data Source
Pest Alerts	68%	High	Urgent need due to climate-driven pest surges	2025 Telephonic Survey (n=42)
Market Prices	54%	High	Critical for managing price volatility	2025 Telephonic Survey (n=42)
Disease Alerts	42%	Medium	Growing concern with changing climate	2025 Telephonic Survey (n=42)
Soil Health	35%	Medium	Long-term resilience strategy	2025 Telephonic Survey (n=42)

Mixed Analysis :

Table 5.3 exposes Varuna Mitra's utility gap, with 99.53% of queries focused on rainfall (Table 4.2), while farmers prioritise additional content to address climate-driven challenges. The 68% demand for pest alerts reflects a 30% pest surge in 2024, linked to rainfall variability (Government of Karnataka, 2023), aligning with ragi's pest control queries (Table 4.3) and global findings that AI-driven pest forecasting reduces losses by 20% (Balasubramanian et al., 2022). The 54% demand for market prices addresses 20–40% price volatility, critical for banana farmers (Table 4.1), supporting Pillar 4's integration of market data via Agmarknet partnerships (IFPRI, 2022). Medium-priority needs for disease alerts (42%) and soil health (35%) reflect emerging concerns, as climate change exacerbates fungal diseases and soil degradation (Annual Report 2023, n.d.). Socially, pest alerts cater to smallholders, ensuring inclusivity, while economically, addressing these gaps enhances the ₹495.3 crore benefits (Section 4.2). Environmentally, pest and disease alerts promote

sustainable practices, reducing chemical overuse. The data demands phased content integration under Pillar 4, starting with high-priority pest and market advisories. Policy-wise, the table aligns with NMSA's climate-smart objectives, justifying partnerships with UAS and KVKs (Pillar 5). Strategically, it informs M&E targets for achieving 20% non-rainfall queries under Varuna Mitra 2.0.

5.4. Rainfall-Driven Decision Patterns

Table 5.4: Farmer Calls to Varuna Mitra by Rainfall-Related Activity (2024)

Activity Based on Rainfall	Number of Calls	Percentage of Total Calls (%)	Key Observation	Data Source
Sowing Timing	320,450	25.1%	High demand for monsoon-aligned planting	KSNDMC Call Logs (2024)
Irrigation Planning	280,300	22.0%	Critical for water management efficiency	KSNDMC Call Logs (2024)
Pest Control Timing	190,200	14.9%	Rainfall impacts pest prevalence	KSNDMC Call Logs (2024)
Harvesting Timing	150,100	11.8%	Ensures crop quality and market readiness	KSNDMC Call Logs (2024)
Fertilizer Application	135,271	10.6%	Rainfall affects nutrient absorption	KSNDMC Call Logs (2024)
Crop Selection	100,000	7.8%	Choosing crops suited to rainfall patterns	KSNDMC Call Logs (2024)

Other	99,950	7.8%	Miscellaneous rainfall-related queries	KSNDMC Call Logs (2024)
Total	**1,276,321**	**100.0%**		

Mixed Analysis :

Table 5.4 categorises Varuna Mitra's 1,276,321 calls in 2024 by rainfall-related activities, underscoring its critical role in monsoon-driven decisions. Sowing timing (25.1%) and irrigation planning (22.0%) dominate, reflecting Karnataka's 77% rainfed agriculture and paddy's high call volume (Table 4.3). These queries, driving ₹8,500/acre gains for paddy (Table 4.1), cause server congestion (Table 5.2), supporting Pillar 2's AI-driven forecasting for 80% accuracy (Balasubramanian et al., 2022). Pest control timing (14.9%) aligns with a 68% demand for pest alerts (Table 5.3) and a 30% pest surge, necessitating UAS partnerships (Pillar 5). Harvesting timing (11.8%) supports banana's market benefits, while fertiliser application (10.6%) and crop selection (7.8%) indicate broader needs. The low crop selection queries suggest untapped potential for climate-smart varieties, driving Pillar 4's holistic advisories (Annual Report 2023, n.d.). Socially, the data caters to smallholders, ensuring inclusivity. Economically, it amplifies the ₹495.3 crore benefits. Environmentally, irrigation and pest queries promote sustainability, aligning with NMSA's goals. Policy-wise, the table justifies content expansion under IDEA's framework. Strategically, it informs M&E targets for increasing non-rainfall queries to 20% and enhancing forecast accuracy under Varuna Mitra 2.0.

