



Water Supply and Demand Trends in the Upper ENNCA, Kenya



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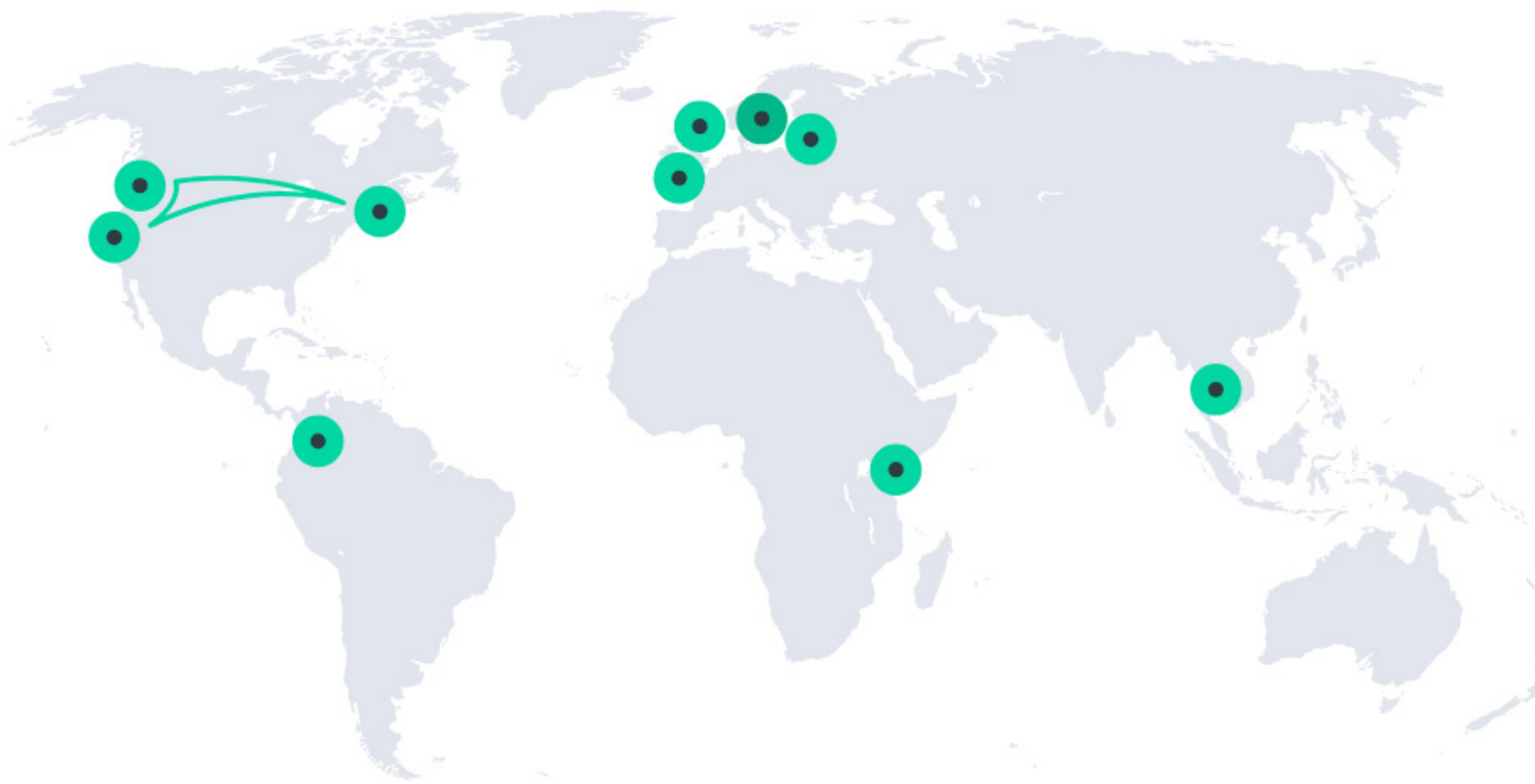
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About the Project

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



EXECUTIVE SUMMARY

The Ewaso Ng'iro North Basin faces critical water security challenges driven by competing sectoral demands, upstream-downstream allocation inequities, climate variability, and fragmented governance across five counties: Laikipia, Samburu, Isiolo, Meru, and Nyeri. This study employed the Water Evaluation and Adaptation Planning (WEAP) system to assess current and future water supply-demand dynamics under multiple scenarios, providing evidence-based recommendations for integrated water resources management that balances agricultural productivity, domestic water security, hydropower generation, and ecosystem health.

This study was made possible through the valuable contributions and collaborative efforts of numerous partners and stakeholders across the Ewaso Ng'iro North Basin. We extend our sincere gratitude to the Centre for Training and Integrated Research in ASAL Development (CETRAD), Mount Kenya Integrated Development Programme (MIDP), National Drought Management Authority (NDMA), Water Resources Authority (WRA), Ministry of Water, Sanitation and Irrigation, and the Kenya Meteorological Department (KMD) for providing essential data, technical expertise, and institutional support that formed the foundation of this modeling exercise. Special appreciation goes to the County Governments of Nyeri, Meru, Isiolo, Samburu, and Laikipia for their active participation, data sharing, and commitment to collaborative water resources planning across the basin.

We are particularly grateful to the Water Resources Users Associations (WRUAs), local communities, civil society organizations, private sector representatives, and all stakeholders who participated in consultative workshops, validation sessions, and scenario co-creation processes. Your deep knowledge of local water challenges, practical insights into community needs, and collaborative spirit in jointly developing the six WEAP scenarios were instrumental in ensuring that this modeling framework reflects real-world conditions and priorities. The participatory approach strengthened the relevance, credibility, and applicability of the findings, transforming this study from a technical exercise into a truly community-informed decision-support tool for sustainable water management in the basin.

Some of the key findings include: **Model Calibration Success:** The WEAP model achieved excellent performance metrics ($NSE=0.72$, $R^2=0.85$, $PBIAS=7.1\%$, $NRMSE=9.2\%$), validating its reliability for water resource planning and scenario analysis across the basin; **Tightening Water Budget:** Despite projected 7.5% rainfall increase by 2050, streamflow decreases by 10% (485 to 438 Mm^3) while evapotranspiration rises 8% and human abstractions surge 40% (245 to 342 Mm^3), indicating intensifying water stress; **Sectoral Water Use:** Domestic consumption dominates at 43% of total water use, while agricultural irrigation (commercial 38%, subsistence 16%) accounts for 54%, highlighting the critical role of efficient water management in both sectors; **Upstream-Downstream Inequity:** Upper catchment counties (Nyeri, Meru, Laikipia) command 99.7% surface water abstractions, creating chronic shortages in downstream pastoral counties (Samburu, Isiolo) where reliance on groundwater reaches 43%; **Climate Vulnerability:** Water supply fluctuates dramatically between wet (520-550 Mm^3) and dry (360-390 Mm^3) years—a 40% reduction—while demand remains stable at 290-350 Mm^3 , creating severe deficits during droughts with water stress exceeding 130%; **Scenario Analysis Results:** Business-as-usual and county-focused scenarios (S1, S2) increase unmet demand to 142-174 units by 2050, while integrated cooperation (S5) and ecosystem restoration (S6) scenarios reduce unmet demand by 78-88%, achieving 48-88% environmental flow requirements compared to just 22% under baseline conditions.

The modeling results demonstrate that fragmented, county-siloed water management approaches will exacerbate water stress, threatening livelihoods and economic development across the basin. Conversely, integrated interventions combining agricultural efficiency improvements (irrigation technology, crop shifting), infrastructure investments (storage expansion, hydropower diversification), and cooperative governance mechanisms can reduce unmet water requirements by 15-25%, lower greenhouse gas emissions, and generate sustained agricultural productivity gains through 2050.

Critical to success is the establishment of legally-binding inter-county water allocation frameworks with benefit-sharing mechanisms that address the upstream-downstream disparity. Without coordinated action, downstream pastoral communities in Samburu and Isiolo—already experiencing 60% food poverty rates—will face escalating water insecurity, while upper catchment agricultural systems risk undermining their own long-term sustainability through over-abstraction.

Urgent priorities include:

- Operationalize basin-wide water allocation agreements through the Ewaso Ng'iro North River Basin Development Authority (ENNDA) with enforcement mechanisms
- Invest in water storage infrastructure (500 Mm³ additional capacity) to buffer seasonal variability and capture wet-season surplus for dry-period use
- Scale agricultural water efficiency through modern irrigation systems achieving 13-33% demand reduction while maintaining productivity
- Implement ecosystem-based adaptation measures prioritizing water tower protection (Mt. Kenya, Aberdares) and environmental flow requirements (targeting 60-80% of natural flows)
- Strengthen hydrometeorological monitoring networks and establish centralized water accounting systems for transparent resource management
- Build inter-county cooperation capacity through joint planning forums, shared benefits mechanisms, and conflict resolution protocols

Conclusion: This WEAP modeling study provides a robust decision-support framework for transforming water governance in the Ewaso Ng'iro North Basin. The analysis demonstrates that integrated, cooperative management approaches can achieve water security for 2.5 million people while protecting critical ecosystems—but only if political commitment and coordinated action are mobilized before deepening water stress forecloses these opportunities. The participatory process that informed this study—bringing together government institutions, communities, and diverse stakeholders in scenario co-creation—demonstrates the collaborative spirit necessary for transforming these recommendations into tangible improvements in water security across all five counties.

