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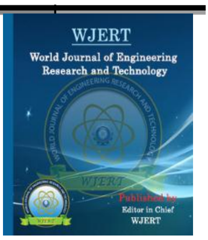

APPLICATION OF IoT-BASED TERRESTRIAL BIODIVERSITY DATA FOR SUSTAINABLE LIVELIHOODS AMONG RURAL COMMUNITIES IN TURKANA COUNTY

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ABSTRACT

This study aimed to explore the application of IoT-based terrestrial biodiversity data for sustainable livelihoods in Turkana County, Kenya. The study used theoretical research findings to connect IoT theory and practice with biodiversity data for sustainable livelihoods. The mixed method was used, with a sample of 384 households in Turkana County. Data was collected through questionnaires, focus group discussions, and key informant interviews. The study found that pastoralists who were aware of terrestrial biodiversity and pastoral advice provided by IoTs used the information to influence their way of life. The findings emphasized the need for initiatives allowing rural populations to utilize IoT technologies for processing and sharing terrestrial biodiversity data. The study's knowledge contribution took the form of an enhanced Sustainable Livelihoods (SLF), where varied responses and systematic analysis made the IoT application relevant for understanding the relationship between terrestrial biodiversity data and sustainable livelihoods. The findings can be used to provide policy recommendations and suggestions for Kenya's future terrestrial biodiversity data plans, policies, and strategies.

KEYWORDS: application, IoT Technologies, Terrestrial, biodiversity, Data, Rural, sustainable, livelihoods.

INTRODUCTION

The Earth's ecosystems, including forests, marshes, rivers, and oceans, support an enormous number of creatures, including humans. Global terrestrial biodiversity data depends on parameters such as biomass, ecosystems, phyla, floras and faunas, hot-spots, genetic erosion, and the impact of aliens (Mora et al., 2011). The objective of biodiversity data initiatives is to create systems that enable data interchange and knowledge synthesis across various local systems and incorporate them in global knowledge architectures (Soberson et al. 2004).

Kenya is one of the 10 mega-biodiverse nations with over 35,000 species of flora and fauna. The country faces numerous environmental issues, including forestation, soil erosion, desertification, water catchment destruction, poaching, pollution, land degradation, loss of biodiversity, degradation of ecosystem and resources, droughts, invasion flash floods, and invasive alien species (M. Catherine, 2023). Data plays a significant role in allowing businesses to gain competitive advantages and researchers to develop new insights and technologies.

The Internet of Things (IoT) has become the norm for addressing human concerns such as biodiversity conservation and livelihoods. This study was inspired by the growing challenges of terrestrial biodiversity data processing, sharing, and access concerns, which is a problem in Turkana County, Kenya. IoT is no longer a support function but a critical enabler for service delivery and management in all sectors. It enhances the effectiveness and efficiency in the operations of modern organizations, playing a critical role in driving economic, social, and political developments in Kenya.

Terrestrial biodiversity contributes to human well-being through supporting, provisioning, regulating, and cultural ecosystem services. However, biodiversity loss and deterioration of ecosystems remain major concerns. Terrestrial biodiversity is also crucial in regulating climate, water quality, pollution, and pollination among others (USAID, 2010).

Climate variability influences terrestrial biodiversity, such as extreme weather events that directly influence ecosystem health and the productivity and availability of ecosystem goods and services for human use. Longer-term changes in climate affect the viability and health of ecosystems, influencing shifts in the distribution of plants, pathogens, animals, and even human settlements.

The Internet of Things (IoT) is currently changing the telecom landscape and penetrating every aspect of our lives. Mobile IoT technology, such as narrowband-IoT (NB-IoT) and long-term evolution (LTE) for machines (LTE-M), represents significant breakthroughs in this rapidly developing area of IoT technology (Smith, 2012). Sensor-enabled mobile phones are now the center of the next revolution in environment monitoring, social networks, green applications, and transport systems due to their pervasive embedded sensors that collect, process, and distribute data around people. Smartphones can be augmented to provide sensing nodes and give gateway functionalities to the internet and cloud.

The Internet of Things (IoT) is transforming the way we live, work, and interact with the world around us. By addressing these challenges and fostering a more sustainable future, we can work towards preserving and protecting our planet's diverse ecosystems and promoting sustainable development. The Internet of Things (IoT) has revolutionized the way we connect and communicate with devices, enabling a new kind of data flow. The Internet will consist of heterogeneously connected devices that will further outspread the borders of the world with physical entities and virtual components (Akhil, 2019). Mobile phones, smartphones, and radio stations are used by people from all walks of life, regardless of class, region, or gender. Many modern mobile phones have radio capabilities, providing portable information via mobile phones.

For marginalized communities, terrestrial biodiversity data, including biological data, physical factors of the environment, biodiversity management, and threats to biodiversity, is vital (FAO, 2016). However, accessing and using this data is challenging due to the lack of information and uncertain nature of environmental issues. This has led to food insecurity, poverty, and loss of livelihoods in rural areas like Turkana County (ASDSP Report, 2014).

There is an urgent need to expand rural people's application of IoT-based terrestrial biodiversity data to address food and nutrition shortages, raise agricultural yields, and improve pastoralists' livelihoods. IoT makes it feasible to rapidly gather, examine, and evaluate a lot of data, and it can also improve human behavior, business operations, and societal systems by making good use of the knowledge gleaned from terrestrial biodiversity (Yohannis *et al*., 2016).

Effective information gathering and usage can help prevent and reduce biodiversity loss, encourage sustainable development, and maintain and extend biodiversity. The study focused on households in Turkana County to see what combinations of IoT technologies can improve their access to terrestrial biodiversity data for sustainable livelihoods while considering intra-household decision-making dynamics. The study also examined the social-cultural context and terrestrial biodiversity data change dynamics, as well as the challenges that these entail, and how this community uses specific IoT devices.

The development of IoT has the potential to revolutionize the way we connect and communicate with devices, enabling us to better understand and manage biodiversity in our daily lives. By leveraging IoT technologies, we can better understand the challenges faced by marginalized populations and develop innovative solutions to address the challenges they face.

REVIEW OF LITERATURE

Application of IoT-based Terrestrial Biodiversity Data

Data sharing is crucial for increasing accessibility of biodiversity data, but implementation remains difficult due to a lack of suitable standards, incentives, and resources. The Internet of Things (IoT) is changing the way organizations process, communicate, share, collaborate, and coordinate daily processes. IoT is ideal for complex and distributed operations, allowing for accurate real-time data acquisition and rapid decision-making. However, IoT data is obtained from various networked sensors, which pose a security challenge.

