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IoT-based precision agriculture and rural livelihood transformation in Bilaspur District, Chhattisgarh

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Abstract
The adoption of IoT-based precision agriculture is changing the Indian agrarian landscape, marked by smallholder farms, monsoon-dependency and low-tech penetration for some time. This article addresses various aspects of the potential and future of Smart Farming systems using IoT for the betterment of Agricultural yield and rural life in Bilaspur District, Chhattisgarh. Adopting an eclectic theoretical approach anchored in the Technology Acceptance Model (TAM), Sustainable Livelihoods Framework (SLF), and Rogers' Diffusion of Innovations (DOI), a four-layer IoT architecture suited to the agro-climatic, socio-economic realities of the Chhattisgarh Plains zone is proposed. It assesses the rollout of Lo-Cost Sensors (soil moisture, pH, temperature, humidity), LoRaWAN communication networks, a cloud-based analytics platform, and AI-powered farmer advisory systems. Literature cites concrete reductions of water use (25-30%), reductions in input costs (20-30%) and increase crop yield (15–20%) from IoT-based interventions, leading to tangible increases in farm household income, food security and climate resilience. The key challenges — digital divide, high upfront cost, small and fragmented landholders, poor/ inadequate rural networks are critically discussed, including policy suggestions from India's Digital Agriculture Mission and AgriStack framework.

Keywords: IoT, precision agriculture, smart farming, rural livelihoods, sustainable development

Introduction

Agriculture is the backbone of rural India and employing around 42% of the total workforce and contributing 17.8% to GDP (Ministry of Agriculture & Farmers' Welfare, 2024) [21]. In Chhattisgarh, the "Rice Bowl of Central India", agriculture is not just an economic activity. It is also a cultural institution that shapes the social life of rural society. Nearly eighty percent of Chhattisgarh"s rural population is directly dependent on farming and allied activities for their livelihood (Department of Agriculture, Government of Chhattisgarh, 2023) [24]. Nevertheless, this segment is facing a combination of structural challenges such as climate change and variability, soil degradation, water shortage, fragmentation of landholdings, asymmetry of market information and low penetration of technology. The small and marginal farmers (< 2 hectares), who dominate the agrarian economy in districts like Bilaspur, suffer greatly due to dependence on rain-fed cultivation (NABARD, 2023) [17]. The technological paradigm of the Internet of Things (IoT) allows for a powerful solution pathway. Through IoT-based precision agriculture (PA), farmers can use real-time data from soil, weather, and crop canopy sensors, along with cloud-based analytics and machine learning (ML) algorithms. As a result, farmers can make better decisions pertaining to irrigation, fertilization, pest control and harvesting. (Farooq *et al*., 2020; Sahoo, 2024) [7, 9] The shift from input-intensive to information-intensive agriculture offers the prospects of raising productivity, minimizing environmental externalities, and improving the economic status of farming households.

This paper discusses the IoT-based precision agriculture and how it helps in improving rural livelihoods in Bilaspur District, Chhattisgarh. The paper is organized as follows: Section II introduces the study area. In Section III, the existing literature is reviewed. The proposed conceptual framework is presented in Section IV. In Section V, the proposed IoT concept is presented. In Section VI, the operational model is presented. In Section VII, implementation issues are discussed. Section VIII contains policy recommendations. And finally Section IX concludes by suggesting future research.

Bilaspur District of Chhattisgarh

1. Geographic and Administrative Profile

The located of Bilaspur district on the Chhattisgarh Plains agro-climatic zone between 21°47'N to 23°8'N and 81°14'E to 83°15'E. Bilaspur is the judicial capital (Nyayadhani) of Chhattisgarh. The geographical area of the district is approximately 3,476–3,508 km² and has been divided into four development blocks, namely Kota, Takhatpur, Bilha, and Masturi. The district has around 11 tehsils, including Bilaspur, Ratanpur, Sipat, Belgahna, Beltara, Bodri, Sakri (District Census Handbook, 2011) [6]. Adjoining districts of Baloda Bazar Bhatapar to the south, Korba and Janjgir-Champa to the east are bounded by Gaurela Pendra Marwahi to the north. Located in the centre of the district is the Arpa River, which along with Maniyari and Leelagar, forms alluvial plains that are highly productive agricultural lands.