Key Highlights

- Sectoral fragmentation undermines water management effectiveness i.e., traditionally, policy silos across water, energy, agriculture and land sectors have historically prevented coordinated resource planning
- Integrated nexus modeling delivers superior planning outcomes than siloed modeling, leading to better-informed decision-making and improved policies
- Collaborative basin management enhances livelihoods and economic productivity
- Ecosystem-based adaptation strengthens climate resilience

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Abbreviations and Acronyms

ACRONYM	MEANING
WEAP	Water Evaluation and Adaptation Planning tool
GCMs	General Circulation Models
RCMs	Regional Climate Models
MABIA	Model for the Assessment of Biofuel Impacts on Agriculture
ENNCa	Ewaso Ng'iro North catchment
EbAs	Ecosystem-based Adaptation practices
LEAP	Low Emission Analysis Platform
IWRM	Integrated Water Resource management
SSPs	Shared Socioeconomic Pathways
CIDP	County Integrated Development Plan
HP	Hydropower
WRA	Water Resources Authority
WEF Nexus	Water-Energy-Food nexus
WRUAs	Water Resources Users Association
BAU	Business as Usual
NSE	Nashe Sutcliffe Efficiency
OND	October-November-December
MAM	March-April-May
RMSE	Root Mean Square Error
PBIAS	Percent Bias
RCPs	Representative Concentration Pathways
SDGs	Sustainable development Goals
KNBS	Kenya National Bureau of Statistics
CBOs	Community Based Organizations
ENNDA	Ewaso Ng'iro North Development Authority
AR6	Sixth Assessment Report
IPCC	Intergovernmental Panel on Climate Change

1.

INTRODUCTION

1.1 Background Information

For decades, water availability in the Ewaso Ng'iro North Basin has declined to critical levels as irrigated agriculture in the upper catchment, along with increased water abstraction for domestic use and commercial horticulture, have radically altered the timing and flow of water downstream to the semi-arid and arid lowlands. The basin is shared by ten counties: Laikipia, Meru (parts of), Nyeri (parts of), Isiolo, Samburu (parts of), Marsabit, Wajir, Garissa (northern half), and Nyandarua (parts of) (ENNDA Strategic Plan, 2023).

Climate change is accelerating temperature increases and rainfall variability, further exacerbating water, food and livelihood insecurity across the basin (MKWEP, 2018), but the rate of change remains deeply uncertain. One way to address this uncertainty is to find cooperative approaches to increase water security across the ten counties and diverse stakeholder groups.

As part of regional water management initiatives including the Mount Kenya Ewaso Water Partnership and development partner programs, this research focused on the Upper Ewaso Ng'iro North basin, with a keen interest in five counties: Laikipia, Samburu, Isiolo, Meru and Nyeri, and the entire Ewaso Ng'iro North River Basin, with goals of building technical capacity and multi-stakeholder cooperation across the counties. This was accomplished by facilitating the development of **integrated water-energy-food nexus** models for the basin using innovative tools like WEAP and LEAP, which support better decision-making and help provide stability, economic prosperity and healthy ecosystems (Davis *et al.*, 2025).

Efforts to attempt to address water conflicts previously focused on water allocation models in isolation, comparing trade-offs between water for upstream commercial agriculture and horticulture versus water for downstream pastoral communities and smallholder farmers. This framing leads to results that are largely win-lose, for instance, if water is allocated for upstream irrigation and urban use, it is not available for downstream pastoral livelihoods, wildlife conservation, and community water needs, and vice versa.

Several studies have used a system of tools to examine trade-offs across water, energy, land, and agricultural sectors. This study used an integrated system of tools to look at trade-offs across the water, energy, environmental and agricultural sectors, including: the Low Emission Analysis Platform (LEAP); the Water Evaluation and Adaptation Planning software (WEAP) (LEAP, 2025; WEAP, 2025). This is an integrated planning framework that can identify policies and infrastructure investments that maximize benefits for water supply, energy access, food security, and economic development, while supporting the Water-Energy-Food (WEF) nexus approach, adopted in the Ewaso Ng'iro North Basin.

1.2 Ewaso Ng'iro North Catchment (ENNCa)

The Ewaso Ng'iro North Catchment (ENNCa) originates from the Aberdare Ranges and Mount Kenya, forming one of Kenya's most critical water towers that supports approximately 2.5 million people across five counties: Laikipia, Meru, Samburu, Isiolo, and parts of Nyeri (**Figure 1**). The river flows northeastward for approximately 700 kilometers, draining a catchment area of about 15,200 km², before terminating in the Lorian Swamp in northeastern Kenya. The catchment exhibits highly variable hydrology characterized by distinct wet (March-May and October-December) and dry seasons, with mean annual rainfall ranging from over 1,200 mm in the upper catchment highlands to less than 300 mm in the lower arid and semi-arid zones. This pronounced climatic gradient creates significant spatial variability in water availability, with the upper catchment contributing to the majority of streamflow while downstream areas experience chronic water scarcity (Kiteme & Giesen, 2004; Notter et al., 2007).

Agricultural activities dominate water demand in ENNCa, accounting for approximately 70-80% of total water abstractions, with large-scale commercial farming concentrated in the upper and middle catchment areas of Laikipia and Meru counties. The catchment supports diverse agricultural systems including large-scale irrigated horticulture, floriculture, wheat farming, and extensive livestock ranching, alongside smallholder rain-fed agriculture and pastoralism in the lower reaches. Land use patterns reflect this agricultural intensity, with approximately 35% of the catchment under agricultural use, 25% rangeland and grassland, 15% forested areas (mainly in the upper catchment water towers), and the remainder comprising bare land and settlements (Muthee et al., 2018). Domestic water demand from rapidly growing urban centers such as Nanyuki, Isiolo, and Meru town, combined with demands from tourism and hydropower generation, creates complex competing water uses. The catchment hosts several hydropower installations including Kamburu, Gitaru, and Kindaruma on tributaries, though these are relatively minor compared to agricultural abstractions.

Water supply challenges in ENNCa are intensifying due to increasing abstractions, climate variability, and land use changes, with downstream communities experiencing severe water stress particularly during prolonged droughts. Studies indicate that actual water abstractions in the upper catchment may exceed allocated permits by 30-50%, leading to reduced downstream flows and periodic complete drying of the river in lower reaches during dry seasons (Lanari et al., 2018). Groundwater resources provide critical supplementary supply, particularly in the lower catchment, though sustainable yields remain poorly quantified. The catchment faces a classic upstream-downstream water allocation conflict, where upstream commercial agriculture and urban centers command the majority of abstractions while downstream pastoral communities dependent on the river for livestock and domestic use face chronic shortages. Climate projections suggest increasing temperature trends of 1-2°C by mid-century and highly uncertain precipitation changes under various scenarios, potentially exacerbating existing water stress conditions and necessitating improved water governance and allocation mechanisms to ensure equitable and sustainable water use across the basin (LVBC & WWF-ESARPO, 2010).

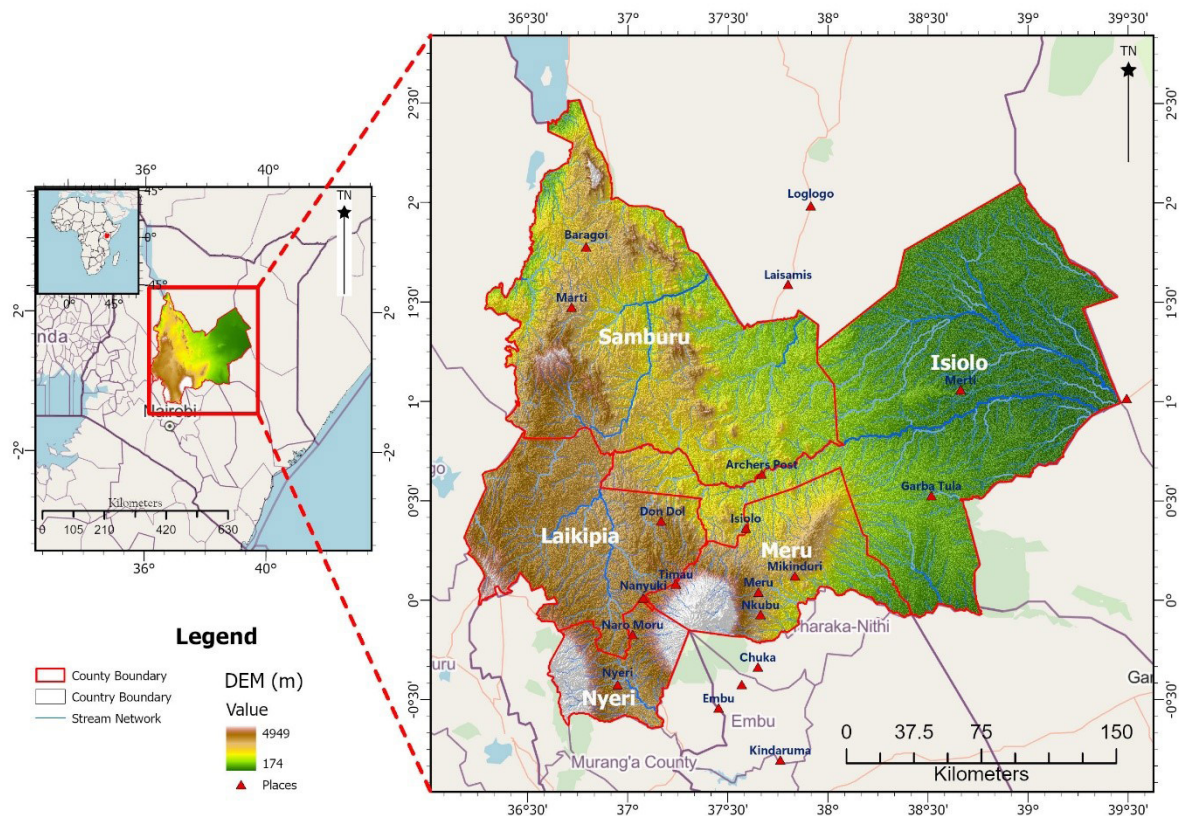


Figure 1: Location of Ewaso Ng'iro North catchment

1.3 Water Supply and Demand Overview

The five counties of Samburu, Isiolo, Laikipia, Meru, and Nyeri form a critical water system within the Ewaso Ng'iro North Basin, that is characterized by significant variations in water availability and access. The region experiences a highland-lowland gradient, with the upper catchment counties of Nyeri and Meru receiving higher rainfall while the downstream counties of Samburu and Isiolo face arid and semi-arid conditions. Population growth has intensified pressure on water resources across all five counties, with Meru County hosting approximately 1.66 million people, Laikipia 583,000, Samburu 367,000, and Isiolo 330,000 residents (KNBS, 2021). However, water access levels vary dramatically across the region. In Isiolo County, approximately 44.5% of the rural population and 67% of the urban population have access to drinking water (Isiolo County Water Strategy 2023-2035, 2023). In the drier counties, domestic water primarily comes from boreholes with average depths of 70 meters and yields of 2 to 6 cubic meters per hour, though some areas experience poor yields of only 1-2 cubic meters per hour due to hard geological formations and limited recharge (Factsheet, 2022). Water scarcity has intensified in recent decades due to inadequate resource management and declining rainfall patterns (B. Kiteme, 2020).