IoT requires highly qualified personnel and complicated integration of systems, networks, and applications for implementation. This ecosystem consists of devices, sensors, networks, cloud storage, and applications, working together to improve strategic positioning proactively and reactively. Organizations must have a clear understanding of the information they need for businesses, the type of information they want from the devices, and the intended use of the information.

IoT uses various physical devices, applications, and technologies, including industrial machinery, wearable devices, and monitoring devices. These devices communicate within a network, encompassing automated homes, smart cars, healthcare services, irrigation supply, smart appliances, air conditioning, smart lighting, and smart thermostats. IoT devices are categorized into three domains: personal usage, industrial fields, and enterprises' utilities. Personal IoT devices include smart devices, while industrial fields include smart systems, security systems, monitoring technologies, and industrial machinery.

In enterprises, IoT devices are diversified, ranging from embedded devices with sensors to cloud platforms. Enterprises aim to enhance efficiency, facilitate business processes, reduce errors, and save time. Connected wireless endpoints in enterprises include security cameras, locks, office printers, scanners, smart meeting rooms, and other emerging technologies that allow workers to transmit data with colleagues, increasing productivity and saving cost and time.

Terrestrial Biodiversity Data Relevance in Rural Communities

Biodiversity information refers to data related to the protection and preservation of the world's diverse species, habitats, ecosystems, and genetic variation. It is crucial for human health, wealth, food, fuel, and services. This research focuses on how rural people use biodiversity data to make decisions about land and resource mobilization mechanisms to improve their livelihood strategies. Studies in Baringo County and Kisii County suggest that such information can have greater acceptance and influence in decision-making if it is appropriately packaged and tailored to farmers' needs.

The study will focus on biodiversity information and support services relevant to biodiversity conservation mechanisms in semi-arid environments, such as plants, animals, bacteria, human life, and climate change. Weather and biodiversity variability information are primarily short-term and of direct significance to rural populations, and if properly packed, can aid in raising farm productivity, assisting farmers in adapting to changes in biodiversity, and improving livelihoods.

Biodiversity information is at the center of decision-making for communities in rural Turkana County to ensure they cope with and adapt to climate change. Precise and timely biodiversity data enables farmers to make decisions about planting and fertilizer application dates, crop types and varieties, livestock stocking rates, market patterns, and changes in farming systems.

Despite significant progress in the preservation, gathering, and analysis of biodiversity data, small-scale rural farmers' ability to turn this data into useful knowledge remains weak. To be relevant to farmers, it must have certain characteristics, such as relevance, access, legitimacy, equity, and integration.

Provided biodiversity information has all of these characteristics and is used correctly by the targeted groups, making it a success. The research will focus on the qualities of access (the quality and frequency with which users can obtain biodiversity information), equity (inviting rural communities excluded from economic activities), and relevance (the urgency, currency, or lead time of biodiversity information). The Sustainable Livelihood Approach (SLF) will inform the interpretative tool in this study, which prioritizes community/household-specific and contextual issues when considering the application of biodiversity data.

The Role of IoTs in Biodiversity Data Dissemination

IoTs have the potential to help rural poor generate the information they need to make better-informed decisions that affect their livelihood strategies and livelihoods. However, these IoTs must be linked to institutions and external players who may impact the rural poor's livelihood. Demand-driven IoTs must be used to meet the specific needs of the rural poor. Rural agricultural communities are using IoTs such as wireless sensor networks, rural community radio frequencies, and smart phones to disseminate biodiversity conservation information to the general public. Technological advancements have led to new methods to employ the same technology, such as the World Bank's IEG (2011), which supports innovation and has the potential to drive massive economic revolution.

IoTs are used in biodiversity conservation and environmental information systems, providing localization and temporal specificity among vulnerable groups in rural areas. Smart phones can boost social capital development, market information flows, and productivity. The spread of mobile broadband opens up various options for biodiversity conservation adaptation, including monitoring, capacity building, and information dissemination.

Radio frequency is crucial for biodiversity information distribution, as it is one of the most effective methods for reaching the general public, particularly the impoverished. It can provide agricultural production information in a language that illiterate farmers can understand and help farmers and researchers communicate by offering climate information on their area.

International organizations, such as the United Nations Development Programme (UNDP) and the World Bank, have highlighted IoTs as effective instruments in various sectors, including increasing the responsibilities of rural communities and reducing social and environmental inequity. IoTs are critical in environmental monitoring and providing information about natural resource-based livelihood assets and biodiversity-related dangers such as drought.

The Internet of Things (IoT) is rapidly being used in disaster prediction and early warning, as well as improving data collection. Agriculture decision-support projects, such as the COMMONSense Net wireless network in drought-stricken villages in Southern Karnataka, have aided village people in managing crop risk through efficient water management and pest prevention. The evidence suggests that allowing farmers to connect to and act on environmental restrictions is the solution.

Application of Terrestrial Biodiversity Data by Pastoralists

Pastoralists rely on locally adapted livestock breeds and crop varieties to manage systems that require mobility and drought tolerance. These breeds are capable of walking long distances and surviving drought, enabling effective management of systems that demand mobility and drought tolerance. Pastoralists are the only groups actively working to maintain the genetic diversity of local breeds.

Pastoralism is heavily reliant on ecosystem services, and traditional management systems naturally adopt principles that target ecosystem health maintenance or enhancement. Pastoralists contribute valuable local knowledge to the management of biodiversity at the species level, as evidenced by a study by the League for Pastoral Peoples and Endogenous Development (LPPED and LPPS 2005).

Many pastoral communities have management systems in place to ensure the conservation of important species, which may otherwise be overlooked. By retaining species and management practices that have evolved in parallel with the local environment, pastoralists retain important species interactions, benefiting many wild species of plants, birds, and insects.

RESEARCH METHODOLOGY

This research utilized a pragmatic approach, combining positivist and interpretivism techniques to better understand the study problem. The mixed-methods approach was employed in Turkana County, Kenya, which is the largest county by land area and has a population of 926,976 (males 52% and 48% females). The study targeted 164,519 households, with 52% being males and 48% being females.

The study used Krejcie and Morgan table to obtain a sample size of 384 households, combining perspectives from Kumar's (1989), Mason's (2010), Glasser and Strauser's (1967), and Miles and Huberman's (1994) perspectives. Twenty-four individuals were selected for the Key Informant Interviews (KIIs) due to their diverse experiences and knowledge on IoTs, livelihoods, and biodiversity data in Turkana County, particularly in Eco-Climatic Zones.

The study employed various data collection processes, including participant observation, document analysis, surveys, questionnaires, interviews, and more. The power of case study research lies in the ability to use all methodologies within the data-collection process and compare within and across cases for research validity.