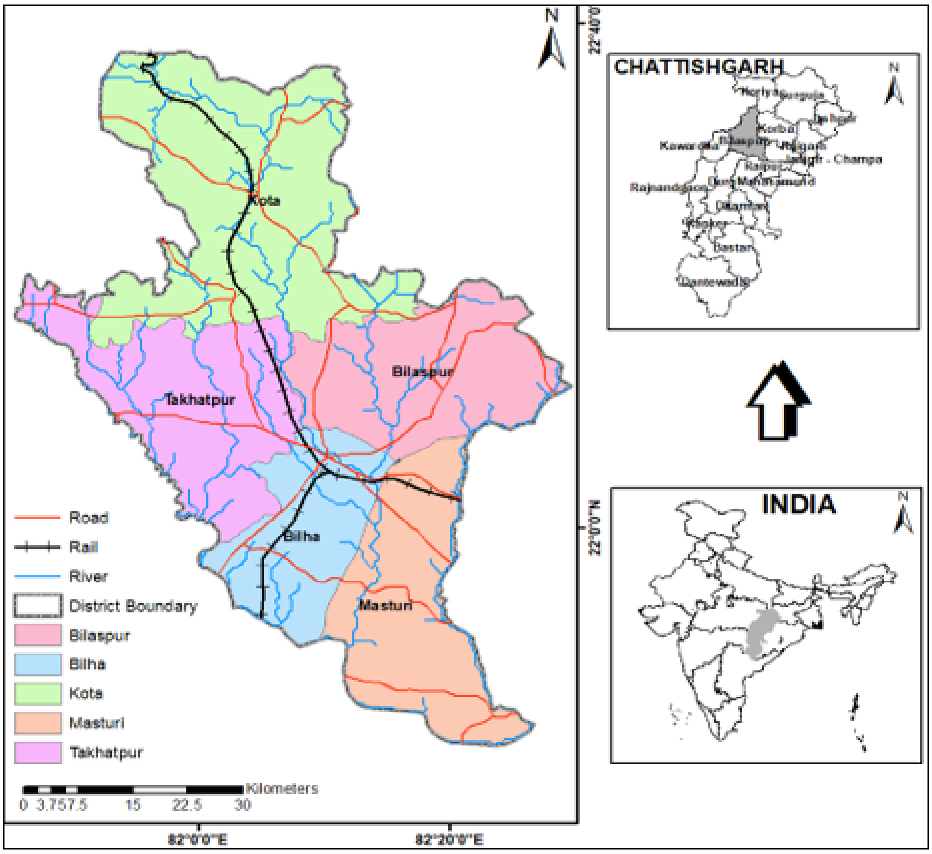

Fig 1: Location map of Bilaspur district, Chhattisgarh (India)

2. Map of Study Area.

1.3 Agro-Climatic and Socioeconomic Context

Bilaspur experiences a sultry monsoonal climate. It has hot summers (April–June, max 45 °C), a rainy season (July–September, average rainfall 1,200–1,400 mm), and cool winters (November–February). Sharma and Verma (2022) [28] state that the Bhata (sandy loam) and Matasi (yellow-white loamy) are the dominant soil types. They are moderately fertile but sensitive to moisture stress and nutrient deficiency.