Excessive water abstraction for irrigation in the Mount Kenya and Nyandarua foot zones has reduced downstream river flows, particularly during dry seasons, severely affecting water users in the lower basin (B. P. Kiteme et al., 2008). The decline in the flow of water levels in the Ewaso Ng'iro River has been attributed to several factors including climate change, illegal upstream abstraction, cultivation on riverbanks, and uncontrolled sand harvesting (Daily Nation, 2023). Competition for water has grown between different user groups (Lesrima et al., 2021), with increasingly expensive alternative sources such as rainwater and groundwater harvesting unable to meet growing demand (Demory et al., 2023). The competition has created sharp conflicts that intensify during dry seasons, sometimes resulting in physical

confrontations between upstream and downstream users (Gichuki, 2002). The upstream-downstream dynamic presents a critical challenge: water allocated for commercial agriculture and horticulture in Laikipia, Meru, and Nyeri directly reduces availability for pastoral communities, smallholder farmers, and wildlife conservation in Samburu and Isiolo.

1.4 Refining the Gap

Several water resource assessment reports in Kenya provide projections of water availability across major basins, yet these analyses often fail to capture the nuanced challenges of localized water management. Regional studies often employ simplified assumptions of the relationships between water sources and user demands, limiting their utility for basin-specific decision making. This study addresses these limitations by delivering a comprehensive analysis of water management challenges specific to this critical highland-lowland system spanning Samburu, Isiolo, Laikipia, Meru, and Nyeri Counties. Through detailed spatial and temporal representation of water supplies and demands, this basin-level investigation goes beyond generalized regional assessments to evaluate the efficacy of specific interventions including infrastructure investments, conservation programs, and refined allocation mechanisms. The analysis accounts for the distinctive upstream-downstream relationships that define water availability patterns in the Ewaso Ng'iro North system, where decisions made in the upper catchment directly influence water security in the arid and semi-arid lowlands.

This research demonstrates the application of the Water Evaluation and Adaptation Planning (WEAP) system as a decision support tool for assessing water management strategies in the Ewaso Ng'iro North Catchment. WEAP provides an integrated platform for examining hydrological dynamics, supply infrastructure, consumption patterns, ecological water requirements, water quality considerations, as well as explore possible socio-economic and management scenarios, within a unified analytical framework (Opere et al., 2022). This approach enables evaluation of how alternative management approaches and climatic conditions influence water accessibility across competing sectors. In this setting, WEAP was used to support analysis of competing demands between intensive commercial farming and horticultural operations in the upper counties of Nyeri, Meru, and Laikipia, and the water requirements of pastoral and mixed farming communities in the downstream counties of Samburu and Isiolo.

The primary aim of this research was to simulate both present and projected water supply and demand in the Ewaso Ng'iro North Basin across multiple scenarios encompassing climate variability, socioeconomic inclusion including demographic expansion and land use transformation, while evaluating how strategic water management interventions can strengthen water security throughout all five counties. Specifically, the research aimed to;

- i. Simulate the current and future water demand and supply, and water balance within the Ewaso Ng'iro North Catchment, quantifying water availability from surface and ground water sources, and assessing demands across various uses – domestic, agricultural (livestock and irrigation), commercial, industrial and ecosystem sectors, under various hydrologic, climate and socio-economic scenarios.
- ii. Assess water development strategies by examining the performance of proposed water development and management alternatives including physical infrastructures (dams and reservoirs), conservation approaches (irrigation efficiencies, water recycling), urban developments, and consumption management initiatives to strengthen water availability, dependency and utilization efficiency in the region.

- iii. Quantify the impacts of climate variability on the basin's hydrology and water users by simulating climate change consequences under alternative emissions (Shared Socioeconomic Pathways-SSPs)
- iv. Generate evidence-informed recommendations for integrated water stewardship, by delivering a thorough understanding of the importance, compromises and predictability of IWRM strategies through a comprehensive scenario evaluation.

Through WEAP modeling, this research characterized the consequences of proposed interventions on water accessibility and dependability, highlighting sector-specific tradeoffs. Through a multi-scenario approach that incorporates future climate patterns, population dynamics, land use changes and a combination of interventions, this study aims to guide stakeholders, including community leadership, regulatory authorities, Community Based Organizations (CBOs) and county leadership, on potential outcomes, and the implementation viability of these interventions. The overarching purpose is **to advance equitable and sustainable water resource utilization** across the Ewaso Ngiro North Basin while safeguarding ecological integrity and sustaining the livelihoods of communities throughout both upstream and downstream zones.

2.

DATA, TOOLS AND METHODS

2.1 Introduction

A comprehensive methodology was employed to assess the water supply and demand, food security, and the nexus between energy, water and food in the Ewaso Ng'iro North Basin. The approach integrated qualitative and quantitative data collection, with water demand and supply modeling using the Water Evaluation and Planning (WEAP) system tailored specifically for the basin. The WEAP model simulated various scenarios of water supply and demand across the five counties (Samburu, Isiolo, Laikipia, Meru, and Nyeri), incorporating climate projections, population growth trajectories, agricultural expansion, and economic development patterns, all these included in such scenarios as: County focus; water and agricultural improvements; energy and climate change; and ecosystem restoration. Food security analysis was integrated into the modeling framework by examining water allocation for irrigation, livestock production, and competing agricultural demands across the upstream-downstream gradient.

The methodology also combined **biophysical modeling results** with **stakeholder consultations**, **policy analysis**, and **governance assessments** to provide a robust framework for evaluating the resilience of the Ewaso Ng'iro North Basin's water-food systems under different future scenarios. This integrated approach enabled the identification of critical trade-offs between water use for commercial agriculture in the upper catchment counties and food security needs of pastoral and agro-pastoral communities in the downstream areas.

2.2 Qualitative and Quantitative Data Collection

The study employed multiple methods to gather both qualitative and quantitative information, including review of written materials, expert consultations, stakeholder discussions, and validation sessions with key actors in Kenya's water sector.

2.3 Review of Policy Documents and Literature

A comprehensive examination of existing literature formed the foundation of this research. Materials reviewed encompass policy frameworks, strategic documents, county management and development plans (CIDPs) relevant to Kenya's water sector, such as the National Water Resources Management Strategy, WRA's 2023-2027 strategic plan, and the Kenya National Water Master Plan 2030. Relevant journal articles, international and regional water governance frameworks were also examined. This desk review established baseline knowledge of current institutional structures, policy environments, and sectoral challenges while highlighting knowledge gaps requiring further exploration.

2.4 Stakeholder Mapping and Consultation

Collaborative workshops brought together representatives from governmental bodies, private organizations, civil society organizations and academia, to review and verify research findings. Workshop objectives centered on confirming insights from documentary review and consultations, examining result implications, and co-developing actionable recommendations for strengthening the region's water management systems. The session additionally provided opportunity for participants to signal interest in ongoing engagement and outline potential future contributions and collaborations.

2.5 Key Informant Interviews

Expert consultations were held with individuals holding specialized knowledge of water resources management practices. Participants included ministry officials from the Department of Water and Sanitation under the Ministry of Environment, Climate Change, and Natural Resources, Water Resource Authority personnel, academic researchers, Non-Governmental Organization leaders working in water conservation, and community Water Resources Users Association (WRUAs). Customised interview guides were developed for distinct respondent categories mentioned, to capture-specific perspectives on water use, policy effectiveness, implementation barriers and enhancement opportunities.

Additional consultations using a flexible interview approach were conducted with diverse water sector participants, including WRUA representatives, commercial water users, county officials, and donor organization staff. This methodology permitted adaptive exploration of topics such as infrastructure challenges, and community engagement. The open-ended format encouraged detailed sharing of practical experiences and viewpoints regarding water governance.

2.5.1 Stakeholder Validation Workshop

A collaborative workshop brought together representatives from governmental bodies and civil society organizations to review and verify research findings. Workshop objectives centered on confirming insights from documentary review and consultations, examining result implications, and codeveloping actionable recommendations for strengthening the basin's water management systems. The session additionally provided opportunity for participants to signal interest in ongoing engagement and outline potential future contributions.

2.5.2 Data Triangulation

Information gathered through all methods underwent systematic examination to identify patterns, obstacles, and prospects within the water management landscape. A triangulation approach strengthened research credibility by cross-checking findings across documentary sources, expert interviews, and workshop discussions to establish consistent themes and note contradictions. Narrative data from consultations and meetings were systematically coded to extract recurring insights, while numerical information from official documents provided corroborating evidence, yielding a holistic assessment of water resources management in the basin.

2.6 The WEAP Model

A comprehensive Water Evaluation and Adaptation Planning (WEAP) System was constructed using spatial and temporal (monthly) datasets to simulate both historical conditions and future climate projections across the five counties. The model utilised WEAP's automated catchment delineation feature, which leverages publicly accessible digital elevation data (DEM) from Hydro sheds to establish watershed boundaries.