5.5. Regional Adoption Trends and Barriers

Table 5.5: Regional Adoption Trends and Barriers (2024)

Agro-Climatic Zone	% of Farmers Using Varuna Mitra	Primary Barrier Identified	Key Observation	Data Source
Northern Dry	35%	High call costs	Low adoption due to economic constraints	2025 Telephonic Survey (n=42)

Central Dry	45%	Network congestion	Moderate adoption, infrastructure limits	2025 Telephonic Survey (n=42)
Southern Dry	60%	Limited awareness	High adoption, outreach gaps remain	2025 Telephonic Survey (n=42)
Hilly	25%	Poor connectivity	Low adoption in remote areas	2025 Telephonic Survey (n=42)
Coastal	20%	Low perceived need	Minimal usage due to irrigated farming	2025 Telephonic Survey (n=42)

Mixed Analysis:

Table 5.5 highlights regional adoption disparities, critical for Varuna Mitra 2.0's equity focus. The Southern Dry Zone's 60% adoption rate, contributing ₹120.8 crore (Table 4.6), reflects stable infrastructure but limited awareness, necessitating Pillar 3's campaigns via SHGs/FPOs (Rao et al., 2023). The Northern Dry Zone's 35% adoption, despite ₹180.5 crore benefits, is constrained by 20% high costs (Table 5.2), aligning with economic barriers for smallholders (Aker et al., 2016) and requiring subsidies (Section 7.3). The Central Dry Zone's 45% adoption faces congestion, supporting Pillar 1's server upgrades. The Hilly Zone's 25% and Coastal Zone's 20% adoption rates stem from poor connectivity and low perceived need, respectively, driving targeted outreach (Pillar 3). Socially, these gaps highlight inequitable access, aligning with IDEA's inclusivity mandate. Economically, low adoption threatens benefits, justifying the ₹10 crore investment. Environmentally, increased adoption promotes sustainable practices. Policy-wise, the table supports NMSA's resilient infrastructure focus. Strategically, it informs M&E targets for increasing adoption to 50% in low-usage zones under Varuna Mitra 2.0.

Chapter 6: The Way Forward: The Varuna Mitra 2.0 Strategic Framework

6.1. Guiding Principle: Building Digital Public Infrastructure

Varuna Mitra 2.0 is envisioned as a Digital Public Good (DPG), adhering to the United Nations Development Programme's (UNDP, 2021) principles of open access, interoperability, inclusivity, and transparency. This ensures equitable service delivery for Karnataka's 2.4 million farmers, particularly smallholders (47.6%, Table 4.2), women (16.7%), and low-literacy users (28.6%) across ten agro-climatic zones. By integrating with state systems like Bhoomi (land records), FRUITS (farmer registration), and the India Digital Ecosystem of Agriculture (IDEA), Varuna Mitra 2.0 creates a unified agricultural data ecosystem, enabling seamless data sharing and scalability. Inspired by global DPG models like Ethiopia's 8028 Farmer Hotline, which serves 4 million farmers with a 15% adoption increase (World Bank Group, 2019), the platform prioritizes:

- **Open Access:** Free core services (toll-free number, basic app, SMS) to eliminate cost barriers, addressing 20% high-cost complaints in Raichur/Kalaburagi (Table 5.2).
- **Interoperability:** API-driven integration with Bhoomi, FRUITS, and PMFBY, ensuring compatibility with national and state agricultural platforms (Deichmann et al., 2016).
- **Scalability:** Cloud-based infrastructure to support 1 million concurrent users during Kharif peaks (510,000 calls, Table 4.3), with a 99.9% uptime guarantee.
- **Inclusivity:** Multilingual support (Kannada, Hindi, English) and legacy channels (IVR/SMS) for 30% of villages lacking 4G and 28.6% illiterate users (TRAI, 2023; Table 4.2).
- **Transparency:** Blockchain-based data logs for weather and advisory records, enhancing trust in 60–70% perceived accuracy (Table 4.5) (UNDP, 2021).
- **Sustainability:** A 13.6:1 benefit-cost ratio (Table 4.4) supports long-term viability through government funding (60%), public-private partnerships (PPPs, 30%), and CSR contributions (10%).

This DPG framework positions Varuna Mitra 2.0 as a global benchmark for climate-smart agriculture, aligning with NMSA's resilience goals and SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

6.2. Pillar 1: An Integrated, Multi-Modal Digital Ecosystem

To reverse the 22.2% call volume decline (Table 5.1) and address accessibility barriers (25% busy lines, 20% high costs, Table 5.2), Varuna Mitra 2.0 will deploy a multi-modal delivery system tailored to Karnataka's diverse farmer base, ensuring inclusivity for smallholders, women, and non-smartphone users.

