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Transformative Role of Information and Communication Technologies (ICTs) in Sustainable Forest Management: A Review

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Abstract

Information and Communication Technologies (ICTs) are increasingly transforming forest management by enabling real-time data collection, advanced analytics, and integrated decision-making systems. Forests, covering nearly one-third of the Earth's land surface, play a crucial role in carbon sequestration, biodiversity conservation, and livelihood support, yet face mounting pressures from deforestation, forest fires, illegal logging, and climate change. ICT tools such as satellite remote sensing, Geographic Information Systems (GIS), drones, Internet of Things (IoT) sensors, artificial intelligence, and mobile-based platforms enhance monitoring accuracy, operational efficiency, and governance transparency. These technologies support forest growth modeling, carbon accounting, biodiversity assessment, and supply chain traceability while strengthening early warning systems for fires and encroachment. ICT-enabled geospatial analysis facilitates landscape-level planning, hotspot identification, and ecosystem-based management. Participatory monitoring platforms further empower local communities by improving data coverage and accountability. In addition, digital governance portals streamline forest clearances, regulatory compliance, and public grievance systems. Despite challenges including infrastructure gaps, technical capacity limitations, and data security concerns, the integration of emerging technologies such as machine learning and blockchain presents new opportunities for sustainable and climate-resilient forestry. Overall, ICT serves as a strategic enabler for enhancing productivity, transparency, and ecological integrity in modern forest management systems.

Keywords: Information and Communication Technologies (ICTs), Forest Management, Remote Sensing and GIS, Carbon Accounting, Biodiversity Conservation

Introduction

Information and Communication Technologies (ICTs) have progressively grown essential in multiple areas, including forestry. These technologies, including hardware, software, telecommunications networks, and information management systems, provide the efficient gathering, transmission, processing, and storage of data (Zakari *et al.*, 2024) ^[29]. Their advancement has been propelled by the increasing demand for prompt, precise information in decision-making processes. In forestry, information and communication technologies (ICTs) improve forest management by refining operations, maximizing productivity, enhancing monitoring systems, and facilitating biodiversity protection (Ali *et al.*, 2025; Kumar *et al.*, 2026) ^[2, 15]. They constitute the foundation of an evolving "information society" in forestry, where efficient communication across systems and stakeholders is crucial for sustainable results. Forests, encompassing about one-third of the Earth's terrestrial surface, are essential for sustaining ecological equilibrium, sequestering carbon, conserving biodiversity, and supporting the livelihoods of millions (Singh *et al.*, 2025) ^[23]. Nevertheless, they are progressively endangered by deforestation, illicit logging, wildfires, and climate change. Conventional forest management methods, while fundamental, frequently lack scalability, precision, and adaptability. In this context, ICTs provide revolutionary capabilities through real-time monitoring, predictive modelling, and integrated decision-support systems (Kumar *et al.*, 2023) ^[12]. The worldwide implementation of technology like satellite remote sensing, Geographic Information Systems (GIS), drone surveillance, and mobile data collecting platforms has transformed the assessment, protection, and utilization of forests (Taylor *et al.*,

2020) [25]. Information and Communication Technologies enhance internal operational efficiency for forestry agencies and companies while promoting transparent governance, community involvement, and evidence-based decision. The increasing accessibility and sophistication of digital technologies necessitate their incorporation into forestry operations as a strategic necessity for ensuring long-term sustainability, climate resilience, and ecosystem integrity (Kumar *et al.*, 2024). This review examines the diverse functions of ICT in forest management, emphasizing its applications in monitoring, carbon accounting, supply chain optimization, biodiversity conservation, and participatory governance, while also considering the challenges and opportunities associated with these innovations.

Information and Communication Technology Applications in Forest Management

Information and Communication Technologies have transformed forest management through real-time data collecting and analysis, automation, and enhanced operational efficiency. Utilizing Geographic Information Systems (GIS), forest managers can strategize harvesting routes to reduce environmental impact while sustaining productivity (Sonti, 2015) [24]. Decision support systems utilizing precise data sets can facilitate forest growth modeling, yield forecasting, and site appropriateness assessment (Yadav *et al.*, 2024) [28]. Moreover, ICT applications in the forestry sector reduce manual labour by digitizing routine processes, thus enhancing productivity and lowering costs (Figure 1).

