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RESEARCH PAPER

Smart Adaptation and the Rise of Surveillance Ecology: The Unintended Impacts of Digital Climate Innovations

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Abstract: As climate change intensifies, digital technologies are being rapidly integrated into climate adaptation frameworks. While these technologies promise real-time environmental monitoring and predictive capacity, they also raise critical ethical, ecological, and social concerns. In the Indian context, the convergence of digital climate technologies with governance frameworks has created both possibilities for smart adaptation and risks inherent in what this study terms "surveillance ecology". This study addresses three questions: (1) How do digital climate innovations both strengthen adaptive capacity and endanger sociopolitical safety? (2) How does surveillance ecology exacerbate existing inequalities in India? (3) How can traditional ecological knowledge be integrated with digital tools to promote inclusive and just climate adaptation? Guided by post-structuralist and decolonial epistemologies, the research employs a qualitative systematic literature review. Findings show that while digital adaptation efforts enhance resilience, they also centralize power, limit community autonomy, and generate unintended rebound effects, such as excessive e-waste and high-energy data infrastructures. The study argues for a paradigm shift from technocratic adaptation to justice-centred innovation. Future research should investigate the ground-level impacts of surveillance ecology and assess how low-carbon digital infrastructures can minimize ecological harm.

Keywords: Surveillance Ecology, Digital Climate Innovation, Traditional Ecological Knowledge, Climate Adaptation, Data Sovereignty, Environmental Justice.

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1. INTRODUCTION

The accelerating climate crisis, evident in the escalating frequency and intensity of floods, droughts, and heatwaves, necessitates not only urgent action but also a reimagining of adaptive capabilities. As the boundaries between climate policy and digital innovation converge, technologies such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, and big data analytics are increasingly being considered as transformative tools (Rauter 2021). These systems enable real-time environmental monitoring, predictive modelling, and optimized resource management-mechanisms essential for navigating climate uncertainties (Selvam and Al-Humairi 2025). In a country like India, ecologically diverse and culturally rich yet digitally fragmented, these technologies are often heralded as solutions that enable climate-smart agriculture, urban flood forecasting, and ecosystem resilience (Pandey and Goyal 2025). However, the incorporation of digital systems into climate governance raises urgent ethical and political concerns.

This study critically examines the tension between smart adaptation and digital overreach in the context of India's socio-ecological and post-colonial landscapes. It argues that while digital climate innovations hold immense promise, they risk reinforcing a technocratic model of governance that privileges urban elites and private actors. The deployment of AI-driven climate forecasting or IoT-based smart agriculture in states such as Maharashtra and Tamil Nadu reveals troubling dynamics: Technologies designed to empower communities often extract data without meaningful consent and consolidate decision-making in centralized, usually corporate domains (Jayadatta 2024). Despite the proliferation of digital climate tools such as geographic information system (GIS)–enabled disaster mapping and IoT-assisted irrigation, academic inquiry remains largely focused on their technical efficiency while overlooking their socio-political consequences, especially for indigenous, rural, and marginalized populations (Mhlongo *et al.* 2023). In a nation shaped by colonial legacies and socio-economic stratification, the implications for data sovereignty, cultural privacy, and digital justice are still inadequately understood.

Importantly, integrating traditional ecological knowledge (TEK) with digital systems offers a path towards inclusive and ethical climate adaptation. However, this synergy remains under-explored in mainstream adaptation planning, despite India's deep reservoirs of indigenous environmental wisdom (Simlai and Sandbrook 2025). To address these gaps, this study poses three fundamental research questions:

1. How do digital climate innovations simultaneously enhance adaptive capacity and pose socio-political risks?

2. In what ways does surveillance ecology exacerbate existing inequities within the Indian context?
3. How can TEK be meaningfully integrated with digital technologies to advance socially just and ecologically grounded adaptation?

These questions challenge the prevailing narrative of techno-solutionism and call for a paradigm shift towards climate futures that are not only digitally smart but also ethically grounded, locally informed, and globally just.

