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Outreach and knowledge mobilization for the effective use of adoptive strategies for land-lake based resilience

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Abstract

Effective land–lake management for resilience requires an integration of knowledge mobilization, capacity building, and collaborative partnerships that bridge science, policy, and community practice. This study aims to enhance understanding of land–lake socio-ecological linkages and to strengthen how geochemical evidence and participatory knowledge are translated into action among diverse actors. The paper draws on outcomes from a series of multi-stakeholder workshops implemented under the Royal Society International Collaboration Grant, "Dynamics of Environmental Geochemistry and Health in a Lake-Wide Basin," held at the Kenya Marine and Fisheries Research Institute (KMFRI) in Kisumu, Kenya, between 2023 and 2024. The workshops brought together government agencies, researchers, extension officers, private sector representatives, and community groups from across the Lake Victoria Basin. Collectively, participants identified critical knowledge and capacity gaps limiting the application of geochemical data to inform management and policy. Through participatory discussions, the workshops emphasized the need to integrate sediment fingerprinting, nutrient mapping, and catchment monitoring into county-level planning. Key themes included hotspot identification, restoration, and evidence-based decision-making to reduce land-to-lake sediment transfers that degrade both terrestrial and aquatic productivity. Participants co-developed pathways for climate-smart and regenerative agri-industries, policy briefs, and communication tools tailored for multiple audiences, including low-literacy and disability-inclusive formats. The process also led to the proposal of a multi-agency coordination committee to oversee ongoing collaboration, data sharing, and monitoring of land–lake activities within the Winam Gulf basin. Anchored in social–ecological resilience and adaptive knowledge mobilization frameworks, the study demonstrates that sustained interaction between scientific diagnostics and community engagement can foster adaptive learning and institutional linkages essential for resilience. The findings underscore the importance of early stakeholder inclusion, transparent data exchange, and participatory governance as foundations for sustainable land–lake management and long-term ecosystem health in the Lake Victoria Basin.

Keywords Geochemistry, Land-lake interphase, Dynamics, Ecosystem health, Lake victoria basin

1 Introduction

The land-lake based adoptive strategies framework requires the integration of community knowledge, scientific research, and collaborative outreach efforts to strengthen resilience across interconnected terrestrial and aquatic systems [48]. These strategies emphasize the dynamic relationships between land uses—such as agriculture, forestry, and urbanization—and lake health, including water quality, sedimentation, and ecological integrity [2]. In recent years, it has become evident that the sustainable management of lakes cannot be decoupled from the socio-ecological dynamics of the surrounding landscapes [63]. Consequently, outreach, capacity-building, and participatory knowledge mobilization have emerged as key pillars in operationalizing land-lake based resilience [54], as demonstrated through recent workshops facilitated under the Royal Society International Collaboration Grant in the Lake Victoria Basin.

In this study, "land–lake resilience" is conceptualized within the broader social–ecological resilience framework [27, 70], referring to the capacity of interconnected terrestrial and aquatic systems—and the communities that depend on them—to absorb, adapt, and transform in response to environmental and socio-economic stressors. Consistent with the community resilience literature [13, 53], we focus on adaptive resilience, recognizing it as the dimension most relevant to participatory management and adaptive governance in the Lake Victoria Basin. This framing aligns with social–ecological resilience theory, which views resilience as the capacity of linked human–environment systems to absorb disturbance, self-organize, and adapt across scales without losing essential structure or function [17, 27]. Within this perspective, land–lake resilience reflects the interdependence between watfeedbackocesses, lake health, and community livelihoods, emphasizing adaptive capacity and cross-scale feedback that sustain system integrity under change.

Our conceptualization also draws from community resilience theory, which emphasizes the roles of social networks, resource access, and adaptive learning in enabling systems to cope with and recover from stress [53]. In this view, land–lake resilience encompasses the absorptive, adaptive, and transformative capacities of riparian communities and institutions to sustain ecosystem services and livelihoods amid environmental change. In addition, the concept of regime shifts [61] provides a useful lens for understanding threshold behaviour in coupled land–lake systems, where small changes in nutrient inputs, land use, or hydrological balance can trigger large, often irreversible ecological transitions. Similar dynamics have been documented in Lake Erie [39], underscoring the importance of early warning diagnostics and adaptive management to prevent undesirable regime changes in the Lake Victoria Basin.

To strengthen analytical grounding, this study adopts principles from the Social–Ecological Systems (SES) Resilience Framework and the Resilience Assessment Workbook [3]. These frameworks explicitly address feedback and dependencies across land and water systems, guiding our integration of geochemical evidence with participatory insights to assess resilience pathways in the Lake Victoria Basin.

Climate change acts as a compounding stressor on these land-lake systems, intensifying existing environmental pressures and creating new challenges [32]. Rising global temperatures, increased frequency of extreme weather events, and altered precipitation regimes disrupt hydrological balances and exacerbate soil erosion, nutrient loading, sedimentation and pollution transfer from land to lake [22]. These disturbances threaten not only aquatic biodiversity but also the socio-economic well-being of communities that depend on freshwater systems for fisheries, agriculture, and domestic utilities.

Globally, lakes are undergoing rapid ecological change driven by both climate variability and human-induced land use transformations [66]. Sediment fluxes, chemical inputs, and temperature-induced stratification are altering aquatic food webs and reducing ecosystem resilience [31]. In this context, adaptive land-lake strategies are not just technical solutions but also socio-political processes that require coordinated action across disciplines and governance levels. Stakeholder engagement, knowledge co-production, and inclusive communication channels are essential components of effective outreach [29].

In Africa, freshwater ecosystems are particularly vulnerable to climate change due to overlapping stressors such as poverty, limited institutional capacity, and high dependence on natural resources [69]. According to the Intergovernmental Panel on Climate Change (IPCC), it is projected that many regions in Sub-Saharan Africa will face increased water scarcity, declining agricultural yields, and amplified risks of ecosystem degradation if adaptive strategies are not adopted [20]. Lakes such as Tanganyika, Malawi, and Victoria are already showing signs of thermal stress, oxygen depletion, and biodiversity loss [56].

The Lake Victoria Basin offers a unique lens into the land-lake climate nexus. Spanning five countries—Kenya, Uganda, and Tanzania, Rwanda, Burundi—the basin supports more than 40 million people and is a hotspot of ecological and socio-economic activity [7]. In Kenya, poor landscape and lakescape management, coupled with upstream deforestation and unsustainable agricultural practices, has accelerated the transfer of sediments and contaminants into the lake system [8]. These dynamics are central to the discussions and problem-identification sessions during the related stakeholder workshops. Recent contributions in Discover Conservation have advanced similar conversations around the co-production of knowledge and participatory resilience frameworks in African socio-ecological systems. For example, Mmbaga & Athumani [49] demonstrated how locally driven conservation initiatives can strengthen adaptive governance across catchment landscapes, while Randriamiharisoa et al. [59] emphasized the role of inclusive community engagement in enhancing ecological resilience. Building on these insights, the present study situates land–lake resilience within a comparable participatory paradigm that links geochemical evidence with stakeholder-led learning and adaptive management in the Lake Victoria Basin. This study provided a critical platform for co-learning, capacity-building, and stakeholder dialogue around land-lake resilience. Through multi-stakeholder engagement, including researchers, community leaders, policymakers, and extension agents, participants identified gaps in technical knowledge, geochemistry monitoring, and policy coordination. Similar participatory platforms have proven effective in other contexts for integrating local knowledge and scientific research [18]. The integration of local observations with scientific assessments allows for a more advanced understanding of land-lake dynamics, particularly in relation to climate-induced changes.

Moreover, the workshops emphasized the need for ongoing extension support services and the institutionalization of collaborative planning processes. These would ensure that strategies developed through outreach activities are not only implemented but regularly evaluated and updated in response to emerging data and climatic shifts [10]. Without continuous capacity-building and institutional support, these interventions run the risk of losing momentum or failing to scale [15]. Incorporating geochemistry into land-lake resilience strategies was a novel and valuable dimension of the stakeholder workshops.

Changes in sediment chemistry, nutrient fluxes, and contaminant loads offer critical indicators of landscape degradation and lake health [33]. However, the translation of complex geochemical data into actionable insights remains a challenge for most stakeholder groups [43]. Critically, the sustainability of outreach and knowledge mobilization efforts depends on institutional support and long-term investment [52]. Ad hoc projects and one-off training sessions are unlikely to produce lasting change unless embedded within formal structures and governance frameworks [57].

