

Transforming Active Community Engagement into Effective Decision-Making Frameworks: A Water-Energy-Food Perspective for the Ewaso Ng'iro North Basin





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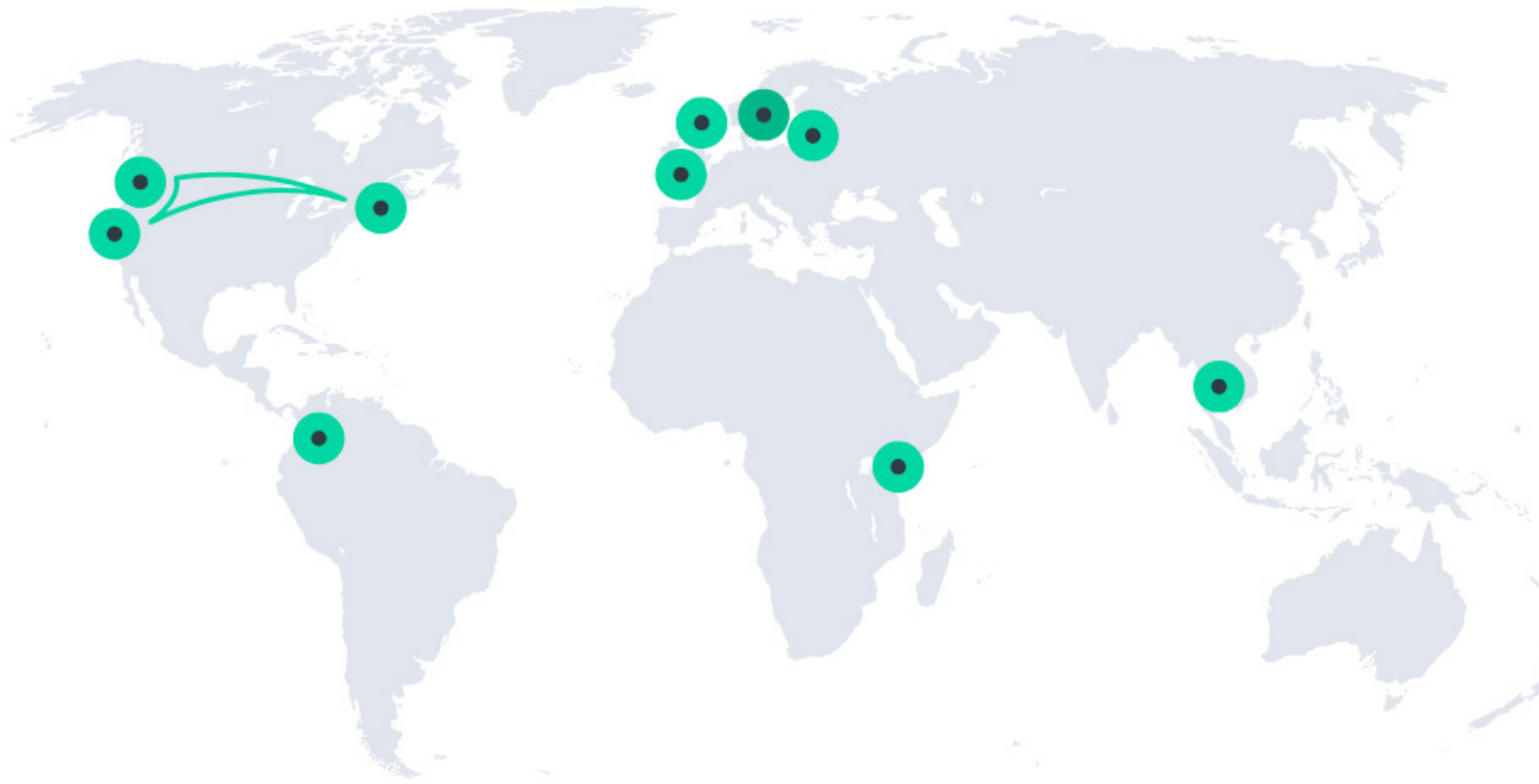
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About the Project

Applying the water-energy-food nexus to promote ecosystem-based adaptation in the Ewaso Ng'iro North Catchment, Kenya

This project seeks to support the Government of Kenya, five county governments (Laikipia, Samburu, Isiolo, Meru and Nyeri), local communities, and agro-based private enterprises to promote ecosystem-based adaptation practices and integrated planning for water, energy, agriculture and land use for resilient livelihoods in the Ewaso Ng'iro North Catchment Area.