2. RESEARCH METHODS AND MATERIALS

This section outlines the study's methodological approach, including the research design, philosophical orientation, data sources, and analytical boundaries. It situates the study within a critical and interdisciplinary framework and explains the rationale for the selection of the literature and the analytical tools, as well as the overall scope of the inquiry. To enhance analytical clarity, a thematic synthesis table is included.

2.1. Research Design and Philosophical Orientation

This study employs a qualitative research design grounded in critical inquiry and guided by post-structuralist and decolonial epistemologies. It offers a critique of surveillance ecology by disentangling the twin functions of climate digital innovations as instruments for intelligent adaptation and facilitators of ecological monitoring. The methodological framework integrates Foucault's theories of biopower and surveillance, as well as post-colonial ecological critiques, to analyse how digital adaptation technologies interact with marginalized ecologies, data governance, and social justice (Sultana 2022).

2.2. Data Sources and Inclusion Criteria

The study conducted a systematic literature review covering digital climate governance, surveillance ecology, environmental equity, and interdisciplinary indigenous knowledge systems. Scientific and institutional documents, including journal articles, technical reports, and UN publications, were reviewed.

2.3. Scope and Limitations

This research provides a theoretically rich, critically engaged synthesis of the secondary literature. However, it does not include primary data collection, such as interviews or field observations. This constraint is addressed through methodological triangulation, a broad temporal scope, and the integration of region-specific case studies from India. Table 1 provides the details of the themes developed in this study.

3. FROM DIGITAL INNOVATION TO SURVEILLANCE ECOLOGY: A THEORETICAL FRAMEWORK

The convergence of digital technologies and ecological systems represents a significant shift in the way power, knowledge, and ethics are negotiated in today's digital world. The efficient synchronization of human and non-human surveillance necessitates cross-disciplinary analysis to predict potential unintended outcomes and promote ethical innovation.

3.1. Digital Modernity: Datafication and the Architecture of Power

The rise of digital modernity, characterized by extensive data consumption, networked connectivity, and the dissemination of personal data, has altered societal structures as well as power dynamics (Vial 2019; Zuboff 2019). Data-driven models reconfigure power via insidious, all-pervasive surveillance. According to Foucault, disciplinary power is ingrained in digital modernity as well as in everyday control and surveillance practices, such as targeted advertising and predictive policing, resulting in an internalization of self-discipline via digital technology. In Zuboff's (2019) surveillance capitalism, corporations and governments are seen as using data to influence behaviour, thereby undermining autonomy and reinforcing observer–observed dynamics within hierarchical systems.

3.2. Surveillance Ecology: Datafication of the Non-Human

Surveillance ecology introduces digital modernity into ecological systems by using real-time, automated technologies such as IoT sensors, drones, and AI-driven analytics to track environmental processes with unprecedented accuracy (Reichstein *et al.* 2025). Quantitative control and economic optimization are the key objectives of digital modernity, whereas surveillance ecology prioritizes ecological resilience and adaptive management. The use of predictive analytics and early-warning systems facilitates more effective responses to climate disasters, such as wildfires and disease outbreaks (Reichstein *et al.* 2025). The governance of and access to these systems are frequently questioned because technologically advanced institutions control ecological data (Hulme 2019). Also, combining close monitoring and accidental data collection from human communities (especially marginalized groups, such as indigenous people) can make it hard to tell the difference between ecological and social surveillance. The use of quantifiable data may undermine TEK, which focuses on how ecosystems interact with each other in a qualitative way.

Table 1: Thematic Synthesis

Theme	Years covered	Method	Research gap	Key findings	Region under focus	Policy relevance
Surveillance ecology	2000–2024	Critical discourse analysis, Foucauldian analysis	The socio-political and ethical implications of ecological monitoring extending into human surveillance remains under-explored	Digital climate technologies (e.g., drones in Kaziranga National Park) risk creating surveillance regimes, eroding privacy and autonomy, particularly for indigenous communities	India, global (Southeast Asia, Australia)	Need for ethical governance frameworks (e.g., CARE, OCAP)[a] to regulate data use and prevent surveillance overreach in climate technologies
Smart adaptation and inequality	2007–2024	Thematic analysis, case studies	Limited focus on how digital adaptation exacerbates spatial and social inequities	Urban-biased initiatives such as India's Smart Cities Mission and smart agriculture marginalize rural and informal communities, redirecting risks (e.g., Chennai's floodwater management)	India, Bangladesh, Sub-Saharan Africa	Inclusive governance and participatory design to ensure equitable access to climate technology and address digital divides