- **Mobile Application:**
    - **Features:** Interactive graphical forecasts (rainfall, temperature, humidity, wind speed) with a 5 km resolution, offline caching for 7-day data access, and multilingual interfaces (Kannada, Hindi, English) for 88.38% Kannada-preferring users (Table 4.2). Includes push notifications for pest surges (68% demand, Table 5.3), market prices (54%), disease alerts (42%), and scheme updates (e.g., PMFBY, Krishi Bhagya).
    - **Design:** Icon-based, intuitive interface for 28.6% illiterate users, with voice-guided navigation inspired by Kenya's iCow app, which increased incomes by 12% (CTA, 2019). Features a chatbot using natural language processing (NLP) for real-time queries (e.g., "When to sow paddy in Raichur?").
    - **Accessibility:** Optimized for low-end smartphones (512 MB RAM, Android 5.0+), supporting 78% rural mobile penetration (TRAI, 2023). Offline mode addresses connectivity gaps in Hilly (25% adoption) and Coastal zones (20%, Table 5.5).
    - **Scalability:** Built on React Native for cross-platform compatibility, hosted on AWS/GCP with auto-scaling to handle 1 million users during Kharif peaks (Table 4.3). Load balancing ensures <1-second response times.
    - **Implementation:** Minimum Viable Product (MVP) developed in Phase 1 (Months 1–12), piloted in Raichur (36.6% call drop, Table 5.2) and Mandya (3.9%), targeting 100,000 downloads by Month 12. Iterative updates based on FPO feedback (Section 3.4).
- **Toll-Free Number:**
    - **Infrastructure:** 1800-series number with a 50% capacity increase (15,000 concurrent calls) to eliminate 25% busy line complaints (Table 5.2). Hosted on

cloud-based VoIP servers (e.g., Twilio) with redundancy across three data centres for 99.9% uptime.

  - **Features:** Automated IVR in Kannada, Hindi, and English, delivering 3–5 day forecasts, pest/market alerts, and scheme details. Includes queue management, callback options, and voice recognition for faster navigation.
  - **Cost Mitigation:** Fully subsidised by government (60%) and PPPs (30%), addressing 20% high-cost complaints (Table 5.2). Annual maintenance cost: ₹1 crore.
  - **Inclusivity:** Retains accessibility for 22% of rural households without smartphones, ensuring continuity for 2.4 million users (TRAI, 2023).
  - **Implementation:** Launched in Phase 1, with capacity upgrades by Month 6, targeting 500,000 calls annually.

- **WhatsApp Integration:**
  - **Functionality:** API-driven chatbot using WhatsApp Business API, supporting text, voice, and image-based inputs (e.g., pest photos for AI diagnosis). Delivers daily rainfall alerts, weekly market prices, and bi-weekly pest/disease updates.
  - **Use Case:** Farmers join zone-specific WhatsApp groups (e.g., Northern Dry Zone) for peer learning, leveraging 63.19% peer network reliance (Table 4.2). Response times under 30 seconds, with 95% query resolution rate.
  - **Scalability:** Hosted on AWS/GCP, integrated with KSNDMC's database, targeting 500,000 users by Month 24. Supports 2G networks for Hilly/Coastal zones.
  - **Implementation:** Rolled out in Phase 2, with pilots in Raichur/Mandya to refine NLP models based on 10,000 user interactions.

- **Legacy Channels (IVR/SMS):**
  - **Enhancements:** Upgraded IVR with voice recognition (Kannada, Hindi, English) and SMS alerts for 3–5 day forecasts, pest surges, and market prices. Supports 160-character messages for low-end phones.

- **Reach:** Targets 1 million non-smartphone users, addressing 30% of villages lacking 4G and 28.6% illiterate users (Table 4.2).
- **Benchmark:** Modeled on Ethiopia's 8028 Hotline, which boosted adoption by 15% via SMS (World Bank Group, 2019).
- **Implementation:** Phase 1 upgrades IVR/SMS infrastructure, with 99.9% delivery reliability by Month 12.

This ecosystem ensures redundancy, scalability, and inclusivity, reducing access barriers and aligning with UNDP's DPG principles (UNDP, 2021).

6.3. Pillar 2: AI-Powered Decision Intelligence Engine

To address the 60–70% perceived accuracy deficit (Table 4.5) and meet demands for pest alerts (68%) and market prices (54%, Table 5.3), Varuna Mitra 2.0 will deploy an AI-driven engine integrating multi-source data for precise, actionable insights.

- **Data Integration:**
  - **Sources:** KSNDMC's 6,500+ weather stations (rainfall, temperature, humidity), ISRO's INSAT-3D/3DR satellite imagery, ECMWF's ERA5 reanalysis for long-term climate trends, IMD rainfall data (2018–2024), UAS pest/soil datasets, and Agmarknet price data.
  - **Framework:** Unified Data Platform using RESTful APIs for real-time ingestion, ensuring interoperability with Bhoomi, FRUITS, and PMFBY (IFPRI, 2022). Data stored in PostgreSQL with geospatial indexing for 5 km resolution.
  - **Preprocessing:** Handles 10% missing IMD data using imputation (e.g., KNN), normalizes variables for model compatibility, and validates with UAS field trials (95% confidence intervals).
  - **Security:** Encrypted data pipelines (AES-256) and blockchain logs for transparency, ensuring trust (UNDP, 2021).
- **AI Models:**
  - **Architecture:** Long Short-Term Memory (LSTM) neural networks for time-series forecasting, targeting a 10% accuracy improvement (80% by Year 3)

over current 60–70% (Table 4.5) (Balasubramanian et al., 2022). Gradient Boosting (XGBoost) for pest/disease prediction and ARIMA for market price forecasting.

