Leveraging IoT-Enabled Biodiversity Monitoring for Sustainable Livelihoods: An Assessment of Rural Community Adaptation Strategies

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ABSTRACT

Rural communities in Turkana County, Kenya, continue to experience the adverse impacts of terrestrial biodiversity variability, resulting in loss of livestock, reduced productivity, and deteriorating livelihoods. In the digital age, Internet of Things (IoT) technologies present promising opportunities for real-time biodiversity monitoring, data sharing, and informed community-based decision-making. The study leveraged IoT-enabled biodiversity monitoring to explore how localized, real-time terrestrial biodiversity data can be communicated and utilized by rural pastoralists to enhance livestock productivity and promote sustainable livelihoods. The study assessed the extent to which rural households have access to IoT technologies, examined how communities utilize IoT-based terrestrial biodiversity data to sustain their livelihoods, and evaluated the effects of employing such data on the adoption of adaptive livelihood strategies. The research was guided by the Innovation Diffusion and Technology Adoption theories to link user adoption, technological practice, and biodiversity data utilization. A mixed-methods approach was employed, integrating quantitative and qualitative data from a sample of 384 households drawn from a target population of 164,519. Data collection tools included questionnaires, focus group discussions, and key informant interviews, while inferential statistics and path analysis were used to determine relationships and variable contributions to leveraging IoT enabled biodiversity monitoring for sustainable livelihoods. The findings revealed that smartphones and radios are the most cost-effective and practical IoT tools for pastoral communities to access real-time biodiversity data and pastoral advisory information. Evidence indicated that IoT-based biodiversity monitoring enhances adaptive capacity, strengthens livelihood assets, and improves long-term sustainability. The study established a framework for developing a request–response IoT- enabled biodiversity monitoring tool illustrating the relationship between biodiversity data utilization and livelihood outcomes. This research adds to the growing discourse on digital sustainability and offers policy recommendations for integrating IoT-enabled biodiversity systems into Kenya’s rural development and climate adaptation frameworks.

Keywords: Internet of Things (IoT), Terrestrial Biodiversity, Livelihood Strategies, Sustainable Development, Pastoral Communities, Digital Sustainability.

INTRODUCTION

Biodiversity forms the foundation of human existence, providing essential ecosystem services that support productivity, health, and the very survival of life on Earth. Despite a growing global consensus about its importance, conservation actions remain insufficient to reverse or even slow biodiversity loss (Díaz et al., 2020; IPBES, 2019). Terrestrial biodiversity comprising forests, grasslands, deserts, and other land-based ecosystems plays a vital role in maintaining ecological balance, supporting food production, regulating

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climate, and sustaining livelihoods. It encompasses an intricate network of species, habitats, and genetic variations that underpin both environmental stability and economic development.

Globally, Earth's ecosystems host about 8.7 million known species (Mora et al., 2011). These living organisms interact in complex ecological systems that provide humans with food, water, medicine, shelter, and other lifesustaining resources. However, human activities, including land degradation, deforestation, pollution, and climate change, continue to threaten these systems, diminishing their ability to sustain life. As Soberson et al. (2004) observed, biodiversity data initiatives aim to enable knowledge synthesis and data exchange across regions to foster conservation at global and local levels.

Africa remains one of the most biologically diverse regions in the world, home to an estimated 50,000–73,000 plant species, 1,100 mammals, 2,500 birds, and over 5,000 freshwater fish species (Cormier-Salem et al., 2018; O'Connell et al., 2019). Eight of the world's 36 recognized biodiversity hotspots are found on the continent (Archer et al., 2018). Yet, the accelerating loss of biodiversity continues to threaten Africa's ecosystems and the millions of people who rely on them for survival.

Biodiversity in Kenya and Turkana County

Kenya is classified among the world's ten mega-biodiverse nations, hosting over 35,000 species of flora and fauna distributed across diverse ecosystems—mountains, forests, rangelands, arid lands, and coastal areas. However, its biodiversity faces increasing threats from habitat loss, unsustainable resource exploitation, and climate variability (Catherine, 2023). These challenges are particularly severe in Turkana County, a semi-arid region in northwestern Kenya. The county faces recurrent droughts, desertification, land degradation, and biodiversity loss, which have significantly undermined local livelihoods and food security (Ithinji, 2020; Turkana County CIDP, 2018–2022).

More than 90% of Turkana's population lives in rural areas, depending on pastoralism and small-scale agriculture. Climate shocks and environmental degradation have caused recurring livestock losses, undermining household incomes and resilience. Biodiversity loss directly translates to livelihood insecurity for these communities, making it critical to enhance adaptive capacity through data-driven decision-making. The Turkana County Environmental Action Plan (2020) recognizes biodiversity as a cornerstone of sustainable livelihoods providing forage, water regulation, soil fertility, and cultural identity. However, the lack of reliable, real-time biodiversity information constrains effective adaptation and ecosystem management.