Indigenous data sovereignty	2006–2024	Policy analysis, conceptual synthesis	Insufficient community control over ecological and cultural data in digital climate systems	Integrating TEK with digital systems (such as the Adivasi Resilience Network) to protect indigenous data rights and avoid data colonialism	India, Canada, New Zealand, Brazil	Rights-based data governance to empower communities and institutionalize data sovereignty in climate policy
Techno-ecological ethics	2000–2024	Discourse analysis, ethical critique	Lack of sustainability and cultural sensitivity in digital climate technology design	Technologies often prioritize efficiency over ecological and social impacts; models such as Kerala's eco-panchayats show potential for eco-sensitive design	India (Kerala), Latin America, global	Policies promoting green coding, renewable-energy integration, and care-centred AI for responsible innovation
Rebound effects and e-waste	2010–2024	Life cycle assessment, empirical review	The environmental costs of digital climate infrastructures remain under-examined	Digital technologies produce 3.2 million tonnes of e-waste annually in India and use 1.5% of electricity through data centres, undermining sustainability	India, China, Nigeria, Germany	Circular economy policies (e.g., 2022 E-Waste Management Rules) and renewable-powered infrastructure to mitigate environmental impacts

TEK and digital integration	2000–2024	Case study analysis, epistemological synthesis	Epistemological marginalization of TEK in digital climate frameworks	Hybrid systems (e.g., Odisha's AI-based monsoon forecasting and Karnataka's People's Biodiversity Registers [PBR]) enhance resilience by blending TEK with GIS/AI, but they require co-design to avoid extractive practices	India (Odisha, Western Ghats, Arunachal Pradesh), Canada, Peru, Australia	Co-creative adaptation policies that institutionalize epistemic pluralism and fund digital initiatives led by indigenous communities

Note: [a] CARE: collective benefit, authority to control, responsibility, ethics; OCAP: ownership, control, access, possession.

Source*:* Authors' compilation

3.3. Synthesizing Paradigms: Tensions and the Ethical Horizon

The two paradigms are founded on datafication and networked connectedness, which allow information sharing between human and non-human domains (Reichstein *et al.* 2025). The public-good nature of surveillance ecology can lead to the perpetuation of power imbalances, since it consolidates data control and potentially excludes vulnerable local populations (Hulme 2019). These dynamics are elucidated through a Foucauldian lens, with surveillance considered a mode of governance that renders people and ecosystems accountable through data trails and algorithms. On the one hand, movements that seek data sovereignty and privacy decry the hegemony of surveillance capitalism; on the other, community monitoring and mainstreaming of indigenous ecological knowledge have the power to redirect surveillance ecology towards inclusivity. These acts of agency highlight the potential to revolutionize surveillance practices by redefining critical digital literacy and ethical standards.

Merging digital modernity and surveillance ecology can help foster a future in which surveillance is embedded in human and non-human practices, offering possibilities for innovation through precision conservation and intelligent urban planning but risking inequalities and eroding freedom (Reichstein *et al.* 2025). The development of AI-driven analytics might augment predictive capacity, but it may also increase bias unless properly controlled. In this age of surveillance, there is a need for interdisciplinary strategies that consider digital and ecological systems as interdependent and adaptable. Enforcing transparency and consent through policies can help mitigate privacy risks, while promoting digital mindsets that prioritize critical engagement with technology will support resistance to exploitative practices (Solberg *et al.* 2020).