2.7 Data Sources and Limitations

The WEAP model utilized diverse data sources, with online databases detailed in Annex I. Primary documentary references included the National Water Master Plan 2030 (2013), the county Integrated Water Resource Management and Development Plans (2017-2022, 2023-2024), Ewaso Ng'iro North and Upper Tana Basin Plans. Additional data was also sourced from relevant literature and the Ministry of Water Resources. Some of the key datasets incorporated include:

- **Climate data:** Observed monthly variables (precipitation, temperature, humidity) through 2014, and CMIP6 projections (2015-2050) at 28 km resolution.
- **Demographics:** Updated census data through 2019 (base data from 2013 master plan reflected 2010 conditions).
- **Infrastructure:** Dam information from government reports and media sources, verified via satellite imagery.
- **Agriculture:** FAO 2015 crop mapping at 8-10 m resolution based on Landsat imagery.
- **Hydrology:** Streamflow data from four stations (1961-2016) for model calibration.
- **Abstraction Data:** was obtained from the Water Resources Authority (WRA)
- **Land use:** In addition to climate data, land-use information is another important input to WEAP catchments. Each sub-catchment is fractionally subdivided into a unique set of independent land-use/land-cover classes. For the ENNCa WEAP model, we have used the European Space Agency's Climate Change Initiative Land Cover database (ESA-CCI-LC) to determine the land cover distribution within each catchment, as shown in Figure 2. The data indicate that four land classes – grassland, shrubland, agriculture, and forest – account for the majority of the basin's area, suggesting that these land classes largely control the hydrological response of the ENNCa region. Grassland predominates across the basin, particularly in Meru (approximately 15,000 km²), while agriculture is concentrated in Nyeri (approximately 14,000 km²) and substantial portions of Rumuruti and Isiolo. Forest cover is most prominent in the Ewaso Ng'iro River catchment and Isiolo, reflecting the upper basin's forested highlands, whereas shrubland is extensive in Samburu and the central basin areas. Wetlands, urban areas, barren/sparse vegetation, and open water account for relatively small portions of the total basin area. The ESA land cover data is only available for 1992 to 2015, which does not coincide with the model's historical climate data record; therefore, we have used a static land cover based on the average of the ESA dataset, meaning the model does not represent land use changes in the basin over time.

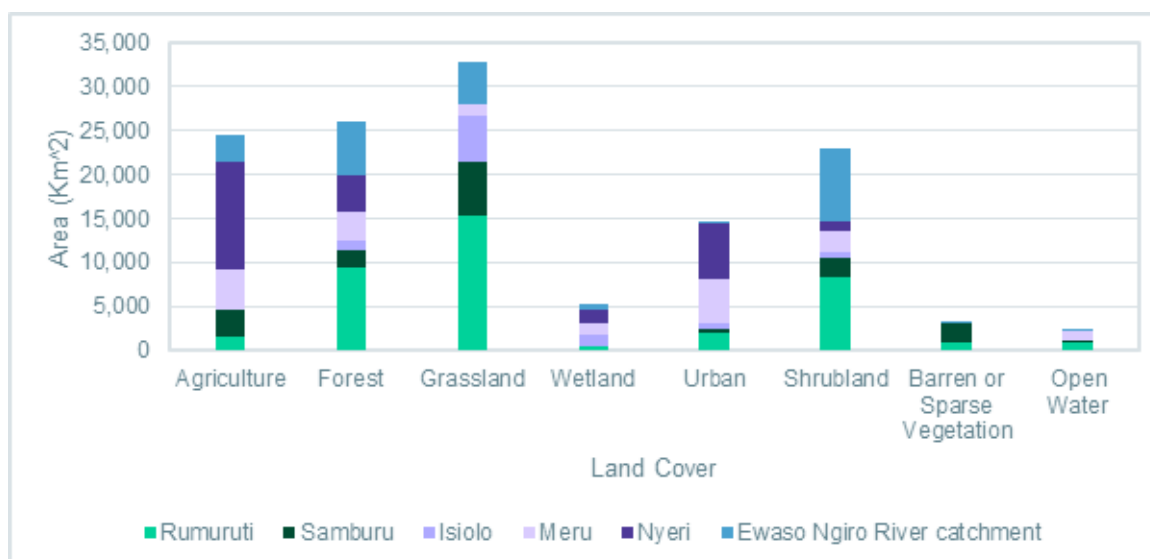


Figure 2: Total land cover within each hydrologic unit of the ENNCA region

- Demands:** Demands are represented in WEAP with demand nodes, with one node per demand type (domestic, livestock, irrigation, etc.) for each sub-catchment where those demands exist. All demands in the ENNCA model were developed based on water demand assessments and abstraction surveys conducted across the basin counties. Where possible, demands are broken into an annual activity level (e.g., population for domestic demands, number of animals for livestock) and a water use rate (e.g., 50L/person/day for domestic use). In WEAP, the annual activity level is multiplied by the water use rate to calculate total demand. Water use rates are saved as key assumptions in the model for easy modification during scenario analysis. Most demands are assumed to be constant throughout the year except irrigation, which varies based on cropping patterns and seasonal water requirements. Consumption rates represent the portion of water that is consumed versus returned to the system—livestock demands assume 100% consumption, while domestic and tourism demand include return flows to groundwater and surface water. Growth rates are applied from the baseline year forward to project future demands based on population growth, livestock trends, and development scenarios specific to each county.

2.7.1 Assumptions

Several key assumptions were adopted in the modeling process. Groundwater recharge and yields were not modeled. Instead, sustainable extraction rates from the CIDPs were applied. Population growth was estimated at county level using the Kenya National Bureau of Statistics (KNBS) census numbers and projections. Agricultural areas were estimated using the FAO 2015 crop map (consistent with the 2020 IWRM plans), with irrigation percentages derived from FAO data. Environmental flows were calculated using the flow duration curve method under class E Environmental management classification.

2.8 Selection of Climate Change Scenarios

Historical Climate data (Precipitation, Temperature and Wind) were obtained from Princeton global meteorological dataset, which provided monthly data at 0.25° resolution from 1948-2014. This dataset blends observational records with reanalysis to support hydrological modeling, including streamflow, groundwater and agricultural water demand estimation. The data similarly allows climate characterization in data scarce regions. Projected climate conditions were derived from the Coupled Model Inter-comparison Project Phase 6 (CMIP6) models within the IPCC's 6th Assessment Report (AR6).

Given the inherent uncertainty in climate projections, Global Climate Models (GCMs) provide a range of potential outcomes useful for water resource planning. The WEAP modeling framework has been widely utilized by researchers and professionals to assess climate impacts across various spatial scales, with its integrated watershed planning approach making it well-suited for assessing these climate uncertainties at multiple scales.

Additionally, the analysis employed a couple of climate change scenarios. Shared Socioeconomic Pathways (SSPs), which describe diverse global development pathways including sustainability, regional rivalry, inequality, fossil fuel dependent growth and middle-ground scenarios. SSP2 represents a moderate baseline, while SSP3 depicts a challenging future (Meinshausen et al., 2020) (Figure 1). These socioeconomic scenarios are paired with Representative Concentration Pathways (RCPs), that specify emission trajectories. RCP 2.6 represents stringent pathways with negative emissions by 2100, RCP4.5 represents an intermediate pathway with emissions peaking around 2040, RCP6.0 reflects high emissions peaking around 2080, and RCP8.5 implies a future with continued high emissions growth, (Gidden et al., 2019) (Figure 2).

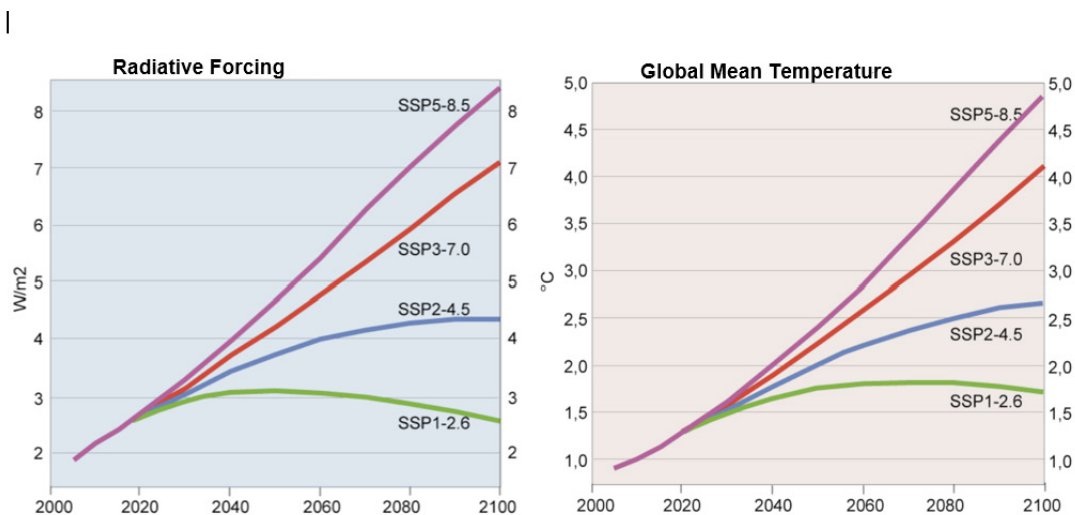


Figure 3: Change in radiative forcing (left) and global mean temperature until 2100 (right)

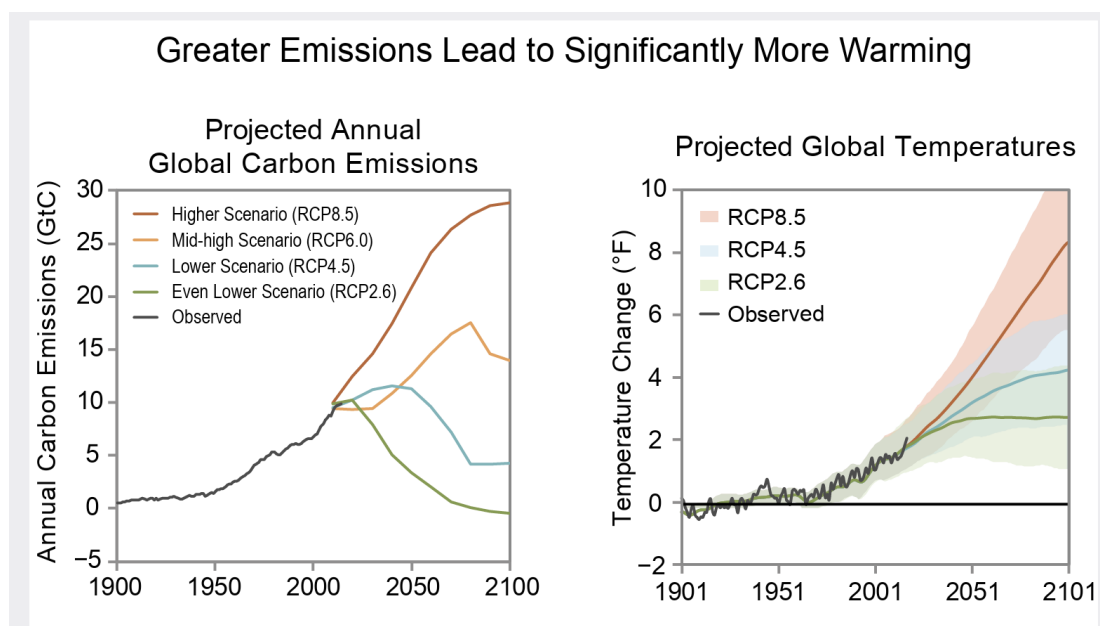


Figure 4: Projected annual carbon dioxide emissions (left) with prospective global temperatures (right)

NOTE:

Figure 1 shows change in radiative forcing and global mean temperature until 2100 compared to pre-industrial values (1850) according to the four SSP standard scenarios. Figure 2 shows the annual historical and a range of plausible future carbon emissions in units of gigatons of carbon (GtC) per year (left) and the historical observed and future temperature change that would result for a range of future scenarios relative to the 1901–1960 average.