IoT and Biodiversity Monitoring

In recent years, digital innovations particularly the Internet of Things (IoT) have shown great potential for environmental monitoring and sustainable development. IoT refers to interconnected systems of sensors, devices, and networks that collect, process, and share data in real time (Smith, 2012; Akhil, 2019). In biodiversity management, IoT technologies can monitor species distribution, track ecosystem health, and relay environmental data to local communities, policymakers, and researchers (Chiara, 2021).

IoT-enabled sensors and mobile applications allow for remote measurement of temperature, humidity, soil moisture, and vegetation cover key indicators of terrestrial ecosystem changes. These data streams can be processed through cloud computing and artificial intelligence systems to generate insights that inform local adaptation strategies. For example, IoT tools have been used to monitor animal migration, detect habitat changes, and forecast drought patterns. This has proven particularly valuable for rural communities that depend on natural resources for their survival. Despite the promise of IoT, challenges persist in data interoperability, access, and utilization. Many biodiversity datasets remain scattered, incomplete, or inaccessible to rural users. Differences in data standards, lack of technical capacity, and poor infrastructure further complicate information sharing (Costello, 2009; Turner et al., 2015). Therefore, developing a localized architectural model that connects IoTenabled biodiversity data with rural livelihood decision-making is both timely and necessary.

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The Role of IoT in Sustainable Livelihoods

IoT technologies align closely with the Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action) and SDG 15 (Life on Land), by promoting data-driven solutions for environmental resilience and biodiversity conservation (Wu et al., 2018). Studies in Africa (Adera et al., 2014; Ospina & Heeks, 2012) show that IoT contributes to poverty reduction and sustainable resource management by facilitating timely information flow and supporting adaptive decision-making.

For pastoral communities, IoT devices such as smartphones and radios serve as accessible platforms for receiving localized environmental updates and biodiversity alerts. These tools empower users to make informed decisions on grazing, migration, and livestock management, ultimately strengthening their livelihood systems. As Aggrey (2021) notes, mobile phones now serve as powerful sensors and gateways that bridge the gap between environmental data and local users. However, while IoT technologies can revolutionize biodiversity monitoring, their integration into rural livelihoods requires consideration of local contexts—social norms, literacy levels, gender dynamics, and access to infrastructure. In Turkana, patriarchal social systems and limited digital literacy present additional barriers to technology adoption (Abdimajid et al., 2019). Hence, IoT solutions must be inclusive, culturally appropriate, and user-centered.

The Need for IoT-Enabled Biodiversity Data Systems

The ability to access and utilize terrestrial biodiversity data determines how well communities can adapt to environmental changes. Although multiple organizations collect biodiversity data, most rural populations lack awareness or technical capacity to interpret and apply this information effectively. IoT offers a way to bridge this gap by automating data collection, processing, and dissemination through affordable devices and networks. Nevertheless, challenges remain. Biodiversity data are often fragmented across institutions, stored in incompatible formats, or inadequately standardized. Security and privacy concerns also arise due to sensitive information about species locations and resource availability. Furthermore, most existing data systems lack scalability and user-friendly interfaces for non-specialist users. These challenges underscore the need for an integrated IoT-based architectural model that ensures accessibility, accuracy, interoperability, and participatory data use.

Biodiversity Loss, Livelihoods, and the Digital Divide

The loss of biodiversity undermines food security, economic stability, and community resilience. For rural pastoralists in Turkana, this translates into livestock deaths, resource conflicts, and forced migration. The Kenya National Bureau of Statistics (2021) reports that 79.4% of Turkana residents live in poverty, with limited access to technological tools that could aid adaptation. As biodiversity continues to decline, the absence of timely, relevant data further limits local response capacity. IoT-driven biodiversity systems can counter this trend by transforming data into actionable knowledge. Through participatory monitoring, rural communities can track environmental changes, anticipate hazards, and implement context-specific adaptation measures. Such systems not only enhance livelihoods but also contribute to broader environmental governance and policy implementation.

Statement of the Problem

Despite the critical role of biodiversity data in environmental management and livelihood resilience, rural communities in Turkana face significant challenges in accessing, processing, and applying this information. Current biodiversity data systems are fragmented, poorly integrated, and rarely aligned with the needs of end users. As a result, pastoralists continue to experience resource losses and livelihood shocks that could otherwise be mitigated through timely, data-informed decisions. Although IoT technologies have advanced globally, their application in biodiversity management and rural development in Kenya remains limited. Many IoT devices lack interfaces tailored to low-literacy populations, while inadequate infrastructure and

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connectivity further constrain usage. There is a growing gap between IoT data generation and community-level utilization, resulting in underuse of valuable environmental data.