Parameter	Details
Area	3,476–3,508 km²
Population (Census 2011) [6]	~1.63 million
Development Blocks	Kota, Takhatpur, Bilha, Masturi
Primary Crop	Rice (Paddy) — Kharif season
Secondary Crops	Wheat, Gram, Maize, Oilseeds
Horticultural Produce	Tomato, Cauliflower, Cabbage, Okra
Dominant Farm Size	Small & Marginal (< 2 ha)
Irrigation Sources	Canals, Tube Wells, Rainfall
Major Rivers	Arpa, Maniyari, Leelagar
Key Institution	KVK Bilaspur (IGKV-affiliated)

Literature Review

1. IoT in Agriculture: Global Context

The use of IoT in agriculture has transitioned from concept to reality fairly rapidly. World over studies have demonstrated the benefits of sensor-enabled monitoring for assessing soil health (Gubbi *et al.*, 2013) [12], automated irrigation management (Kamienski *et al.*, 2019) [13] and AI-enabled pest, and disease detection (Kamilaris & Prenafeta-Boldú, 2018) [14]. The cloud platforms like Thing Speak, Firebase and AWS IoT can help manage the storage of data easily in a scalable manner along with direct analysis and remote decision-making support (Wolfert *et al.*, 2017) [30]

2. IoT-Based Smart Farming in India

In India, use of IoT in agriculture is still in the infancy stage yet accelerating. Research papers indicates the implementation of lowcost sensor network using Arduino and ESP32 microcontroller for monitoring soil moisture, pH, temperature and humidity in field condition (Kumar *et al.*, 2024; Sahoo, 2024) [9, 16]. The Digital Agriculture Mission (DAM) of the Government of India and AgriStack initiative seeks to develop a digital ecosystem for Indian agriculture. DAM will include a farmer registry, assessment of crop health, and market intelligence (NITI Aayog, 2021; Ministry of Agriculture, 2023) [23, 24]. In Chhattisgarh, pilot projects have enrolled over 6,000 farmers in various districts, leveraging AI-driven mobile apps, as well as soil and moisture sensors and weather forecasting technology. As per a report by the Government of Chhattisgarh (2024) [11], adaptive measures enhance crop management practices while reducing the cost of inputs by about 30%.

3. Transformation of rural livelihood through technology

The Sustainable Livelihoods Framework, which was devised by DFID (1999) [4] is useful for us in understanding how interventions in technology, through change in five capital assets, specifically affects rural well-being. These five capital assets are human, social, natural, physical, and financial. The studies by Prem *et al.* (2023) and Madrewar *et al.* (2024) [18, 24] have shown that IoT-enabled precision agriculture can affect all five dimensions of capital. This includes (a) enhancement of technical knowledge (human capital); (b) formation of farmer collectives (social capital); (c) soil and water conservation (natural capital); (d) building digital infrastructure (physical capital); and (e) increase in farm income (financial capital).

4. Research Gap

Even as the literature on IoT in Indian agriculture is expanding, there is a significant gap in the district-level studies that fuse technology architecture with livelihood analysis. This is especially true for states in Central India like Chhattisgarh. Most of the existing findings examine either the technical side of the sensor installation or the macroeconomic agricultural policy but do not study about the micro-level socio-economic transformation driven by IoT in specific agro-climatic region. This paper tries to overcome that gap by presenting a complete framework for Bilaspur District.

Theoretical Structure.

1. Integrated Theoretical Model

This research utilizes a combined conceptual framework that integrates three existing theories.

1. The Technology Acceptance Model (TAM) proposed by Davis in 1989 [3] explains how usefulness and ease of use foster the adoption of an IoT technology by a farmer. The adoption is further moderated by social influence and facilitating conditions.
2. The Sustainable Livelihoods Framework introduced by DFID in 1999 [4] provides a holistic way of assessing how a change in the five capital assets also changes the lives of people concerned. In IoT-enabled agriculture, the five capital assets are human, social, natural, physical, and financial.
3. This model describes the diffusion of an innovation among the farming community where the innovation is an Internet of Things (IOT) technology. The process is guided by five groups of different categories, including innovators; early adopters; early majority; late majority; and laggards. These groups are affected in their decision-making by the relative advantage of IOT technology; compatibility with their values; complexity of the technology; trialability; and observability.