From a policy perspective, aligning land-lake resilience strategies with riparian country specific and regional development plans like the Kenya's Vision 2030, the Lake Victoria Basin Commission's development plans, and climate adaptation frameworks can enhance coherence and impact [62]. Policies that promote land tenure security, incentivize sustainable land use, and strengthen environmental monitoring systems are key enablers of the adaptive strategies proposed in this study.

The workshops and engagements described in this paper underscore the importance of participatory, knowledge-driven approaches to land-lake resilience. As climate change accelerates, the integration of scientific data, community knowledge, and policy coordination becomes ever more critical [26]. The experiences shared herein provide a blueprint for how outreach and knowledge mobilization can catalyze adaptive strategies that are both effective and equitable in the Lake Victoria Basin and beyond. The land–lake adaptive strategies framework applied in this study integrates three interlinked components: (i) systems thinking, which conceptualizes land and lake processes as coupled socio-ecological subsystems; (ii) community-driven research, emphasizing participatory diagnosis and locally defined priorities; and (iii) adaptive knowledge mobilization, focusing on iterative learning and the co-creation of actionable outputs. Together, these elements provide a dynamic structure for linking geochemical insights with stakeholder-led strategies to enhance land–lake resilience. Therefore, the present paper focuses on the use of engagement workshops for enhancement of the literacy and dynamism of land-lake based socio-ecological functions and transformation of the information into experiential knowledge using an inclusive team based on the dynamics of environmental geochemistry and health in a Lake-wide Basin and using a case study of Lake Victoria Basin. The study is anchored in a social–ecological resilience framework [17, 26], integrating geochemical diagnostics with participatory knowledge mobilization to bridge technical and community-based understanding of land–lake linkages. This framing positions the work within emerging interdisciplinary approaches that combine environmental data and stakeholder co-learning for adaptive management.

2 Materials and methods

This study adopted a participatory, transdisciplinary approach centred on stakeholder engagement, capacity-building workshops, and co-creation of knowledge activities to investigate and discuss effective strategies for enhancing land-lake based resilience in the Lake Victoria Basin. The methodology was guided by principles of systems thinking, community-driven research, and adaptive knowledge mobilization.

2.1 Study design and conceptual framework

The study employed a qualitative action research design anchored in collaborative knowledge exchange between scientists, local communities, policymakers, and non-governmental organizations. The conceptual framework was based on a socio-ecological systems model, focusing on the dynamic interactions between land use, aquatic ecosystems, and climate change (Fig. 1). This framework guided the identification of intervention hotspots, gaps in knowledge, and entry points for adaptive management strategies.

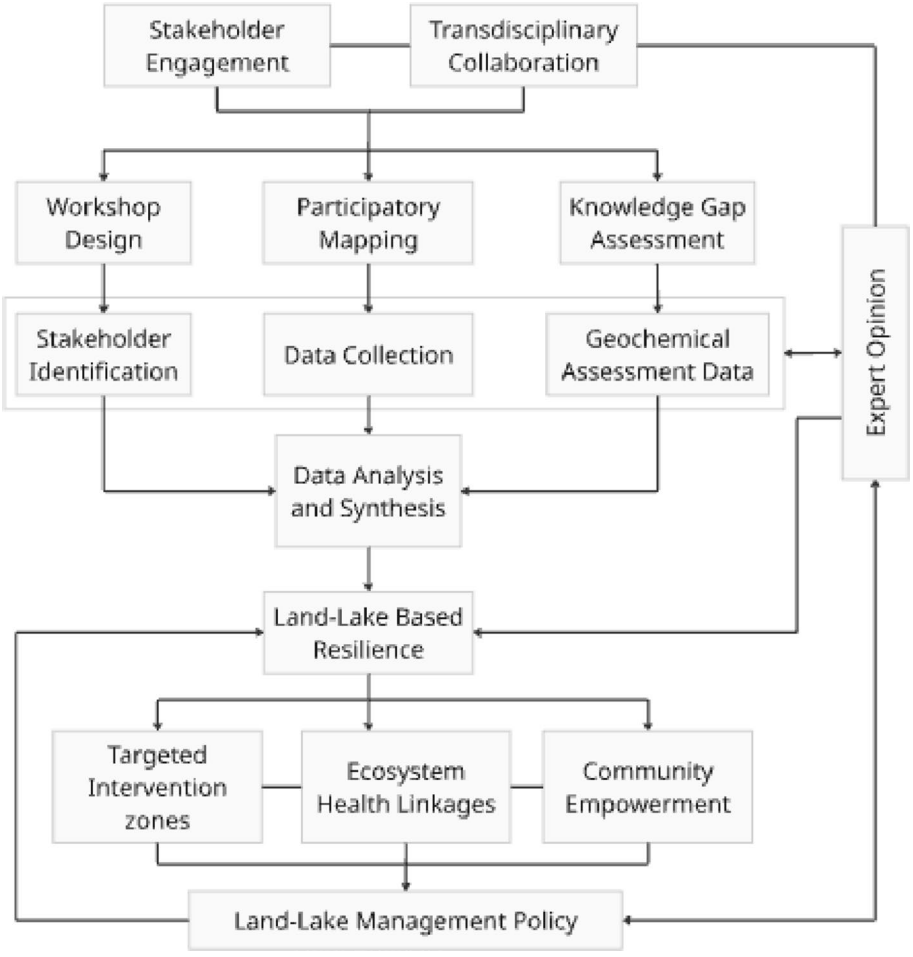

Fig. 1 A flow diagram showing the conceptual framework of the study. The arrows show the direction and pathways of processes culminating into a land-lake based adoptive strategies framework that could co-create a land-lake management policy

2.2 Study area

This study was conducted within the Kenyan portion of the Lake Victoria Basin (Fig. 2), with a particular focus on activities centred at the KMFRI freshwater research headquarters in Kisumu. The area represents a critical node in the land-lake interface, where human activities such as agriculture, urbanization, and informal settlements interact directly with the ecological processes of the lake (Marriott et al. 2023). Kisumu County was selected as the primary site of stakeholder engagement workshops, owing to its strategic location along the Winam Gulf (also Nyanza Gulf- Kavirondo Gulf) of Lake Victoria and its ecological and socio-economic significance in the Lake Victoria system. Other than the land-lake geochemistry and health experts from United Kingdom and within Kenya, the workshops also drew participants from a range of lake-adjacent Kenyan counties of Kisumu, Homa Bay, Siaya, Busia, and Migori, where land degradation, sedimentation, and water quality issues are most pronounced.

The Lake Victoria Basin in Kenya experiences multiple stressors, including land-use change, catchment degradation, climate variability, and point and non-point pollution sources. The interaction between upstream land management practices and downstream aquatic ecosystem health provided a pertinent context for examining the transfer of

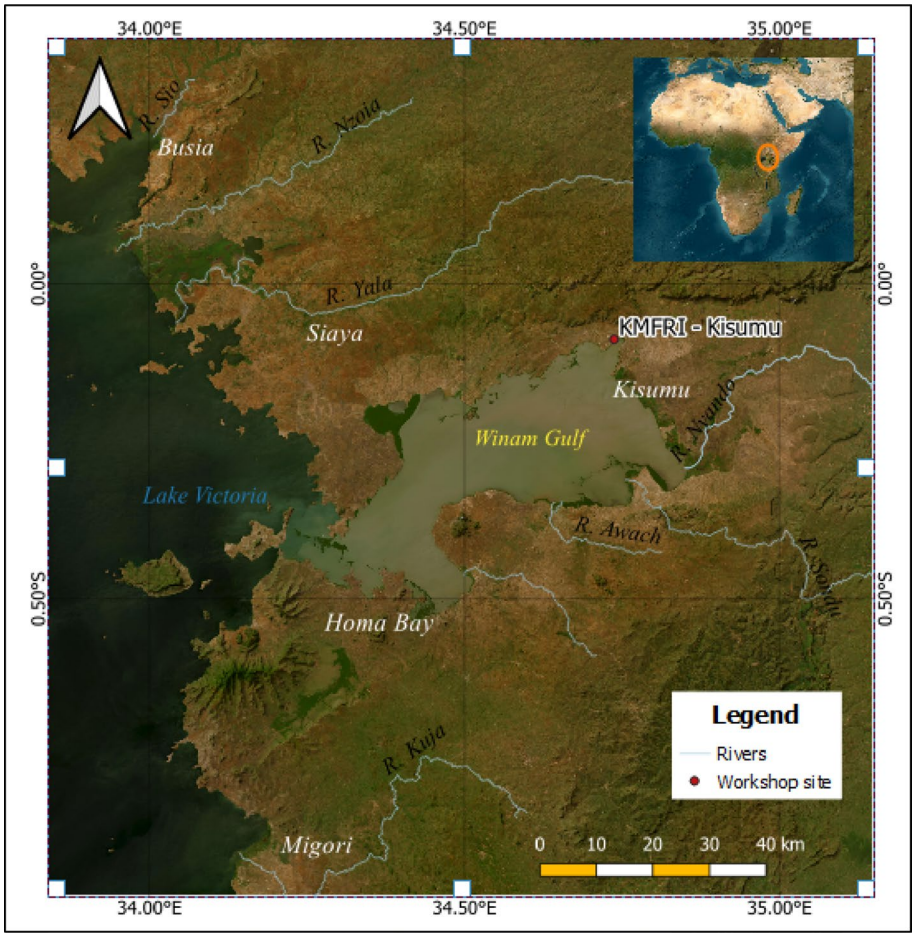

Fig. 2 A Google map image showing the selected workshop site of the land-lake interphase of the Winam Gulf in the Lake Victoria Basin and the major basin hydrological features
(Source: (Google, n.d))

sediments, nutrients, and contaminants from land to lake, a core concern raised during the stakeholder engagement process.