Through this inquiry, the study bridges technology, ecology, and socio-economic dimensions to create a framework for digital inclusion and environmental resilience. This research contributes to the growing body of knowledge on digital sustainability and the intersection between ICT and environmental management. Practically, the findings will: For policymakers, the study offers guidance on designing inclusive digital ecosystems that empower local communities. For researchers, it presents a conceptual and methodological contribution to the integration of IoT in biodiversity science. Ultimately, this research demonstrates how IoTenabled biodiversity monitoring can become a tool for adaptive livelihoods, resilience building, and sustainable rural transformation.

This study responds to this gap by developing and validating an IoT-enabled biodiversity monitoring tool for processing and sharing terrestrial biodiversity data. The model aims to support real-time decision-making, enhance community adaptation, and promote sustainable livelihoods in Turkana County.

LITERATURE REVIEW

Rural livelihoods in developing regions are under increasing pressure from environmental variability, declining biodiversity, and the impacts of climate change. In ecosystems such as Turkana County, Kenya, the deterioration of terrestrial biodiversity ranging from pasture cover loss to water scarcity directly undermines the sustainability of pastoral livelihoods. As communities seek adaptive strategies, digital technologies, particularly the Internet of Things (IoT), are emerging as critical enablers for real-time monitoring, data-driven decision-making, and sustainable livelihood transformation. IoT technologies, when integrated with biodiversity monitoring, provide unprecedented opportunities for capturing, processing, and disseminating environmental data to inform local livelihood strategies.

A livelihood comprises the capabilities, assets (both tangible and intangible), and activities required for a means of living (Chambers & Conway, 1992). Livelihood strategies refer to the range and combination of activities and choices people make to achieve their livelihood goals, including production activities, investment decisions, and social support mechanisms. A livelihood is considered **sustainable** when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for future generations (DFID, 1999).

Rural households often depend heavily on natural resources for their livelihoods grazing lands, water sources, and biodiversity. As such, environmental changes directly influence their well-being. The Sustainable Livelihood Framework (SLF) identifies five key livelihood assets natural, human, social, physical, and financial capital that interact with institutional and policy contexts to shape livelihood outcomes. Integrating IoT-based biodiversity monitoring into this framework offers a technological mechanism for enhancing access to information about these assets, thereby enabling informed livelihood decisions and promoting resilience.

The Internet of Things (IoT) refers to interconnected systems of devices that collect, process, and exchange data over networks with minimal human intervention. In biodiversity monitoring, IoT encompasses remote sensors, unmanned aerial vehicles (drones), GPS trackers, and edge computing systems that record environmental variables such as soil moisture, vegetation indices, temperature, and animal movements. According to Ahmed et al. (2020), IoT technologies enhance the spatial and temporal resolution of ecological data, providing realtime insights into ecosystem dynamics. In terrestrial biodiversity contexts, IoT-enabled sensors can monitor grazing patterns, vegetation regeneration, and wildlife distribution, offering critical feedback for resource management. The continuous flow of such data supports evidence-based decisions among rural communities, conservation agencies, and policymakers.

Moreover, IoT-based biodiversity data contribute to the digitization of environmental knowledge systems. By enabling near real-time communication between the environment and decision-makers, IoT transforms static ecological observations into actionable intelligence. This is particularly relevant for arid and semi-arid lands (ASALs) like Turkana, where environmental variability is high, and livelihood security depends on adaptive responses. The integration of IoT systems into rural development aligns with theories of technological diffusion and adoption. Rogers' (2003) Diffusion of Innovation Theory provides a useful lens for understanding how individuals and communities adopt new technologies. Adoption is influenced by factors such as perceived usefulness, ease of use, compatibility with existing practices, and social influence. In rural contexts, these determinants interact with infrastructural, economic, and cultural variables that either facilitate or hinder technology uptake.

IoT technologies, when introduced in pastoral or agro-ecological settings, have shown potential to transform livelihood strategies. For instance, studies by Misra et al. (2021) demonstrate that IoT-based weather and soil sensors enhance crop and livestock productivity by guiding appropriate timing for planting, grazing, and migration. Similarly, in East African pastoral systems, IoT-based mobile alerts have been used to disseminate rangeland conditions and drought forecasts, helping herders make proactive decisions (Kuria et al., 2019). Through access to accurate terrestrial biodiversity data, rural communities can diversify their livelihood portfolios, reduce risks, and strengthen resilience. Information on forage availability, animal disease patterns, or water quality can inform herding routes, market engagements, and resource-sharing arrangements. Hence, IoTbased biodiversity data act as a catalyst for innovation in local livelihood practices.