The project seeks to apply ecosystem-based adaptation (EbA) and the nexus approaches to facilitate the co-production of resilient water-energy-food (WEF) knowledge with stakeholders (policymakers, local community groups, private sector, and non-governmental organizations) to inform decision and policymaking.

The project will contribute towards several development objectives which are in line with the Kenya Vision 2030 priorities, the Ewaso Ng'iro North Development Area (ENNDA) Integrated Regional Development Plan (2010-2040), the ENNDA catchment management strategy and the reformulation and implementation of CIDPs. These include increasing food security, especially pastoral livestock production; resilience through livelihoods diversification; employment creation through EbA solutions; agricultural growth; the conservation and safeguarding of critical habitats, including wildlife-protected areas and community wildlife conservancies. At the governance level, the nexus approach is expected to promote cooperation among actors and policy coherence across “policy silos”, i.e. sectors, levels and scales and the key added value of the nexus approach is in integrating across the various plans and strategies, promoting synergies and generating co-benefits.

Expected results

- WEF nexus models and development scenarios for Ewaso Ng'iro North Catchment Area (ENNCA)
- Identification, validation, and promotion of innovative Ecosystem-based nexus solutions among key stakeholders in the ENNCA region
- Increased awareness of cross-sectoral interactions (water, energy, agriculture, and land) during the implementation, upscaling, out scaling, and transfer of ecosystem-based nexus solutions at the sub-national and national level





Abstract

Integrated water resource management in transboundary basins requires participatory frameworks that bridge technical modeling with stakeholder knowledge. This study presents a participatory Water-Energy-Food (WEF) nexus assessment methodology applied to the Ewaso Ng'iro North Basin (ENNB), Kenya, spanning five counties with 3.4 million inhabitants. Combining the UNECE Nexus Assessment methodology with WEAP (Water Evaluation and Planning) modeling and GIS-based spatial analysis, we engaged stakeholders through structured workshops to co-develop decision-making scenarios. The methodology integrated qualitative participatory processes—including problem identification, hotspot mapping, priority matrices, and trade-off analysis—with quantitative hydrological modeling across 12 sub-catchments. Seven scenarios were co-created: baseline/reference, increased water productivity, wastewater reuse, transboundary cooperation, integrated strategies, technology adoption, and water supply improvements. Results demonstrate that the Integrated Nexus scenario reduces unmet water demand from 78 Mm³/year (business-as-usual) to 18 Mm³/year, stabilizes groundwater levels (0.1 m/year vs. 1.5 m/year depletion), increases agricultural productivity by 24%, and reduces energy requirements by 35%. The participatory approach achieved 78% spatial correspondence between stakeholder-identified and technically-assessed hotspots, validating local knowledge integration. This framework transformed passive consultation into active co-creation, providing a replicable model for nexus-based governance in data-scarce transboundary contexts.

Keywords: Water-Energy-Food nexus; participatory decision-making; WEAP modeling; stakeholder engagement; ecosystem-based adaptation; Kenya ASALs; transboundary governance



1.

Introduction

The Water-Energy-Food (WEF) nexus framework provides a strategic roadmap for synchronizing policies across interconnected resource sectors (Hoff, 2011). In transboundary basins characterized by competing jurisdictions and diverse livelihood systems, the nexus approach offers particular value by revealing hidden trade-offs and identifying synergistic interventions that sectoral planning would overlook (Albrecht et al., 2018). However, translating nexus concepts into actionable governance frameworks remains challenging, particularly in contexts characterized by data scarcity, weak institutional coordination, and diverse stakeholder interests (Shannak et al., 2018).

The Ewaso Ng'iro North Basin (ENNB) in Kenya exemplifies these challenges. Spanning five counties—Nyeri, Meru, Laikipia, Samburu, and Isiolo—the basin supports approximately 3.4 million people across livelihood systems ranging from intensive highland agriculture to extensive lowland pastoralism (KNBS, 2019). The basin's primary goal under nexus governance is to amplify 'nexus synergies'—such as using solar energy to power efficient drip irrigation—while reducing the damaging trade-offs that occur when upstream water use for food production compromises downstream energy security and livestock survival (Bleischwitz et al., 2018).