This region was also prioritized due to its policy relevance, presence of active research and extension institutions such as KMFRI and the Lake Victoria Basin Commission (LVBC), and accessibility for both local and international partners collaborating under the Royal Society International Collaboration Grant (2023–2024). These workshops thus served as pilot engagements for developing and testing participatory approaches to climate-resilient land-lake adaptive strategies.

2.3 Stakeholder identification and engagement

Stakeholders were identified using purposive and snowball sampling methods [9]. They included county governments, environmental agencies, farmers, fisherfolk, youth and women's groups, academic institutions, and international collaborators. Stakeholder mapping exercises were conducted to assess roles, influence, interests, and knowledge needs. This process ensured diverse representation in workshop activities and follow-up actions. The process of knowledge co-production in environmental governance is inherently shaped by dynamics of power and privilege. Feminist and critical scholarship [25, 34, 38] emphasizes that participation is not neutral but mediated by social structures such as gender, class, and institutional authority. In this study, deliberate efforts were made to ensure inclusive representation—particularly of women, youth, and persons with disabilities—during workshops and policy dialogues. Drawing from disability-inclusive research approaches [30, 65], facilitation methods were adapted to ensure accessibility, for instance through use of local languages, visual tools, and simplified geochemical infographics. These practices align with feminist political ecology principles, promoting equitable recognition of diverse knowledge forms and ensuring that scientific insights and community experiences inform one another on equal footing.

Special consideration was given to inclusion and representation during stakeholder recruitment. Participants were purposively selected to ensure gender balance, youth engagement, and the participation of persons with disabilities through collaboration with county social departments and local associations. Facilitation methods included the use of local languages, accessible venues, and visual aids to promote equitable participation. Feedback from these groups directly influenced the prioritization of resilience actions, particularly on community awareness, adaptive farming, and inclusive policy design.

2.4 Workshops and participatory sessions

The multi-stakeholder workshops engaged 29 participants drawn from research institutions, county governments, national agencies, and community organizations across the Lake Victoria Basin. Participants represented institutions including KMFRI, KALRO, NEMA, the State Department for Blue Economy and Fisheries (SDBEF), County Governments of Kisumu, Siaya, Homa Bay, and Migori, the University of Eldoret, IFDC, LBDA, and community-based networks such as the Kenya National BMU Network [35, 36].

The group composition was balanced, comprising technical experts, policymakers, researchers, private sector actors, and local practitioners, with a near gender balance (52% men and 48% women) and participation from youth and persons with disabilities.

Roles ranged from senior directors and county officers to research scientists and extension staff, fostering both vertical (national–county) and horizontal (sectoral) linkages. Approximately half of the participants attended more than one session, ensuring continuity of discussion and validation of emerging insights. This composition ensured inclusivity and representativeness in identifying adaptive strategies for land–lake resilience.

A series of four multi-stakeholder workshops were conducted between June 2023 and February 2024 at KMFRI Kisumu and partner institutions. Each workshop followed a structured format:

i. Day 1: Context setting, presentations on land-lake dynamics, and introductions to climate change challenges;
ii. Day 2: Breakout group discussions, participatory mapping, and identification of intervention hotspots; and.
iii. Day 3: Reflection and co-design of outreach and adaptation strategies, followed by joint planning for implementation.

Participatory tools such as problem-tree analysis, SWOT (strengths, weaknesses, opportunities and threats) analysis, visioning exercises, and landscape-lakescape storytelling were employed to facilitate mutual learning. The workshops formed part of a hybrid applied research initiative, integrating academic analysis with capacity-building, participatory evaluation, and policy engagement. While grounded in research principles designed to generate transferable knowledge, the process was co-designed with local institutions to ensure immediate practical relevance and uptake in land–lake management planning. This dual orientation positioned the study at the intersection of scholarly inquiry and applied program evaluation, allowing findings to inform both theory and practice in resilience governance.

2.5 Data collection and documentation

Qualitative data were collected through observation notes, video recordings, participant reflections, and workshop transcripts. Quantitative data included structured questionnaires evaluating participant knowledge before and after the workshops. All sessions were audio-recorded and transcribed verbatim for analysis.

2.6 Knowledge gap analyses

A knowledge gap assessment was conducted through pre- and post-workshop surveys and focused group discussions [9]. Participants were asked to identify areas where more data, training, or support was needed to enhance planning for resilience-oriented actions. The assessment revealed deficiencies in geochemical data literacy, adaptive planning, and local climate impact modelling. These gaps informed subsequent research priorities and extension content.

2.7 Geochemical and landscape assessment integration

To support evidence-based decision-making, the study incorporated outputs from prior geochemical surveys conducted by the British Geological Survey (BGS) and KMFRI [11, 37, 46]. These included maps of nutrient loading, sediment fluxes, and contaminant concentrations in inflowing rivers and lake sections. Workshop facilitators used simplified

versions of these datasets to build awareness and inform discussion about land-to-lake impacts under climate change.

2.8 Data analyses

Thematic content analysis was employed to analyse qualitative data. Transcripts were coded using Microsoft Excel data sheets, following grounded theory principles such as those outlined in Aura et al. (2021). Codes were then clustered into themes such as "adaptive capacity," "land use pressures," "institutional coordination," and "climate information use." Quantitative results were analysed using descriptive statistics (means, frequencies, percentages) to assess changes in participant knowledge and perceptions. Thematic content analysis was guided by two analytical constructs: adaptive capacity, referring to the ability of actors to learn and adjust practices in response to change, and knowledge co-production, emphasizing the joint creation of knowledge across scientific and community domains. Codes and categories were derived inductively from transcripts and then mapped onto these constructs to interpret how participants engaged with geochemical and policy information. The integration of qualitative and quantitative results provided a triangulated understanding of stakeholder engagement outcomes and informed targeted policy recommendations. In addition to thematic coding, qualitative text data were visualized using a refined word cloud analysis following the interpretability recommendations of [47]. Rather than relying solely on word frequency, contextual weighting was applied to cluster semantically related terms (e.g., "capacity," "training," "empowerment") and emphasize thematic prominence. This approach enhanced interpretability, enabling the visualization to serve as a conceptual summary of key ideas raised during stakeholder sessions rather than a decorative representation. Qualitative data from workshops were transcribed and thematically coded using inductive analysis to identify recurring concepts related to engagement, communication, and adaptive strategies. Coding frequency was used to gauge the relative prominence of themes, while representative quotations were selected to illustrate stakeholder perspectives on intervention design and knowledge translation.

2.9 Synthesis and co-development of recommendations

Findings from each workshop were synthesized into technical briefs and policy memos. These documents were validated with participants and updated iteratively. The co-developed outputs included:

i. A list of priority adaptation interventions.
ii. A stakeholder-led coordination framework.
iii. An outreach toolkit with simplified geochemical insights; and.
iv. Recommendations for integrating land-lake strategies into county climate action plans.

3 Results and discussion

The findings are interpreted through a resilience and knowledge mobilization lens, highlighting how participatory interactions can function as boundary processes linking scientific diagnostics, governance mechanisms, and community adaptation strategies [26, 51]. The use of communication tools such as infographics, policy briefs, and baraza dialogues aligns with Nguyen et al. [51] knowledge–action framework, where

these materials act as boundary objects within the mediation sphere—facilitating shared understanding and translation of scientific and community knowledge across stakeholder groups.

