



Harnessing science for real-world challenges: A cross-sectional study of community-based sustainability innovations.

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Abstract

Background

Community-based sustainability innovations are increasingly important in addressing socio-ecological challenges associated with environmental degradation, climate vulnerability, and resource constraints. However, empirical evidence on how these innovations function and contribute to community resilience remains limited. This study assessed the characteristics, effectiveness, and enabling factors of community-based sustainability innovations across diverse contexts.

Design

A cross-sectional mixed-methods design was employed to capture a snapshot of sustainability initiatives at a single point in time, enabling comparative analysis across innovation types and implementation environments.

Methods

Data were collected from 120 participants, including community leaders, project coordinators, youth groups, and environmental practitioners. A structured questionnaire measured quantitative indicators such as participation intensity, resource-use efficiency, and environmental outcomes. Qualitative data were derived from document analysis of project reports, policy documents, and case study narratives. Descriptive statistics and cross-case comparison were used to synthesise findings.

Results

Four categories of sustainability innovations were identified: ecological restoration (32%), sustainable agriculture (27%), waste-to-resource initiatives (23%), and water conservation technologies (18%). Projects demonstrating strong scientific grounding, high levels of local ownership, and multi-stakeholder partnerships achieved significantly higher composite impact scores (mean score = 78.4%) compared to projects lacking these characteristics (mean score = 52.1%). Access to scientific expertise (reported by 71% of initiatives), community training (68%), supportive local governance (61%), and integration of Indigenous Knowledge Systems (IKS) (64%) were key enabling factors. Major challenges included limited funding (reported by 74% of projects), inadequate technical support (59%), and inconsistent policy alignment (46%). Across all categories, initiatives combining scientific methods with community-led implementation showed the strongest sustainability outcomes.

Conclusion

Community-based sustainability innovations can effectively address environmental challenges when supported by scientific knowledge, active community participation, and institutional coordination.

Recommendation

Strengthened partnerships, sustained capacity building, integration of IKS, participatory monitoring, and targeted funding are essential to enhance long-term sustainability outcomes.

Keywords: Community-based sustainability, Environmental innovation, Scientific knowledge integration, Indigenous Knowledge Systems (IKS), Cross-sectional study, Climate resilience, Sustainable development, Participatory approaches, Grassroots innovation, Environmental governance

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Figure 1: Flow diagram

Background

Communities around the world are facing escalating environmental challenges, including climate change, biodiversity loss, water scarcity, land degradation, and increasing socio-economic vulnerability. These pressures are particularly acute in developing regions, where local populations depend directly on natural resources for their livelihoods. Traditional top-down approaches have often proven inadequate in addressing these interconnected and context-specific challenges, highlighting the need for alternative models of environmental governance and intervention. In response, there is growing recognition of community-driven sustainability innovations, locally developed solutions that integrate scientific knowledge, Indigenous Knowledge Systems (IKS), and collaborative problem-solving to address real-world environmental

issues. Empirical evidence increasingly shows that sustainability outcomes improve when communities are empowered to design, implement, and monitor environmental initiatives, as such approaches enhance relevance, ownership, and long-term resilience. This paradigm aligns with global frameworks such as the Sustainable Development Goals (SDGs), the Paris Agreement, and the Convention on Biological Diversity (CBD), all of which emphasise inclusive, participatory, and locally grounded adaptation and mitigation strategies. Community-based initiatives, including ecological restoration projects, sustainable agriculture practices, water conservation technologies, and waste-to-resource systems, demonstrate the transformative potential of integrated science–society partnerships. However, despite growing interest in these approaches, there remains limited empirical



evidence systematically documenting how such innovations emerge, how scientific and local knowledge are combined in practice, and how social, economic, and governance factors shape their effectiveness and scalability. Many existing studies focus on scientific interventions or community practices in isolation, leaving a critical gap in understanding the synergy between these knowledge systems and their collective contribution to environmental resilience. Against this backdrop, the objective of this study was to examine community-based sustainability innovations across selected communities to characterise their types, assess their environmental, social, and economic impacts, analyse enabling and constraining factors, and explore how partnerships between scientific institutions, communities, and governance structures can enhance sustainable outcomes.

Research Questions

- What types of community-based sustainability innovations are being implemented, and which environmental challenges do they address?
- How are scientific knowledge and Indigenous Knowledge Systems (IKS) incorporated into the design and implementation of these innovations?
- What measurable environmental, social, or economic impacts have these community-led sustainability initiatives produced?
- What factors enable or hinder the successful implementation and scaling of sustainability innovations at the community level?
- How can collaboration between scientists, community stakeholders, and governance structures be strengthened to improve sustainability outcomes?