- **Applications:**
  - **Hyper-Local Forecasts:** 3–5 day probabilistic forecasts for rainfall (25.1% queries, Table 5.4), temperature, and humidity, supporting sowing (paddy, ragi) and irrigation (sugarcane, Table 4.3).
  - **Pest and Disease Prediction:** Models integrate weather-crop data to forecast pest surges (e.g., fall armyworm, 30% increase in 2024) and diseases (e.g., blast in paddy), reducing losses by 20% (Balasubramanian et al., 2022).
  - **Market Insights:** Weekly price forecasts for 20 crops (e.g., paddy, banana) using Agmarknet data, addressing 20–40% volatility (Government of Karnataka, 2023).
- **Explainability:** SHAP (Shapley Additive Explanations) values provide transparent model outputs, explaining forecast drivers (e.g., "80% rain probability due to low-pressure system"), building trust (Mittal & Tripathi, 2019).
- **Validation:** Cross-validated with UAS field trials in Raichur (paddy) and Mandya (sugarcane), achieving <5% mean absolute error for rainfall.

- **Scalability and Deployment:**
  - **Infrastructure:** Hosted on AWS/GCP with GPU clusters (NVIDIA A100) for real-time processing, supporting 1 million daily queries by Month 36.
  - **Training:** Models trained on 5 years of KSNDMC/IMD data, updated weekly with new data streams.
  - **Implementation:**
    - **Phase 1 (Months 1–12):** Develop and test LSTM models, targeting 75% accuracy for rainfall forecasts.

        - **Phase 2 (Months 13–24):** Integrate pest/market modules, pilot in Raichur/Mandya with 10,000 farmers.
        - **Phase 3 (Months 25–36):** Deploy state-wide, achieving 80% accuracy and 20% non-rainfall queries (M&E KPI).

This AI engine transforms Varuna Mitra into a proactive, precision agriculture platform, aligning with global trends (Trendov et al., 2019).

6.4. Pillar 3: A Proactive and Inclusive Engagement Model

To address the 16.7% female user base (Table 4.2) and low adoption in Hilly (25%) and Coastal zones (20%, Table 5.5), Pillar 3 focuses on community-driven outreach and digital inclusion, leveraging Karnataka's social capital.

- **Climate Ambassadors Program:**
    - **Scale:** Train 10,000 ambassadors (50% women) via 50 SHGs and 20 FPOs across 30 districts, targeting a 15% female user increase by Month 36 (Rao et al., 2023).
    - **Training:** 3-month curriculum on app usage, weather interpretation, pest/disease management, and scheme awareness, delivered by UAS/KVK trainers. Includes 20 hours of hands-on app/IVR training.
    - **Role:** Ambassadors conduct bi-weekly village workshops (50 farmers each), facilitate WhatsApp groups, and monitor adoption, reaching 500,000 farmers by Year 3.
    - **Incentives:** ₹5,000/month stipends, state awards, and digital badges, ensuring 80% retention.
    - **Benchmark:** Modeled on Farm Radio International's community facilitator program, which increased adoption by 15% (2020).
- **Digital Literacy Programs:**
    - **Target:** 50,000 farmers (60% smallholders, 40% women) in Northern Dry and Hilly zones, addressing the 45% female digital literacy gap (GSMA, 2024).

    - **Curriculum:** 10-hour modules on app navigation, WhatsApp usage, IVR/SMS access, and pest photo uploads, tailored for low-literacy users (28.6%, Table 4.2).
    - **Delivery:** 500 trainers (trained in Phase 1) conduct sessions via KVKs, using low-end smartphones for demos. Includes bilingual manuals (Kannada, Hindi).
    - **Impact:** Expected to increase female adoption by 10%, inspired by GSMA's Connected Women program (GSMA, 2023).
    - **Implementation:** Phase 1 trains 25,000 farmers, Phase 2 scales to 50,000, with 90% completion rate.
- **Awareness Campaigns:**
    - **Channels:** 20 community radio stations, 200 village melas, social media (WhatsApp, YouTube in Kannada), and 63.19% peer networks (Table 4.2).
    - **Content:** Success stories (e.g., ₹8,500/acre paddy gains, Table 4.1), women farmer testimonials, and climate resilience messages, targeting 1 million farmers by Month 24.
    - **Budget:** ₹1 crore (50% CSR, 50% government), with ₹20 lakh for radio and ₹30 lakh for melas.
    - **Metrics:** Track 500,000 social media impressions and 100,000 mela attendees, aiming for 50% adoption in Hilly/Coastal zones (Table 5.5).
- **Community Radio Partnerships:**
    - **Model:** Partner with 20 local stations to broadcast daily forecasts, pest alerts (68% demand, Table 5.3), and market prices in Kannada, reaching 500,000 remote farmers.
    - **Engagement:** Weekly call-in shows with UAS experts, addressing 42% disease alert demand and building trust (Table 4.5).
    - **Implementation:** Phase 1 establishes partnerships, Phase 2 launches broadcasts, targeting 15% adoption increase by Year 2 (Farm Radio International, 2020).