3.1 Leveraging geochemical intelligence for targeted land-lake resilience strategies

3.1.1 Identification: hotspot mapping and monitoring

Stakeholders in land management proposed developing soil erosion maps to highlight intervention zones, where restoration is urgently required. Lake stakeholders, on the other hand, prioritized the monitoring of chemical accumulation in water bodies, indicating a more dynamic approach. This divergence highlights the need for integrative frameworks that blend static and continuous monitoring systems [45]. Figure 3 shows the information and process flows involved in Geochemica Intelligence or Land-Lake

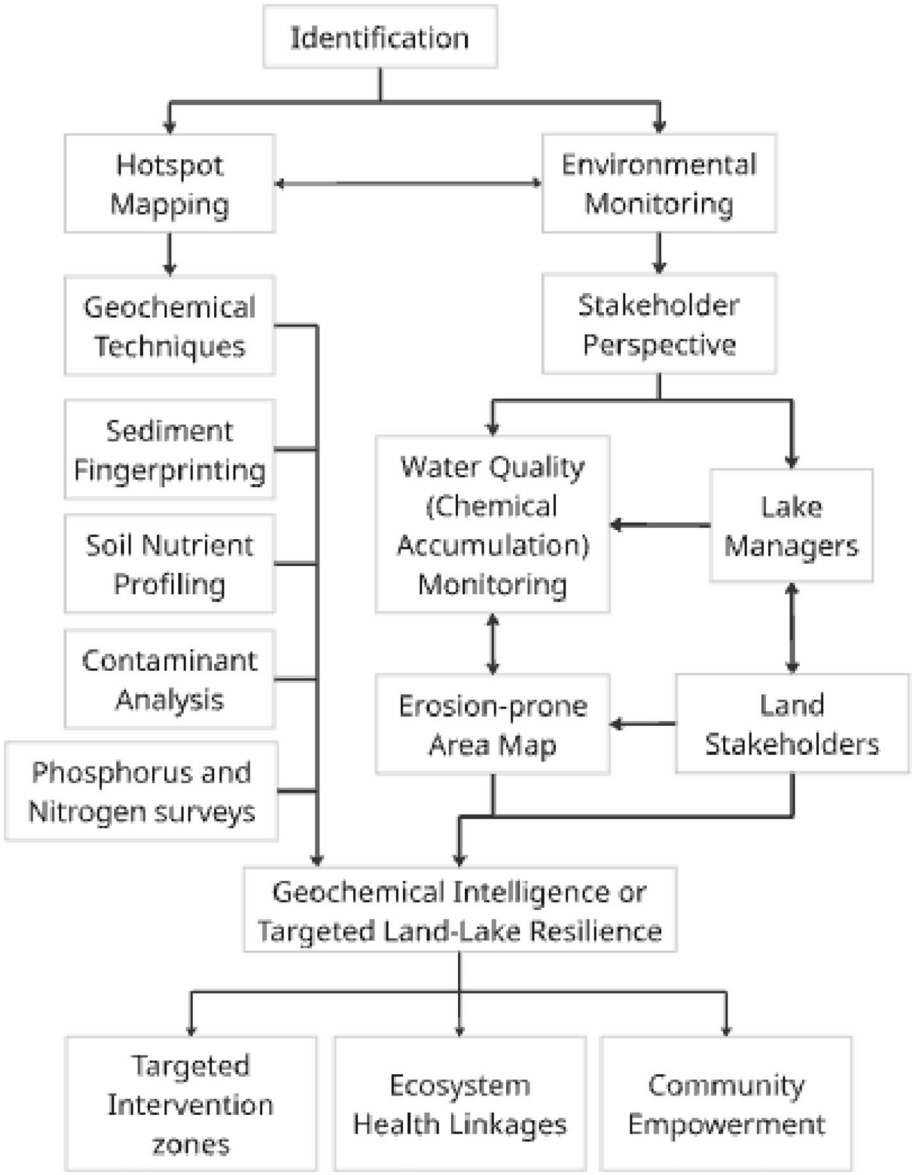

Fig. 3 Flow diagram showing the identification process of the outcomes of the study. The arrows show the direction and pathways of processes culminating into the geochemical intelligence or land-lake resilience

resilience. Geochemical data plays a pivotal role in identifying critical zones of environmental stress across the land-lake continuum. Through sediment fingerprinting, soil nutrient profiling, and contaminant analysis, geochemical techniques provide spatially explicit insights into erosion-prone areas and sediment influx points.

Integrated hotspot mapping not only identifies areas with high erosion risk but also supports the diagnosis of declining soil health and aquatic degradation. In Lake Victoria, hotspots of phosphorus and nitrogen accumulation, identified via geochemical surveys, have been linked to eutrophication and fish kills [8, 72]. This reveals how geochemical intelligence can act as a bridge between landscape degradation and aquatic ecosystem health. Participatory hotspot identification that combines local knowledge and geoscience data can also empower communities and enhance co-management, particularly in spatially complex catchments like the Winam Gulf [64]. The research team recognizes that positionality and institutional context influence both the design and interpretation of participatory processes. As noted in reflexive environmental research [45, 60], researchers and funders inevitably shape which strategies gain prominence through their mandates, expertise, and resource framing. In this study, facilitation choices and data priorities were influenced by the project's geochemical focus and policy-driven funding structure, which may have elevated technically oriented solutions over social or locally embedded strategies. Acknowledging these dynamics strengthens transparency and underscores the importance of continuous reflexivity in collaborative resilience planning.

In this case, evidence of geochemical insights that shaped policy was particularly of sediment fingerprinting and nutrient source tracing that were directly used to identify erosion hotspots in Rivers Kibos and Nyando sub-catchments, that prompted local and county government officers to prioritize riparian buffer restoration in subsequent planning meetings. These insights also shaped the content of a joint KMFRI–NEMA policy brief recommending integrated land-use controls and catchment monitoring as tools for lake protection.

3.1.2 Intervention: restoration, mitigation, and soil management

Once hotspots are identified, geochemical data becomes a foundational tool in guiding appropriate interventions. Land management participants underscored the need to use geochemical evidence to inform decisions on fertilizer use, crop selection, and soil conservation strategies. Geochemical baselines help match interventions to site-specific needs, ensuring that resources are used efficiently. For example, areas with nutrient-poor soils may benefit from organic amendments, while erosion hotspots may require terracing or vegetative buffers [14]. At the lake level, geochemical analysis supports dredging, wetland restoration, or silt trap installations to reduce sedimentation and pollutant loading. Both land and lake managers emphasized the importance of catchment-scale planning, especially given the interconnected nature of land use and lake health. The concept of targeted mitigation, made possible through geochemical evidence, was a recurrent theme. This is essential for systems like Lake Victoria, where resource constraints necessitate prioritization. Moreover, participants highlighted the importance of community engagement in intervention design. According to Adefila et al. [1], translating technical findings into local languages and formats fosters adoption, enabling geochemically

informed interventions to align with indigenous knowledge and farming practices. This emerged as a popular idea among the workshop participants.

3.1.3 Information: strategy, planning, and policy integration

Scientific evidence from geochemical monitoring must be mainstreamed into development plans and environmental policies for sustainable impact. Land stakeholders proposed that data be used to design hotspot-specific intervention policies, while lake stakeholders emphasized the need for pollution regulation and broader land-lake policy frameworks (Table 1). Both groups recognized that geochemical data can inform zoning, extension services, and environmental subsidies, echoing global best practices where evidence-based planning enhances resource governance. When layered with socioeconomic data, geochemical insights become even more powerful, revealing not only where degradation occurs but also whom it affects most.

However, converting complex scientific outputs into actionable policies remains a challenge. Stakeholders suggested creating multi-stakeholder platforms and county-level technical committees to facilitate data translation. Efforts must be made to simplify data into formats accessible and easily consumed by policymakers and the public. Building these communication bridges is key to effective governance, enabling geochemical data to shape both top-down legislation and bottom-up behavioural change. The International Water Resource Management (IWRM)in the Mekong and Nile basins are some of the global examples that offer lessons showing that integrating scientific monitoring with participatory governance enhances resilience in multi-stakeholder water systems [18].