On average, an analysis of CMIP6 climate projections for all of Kenya indicates that temperatures are increasing and will be 1.5 degrees hotter from 2035–2065 than they were from 1985–2014. The projections on average also project an increase in precipitation, by 12%.

2.8.1 WEAP Scenario Development

WEAP’s scenario analysis capability makes it valuable for assessing water system vulnerabilities under different uncertainties and evaluating management strategies to improve water security (WEAP, 2025). Following consultations with diverse stakeholders across the Ewaso Ng’iro North catchment, in combination with desk review of relevant plans and policy documents, a total of six scenarios were implemented in WEAP. Multiple model simulations were conducted to examine water demand and supply reliability under the different scenarios. The scenarios are summarized in Table 1.

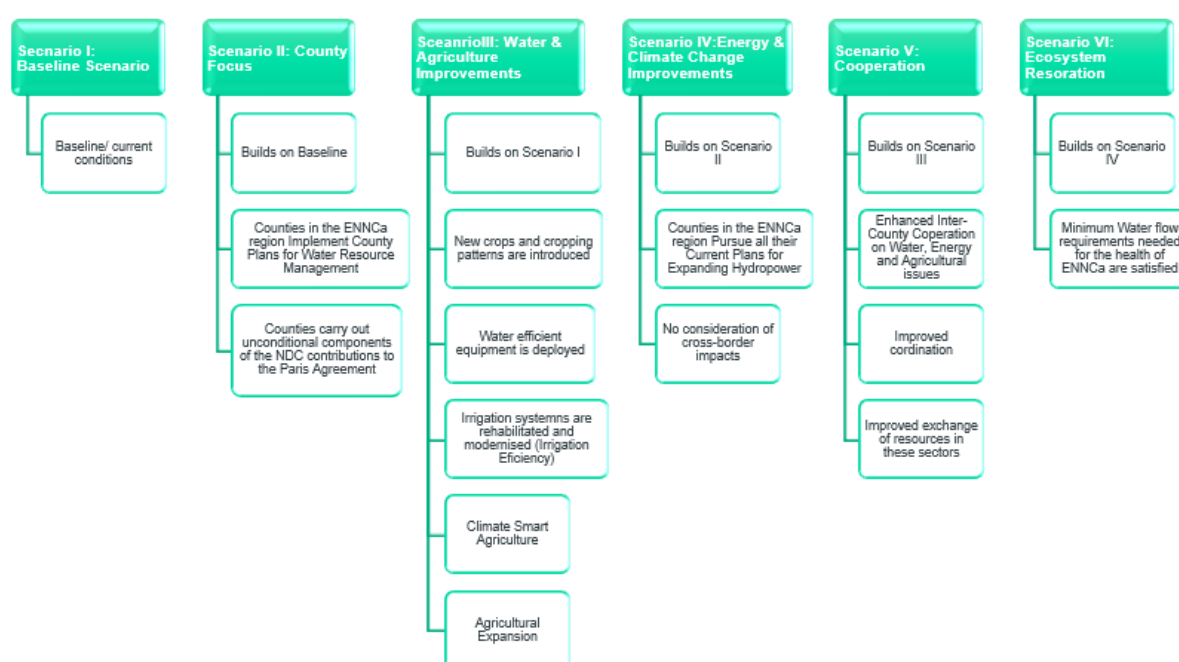


Figure 5: Scenarios implemented in WEAP

2.8.2 Implementing Scenarios in WEAP

Six scenarios were explored with the WEAP model of the ENNCA. The implementation of the six scenarios are summarised in Table 2. These include.

Table 1: Implementation of the WEAP Scenarios

Scenario	Hydropower	Agriculture	Water Allocation	Ecosystem
S1: Baseline	No hydropower expansion	Crop areas fixed at 2020 levels. Yields follow past trends	Set in accordance with current National & County priorities	Lowest priority
S2: County Focus	Baseline + 18 small-scale hydropower plants	Baseline + Shift to higher value crops in counties	Same as above	Same as above
S3: Agriculture	Same as above	S2 + a range of investments to improve water use and yield	Same as above	Same as above
S4: Energy & Climate	Informed by LEAP model	Same as above	Same as above	Same as above
S5: Cooperation	Same as above	Same as above	Water in upper basin is release to meet all downstream demands	Same as above
S6: Ecosystems	Same as above	Same as above	Same as above	Highest priority

Details of the WEAP implementation in each scenario are provided below:

Scenario 1 (S1): Baseline

- **Hydropower:** current hydropower demand. No expansions
- **Agriculture:** Total irrigated area is fixed at 2020 levels; Cropping patterns are unchanged; Potential yields continue increasing at same rate as historical trends (1990-2020).
- **Water Allocation:** Allocation priorities range from 1 to 99, with 1 the highest priority and 99 the lowest; demand priorities must be greater than storage priority to withdraw water from storage. For the Ewaso Ng'iro North basin, a two-tier system was followed, with allocations.
 - » Tier 1: Position within watershed
 - » Tier 2: Water use

Scenario S2: County Focus

- **Hydropower:** Hydropower development in the Ewaso Ng'iro North catchment is concentrated in the upper catchment counties (Meru, Nyeri) with reliable water flows from Mt. Kenya and Aberdare water towers, while downstream counties (Samburu, Isiolo) face hydrological constraints that limit hydropower viability. Development of 18 small-scale hydropower sites with individual capacities ranging from 300 kW to 3 MW, distributed across river systems on Mt. Kenya's eastern slopes; Total estimated combined capacity of approximately 27-54 MW across all identified sites.
- **Agriculture:** Increase value added by shifting to higher valued crops in the counties: 50 percent of wheat areas replanted with cassavas
- **Water Allocation:** Same as Scenario 1.

Scenario S3: Agriculture

- **Hydropower:** Same as Scenario 2
- **Agriculture:** Focus on improving water use and agricultural practices throughout the basin via:
 - » Increasing irrigation efficiencies achieved through application of water saving technologies in each basin county.
 - » Reducing conveyance losses in each basin in the counties.
 - » Improving yields in Samburu, Isiolo, Meru, Nyeri & Laikipia
 - » Expanding irrigated areas in Ewaso Ng'iro North Basin;
 - » Adding 500 million cubic meters of new storage in each county
 - » Shifting from wheat to cassava in the counties (same as Scenario 2).
- **Water Allocation:** Same as Scenarios 1 and 2.

Scenario S4: Energy & Climate

- **Hydropower:** Any changes are passed to WEAP from LEAP.
- **Agriculture:** Same as Scenario 3.
- **Water Allocation:** : Same as Scenarios 1, 2, and 3.

Scenario S5: Cooperation

- **Hydropower:** Same as Scenario 4.
- **Agriculture:** Same as Scenarios 3 and 4.
- **Water Allocation:** : Allocation priorities changed such that dams in upper basin release to meet water demands in downstream users (Isiolo and Samburu)

Scenario S6: Ecosystems

- **Hydropower:** Same as Scenarios 4 and 5.
- **Agriculture:** Same as Scenario 3-5.
- **Water Allocation:** Same as Scenario 5, except that the highest priority is assigned to ecosystems/flow requirements
- **Ecosystems:** Flow Requirements set along Ewaso Ng'iro at each border crossing:
 - » Flow Requirements set based on estimated natural flows for each climate scenario.
 - » **FDCShift Method:** Sets flow requirements based on the extent to which the basin has been modified from natural conditions, with a higher degree of modification resulting in a lower flow requirement.

2.8.3 The WEAP Model

The Ewaso Ngiro North WEAP model subdivided the basin into multiple sub-catchments (SCs), represented as catchments in WEAP. Seven sub catchments were automatically delineated. The model used WEAP's rainfall-runoff soil moisture method to simulate the sub-catchments and their contributions to streamflow and groundwater, which constitute the watershed's hydrology. For each sub-catchment, climate data is entered, and as rainfall occurs, the proportion of water contributing to evapotranspiration, groundwater, or surface water is adjusted based on the sub-catchment's land use, slope, soil type, and other physical characteristics during calibration. WEAP calculates the proportions of rainfall that partition into evapotranspiration, soil moisture storage, baseflow to groundwater, interflow to the river, and surface runoff to the river in each time step, thereby simulating the complete water balance for each sub-catchment across the Ewaso Ngiro basin.