For communities spanning the diverse climates of Nyeri, Meru, Laikipia, Samburu, and Isiolo, an integrated approach is the only viable path toward meeting the Sustainable Development Goals (SDGs) (Castor et al., 2020). By managing friction points between different resource users, the ENNB can move closer to achieving SDG 2 (Zero Hunger) by securing food supply for both high-altitude farmers and lowland pastoralists; SDG 6 (Clean Water and Sanitation) by ensuring the Ewaso Ng'iro river maintains sufficient flow for all sub-catchments; SDG 7 (Sustainable Energy) by expanding renewable energy solutions for water pumping in remote areas; and SDG 12 (Sustainable Resource Management) by promoting accountability among large-scale abstractors (Sindico, 2016).

While the WEF nexus was once a purely academic concept, it has evolved into a practical necessity for basin-level policy-making. Modern methodologies now exist to translate these theories into action. Through comprehensive assessment tools identified by UNECE (2018) and others (Ramos et al., 2020), basins can now utilize data-driven models to address both the physical water scarcity and the social inequities within governance systems. These tools allow stakeholders to move beyond 'informed participation' toward 'decisive action' that respects ecological limits.

This study addresses the gap between nexus theory and governance practice by developing and testing a participatory decision-making framework that integrates qualitative stakeholder engagement with quantitative WEAP modeling. The specific objectives were: (1) to develop a participatory methodology combining stakeholder knowledge with technical analysis; (2) to co-create and evaluate decision-relevant scenarios for water-food interactions; (3) to quantify nexus trade-offs and synergies across intervention pathways; and (4) to demonstrate framework applicability for policy decision-making in transboundary contexts.



2.

Case Study

The Ewaso Ng'iro North Basin originates from Mount Kenya (5,199 m) and the Aberdare Ranges, draining approximately 15,200 km² before terminating in the Lorian Swamp. The basin exhibits a pronounced climatic gradient—from humid highlands receiving over 1,200 mm annual rainfall to arid lowlands receiving less than 300 mm—creating fundamental disparities in water availability across administrative boundaries (Notter et al., 2007).

The basin was delineated into 12 sub-catchments for modeling purposes: four upper sub-catchments (Upper Ewaso, Naro Moru, Burguret, Timau) in Nyeri and Meru Counties characterized by intensive agriculture; five middle sub-catchments (Ontulili, Teleswani, Ngare Ndare, Mutara, Sirimon) in Laikipia County with mixed commercial farming and ranching; and three lower sub-catchments (Archer's Post, Merti, Lorian) in Samburu and Isiolo Counties dominated by pastoralism.

The basin faces interconnected water, food, and energy challenges. Water stress averages 79% basin-wide, with downstream counties experiencing critical stress exceeding 85% during dry seasons. Agricultural water demand accounts for 67% of total abstractions (218 Mm³/year), creating upstream-downstream tensions. Energy poverty affects 55% of households, with 78-92% of rural populations in Samburu and Isiolo dependent on biomass fuels (WRA, 2021).



3.

Materials and Methods

3.1 Conceptual Framework

The participatory decision-making framework integrated the UNECE Water-Food-Energy-Ecosystems Nexus Assessment methodology (UNECE, 2018) with Hoff's analytical framework (Hoff, 2011). The UNECE methodology provides structured processes for transboundary nexus assessment emphasizing stakeholder participation, governance analysis, and identification of intersectoral solutions. Hoff's framework organizes analysis into six categories: nexus framing, opportunities, technical solutions, stakeholders, framework conditions, and governance innovations.

Figure 1 presents the schematic diagram of the participatory nexus methodology, illustrating the integration of qualitative stakeholder processes with quantitative technical modeling through five interconnected phases: (1) Stakeholder Mobilization and Problem Identification; (2) Participatory Hotspot Mapping and Priority Matrix Development; (3) Nexus Trade-off and Synergy Analysis; (4) Scenario Co-creation and WEAP Model Integration; and (5) Validation, Cost-Benefit Analysis, and Decision Support. Each phase combined community-based participatory methods with GIS and WEAP technical analysis, creating feedback loops that refined both stakeholder understanding and model parameterization.