2. Visualizing the model

The conceptual model (figure 4) illustrates the relationship between the independent variable (IoT technology adoption), intervening variable (precision agriculture practices), dependent variable (rural livelihood transformation, moderating variable (enabling environment) and control variable (barrier to adoption). The connection is through feedback and iterative improvement loop. This is an interactive figure, which is an open concept model. You can view figure 4 for the interactive version.

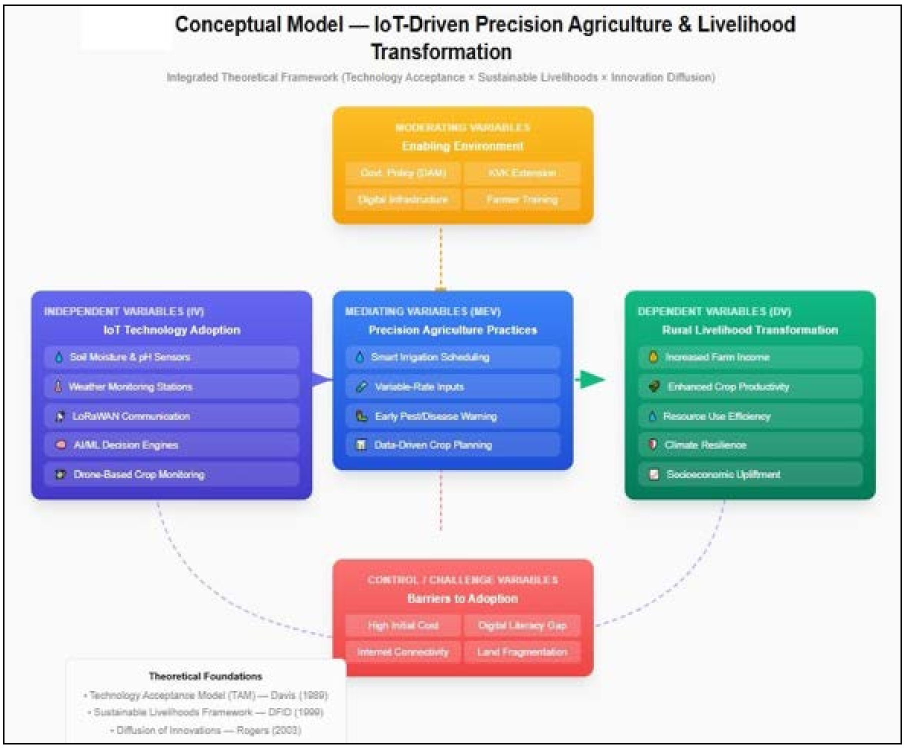

Fig 2: Conceptual Model

Variable Specification

Variable Category	Variables	Indicators
Independent (IV)	IoT Technology Adoption	No. of sensors deployed; Types of sensors; Communication protocol coverage; ML model accuracy
Mediating (MeV)	Precision Agriculture Practices	Smart irrigation frequency; VRT fertilizer usage; Pest detection rate; Crop planning accuracy
Dependent (DV)	Rural Livelihood Transformation	Farm income change (%); Crop yield (kg/ha); Water use efficiency; Climate resilience index; Socioeconomic status score
Moderating (MoV)	Enabling Environment	Govt. policy support; KVK extension intensity; Digital infrastructure availability; Farmer training programs
Control (CV)	Barriers to Adoption	Initial cost (₹); Digital literacy score; Internet connectivity (Mbps); Average farm size (ha)

A system architecture based on IoTs for precision agriculture

5.1 Four-Layer Architecture System.

A four-layer architecture has been proposed for Bilaspur District (Farooq *et al*. 2020; Sahoo, 2024; Kumar *et al*. 2024) [7, 9, 16] which has been adapted from various literature. Explore the interactive figure of IoT system architecture. The interactive figure of IoT system architecture is shown in the figure.