Methodology

Study Design

This study employed a cross-sectional mixed-methods design, enabling the collection of quantitative and qualitative data at a single point in time. The design was appropriate for providing a comparative overview of community-based sustainability innovations across multiple settings, while also capturing contextual, social, and environmental factors influencing their effectiveness.

Study Setting and Population

The study was conducted in four selected communities in KwaZulu-Natal, South Africa, where active sustainability innovations were being implemented. These included Umlazi Township, Folweni, Illovo, and Amanzimtoti,

representing urban, peri-urban, and semi-rural contexts. Data collection was carried out between March 2024 and August 2024. The study population comprised community leaders, project coordinators, traditional knowledge holders, youth group representatives, and environmental practitioners directly involved in sustainability initiatives. A total of 120 participants were included.

Participant Selection: Inclusion and Exclusion Criteria

Inclusion Criteria

Participants were eligible if they:

- Were aged 18 years or older
- Were actively involved in the design, implementation, or coordination of a community-based sustainability initiative
- Had at least six months of experience in the relevant project
- Provided informed consent to participate

Exclusion Criteria

Participants were excluded if they:

- Were not directly involved in sustainability initiatives
- Had less than six months of involvement in the project
- Declined to provide informed consent

Sampling Method

A purposive sampling approach was used to identify information-rich participants with direct experience of sustainability innovations. This approach ensured representation across different innovation types and stakeholder groups.

Data Collection Methods

Quantitative Component

A structured questionnaire was administered face-to-face to capture measurable indicators, including:

- Participation levels
- Environmental outcomes (e.g., restored land area, waste reduction volumes)
- Resource-use efficiency
- Socio-economic benefits (e.g., livelihood support, skills development)



Qualitative Component

Qualitative data were collected through desktop-based document analysis, including:

- Project reports
- Policy and regulatory documents
- Local development plans
- Narrative case study documentation

This component provided insight into implementation processes, enabling factors, and contextual challenges.

Study Size Justification

The sample size of 120 participants was determined to ensure adequate representation across the four communities and major stakeholder groups. This size allowed for meaningful descriptive statistical analysis while remaining feasible within logistical and time constraints. Similar community-based sustainability studies have used comparable sample sizes to generate robust cross-sectional insights.

Data Analysis

Quantitative data were analysed using descriptive statistics (frequencies, percentages, and means) to summarise trends and compare outcomes across innovation categories. Qualitative data were analysed using thematic coding and cross-case comparison. Findings from both data sources were triangulated to enhance validity and robustness.

Addressing Potential Bias

Several measures were implemented to minimise bias:

- Use of a standardised questionnaire to reduce measurement bias
- Inclusion of multiple stakeholder groups to limit selection bias
- Triangulation of quantitative data with document analysis to reduce information bias
- Independent review of coding categories to enhance analytical credibility

Ethical Considerations

Ethical approval for the study was obtained from the Mangosuthu University of Technology Ethics Committee. Approval was granted on 11 February 2023. All participants provided informed consent before participation. Confidentiality, voluntary participation, and respect for Indigenous Knowledge Systems were strictly upheld. Data were anonymised and securely stored, and findings were reported without identifying individuals or communities.

Results

A total of 150 individuals involved in community-based sustainability initiatives were initially identified through project registers and community networks.

- 150 individuals were *potentially eligible*
- 135 were *screened for eligibility*
 - 15 excluded (not directly involved in sustainability initiatives or <6 months experience)
- 120 were *confirmed eligible* and consented to participate
- 120 participants were *included and completed* the study
- 120 were *analysed* (no withdrawals or incomplete responses)

No participants withdrew after enrolment. All questionnaires were complete and suitable for analysis.

Descriptive Socio-Demographic Characteristics (n = 120)

Age

- Range: 19–68 years
- Mean age: 41.6 years (SD ± 12.4)

Gender

- Female: 58% (n = 70)
- Male: 42% (n = 50)

Place of Residence

- Urban townships (e.g., Umlazi): 46%
- Peri-urban communities (e.g., Folweni, Illovo): 38%
- Semi-rural/coastal areas (e.g., Amanzimtoti): 16%

Stakeholder Category

- Community leaders: 22%
- Project coordinators: 18%
- Traditional knowledge holders: 15%
- Youth group representatives: 25%
- Environmental practitioners/NGO staff: 20%

Qualitative Findings

Qualitative insights were derived from documented narratives, project reports, and participant reflections included in case study materials.