3.2 Qualitative Analysis: Stakeholder Engagement Process

3.2.1 Participant Selection and Workshop Structure

Stakeholder workshops convened participants across three cluster workshops organized by geographic zones. Participants were purposively selected to represent four stakeholder categories: community representatives including farmers, pastoralists, women's groups, and youth organizations (n=52, 35%); county technical staff from water, agriculture, environment, and planning departments (n=48, 33%); Water Resources Authority (WRA) and Water Resource Users Association (WRUA) representatives (n=28, 19%); and partner organization staff from NGOs, research institutions, and development agencies (n=19, 13%).

Each two-day workshop followed a structured five-phase process: Phase 1 involved problem identification and cause-impact analysis using problem tree methodology; Phase 2 conducted participatory hotspot mapping using printed base maps and GIS-enabled tablets; Phase 3 developed priority matrices ranking challenges by severity (30%), spatial extent (20%), population affected (25%), and intervention urgency (25%); Phase 4 analyzed nexus trade-offs and synergies through structured cross-sectoral exercises; and Phase 5 focused on solution co-creation, scenario development, and cost-benefit estimation.

3.2.2 Participatory Nexus Mapping Exercise

Stakeholders were guided through a systematic nexus challenge mapping exercise across the three sectors. For water challenges, participants identified issues including declining river flows, groundwater depletion, water quality degradation, and upstream-downstream allocation conflicts. For food/agriculture challenges, issues included declining crop yields, livestock water scarcity, rangeland degradation, and irrigation expansion pressures. For energy challenges, participants mapped biomass depletion, limited electricity access, and high pumping costs for irrigation.

Critically, facilitators guided participants to analyze cross-sectoral linkages: how water scarcity affects food production and energy for pumping; how energy poverty constrains irrigation and food processing; and how agricultural practices impact water quality and availability. This explicit nexus framing distinguished the approach from conventional sectoral consultations.

3.3 Quantitative Analysis: WEAP Model Configuration

3.3.1 Sub-basin Delineation and Spatial Framework

The WEAP model (Yates et al., 2005) was configured for the 12 sub-catchments using 30m SRTM digital elevation data processed in ArcGIS 10.8. Sub-basin boundaries were delineated based on topography and validated against WRA administrative boundaries. The model integrated GIS layers including land use/land cover (RCMRD 2015), soil types (ISRIC SoilGrids), and infrastructure locations (dams, boreholes, irrigation schemes).

3.3.2 Water Demand Data

The model incorporated 35 demand sites representing all major water use sectors. Municipal/domestic demand was estimated for 5 urban centers (Nanyuki, Meru, Isiolo Town, Archer's Post, Wamba) serving 820,000 population at consumption rates of 50-80 L/person/day based on water utility records. Rural domestic demand was distributed across sub-catchments using census population data (KNBS, 2019) at 20-40 L/person/day.

Irrigation demand was calculated for 18 schemes covering 30,400 ha crop water requirements (MABIA), cropping patterns (county agricultural statistics), and irrigation efficiencies (45-70% for surface irrigation, 80-90% for drip systems). Livestock demand was estimated for 5 zones supporting 850,000 Tropical Livestock Units (TLUs) at 20-40 L/TLU/day based on herd composition and seasonal movements. Industrial demand was estimated for 15 facilities including commercial farms, processing plants, and tourist lodges at 5-50 m³/day per facility.

3.3.3 Water Supply Sources

Three categories of water supply were configured. Surface water supply included 28 river intakes along the Ewaso Ng'iro mainstem and tributaries, with monthly flow time series derived from 7 WRA gauging stations (2010-2023) and extended using rainfall-runoff modeling calibrated to CHIRPS precipitation data. The model included 8 dams and reservoirs with combined storage of 12.5 Mm³.

Groundwater supply was represented through 42 borehole nodes with extraction rates of 5-120 m³/hour based on WRA borehole records. Aquifer sustainable yields were estimated from pump test data and recharge calculations. Treated wastewater was included as a potential supply source for 3 urban centers with current treatment capacity of 8,500 m³/day and potential expansion to 15,000 m³/day under intervention scenarios.

