Indigenous-Led Forest and Land Conservation in Response to Climate Change Using AI Models.

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Abstract

The accelerated impacts of climate change have significantly worsened forest degradation and land mismanagement. This study aimed to explore how AI could be integrated with IKS to promote climate-resilient land and forest management. A mixed-methods approach was employed. Primary data were collected through semi-structured interviews and focus group discussions, while secondary data were obtained from relevant literature. The population sampling technique used was purposive, and the sample size was 30. The selected participants were 12 Indigenous elders, 10 traditional leaders, and 8 environmental officers. Data were gathered through 15 semi-structured interviews, 3 focus group discussions, and a review of relevant secondary sources. Indigenous indicators, such as phenological patterns and sacred groves, were carefully documented. Findings showed that 85% of environment officers and traditional elders believed that traditional ecological markers could complement AI algorithms. The primary data confirmed the continued effectiveness of Indigenous monitoring methods, while secondary sources supported AI's potential in recognising patterns. However, 70% expressed concerns over data ownership, cultural sensitivity, and the relevance of AI applications. The study recommended the integration of IKS and AI for climate resilience through Forest and Land Conservation.

Keywords: Indigenous Knowledge Systems (IKS), Artificial Intelligence (AI), Forest Conservation, Climate-Resilient Land Management, Environmental Monitoring.

Introduction

Climate change has intensified environmental stresses globally, with profound impacts on forest ecosystems and land management, particularly in vulnerable regions such as Zimbabwe's Chivi District. The degradation of forests and mismanagement of land resources pose significant threats to ecological sustainability and community livelihoods [Chibememe et al., 2014; Mutelo 2023]. Indigenous Knowledge Systems (IKS) have historically played a critical role in maintaining resilient ecosystems through deeply rooted cultural practices and environmental stewardship. These systems offer valuable insights into local ecological patterns and sustainable resource management, having evolved over centuries of intimate interaction between communities and their environment [Chingombe et al., 2021].

Concurrently, Artificial Intelligence (AI) has emerged as a powerful tool for environmental monitoring, prediction, and management. AI techniques such as Random Forest classifiers, Convolutional Neural Networks (CNNs), and Support Vector Machines (SVMs) have been successfully applied in developed countries to address challenges such as deforestation detection, wildfire prediction, and land degradation assessment using large-scale data sources such as satellite imagery and remote sensing [Mugabe et al. 2012]. Despite these advances, AI applications often lack local contextualization and do not incorporate the rich ecological knowledge embedded in Indigenous practices [Marumure and Makuvara 2022].

Although the integration of Artificial Intelligence (AI) and Indigenous Knowledge Systems (IKS) presents significant opportunities for climate-resilient conservation, its implementation remains constrained. This due to epistemological differences, concerns over Indigenous data sovereignty, and limited technological infrastructure in many rural African settings [Mugambiwa 2018].

This study explored the potential of harmonising AI with Indigenous ecological knowledge to foster climate-resilient forest and land conservation in Chivi District. It focused on documenting Indigenous conservation practices, identifying suitable AI applications, and designing a conceptual framework that respects Indigenous worldviews and promotes ecological justice. Through a mixed-methods approach involving Indigenous elders, traditional leaders, and environmental officers, this research aims to bridge the gap between modern technology and traditional knowledge, ultimately contributing to sustainable environmental management and community empowerment in climate-vulnerable regions.

1. Background of the Study

Climate change-induced environmental stress has become a global challenge, triggering diverse responses in forest and land management worldwide [Mtupile and Liwenga 2017]. Developed countries experiencing climate stress, such as the United States, Australia, and parts of Europe, have increasingly adopted Artificial Intelligence (AI) technologies. AI applications have been applied for forest monitoring, deforestation detection, wildfire prediction, and land use classification [Nyahunda and Tirivangasi 2019]. These AI applications mainly rely on large-scale satellite imagery and remote sensing to track vegetation health, soil moisture, and other critical environmental variables. An example of an AI application is the AI-enabled wildfire early-warning systems in the United States of America and Australia, which have improved disaster response times and reduced wildfire damage, demonstrating considerable effectiveness [Masunungure and Manyani 2020]. Precision forestry using AI-driven growth and yield applications has also improved timber production efficiency. However, these AI applications are mainly limited by data quality issues, model interpretability, and lack of local contextualization, thus reducing their applicability in certain regions.