3.2 Scaling science into practice: pathways for applying land-lake research

3.2.1 Identification: from site-specific insights to catchment-level mapping

There was general concurrence among stakeholders that research application must begin with robust identification frameworks that scale from site-specific data to

Table 1 Summary by thematic areas that were employed in the workshops for knowledge exchange

Theme	Land management responses	Lake management responses	Common threads/insights
Identification—hotspot mapping & monitoring	• Develop erosion maps to locate priority intervention zones • Use mapping to assess soil health	• Monitor geochemical accumulation zones • Determine chemical concentrations in the lake • Create dynamic monitoring plans	• Both groups value geochemical data for locating problem areas • Land focus is static mapping; lake focus is dynamic, continuous monitoring
Intervention—restoration, mitigation, soil management	• Base restoration efforts on geochemical evidence • Use data to inform fertilizer application and crop selection • Guide mitigation strategies	• Use data to inform agricultural practices to reduce runoff • Sensitize communities on land-lake linkages and impacts of sediment inflow	• Emphasis on targeted interventions to optimize resource use • Shared recognition of need for catchment-wide strategies supported by geochemical diagnostics
Information—strategy, planning & policy integration	• Translate geochemical data into actionable policy • Develop intervention-specific land use policies • Provide simplified decision support tools	• Advocate for pollution control policies and lake-wide management regulations • Use data to support law and policy enforcement on water quality	• Strong need for science-policy linkage • Demand for simplified, accessible formats for decision-makers and communities • Alignment with county/national policy

catchment-wide strategies. Extension services can use localized geochemical assessments to diagnose soil fertility issues, sediment origins, or contaminant risks in individual farms or wetlands. Simultaneously, watershed-level geochemical mapping supports macro-level planning, ensuring that interventions at the micro-scale contribute to system-wide goals. It has been observed that this nested approach is critical for regions like the Lake Victoria Basin, where land degradation and water pollution are unevenly distributed [50, 55].

Urban and peri-urban areas were also highlighted as essential nodes of analysis, as they contribute significantly to catchment pollution through unregulated waste disposal and land cover change. Applying geochemical data approaches to monitor these urban influences expands the traditional focus on rural agricultural lands and reflects the growing complexity of land-water interactions. Combining site and system perspectives enhances scalability—ensuring that research insights can travel from farm-level decisions to county development agendas [4].

3.2.2 Intervention: scaling solutions through policy and extension services

Implementing interventions at scale requires moving from knowledge generation to knowledge mobilization. Participants outlined a logical chain consisting of evidence → policy reform → extension delivery → community uptake. Geochemical data can inform every step of this chain, particularly when integrated with social data and participatory tools. For instance, mapping erosion hotspots with community members and co-designing solutions fosters trust and promotes adoption. Moreover, using geochemical evidence to train extension officers helps ensure that their advice is context-specific and scientifically grounded [40, 58].

Scaling also demands monitoring frameworks that evaluate both environmental and social outcomes. Participants proposed using geochemical baselines to track the impact of interventions over time, such as changes in nutrient runoff, sediment delivery, or crop productivity. Successful strategies must be adaptable to local conditions but grounded in standard indicators for comparability across the basin. It has been noted that by embedding geochemical evidence in land-use planning, extension curricula, and environmental impact assessment procedures, research transitions from pilot to policy, enabling region-wide transformation [15, 28].

Participants collectively identified pathways linking geochemical research to decision-making. Outputs included training on policy brief preparation, agreement on forming a multi-agency committee for the Winam Gulf Basin, and a plan to develop a virtual data-sharing platform for research dissemination. These initiatives demonstrate direct institutional engagement and commitment to sustain collaboration beyond the project period. The post-workshop collaborations have since catalyzed the integration of land–lake data into county planning processes, underscoring the value of early and continuous community engagement. As emphasized in the Winam Gulf proceedings [36], long-term impact depends on maintaining resourced platforms and inter-agency networks to ensure that research outputs translate into sustained land–lake management practices.

3.2.3 Information: empowering multi-stakeholder actors for uptake

To ensure application at scale, geochemical information must be tailored to and distributed across a broad range of stakeholders. Farmers, fishers, county planners, NGOs,

and private actors such as fertilizer companies all require data in different formats and levels of detail. Participants recommended developing simplified toolkits, infographics, and dashboards to disseminate findings and promote action. Additionally, participatory data-sharing platforms can allow for collaborative decision-making and local validation of research outputs. Table 2 shows the specific stakeholder insights corresponding to each dimension.

Capacity building was highlighted as a key enabler of uptake. Training programs for government officers, extension staff, and local leaders can strengthen their ability to interpret geochemical data and act upon it. This aligns with Kenya's National Climate Change Action Plan (KNCCAP), which emphasizes science-policy integration and capacity development as pillars of adaptation. As climate impacts intensify, empowering frontline stakeholders with geochemical tools ensures that local responses are timely, evidence-driven, and scalable [62].

3.3 Designing the next generation of collaborative research on land-lake systems

3.3.1 Identification: designing transdisciplinary research on hotspots and indicators

Future land-lake research must begin with comprehensive diagnostics that integrate geochemical monitoring with ecological, climatic, and socioeconomic indicators. Participants called for more nuanced studies of potentially toxic elements, nutrient fluxes, and sediment transport—especially in areas affected by mining, agriculture, or urbanization. According to Suding and Hobbs [67], by identifying degradation pathways and ecological thresholds, such studies can guide restoration priorities and help prevent irreversible ecosystem shifts.

Geochemical assessments should also incorporate local knowledge systems and community observations. This pluralistic approach enhances the credibility and usability of findings while ensuring that research questions reflect community priorities. Multidisciplinary teams—including environmental chemists, soil scientists, economists, and social scientists—are needed to design and implement such diagnostic frameworks. This diversity mirrors successful case where watershed research platforms in the Volta and Limpopo basins with holistic data sets underpinning coordinated management actions [12].

3.3.2 Intervention: from evidence-based innovation to smart farming and restoration

Future interventions must be both innovative and grounded in evidence. Smart farming systems—incorporating precision agriculture, organic amendments, and agroecological zoning—were proposed as scalable mitigation strategies. Geochemical data can inform such systems by identifying optimal nutrient blends, contaminant hotspots, and areas in

Table 2 Scaling and application of geochemical research with the specific stakeholder insights corresponding to each dimension

Dimension	Stakeholder insights
Where	• Apply research at both smallholder (farm) and catchment scales • Include urban/peri-urban areas • Target hotspot counties within Lake Victoria Basin
How	• Follow evidence → policy → extension → community pathway • Promote community-led adoption • Integrate monitoring and feedback loops into implementation
Whom	• Engage a range of actors: farmers, fishers, extension officers, county/national governments, NGOs, private sector • Support multi-level, cross-sectoral teams

need of land-use transition. This relies on the conclusions by Keesstra et al. [41] nature-based solutions like reforestation, wetland conservation, and buffer establishment rely on geochemical mapping to optimize site selection and ecological benefit.

Participants also highlighted the value of low-cost technologies (e.g., portable soil scanners, bioindicators) for expanding geochemical surveillance across resource-limited settings. These tools democratize environmental monitoring, enabling local governments and communities to take ownership of resilience efforts. Linking intervention data to M&E frameworks further ensures accountability and learning—enabling future projects to evolve based on feedback and impact metrics [18].

3.3.3 Information: collaborative frameworks and institutionalizing knowledge sharing

Effective collaboration in future projects depends on robust information-sharing platforms and coordination structures. Participants suggested establishing county-level land-lake committees and basin-wide research consortia to harmonize activities, pool data, and mobilize resources (Table 3). These bodies could facilitate joint training programs, promote open data standards, and align county development plans with shared environmental targets. As one county fisheries officer observed, "*when technical findings are translated into our local language and shared through barazas, people feel ownership and understand how their practices affect the lake*." Similarly, a community group leader noted, "*we need more platforms where scientists and farmers meet regularly, not just during projects*." These reflections, echoed across several workshops, reinforce the centrality of inclusive communication and iterative engagement in building adaptive capacity.

Institutionalizing collaboration also involves policy review and mandate alignment. Agencies like KMFRI, National Environment Management Authority (NEMA), and county governments must clarify roles in land-lake governance and standardize data reporting formats. This ensures that geochemical research feeds directly into environmental regulation, land-use permitting, and development planning. By embedding data protocols in governance structures, research becomes a continuous input into decision-making rather than an external exercise [57, 62].