3.3.4 Connecting Water Supplies and Demands

Demand sites were linked to supply sources through transmission links with specified loss rates (5-20% for pipelines, 30-40% for unlined canals). Allocation priorities followed national policy guidelines: Priority 1 (domestic supply), Priority 2 (livestock watering), Priority 3 (environmental flows), Priority 4 (irrigation), Priority 5 (industrial use). Environmental flow requirements were set at 10% of mean annual runoff as baseline, increasing to 30% during low-flow periods following WRA guidelines.

3.3.5 Historical Trends, Droughts, and Climate Projections

Historical analysis (1985-2023) revealed declining trends in dry season flows (-2.3% per decade) and increasing drought frequency. Major drought years (1999-2000, 2008-2011, 2016-2017, 2022) showed basin-wide water stress exceeding 95%, with complete cessation of environmental flows and widespread livestock mortality in downstream areas.

Future projections utilized IPCC's AR6 CMIP6 climate projections downscaled for the African region 5 GCMs under two scenarios, SSP2-4.5 and SSP5-4.5. The projections indicate 15-25% reduction in mean annual water availability, with more severe impacts during dry seasons (25-40% reduction) and increased inter-annual variability. Temperature increases of 1.0-2.0°C by 2040 will elevate evapotranspiration demands by 5-12%.

3.4 Process of Scenario Development

Scenario development followed a participatory, iterative approach integrating stakeholder visioning with technical feasibility assessment. During initial workshops, stakeholders articulated desired futures for their counties and the basin, identifying priority interventions and governance arrangements. The technical team synthesized these inputs with literature review and expert consultation to formulate seven distinct scenarios representing alternative development pathways.

Table 1: Scenarios developed through stakeholder dialogue and technical analysis

Scenario	Description	Key Interventions	Stakeholder Priority
S0: Baseline/Reference	Counties implement existing plans without coordination	Current abstraction rates continue; fragmented governance persists; no new major investments	Reference only
S1: Increased Water Productivity	Focus on producing more crop per drop through improved varieties and practices	Climate-smart varieties (+15% yield); deficit irrigation; soil moisture management; mulching	High (Meru, Nyeri)
S2: Wastewater Reuse	Treated wastewater for peri-urban agriculture and environmental flows	Treatment plants in 3 towns; 15,000 m ³ /day capacity; nutrient recovery; irrigation of 2,000 ha	Medium (urban areas)
S3: Transboundary Cooperation	Inter-county agreements for coordinated water allocation and benefit sharing	Basin allocation agreements; scheduled releases; joint monitoring; conflict resolution mechanisms	Very High (all counties)
S4: Technology Adoption	Modern irrigation and energy systems deployment	Drip irrigation (18,000 ha); solar pumping (1,850 units); smart water meters; remote monitoring	High (Laikipia, Meru)
S5: Water Supply Improvements	New infrastructure for storage and distribution	2 new small dams (8 Mm ³); 35 strategic boreholes; pipeline extensions; sand dams (45 units)	High (Samburu, Isiolo)
S6: Integrated Nexus	Comprehensive integration of all interventions with EbA and governance reform	Combines S1-S5 + riparian restoration (500 km); agroforestry (45,000 ha); rangeland management (80,000 ha)	Highest (72% preference)

Stakeholder dialogue and exercises formulated these scenarios through iterative refinement. During workshops, participants debated intervention priorities, discussed feasibility constraints, and negotiated trade-offs between upstream and downstream interests. Return workshops validated scenario parameters against local realities, adjusting adoption rates, timelines, and costs based on community feedback. This co-creation process ensured scenarios reflected both technical feasibility and social acceptability.



4.

Results and Discussion

4.1 Qualitative Analysis: Stakeholder-Guided Nexus Challenge Mapping

The participatory mapping exercise identified challenges across water, food, and energy sectors, which were consolidated into several priority issues through the ranking process. Water sector challenges dominated (48%), followed by food/agriculture (35%) and energy (17%). Spatial analysis revealed distinct issue profiles across catchment zones, with upper catchment stakeholders emphasizing water quality and over-abstraction, middle catchment focusing on allocation conflicts, and lower catchment prioritizing chronic scarcity and energy poverty.