4. SURVEILLANCE ECOLOGY VERSUS TRADITIONAL ENVIRONMENTAL MONITORING: A COMPARATIVE ANALYSIS

Surveillance ecology represents a paradigm shift in environmental monitoring because it alters the mechanisms by which ecological systems are observed and interpreted using digital platforms (Afoma *et al.* 2025). However, this change is not without its drawbacks. Power asymmetries are often reproduced by depending on centralized data infrastructures and algorithmic governance. The transition towards a techno-centric approach should be preceded by the deconstruction of the binary between "traditional" and "modern" systems of knowledge. TEK's integration with digital technologies is a move towards more inclusive climate adaptation that is sensitive to environmental conditions. In Australia, Aboriginal "cultural burning" is now regulated by satellite-based fire detection to prevent wildfires without compromising the ecological balance (Singh and Srivastava 2025). In a similar vein, Inuit-led marine-monitoring programmes utilize both oral traditions and satellite monitoring to support sustainable harvesting (Huntington *et al.* 2004).

The Indian landscape presents a similar transformation. The incorporation of tribal knowledge, derived from phenological cues such as bird migration and flowering patterns, into AI-driven weather models in Odisha is now helping enhance climate-smart agricultural planning (Behera *et al.* 2023). Besides ecological tracking, TEK–digital synergies are helping improve climate-sensitive livelihoods. The Quechua people in the Peruvian Andes have integrated traditional planting calendars with weather data, which can be processed and analysed using IoT technology to reset agricultural cycles (Hirsch 2025). Nevertheless, this amalgamation poses risks. Digital deployments in indigenous territories often replicate data colonialism, where knowledge is extracted, anonymized, and distributed through exclusionary techno-scientific systems without any agreement or reciprocity. The use of drones for surveillance in Indian forests has been criticized as misrepresenting complex socio-ecological interactions and encroaching on cultural spaces.

The Whanganui River Monitoring Initiative in New Zealand provides models for equitable digital integration through co-design frameworks (Talbot-Jones & Bennett, 2022). To address illegal logging in Brazil's Amazon, indigenous groups have begun using drones and encrypted data systems, setting a precedent for digital environmental governance that upholds indigenous territorial and data sovereignty. In Arunachal Pradesh and Nagaland, two Indian states with high tribal populations, efforts are being made to digitize traditional forest management practices using secure mobile platforms (Saikia *et al.* 2020). Finally, integrating surveillance ecology and TEK demands more than just a technical merger; it also requires an epistemological shift. Indigenous group–led research, community-based data infrastructure, and digital capacity–building initiatives are crucial institutional reforms that can re-position traditional knowledge systems from the margins to the core of climate governance.

5. KEY APPLICATIONS OF SURVEILLANCE ECOLOGY IN DIGITAL CLIMATE INNOVATION IN INDIA

Surveillance ecology, which involves the use of advanced technologies such as AI, machine learning, IoT, blockchain, and remote sensing to monitor and control environmental systems, has had a significant impact on climate innovation (Bublitz *et al.* 2019). The integration process in India is led by the PBR. The National Biodiversity Authority initiated the PBR programme, which records indigenous and community-owned ecological knowledge, including local taxonomy, ethno-botany, and seasonal observations, through GIS and remote sensing data (Dafe and Kadu 2025). Tribal communities in Karnataka's Biligiri Rangaswamy Temple Sanctuary identify ecologically sensitive mistletoe-infected fruit trees and use satellite imagery to guide sustainable farming practices (Rist *et al.* 2010). In Odisha, tribal communities use TEK-based monsoon forecasting and AI-generated meteorological forecasts to assist them in adaptive agricultural planning.

These developments in techno-cultural convergence serve to strengthen the community. The Pachmarhi Biosphere Reserve in Madhya Pradesh hosts the Korku and Gond tribes, who manage more than 120 plant species for rituals, food, and medicinal use. Integrating their knowledge with IoT-based monitoring of soil and water systems helps improve agro-ecological planning (Kala 2022). Integration of policy and research can play a key role in climate change strategies. PBR's work includes both identifying climate indicators that are relevant to the local environment and calibrating digital output in culturally meaningful ways. Forest health information from tribal elders is systematically incorporated into remote sensing analyses in the Western Ghats, with implications for conservation practice and climate adaptation under India's National Action Plan on Climate Change (Basavarajaiah *et al.* 2020).