Optimization of Supply Chains and Transformation of Industries

The use of ICT in the forestry sector, particularly in the timber supply chain, has resulted in substantial transformation. The forest sector, being highly dependent on environmental sustainability, benefits immensely from ICT-enabled tools that enhance efficiency, reduce operational costs, and promote transparency (Abdulkadir *et al.*, 2024) [1]. Digital platforms enable traceability systems to monitor timber from origin to market, guaranteeing legal adherence and ethical procurement (Kaulen *et al.*, 2023) [9]. These improvements have enhanced the competitiveness of forest-based products while strengthening sustainable forest management practices.

ICT for Forest Carbon Management and Climate Action

Technological interventions are becoming essential in tackling climate change issues associated with forest ecosystems. One major application is forest carbon management. Precise assessment of forest cover, carbon reserves, and greenhouse gas emissions resulting from deforestation necessitates sophisticated technology such as satellite images and hyperspectral imaging (Huang *et al.*, 2022) [8]. Machine learning (ML) and data analytics facilitate predictive modeling that guides forest conservation measures (Ali *et al.*, 2025) [2]. These tools help quantify carbon sequestration potential, detect degradation patterns, and support carbon market participation, making them indispensable in climate mitigation efforts.

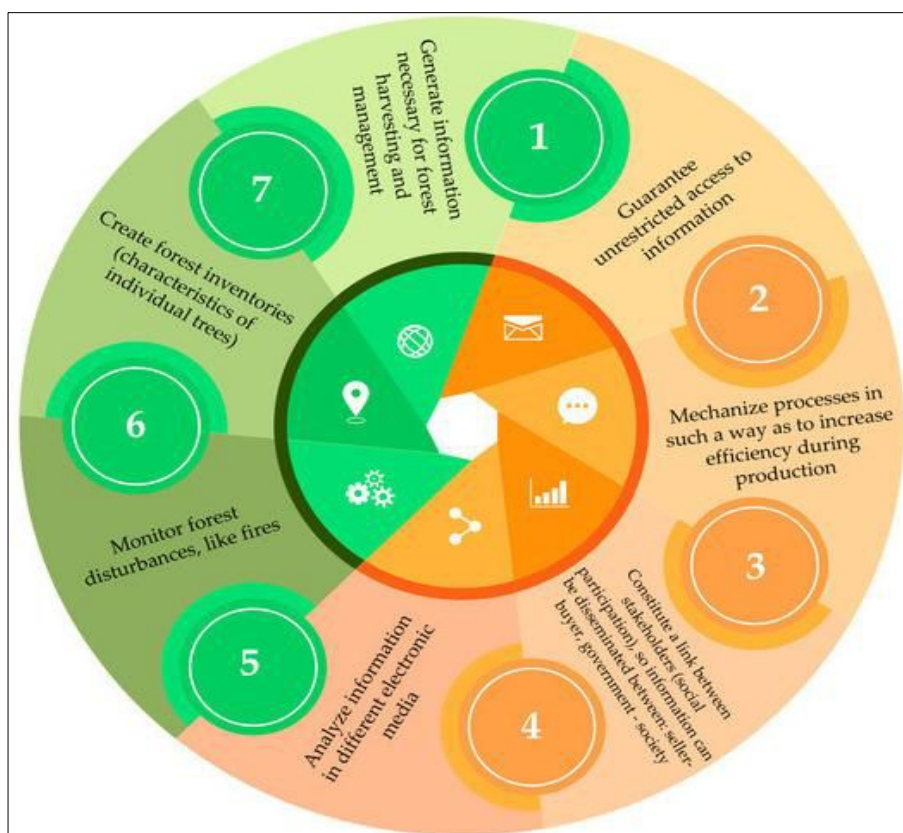


Fig 1: Applications of Information and Communication Technologies in Forest Management (Source: Gavilanes Montoya *et al.*, 2023) [6].

Surveillance and Monitoring Systems

Surveillance and monitoring are critical aspects of ICT application in forestry, especially in regions facing threats from forest fires, illegal logging, and human-wildlife

conflict. Technologies such as drones, thermal sensors, AI-enabled cameras, and geofencing provide real-time updates on forest conditions (Rajagopal *et al.*, 2026) [20]. For instance, distributed antenna systems (DAS) paired with

thermal sensors can detect early signs of forest fires by monitoring temperature fluctuations (Vieira *et al.*, 2025) [27]. Cameras integrated with machine vision (MV) and AI allow for instant identification of threats like unauthorized entry or illicit tree felling (Kumari *et al.*, 2026) [13]. These tools augment manual patrolling, providing forest personnel with actionable intelligence for timely interventions.