Participatory hotspot mapping identified 34 water stress hotspots, 28 food insecurity hotspots, and 19 energy poverty hotspots. Critically, 12 locations were identified as multi-sectoral hotspots experiencing severe challenges across all three nexus dimensions, concentrated in the lower catchment downstream of Archer's Post. Stakeholder-identified hotspots achieved 78% spatial correspondence with WEAP-modeled water stress indices, validating local knowledge as a reliable foundation for technical analysis.

The importance of this collaborative mapping and prioritizing of nexus challenges goes beyond realizing the multi-sectoral impact of the challenge in question. Using a participatory approach builds consensus among stakeholders on the potential implications of the issues as well as on the solutions. It helps stakeholders to realize how their sectoral strategies might exacerbate or mitigate risks in other sectors. The nexus framework gives equal weight or importance to all sectors, unlike other frameworks such as Integrated Water Resource Management (IWRM) that looks to other sectors as water users only (Almulla et al., 2018). This was the first time such a participatory nexus framework was implemented in Ewaso Ng'iro basin, representing a valuable science-based contribution to inform sustainable resource management that would otherwise be difficult to achieve.

4.2 Nexus Synergies and Trade-offs Identified

Systematic analysis of cross-sectoral linkages revealed both synergies and trade-offs that would remain invisible in conventional sectoral planning. Key synergies identified included solar-powered irrigation reducing both energy costs and groundwater pumping emissions while improving water access; riparian restoration simultaneously increasing water yields, providing livestock fodder, and sequestering carbon; and wastewater reuse reducing freshwater abstraction while providing nutrient-rich irrigation water.

Critical trade-offs included upstream irrigation expansion increasing food production but reducing downstream flows for pastoral communities; afforestation during establishment phase temporarily reducing water yields before long-term benefits materialize; and efficiency improvements potentially being captured as expanded irrigation rather than downstream flow improvements without governance mechanisms. These insights directly informed scenario design, ensuring interventions included necessary governance components to realize synergies while mitigating trade-offs.

4.3 Scenario Analysis Results

WEAP modeling evaluated each scenario against baseline conditions for the 2025-2050 projection period under SSP2-4.5 climate assumptions. Table 2 summarizes key outcomes across four critical indicators: groundwater level change, unmet water demand, agricultural productivity, and energy requirements.

Table 2: Scenario impacts on key nexus indicators

Scenario	Groundwater Level (m/yr change)	Unmet Demand (Mm ³ /yr)	Agricultural Productivity (% change)	Energy Requirements (% change)
S0: Baseline/ Reference	-1.5	78	-18%	+25%
S1: Water Productivity	-0.9	52	+8%	+12%
S2: Wastewater Reuse	-1.2	62	+5%	+18%
S3: Transboundary Cooperation	-0.8	45	+12%	+8%
S4: Technology Adoption	-0.6	38	+15%	-28%
S5: Water Supply Improvements	-0.7	42	+10%	+15%
S6: Integrated Nexus	-0.1	18	+24%	-35%

Note: Negative groundwater values indicate depletion; positive agricultural productivity indicates improvement over baseline.

The Integrated Nexus scenario (S6) demonstrated superior performance across all indicators. Groundwater depletion was reduced from 1.5 m/year under baseline to 0.1 m/year—effectively achieving sustainable abstraction rates through combined efficiency improvements and enhanced recharge from ecosystem restoration. Unmet water demand declined from 78 Mm³/year to 18 Mm³/year (77% reduction), with downstream counties (Samburu, Isiolo) experiencing 48% and 42% reductions in water deficits respectively.

Agricultural productivity increased by 24% through combined effects of improved water availability, climate-smart practices, and efficient irrigation technologies. Energy requirements decreased by 35% primarily through solar pumping adoption replacing diesel systems, demonstrating strong nexus synergies where renewable energy deployment simultaneously advances water security and reduces operational costs.