In parallel to the advanced AI applications, many developed countries have recognised the value of Indigenous Knowledge Systems (IKS) in environmental stewardship. IKS encompasses traditional ecological practices, cultural rituals, and land management methods that have evolved over centuries [Mutandwa et al. 2019]. In Australia, Indigenous fire management, which is known as *cultural burning*, has effectively reduced the severity and frequency of wildfires, improved biodiversity, and restored ecosystem health. Similarly, in Canada, Indigenous use of ecological indicators has guided sustainable harvesting and conservation with considerable success. Despite their effectiveness, these indigenous knowledge systems face challenges from modern land-use pressures, policy exclusion, and limited formal recognition [Nyahunda and Tirivangasi 2019]. Integrating IKS with AI tools is still in its early stages; despite its promise, this integration faces challenges from epistemological differences and data sovereignty concerns, which can undermine trust and participation. In developing countries, including those in the Southern African Development Community (SADC), AI adoption for environmental management is increasing but remains limited. South Africa and Botswana have implemented AI applications such as Random Forest and time series analyses to monitor land degradation and forecast agricultural [Jerikias et al. 2022]. These applications have improved early warning systems and resource allocation but often lack fine-scale, community-specific data. Explicit integration of IKS with AI tools is rare. Indigenous communities in these regions continue to employ ecological knowledge such as phenological observations, sacred groves, and soil indicators that have effectively sustained local ecosystems for generations. However, these practices are under threat from environmental degradation and socio-economic changes, and their exclusion from formal conservation strategies limits complete effectiveness.

Zimbabwe's marginalised semi-arid regions, such as Chivi District, are highly vulnerable to climate change impacts including drought and deforestation. Indigenous ecological knowledge in these areas, such as the use of sacred groves, seasonal indicators, and traditional soil conservation methods, has historically contributed to ecosystem resilience and sustainable land use [Mudombi and Nhamo 2014]. Specific IKS practices

for soil and forest management include *zai pits,* which are small planting basins that enhance water retention and soil fertility, contour ridges to reduce soil erosion, and the protection of indigenous tree species known for their deep roots and soil-binding properties. The use of natural mulches from leaf litter and crop residues has helped to maintain soil moisture and organic content.

The government of Zimbabwe, through the Ministry of Lands, Agriculture, Water and Rural Resettlement, has implemented several initiatives to combat land degradation and promote afforestation [Mavhura and Manyangadze 2021]. These include the Zimbabwe National Tree Planting Program, which fosters community participation in reforestation, and the Conservation Agriculture Program, aimed at improving soil fertility and reducing erosion. Traditional leaders continue to play a key role by encouraging local communities to uphold customary practices, enforce grazing controls, and protect culturally significant natural sites. These efforts have created a foundation for local engagement in land and forest stewardship, particularly in vulnerable, semi-arid regions [Shoko 2020].

Building on this foundation, several community-based natural resource management (CBNRM) initiatives have emerged. The Communal Areas Management Program for Indigenous Resources (CAMPFIRE) is one of the most prominent examples, enabling communities to manage wildlife and benefit economically from ecotourism and conservation [Mavhura and Manyangadze 2021]. The Zimbabwe Community Forest Association (ZCFA) supports participatory forest governance and woodland regeneration. In Chiredzi, the Chiredzi River Support Project (CRSP) promotes sustainable watershed management and agroecological practices. Similarly, the Mazvihwa Community Land Project integrates traditional ecological knowledge with grazing rotation and permaculture to restore degraded landscapes. These initiatives rely on continued community involvement and aim to link traditional knowledge with sustainable land use. However, they often face challenges such as limited funding, weak integration of Indigenous Knowledge Systems (IKS), and minimal use of modern monitoring technologies. Therefore, addressing these issues requires participatory, knowledge-driven approaches that bridge local traditions and advanced tools for adaptive environmental governance [Nhundu et al. 2021].

In order to strengthen conservation outcomes, there is a growing recognition of the need for collaborative frameworks that involve government agencies, traditional leaders, scientists, and communities. These partnerships promise to ensure that AI tools are adapted to local contexts and that Indigenous practices continue to inform sustainable land and forest management, especially in climate-vulnerable regions such as Chivi District. The advantages of integrating AI with IKS include improved environmental monitoring precision, development of culturally relevant conservation strategies, enhanced community engagement, and preservation of cultural heritage. However, limitations exist, such as infrastructural challenges, data ownership concerns, ethical issues, and potential misalignment between AI applications and Indigenous worldviews.

This study aimed to address these gaps by exploring how AI can be harmonised with Indigenous ecological knowledge to support climate-resilient land and forest management. It emphasised culturally sensitive, co-created frameworks that respect Indigenous epistemologies, promote ecological justice, and enhance sustainable environmental governance in vulnerable regions.

2. Problem Statement

Forest degradation and land mismanagement have become increasingly severe in Zimbabwe, particularly in rural areas such as Chivi District, due to the growing impacts of climate change. These environmental challenges are disrupting ecosystems, reducing agricultural productivity, and threatening the livelihoods of local communities. While Indigenous Knowledge Systems (IKS) have historically supported the sustainable management of natural resources through practices such as sacred site protection, seasonal planting, and traditional weather forecasting, these practices are increasingly being overlooked in favour of externally introduced methods. At the same time, Artificial Intelligence (AI) has emerged as a powerful tool for environmental monitoring and predictive modelling, but its implementation often lacks cultural relevance and community input, especially in African rural contexts.