Managing Forest Fires and Encroachment

India, with about 11% of its forest area categorized as highly fire-prone, faces severe challenges in forest fire management. ICT tools can serve as an early warning system through real-time video analysis and temperature sensing (Figure 2). Since most forest fires in India are anthropogenic, surveillance technologies can be strategically deployed to prevent ignition or suppress fires early (Bisht and Singh, 2025) [5]. Similarly, illegal felling and encroachment pose significant risks to protected areas. Regular drone surveillance, perimeter monitoring, and AI-

based alert systems can effectively reduce such activities by improving response times and strengthening legal enforcement (Okolo *et al.*, 2022) [18].

Mitigating Human-Wildlife Conflict

Human-wildlife conflict is another domain in which ICT is essential. Fauna frequently venture from woodlands into urban areas in pursuit of sustenance, resulting in conflict and ecological disturbance. Information and Communication Technology technologies such as GPS and RFID tags, in conjunction with geofencing and AI-enabled cameras, facilitate the monitoring of animal movements and provide real-time alerts to officials (Gupta, 2024) [7]. These non-invasive techniques facilitate coexistence by minimizing unexpected interactions and harm. Technical fabrics that provide protection to humans during animal treatments illustrate the transdisciplinary characteristics of ICT solutions in forest management.

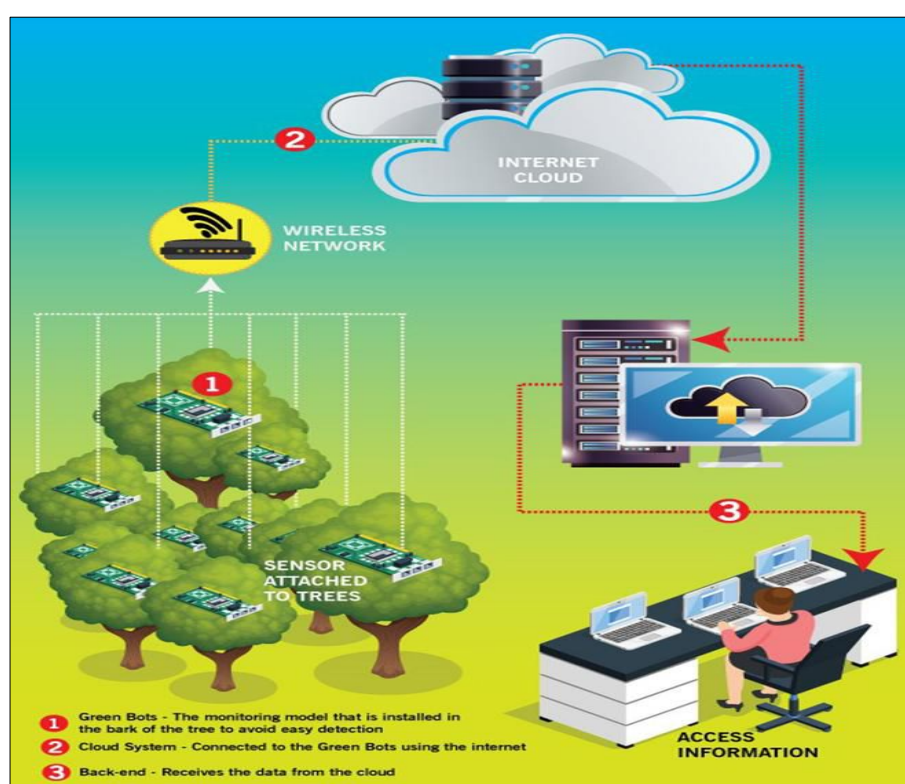


Fig 2: IoT-Based Tree Health Monitoring System Using Wireless Sensor Network and Cloud Computing (Source: Shah, 2020) [21].

Digital Notifications and Targeted Interventions

Digital alarm systems are crucial for enhancing situational awareness among forestry personnel. These systems can relay information about fires, invasions, or wildlife migration across forest areas in real time, facilitating a swift and coordinated reaction. Moreover, ICT can be customized to tackle location-specific challenges. In locations impacted by Invasive Alien Plant Species (IAPS) such as *Lantana camara* or excessive pine needles, technology can facilitate the conversion of this biomass into useable energy, thus mitigating fuel for forest fires and advancing bioeconomy objectives (Kaushik and Arora, 2024) [10].