The researcher analyzed, described, and interpreted data based on research objectives and questions, and presented the data in various forms such as frequencies, tables, percentages, and explanatory notes. The mixed-methods approach allowed for flexibility in interpreting field data, allowing for better understanding of the study problem. The study's findings can be used to inform future research on IoTs, livelihoods, and biodiversity in Turkana County.

RESULTS

The study involved a household survey, focus group discussions, and 24 interviews with ICT Managers and terrestrial biodiversity professionals. It evaluated and validated the model using 30 content developers, ICT officers, and software developers.

Table 1: Response Return Rate.

Respondents	**Questionnaires Administered**	**Duly filled and returned Questionnaires**	**Return Rate (%)**
Household Survey Questionnaires	384	348	90.63
	Conducted	**Returned**	**Return Rate (%)**
Pastoralists FGDs	2 (8)	2 (8)	100%
Key informant Interviews	24	24	100%
NB-IoT Model Validation	30	20	66.67%

Source: Field Survey (2023)

The study involved 348 questionnaires, 2 focus group discussions, and 24 key informant interviews. It validated the NB-IoT model with 20 content developers, ICT officers, and software developers. The response rate for household survey respondents was 90.63%, while the validation and evaluation exercise had a response rate of 66.67%. Table 1 summarizes respondents' results.

Distribution of Respondents Per Sub- County

This study examines respondents' distribution per sub county and eco-climatic zones to analyze the adoption of NB-IoT model for processing and sharing biodiversity data in eco-climatic zones.

Table 2: Distribution of Respondents' per Sub-County & Eco-climatic Zones.

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

Source: Field Survey (2023)

The study found that Turkana West had 28.4% of respondents, while Turkana Central had 25.6%. The lowest percentages were from Turkana North and Kibish sub-counties, with 7.8% and 3.2%, respectively. The respondents were grouped into Eco-Climatic Zones, with EZ VI having 48.56%, EZ V and EZ IV having 28.45% and 22.99%, respectively. The 24 key informants were ICT managers and professionals working with biodiversity conservation organizations in the county. The ICT managers played a crucial role in confirming the functional and user satisfaction requirements of NB-IoT.

Respondent's Demographic Characteristics

The study examined how demographic characteristics, including gender, age, marital status, literacy, and education, affect respondents' access to IoT devices for processing and sharing terrestrial biodiversity data for sustainable livelihoods.

Respondents' Gender

The study sought the gender of the respondents.

Table 3: Respondents' Gender.

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

Source: Field survey (2023

The household survey included 202 male and 146 female respondents, with 58.05% and 41.95% being useful for joint intra-household decision-making consultations. Both genders were useful for consultations.

Respondents’ Age

Respondents were asked about their ages, highlighting household responsibilities and the IoT device's role in processing and sharing biodiversity data for sustainable livelihoods.

Table 4: Age of Respondents.

Indicator Variable	Category	Frequency	Frequency (%)
Age	18-30 years	65	18.68
	31-45 years	178	51.15
	46-60 years	60	17.24
	Above 60	45	12.93
	Total	**348**	**100**

Source: Field Survey (2023)

The household survey revealed that the majority of respondents were aged between 31 and 45 years (51.15%), with 18.68% aged between 18 and 30 years. 87.07% were aged between 18 and 60 years, while 12.93% were above 60 years, with the lowest ratios.

Respondents’ Marital Status

The study sought the respondents’ marital status this was essential in finding out how the respondents use of IoT devices for processing and sharing of terrestrial biodiversity data.

Table 5: Respondents' Marital Status.

Indicator Variable	Category	Frequency	Frequency (%)
Marital Status	Never married with 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**

Source: Field Survey (2023)

The results in table 5 show that the majority of the respondents (56.61%) are married and living together, while 14.08% were divorced/separated/widowed. There were also 11.78% respondents who were married but living apart.

Respondents' Household size

The study sought to find out the respondents' household size.

Table 6: Respondents' Household Size.

Indicator Variable	Category	Frequency	Frequency (%)
Household Size	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**

Source: Field Survey (2023)

Table 6 indicates that 29.89% of the respondents had a household size of 5 to 7 members, while 26.15% of the respondents had 8 to 10 members. The majority (81.33%) of the respondents had a household size of between 2 and 10 members.

Literacy and Level of Education

Respondents' literacy and education levels were assessed to demonstrate their use of IoT devices for accessing, processing, and sharing terrestrial biodiversity data for sustainable livelihoods in Turkana County.

Table 7: Table Literacy and Level of Education of the Respondents.

Indicator Variable	Category	Frequency	Frequency (%)
Able to read	Yes	218	62.64
	No	130	37.36
	Total	**348**	**100**
Able to write	Yes	222	63.79
	No	126	36.21
	Total	348	100
Education	None	83	23.85
	Primary	93	26.72
	Secondary	99	28.45
	College	28	8.05
	University	45	12.93
	Total	**348**	**100**

Source: Field Survey (2023)

Most respondents had literacy skills (62.64%) and writing skills (63.79%). Primary and secondary education was the highest level of education, with 53% of residents having basic education. 23.85% had no education, while 20.98% had post-secondary education.

Demographic Characteristics of FGD Participants

The following demographic characteristics; age, household size, level of education head of household, years of experience in pastoralism and marital status were also sought from FGD participants to find out how they affect their access and use of IoT devices to process and share terrestrial biodiversity data.

Table 8: Demographic Characteristics of FGD Participants.

Indicator Variable	Category	Frequency	Frequency (%)
Age	18-30	3	18.75
	31-40	5	31.25
	41-60	5	31.25
	>60	3	18.75
	Total	**16**	**100**
Household Size	2-4	2	12.50
	5-7	9	56.25
	8- 10	4	25.00
	>10	1	6.25
	Total	**16**	**100**
Level of Education	Primary	8	50.00
	Secondary	5	31.25
	College	3	18.75
	Total	**16**	**100**
Head of Household	Yes	14	87.50
	No	2	12.50
	Total	**16**	**100**
Marital Status	Married Living apart	4	25.00
	Single	1	6.25
	Polygamous Marriage	3	18.75
	Widow	2	12.50
	Married living together	6	37.50
	Total	**16**	**100**
Years of Experience in Pastoralism	8-10	6	**37.50**
	11-20	5	**31.25**
	21-30	3	**18.75**
	31-40	2	**12.50**
	Total	**16**	**100**

Source: Field Survey (2023)

From table 8 for the FGDs, majority of the respondents had primary education as their highest level of education. Marital status was considered because it had implications on who was the household head and the decision-maker. While married women have to contend with challenges of cultural expectations that they should defer to the authority of their spouses, unmarried women tend to be deprived of the right to access and own land. These dynamics mean that for the policy makers and implementers who seek to deepen and spread the use of terrestrial biodiversity data in the ASAL pastoralists, the starting point must target men and women at household levels.