Empirical studies globally demonstrate that IoT applications positively affect livelihood strategies by improving access to information, enhancing efficiency, and reducing uncertainty. In India, Patel et al. (2020) reported that IoT-enabled agricultural advisory systems improved farmers' productivity and income by providing tailored, localized data. In Ethiopia, Mengistu et al. (2022) found that digital climate information services helped smallholders adopt adaptive practices, including water harvesting and crop diversification. In the African context, rural adoption of IoT has often been mediated through mobile devices, particularly smartphones and radios, which act as information gateways. A study by Duncombe (2012) highlighted that mobile-based IoT applications facilitate communication between rural users and service providers, thereby improving market access and resource management. Likewise, Mwangi et al. (2021) observed that IoT-supported environmental monitoring improved the resilience of pastoral systems in northern Kenya by informing herd management decisions.

However, the extent of impact depends on accessibility, digital literacy, and institutional support. For example, Okello et al. (2023) found that while IoT systems improved environmental data accuracy in rural Uganda, their uptake among smallholders remained low due to high costs and lack of technical skills. Such findings emphasize the need for context-specific approaches that consider social, cultural, and economic realities.

Theoretical Foundations

Two theoretical perspectives provide a foundation for understanding how IoT-based terrestrial biodiversity data influence livelihood strategy adoption. The Diffusion of Innovation Theory (Rogers, 2003) explains how innovations spread through social systems over time. The rate and extent of IoT adoption depend on perceived relative advantage, compatibility with local practices, complexity, trialability, and observability. In pastoral contexts, IoT technologies must demonstrate tangible benefits such as improved herd health or reduced losses to motivate adoption. While the Technology Acceptance Model (Davis, 1989) framework posits that perceived usefulness and perceived ease of use determine users' attitudes toward technology. In biodiversity monitoring, these perceptions are shaped by users' ability to interpret data outputs and integrate them into livelihood decisions. Hence, simplified data visualization and local language interfaces are crucial. The intersection of these theories provides a conceptual basis for assessing the behavioral and contextual factors influencing how IoTenabled biodiversity data shape livelihood strategies.

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IoT-Based Terrestrial Biodiversity Data and Sustainable Livelihood Assets

Natural Capital: IoT sensors enable continuous monitoring of rangeland conditions, water resources, and vegetation cover, thereby supporting informed natural resource management. By preventing overgrazing and facilitating rotational grazing, IoT contributes to sustaining biodiversity and ecological balance (Zhang et al., 2018). Human Capital: Access to real-time environmental data enhances local knowledge and decision-making capacity. Training communities to interpret IoT data strengthens adaptive skills, contributing to human capital development. Furthermore, local youth can engage in device maintenance, creating new employment opportunities.

Social Capital: IoT platforms often foster community networks for data sharing, cooperation, and resource governance. Collective access to biodiversity data enhances social cohesion, as communities coordinate grazing, water use, and conflict resolution based on shared information. Physical Capital: IoT devices themselves— sensors, communication networks, and data centers constitute new physical infrastructure supporting rural development. Integration with existing systems, such as local radio or telecommunication networks, expands technological reach and utility. Financial Capital: Improved resource management and reduced losses from environmental shocks translate into better financial outcomes. Additionally, data-driven resource use can attract investment in eco-enterprises, conservation initiatives, and sustainable land-use practices.

Challenges in Employing IoT-Based Biodiversity Data

Despite its transformative potential, several challenges constrain effective use of IoT-based terrestrial biodiversity data in rural contexts. These include:

1. Many rural areas lack reliable power, internet, and data storage systems necessary for IoT functionality.
2. IoT sensors and communication systems are often expensive for small-scale pastoralists or community based organizations.
3. A lack of technical knowledge impedes local users from interpreting IoT data effectively.
4. Traditional norms and weak institutional frameworks sometimes resist technological change or fail to support data-driven decision-making.
5. Questions about who owns and controls biodiversity data remain unresolved in many rural projects.

Addressing these constraints requires participatory design, capacity building, and policy alignment to ensure inclusive and ethical use of IoT technologies.

Across the reviewed literature, a clear pattern emerges: IoT-based biodiversity monitoring enhances the capacity of rural communities to make informed livelihood choices, manage resources sustainably, and build resilience against ecological shocks. However, the magnitude of these effects is mediated by contextual variables such as education level, infrastructure access, and institutional support. Empirical evidence from Africa and Asia consistently indicates that communities using IoT-enabled data demonstrate improved environmental awareness, resource utilization efficiency, and income diversification. The most significant benefits occur when IoT systems are integrated with local knowledge systems and social networks, ensuring cultural compatibility and local ownership. Moreover, studies underscore the importance of feedback loops where communities not only receive data but also contribute to data generation and interpretation. This participatory model enhances trust and ensures that IoT technologies support rather than supplant indigenous knowledge practices.

Despite growing literature on IoT applications in agriculture and environment, few studies have explicitly examined the link between IoT-based terrestrial biodiversity data and livelihood strategy adoption among pastoral communities. Existing research often focuses on technological feasibility rather than socio-economic outcomes. Additionally, limited empirical evidence exists from arid and semi-arid regions such as Turkana, where biodiversity data can directly influence survival strategies. By integrating innovation diffusion theory

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with the sustainable livelihood framework, the study contributes to theoretical and practical understanding of how digital transformation can promote resilience and sustainability in marginalized rural settings.