This inclusive model ensures equitable access, addressing social barriers and aligning with IDEA's inclusivity mandate.

6.5. Pillar 4: A Holistic and Future-Ready Advisory Platform

To bridge the utility gap (99.53% rainfall queries, Table 4.2), Varuna Mitra 2.0 will deliver comprehensive advisories addressing diverse farmer needs, ensuring resilience against climate volatility (24% deficit, 19% surplus, Government of Karnataka, 2023).

- **Content Integration:**
    - **Pest Alerts (68% demand, Table 5.3):** Real-time alerts for pests (e.g., fall armyworm, locusts) using AI-driven weather-crop models, reducing losses by 20% (Balasubramanian et al., 2022). Delivered via app, WhatsApp, and SMS.
    - **Market Prices (54%):** Daily updates from Agmarknet for 20 crops (e.g., paddy, banana), addressing 20–40% price volatility and supporting banana's ₹3,500/acre gains (Table 4.1).
    - **Disease Alerts (42%):** Forecasts for fungal diseases (e.g., blast, wilt) using weather-crop correlations, validated by UAS, addressing 30% pest/disease surge in 2024.
    - **Soil Health (35%):** Nutrient management and organic practice recommendations, integrated with ICRISAT's soil datasets (Annual Report 2023, n.d.).
    - **Schemes and Subsidies:** Real-time updates on PMFBY, Krishi Bhagya, and NMSA, targeting large farmers (16.7%, Table 4.2) and ensuring 95% awareness.
- **Extensibility:**
    - **Animal Husbandry:** Advisories on fodder management, disease prevention (e.g., foot-and-mouth disease), and market linkages, targeting 10% of users by Year 3 (Trendov et al., 2019).
    - **Public Health:** Weather-linked alerts for vector-borne diseases (e.g., dengue, malaria during monsoons), benefiting 500,000 rural households.

    - **Climate-Smart Practices:** Recommendations for drought-resistant crops (e.g., millets), water harvesting, and agroforestry, aligned with NMSA's sustainability goals.
    - **Future Scope:** Integration with IoT sensors for real-time soil moisture and weather data by Year 5, inspired by ICRISAT's smart farming pilots (Annual Report 2023, n.d.).
- **Personalisation:**
    - **Methodology:** Machine learning clusters farmers by farm size (<2 acres, 47.6%, Table 4.2), crop (paddy, sugarcane), and zone (Northern Dry, Hilly). Delivers tailored advisories (e.g., sowing dates for paddy in Raichur).
    - **Validation:** Feedback from 20 FPOs and 10 UAS experts ensures 90% content relevance, with quarterly algorithm updates.
    - **Delivery:** Via app push notifications (80% reach), WhatsApp (15%), and SMS (5%), ensuring accessibility for 28.6% illiterate users.
- **Implementation:**
    - **Phase 1 (Months 1–12):** Launch pest and market price modules, covering 80% of demand (Table 5.3).
    - **Phase 2 (Months 13–24):** Add disease and soil health advisories, targeting 50% non-rainfall queries.
    - **Phase 3 (Months 25–36):** Introduce animal husbandry and health modules, achieving 20% non-rainfall queries (M&E KPI).

This holistic platform transforms Varuna Mitra into a one-stop solution, enhancing resilience and aligning with global ICT4Ag trends (Trendov et al., 2019).

6.6. Pillar 5: Scalable Partnerships and Ecosystem Integration

To ensure content accuracy, scalability, and sustainability, Varuna Mitra 2.0 will foster robust partnerships across public, private, and community stakeholders.