The MABIA model was used for modeling crop water requirements and the different water balance components as well as analysis and simulation of agricultural water demands, flow and recharge in the Ewaso Ngiro North Basin

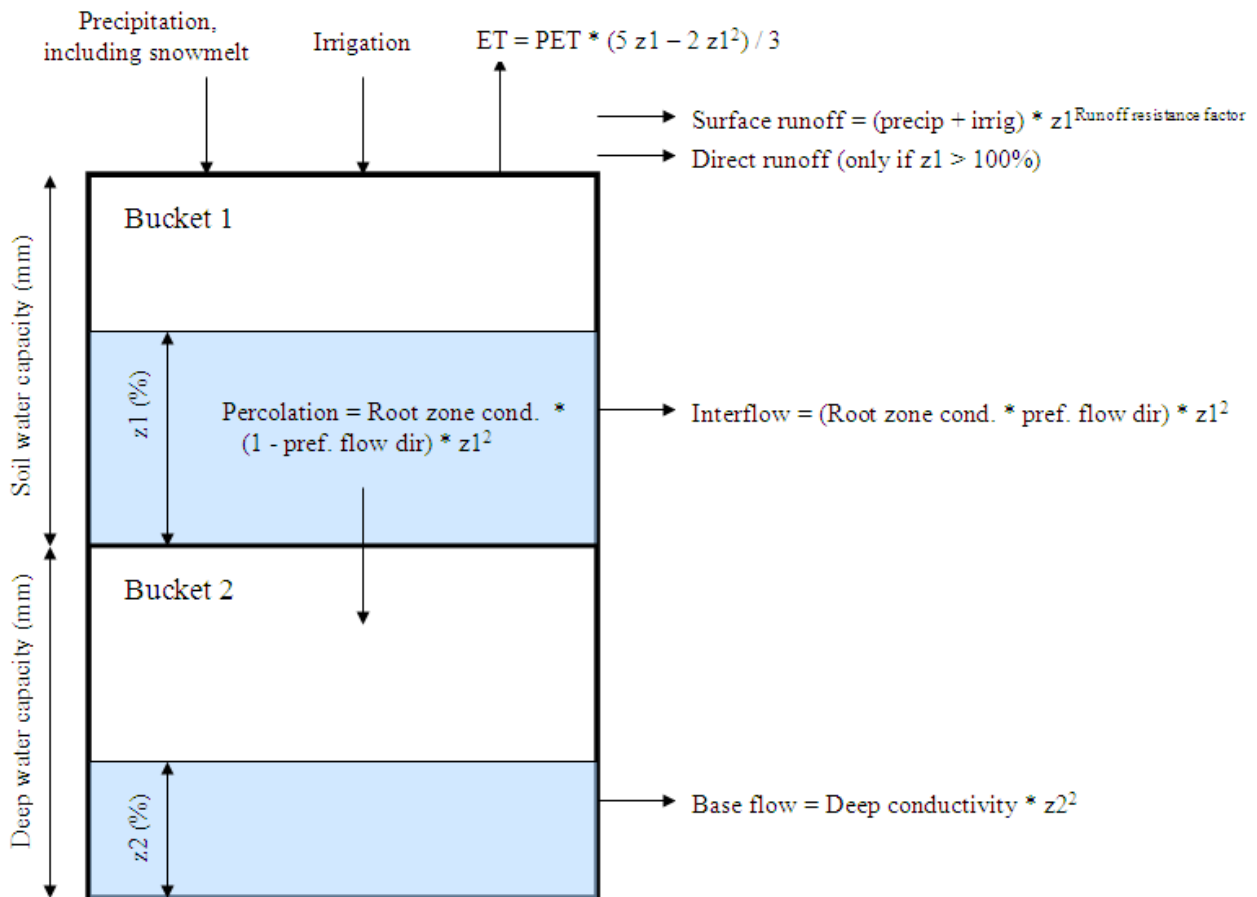


Figure 6: Conceptual diagram and calculations included in WEAP's soil moisture method for modeling catchment hydrology.

3.

RESULTS AND DISCUSSION

3.1 Introduction

This section presents the findings of the scoping study on water resources in Ewaso Ng'iro North catchment (ENNCa). This section is structured to provide a detailed analysis of the data collected through the methodology stated in chapter 2 i.e., document analysis, key informant interviews, stakeholder participation and the Water Evaluation and Adaptation Planning (WEAP) simulations. First the stakeholder perspectives will be presented, then trends in water supply and demand. Each subsection will discuss the results, highlighting critical insights and implications for sustainable water management in the ASALs.

3.1.1 Stakeholder Perspectives on water Resources Management in the Upper Ewaso Ng'iro North Catchment

Based on the participatory engagement undertaken during this study, a stakeholder workshop was convened with representatives from all five counties within the Ewaso Ng'iro North catchment—Samburu, Isiolo, Meru, Laikipia, and Nyeri. The workshop provided a platform for collaborative problem identification, where participants mapped out the key water resource challenges facing their respective counties, analyzed the underlying causes and potential impacts of these challenges, and identified critical hotspot areas experiencing the most severe water stress. Through facilitated group discussions and technical sessions, county stakeholders developed a priority matrix to systematically rank the identified problems based on criteria such as severity, spatial extent, population affected, and urgency of intervention. This participatory approach ensured that local knowledge and county-specific contexts informed the water demand assessment and modeling framework, strengthening the relevance and applicability of the study findings to support evidence-based water resource management and planning decisions across the catchment. Summaries of outputs are presented in Table 2. the Ewaso Ng'iro North Basin

Table 2: Combined County Problems, Solutions and EbA Solutions

Laikipia	Meru	Nyeri	Samburu	Isiolo
EbA PRACTICES/ SOLUTIONS	EbA Practices/ Solutions	Eba Practices/ Solutions	Solution/ EBA solutions	Solution/ EBA solutions
1. Water scarcity - Catchment conservation and protection - Reafforestation of degraded areas - Conservation along river lines - Conservation of wetlands & springs - Embrace climate smart grazing like zero grazing - Reseeding of Rangelands - Keeping of climate- smart animal breeds and seeds varieties - Enhancement of Construction of communal water points	1. Water Scarcity - Agroforestry, - Water harvesting technologies, - climate smart agriculture, - enhance catchment protection; - Reclaim, rehabilitate & protect wetlands and springs - Enhance transparent water allocation plan	1. Water scarcity - Regenerative agriculture e.g. minimum tillage. - Agroforestry - Afforestation - Re-afforestation - Provision of water infrastructures. - Protection of riparian and wetlands - Planting and protection of indigenous species - Water and soil conservation measure - Biodiversity conservation - Construction of common water intakes	1. Water Scarcity. - Rehabilitation of degraded lands. - Water infrastructure. - Catchment - Protection. - Rehabilitation - Of water infrastructure. - Wetland protection. - Strengthening of Water Service providers (SAWASCO)	1. Water Scarcity. - Sub-catchment protections e.g., springs and planting trees - Promotion of water efficient technologies e.g., climate smart agricultural practices - Construction of sand dams, earth pans - Promotion of sustainable land use practices - Integration of Social Behaviour Change (SBC)
2. Low food production - Adoption of agro-ecology practice - Implementation of good agricultural practices - Aggregation of food - Use of solar-based water pumping machines	2. Environmental degradation - Improve carbon sequestration by planting more trees - Community policing to curb the harvest of timber/charcoal burning - Encourage people on the riparian to conduct afforestation	2. Land Degradation - Climate smart agriculture - Agroforestry, Afforestation and Re-afforestation - Rotational grazing - Mulching and Growing cover crops - Conservation agriculture - Fodder and pasture production - Water and soil conservation measure - Biodiversity conservation - Participate in trans-boundary peace forums.	2. Food Scarcity - Conservation / Climate Smart agriculture. - Kitchen Gardens. - Irrigation. - Planned grazing. - Storage of Acacia Pods.	2. Floods - Regulation OF and Harvesting - Construction of water dams and check dams - Restoration of wetlands - Sub-Catchment protection activities e.g., Tree planting - Integration of Social Behaviour Change (SBC)

3. Land degradation • Development of programs for reseedling of rangelands • Proper management of invasive species • Capacity building of communities on controlled stocking	3. Pollution • Support of environmental clean ups • Formation of intercounty environmental committees • Relocate pit latrines away the water bodies (at least 30 m away)	3. Low agricultural productivity • Conservation agriculture • Agroforestry • Intensification of agro-production practices. • Mulching, and Growing cover crops • Enforcement of land use policies e.g. change user. • Production of Water efficient crops (tolerant varieties • Water harvesting and storage facilities • Water and soil conservation measure • Diversification of enterprises • Intercropping and/or Drip Irrigation • Support with farm inputs e.g. certified seeds/ seedlings	3. Land Degradation • Sustainable land management practices (gabions, semicircular bands) • Afforestation and reforestation	3. Low crop and livestock production. • Promotion of Agroecology • Pest and disease management • Development of integrated database on crop and livestock production • Strengthening Detha System • Integration of SBC (Social Behavior Change)
3. Low crop and livestock production. • Promotion of Agroecology • Pest and disease management • Development of integrated database on crop and livestock production • Strengthening Detha System • Integration of SBC (Social Behavior Change)	4. Food shortages • Climate smart agriculture • Promote low-cost crop value addition technologies • Promote low-cost food storage	4. Low Value Addition • Processing of honey by youth and women groups. • Gender friendly markets • Improved access to financial services • Enforcement and implementation of relevant policies and regulation • Training and capacity building on value addition and technologies.	4. Resource based conflicts • Planned grazing system	4. Land/Habitat degradation. • Community based approaches in land management and restoration • Upscaling the planned grazing e.g., Detha • Upscaling research, innovation and monitoring of invasive species • Civil education and awareness of sustainable land use • Assisted natural regeneration

5. Over abstraction • Development and implementation of water allocation plans for every River Basins • Continuing enforcement with Water Permitting conditions • Construction of common water intakes • Enhanced compliance with Water use permit conditions	5. Poor Enforcement of Water Act • Centralization and digitization of information • Awareness of communities on the new policies • Community involvement in policy formulation	5. Water pollution • Establishment of community waste disposal sites. • Awareness creation on safe disposal, use of agro-chemicals • Decentralized treatment facilities • Mapping of hot spot areas. • Established common watering points.	5. Deforestation • Participatory Forest Management (PFM).	
6. Encroachment of water catchment & Riparian areas • Erosion sediment survey • Water catchment reclamation	6. Poor nutrition • Sensitization and training of local communities • Promote local foods for the right diet • Vitamin supplementation • Promote kitchen gardens and use	6. Loss of Biodiversity • Promotion of alternative energy saving technologies (jikos, biogas). • Climate smart agriculture • Agroforestry, Afforestation and Re-afforestation • Rotational grazing • Growing cover crops and Conservation agriculture • Enforcement of land use policies • Fodder and pasture production • Water and soil conservation measure • Biodiversity conservation		