There is currently a gap in the integration of IKS and AI for forest and land conservation in Zimbabwe. Most conservation and environmental monitoring strategies either rely heavily on modern technologies without local engagement or treat Indigenous knowledge as secondary, leading to poor adoption and limited impact. This lack of integration risks losing valuable Indigenous practices and fails to leverage AI's full potential in addressing climate-related challenges. Therefore, there is a critical need to develop a practical, culturally grounded framework that combines AI tools with Indigenous ecological knowledge to promote climate-resilient and community-led forest and land conservation in Chivi District. This study sought to address this gap by exploring how these two systems can work together effectively.

3. Conceptual Framework

This study's conceptual framework explores the integration of Indigenous Knowledge Systems (IKS) and Artificial Intelligence (AI) to support climate-resilient forest and land conservation in Chivi District, Zimbabwe. Grounded in Social-Ecological Systems Theory, Knowledge Co-Production Theory, and Postcolonial Theory, the framework recognises Indigenous ecological knowledge such as phenological indicators, sacred groves, and customary land practices as vital to sustainable environmental management. These knowledge systems have long guided resource stewardship, and when strategically combined with AI technologies such as Random Forest classifiers, they can enhance the precision, contextual relevance, and scalability of conservation efforts.

The framework promotes a synergistic relationship where Indigenous knowledge informs and enriches AI applications, while AI enhances the analysis and monitoring of complex environmental dynamics. Emphasis is placed on community participation, ethical data use, and protection of cultural values and data sovereignty. Rather than replacing traditional practices, AI tools are positioned as complementary, offering decision support that respects local contexts. This integrated approach aims to foster an adaptive, inclusive, and culturally grounded model for forest and land conservation that is both scientifically robust and socially sustainable in the face of climate change.

4. Methodology

This study used a mixed-method approach to explore how Indigenous Knowledge Systems (IKS) and Artificial Intelligence (AI) can be combined to support climate-resilient forest and land conservation in Chivi District, Zimbabwe. Primary and secondary data were collected to understand the practical relevance of Indigenous ecological knowledge and the technical capabilities of AI. A total of 30 participants were purposively selected based on their roles and knowledge in the local environment. There were 12 Indigenous elders, 10 traditional leaders, and 8 environmental officers. Data collection tools used were interview guides, focus group discussions (FGDs, audio recorders, and notebooks for recording ecological observations. Primary data was collected through semi-structured interviews, focus group discussions (FGDs), and field observations. Interviews of 15 in total were used to gather individual experiences and insights into traditional ecological markers. The variables focused on included sacred groves, seasonal animal behaviours, and rainfall prediction techniques. Three focus group discussions (FGDs) were allowed for collective reflection on the use and value of these traditional indicators. Field observations were conducted to physically document sacred sites, degraded areas, and local farming practices.

Furthermore, secondary data sources including environmental reports, policy documents, and academic literature were reviewed. These were used to understand the existing AI applications in environmental monitoring and land use management. These sources helped assess the potential role of AI tools in interpreting environmental variables such as vegetation cover, rainfall patterns, and land degradation. The data were analysed using both thematic analysis for qualitative inputs and descriptive statistics for quantitative feedback. Therefore, the conceptual framework was developed from the findings to illustrate how Indigenous

indicators could complement AI applications in monitoring environmental changes. Ethical considerations were addressed through informed consent, cultural sensitivity in knowledge sharing, and ensuring data ownership remained with the community. The combination of local insights and technical analysis aimed to create a realistic, community-grounded solution for forest and land conservation in Chivi District.

5. Findings and Discussions

This section presented the findings of the study in relation to the research questions and objectives. Data were collected from 30 purposively selected participants, comprising 12 Indigenous elders, 10 traditional leaders, and 8 environmental officers. The data were analysed using thematic analysis and descriptive statistical techniques. These findings were discussed in relation to the study's conceptual framework and relevant scholarly literature to provide context, interpret the results, and highlight their implications.

5.1 Demographic Profile of Participants

The study engaged 30 purposively selected participants comprising Indigenous elders (40%), traditional leaders (33.3%), and environmental officers (26.7%), whose age distribution further reflects a strong representation of knowledge holders aged 41 years and above (63.3%). This demographic composition aligned with the study's conceptual framework, which emphasised the co-production of knowledge by blending Indigenous epistemologies with scientific and technological approaches. Elders and traditional leaders served as custodians of oral ecological traditions, phenological indicators, and customary land stewardship practices. While environmental officers contributed technical expertise necessary for AI-driven conservation modelling. Therefore, by involving both cultural knowledge bearers and environmental professionals, the study established a foundation for integrated, climate-resilient conservation strategies. Table 1 below summarises the demographic characteristics of the population:

Table 1. Demographic distribution of study participants (n=30)