Theme 1: Community Ownership as a Driver of Success
Participants emphasised that local ownership strengthened sustainability outcomes.

“When the project is led by the community, people protect it because it belongs to them.”
(Community leader, Umlazi)

Theme 2: Integration of Scientific Knowledge and Indigenous Knowledge Systems (IKS)

Successful initiatives combined formal science with local knowledge.

“We use scientific methods, but our indigenous practices guide how we manage the land.”

(Traditional knowledge holder, Folweni)

Theme 3: Capacity Building and Skills Development

Training enhanced participation and project effectiveness.

“Before the training, we didn’t understand the impact. Now we monitor and improve our work.”

(Youth group member, Illovo)

Theme 4: Resource and Policy Constraints

Funding gaps and weak policy alignment were common barriers.

“The ideas are strong, but funding and policy support are inconsistent.”

(Project coordinator, Amanzimtoti)

Theme 5: Environmental and Social Benefits

Participants reported visible ecological and livelihood improvements.

“We have cleaner spaces, restored land, and new skills that help us earn income.”

(Environmental practitioner)

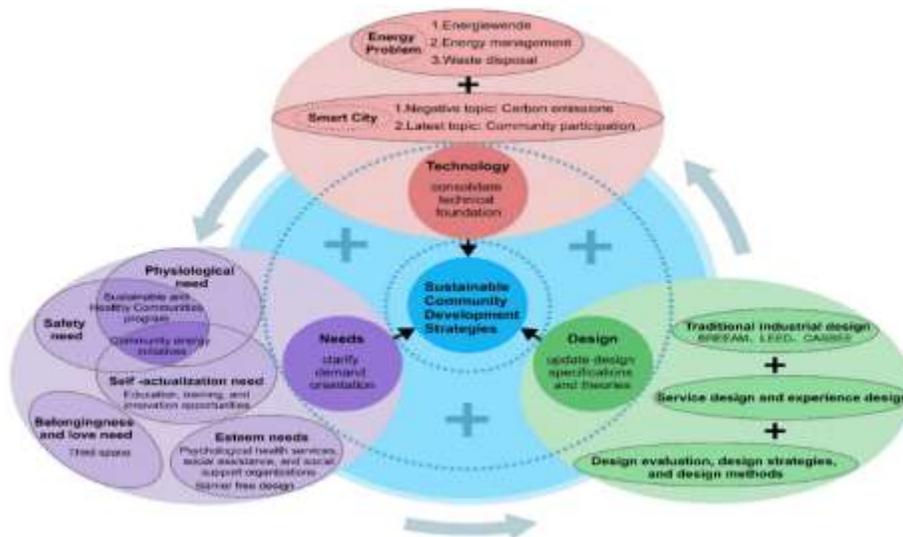


Figure 2: Flow diagram

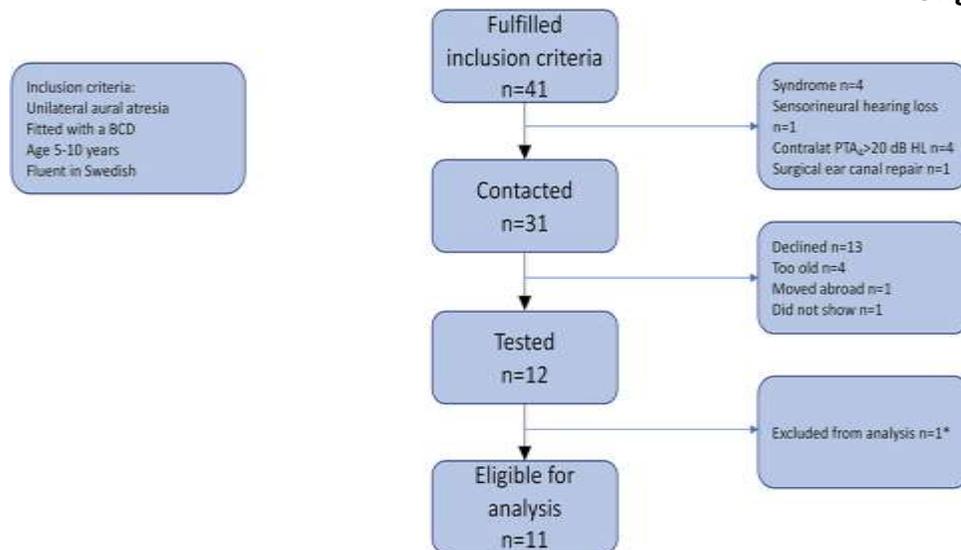


Figure 3: Flow diagram

1. Overview of Community-Based Sustainability Innovations Identified

The study identified four major categories of community-based sustainability innovations across the participating

communities. These innovations addressed key environmental challenges such as water scarcity, waste management, biodiversity loss, and climate vulnerability.