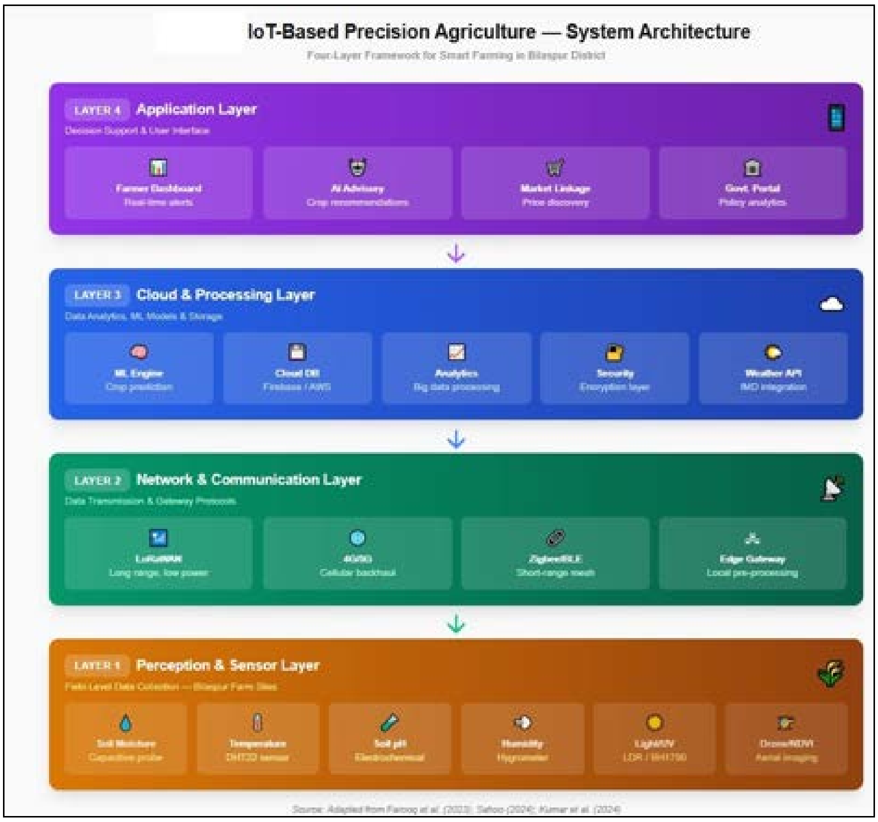

Fig 3: IoT-Based Precision Agriculture

Layer 1 is the perception and sensor layer.

The physical sensing infrastructure deployed over the paddy fields, horticulture plots and mixed cropping area in four development blocks is contained in this layer. Essential Parts Consist of.

- Capacitive Soil Moisture Probes monitor volumetric water content and soil moisture in
- real time.
- DHT22 Sensors for measuring ambient temperature and humidity.
- Electrochemical Soil pH Sensors for determining soil acidity/alkalinity.
- The BH1750 Light Sensors can be used to measure solar radiation and photosynthetically
- active radiation (PAR).
- Drones equipped with NDVI for aerial crop health evaluation and canopy examination.

Layer 2 is the network and communication layer

Data collection from distributed sensor nodes is communicated through multi-protocol.

- LoRaWAN is used to transmit low power data over long distances. It has a range of up to
- 15 km. It is ideal for Bilaspur's agriculture as the signals from these produce higher
- efficiency due to the low density of the network.
- The purpose of Zigbee/BLE a short-range mesh network is to cluster sensor nodes.
- 4G or 5G connectivity system to connect to the cloud
- Edge Gateways are local nodes in a system that do a pre-processing job.

Layer 3 cloud processing layer

Residing on platforms like firebase, things speak or AWS IoT Core. The centralized data processing and analysing engine.

- The 'machine learning engine' will predict crop yield, determine irrigation scheduling and
- forecast pest/disease. Random Forest, LSTM and CNN has been used for the same.
- Mapping of Spatial Variability and Historical Trend Analysis through Big Data Analytics.
- We incorporate real-time feeds from the India Meteorological Department (IMD).