3.4 Bridging the gap: connecting science, policy, and communities for systemic impact

Participants proposed key actions that influence policy through research (Table 4). Influencing decision-makers with scientific research requires deliberate, strategic communication and stakeholder engagement. Workshops revealed that passive dissemination

Table 3 Priorities for future collaboration using geochemical methods

Aspect	Insights
What (research focus)	• Soil health and climate-resilient agriculture • Pollution pathway tracking (e.g., PTEs) • Urban influence on sediment/nutrient transfer • Agroforestry and aquaculture
Whom (collaborators)	• Multidisciplinary teams: KMFRI, BGS, ICRAF, universities, NGOs, private firms, NEMA, county governments, communities
How (approach)	• Co-design of monitoring systems • Simplified data outputs • Formation of coordination committees • Shared platforms for data and training

KMFRI Kenya marine and fisheries research Institute, *BGS* British geological Survey, *ICRAF* World agroforestry Centre, *NGOs* Non-Governmental Organizations, *NEMA* National environmental management authority

Table 4 Influencing policy through research based on thematic strategies and resultant key actions

Strategy	Key actions
Dissemination	• Produce policy briefs, infographics, toolkits • Localize findings per county/region • Share via extension services, media, and online platforms
Engagement	• Conduct sensitization workshops for decision-makers • Use participatory models (citizen science, co-design) • Build collaborative platforms for exchange
Leverage points	• Link research to economic/livelihood outcomes (e.g., food security, reduced flooding) • Integrate findings into climate action plans and land use frameworks

Table 5 Key responses on policy briefs and community engagement ($n = 24$)

Response	Frequency	Percentage (%)
Simplifying complex research for policy influence (land sector)	9	81.8% (of 11 land)
Role of community-led evidence (land stakeholders)	7	63.6% (of 11 land)
Role of community-led evidence (lake stakeholders)	6	60.0% (of 10 lake)
Disconnection between research institutions and county departments (lake)	6	60.0% (of 10 lake)
Low uptake of briefs without community buy-in (land stakeholders)	6	54.5% (of 11 land)

through journal articles is insufficient. Instead, creating diverse outputs such as policy briefs, farmer-friendly brochures, and open-access dashboards can enhance the accessibility and usability of scientific data. Locally contextualizing findings—tailoring outputs to specific counties, community groups, or ecological zones—was repeatedly emphasized. Storytelling, data visualizations, and social media were mentioned as complementary tools to bridge the science-society gap.

Beyond communication, multi-sectoral engagement is crucial. Researchers should proactively build relationships with county governments, environmental regulators, civil society organizations, and community leaders. Participatory models like citizen science and collaborative scenario planning can increase community ownership and ensure that policies reflect ground realities [16]. Furthermore, advocacy efforts that highlight co-benefits—such as improved yields, reduced flood risk, and cleaner water—can incentivize policy uptake. Demonstration projects showcasing the tangible impact of geochemically-informed interventions are powerful advocacy tools. As Kenya operationalizes its climate and green economy frameworks [62], such cross-scalar, evidence-based collaboration is timely and necessary. Consistent with the SES Resilience Framework and Resilience Assessment Workbook [3], our findings highlight that resilience in land–lake systems is co-produced through both biophysical feedbacks and social learning processes operating across scales.

3.5 Insights from stakeholder exercises on policy engagement and research mobilization

3.5.1 Policy briefs and community engagement

The first set of exercises explored participants' experiences with translating research into policy briefs and how community engagement influences uptake (Table 5). Stakeholders emphasized that effective policy briefs should distil complex scientific findings into accessible, action-oriented messages. Success hinges on clear structure, empirical grounding, and alignment with policy priorities. Issues such as unsustainable land use, improper drainage, and soil degradation were commonly cited as topics successfully addressed in past briefs. Importantly, participants highlighted the role of simplicity and

relevance in enhancing the appeal of policy briefs to decision-makers, who often lack technical backgrounds but are positioned to drive change.

Community engagement emerged as a critical element in influencing behaviour and policy uptake. The West Pokot Farmer Research Network was cited as a best-practice example, where early involvement of communities in identifying challenges and co-creating solutions led to the adoption of a policy on sand harvesting. Similar success stories involved fertilizer use optimization and erosion control through capacity-building initiatives. In Exercise 2, participants further clarified that policy briefs target a wide audience—including national and county officials, NGOs, and the public—and must include structured elements like problem statements, recommendations, and implementation plans. While some briefs lead to concrete policy action, others stall due to bureaucratic inertia, emphasizing the need for strategic framing, timing, and multi-level stakeholder engagement [42].

The second set of exercises explored participants' experiences with translating research into policy briefs and how community engagement influences uptake. Table 5 illustrates the key themes, showing that simplifying complex research for policy influence was a dominant challenge, particularly for land-sector stakeholders (81.8%). This highlights a clear communication gap that limits uptake of geochemical evidence in formal decision-making channels. Stakeholders emphasized that effective policy briefs must distil complex scientific findings into accessible, action-oriented messages. Success hinges on clear structure, empirical grounding, and alignment with policy priorities.

Issues such as unsustainable land use, improper drainage, and soil degradation were commonly cited as topics successfully addressed in past briefs. Community engagement emerged as a critical element in influencing behaviour and policy uptake. As noted in the table, both land and lake actors recognized the role of community-led evidence (noted by 63.6% of land and 60% of lake participants), with examples like the West Pokot Farmer Research Network cited as best-practice. In this initiative, early involvement of communities in identifying challenges and co-creating solutions led to the adoption of a county policy on sand harvesting.

Furthermore, the table reveals, lake stakeholders emphasized challenges such as the disconnection between research institutions and county departments (60%), pointing to institutional silos that inhibit integrated policymaking. In Exercise 2, participants clarified that policy briefs target a wide audience—including national and county officials, NGOs, and the public—and must include structured elements like problem statements, recommendations, and implementation plans. However, low uptake of briefs without community buy-in (54.5% of land stakeholders) emphasized the importance of inclusive design processes. Strategic framing, timing, and multi-level stakeholder engagement were identified as critical success factors.

3.5.1.1 Community feedback and trust-building through policy briefs Figure 4 illustrates the extent to which policy briefs have influenced community-level understanding and engagement in land-lake resilience efforts. A high proportion of stakeholders (87.5%) reported that policy briefs enhanced understanding of land-lake interactions. This underscores the value of knowledge translation tools in bridging scientific evidence with grassroots awareness. Furthermore, 83.3% indicated that locally adapted communication tools fostered community trust, signalling the importance of cultural and contextual relevance

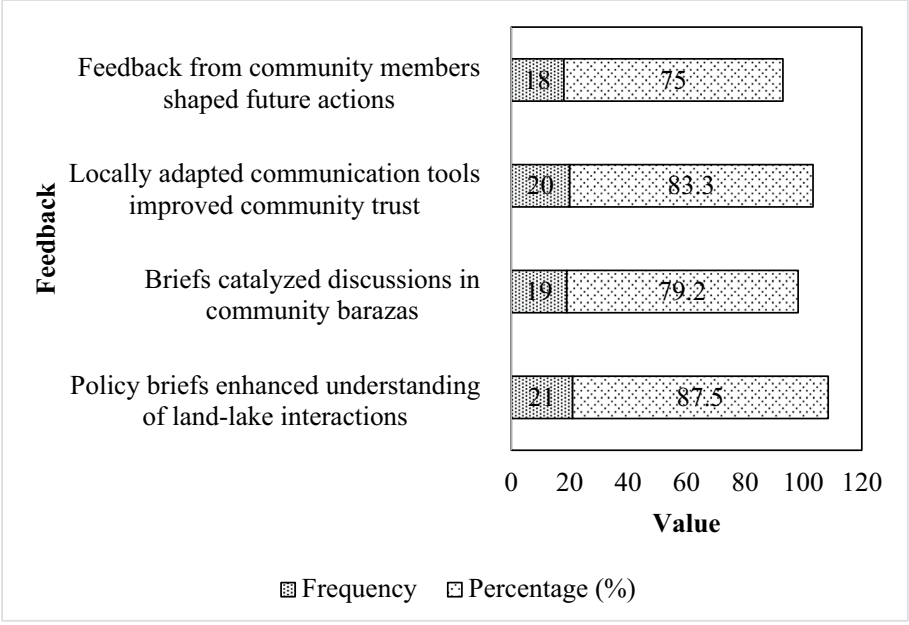

Fig. 4 Community feedback and trust-building through policy briefs. The feedback areas are scored in percentages

in dissemination practices. By tailoring messaging to the lived realities of stakeholders, researchers can build rapport and facilitate inclusive learning.