7. Droughts and floods • Agro-forestry and reafforestation • Afforestation • Planting of cover crops/ ground cover • Construction of water harvesting infrastructure like check-dams	7. Invasive plant species			
8. High demand for energy • Tap into blue energy • Use of biogas				
9. Water resource pollution • Conservation of riparian lands/ areas • Construction of designated areas for waste disposal				
10. Sand harvesting • Afforestation along the riverbanks • Construction of gabion in the degraded riverbanks and check- dams, and dykes				

3.1.2 Challenges to Water Resources Management in the Ewaso Ngiro North Catchment from Stakeholder Analysis

The Ewaso Ngiro North catchment faces multiple interconnected challenges that threaten sustainable water management:

- 1. Climate Variability and Change** - High rainfall variability, increasing drought frequency, and unpredictable seasonal patterns disrupt water availability and agricultural planning, particularly affecting arid downstream areas.
- 2. Competing Sectoral Water Demands** - Intensive competition exists between large-scale commercial agriculture, smallholder irrigation, pastoral livestock watering, domestic consumption, hydropower, and environmental flows.
- 3. Upstream-Downstream Inequities** - Upper catchment abstractions by Nyeri, Laikipia, and Meru significantly reduce flows reaching downstream Samburu and Isiolo, creating chronic water stress and inter-county conflicts.
- 4. Fragmented Governance** - Weak inter-county coordination, absence of binding water allocation agreements, and limited enforcement capacity result in unregulated abstractions and conflicting development priorities.
- 5. Catchment Degradation** - Deforestation of water towers (Aberdare and Mount Kenya forests), riparian zone encroachment, and wetland conversion reduce natural water storage and regulation capacity.
- 6. Inefficient Water Use** - Predominance of flood irrigation, high conveyance losses in aging infrastructure (40-50%), and inadequate storage facilities waste limited water resources.
- 7. Data and Monitoring Gaps** - Non-functional hydrometric stations, limited groundwater monitoring, and outdated agricultural statistics (mostly from 2010-2015) constrain evidence-based planning.
- 8. Population Growth and Land Use Change** - Rapid urbanization and agricultural expansion drive escalating water demands while converting rangelands, intensifying resource competition.
- 9. Human-Wildlife Conflicts** - Wildlife damages crops and infrastructure, competition for water sources, and restricted access to protected areas complicate water management.
- 10. Limited Financial Resources** - County fiscal constraints and competing development priorities limit investments in water infrastructure, monitoring systems, and management capacity.
- 11. Weak Regulatory Enforcement** - Unauthorized abstractions, illegal boreholes, and non-compliance with regulations persist due to insufficient personnel, resources, and political interference.
- 12. Socio-Cultural Barriers** - Conflicts between traditional and formal governance systems, exclusion of women and marginalized groups from decision-making, and non-recognition of customary pastoral water rights impede cooperative management.

3.1.3 County Governments' Initiatives on Integrated Water Resources Management

County governments within the Ewaso Ngiro North catchment have undertaken various initiatives to enhance water resources management as outlined in their County Integrated Development Plans (CIDPs) 2023-2027, though implementation levels vary across the five counties:

Meru County has prioritized reliable water supply across the county, particularly in semi-arid wards, as a flagship initiative in their CIDP 2023-2027. The county emphasizes water availability, optimizing water allocation, and water conservation measures integrated with climate change adaptation strategies. CIDP focuses on investing resources to improve livelihoods at the grassroots level, with specific attention to smallholder agriculture and water resource management.

Laikipia County has invested in drought mitigation measures including borehole drilling, water pan construction, and water distribution systems, particularly along the Ewaso Narok river. The county's Climate Change Action Plan 2023-2027 emphasizes building resilience through enhanced water security, improved water infrastructure, and fostering stakeholder collaboration. The CIDP highlights water resource development as critical infrastructure supporting the county's four-pillar manifesto focused on security, community cohesion, Maendeleo Mashinani (grassroots development), inclusive government, and infrastructure development.

Nyeri County CIDP 2023-2027 integrates water and sanitation as key components of its social pillar, focusing on transformation in health, environment, housing, and urbanization. The county has prioritized water resource management including construction of dams, water pans, and borehole drilling to improve water access. The plan emphasizes strategic investments in smallholder agriculture and informal sectors while focusing on water security for both urban and rural populations.

Samburu County has expanded irrigation schemes in arid regions (including Kilimani-Game, Galana, Gafarsa, Malkadaka, Rapsu) to boost year-round farming. During FY 2023-2024, the county drilled and equipped six borehole sites, solarized four previously unequipped boreholes, and completed 38 kilometers of water pipeline extensions across the county. The CIDP 2023-2027 focuses on livestock production improvements and agricultural diversification alongside water infrastructure development.

Isiolo County developed a comprehensive County Water Strategy 2023-2035 aligned with CIDP 2023-2027, aiming to enhance water security through sustainable water management practices, improved infrastructure, and stakeholder collaboration. The county has rehabilitated irrigation infrastructure along the Ewaso Ngiro River, developed water pan and borehole infrastructure, and promoted agro-pastoralism. The water strategy addresses water scarcity, inadequate infrastructure, and unsustainable management practices affecting food security and environmental sustainability.

Crosscutting Basin-Level Initiatives: Counties participate in multi-stakeholder platforms through the Ewaso Ngiro North River Basin Development Authority (ENNDA) and engage with the Water Resources Authority (WRA) for coordinated water allocation. The Basin-wide Integrated Water Resources Management and Development Plan (2020) provides strategic direction for collaborative management across the catchment.

3.2 WEAP Model Simulations

This section presents the findings of the scoping study on water resources in Ewaso Ngiro North catchment (ENNCa). This section is structured to provide a detailed analysis of the data collected through the methodology stated in chapter 2 i.e., document analysis, key informant interviews, stakeholder participation and the Water Evaluation and Adaptation Planning (WEAP) simulations. First the stakeholder perspectives will be presented, then trends in water supply and demand. Each subsection will discuss the results, highlighting critical insights and implications for sustainable water management in the ASALs.

3.2.1 Model Performance (Calibration and Validation)

Before using the model to evaluate the performance of water supply reliability within the Ewaso Ngiro Basin, it was necessary to first calibrate the hydrological routines to ensure that it can adequately estimate flows in rivers.

The first step in calibrating any model is to select a historical period of record that includes concurrent input and observation data that cover a period long enough to capture the range of conditions (wet and dry) within a basin. In this case, the main input data for the WEAP model include climate data and the observation data are gaged streamflow. We selected the fifteen-year period from 1961 to 1975, during which there were multiple stream gauges containing several years of flow data. These included the following locations:

- 5BB02E at waso Ngiro
- 5BC06 at Buguret
- 5BC08 at Engare Ngobit
- 5BE01 at Nanyuki
- 5BE02 at Ontulili
- 5BE06 at Timau
- 5BE07 at Likii
- 5D05 at Ewaso Ngiro
- 5D08 at Isiolo
- 5E03 at Ewaso Ngiro Lower

The WEAP model was calibrated to historical stream flows at each of these locations using a combination of manual methods and computer algorithms, such as the PEST software (Doherty, 2002). Five land use parameters were adjusted to achieve calibration to streamflow at various locations. The parameters are the **evapotranspiration coefficient** (Kc), soil water **capacity** (SWC), **runoff resistance factor** (RRF), **root zone conductivity** (RZC), and the **preferred flow direction** (PFD). Model simulations are most sensitive to SWC, RZC, and RRF. Thus, initial calibration focused on these three parameters. Further refinement to the shape and timing of the resulting hydrographs was accomplished by adjusting Kc and PFD.

The WEAP model calibration metrics demonstrated **good to very good performance** that meets international standards for hydrological modeling (**Table 3**), with the Nash-Sutcliffe Efficiency of 0.72 exceeding the 0.70 threshold for acceptable model performance and R-squared of 0.85 indicating excellent correlation between simulated and observed flows. The low percent bias values (7.1% and 11.35%) confirm minimal systematic error with the model slightly underestimating flows, while the normalized RMSE of 9.2% and standard deviation ratio of 0.95 reveal outstanding precision and accurate representation of flow variability. Although the Kling-Gupta Efficiency of 0.68 falls slightly below the ideal 0.70 target, all metrics collectively indicate the model is well-calibrated and reliable for water resource planning, allocation studies, scenario analysis, and policy decision-making in the Ewaso Ngiro North Basin.

Table 3: Calibration Metric for the WEAP Model

Calibration Metric	Value
Nash-Sutcliffe Efficiency (NSE)	0.72
Percent Bias (PBIAS)	7.1%
Ratio of Standard Deviations (SDR)	0.95
Kling-Gupta Efficiency (KGE)	0.68
Percent Bias (PBIAS)	11.35%
Root Mean Square Error (RMSE)	0.57
R-Squared (r2)	0.85
Normalised RMSE (NRMSE)	9.2%

The calibration period (1990-2000) time series (Figure 7) demonstrates that the model successfully captures the temporal dynamics and hydrological behavior of the Ewaso Ngiro North Basin, with both observed and simulated data showing excellent agreement in identifying the timing and occurrence of all major runoff events throughout the 1990-2000 period. The model correctly represents the ephemeral nature of the stream with extended zero-flow periods between rainfall events, accurately simulates the interannual variability with wet years (1997-98) and dry years clearly distinguished, and demonstrates strong responsiveness to rainfall patterns by generating flow peaks that coincide with observed events in 1990-91, 1992-93, 1993-94, and the exceptional 1997-98 El Niño period. Both datasets reveal consistent seasonal patterns where the basin experiences clustered wet periods followed by prolonged dry spells, indicating the model has effectively incorporated the basin's hydrological processes including rainfall-runoff relationships, transmission losses, and the influence of antecedent moisture conditions. The visual alignment of peak occurrences between the two time series confirms the model's ability to capture the critical flood-generating mechanisms in this ASAL environment, providing a solid foundation for scenario analysis and water resource planning once magnitude adjustments are applied through calibration to fine-tune the flow volumes while maintaining this excellent temporal structure.