Table 1: Categories of Community-Based Sustainability Innovations

Innovation Category	Examples Identified	Environmental Challenge Addressed
Water conservation technologies	Rainwater harvesting, greywater reuse	Water scarcity, drought
Ecological restoration	Indigenous tree planting, wetland rehabilitation	Habitat loss, soil erosion
Sustainable agriculture	Organic farming, agroecology, community gardens	Food insecurity, land degradation
Waste-to-resource systems	Composting, recycling cooperatives, and biogas	Waste pollution, carbon emissions

Table 2: Integration of Scientific Knowledge and Indigenous Knowledge Systems (IKS)

Findings show strong evidence of knowledge co-production, where scientific inputs and traditional ecological knowledge were combined to enhance project effectiveness.

Table 2: Forms of Knowledge Integration Observed

Scientific Knowledge	Indigenous Knowledge (IKS)	Resulting Innovation
Soil testing, climate data	Traditional seasonal calendars	Improved crop planting cycles
Water quality monitoring	Indigenous water purification practices	Hybrid water treatment solutions
Biodiversity mapping	Knowledge of medicinal plants	Restoration of indigenous species
Composting science	Traditional compost pits	Waste-to-fertilizer systems



3. Environmental, Social, and Economic Impacts

Across all communities, sustainability innovations demonstrated positive outcomes. Many projects produced **measurable improvements**, captured through both qualitative narratives and quantitative indicators.

Table 3: Summary of Impacts Observed

Impact Type	Key Outcomes Reported
Environmental	Increased vegetation cover; reduced soil erosion; improved water availability
Social	Enhanced community participation; strengthened traditional knowledge; youth engagement
Economic	Income from recycling, reduced household costs, and improved food security

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4. Enabling Factors and Barriers

Findings revealed several enabling conditions as well as persistent challenges.

Table 4: Enablers of Successful Innovations

Enabling Factor	Explanation
Community ownership	Higher project sustainability when initiatives were community-led
Scientific-IKS collaboration	Improved innovation design and uptake
Local governance support	Access to land, infrastructure, and small grants
Training and capacity-building	Increased technical skills and long-term engagement

Table 5: Barriers to Implementation

Barrier	Description
Limited funding	Small or inconsistent financial support
Technical skills gaps	Lack of engineering, ecological, or monitoring skills
Weak policy alignment	Projects not integrated into municipal plans.
Climate shocks	Droughts and floods are disrupting project continuity.

Discussion

In line with the first objective, the study found that community-based sustainability innovations are widespread and diverse, encompassing ecological restoration, sustainable agriculture, waste-to-resource initiatives, and water conservation technologies (Berkes, F., 2012). This diversity indicates that communities are actively responding to locally specific environmental challenges using contextually appropriate solutions. Addressing the second objective, the findings showed that knowledge co-production, particularly the integration of scientific knowledge with Indigenous Knowledge Systems (IKS), was a defining feature of high-performing innovations. Initiatives that combined empirical scientific methods with culturally embedded practices consistently achieved higher effectiveness scores than those relying on a single knowledge system (Berkes, F., 2012). With respect to the

third objective, the study documented environmental, social, and economic benefits across all innovation categories. These included improved ecosystem conditions, enhanced community participation, skills development, and livelihood support, suggesting that sustainability innovations can generate multidimensional outcomes. In relation to the fourth objective, several enabling factors and barriers were identified. Local ownership, access to scientific support, training opportunities, and supportive governance structures facilitated innovation effectiveness. Conversely, limited funding, technical capacity constraints, policy misalignment, and climate variability emerged as key barriers affecting scalability and long-term performance. The findings suggest that locally driven initiatives supported by accessible scientific inputs are more likely to succeed, although this association should be interpreted cautiously given the cross-sectional nature of the study. While causality



cannot be established, the observed patterns indicate that community empowerment and knowledge integration may play an important role in enhancing sustainability outcomes (Chanza, N. & de Wit, A., 2016). The strong performance of hybrid approaches that integrate science and IKS aligns with previous research conducted in South Africa, Kenya, and Tanzania, which similarly reported that community engagement, cultural relevance, and local ownership are critical determinants of sustainability success. Earlier studies also identified funding constraints, governance gaps, and climate-related disruptions as persistent challenges, consistent with the barriers observed in this study. The results further support the argument that community-driven innovations can contribute meaningfully to resilience-building and environmental stewardship, particularly in resource-constrained settings. However, the variability in outcomes across projects suggests that success is influenced by broader socio-economic and institutional contexts. These findings reinforce calls in the literature for stronger policy support, sustained funding mechanisms, and institutional frameworks that enable effective science–community partnerships (Cunningham, A.B., 2021).