TEK's engagement with surveillance ecology has the potential to support climate innovation grounded in justice and resilience. However, when community-based knowledge is digitized, there is a risk of unauthorized extraction, documentation without consent, and loss of community control over its use. Blockchain-based systems offer one possible safeguard by enabling decentralized and traceable data storage, as seen in Odisha's biodiversity documentation efforts (Ludwig and Macnaghten 2020).

In the Himalayan regions, predictive frameworks combining Bhotiyan knowledge of glacial retreat with satellite-based hydrological models are used to anticipate water availability under climate stress. Despite such contributions, TEK is often dismissed as anecdotal within dominant techno-scientific paradigms. Institutional measures, including funding for indigenous-led research, support for community-managed digital infrastructure, and inclusive curricular reforms, are therefore essential. Initiatives such as the PBR show that when communities retain agency, they can steward both biodiversity and their digital future (Kala *et al.* 2022).

6. SMART INNOVATIONS, UNEQUAL OUTCOMES: ENVIRONMENTAL AND SOCIAL COSTS OF CLIMATE TECHNOLOGY

The incorporation of digital innovations into climate adaptation frameworks has ushered in a new era of environmental governance, promising efficiency, predictive capability, and resilience (Argyroudis *et al.* 2022). This section critically questions the dualities in climate technologies, drawing from empirical examples from India and other nations. The environmental toll of digital climate technologies stems from their energy-intensive infrastructure. The use of large data centres by cloud computing systems, particularly those powered by AI, is a significant contributor to carbon emissions. The data centre industry in India is expected to experience significant growth due to the digital economy; it currently accounts for approximately 1.5% of the country's electricity consumption, with much of it derived from fossil fuels (Inshakova and Kachalov 2022). The National Supercomputing Centre in China exemplifies a global paradox, as it relies on a carbon-intensive energy matrix to deliver advanced digital solutions to mitigate climate change (Lee *et al.* 2024).

The depletion of rare earth minerals and the proliferation of e-waste during device life cycles contribute to ecological crises. In India, the accelerated uptake of digital devices, particularly smartphones and IoT-enabled agricultural tools, has driven an e-waste surge that now exceeds 3.2 million tonnes annually (Rajesh Kumar *et al.* 2024). A substantial portion of this waste is processed in informal sectors without safety protocols, resulting in hazardous substances being released into the environment. In vulnerable ecological zones, ecosystem dynamics are often impacted by smart adaptation technologies, leading to negative consequences. The use of drones to monitor mangrove health in India's Sundarbans region has disrupted avian migration patterns, raising concerns about the potential benefits of digital surveillance for biodiversity conservation. Intelligent irrigation systems used in the Mississippi River Basin have increased groundwater extraction in America, potentially impairing the ability of local wetlands to adapt (Mallick 2025).

Social inequality arising from digital climate solutions remains a significant concern. Under India's Smart Cities Mission, the use of AI-based flood prediction models in informal settlements illustrates this tension. Although designed to enhance risk preparedness, such technologies are often implemented without meaningful community engagement and tend to prioritize infrastructure protection over the everyday vulnerabilities of residents. In some cases, flood-risk data have been used to increase surveillance or to legitimize displacement and eviction, thereby deepening insecurity rather than strengthening resilience. Similar contradictions are evident in ecosystem-based adaptation (EbA) initiatives. In the Western Ghats, afforestation programmes involving exotic plant species have reduced soil erosion but have also disrupted native biodiversity and weakened ecosystem services. More broadly, fragmented climate governance and the limited incorporation of local ecological knowledge have limited EbA's transformative potential in India (Chaudhary *et al.* 2021).

Rebound effects present a further complication in the sustainability calculus. Environment-friendly technologies frequently require an increased use of resources. IoT-enabled precision agriculture in India has resulted not only in higher productivity but also in increased energy and water consumption, thereby offsetting the environmental benefits (Kapil *et al.* 2025). In Kaziranga National Park, India, drone-based wildlife monitoring has contributed to anti-poaching efforts but has raised concerns among indigenous communities about privacy, autonomy, and potential data misuse.