The literature affirms that IoT-enabled biodiversity monitoring holds transformative potential for rural sustainability. By linking ecological intelligence to livelihood decisions, IoT technologies empower communities to adapt to environmental change, diversify income sources, and strengthen resilience. However, realizing these benefits requires supportive infrastructure, digital literacy, and participatory governance mechanisms that ensure inclusivity and ownership. This review thus establishes a strong conceptual foundation for examining the effects of employing IoT-based terrestrial biodiversity data on the adoption of livelihood strategies, with implications for policy, research, and practice in sustainable rural development.

RESEARCH METHODOLOGY

Research Philosophical Paradigm

The study adopted a pragmatist philosophical paradigm**,** which emphasizes the use of multiple methods to understand complex social and technological phenomena. Pragmatism allows for flexibility in combining quantitative and qualitative approaches, thereby accommodating both objective and subjective realities (Creswell & Plano Clark, 2011). The choice of pragmatism was influenced by the interdisciplinary nature of this research, which intersects environmental science, information technology, and rural livelihoods. It enabled the study to measure quantifiable relationships such as the effect of IoT access on livelihood outcomes while also interpreting community experiences, perceptions, and adaptive behaviors. This philosophical stance provided a coherent basis for integrating IoT system modeling with social inquiry, ensuring that the research captured both technical efficiency and human adaptability.

Research Design

A case-study design was employed to investigate IoT-based biodiversity monitoring within its real-world context (Yin, 1994). This design provided a comprehensive view of how IoT technologies are applied in rural Turkana to collect, share, and utilize biodiversity data for livelihood improvement. The study used a mixed-methods approach through a concurrent triangulation strategy, enabling simultaneous collection of quantitative and qualitative data. Quantitative methods established measurable relationships between IoT use and livelihood outcomes, while qualitative methods provided depth, context, and explanation of observed trends (Creswell, 2014). Triangulation ensured validity, reduced methodological bias, and allowed the findings from one dataset to reinforce and clarify the other. This approach was suitable because the research sought not only to quantify relationships but also to understand the contextual realities influencing IoT adoption and livelihood transformation in a pastoral setting.

Study Area

The study was conducted in Turkana County**,** located in north-western Kenya, covering approximately 77,000 km². The county is predominantly arid and semi-arid, characterized by recurrent droughts, erratic rainfall, and frequent biodiversity variability that directly influence pastoral livelihoods. Turkana has an estimated population of 926,976 (KNBS, 2019), most of whom depend on livestock rearing, small-scale farming, and natural resource use. The region's fragile ecosystems, limited access to digital infrastructure, and exposure to climate-related shocks make it an ideal environment for exploring how IoT-enabled biodiversity data can support adaptive livelihood strategies and environmental sustainability.

Target Population

The target population comprised 164,519 rural households distributed across the seven sub-counties of Turkana: Central, West, East, North, South, Loima, and Kibish. These households were the unit of analysis

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because they represent decision-making entities responsible for livestock management, farming, and resource use. In addition to households, the study engaged key informants including officials from the Turkana County Government (environment, ICT, and livestock departments), staff from biodiversity and conservation agencies, representatives from NGOs, and IoT technology practitioners. This multi-actor perspective ensured comprehensive insights into both user experiences and institutional dynamics.

Sampling Procedures and Sample Size

The study used a multistage sampling strategy that integrated stratified**,** systematic random**,** and purposive techniques to ensure representativeness and inclusivity.

1. Stratification: Turkana was stratified according to its ecological and livelihood zones (Eco-Climatic Zones IV–VI).

2. Purposive Selection**:** Fourteen wards were purposively chosen based on biodiversity significance, exposure to climate risks, and presence of IoT or ICT initiatives. This selection was done in collaboration with institutions such as the NDMA, FAO, and the Catholic Diocese of Lodwar.
3. Random Sampling: Within each ward, households were randomly selected to participate in the survey.

Using the Krejcie and Morgan (1970) formula, a representative sample of 384 households was derived from the 164,519 households. The sample was proportionately distributed among sub-counties based on population size to ensure balanced representation.

Additionally, 24 key informants and 30 technical experts (ICT and biodiversity specialists) were included for qualitative interviews and model validation, respectively. Two focus group discussions (FGDs) were conducted, each comprising eight participants balanced by gender, to enhance contextual understanding and participatory validation.

Data Collection Methods

The study used multiple data collection tools to ensure comprehensive and triangulated evidence.