Age was a factor as it determines the chances of being household heads, gives indications of the extent of and experience in pastoralism, versatility with IoT devices, as well as the perceptions of pastoralism as an economic activity. All the participants had between 8-40 years of pastoralism experience. Many of the households had between 5 to 7 members. Male participants were considered decision-makers since they are the household heads.

Demographic Information of Key Informant Participants

The demographic information of the key informant interviewees was also sought to show their views on the factors that would influence use and access of IoT devices for processing and sharing terrestrial biodiversity data. The demographic information was important as they provided information on the various requirements of NB-IoT infrastructure for designing the NB-IoT model.

Table 9: Demographic Information of Key Informant Interviewees.

Variable Indicator	Category	Frequency	Frequency (%)
Age	18-30	6	25.00
	31-40	8	33.33
	41-60	10	41.67
	Total	**24**	**100**
Level of Education	PhD	1	4.17
	MA	2	8.33
	BSc. IT	8	33.33
	BSc. Environmental Science	4	16.67
	BA	7	29.17
	Diploma	2	8.33
	Total	**24**	**100**
Organization	National Government	8	33.33
	County government	4	16.67
	NGO	6	25.00
	CBO	2	8.33

	Media	2	8.33
	Diocese of Lodwar	2	8.33
	Total	**24**	**100**
Position in Organization	County Directors	4	16.67
	Chairperson	1	4.17
	Head of Radio Programming	2	8.33
	ICT manager	8	33.33
	Station Manager	4	16.67
	Regional Directors	5	20.83
	Total	**24**	**100**
Years of work experience	3-6	12	50.00
	7-15	8	33.33
	>15	4	16.67
	Total	**24**	**100**

Source: Field Survey (2023)

The interviewees were aged 41-60, with eight between 31-40 and six between 18-30. They had various education levels, including Ph.D., Master's, Bachelor of Science, Bachelor of Arts, and Diploma holders. Most had 3-6 years of experience in generating biodiversity data, training, and disseminating it in Turkana County. Most had expertise in biodiversity adaptation and dissemination.

Application of IoT-based Terrestrial Biodiversity Data

This section presents data on application, usability, awareness, knowledge of NB-IoT based terrestrial biodiversity data by the respondents. It also seeks to establish the frequency of use of IoT devices in processing and sharing terrestrial biodiversity data.

Knowledge and Awareness of Terrestrial Biodiversity Data

It was important to understand the participant’s knowledge on fauna, flora, natura, habitats (forests, deserts and wetlands), protected areas, conservation measures, biodiversity data and information and biodiversity threats, these were based on the Eco-Climatic Zones selected for this study.

Table 10: Awareness and Use of Biodiversity Data by Respondents.

Awareness and use of Biodiversity Data *(5 = Strongly Agree; 4 = Agree; 3 = Neutral;2 = Disagree; 1 = Strongly Disagree)*	**5**	**4**	**3**	**2**	**1**	**Mean**	**CV**
Fauna	192	68	35	30	23	4.08	0.205
Flora	189	64	34	35	24	4.04	0.203
Habitats	190	56	48	30	24	4.03	0.202
Natura	180	80	22	38	28	4.00	0.201
Protected Areas	175	93	31	32	17	3.96	0.199
Conservation Measures	176	95	29	29	19	3.94	0.198
Geographical Ranges	199	89	27	13	20	3.93	0.197
Biodiversity data and information	198	73	59	10	8	3.86	0.194
Biodiversity Threats	172	76	49	28	23	3.85	0.193

Source: Field Survey (2023)

Table 10 indicates that respondents have knowledge and awareness of various types of biodiversity data, with a mean of over 3.5 for all indicators. The coefficient of variation (CV) was assessed for each measured indicator variable to differentiate similarities and rank them in terms of terrestrial biodiversity data knowledge and awareness. The low dispersion of respondents around the mean indicates that over 80% are aware of terrestrial biodiversity data, highlighting its importance in sustainable livelihoods.

Areas Application of Terrestrial Biodiversity Data

The areas of application of terrestrial biodiversity data was sought ranging from strongly agree (5) to strongly disagree (1) from the respondents. It was important to understand how the respondents apply the terrestrial biodiversity data for sustainable livelihoods.

Table 11: Areas of Application of Terrestrial Biodiversity Data.

Areas of application of TBD *(5 = Strongly Agree; 4 = Agree; 3 = Neutral; 2 = Disagree; 1 = Strongly Disagree)*	**5**	**4**	**3**	**2**	**1**	**Mean**	**CV**
Plants maintain atmosphere	292	28	18	6	4	4.72	0.237
Plants prevent soil erosion	288	36	24	0	0	4.75	0.239
Birds/insects pollinate plants	312	21	15	0	0	4.85	0.244
Natural predators control insects	218	98	16	9	7	4.47	0.224
Wild plants and animals maintain valuable genetic variation	316	22	10	0	0	4.88	0.245
Humans get different products from biodiversity	334	14	0	0	0	4.96	0.249
Certain species warn humans of toxins in the environment	263	64	21	0	0	4.70	0.236

Source: Field Survey (2023)

Table 11 reveals that respondents use terrestrial biodiversity data for livelihood benefits, with an average mean of over 4.00 for all variable constructs. They strongly agree that plants maintain the atmosphere, prevent soil erosion, pollinate plants, control insects, maintain genetic variation, provide different products from biodiversity, and warn humans of toxins in the environment. The coefficient of variation (CV) values are close to each other, indicating a low dispersion of respondents around the mean, indicating that over 85% of respondents apply and use terrestrial biodiversity data.

Areas of Application of Terrestrial Biodiversity Data by FGDs and KIIs

The FGD and KIIs respondents were engaged on the application, usability and awareness of terrestrial biodiversity data. It was important to note the KIIs and FGDs views on how terrestrial biodiversity data is applied, used and its awareness for sustainable livelihoods in Turkana county.

Table 12: Application, Usability and Awareness of Terrestrial Biodiversity from KIIs & FGDs.