Notably, briefs were also credited with catalyzing community baraza discussions (79.2%) and influencing future actions based on feedback from local members (75%). These findings reflect the dynamic nature of community engagement, where policy communication is not unidirectional but rather iterative and responsive. Community-led discussions in barazas serve as important platforms for validating, contesting, and operationalizing scientific input, supporting collaborative governance. The feedback loop between communities and policymakers fosters a co-production of knowledge model that enhances the legitimacy and uptake of environmental interventions. The outcomes reported here complement recent work published in Discover Conservation that underscores participatory pathways for resilience and ecosystem stewardship [49, 59]. Our approach extends these frameworks by integrating geochemical intelligence and community knowledge into a unified decision-support process for land–lake management. In doing so, it provides a novel empirical illustration of how transdisciplinary collaboration can translate scientific data into actionable, context-sensitive adaptation strategies in East Africa's freshwater basins. As such, embedding participatory mechanisms in policy communication strategies is vital for sustained environmental stewardship.

3.5.2 Data harmonization and knowledge mobilization

In exercise 3, participants collectively called for a more coherent and accessible research ecosystem to support land-lake resilience efforts (Table 6). They proposed the formation of a regional, open-access research hub that would facilitate data harmonization, integration with county agricultural systems, and standardized protocols across institutions. This hub would be anchored in a multi-agency collaboration involving key actors such as KMFRI, Kenya Agricultural Research Organization (KALRO), Kenya Forest Research Institute (KEFRI), Lake Basin Development Authority (LBDA), academia, and county

Table 6 Key findings from workshop exercises

Exercise	Focus area	Key insights	Implications
Exercise 1	Policy brief preparation	Successful briefs rely on empirical evidence and simple language; focus areas include land use, safe drainage, and soil degradation	Clear, accessible briefs are more likely to influence policy when grounded in local issues
	Community engagement	Participatory strategies such as Farmer Research Networks (e.g., West Pokot) enhance legitimacy and adoption of briefs	Sustained engagement builds trust and ownership, increasing chances of policy uptake
Exercise 2	Policy brief structure and targeting	Briefs target government, NGOs, and the public; effective briefs follow structured formats with evidence, recommendations, and implementation plans	Standardization and clarity enhance comprehension and policy responsiveness
	Challenges in policy uptake	Policy brief success varies—some influence legislation, others remain unused due to bureaucracy	Bridging the gap requires strategic timing, advocacy, and follow-through mechanisms
Exercise 3	Research coordination and dissemination	Stakeholders support a regional hub, shared platforms, and integration with AMIS; standardization is key	Harmonized systems can reduce duplication, improve access, and inform policy decisions effectively
	Knowledge mobilization channels	Effective channels include open-access tools, local media, and public participation groups	Localized and diversified dissemination improves reach and relevance across audiences

governments. Stakeholders underscored the importance of sustained financial investment, digital infrastructure, and expert input—particularly in science communication and community translation—to ensure the platform's effectiveness.

Participants also recognized the need for enforcement and institutional support to sustain coordination. The National Council for Science Technology and Innovation (NACOSTI) was identified as a key player in regulating research quality, promoting open data policies, and standardizing methodologies. Dissemination strategies beyond formal channels were encouraged, including radio, Short Message Service (SMS), schools, and local influencers to bridge the gap between researchers and grassroots communities. These ideas resonate with global principles of science-policy integration, co-production, and transdisciplinary research [44]. Institutionalizing such frameworks can address fragmentation in research outputs and improve responsiveness to ecological challenges in the Lake Victoria Basin.

The translation of workshop outputs into long-term knowledge use can be understood through the "mediation sphere" of Nguyen et al. [51] knowledge mobilization framework, which highlights how social relationships, institutional contexts, and boundary-spanning actors enable knowledge to circulate beyond project boundaries. In this study, multi-level interactions between researchers, county officers, and community representatives created an enabling environment for continued learning and adaptive action. This relational approach ensured that participatory outputs—such as policy briefs, baraza dialogues, and training materials—were embedded within existing governance and communication networks, enhancing their sustainability and real-world impact.

This analysis aligns with broader feminist and critical perspectives that interrogate power and inclusion in environmental governance [25, 34, 38] and draws on disability studies emphasizing equitable participation [30, 65]. In line with Nguyen et al. [51], these insights reinforce the role of social mediation and boundary-spanning interactions as central to effective knowledge mobilization.

The data suggest that harmonized datasets play a pivotal role in enhancing the effectiveness of resilience-building strategies within the Lake Victoria Basin (Fig. 5). A

significant majority (87.5%) of respondents indicated that harmonized data facilitated knowledge exchange between researchers and the community, underscoring its value in bridging scientific research and local knowledge systems [18]. Furthermore, 83.3% reported that harmonized data helped align local strategies with scientific insights, which is critical for ensuring evidence-based decision-making and adaptive management. Improved cross-sectoral collaboration (75%) and increased stakeholder confidence in co-developed actions (79.2%) further highlight the integrative role of harmonized data in fostering trust, coordination, and joint action among diverse actors. These findings reflect the importance of data harmonization in promoting inclusive, science-informed, and community-driven environmental governance (Table 7).

3.5.2.1 Strengthening decision-making through integrated knowledge processes The integration of scientific and local knowledge across various stages of policy and practice—ranging from identification to harmonization—has emerged as a cornerstone of effective environmental governance. The engagement of stakeholders in identifying challenges ensures that interventions are grounded in local realities, increasing their relevance and potential for success. Subsequent interventions benefit from this contextual clarity, allowing for the tailoring of actions that are both responsive and adaptive to shifting environmental and socio-economic dynamics. The process also supports the co-production of knowledge, where science and community insights intersect to inform more holistic and sustainable solutions [5].

In addition, the generation and dissemination of targeted information, such as policy briefs, play a critical role in translating complex scientific findings into actionable guidance for decision-makers. When this information is further harmonized across sectors and stakeholders, it fosters alignment, reduces redundancy, and supports coordinated responses. This harmonization strengthens multi-level governance and promotes accountability, particularly in cross-cutting environmental issues such as land-lake resilience and ecosystem health [23]. Altogether, the structured flow from identification to

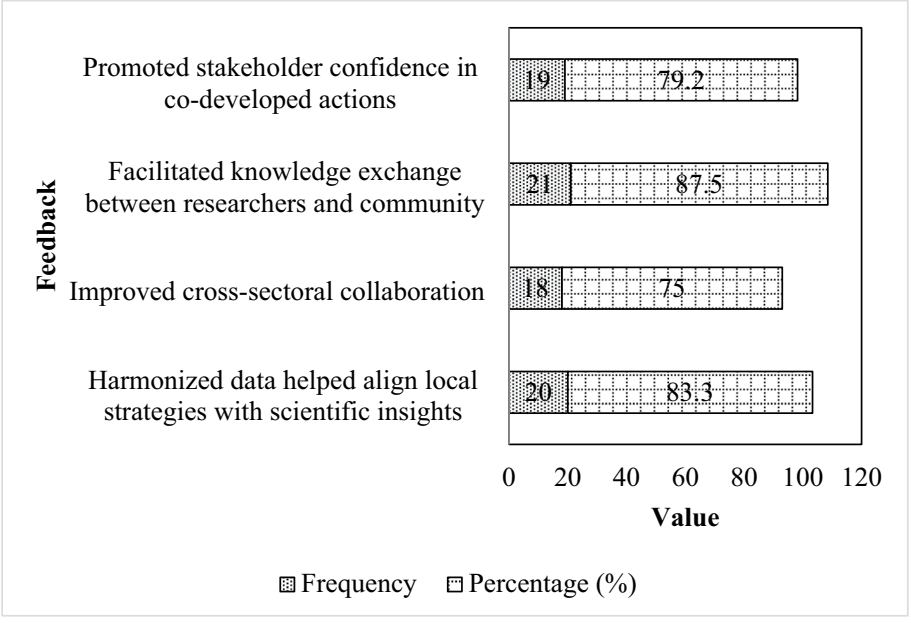

Fig. 5 The role of harmonized data in enhancing stakeholder engagement and collaborative governance