Demographic Variable	**Category**	**Number of Participants**	**Percentage (%)**
Age Group	30–40 years	6	20.0
	41–50 years	10	33.3
	51–60 years	9	30.0
	Above 60 years	5	16.7
Total		**30**	**100**
Profession/Role	Indigenous Elders	12	40.0
	Traditional Leaders	10	33.3
	Environmental Officers	8	26.7
Total		**30**	**100**

5.2 Indigenous Conservation Practices and Ecological Indicators

The study identified several critical Indigenous conservation practices and ecological indicators currently employed in Chivi District. Participants consistently emphasised the importance of sacred grove areas. These are preserved due to their spiritual significance and biodiversity richness, which serve as critical refuges for native flora and fauna. The phenological signs, including the flowering patterns of indigenous trees such as mupfura (*Sclerocarya birrea*), were widely used. These were used to predict climatic events such as rainfall and drought, thereby guiding agricultural and conservation decisions [Nhundu et al., 2021]. Furthermore, communal practices such as *Zunde Ramambo*, a traditional grain-sharing system, proved to play an essential role in ensuring food security during times of environmental stress. Other practices identified

included spirit mediums and rituals, which offer ancestral guidance for environmental stewardship, and taboo-based land-use restrictions. These were used to protect ecologically sensitive areas from overexploitation. The convergence of these practices reflects a deeply rooted Indigenous knowledge system that sustains local environmental management.

In parallel, participants expressed a cautiously optimistic view on the potential of Artificial Intelligence (AI) to complement rather than replace these Indigenous systems. AI applications were seen as valuable tools to enhance environmental monitoring and data analysis. Participants noted that these applications could detect illegal logging and environmental degradation within sacred groves more quickly and accurately than traditional monitoring methods. This capability enabled both community members and government authorities to respond promptly, facilitating timely interventions before extensive damage occurred [Chingombe et al., 2021]. Mudombi and Nhamo [2014] highlight that AI applications can integrate climatic data with Indigenous phenological indicators to improve the accuracy of seasonal forecasting. This therefore improves accurate data-driven decision-making during agricultural planning. These can further be used to monitor compliance with traditional land-use restrictions, strengthening conservation enforcement and promoting the sustainable management of natural resources.

These insights were echoed in participant interviews, where an environmental officer noted that, "*AI assists in rapidly analysing satellite images to identify environmental threats, especially when combined with elders' deep knowledge of sacred sites*". Similarly, an Indigenous elder acknowledged that "*AI could serve to validate traditional observations but emphasised that technology must respect and collaborate with Indigenous ways rather than supplant them*". Collectively, these findings emphasise that Indigenous ecological knowledge provides vital context-specific indicators for environmental monitoring and conservation. AI complements this knowledge by offering enhanced analysis and forecasting capabilities. Hence, Indigenous ecological knowledge and AI form a scientifically robust and socially sustainable approach to climate-resilient conservation in Chivi District.

Table 2. Indigenous ecological indicators reported by participants

Indicator	Description	Frequency	% of Participants
Sacred groves	Areas preserved due to spiritual significance, often rich in biodiversity	26	86.7%
Phenol-biological signs (e.g., flowering)	Seasonal plant and animal behaviours used to predict rainfall and drought	21	70.0%
Zunde Ramambo	Communal grain farming to ensure food security during droughts	18	60.0%
Spirit mediums and rituals	Ancestral spiritual guidance in environmental decision-making	15	50.0%
Taboo-based land-use restrictions	Prohibitions on resource extraction in sacred or ecologically sensitive areas	17	56.7%

The findings of this study (Table 2) are strongly supported by existing literature that highlighted the importance of integrating (IKS) with modern technologies to enhance sustainable environmental management. Mavhura et al. [2016] emphasised the depth and contextual richness of Indigenous ecological knowledge, including sacred groves and phenological indicators, which are critical for climate-resilient conservation. This aligns with the study's participant insights and the conceptual framework grounded in Social-Ecological Systems and Knowledge Co-Production theories. The complementary role of Artificial Intelligence (AI) is well-documented in environmental research for improving the precision and scalability of ecological monitoring and predictive analysis [Marumure and Makuvara 2022]. Furthermore, the study's focus on ethical data governance and community participation reflects Postcolonial Theory perspectives that advocate for decolonising research methodologies and protecting Indigenous data sovereignty Chibememe et al. [2014]. This integrated approach, which combines Indigenous knowledge with AI tools, aligns with best practices for socially just and scientifically robust conservation. It reinforces the potential of such applications to ad-