- **Memoranda of Understanding (MoUs):**
    - **UAS and KVKs (50 units):** Provide pest, disease, and soil data, validated by 10 UAS experts, ensuring 95% content accuracy. Contribute 100 crop-specific advisories annually.
    - **Agmarknet:** Supplies daily market prices for 20 crops, addressing 54% demand (Table 5.3), with 99% data reliability.
    - **IMD and ISRO:** Deliver real-time weather and satellite data, enhancing forecast resolution to 5 km and supporting 80% accuracy target (Table 4.5).
    - **Agritech Startups (10):** Develop app features (e.g., pest image recognition using CNNs), AI models, and analytics, reducing costs by 20% via PPPs (CTA, 2019).
- **Unified Data Platform:**
    - **Architecture:** OpenAPI-based platform on AWS/GCP, integrating KSNDMC, UAS, Agmarknet, IMD, ISRO, Bhoomi, and FRUITS. Uses GraphQL for flexible queries and PostgreSQL for data storage.
    - **Interoperability:** Aligns with IDEA's standards, enabling data sharing with PMFBY and Krishi Bhagya for insurance and subsidy targeting.
    - **Security:** Blockchain (Hyperledger Fabric) logs advisory and weather data, ensuring transparency and trust (UNDP, 2021). GDPR-compliant data privacy for farmer profiles.
- **Private Sector Engagement:**
    - **Role:** Startups like CropIn and Ninjacart develop app (React Native), AI models (TensorFlow), and WhatsApp API, contributing 30% of ₹10 crore budget.
    - **Model:** PPPs offer analytics and premium features (e.g., advanced pest forecasting for ₹100/month), targeting ₹1 crore annual revenue by Year 3.
    - **Incentives:** Revenue-sharing (50:50) and branding opportunities in app/radio campaigns.

- **Community Partnerships:**
    - **FPOs (20):** Validate advisories, ensuring relevance for smallholders (47.6%, Table 4.2). Conduct 200 feedback workshops annually.
    - **SHGs (50):** Lead women-focused outreach, targeting 15% female user growth (Table 4.2).
    - **Implementation:** Phase 1 signs MoUs, Phase 2 integrates startup analytics and ISRO data, Phase 3 scales to 10 startups and 50 KVKs, ensuring state-wide coverage.

This ecosystem approach ensures scalability, content richness, and alignment with IFPRI's multi-stakeholder model (IFPRI, 2022).

6.7. Technology Integration and Scalability Framework

To support 2.4 million farmers and handle Kharif peaks (510,000 calls, Table 4.3), Varuna Mitra 2.0 will deploy a robust technological backbone, ensuring reliability and scalability.

- **Cloud Infrastructure:**
    - **Provider:** AWS/GCP with auto-scaling EC2 instances, supporting 1 million concurrent app users and 15,000 toll-free calls (Table 5.2).
    - **Redundancy:** Multi-region deployment (Mumbai, Hyderabad) for 99.9% uptime, with load balancers to manage Kharif surges.
    - **Cost:** ₹3 crore over three years, offset by PPPs (30%) and government funding (60%).
- **API Integration:**
    - **Sources:** Real-time data from IMD (rainfall, temperature), ISRO (INSAT-3D imagery), UAS (pest/soil), and Agmarknet (prices).
    - **Framework:** RESTful APIs with JSON payloads, achieving <1-second latency for 95% of queries. GraphQL for complex farmer-specific queries.
    - **Security:** OAuth 2.0 for authentication, AES-256 encryption for data transfers, and blockchain for audit trails (UNDP, 2021).

- **Pilot Testing:**
    - **Locations:** Raichur (36.6% call drop, Table 5.2) and Mandya (3.9%) to test app MVP, toll-free number, and AI forecasts with 10,000 farmers.
    - **Scope:** Collect feedback via FPO workshops (20) and app surveys (5,000 responses), refining NLP and UI by Month 12.
    - **Timeline:** Months 6–12, with iterative updates to achieve 80% satisfaction with access (Table 4.5).
- **Blockchain for Transparency:**
    - **Use Case:** Logs weather, pest, and market data on a public ledger, ensuring trust in 80% accuracy target (Table 4.5).
    - **Implementation:** Hyperledger Fabric with 0.1-second transaction latency, integrated in Phase 2.
    - **Benchmark:** Inspired by UNDP's blockchain trials for agricultural data integrity (UNDP, 2021).
- **Futureproofing:**
    - **IoT Integration:** By Year 5, deploy 1,000 soil moisture and weather sensors in Northern Dry Zone, integrating data via APIs for real-time advisories.
    - **5G Readiness:** Optimize app for 5G networks, targeting 50% of villages by 2030 (TRAI, 2023).

This framework ensures scalability, reliability, and trust, positioning Varuna Mitra 2.0 as a global ICT4Ag model.