The future of climate adaptation in India and elsewhere entails structural shifts across energy, governance, and behaviour. India's emerging solar-powered data centres, led by firms such as Adani Green Energy, illustrate how renewable energy can be embedded in digital infrastructure to reduce climate costs. On the e-waste front, the 2022 E-Waste Management Rules mark a policy turning point but require effective public–private partnerships to strengthen enforcement and expand responsible recycling practices (Srivastava *et al.* 2025). Equity-based governance is also crucial. India's National Adaptation Fund for Climate Change can be used to link digital tools to community-led EbA, as seen in the participatory watershed management projects in Rajasthan (Chaudhary *et al.* 2021).

7. BRIDGING EPISTEMOLOGIES: CO-CREATING CLIMATE RESILIENCE THROUGH DIGITAL TOOLS AND TEK

The growing urgency of climate change concerns has spurred a surge in digital innovations aimed at transformative solutions. This section examines how the combined use of TEK and digital tools bridges knowledge gaps, overcomes systemic inequalities, and fosters co-creation for just climate adaptation. Digital tools need to integrate environmental objectives such as minimizing carbon footprints and encouraging material circularity in order to be sustainable. IoT-based precision agriculture in India's Punjab is a good example of this integration, as it employs real-time data analytics to maximize irrigation and fertilizer application, thereby lowering costs and preventing groundwater depletion. Facilities such as the Attero Recycling plant recover rare-earth elements from used electronics using scalable models (Khanna and Kaur 2023).

TEK, based on lived experience and ecological inter-symbiosis, provides information that cannot be easily recorded using conventional scientific methods (Vinyeta and Lynn 2013). In Tamil Nadu's coastal villages, communities use bird migration and tide patterns as storm indicators; this knowledge has now been incorporated into mobile applications by fusing the indigenous signs with satellite images to enhance forecasting accuracy and community trust. TEK's survival calls for conscious maintenance and moral integration (Abijith *et al.* 2023). Digitizing TEK using geospatial technologies transforms it into a strategic resource for climate resilience. GIS platforms archive oral histories, indigenous maps, and spatial memory to model landscape changes. In the Western Ghats, GIS-based participatory watershed management incorporates tribal knowledge of seasonal water sources and forest dynamics, thereby creating strong hydrological models. AI systems enhance forecasting by incorporating TEK-informed indicators such as animal behaviour or phenological cues. In Odisha, flood-risk models integrating tribal knowledge of river patterns have improved early-warning protocols for cyclones (Pal *et al.* 2025).

The incorporation of TEK into digital climate innovations faces ethical, political, and methodological challenges. Power asymmetries often reduce TEK holders to passive subjects rather than active co-creators, with tokenistic engagement creating colonial hierarchies in digital form. Intellectual property concerns are a major issue, as TEK appropriation without legal safeguards exacerbates inequities (Ludwig and Macnaghten 2020). New Zealand's Māori Data Sovereignty Network empowers indigenous communities to retain control over their knowledge, a model India's varied legal system lacks (Lilley *et al.* 2024). Empirical evidence from India and globally demonstrates the effectiveness of TEK–digital integration. In Rajasthan, the Barefoot College empowers rural women to combine traditional water harvesting with solar-powered irrigation, creating community-owned, climate-resilient infrastructure. The Nicobarese community's coastal knowledge informs GIS-based mangrove restoration in the Andaman and Nicobar Islands to buffer the effects of cyclones. In Arunachal Pradesh, the Apatani tribe's centuries-old wet rice cultivation techniques are monitored by AI to enhance yields and ecological balance (Vinyeta and Lynn 2013). The special reports of the Intergovernmental Panel on Climate Change increasingly recognize TEK's legitimacy in climate action. Capacity-building initiatives should include technological training, epistemic recognition, and rights-based education. In India's Scheduled Tribe areas, digital literacy programmes prioritizing resource sharing and collaborative climate knowledge can facilitate access to GIS and AI tools. Tamil Nadu's weather apps, combining TEK indicators with real-time updates, highlight the potential of hyperlocal adaptation tools.