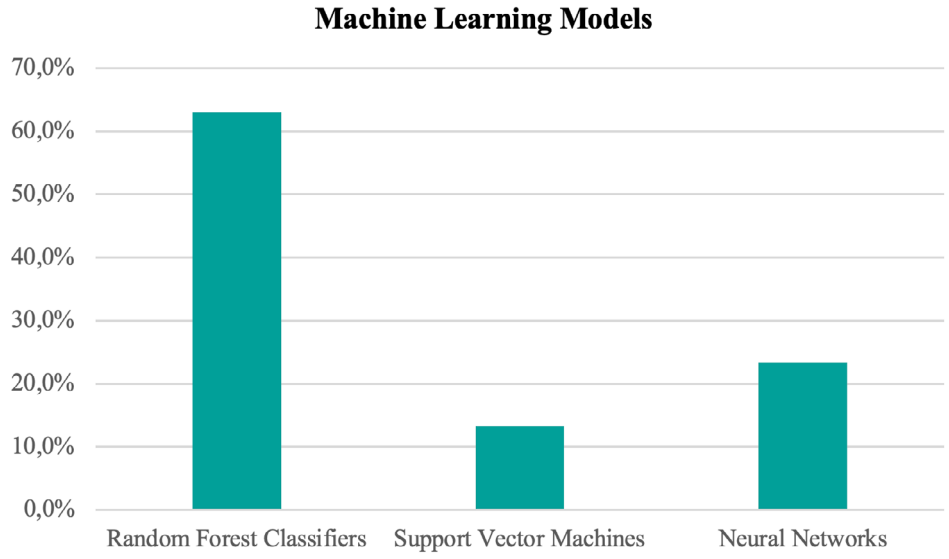
dress complex climate challenges while respecting and preserving cultural values.

5.3 AI Applications for Climate-Resilient Environmental Monitoring

The determination of the most appropriate AI applications for supporting climate-resilient environmental monitoring in Chivi District was derived through qualitative data. This was collected via semi-structured interviews and focus group discussions with 30 purposively selected participants, including Indigenous elders, traditional leaders, and environmental officers. These tools enabled a nuanced understanding of local environmental challenges, Indigenous ecological knowledge, and perceptions regarding the integration of Artificial Intelligence in conservation efforts. The interactive nature of FGDs facilitated collective validation of suitable AI techniques, reflecting the principles of Knowledge Co-Production Theory that emphasise collaborative generation of knowledge between Indigenous communities and technical experts.

The study collected data through semi-structured interviews and focus group discussions to identify the AI applications most appropriate for supporting climate-resilient environmental monitoring in Chivi District. The qualitative data revealed a strong preference for Random Forest classifiers, with 63.3% of participants endorsing this model due to its strength in handling complex, non-linear environmental data and its compatibility with Indigenous ecological indicators. Neural Networks were supported by 23.3% of respondents, noted for their ability to model intricate patterns, while Support Vector Machines (SVM) received 13.3% backing, primarily for their effectiveness in classification tasks. Furthermore, the importance of safeguarding Indigenous knowledge and data sovereignty emerged strongly in discussions, supporting the Postcolonial Theory embedded in the conceptual framework. Participants voiced concerns about ethical data handling and the necessity of ensuring that AI tools complement rather than supplant Indigenous practices. The AI applications developed using Random Forest, SVM and Neural Networks were seen not as replacements but as complementary decision-support systems. These can enhance local capacity for climate adaptation and forest conservation. These preferences were summarised in Table 3 below.

Fig 1. AI Applications Using Different Machine Learning Models



The study's findings indicated a significant preference for Random Forest Classifiers, with 63.3% (n=19) of participants, which were 7 environmental officers, 6 traditional leaders, and 6 indigenous elders. During Focus Group Discussions (FGDs), participants explained that the application that employed Random Forest had the ability to handle multiple inputs such as soil moisture, vegetation cover, and rainfall trends, which resonated with Indigenous ecological practices, which are themselves based on multiple natural indicators. One participant, a traditional leader, said that, "*Our ancestors never relied on one sign. They observed many things: the trees, the stars, the wind. So, if the machine can do the same with data, it will be very helpful to us*."

This insight supports the co-creation conceptual framework supporting the study, promoting complementarity between AI and IKS. According to Makondo and Thomas [2018], the success of technology in community-based conservation is linked to its alignment with local epistemologies. Therefore, the application model provided a technical analogy to the multi-indicator systems of Indigenous knowledge.

Conversely, the application model implementing Support Vector Machines (SVMs) was supported by only 13.3% (n=4), mainly younger environmental officers familiar with digital classification systems. FGDs revealed that while SVMs were acknowledged for their accuracy in binary classification, participants found them less intuitive and less flexible than Random Forests in real-world circumstances. Meanwhile, applications implementing Neural Networks received endorsement from 23.3% (n=7) participants, primarily young traditional leaders and two officers, due to their capacity to identify complex non-linear patterns. However, many elders and some leaders voiced ethical concerns, citing a lack of explainability and data transparency, core tenets in the conceptual framework and the AI ethics literature Chibememe et al. [2014]. One elder said that during an FGD:

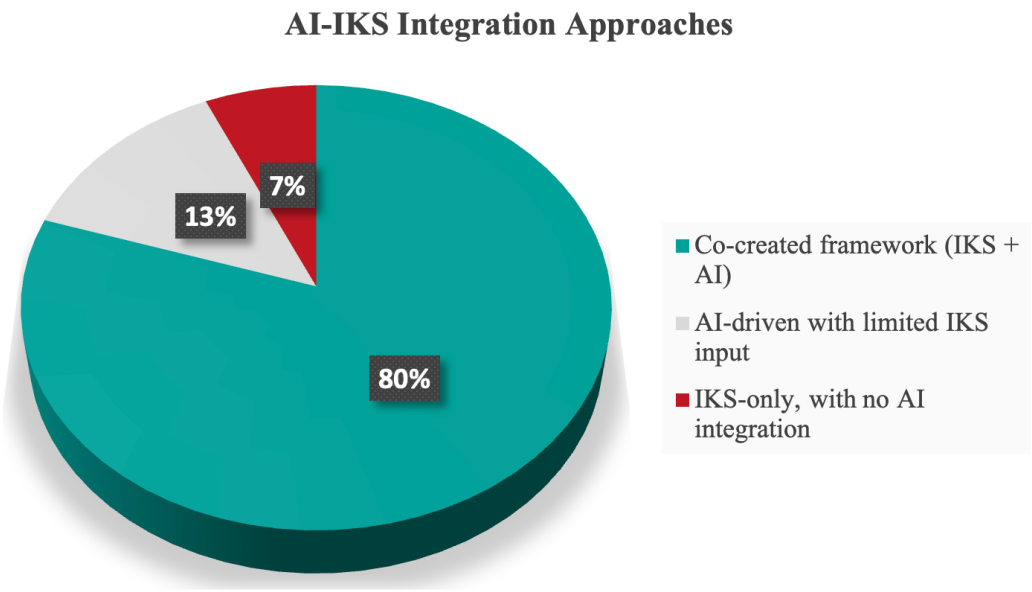
> *"If the system cannot explain why it gave a result, then it is not wiser than the people. We need to see the thinking of the tool."*

These findings reinforced the importance of participatory design, where Indigenous values and practices shape the selection and application of AI applications. The Random Forest's popularity is not only technical but also symbolic; it reflects a model that mimics Indigenous reasoning and pluralistic knowledge systems. The discussion confirms the conceptual framework of integration developed in the study, showing that culturally-aligned, interpretable AI applications have the highest potential for uptake and sustainability in forest and land conservation efforts in Chivi District.

5.4 Integrating Indigenous Knowledge and AI for Conservation

The integration of Indigenous Knowledge Systems (IKS) with Artificial Intelligence (AI) emerged as a critical theme from semi-structured interviews and focus group discussions. Participants consistently emphasised that effective integration requires a respectful and collaborative approach. They noted that Indigenous ecological knowledge should serve as the foundational data input and validation point for AI applications. This aligned with Knowledge Co-Production Theory, advocating for the joint creation of knowledge through partnerships between Indigenous communities and scientific practitioners. The phenological events identified by elders were flowering or bird migrations signalling seasonal changes. These could be encoded as key ecological indicators within AI applications to improve the accuracy of environmental monitoring and prediction of climate impacts. The sacred groves and customary land-use maps could be digitised and integrated into geospatial AI analyses. Therefore enhancing the precision and cultural relevance of conservation zoning. Furthermore, the findings revealed that AI tools could analyse large-scale environmental data while being continuously calibrated and validated using Indigenous observations. This therefore revealed that AI complements rather than replaces traditional practices. This approach reflected Social-Ecological Systems Theory by recognising the interdependence between Indigenous communities and their environment. Hence, the findings suggested that the integration of IKS with AI through participatory and ethical frameworks can foster adaptive, scientifically strong, and socially sustainable forest and land conservation strategies.

Fig 2. Participant Preferences on AI-IKS Integration Approach



The findings of this study in fig 2 revealed a strong preference among participants for a co-created framework that integrates IKS and Artificial Intelligence (AI) for climate-resilient forest and land conservation in Chivi District. A significant 80% of respondents expressed support for a model that combines the wisdom of Indigenous practices alongside modern AI tools. This highlighted a growing awareness of the potential benefits of hybrid conservation strategies. These findings align with the co-production of knowledge framework proposed by Tengo et al. (2017), which advocates participatory approaches to environmental governance that integrate scientific and Indigenous knowledge systems. The conceptual framework developed in this study operationalises this approach by incorporating local ecological indicators, such as sacred groves, animal behaviour, and seasonal weather patterns, into AI applications, while ensuring community-led oversight and control of data processes [Mtupile and Liwenga 2017].

The demographic data revealed that the majority of participants were above the age of 40, and included a balanced mix of Indigenous elders, traditional leaders, and environmental officers. These groups bring diverse yet complementary insights; elders and traditional leaders contributed nuanced cultural and ecological knowledge, while environmental officers provided technical perspectives on how AI could enhance monitoring and decision-making[Mugabe et al. 2011]. In line with this, 91.7% of elders, 80% of traditional leaders, and 62.5% of environmental officers supported the co-creation model. One traditional leader remarked, "AI should not replace our ways but help us understand the changes faster. It must listen to our knowledge." This sentiment reinforces the position of Mavhura et al. [2016], who argue that for conservation to be effective and ethical, it must centre Indigenous agency and knowledge.