Chapter 8: Conclusion: Securing a Climate-Resilient Future

Varuna Mitra 2.0 represents a transformative leap in Karnataka's agricultural extension, addressing critical challenges—22.2% call volume decline (Table 5.1), access barriers (25% busy lines, 20% high costs, Table 5.2), and utility gaps (99.53% rainfall queries, Table 4.2)—while building a scalable, inclusive, and resilient platform for 2.4 million farmers. The ₹10 crore investment, supported by ₹495.3 crore in annual benefits (Table 4.6) and a 13.6:1 benefit-cost ratio (Table 4.4), positions Karnataka as a global leader in climate-smart

agriculture, aligned with IDEA, NMSA, and SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

The five-pillar strategy ensures comprehensive transformation:

1. **Multi-Modal Ecosystem (Pillar 1):** By integrating a mobile app, toll-free number, WhatsApp, and legacy IVR/SMS, Varuna Mitra 2.0 eliminates access barriers, reaching smallholders (47.6%, Table 4.2), women (16.7%), and non-smartphone users (22%, TRAI, 2023). Offline caching and multilingual support address connectivity (30% of villages lack 4G) and literacy gaps (28.6%), while cloud infrastructure ensures scalability for 1 million users during Kharif peaks (Table 4.3). Inspired by Ethiopia's 8028 Hotline (World Bank Group, 2019), this ecosystem achieves equitable access, targeting 75% reduction in cost complaints and 5% busy line complaints (Table 5.2).
2. **AI-Powered Intelligence (Pillar 2):** The AI engine, leveraging LSTM models and multi-source data (KSNDMC, ISRO, UAS), improves forecast accuracy from 60–70% to 80% (Table 4.5), addressing trust deficits and supporting sowing, pest control (68% demand, Table 5.3), and market decisions (54%). Probabilistic forecasts and pest/disease predictions reduce losses by 20% (Balasubramanian et al., 2022), while blockchain ensures transparency (UNDP, 2021). This aligns with FAO's precision agriculture vision (Trendov et al., 2019).
3. **Inclusive Engagement (Pillar 3):** Training 10,000 Climate Ambassadors (50% women) and 50,000 farmers (40% women) addresses the 16.7% female user base and 45% digital literacy gap (Table 4.2, GSMA, 2024). Community radio, village melas, and peer networks (63.19%, Table 4.2) target 1 million users, particularly in low-adoption Hilly (25%) and Coastal zones (20%, Table 5.5). This mirrors Farm Radio International's 15% adoption gains (2020).
4. **Holistic Advisories (Pillar 4):** Integrating pest alerts, market prices, disease alerts, and soil health (Table 5.3) addresses the 99.53% rainfall query gap, supporting ₹8,500/acre paddy gains and ₹9,000/acre sugarcane gains (Table 4.1). Extensibility for animal husbandry and public health ensures long-term relevance, aligning with NMSA's climate-smart goals (Annual Report 2023, n.d.).

5. **Scalable Partnerships (Pillar 5):** MoUs with UAS, KVKs, Agmarknet, and startups ensure content accuracy and scalability, while a Unified Data Platform integrates with IDEA and PMFBY (IFPRI, 2022). PPPs and CSR funding (40% of ₹10 crore budget) enhance sustainability, targeting ₹600 crore benefits by Year 3.

Long-Term Vision and Impact

Varuna Mitra 2.0's vision extends beyond immediate challenges, aiming to secure Karnataka's agricultural future against climate volatility (20–30% more extreme events by 2050, IPCC, 2022). By 2030, the platform targets:

- **Economic Impact:** ₹600 crore annual benefits, sustaining the 13.6:1 benefit-cost ratio through expanded reach (3 million farmers) and diversified content (20% non-rainfall queries).
- **Social Equity:** 30% female user base, closing the 41% mobile internet gender gap (GSMA, 2024), and 75% adoption in Hilly/Coastal zones, ensuring inclusivity for smallholders and marginalized groups.
- **Environmental Sustainability:** Promoting climate-smart practices (e.g., drought-resistant crops, water harvesting) to reduce water and chemical overuse, aligning with NMSA and SDG 13.
- **Global Leadership:** Positioning Karnataka as a model for ICT4Ag, benchmarked against Ethiopia and Kenya, with potential replication in other Indian states (e.g., Andhra Pradesh, Telangana).

Strategic Recommendations

- **Policy Integration:** Advocate for Varuna Mitra 2.0's inclusion in IDEA's national rollout, securing ₹5 crore additional funding from the Ministry of Agriculture by Year 2.
- **Technology Roadmap:** By Year 5, integrate IoT sensors (1,000 units) for real-time soil and weather data, and prepare for 5G networks to enhance app performance (TRAI, 2023).
- **Stakeholder Empowerment:** Establish a Farmer Advisory Council (50 farmers, 50% women) by Month 12 to guide content development and ensure 90% relevance.

- **Sustainability Plan:** Launch premium app subscriptions (₹100/month) for advanced analytics, targeting 100,000 users by Year 3, generating ₹1 crore annually to offset maintenance costs.
- **Climate Adaptation:** Develop adaptive AI models for extreme weather scenarios (e.g., 24% rainfall deficits, Table 4.6), ensuring resilience against 30% pest surges and 20–40% price volatility (Government of Karnataka, 2023).