1. Questionnaires: Structured questionnaires were administered to 384 households to collect data on demographics, IoT device access, biodiversity data usage, and livelihood practices. The questionnaire included Likert-scale items measuring perceptions and impacts of IoT adoption.
2. Key Informant Interviews (KIIs): Semi-structured interviews were conducted with biodiversity officers, ICT experts, and policy implementers to gather expert insights on IoT deployment and ecosystem management.
3. Focus Group Discussions (FGDs): FGDs were held to capture community perspectives on IoT adoption, local knowledge integration, and challenges in accessing biodiversity information.

Data Analysis

The data analysis process adhered to the mixed-methods concurrent triangulation strategy, ensuring both quantitative and qualitative robustness.

Quantitative Analysis

Quantitative data were coded and analyzed using SPSS Version 28**.** Descriptive statistics (frequencies, percentages, means, and standard deviations) summarized respondents' characteristics and IoT usage patterns. Inferential statistics including correlation and multiple regression were used to test hypotheses on the relationship between IoT access, biodiversity data utilization, and livelihood outcomes.

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Qualitative Analysis

Qualitative data from FGDs and KIIs were analyzed thematically following Braun and Clarke's (2006) six-step approach: familiarization, coding, theme identification, review, definition, and reporting. Emerging themes such as "information access barriers," "trust in IoT data," and "community adaptation practices" were identified. NVivo software was used for coding and organization of qualitative narratives. Integration of quantitative and qualitative results was achieved during interpretation, ensuring a holistic understanding of IoT's role in shaping livelihood strategies.

Validity and Reliability of Research Instruments

Validity

Instrument validity was achieved through multiple processes:

1. Face and Content Validity: Tools were reviewed by supervisors and domain experts in IoT and biodiversity management to ensure comprehensive coverage.
2. Construct Validity: Items were aligned with the theoretical constructs derived from Innovation Diffusion Theory and the Sustainable Livelihood Framework.
3. Pilot Testing: A pilot study in one ward of Turkana refined question clarity, structure, and logical flow.

Reliability

Reliability testing ensured consistency and dependability of measurement. Using Cronbach's Alpha**,** a coefficient of 0.816 was obtained, exceeding the 0.70 threshold recommended by George and Mallery (2003). The split-half method further confirmed internal consistency, demonstrating that the instruments reliably measured the intended constructs.

Ethical Considerations

Ethical approval was obtained from the Kibabii University Research Ethics Committee and a research permit issued by the National Commission for Science, Technology and Innovation (NACOSTI)**.** Prior to data collection, participants received information sheets explaining the study's objectives, potential benefits, and their rights. Informed consent was obtained, and respondents were assured of anonymity, confidentiality, and voluntary participation. Data were securely stored and used solely for academic purposes. Special care was taken to respect cultural norms within Turkana communities, ensuring inclusivity of marginalized groups such as women and youth in interviews and focus groups.

FINDINGS

This section presents the findings from the study on the influence of IoT-enabled terrestrial biodiversity data (TBD) on livelihood strategies among rural communities in Turkana County, Kenya. The results are based on both quantitative and qualitative data collected through questionnaires, focus group discussions (FGDs), and key informant interviews (KIIs). Findings are organized around the study objectives and supported by descriptive tables with concise interpretations.

Distribution of Respondents per Sub-County and Eco-Climatic Zones

Distribution by sub-county was essential in ensuring representation across Turkana's diverse eco-climatic zones, providing localized insights for sustainable livelihood analysis.

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Table 1: Distribution of Respondents per Sub-County

Sub-County	**Frequency**	**Frequency (%)**
Turkana West	99	28.4
Turkana Central	89	25.6
Turkana South	44	12.6
Turkana East	36	10.3
Loima	42	12.1
Turkana North	27	7.8
Kibish	11	3.2
Total	**348**	**100**

Table 2: Distribution of Respondents per Eco-Climatic Zones

Eco-Climatic Zone (EZ)	**Frequency**	**Frequency (%)**
EZ VI	169	48.6
EZ V	99	28.5
EZ IV	80	22.9
Total	**348**	**100**

Respondents were well distributed across sub-counties and eco-climatic zones, ensuring a balanced representation. Turkana West and Central recorded the highest participation, reflecting their population densities and accessibility. This distribution enhanced the reliability of the study results.

Demographic Characteristics of Respondents

Gender of Respondents

Table 3: Respondents' Gender

Indicator Variable	**Category**	**Frequency**	**Response (%)**
Gender	Male	202	58.05
	Female	146	41.95
Total		**348**	**100**

Males constituted 58.05% of respondents, reflecting their dominance in decision-making and livestock ownership. However, the inclusion of 41.95% female respondents ensured gender balance, highlighting both genders' perspectives on IoT use for biodiversity and livelihoods.

Age of Respondents

Table 4: Age of Respondents

Category	**Frequency**	**Frequency (%)**
18–30 years	65	18.68

31–45 years	178	51.15
46–60 years	60	17.24
Above 60 years	45	12.93
Total	**348**	**100**

Respondents aged 31–45 years formed the majority (51.15%), representing the most economically active group. This age group was more receptive to new technologies, positively influencing IoT adoption in biodiversity monitoring.