4.4 Comparison with Single-Sector Approaches

Results demonstrate that no single intervention solves all nexus challenges. The Technology Adoption scenario (S4) achieved strong energy savings (-28%) but only moderate water stress reduction. The Transboundary Cooperation scenario (S3) effectively reduced unmet demand but required complementary technical interventions for agricultural productivity gains. Water Supply Improvements (S5) provided critical benefits for downstream areas but without efficiency measures risked inducing additional upstream demand.

The Integrated Nexus approach's superiority derives from capturing synergies across intervention types while mitigating trade-offs through governance mechanisms. Ecosystem-based adaptation components (riparian restoration, agroforestry, rangeland management) provided foundational infrastructure that amplified technology intervention benefits. Transboundary cooperation ensured efficiency gains translated to downstream flow improvements rather than expanded upstream consumption.

4.5 Cost-Benefit Analysis and Cost of Inaction

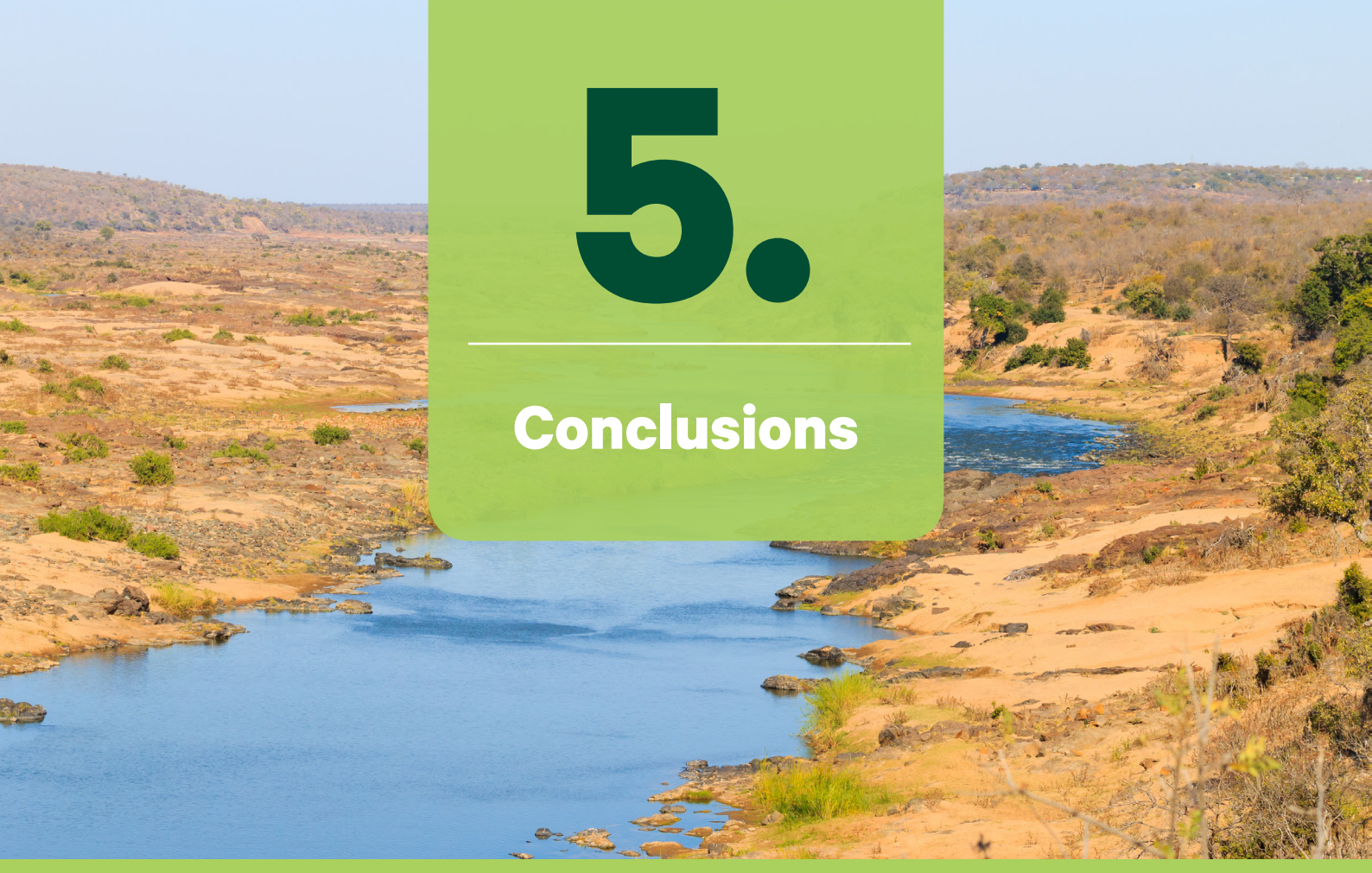
Implementation costs for the Integrated Nexus scenario were estimated at KES 4.2 billion (USD 29 million) over a 10-year period. Annual benefits were quantified at KES 12.8 billion (USD 90 million) including water supply improvements (KES 3.8 billion), agricultural productivity gains (KES 5.2 billion), energy cost savings (KES 2.1 billion), and avoided environmental degradation (KES 1.7 billion)—yielding an aggregate benefit-cost ratio of 3.1:1.