ConstructVariable	Factors	Key Findings
Terrestrial Biodiversity Data	TBD requirements	• Most pastoralists are aware of terrestrial biodiversity data and its importance. • Most pastoralists have not exploited the full potential of TBD • The data on flora, fauna, biodiversity threats and habitats are important to pastoralists • Broad comparative assessment of species pools was important to most respondents • The TBD data should be informative
	Accuracy	• To build trust, TBD should be tailored to local needs and reflected the EZs where pastoralists live. • Relevant and complete to the pastoralists' decision-making needs and wants
	Timeliness	• TBD not provided within a reasonable timescale to make it salient.
	Reliability	• TBD fulfills the test of time. • Does TBD contradict other trusted resources
	Relevance	• The need for TBD to be relevant and be meaningful to users • Does the data show concurrency? TBD users need concurrent data
	Credibility	• Lack of the right local content from TBD providers and quality assurance • Lack of quality of service in the IoT devices

	Contextualization	- TBD translated into local language and translated into simple formats - The need for modern scientific biodiversity knowledge to complement the indigenous knowledge
	Legitimacy	- The need for validity of TBD coming from various sources - Fairness and transparency
	Complementary Information and Services	- The need for complementary services (financial, Insurance, pastoralist-advisories) to augment terrestrial biodiversity data services increased - Willingness to pay.

Source: Field Survey (2023)

Table 12 summarizes the responses of the field visits and field visits (FGDs) and KIIs. All participants applied terrestrial biodiversity data and were aware of the need for updates on terrestrial biodiversity data aspects like fauna, flora, natura, and habitat threats. The access and use of information on biodiversity patterns was valuable for pastoralists planning. Respondents who were above 60 years of age relied heavily on traditional knowledge to predict occurrences, but they expressed that this was not always accurate anymore due to the unpredictability of climate patterns brought about by climate change. They opined that a lot has changed, especially in the wake of technology.

Key informants believed that pastoralists understood the biodiversity changes that occurred in their different areas of living and did not exploit the available biodiversity data and information to its full potential. However, some informants engaged more with pastoralists by understanding what biodiversity data and information pastoralists need, such as in what format they prefer and its use. The level of education and age was a factor where the participants were concerned, but not for the key informants. The younger participants in the field visits, between the ages of 18-30, were more competent in the use of IoT devices and were able to understand the terrestrial biodiversity data relayed through the IoT devices.

Some participants in the field visits had lost interest or had no trust in biodiversity data broadcasted over IoT devices mainly because they perceived it as unreliable and not location-specific. They felt that if the terrestrial biodiversity data was more legitimate, accurate, timely, relevant, current, and easy to understand, it would help them better prepare for their animals for pasture and water.

The challenge most participants experienced was the onset and duration of rain, which is a key factor for planning their flora, fauna, and habitat. Some key informants claimed there is always room for improvement in terrestrial biodiversity accuracy but the clarity of how to do this was not clear. Some stakeholders wished daily, weekly, and fortnight updates were delivered more consistently as respondents used it to monitor conditions as events unfolded.

Several terrestrial biodiversity service providers, apart from KWS and KFS, provided local content apart from KWS and KFS. They stressed the importance of quality assurance and quality of service for the IoT infrastructure. If terrestrial biodiversity data was inaccurate, it had a significant impact on cattle, sheep, and goats' production and food security.

KWS localized and repackaged the biodiversity information into user-friendly products, including related advisories for pastoralists. The participants collectively agreed that they trusted the localized terrestrial biodiversity data and information in the local Ng'aturkana language and translated it into comprehensible formats from the scientific data. However, translation of biodiversity data and information into the local dialect was costly and time-consuming, yet this is a requirement for many participants.

Additional services, such as financial and insurance services, were recognized as needed by pastoralists to add value to their planning and increase their willingness to pay for terrestrial biodiversity data services.

Frequency of Use of IoT Devices to Access Terrestrial Biodiversity Data

The researcher aimed to determine the frequency of IoT devices accessing terrestrial biodiversity data for a model for processing and sharing TBD. This information is crucial for the study's design and mplementation.

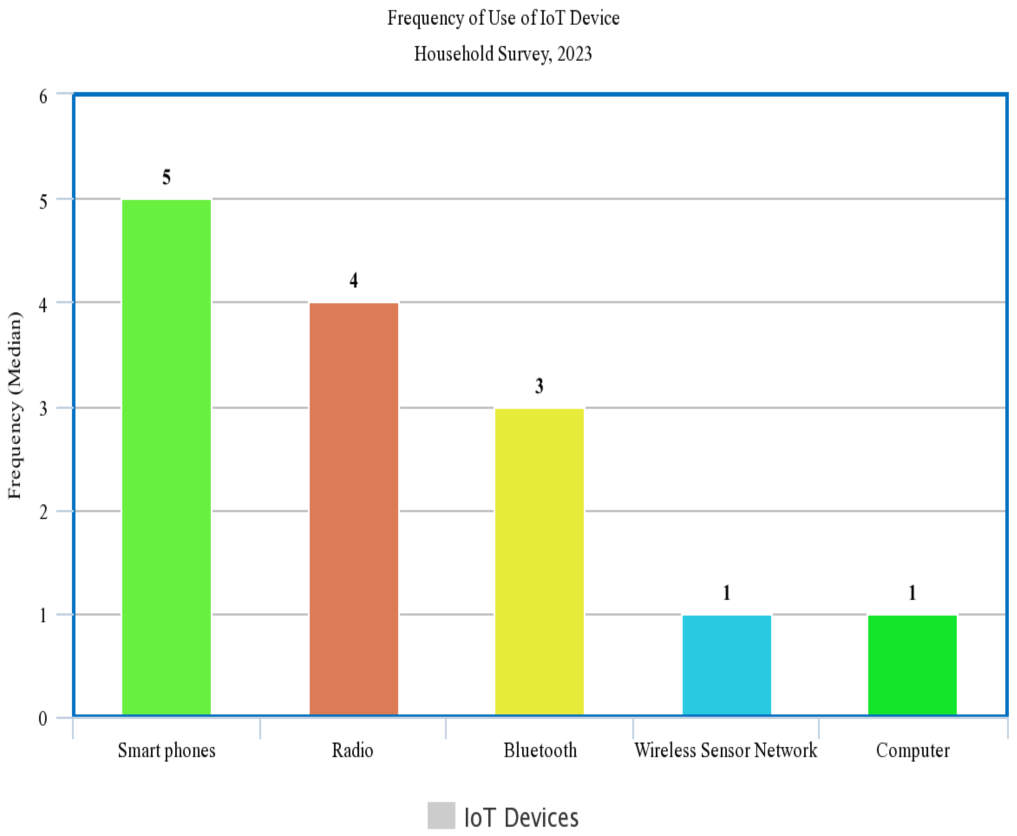

Figure 1: Frequency of Use of IoT Device to Access TBD by Households in Turkana county.

The figure 1 shows, the results of how frequently IoT devices are used to access biodiversity data by the respondents. Respondents use smart phones always, the radio sometimes, Bluetooth being neutral and they rarely use the wireless sensor and computer (smart phone=5, Radio=4, Bluetooth = 3, Wireless Sensor Network = 1 and Computer =1) in accessing terrestrial biodiversity data.