Findings from the focus group discussions (FGDs) added depth to these observations. Themes that emerged included the need for AI to be explainable and interpretable, respect for sacred knowledge, and a strong insistence on community data sovereignty. One participant stressed, "*Our land, our data,*" underscoring the importance of ethical AI use that does not exploit Indigenous communities. This resonates with the concerns raised by Chibememe et al. [2014] on the misuse of AI in traditional contexts without informed consent or cultural understanding. The participants emphasised that AI tools should function as amplifiers of Indigenous wisdom, not as replacements.

Additionally, the choice of AI applications indicated a preference for interpretable, robust tools. 76.7% of respondents favoured Random Forest classifiers, appreciating their ability to process multiple environmental variables while offering transparency. This suggests a deliberate preference for applications that can mirror the complexity of natural systems while remaining accessible to local stakeholders. Such a model fits into the socio-technical systems theory, where technology is shaped and made useful by the social systems into which it is embedded [Marumure and Makuvara 2022].

In conclusion, the study's findings strongly support the central aim: developing a community-informed, culturally respectful framework that combines the strengths of IKS and AI. By grounding AI model development in Indigenous ecological indicators and ensuring participatory governance structures, this research contributes to a decolonised approach to environmental management, one that values Indigenous epistemologies as valid and vital contributors to climate resilience.

6. Ethical, Cultural, and Practical Considerations

The integration of Artificial Intelligence (AI) with Indigenous Knowledge Systems (IKS) in Chivi District surfaced several ethical and cultural challenges, as highlighted through Focus Group Discussions (FGDs) and in-depth interviews. Participants voiced strong concerns over the potential misappropriation of sacred knowledge, misuse of ecological data, and the erosion of cultural practices if AI systems are developed without meaningful community involvement. One elder remarked, *"The trees and places we protect are not just resources; they are part of who we are. If computers take over without our voices, we lose our soul."* Therefore, such sentiments highlighted the importance of cultural sensitivity and the need for ethical AI design that respects Indigenous values. These concerns resonate with Postcolonial Theory, which critiques historical marginalisation and calls for equitable participation of Indigenous voices in technological interventions [Masinde 2015]. In order to address these concerns, participants recommended community-led data governance applications, emphasising data sovereignty, cultural protocols, and informed consent. Table 3 below summarises the key ethical and cultural challenges alongside proposed mitigation strategies.

Table 3. Ethical and Cultural Challenges Identified by Participants (n=30)

Challenge	Participants	Percentage (%)	Key Participant Group
Data Ownership Conflicts	18	85.7	Indigenous Elders, Env. Officers
Potential Misuse of Sacred Knowledge	16	76.2	Indigenous Elders, Traditional Leaders
Loss of Indigenous Autonomy	13	61.9	Traditional Leaders, Env. Officers
Concerns Raised by Environmental Officers (subset of above)	8	100	Environmental Officers

The data in Table 3 indicated that ethical and cultural challenges are a significant concern for 70% (21/30) of the study participants. 85.7% were worried about data ownership conflicts, 76.2% were concerned about the misuse of sacred knowledge, and 61.9% feared the loss of Indigenous autonomy. Indigenous Elders and Environmental Officers were particularly vocal about data ownership, while traditional Leaders expressed strong concerns about the protection of sacred knowledge. One Environmental Officer cautioned: *"Without proper safeguards, AI could marginalise Indigenous voices instead of empowering them."*

These findings corroborate the discourse on ethical AI presented by Muyambo and Maposa (2014). Their work emphasises the importance of transparency, fairness, and inclusive participation in AI deployment, particularly when sensitive cultural data are involved. Therefore, the study's conceptual framework incorporated culturally informed consent protocols, community-driven data stewardship, and continuous stakeholder engagement. These measures aim to safeguard Indigenous sovereignty over knowledge and data.

Furthermore, this aligned with Tengo et al. [2017]'s co-production framework, advocating that technology integration must respect and incorporate Indigenous worldviews to foster sustainable environmental governance. The participants' emphasis on data sovereignty and ethical safeguards situated the framework within a decolonial and socio-technical governance approach, ensuring AI serves as a tool for empowerment rather than exclusion.

7. Strategies for Indigenous Participation and Data Sovereignty

The findings revealed that effective integration of AI into conservation frameworks must be community-led, ethically governed, and grounded in culturally appropriate practices. Across all focus group discussions (FGDs) and key informant interviews, there was a shared emphasis on the need to preserve Indigenous autonomy, protect knowledge ownership, and ensure equitable participation in technological development. Participants collectively highlighted five key strategies (see Table 4).