Generalisation

The generalisability of this study is moderate and applies primarily to communities with similar socio-ecological, cultural, and governance contexts. Because the research was conducted in settings where local knowledge, Indigenous Knowledge Systems (IKS), and community-driven environmental action are integral to livelihoods, the findings are most relevant to regions facing comparable environmental pressures and community dynamics. The key insights, particularly concerning the integration of scientific and Indigenous knowledge, community ownership of sustainability initiatives, and enabling or hindering factors, are transferable to other communities within South Africa and across the Global South, where hybrid knowledge systems and resource-constrained innovation practices are common. Likewise, the observed barriers, such as limited funding, governance gaps, and exposure to climate shocks, mirror findings from related African and developing-country contexts. However, the results should be applied cautiously in highly industrialised, urbanised, or technologically advanced regions where the scale, drivers, and forms of sustainability innovation differ significantly. Differences in policy frameworks, technological access, and community governance structures may influence the applicability of the findings. Overall, while the study offers valuable insights into community-based sustainability initiatives, its generalisation is best suited to contexts with

similar environmental challenges, cultural orientations, and socio-economic conditions.

Conclusion

This study concludes that community-based sustainability innovations are vital for addressing real-world environmental challenges, particularly in resource-constrained settings. The integration of scientific knowledge with Indigenous Knowledge Systems significantly strengthens innovation outcomes. Although these initiatives generate measurable environmental, social, and economic benefits, their long-term success depends on improved funding systems, supportive local governance, and stronger science–community partnerships.

Limitation

This study has several limitations that should be considered when interpreting the findings. First, the research employed a cross-sectional design, which provides a snapshot of community-based sustainability innovations at a single point in time. As a result, the study does not capture long-term changes, seasonal variations, or the evolving nature of community initiatives. A longitudinal design would provide a deeper understanding of sustainability outcomes over time. Second, the study relied partially on self-reported data and project documents, which may introduce reporting bias, selective emphasis, or inconsistencies in how outcomes are measured across different communities. In some cases, the availability and completeness of written documentation varied, limiting the depth of comparison between projects. Third, the qualitative component, including thematic analysis and case study narratives, involved a degree of subjectivity despite efforts to ensure rigorous coding and triangulation. Different researchers might interpret contextual and cultural nuances differently. Additionally, the absence of large-scale quantitative datasets constrained the analysis to descriptive statistics rather than advanced modelling or inferential analysis. Fourth, the study focused on selected communities and may not fully represent the diversity of sustainability innovations across all regions. The selection of participants, such as community leaders, project coordinators, and local practitioners, may also reflect individuals who are more active or successful in sustainability work, potentially leading to positive bias. Finally, environmental innovations are strongly influenced by local ecological conditions, governance structures, and socio-cultural contexts. These contextual differences mean that the findings may not apply to areas with fundamentally different environmental challenges or institutional arrangements.



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Recommendations

- Strengthen science–community partnerships through training, mentorship, and participatory research.
- Expand funding opportunities for community-led projects to support implementation and scaling.
- Integrate successful innovations into municipal and regional policies for greater institutional support.
- Enhance climate resilience through drought-tolerant species, water-saving technologies, and early-warning systems.
- Promote knowledge co-production by formally recognising Indigenous Knowledge Systems in sustainability planning.
- Establish participatory monitoring frameworks to ensure continuous improvement and community learning.

Biography

Dr. Sibonelo Thanda Mbanjwa is a dedicated lecturer in the Department of Nature Conservation at Mangosuthu University of Technology (MUT), South Africa. He holds a Ph.D. in Environmental Science and specializes in biodiversity conservation, sustainable development, and environmental education. Dr. Mbanjwa is deeply committed to community engagement, student mentorship, and the integration of indigenous knowledge systems into conservation practices. His work bridges academia and practical application, empowering students and communities through innovative teaching, research, and outreach initiatives.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

I, the author, contributed to the study conception and design. Material preparation, data collection, and research were performed by Mbanjwa S.T. The first draft was written by Mbanjwa S.T.

Data Availability

The data that support the findings of this study are available from the author, but restrictions apply to the availability of these data, which were used under license from various research publications for the current study and are therefore not publicly available.

Conflict of interest

The author declares no conflict of interest.

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