The safety of data is guaranteed through end-to-end encryption, role-based access control, and blockchain-based audit trails.

Layer 4 Application Layer

The interface layer for farmers that translates analytics into actions.

- Farmer Dashboard is a mobile app that provides farmers with SMS alerts in Hindi that help
- show the field status for real-time irrigation recommendations and pest warnings.

- The AI Advisory System provides personalized crop management advice based on local
- environments.
- The Market Linkage module ensures integration with e-NAM and local mandi prices to
- help sell.
- A government portal with district-level aggregated data for officers and policymakers.

System Specifications for Bilaspur Deployment

Component	Specification	Estimated Cost (per unit)
Soil Moisture Sensor	Capacitive v1.2, 3.3V–5V	₹150–300
DHT22 Temperature & Humidity	±0.5°C, ±2% RH	₹200–350
Soil pH Sensor	Analog, 0–14 range	₹500–800
Arduino/ESP32 MCU	240MHz dual-core, Wi-Fi + BLE	₹400–700
LoRaWAN Gateway	RAK7243, 8-channel	₹15,000–25,000
Solar Power Unit	10W panel + 12V battery	₹2,000–3,500
Cloud Platform	ThingSpeak/Firebase (free tier)	₹0–500/month

Implementation framework and operational process.

1. Stepwise Implementation Strategy.

The introduction of IoT-based precision agriculture in Bilaspur is through a three-phase model. During

Phase I: Pilot (Year 1), we will deploy sensor networks in 50 farm plots in 2 blocks (Kota and Masturi) associated with KVK Bilaspur involving 200 farmers. Conduct assessment of soil, water and crop yield to get baseline data.

Phase II Expansion (Year 2–3): Expansion to all 4 blocks to cover 1000 farmers. Incorporate advisory services for AI and ML while adding market linkage modules. Organize training workshops in collaboration with IGKV.

Phase III Institutionalization (Years 3-5): Attain full coverage of the district with self-sustaining farmer-managed sensor networks. Integrate with the state's Agri Stack platform for seamless data exchange.

2. Operational Flow Diagram

The step-by-step workflow from sensor deployment to livelihood transformation outcome is detailed in the flow diagram below:

IoT Precision Agriculture Implementation Workflow
From Sensor Deployment to Rural Livelihood Transformation in Bilaspur District
START
Project Initiation by KVK Bilaspur & IGKV
↓
Step 1: Need Assessment & Site Selection
Identify target villages, farmer groups, soil types (Bhata, Matasi), and cropping patterns across Kota, Takhatpur, Bilha, Masturi blocks
↓
Step 2: IoT Infrastructure Deployment
Install soil moisture, pH, temperature, humidity sensors; set up LoRaWAN gateways; configure edge nodes and solar power units
↓
Step 3: Real-Time Data Collection & Transmission
Sensors collect continuous field data → transmitted via LoRaWAN/4G → stored on cloud platform (ThingSpeak/Firebase)
↓
Step 4: AI/ML-Based Data Analytics
ML models analyze soil health, predict irrigation needs, detect pest/disease outbreaks, optimize fertilizer dosage
↓
🔀 Decision
Threshold exceeded?
☑ YES →
Trigger automated action (irrigate / alert / spray)
✖ NO →
Continue monitoring cycle
↓
Step 5: Advisory Delivery to Farmers
SMS/App-based alerts in Hindi → customized crop advisories → market price information → weather warnings
↓
Step 6: Farmer Action & Resource Optimization
Precision irrigation → targeted fertilizer → optimized planting schedules → reduced input waste by 20–30%
↓
Step 7: Livelihood Transformation Outcomes
💰
Income ↑15-20%
💧
Water ↓25-30%
🌾
Yield ↑15-20%
↓
Feedback Loop & Scale-Up
Data feeds back → model refinement → expand to new blocks

Fig 4: for the full interactive workflow visualization.