The cost of inaction under baseline trajectories was estimated at KES 16.2 billion annually by 2040 (USD 113 million), comprising water scarcity losses, agricultural productivity decline, energy poverty impacts, and environmental degradation costs. This stark asymmetry between intervention costs (KES 4.2 billion one-time) and inaction costs (KES 16.2 billion recurring annually) provided compelling justification for stakeholder commitment to implementation.

4.6 Stakeholder Validation and Scenario Preferences

Validation workshops (n=68 participants) assessed scenario preferences and implementation feasibility. The Integrated Nexus scenario received overwhelming support (72% first preference), followed by Transboundary Cooperation (15%), Technology Adoption (8%), and others (5%). Stakeholder reasoning emphasized that single interventions, while beneficial, fail to address systemic interdependencies. As articulated by participants: 'We have learned from past failures—integration is essential' and 'Water projects without considering energy access don't help our communities.'

County-specific preferences revealed nuanced priorities: Nyeri and Meru favored productivity and efficiency interventions; Laikipia emphasized technology adoption and coordination mechanisms; Samburu and Isiolo prioritized water supply improvements and energy access. All counties prioritized transboundary cooperation components, validating the integrated approach's emphasis on governance alongside technical interventions.



5.

Conclusions

This study developed and demonstrated a participatory framework that transforms stakeholder engagement from passive consultation into active co-creation of decision-relevant WEF nexus scenarios. The framework successfully integrated qualitative participatory methods with quantitative WEAP modeling and GIS analysis, generating technically robust and socially legitimate interventions for the Ewaso Ng'iro North Basin.

Key findings include: First, participatory nexus mapping achieved 78% spatial correspondence with technical assessments, validating local knowledge integration for resource planning in data-scarce contexts. Second, the Integrated Nexus scenario outperformed all single-sector alternatives, reducing unmet water demand by 77% (78 to 18 Mm³/year), stabilizing groundwater (0.1 vs. 1.5 m/year depletion), increasing agricultural productivity by 24%, and reducing energy requirements by 35%. Third, ecosystem-based adaptation components provided foundational infrastructure amplifying technology intervention benefits, with riparian restoration alone yielding 17.8:1 benefit-cost ratio. Fourth, governance mechanisms—particularly transboundary cooperation—proved essential for ensuring efficiency gains translate to equitable downstream benefits rather than expanded upstream consumption. Fifth, the cost of inaction (KES 16.2 billion/year by 2040) vastly exceeds intervention costs (KES 4.2 billion total), providing compelling economic justification for integrated action.

The participatory nexus framework represents a valuable science-based contribution to inform sustainable resource management. By engaging decision-makers directly in analysis and scenario development, the process generated outputs immediately usable in county planning processes, with several priority interventions already incorporated into County Integrated Development Plans for 2023-2027. The framework provides a replicable model for nexus-based governance in transboundary basins globally, particularly in contexts characterized by competing jurisdictions, diverse livelihood systems, and data limitations.

Future research should focus on longitudinal monitoring of implementation outcomes, comparative analysis across multiple basins, development of digital tools for participatory nexus mapping at scale, and deeper integration of climate uncertainty into scenario analysis. As climate change intensifies resource pressures across Africa's arid and semi-arid lands, such integrated participatory approaches become increasingly essential for achieving water, energy, and food security within planetary boundaries.

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