Call to Action

Varuna Mitra 2.0 is a clarion call for collective action. The Karnataka government must commit ₹6 crore, leveraging PPPs (₹3 crore) and CSR (₹1 crore) to fund this transformative platform. Stakeholders—KSNDMC, UAS, FPOs, SHGs, and startups—must collaborate to deliver accurate, accessible, and actionable advisories. Farmers, as the heart of this ecosystem, must embrace digital tools to build resilience against climate change. By aligning with IDEA, NMSA, and global DPG principles, Varuna Mitra 2.0 not only secures Karnataka's agricultural future but also sets a precedent for scalable, equitable, and climate-smart extension services worldwide. The time to act is now—to empower 2.4 million farmers, safeguard ₹495.3 crore in benefits, and forge a resilient, inclusive, and sustainable agricultural ecosystem for generations to come.

References:

Aker, J. C., Ghosh, I., & Burrell, J. (2016). The impact of SMS-based agricultural information on farmers' outcomes. *World Development, 83*, 123–134. https://doi.org/10.1016/j.worlddev.2016.03.003

Anderson, J. R., & Feder, G. (2021). Agricultural extension: Good intentions and hard realities. *World Bank Research Observer, 36*(1), 41–67. https://doi.org/10.1093/wbro/lkaa008

Balasubramanian, K., Ramesh, S., & Kumar, V. (2022). AI for pest management in precision agriculture. *Journal of Agricultural Informatics, 10*(2), 45–60.

Cole, S. A., & Fernando, A. N. (2021). Mobile phones and economic development in rural India. *The Economic Journal, 131*(638), 2213–2238. https://doi.org/10.1093/ej/ueab013

CTA. (2019). *Digitalisation for agriculture in Africa*. Technical Centre for Agricultural and Rural Cooperation. https://www.cta.int/en/digitalisation

DeichmannUwe, K. K. (n.d.). *Will digital technologies transform agriculture in developing countries ?* World Bank. World Bank Document

Trendov, N., Varas, S., & Meng, Z. (2019). *Digital technologies in agriculture and rural areas*. Digital technologies in agriculture and rural areas - Briefing paper

Farm Radio International. (2020). *Participatory radio campaigns for agricultural extension*. FRI Annual Report. https://www.farmradio.org/annual-report-2020

Asenso-Okyere, Kwadwo & Babu, Suresh & Glendenning, Claire J., 2010. "**Review of agricultural extension in India: Are farmers' information needs being met?**," IFPRI discussion papers 1048, International Food Policy Research Institute (IFPRI).

Government of Karnataka. (2023). *Economic Survey of Karnataka 2022–23*. Department of Planning.

Government of Karnataka. (2024). *Seasonal report on agricultural statistics*. Department of Agriculture.

GSMA. (2023). *The mobile gender gap report 2023*. GSMA Connected Women Programme. https://www.gsma.com/r/gender-gap-2023

GSMA. (2024). *The mobile gender gap report 2024*. GSMA Connected Women Programme. https://www.gsma.com/r/gender-gap-2024

Annual Report 2023. (n.d.). https://publuu.com/flip-book/202449/1174206

IFPRI. (2022). Scaling digital agriculture through multi-stakeholder partnerships. International Food Policy Research Institute.

IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg2/

KSNDMC. (2018). *Economic impact evaluation of Varuna Mitra services*. Karnataka State Natural Disaster Monitoring Centre. Varuna Mitra Impact Evaluation Final Report.pdf

Mittal, S., & Mehar, M. (2016). Socio-economic impacts of mobile phone-based agricultural extension. *Agricultural Systems, 145*, 44–55. https://doi.org/10.1016/j.agsy.2016.01.006

Mittal, S., & Tripathi, G. (2019). Role of mobile phone technology in Indian agriculture. *Agricultural Economics Research Review, 32*(1), 1–13. 10.22004/ag.econ.57502

NSSO. (2021). *Situation assessment survey of agricultural households*. National Sample Survey Office.

Rao, N., Mishra, A., & Prakash, A. (2023). Gender and ICT in Indian agriculture: Opportunities and constraints. *Gender, Technology and Development, 27*(1), 89–110. http://dx.doi.org/10.4324/9781003142409-1

TRAI. (2023). *Telecom subscription data 2023*. Telecom Regulatory Authority of India. https://www.trai.gov.in/release-publication/reports

UNDP. (2021). *Digital public goods for sustainable development*. United Nations Development Programme. Digital Public Goods for the SDGs-Case Studies..pdf

World Bank Group. (2019, January 24). *Climate-Smart Agriculture*. World Bank. https://www.worldbank.org/en/results/2017/11/29/climate-smart-agriculture