3. Expected Impact Metrics

Based on literature synthesis from comparable IoT deployments in India and globally, the following impact metrics are projected for Bilaspur:

Impact Dimension	Metric	Expected Improvement
Water Use Efficiency	Litres/kg of grain produced	↓ 25–30% reduction
Input Cost	₹/hectare for fertilizer & pesticide	↓ 20–30% reduction
Crop Yield	Kg/hectare (rice paddy)	↑ 15–20% increase
Farm Income	₹/household/season	↑ 15–20% increase
Pest/Disease Loss	% crop loss	↓ 30–40% reduction
Climate Resilience	Yield stability index	↑ Improved stability

Thematic Overview: Mind Map

The interconnected themes of this study — encompassing IoT technologies, precision agriculture practices, rural livelihood dimensions, Bilaspur's local context, implementation challenges, and the policy framework — are visualized in the comprehensive mind map below:

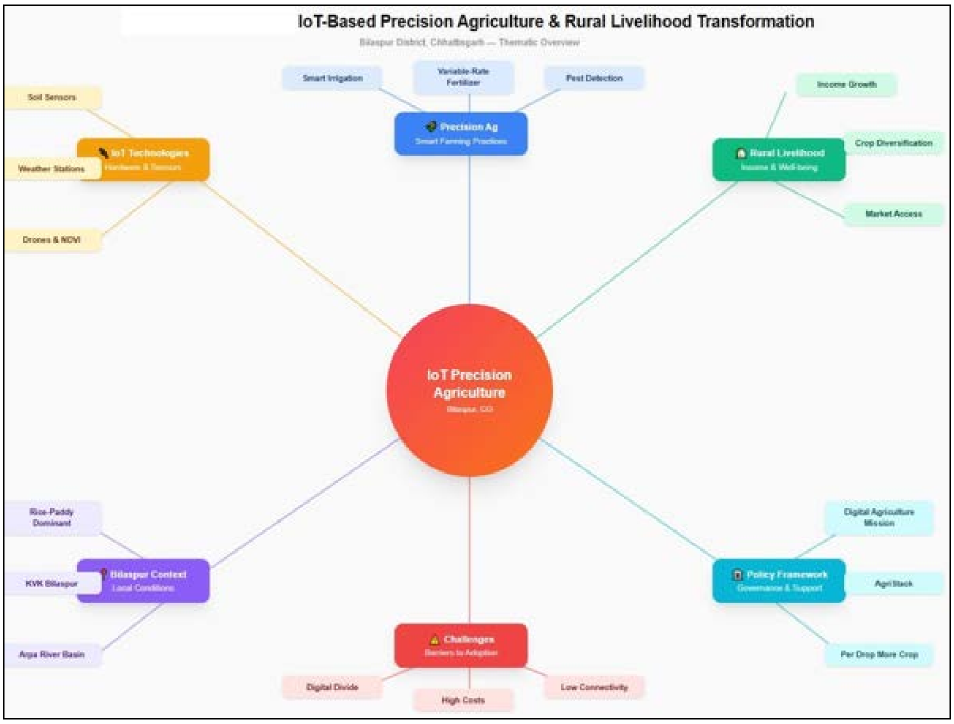

Fig 5: for the full interactive mind map visualization.

Difficulties and Obstacles to Taking Up Technological Issues

1. **Internet connectivity is restricted:** While 4G is available in Bilaspur city and block headquarters, there is no reliable broadband in many villages, especially in Kota and Masturi blocks. Despite LoRaWAN mitigating this between sensor and gateway, cloud uploads need cellular backhaul.

2. **Energy Constraints:** Our sensor must operate continuously. Thus, it should be enabled with a reliable energy source. Solar-powered kits are a feasible option, but they need to be spent upfront.

3. **Periodic sensor** recalibration (i.e., every 3-6 months) is required for low-cost sensors to maintain accuracy. This adds to the operational burden for smallholder farmers.