8. BRIDGING THE DIGITAL DIVIDE AND ENSURING JUSTICE IN CLIMATE TECHNOLOGY ADOPTION

As climate change accelerates, digital technologies such as climate advisory platforms, early-warning systems, and smart agricultural tools are transformative for increasing resilience and facilitating low-carbon transitions. However, their potential is limited by structural barriers, particularly in India, where digital access and literacy remain uneven. By 2023, India's internet penetration reached 46%, with rural regions lagging behind. Rural farmers struggle to adapt to changing monsoon conditions due to limited access to effective climate advisory tools (Narayanan *et al.* 2025). Expanding the reach of equitable, sustainable digital infrastructure is critical. India's BharatNet programme, which aims to connect 250,000 villages with broadband, achieved 60% coverage in 2024 (DoT 2024). Pairing connectivity with renewable energy enhances sustainability. The Digital Village initiative in Gujarat combines the creation of solar-powered Wi-Fi hotspots with local services, boosting agricultural productivity by 15% by providing access to real-time meteorological data (GoI 2023).

Infrastructure alone is insufficient, however; customized digital literacy is critical to bridging the digital divide. The Digital Green programme in Maharashtra trains women farmers to share climate-friendly practices via vernacular-language videos, increasing the adoption of sustainable practices by 25%. India's mKRISHI app, developed with inputs from Tamil Nadu farmers, integrates AI forecasts with traditional practices such as intercropping, increasing yields by 20% (Kumar 2025). Digital climate technologies pose ecological and ethical risks and require systemic safeguards. Data centres are projected to account for 8% of global emissions by 2030, and India's 5G and IoT proliferation generates 50,000 tonnes of ethylene oxide annually (Maji *et al.* 2025). Ethical concerns include surveillance and data extraction, as seen in Punjab, where farmers reported unauthorized data use by agribusinesses.

Gender-based digital exclusion impedes equitable adaptation. In India, only 20% of women own smartphones, limiting their access to climate advisories (Rowntree 2019). Brazil's AgroSmart platform subsidizes smart devices for smallholders; this resulted in a 15% increase in yields (Rashid and Gani 2025). In India, hybrid models such as AI-enabled flood alerts complement indigenous strategies, as seen in the Sundarbans mangrove restoration (Selvakumar *et al.* 2025). Dynamic feedback mechanisms, such as Australia's Fire Hawk platform, should be embedded in India's smart agriculture innovations to enable iterative refinement. A decisive shift towards ecologically sensitive and socially embedded digital adaptation is needed. To address urban bias, India's Smart Cities Mission, which integrates IoT for climate resilience, must be extended to rural areas (MoHUA 2024). Strategic public–private collaborations, such as the TCS partnership in mKRISHI, can accelerate the dissemination of affordable, context-responsive technologies (Kumar 2025).

9. ETHICAL CHALLENGES AND JUSTICE IMPERATIVES IN DIGITAL CLIMATE TECHNOLOGIES

Digital climate technologies have the potential to enhance forecasting, monitoring, and adaptive capacities. However, there are serious ethical concerns regarding their application that cannot be addressed with an abstract warning but require a specific response via participatory governance (Jasanoff 2016). When used in centralized administrative and corporate systems, these technologies become more integrated, which poses the threat of surveillance ecology due to uncontrolled data mining, the unreliability of the algorithm, and poor mechanisms for gathering consent from communities (Zuboff 2019). To address these risks, it is necessary that techno-solutionism be replaced by institutionalized ethical governance.

First, data governance should shift beyond general privacy norms to climate-specific regulation protections. Data collection by drones, IoT sensors, and AI-based analytics in rural and indigenous areas must be restricted to ensure that the datasets do not serve to police, commercially profile, or spy on the population (Thakur *et al.* 2021). These protections may be implemented in the form of binding principles based on climate and digital governance models and should mandate renewal and re-negotiation for secondary data use at the community level. Second, indigenous data sovereignty needs to be converted into an institutional practice that is enforceable. Although frameworks such as CARE and OCAP are commonly cited normatively, their success relies on tangible processes, for example, community-owned data repositories, veto powers over data sharing, and legally recognized custodianship of TEK (Carroll *et al.* 2020; Kukutai and Taylor 2016). Through statutory recognition, India's PBR provide an institutional point of entry for ethical governance and can be empowered as community-owned digital infrastructure to eliminate data colonialism (Agrawal 2002).