Relevance of Terrestrial Biodiversity Data relayed via IoT Devices

The study sought to understand if the terrestrial biodiversity data relayed via the IoT device were relevant to the respondents. This was important since it would help the researcher measure the effectiveness of the model and its intended use in processing and sharing biodiversity data.

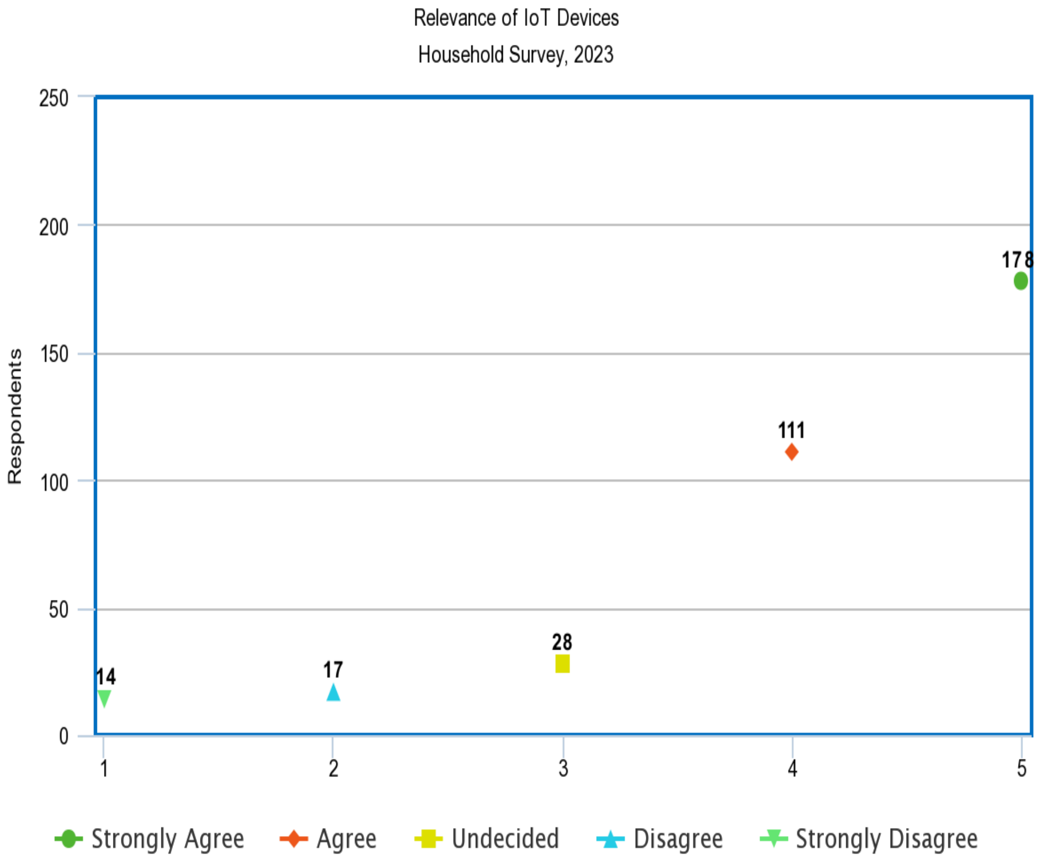

Figure 2: Relevance of Terrestrial Biodiversity Data relayed via IoT Devices.

Figure 2 shows the results on the respondents who found terrestrial biodiversity data accessed through IoT devices to be relevant. The data was categorized using the Likert scale of Strongly Agree (5), Agree (4), undecided (3), disagree (2) and strongly disagree (1). The majority of the respondents 289 (83.05%) agreed that they find relevance in terrestrial biodiversity data accessed through IoT devices while 28 (8.05%) were undecided and 31 (8.90%) disagreed.

Accuracy and Timeliness of the Terrestrial Biodiversity Data Shared through IoT Devices

The accuracy and timeliness of terrestrial biodiversity data share through IoT devices was sought. This was necessary as it helps respondents make better decisions. This information also ensured that the proposed model is designed to achieve this.

Table 13: Accuracy and Timeliness of Terrestrial Biodiversity Data via IoT Devices.

Timeliness *(5 = Strongly agree; 4 = Agree; 3 = undecided; 2 =Disagree; 1 = Strongly disagree)*	**5**	**4**	**3**	**2**	**1**	**Mean**	**CV**
Radio	196	78	30	21	23	4.16	0.209
Smart Phone	192	82	32	26	16	4.17	0.209
Wireless Sensor Network	11	12	34	105	186	1.72	0.086
Computer	10	15	32	103	188	1.74	0.087
Accuracy	**5**	**4**	**3**	**2**		**Mean**	**CV**
Radio	194	75	30	24	25	4.15	0.208
Smart Phone	192	82	32	26	16	4.17	0.209
Wireless sensor Network	12	13	34	104	185	1.74	0.086
Computer	11	17	36	98	186	1.76	0.088

Source: Household Survey (2023)

Table 13 shows that radio and smart phones are the most accurate and timely in communicating terrestrial biodiversity data, with a median of over 4.00. Wireless sensors and computers have an average mean of 1.72 and 1.74, respectively. The coefficient of variation (CV) measures the relative data points around the mean, showing the data distribution and computation of variables. The smart phone and radio ranked equal for timeliness and accuracy, while the wireless sensor network and computer were least ranked.

Readiness to Pay for Terrestrial Biodiversity Data Services

Readiness to pay more for processing and sharing of terrestrial biodiversity data was sought. This was important as it showed the readiness of the respondents to adopt a model which would serve them even if it would cost more.

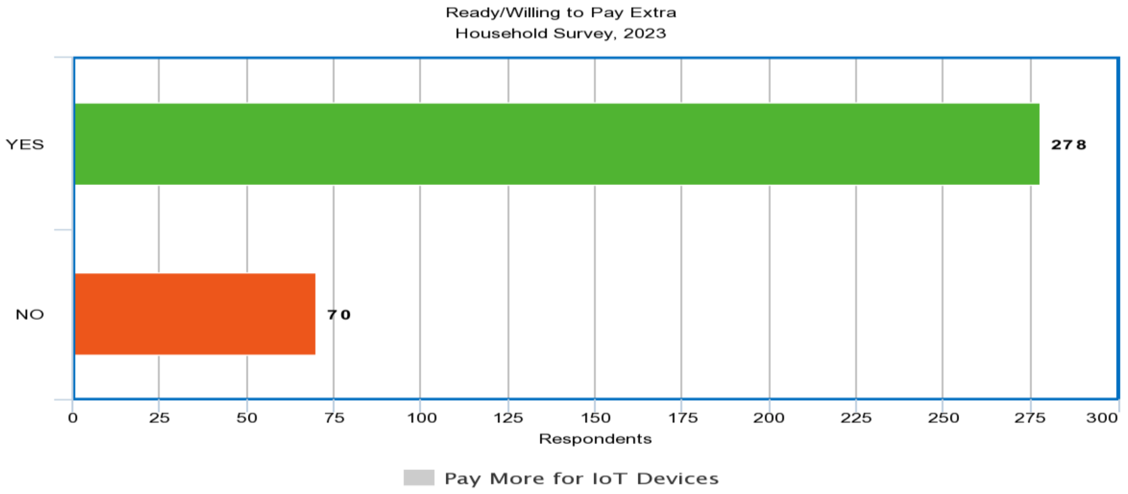

Figure 3: Ready/willing to pay extra for Terrestrial Biodiversity Data Services.