Table 7 Selected and key responses of the workshops

Question	Responses
1 A. How do you prepare and communicate a policy brief on land/lake issues?	• Policy brief is short and based on research/data to inform decisions • Addresses emerging issues like soil erosion, pollution, land use • Should be simple, short (1–2 pages), and use non-technical language • Targeted at policy makers, developed after stakeholder input • Validated and disseminated through counties or line ministries • Should include evidence from reports, barazas, or community feedback
1B. How do you engage communities to change behavior or practice?	• Use on-farm demos, field schools, barazas, tree planting, afforestation • Train and involve community champions, opinion leaders • Use local languages and cultural approaches like drama or song • Conduct sensitization forums and workshops • Encourage citizen science and participatory research • Leverage social media and mobile communication (WhatsApp, SMS)
2 A. Who is the target audience for policy briefs?	• County and National Governments (CECMs, Chief Officers, Ministries) • County Assembly Committees and Legislators • NGOs, Donor organizations, Advocacy and Faith-based groups • Community members, local opinion leaders, private sector investors • Technical personnel in implementation agencies
2B. What are the contents of a good policy brief?	• Title, institution, authorship, contact info • Introduction, background, and problem statement • Research findings and evidence • Recommendations with justification • Policy and implementation implications • References, estimated costs, penalties, and timelines
2 C. What happens after a policy brief is submitted?	• Goes to relevant ministry or cabinet for review • Tabled in assembly or public participation forums • Can become a bill/law if accepted • Disseminated for community implementation • May influence program design or stay archived if not implemented
3 A. How can we coordinate and disseminate data/research?	• Use central data hubs (e.g., KALRO, NACOSTI, LBDA, KEFRI, KMFRI) • Develop institutional communication and dissemination policies • Use social media, barazas, and sector reports • Create platforms for data sharing across stakeholders • Leverage community-driven platforms and NGOs
3B. What resources and expertise are needed for a working group?	• Technical experts, researchers, extension agents, lawyers, analysts • Stakeholders like KALRO, KEFRI, NEMA, KMFRI, NGOs • Funding for meetings, research, and communication tools • Training and capacity building for data handling • Platforms for public engagement (churches, schools, barazas)
3 C. How do we ensure research is harmonized and data quality enforced?	• Use NACOSTI as main research regulator • Assign experts per discipline for review • Develop legal and institutional frameworks • Stepwise data validation: researcher → institution → regulator • Create enforcement structures and review permits
3D. How do you communicate research/policy to decision makers?	• Use policy briefs and executive summaries • Target cabinet meetings, CECMs, and county forums • Use media: radio, SMS, local language leaflets, iCow • Leverage barazas, churches, funerals, community groups • Coordinate via CIDP, CEAP, stakeholder platforms, and RASCOM

CECMs Country executive committee members (equivalent of ministers at the County level); *chief Officer* equivalent of principal secretary at County level; *NGOs* Non-government organizations; *KALRO* Kenya agricultural and livestock research organization; *NACOSTI* National commission for Science, technology and Innovation; *LBDA* Lake basin development Authority; *KEFRI* Kenya forestry research Institute; *KMFRI* Kenya marine and fisheries research Institute; *NEMA* National environmental management Authority; *SMS* Short message Service; *CIDP* County integrated development Plan; *CEAP* County environment action Plan; *RASCOM* Regional African satellite communication organization

harmonization reflects a dynamic and participatory approach to environmental management, advancing both the legitimacy and effectiveness of resilience strategies.

The resilience model informing this study aligns most closely with the adaptive management dimension of the resilience spectrum [13], emphasizing learning, feedback, and

Fig. 6 A summarized representation of strengthening decision-making through integrated knowledge processes

iterative adjustment of strategies. While primarily adaptive, the approach also revealed transformative tendencies, as cross-sectoral dialogue and new institutional linkages began to reshape understanding of land–lake interactions. Evidence of resilience was reflected in the uptake of co-developed action points, integration of geochemical insights into county planning discussions, and enhanced stakeholder capacity to interpret environmental data for decision-making. These outcomes demonstrate how systems thinking and knowledge mobilization principles translated into tangible adaptive learning processes (Fig. 6).

The participatory processes applied in this study were positioned within what Arnstein [6], describes as the "partnership" level of the ladder of participation, where decision-making power is shared between technical experts and community actors. Similarly, Eyben [24], and Wilcox [71] emphasize that meaningful participation requires recognizing local and Indigenous knowledge as legitimate and co-equal forms of expertise. In line with these frameworks, our workshops were designed to enable two-way learning—where geochemical data interpretation informed local understanding of land–lake linkages, and community observations, in turn, shaped the prioritization of intervention hotspots and outreach tools. This approach reflects a co-production model rather than a top-down translation of scientific knowledge.

Despite efforts toward inclusive representation, we recognize that participation within the workshops may not have fully captured the diversity of community perspectives. As noted in participatory research literature [19, 21, 68], social hierarchies and structural inequalities often influence whose voices are most audible in collective decision processes. In our case, gender roles, economic status, and physical ability may have shaped both the comfort and visibility of participants during discussions. To mitigate these effects, facilitators employed participatory tools such as breakout groups, mixed seating arrangements, and local-language discussions that allowed quieter voices to emerge and influence group priorities.

While the participatory design promoted broad inclusion, limitations remain regarding representativeness and equity of knowledge uptake. Some groups—particularly women, youth, and persons with disabilities—may still face structural barriers to sustained engagement, including time constraints, mobility challenges, and limited access to decision-making forums. These factors likely shaped the distribution of knowledge

contributions and their subsequent uptake. Future participatory frameworks should therefore integrate gender-responsive facilitation, accessible communication formats, and feedback loops that ensure the continuity of marginalized voices in policy processes.

The findings reaffirm the value of the land–lake adaptive strategies framework, particularly its grounding in systems thinking and adaptive knowledge mobilization. Community-driven engagement enabled feedback loops between scientific diagnostics and stakeholder perspectives, illustrating how iterative learning supported the translation of technical evidence into locally relevant management strategies. The workshops led to tangible outputs, including the co-development of a policy brief on land–lake resilience and a stakeholder coordination framework for county-level implementation. Pre- and post-session reflections revealed shifts in perception, with participants increasingly emphasizing the role of land-use governance and multi-sector data sharing in sustaining lake health.

By integrating geochemical diagnostics with participatory engagement, this study contributes empirical evidence on how data-driven environmental monitoring can inform adaptive governance in the Lake Victoria Basin. Anchoring the analysis within social–ecological resilience and knowledge co-production frameworks enhances analytical depth, showing how community learning and institutional collaboration underpin adaptive capacity. Future work should continue to operationalize these theoretical perspectives to evaluate long-term resilience outcomes and governance transformations in similar land–lake systems.

4 Conclusion and recommendations

The findings presented in this study illustrate the potential of integrating geochemical intelligence with participatory knowledge mobilization to inform resilience-oriented planning in the Lake Victoria Basin. However, these approaches should be viewed as enabling frameworks rather than direct drivers of resilience outcomes. Achieving tangible and lasting resilience depends on factors beyond the project's scope, including governance effectiveness, policy uptake, and equitable resource access. The study therefore contributes actionable insights for adaptive management while acknowledging that sustained institutional support and long-term commitment are essential for realizing resilience in practice. To address the identified gaps, the study recommends that multi-agency platforms to be established to support centralized data sharing, with oversight from national bodies to ensure consistency and quality control. Investments in capacity building—particularly in geochemical data interpretation—should target both county officials and local communities to bridge technical divides. Moreover, efforts to simplify scientific outputs into action-oriented messages through policy briefs, SMS, and infographics should be institutionalized across land and lake sectors. Finally, embedding community voices early in research and policy design will be crucial in fostering trust and increasing the uptake of resilience strategies. To enhance inclusivity, future knowledge mobilization efforts should incorporate accessible formats such as audio briefs, illustrated infographics, and community theatre—approaches shown to support participation among persons with disabilities and low-literacy groups [30, 65].

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Author contributions
C.M.A: writing-original draft, conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, validation, writing-review and editing. H.A: conceptualization, data curation, formal analysis, investigation, methodology, software, writing-original draft, and editing. C.O: conceptualization, methodology, writing-original draft, writing-review and editing. S.M: conceptualization, methodology, writing-original draft, writing-review and editing. O.S.H: resources, funding, methodology, writing-review and editing. J.I: conceptualization, methodology, supervision, and writing-original draft. M.J.W: resources, conceptualization, formal analysis, funding acquisition, investigation, methodology, validation, writing–original draft, writing-review and editing. O.O: data curation, formal analysis, methodology, resources, funding, supervision, writing-original draft, writing-review and editing. W.H.B: project administration, resources, funding, validation, visualization, writing-review and editing. All authors reviewed the manuscript.

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Data availability
The data of this manuscript will be available upon request.

Declarations

Ethics approval and consent to participate
The current study was conducted in line with the standard operating procedures (SOPs) and ethical approval of the Kenya Marine and Fisheries Research Institute (KMFRI) guidelines for research registered with the National Commission for Science, Technology, and Innovation (NACOSTI) registration number NACOSTI/2016/05/001. Additionally, the study received approval from the project donor (The Royal Society, ICA\R1\1910770 and NERC National Capability Science International Award, NE/X006255/1 regulation and fiduciary rules. All participants gave informed consent to participate.

Consent for publication
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