Third, participatory design should be considered as not just a regulation but a best practice. The use of climate technologies in vulnerable areas should involve obligatory co-design procedures, involving local governments, indigenous councils, and community representatives in pre-implementation consultation, feedback, and post-implementation reviews. In the absence of local participation, digital systems are liable to replicate technological colonialism (Couldry and Mejias 2019). Fourth, institutional controls are necessary to regulate algorithms in climatic governance. Flood control, crop advisories, and conservation zoning decision support systems based on AI should be subjected to transparency audits by independent audit bodies and follow explanatory guidelines, especially where transparency is needed about how algorithms influence access to land, resources, or relocation sites (Burrell 2016; Vinuesa *et al.* 2020). Lastly, ethical climate technologies must consider their ecological footprints. Climate adaptation data centres, sensor networks, and digital infrastructures should maintain low-carbon standards, for instance, by using renewable energy and life-cycle analysis to prevent rebound and reduce e-waste. Collectively, these measures re-brand ethics as a moral sidecar to governance, and surveillance ecology as an avoidable risk to an accountable, justice-centred innovation.

10. IMPLICATIONS OF THE STUDY AND FUTURE RESEARCH DIRECTIONS

This study shows that digital climate innovations are a double-edged tool, as they help increase adaptive capacity but also create new surveillance, exclusion, and ecological costs (Zuboff 2019). The main implication here is that technological capability alone cannot achieve climate resilience; it is the structure of governance that determines the final results (Jasanoff 2016).

On the policy front, the findings highlight the need for climate-specific digital governance frameworks. Current climate policies in India focus on mitigation and adaptation targets but do not address data ownership, surveillance risks, and algorithmic decision-making (Marda 2018). It is necessary to integrate digital governance arrangements with national adaptation programmes and state action plans on climate change so that climate technologies are regulated with attention to their social and political impacts rather than being treated as neutral technical tools.

At the institutional level, the study underscores the significance of decentralized governance systems. Community-led institutions, such as biodiversity committees, tribal councils, and panchayats, act as mediators between digital systems and actual living ecological realities, providing contextual inputs and reducing power asymmetries (Agrawal and Gibson 1999; Ostrom 2010).

On the technological front, the findings recommend low-carbon and circular infrastructures. Climate technologies should be assessed not only on their adaptive efficiency but also on their material and energy footprints, which can be reduced by having renewable energy–powered data centres, extended producer responsibility, and sustainable procurement guidelines. Future research should prioritize field-based empirical studies that examine how surveillance ecology is experienced by indigenous and rural communities, along with comparative analyses of state-level governance practices. It should also focus on developing interdisciplinary and scalable co-design frameworks that integrate TEK with AI, GIS, and IoT technologies while explicitly avoiding epistemic extraction (Kukutai and Taylor 2016).

11. CONCLUSION

Digital technologies have become essential tools for climate adaptation, offering real-time surveillance, predictive analytics, and optimal resource management. However, without proactive governance arrangements, these technologies may become a form of surveillance ecology, where ecological surveillance expands into social surveillance, thereby contributing to inequality and loss of autonomy. The study shows that the main issue is not the technology but rather the absence of a just institutional design. Surveillance ecology is organized around centralized, opaque, and extractive forms of governance, whereas participatory, decentralized, and rights-based approaches allow the development of ethical resilience.

One pathway towards inclusive digital adaptation is the integration of TEK with digital tools, provided that TEK holders retain control over how their knowledge is documented, interpreted, and used; this can be achieved through institutional safeguards, community-managed biodiversity registers, and consent-based data systems. It is also necessary to reduce the environmental footprint of digital climate innovations by using renewable energy–powered infrastructure, developing a circular economy, and regulating digital supply chains. Finally, the study suggests a shift away from technocratic approaches to climate adaptation towards an innovation framework in which data sovereignty, participatory institutions, algorithmic responsibility, and ecological accountability are prioritized.

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