Marital Status of Respondents

Table 5: Respondents' Marital Status

Category	**Frequency**	**Frequency (%)**
Never married, no children	23	6.61
Never married, with children	38	10.92
Married, living together	197	56.61
Married, living apart	41	11.78
Divorced/Separated/Widowed	49	14.08
Total	**348**	**100**

Most respondents (56.61%) were married and living together, implying stable households. Marital status influenced decision-making and technology adoption, with married couples having more collaborative access to IoT devices.

Household Size

Table 6: Respondents' Household Size

Category	**Frequency**	**Frequency (%)**
One member	11	3.16
2–4 members	88	25.29
5–7 members	104	29.89
8–10 members	91	26.15
More than 10 members	54	15.51
Total	**348**	**100**

Most households had between 5–7 members (29.89%). Larger households were associated with increased labor availability but also higher dependency ratios, influencing how IoT technologies were accessed and used.

Literacy and Level of Education

Table 7: Literacy and Level of Education of Respondents

Indicator	**Category**	**Frequency**	**Frequency (%)**
Able to read	Yes	218	62.64

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	No	130	37.36
Able to write	Yes	222	63.79
	No	126	36.21
Education	None	83	23.85
	Primary	93	26.72
	Secondary	99	28.45
	College	28	8.05
	University	45	12.93
Total		**348**	**100**

Over 60% of respondents were literate, while 55% had only basic education. Education level influenced comprehension of biodiversity information and ability to use IoT tools effectively.

Demographic Characteristics of FGD Participants

Table 8: Demographic Characteristics of FGD Participants

Variable	**Category**	**Frequency**	**(%)**
Age	18–30	3	18.75
	31–40	5	31.25
	41–60	5	31.25
	>60	3	18.75
Household Size	2–4	2	12.5
	5–7	9	56.25
	8–10	4	25
	>10	1	6.25
Level of Education	Primary	8	50
	Secondary	5	31.25
	College	3	18.75
Head of Household	Yes	14	87.5
	No	2	12.5
Marital Status	Married together	6	37.5
	Married apart	4	25
	Polygamous	3	18.75
	Widow	2	12.5
	Single	1	6.25

Most FGD participants were household heads aged 31–60 years. This group had extensive pastoral experience and played a key role in biodiversity-related decisions. Education gaps limited IoT use among older members, though youth showed greater adaptability.

Demographic Information of Key Informants

Table 9: Demographic Information of Key Informant Interviewees

Variable	**Category**	**Frequency**	**(%)**
Age	18–30	6	25

	31–40	8	33.33
	41–60	10	41.67
Education	PhD	1	4.17
	MA	2	8.33
	BSc. IT	8	33.33
	BSc. Env. Sci	4	16.67
	BA	7	29.17
	Diploma	2	8.33
Organization	Nat. Govt	8	33.33
	County Govt	4	16.67
	NGO	6	25
	CBO	2	8.33
	Media	2	8.33
	Diocese	2	8.33

Most key informants were professionals with ICT and environmental backgrounds, enhancing the credibility of insights into IoT-based biodiversity systems. Their experience supported the validation of the architectural model.

Natural Capital

Table 10: Access to and Utilization of Natural Capital

Construct	Key Findings
Natural Capital	○ Communal land ownership dominant. ○ Boreholes and rivers were main water sources. ○ IoT-based biodiversity data improved planning for grazing and water access.

IoT-enabled biodiversity alerts allowed pastoralists to plan migration, grazing, and sales in anticipation of droughts. Water access projects supported by NGOs improved resilience and sustainability.

Human Capital

Table 11: Access to and Utilization of Human Capital

Construct	Key Findings
Human Capital	○ Literacy gaps affected IoT proficiency. ○ IoTs supported learning and access to biodiversity data. ○ • Extension services enhanced knowledge and adaptive capacity.

IoT devices bridged knowledge gaps by delivering biodiversity and weather updates. Partnerships with KWS, KFS, and ASDSP enhanced human capacity and enabled evidence-based decisions in pastoralism.

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Financial Capital

Table 12: Access to and Utilization of Financial Capital

Construct	**Key Findings**
Financial Capital	○ IoT platforms provided access to financial services. ○ Improved market information increased income. ○ Mobile money facilitated savings and remittances.

Mobile banking through M-Pesa, Airtel Money, and T-Kash strengthened financial inclusion. IoT-based market data improved livestock pricing decisions, empowering both men and women economically.

Social Capital

Table 13: Access to and Utilization of Social Capital

Construct	**Key Findings**
Social Capital	○ IoTs enhanced communication in CFAs and SHGs. ○ Smart phones strengthened social connectivity. ○ Mutual trust and cooperation increased through digital platforms.