Socioeconomic challenges

1. Over half the farmers in Bilaspur (especially 50 years+) have little experience with smartphones and other digital interfaces. This requires Hindi language, voice-enabled and very intuitive application designs.
2. The individual costs of the sensors range from ₹150–800, but a complete IoT node with the gateway, solar power, and cloud connectivity costs about ₹25,000–40,000, a huge investment for marginal-income farmers.
3. Average farm size in Bilaspur is less than two hectares-sometimes divided into a set of non-contiguous plots. This makes the deployment of sensor networks logistically difficult and cost per hectare comparatively higher.

Issues Faced by Institutions

1. The Available Capacity of KVK Bilaspur Extension Service with Staff and Resources. To expand the Internet of Things initiatives across the district will demand a large increase in capacity.
2. The question of who owns the technology, the data-related issues, privacy, consent is yet to be resolved. Farmers should maintain authority over their field data. Take care. The introduction of IoT interventions may

benefit those farmers who are technologically literate and rich. This would widen the rural digital divide unless the gap of digital literacy and data sovereignty protections are addressed.

Suggestions for Policies

The study analysis suggests the following policy recommendations to accelerate IoT-based precision agriculture in Bilaspur District.

1. The state government should provide a subsidy of 60-80% on IoT sensor kits for small and marginal farmers through existing schemes such as the Sub-Mission on Agricultural Mechanization (SMAM).
2. Community Sensor Networks (CSNs): Set up sensor infrastructure owned by the community rather than individuals. The infrastructure will be set up by Farmer Producer Organizations (FPOs) to manage it jointly. This helps reduce the cost of sensors for individual farmers.
3. KVK-IoT Integration Program: Dedicated IoT demonstration farms, trained extension workers, including digital agriculture modules in farmer training curricula, strengthen KVK Bilaspur.
4. We will align with the BharatNet programme to provide fibre-optics connectivity to all the gram panchayats in Bilaspur for reliable cloud connectivity for IoT.
5. Make sure that the IoT data from the sensor network of Bilaspur can go into the AgriStack national infrastructure so that it can be cross-verified with the law.
6. Creative development of advisory systems to serve as an enabler for decisions in indigenous dialects through Artificial Intelligence.
7. One suggestion refers to creating a PPP model for scaling up, which encourages PPPs with agri-tech companies (CropIn, Fasal, DeHaat, etc.) to co-fund IoT infrastructure and provide technical maintenance.

In conclusion, future research directions.

This Paper deals with Role of IoT Based Precision Agriculture in Improving Rural Livelihoods in Bilaspur District, Chhattisgarh. By applying the well-established theoretical frameworks of TAM, SLF, and DOI to a four-layer IoT architecture intuitively close to local agro-climatic and other socioeconomic factors, the study has shown that data-driven smart farming can lead to a measurable increase in crop productivity (15-20%), water use efficiency (25-30%) and income of farm households (15-20%). Nonetheless, transforming the service delivery systems of both government and private sector institutions is possible provided, digital infrastructure, financial capacity, institutional capability and data governance. The phased model for implementation from pilot to scale-up to institutionalization is useful for KVK Bilaspur and other stakeholders like IGKV, Chhattisgarh Department of Agriculture and private agri-tech partners.

Further Study Suggestions

1. A longitudinal quasi experiment across four blocks of Bilaspur to measure impact of IoT on indicators of livelihood would be conducted.
2. Consider the cost implications of IoT investment in terms of adopting IoT at either a basic level or core level.
3. To examine farmer perception, structured surveys shall be conducted with TAM-based instruments to analyse the attitude, perceived usefulness and intention to adopt farmer with IoT.
4. Climate-smart IoT: Study and implement IoT applications along with climate-smart agriculture (CSA). Specifically, conservation agriculture, agroforestry, and climate Indexed Crop Insurance (CICI) etc.
5. Explore solutions that ensure farmer data sovereignty and transparency in the supply chain through blockchain technology.

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