Source: Household Survey (2023)

Figure 3 indicates that 79.9 %, of the respondents (f=278) are ready and are willing to pay extra if the terrestrial biodiversity data communicated through the IoT devices are relevant, accurate and timely.

Delivery Methods of Terrestrial Biodiversity Data

The study sought from the FGD and KIIs respondents on the delivery methods and IoT device functionalities that they would prefer. This was important since it would help the researcher deal with issues of linking IoT device into its platform and for designing IoT devices functionalities in the proposed model

Table 14: Delivery Methods of TBD and Different IoT Devices.

IoT Device	Functionalities	Pros	Cons
Smart Phone	Text	• Works on all types phones. • Works with all technologies (android, windows, IoS for apple, Symbian) • Low set-up costs. • Low technical set-up. • Storage enables later viewing of SMS.	• Limitation due to illiteracy (both language and technical). • Costly to transmit in Local language and it escalates in line with scale. • Limitation on content (number of words per text)
	Voice	• Works on all types of phones. • Potential to reach more people. • Preference of interactive voice response (IVR) in Ng'aturkana • Richer in content. • Higher quality of service	• High upfront set-up costs. • IVR systems are challenging to install and configure. • The need for significant infrastructure support to deal with incoming calls.
	Data	• Richer user experience (functionality and content). • Fewer limitation of content (as number of words, broader access to content) • Helps overcome illiteracy by use of GUI	• Limitation due to technology literacy • Smartphone requirement and cost implications
Community FM Radio Station	Voice	• Potential to reach more people • TBD disseminated in the local language to overcome illiteracy • Two-way communication • TBD is "free"	• Access to programs not frequent • Lack of airtime to call back • Users must adhere to providers' programming
Wireless Sensor Network	Sensing	• Potential of air pollution monitoring • Potential forest fires detection • Potential of greenhouse monitoring • Landslide detection	• Hardware constraints • Scalability issues • Nodes failure • High production costs • Sensor network topology

			issues
	Processing	• Managing data collection from the sensors • Performing power management functions • Interfacing the sensor data to the physical radio layer • Managing the radio network protocol	• Hardware constraints • Scalability issues • Nodes failure • High production costs • Sensor network topology issues
Computer	Internet	• TBD is disseminated by KWS & KFS to various stakeholders and intermediaries • TBD available on websites	• Poor network connectivity • Poor electricity coverage • Expensive to own
Bluetooth	Data	• Removes the problem of radio interference • Low power consumption • Overcomes the constraints of the line of sight and one-to-one communication	• Slower • Smaller data range • Security issues while data is transferring. • Lower bandwidth
	Voice	• Removes the problem of radio interference • Low power consumption • Overcomes the constraints of the line of sight and one-to-one communication	• Slower • Smaller data range • Security issues while data is transferring. • Lower bandwidth

Source: Field Survey (2023)

The study focuses on the delivery methods of terrestrial biodiversity data, with key informants stating that they have established a biodiversity data sharing mechanism in their group. These predictions were disseminated through FM radios, smart phones, wireless sensor networks, and/or the internet to relevant institutions who relayed the data and information to communities. KWS and KFS broadcast prediction data and information in Ng'aturkana through community radios and smart phones using the Short Message Service for daily predictions for households. FGD participants expressed preference for terrestrial biodiversity data in Ng'aturkana and two-way voice-activated communication so they can ask questions.

Key informants believe that IoTs play a crucial role in persuading residents to use technology to address biodiversity-related challenges and enhance productivity. They emphasize the importance of providing rural residents with greater access to terrestrial biodiversity data and information to achieve sustainable livelihoods. FAO-Kenya uses various avenues for relaying terrestrial biodiversity data and pastoralists' advisories, including weekly programs on television (My Wild Africa) on citizen TV, a mobile web-based application platform (DigiCow, i-conserve), and radio programs. Kenya Forest Services also relays biodiversity data using brochures, periodically sponsored radio programs, 'barazas' field visits, and trade fairs.

The findings indicate that only FAO, radio stations, KWS, and KFS communicated biodiversity data and information regularly. The rest mostly conveyed periodic information on disease breakouts, threats, foreseen droughts, or during emergency situations. KWS targeted pastoralists, agricultural and media stakeholders while the rest passed the information to the community. A KII respondent from RLACC said that they mainly target smallholder pastoralists, who are drivers of many African economies but their potential is tamed by the unavailability of relevant information whereby biodiversity information is vital and inappropriate pastoralist methods.

CRS-Kenya County Director stated that their primary target is the general public due to financial challenges, using media tools such as the radio, mobile phone, and the Internet. They communicate biodiversity data and information, weekly and monthly predictions, warnings and advisories, and information on impending drought, threats, and other effects on pastoralists.

FGD respondents agreed that the primary source of terrestrial biodiversity data and information was the local radio broadcast, which always broadcasts news on the biodiversity data we should expect locally, especially after the news prime times. Some respondents found it more convenient to tune to the radio station during "news time," confirming the need for proper timing and timing when reaching out to pastoralists using radio shows.

In addition to biodiversity data, pastoralists-advisory information would be useful in helping them prepare for biodiversity change, such as an Almanac indicating the month suitable for selling off animals, information on how to control cattle diseases, and information on habitat availability in the neighborhood. The chairperson of the CFA explained that IoTs help them obtain first-hand knowledge of significant issues on biodiversity change variability, and therefore is equipped to guide others in community association groups in making better decisions for their pastoralist and agricultural activities.