Social networks were critical in spreading IoT-based biodiversity knowledge. WhatsApp and radio networks supported peer learning, strengthened cohesion, and improved coordination for environmental action.

Physical Capital

Table 14: Access to and Utilization of Physical Capital

Construct	**Key Findings**
Physical Capital	○ IoT access reduced transport costs. ○ Men owned most IoT devices. ○ Biodiversity messages received via SMS and radio improved decision-making.

Physical capital improved through better IoT access, reducing information asymmetry. However, rural electrification and network limitations remained barriers, prompting adoption of solar energy as an alternative.

DISCUSSION

The study examined how IoT-based terrestrial biodiversity data (TBD) influences livelihood strategies and sustainability among rural communities in Turkana County. The results revealed that integrating IoT technologies in biodiversity monitoring enhances access to environmental information, decision-making, and resilience. For natural capital, IoT-based biodiversity data improved land and water resource management. Realtime updates through mobile phones and community radios helped pastoralists plan grazing and water access, reducing the risks of drought, pasture loss, and livestock deaths. These early warnings strengthened preparedness and minimized food insecurity.

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In terms of human capital, the study found that most IoT users had basic education levels, though limited literacy affected their ability to interpret scientific biodiversity data. Participants preferred voice messages and radio programs in the Ng'aturkana language. This calls for localized communication and capacity building to enhance digital literacy and interpretation of biodiversity information. Regarding financial capital, IoT use strengthened access to financial services such as M-Pesa and Airtel Money. Mobile banking and social savings groups (ROSCAs) empowered rural communities, particularly women, to pay school fees, buy household essentials, and invest in IoT tools. Access to real-time biodiversity data also helped pastoralists identify better markets and prices for livestock, increasing income and economic stability.

For social capital, the study established that self-help groups and community networks were vital channels for sharing IoT-based biodiversity and pastoral advisories. These groups fostered trust, cooperation, and knowledge exchange, enhancing adaptation capacity and improving livelihood outcomes. Reliable biodiversity data shared through trusted community networks strengthened decision-making and built resilience against environmental shocks. In physical capital, IoT technologies reduced travel costs and improved access to biodiversity data. However, rural infrastructure gaps limited electricity, poor internet, and unequal access to devices hindered wider adoption. Men owned most IoT devices, while women and older adults had limited access. Despite this, smartphones and radios remained the most accessible technologies for biodiversity communication in rural Turkana. Overall, the integration of IoT-based biodiversity data improved productivity, decision-making, and adaptation strategies, demonstrating the transformative role of digital technology in promoting sustainable rural livelihoods.

CONCLUSION

The study concludes that IoT technologies have enhanced rural households' ability to access, process, and share terrestrial biodiversity data. Tools such as smartphones and radios improved communication, access to markets, and environmental awareness, leading to better livelihood outcomes. IoT strengthened the five livelihood assets: natural, human, financial, social, and physical capital. It increased access to information, reduced transaction and transport costs, and fostered collaboration. However, realizing the full potential of IoT requires addressing cultural barriers, literacy challenges, and unequal access to technology especially for women and marginalized groups.

The study demonstrated that IoT success depends not only on technology availability but on how it is applied within community systems. Trust, local relevance, and participatory use were key factors in adoption. The developed IoT-based Architectural Model (TBDAM) illustrates how IoT systems can connect biodiversity data to sustainable livelihood strategies. The model provides a practical framework for policymakers and practitioners to promote inclusive, data-driven environmental management. The mixed methods approach used combining quantitative analysis with qualitative insights validated the model and highlighted the significance of contextual factors in IoT adoption. Ultimately, the research confirms that IoT-based biodiversity systems can empower rural communities to adapt to biodiversity change while improving economic and social well-being.

Contribution to Knowledge

This study contributes to knowledge by:

1. Providing empirical evidence from an under-researched pastoral context on how IoT improves access to biodiversity and livelihood data.
2. Demonstrating the importance of local language, trust networks, and digital literacy in IoT adoption.
3. Offering a practical framework to guide policy, ICT innovation, and environmental conservation in arid and semi-arid regions. iv. Supporting ICT4D discourse by showing how IoT can integrate technology, sustainability, and community empowerment.

RECOMMENDATIONS

1. Integrate IoT-based biodiversity systems into county and national environmental policies.
2. Strengthen digital literacy and biodiversity data interpretation, especially for women and youth.
3. Disseminate biodiversity information in local languages using voice and radio formats.
4. Expand rural connectivity, energy access, and affordability of IoT devices.
5. Encourage collaboration between government, academia, mobile operators, and NGOs to expand IoT adoption.
6. Develop standardized protocols and ensure privacy in IoT data handling.

Suggestions for Further Research

Further research should explore advanced IoT analytics, interoperability, and security frameworks. Studies focusing on gender, indigenous knowledge systems, and socio-cultural factors will provide deeper insights into equitable technology adoption and biodiversity data utilization.

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