Geospatial Technology in Forestry Resource Management

Geospatial technologies, especially Geographic Information Systems (GIS) and Remote Sensing (RS), are essential for

contemporary forest resource planning. They enable forest managers to examine spatial patterns and temporal variations across extensive and remote terrains (Sonti 2015) [24]. Satellite imaging facilitates the categorization of land use and land cover, aiding in the identification of forest degradation, deforestation hotspots, and afforestation areas (Bera *et al.*, 2021) [3]. GIS platforms provide overlay assessments of topography, soil composition, hydrology, and vegetation to identify the most appropriate locations for plantation or conservation initiatives (Pandey *et al.*, 2011) [19]. Multi-temporal satellite data facilitates trend analysis and the monitoring of forest encroachment, unlawful land conversion, and the proliferation of invasive species (Mao *et al.*, 2020) [16]. Geospatial technologies facilitate ecosystem-based forest management solutions that reconcile conservation and development objectives by integrating biophysical data with socio-economic variables.

Monitoring Forest Biodiversity Utilizing Information and Communication Technology

Biodiversity conservation is fundamental to sustainable forestry, and information and communication technologies offer unique solutions for species monitoring and habitat preservation (Ullah *et al.*, 2025) ^[26]. Technologies including video traps, acoustic sensors, and drone-mounted sensors facilitate non-invasive wildlife observation. These instruments are especially effective in observing elusive or nocturnal species, which are ordinarily challenging to investigate through conventional fieldwork. Acoustic monitoring systems, augmented by AI, can discern certain animal vocalizations (e.g., birds, amphibians, or monkeys), which are subsequently employed to assess population densities and track alterations in biodiversity (Sharma *et al.*, 2023) ^[22]. Remote sensing, especially high-resolution and hyperspectral photography, facilitates habitat classification and monitoring, enabling the detection of alterations resulting from logging, agriculture, or climate stresses.

The Function of Information and Communication Technology in Participatory Forest Monitoring

Participatory forest monitoring entails the active involvement of local communities in data collecting, significantly augmented by mobile-based ICT solutions. Open-source applications such as Open Foris, Collect Earth, and GeoODK enable community members to map deforestation, evaluate forest health, or report unlawful actions utilizing cellphones or tablets (Bhunja *et al.*, 2020) ^[4]. The democratization of data gathering enhances spatial coverage, timeliness, and reliability in forest monitoring. Moreover, community-based monitoring enhances forest governance by promoting transparency and accountability. ICT tools facilitate real-time data exchange with governmental bodies, researchers, and conservation NGOs, promoting expedited responses and inclusive decision-making (Ncube and Ngulube, 2024) ^[17]. These platforms frequently incorporate offline capabilities, essential in isolated forest areas with inadequate internet access.

Table 1: Benefits and Challenges of ICT in Sustainable Forest Management

Aspect	Benefits	Challenges
Monitoring & Surveillance	Real-time alerts, automated patrolling	Connectivity issues in remote areas
Data Collection	Accurate, time-series datasets	Requires technical expertise
Forest Carbon Estimation	Supports REDD+, climate reporting	Calibration of models, validation required
Participatory Monitoring	Empowers communities, improves coverage	Digital literacy among local stakeholders
Policy & Governance	Enhances transparency, faster clearances	Integration with existing systems and resistance to change

Interface of Policy and Governance with Information and Communication Technology

Information and Communication Technologies (ICTs) significantly enhance forest governance by digitizing administrative operations and fostering increased public interaction. E-governance platforms can optimize forest clearance processes, guarantee adherence to environmental standards, and enhance inter-agency collaboration. For example, platforms such as India's PARIVESH or CAMPA websites consolidate data on forest land diversion, compensatory afforestation, and environmental approvals in real-time. Furthermore, ICT facilitates the incorporation of policy feedback systems. Platforms such as MyGov or environmental grievance redressal platforms enable users to report unlawful logging or forest fires, supplying actionable intelligence to forestry agencies (Kumar *et al.*, 2026) ^[13]. These interfaces enhance environmental democracy by rendering forest governance more inclusive, data-informed, and responsive.

Challenges and the Path Ahead

Notwithstanding the benefits, the deployment of ICT in forestry encounters obstacles like infrastructure expenses, insufficient technical proficiency, and data security issues (Table 1). An integrated strategy that encompasses policy support, capacity enhancement, and investment in innovation is necessary. Integrating local and indigenous knowledge with digital systems can improve forest management. Emerging technologies such as artificial intelligence, remote sensing, and blockchain offer potential for advancements in sustainable forestry.

Conclusion

Information and Communication Technologies have emerged as potent instruments in transforming the forestry business. These technologies facilitate comprehensive forest

management by providing forest monitoring and planning, carbon accounting, and animal protection. Their contribution to advancing sustainability, fostering accountability, and facilitating climate action renders them essential for attaining long-term conservation objectives. Although not a singular answer, ICT serves as a vital facilitator that enhances policy and community-driven initiatives in forest conservation.

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