To overcome distrust of the accuracy of biodiversity data, KWS and KFS have facilitated training to the first point of contact, the intermediaries. A hybrid of communication methods, including face-to-face interactions and capacity training, has been employed to make biodiversity data more clear and accessible to users. Chiefs' barazas are conducted in the dominant language (Ng'aturkana) for faster assimilation and implementation, while seminars and Trainers of Trainers sessions involve more educated community members. These barazas also inform residents of periodic predictions and how to prepare for extreme weather patterns, such as when to sell cattle to avoid deaths during extreme droughts. This approach enables conversations to emerge among community members and provides opportunities for those who need clarity to obtain the same from leaders and share experiences.

Both rural communities in Turkana prefer terrestrial biodiversity data and information in a location-specific format due to eco-climatic variations in Turkana. Respondents prefer terrestrial biodiversity data in the local dialect and voice-activated formats for inquiries and clarifications. Receiving terrestrial biodiversity data by key informants, intermediaries, and CFA leaders is free of charge, but service providers charge for further information. Organizations that produce pamphlets distribute them to their target groups at no cost, ensuring that biodiversity data is affordable and accessible to everyone in the community.

However, issues of clarity and ease of understanding of terrestrial biodiversity data raise concerns. For example, many small-scale pastoralists are illiterate and ignorant, and interpreting information in their native language is difficult due to financial constraints. Collaboration with other stakeholders, such as radio stations broadcasting in the vernacular language, is crucial for addressing these challenges.

Key informants from local radio stations are happy that they can use the local language to reach the public, and the Turkana County Ministry of Agriculture and Environment officials also use both English and Swahili in publications. Using a variety of complementary communications is crucial for farmers' trust and acceptance of terrestrial biodiversity data. Key informants suggest using radio shows, videos, and voice-activated messages to raise awareness and sensitize pastoralists on issues.

Various ways for enhancing the dissemination of terrestrial biodiversity data include offering extensive capacitive training to pastoralists, organizing trade fairs, offering toll-free services for biodiversity data, using complementary communications approaches, collaborating among organizations, creating awareness to the public on the importance of receiving biodiversity information, and utilizing bulk SMS methods to reach all pastoralists.

DISCUSSIONS

The study focuses on the application and use of NB-IoT-based terrestrial biodiversity data, its usability, knowledge and awareness, frequency of use, relevance, accuracy, and timeliness. It also addresses their willingness to pay more for access to TBD and their methods of delivery.

The qualitative and quantitative findings support the idea that pastoralists who had access to and were aware of data on terrestrial biodiversity and pastoral advice provided by IoTs used the information to influence their way of life. The production of their animals has increased, as have their savings and incomes, giving them more access to loans and stable living conditions. Most pastoralists claimed that they had benefited from better understanding and awareness of terrestrial biodiversity data, including flora, animals, natura, conservation measures, geographical ranges, and biodiversity threats. This information was gathered from focus groups and key interviews.

Most participants accurately utilized the knowledge and information they had gained, which increased productivity in the pastoral sector and enhanced living conditions. The change in terrestrial biodiversity was made easier for pastoralists to adapt to. This indicates that the accuracy, utilization, and application of the information accessed had an impact on the production of the pastoralists. After receiving IoT-based data on terrestrial biodiversity, the population of Turkana County were able to practice modern pastoralism and attain food security. Water conservation and livestock pasture management were two of the contemporary pastoralism methods that were embraced by the pastoralists.

The respondents added that they use IoT-based terrestrial data and information to preserve the environment, avoid soil erosion, benefit birds and other creatures, and the sustainability of their way of life. Ecosystems that have been preserved and restored as well as the biodiversity they support can help slow down climate change and boost a region's capacity to withstand pressure from growing populations and natural disasters. All communities gain from healthy ecosystems in the form of clean air, water, food, raw materials, and medicines.

The study further established that pastoralists were able to more efficiently use their land and scarce water resources by applying and using specially created IoT-based terrestrial biodiversity data (fauna, flora, conservation measures, biodiversity threats, and pastoral advisories). The pastoralists were then in a position to plan for their animals and time the drought effectively.

Participants in the KIIs and FGDs applied and used data on terrestrial biodiversity, believing that biodiversity is significant on three levels: the genetic, species, and ecosystem levels. Pastoralism has a crucial role to play in the conservation and sustainable use of biodiversity at each level due to the strong ties between pastoral peoples, the ecosystems in which they live, and the animals they raise.

Radios are the most widely used Internet of Things (IoT) device to access TBD, particularly in regions where there are physical barriers to access and share data. Pastoralists could overcome geographic limitations via radio broadcasts, making radio a key resource for pastoralism. However, rural populations' limited access to essential IoT equipment, such as radios and smartphones, hinders their ability to make decisions on TBD as households.

The results of the household survey revealed difficulties with IoT access in terms of accessibility, availability, affordability, and service quality. People in rural areas are more likely than any other population group to be impacted by the low usage of IoTs. The technology acceptability study examined the residents' actual experiences based on the relevant information that was available.

Despite these obstacles, pastoralists from neighboring communities were able to access and use TBD because of social capital and communication channels using IoT devices. Credit, savings, and remittances are some examples of financial services provided by IoTs that have facilitated improved access to TBD and increased their ability to support themselves through livestock farming. Some people found that having access to NB-IoT-based TBD improved their financial situation and raised remittances from relatives living overseas and in other cities.

CONCLUSIONS

The study found that various factors influenced the performance of IoT-based terrestrial biodiversity data and its impact on sustainable livelihoods. Understanding the TBD requirements of pastoralists in their unique technological, social-cultural, and social-economic contexts was crucial for the success of IoT-based TBD services. The study found that enhanced IoT provided pastoralists with additional options, empowering them to seek more TBD. The solution rested on how IoT was applied in a community environment to benefit the users.

IoTs provided quick and convenient communication options for rural households, boosting their capacity to access and utilize resources for their subsistence. Popular IoT devices, such as smartphones and local community FM radio stations, reduced poverty and improved rural residents' standard of living. Social networks improved people's capacity to respond to crises and collaborate, reducing costs and enhancing productivity. Smartphones also reduced travel expenses, increasing productivity and the capacity to send and receive money. NB-IoT devices, particularly smartphones, enabled real-time communication of TBD, enabling better markets, pricing, and time savings.

RECOMMENDATIONS

The research aims to enhance local stakeholders' understanding of using IoT devices to access terrestrial biodiversity data. It suggests connecting with pastoralism experts and exchanging technical information. IoT service providers, such as mobile phone companies and community radio stations, can increase their clientele in rural areas through innovative packages, budget-friendly packages, and tailored messaging. This knowledge will benefit policymakers, researchers, practitioners, and rural communities, promoting better use of IoTs for data on terrestrial biodiversity and commissioning relevant research. The study's shortcomings may serve as a foundation for further research, aiming to understand the many IoT devices that enable timely transmission of data to meet development goals.

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