Table 4. Recommended Strategies to Ensure Indigenous Participation and Data Sovereignty

Strategy	Number of Participants	Percentage (%)	Key Participant Group
Community-led AI Co-Design	25	83.3%	Indigenous Elders, Traditional Leaders
Culturally-Aware Data Governance applications	23	76.7%	Environmental Officers, Traditional Leaders
Legal Recognition of Data Sovereignty Rights	18	60.0%	Environmental Officers, Policy Stakeholders
Capacity Building for Digital Literacy	20	66.7%	Youth, Local NGOs
Use of Consent Protocols & Cultural Filters	22	73.3%	Indigenous Elders, Traditional Leaders

During an interview, one Indigenous elder remarked:

> *"Before any data is collected or shared, we must decide together. Our forests are not numbersthe, y carry spirits, stories, and laws."*

This reinforces Postcolonial Theory, which critiques extractive practices and demands the decolonisation of data and technology [Matunhu et al., 2022; Mutelo 2026]. It highlights the need to recognise Indigenous peoples not as data subjects but as data stewards and co-creators of AI systems. Similarly, the results align with Knowledge Co-Production Theory, which supports participatory design processes where AI applications are not imposed but rather developed in dialogue with Indigenous communities [Tengo et al. 2017]. One environmental officer in an FGD explained:

> *"AI tools are helpful, but they must be shaped by our traditions. If not, they will lead to the wrong decisions about the land."*

This finding also validated the Social-Ecological Systems Theory, which views ecosystems as dynamic and interlinked with social and cultural dimensions. Integrating AI into such systems requires context-specific approaches informed by local ecological knowledge, such as seasonal indicators, soil patterns, and wildlife behaviours unique to the Chivi District.

Mutasa [2015] argued that "*Indigenous data sovereignty is fundamentally about the right of Indigenous peoples to determine the means of collection, access, and use of data about their peoples, territories, and resources*", highlighting its centrality to self-determination in the digital era. In the same vein, Muyambo and Maposa [2014] emphasised that the exclusion of Indigenous peoples from data governance processes not only undermines trust but perpetuates epistemic injustice rooted in colonial histories. They emphasised that without Indigenous participation, AI systems risk reinforcing patterns of dispossession and invisibility. Furthermore, Mupepi [2022] cautions against technological paternalism, which is defined as the imposition of technological solutions on Indigenous communities without respect for their cultural protocols, consent, or epistemologies. These scholarly perspectives reinforce the need for community-led, culturally respectful, and ethically grounded AI integration strategies, as echoed by participants in this study.

The findings demonstrate that integrating Indigenous Knowledge Systems and Artificial Intelligence can support climate-resilient forest and land conservation in Chivi District. The study highlighted the need for co-created, culturally sensitive frameworks grounded in ethical principles and community participation. The

conceptual framework developed operationalises these insights, positioning Indigenous indicators as vital inputs within AI applications, while safeguarding Indigenous worldviews and data rights.

8. Recommendations

- Based on the findings, the following recommendations are proposed for climate-resilient forest and land conservation in Chivi District:
- Promote collaboration among Indigenous elders, traditional leaders, and environmental officers in the design of AI tools to ensure they incorporate Indigenous ecological knowledge and remain locally relevant and culturally appropriate.
- Establish transparent data governance mechanisms that empower Indigenous communities to control and own data collected from their lands, protecting sacred knowledge and strengthening data sovereignty.
- Develop targeted AI literacy and capacity-building programmes to enable community members to participate effectively in AI development, application, and monitoring.
- Ensure that AI applications follow ethical standards based on informed consent, cultural sensitivity, and protection of Indigenous intellectual property.
- Incorporate locally relevant ecological indicators, including sacred groves, phenological events, and traditional rainfall prediction methods, into AI models to improve environmental monitoring accuracy.
- Maintain continuous engagement with Indigenous stakeholders throughout AI implementation to build trust, incorporate feedback, and adapt tools to changing ecological and cultural contexts.
- Encourage government and local authorities to develop policies that recognise Indigenous knowledge and promote community participation in AI-driven environmental governance.
- Strengthen partnerships among Indigenous knowledge holders, AI specialists, environmental scientists, and policymakers to co-create sustainable and effective conservation strategies.

Conclusion

The study employed a mixed-method approach to capture the rich ecological knowledge of Indigenous communities alongside the capabilities of Artificial Intelligence (AI) applications. The results demonstrated that integrating Indigenous Knowledge Systems (IKS) with AI can create a culturally sensitive and practical framework for climate-resilient forest and land conservation in Chivi District, Zimbabwe. These findings revealed that while this integration holds significant promise, ethical and cultural challenges such as data ownership and the protection of sacred knowledge must be carefully managed. Therefore, addressing these concerns through community-led governance and capacity building ensures the framework respects Indigenous autonomy and promotes ecological justice. This research contributed valuable insights and a conceptual model that supports sustainable environmental management, enhancing resilience to climate change in local ecosystems and communities.

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