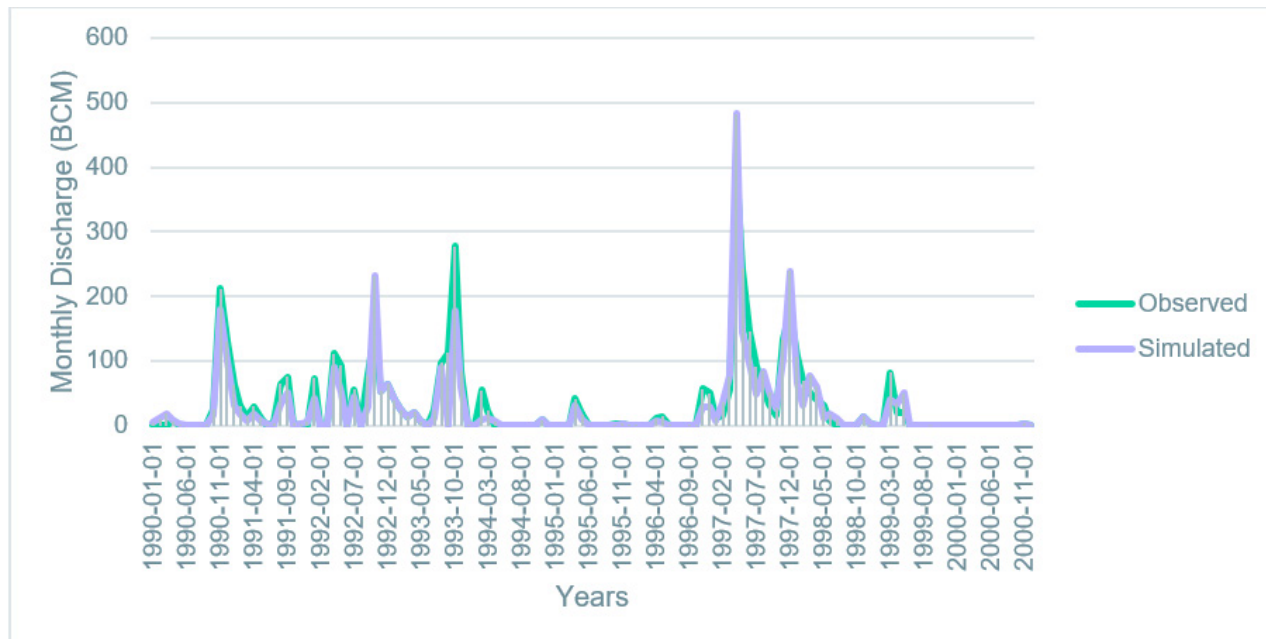


Figure 7: Observed and simulated discharge for gauge 5D05 at Ewaso Ngiro

The average monthly discharge (Figure 8) comparison demonstrates that the model successfully captures the fundamental hydrological seasonality of the Ewaso Ng'iro North Basin, accurately representing the characteristic bimodal rainfall pattern with distinct peaks during the long rains (April-May, ~75 MCM) and short rains (November, ~60 MCM observed) that define water availability in East African ASAL regions. The model shows particularly strong agreement during the long rains season where April flows are nearly identical (~77 MCM) and May flows closely match observed patterns, indicating excellent representation of the primary recharge period that sustains most water resource activities in the basin. Both datasets identify September as the critical low-flow month (~18 MCM), confirming the model's ability to capture the water stress period when demand management becomes essential, and demonstrate consistent behavior across the dry season months (January-March, June-August) where flows remain relatively stable at 20-30 MCM. The observed differences, particularly the model's higher response during November (88 vs 60 MCM), reveal that the model is highly sensitive to short-duration rainfall events characteristic of the short rains, which provides valuable information about the basin's potential hydrological response under different climate scenarios and makes it particularly useful for exploring water availability under changing rainfall patterns expected with climate change in the region.

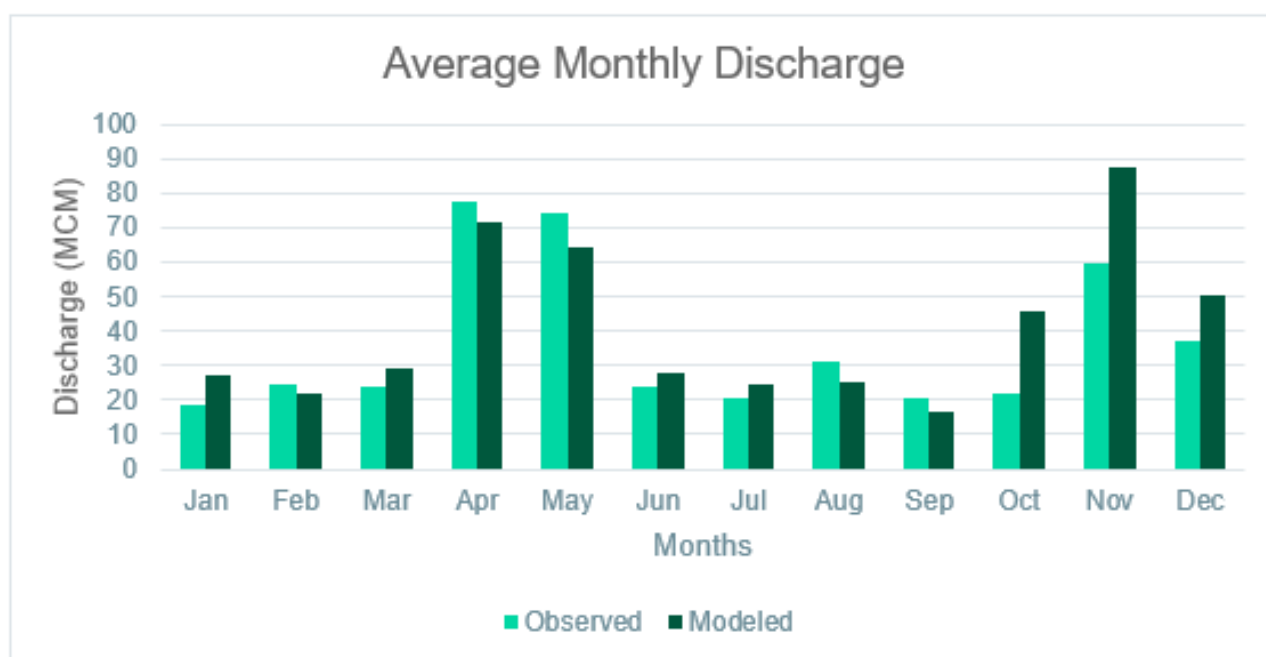


Figure 8: Comparison between modeled and observed WEAP outputs for Gauge 5D05, Ewaso Ng'iro

The flow duration curve (Figure 9) shows reasonably good agreement between modeled and observed streamflow across most flow regimes in the Ewaso Ng'iro North Basin. Both curves exhibit the characteristic steep decline typical of ephemeral streams in ASAL regions, with high flows occurring less than 20% of the time and flows approaching zero for more than 60% of the period. The modeled values slightly underestimate mid-range flows (15-40% exceedance probability) but closely match observed flows at both high-flow extremes and low-flow conditions. This pattern indicates the original model captures the overall flow variability and intermittent nature of the stream well, though the ML calibration would further improve the representation of medium-flow events that are critical for water resource planning and allocation decisions in the basin.

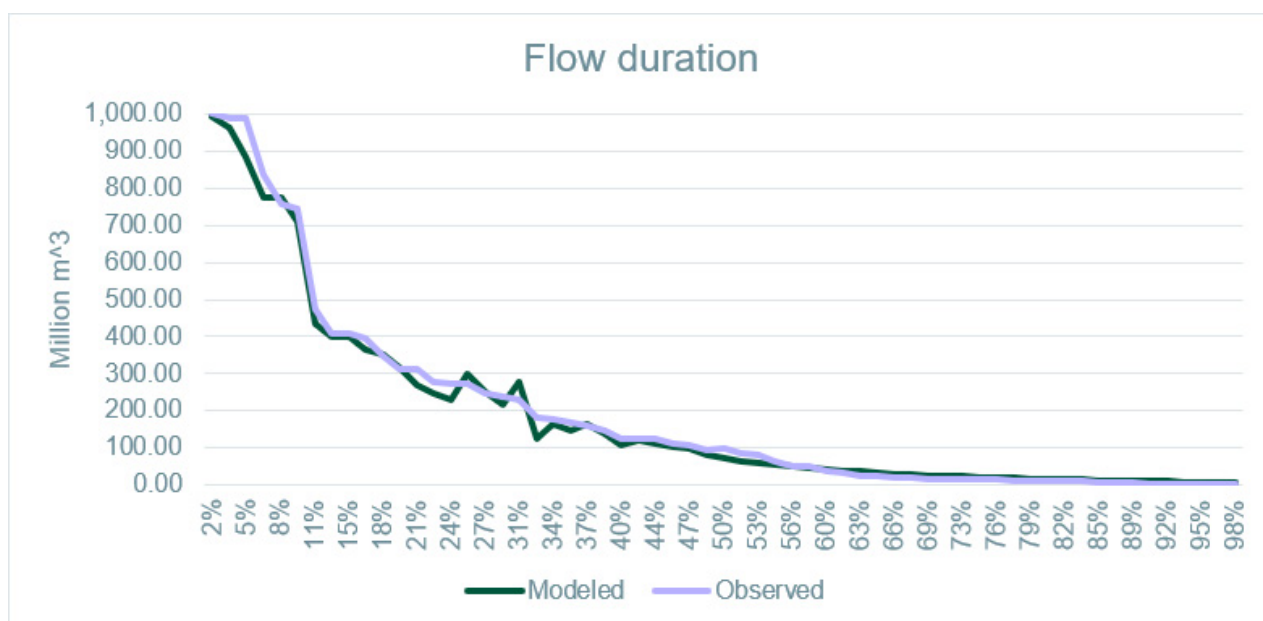


Figure 9: Flow Duration Curve

3.2.1.1 Water Balance (Available water)

Table 5 reveals concerning trends in water availability from 2020 to 2050 despite modest precipitation increases. While rainfall is projected to rise by 7.5% (from 8,540 to 9,180 Mm³), streamflow decreases by nearly 10% (from 485 to 438 Mm³) i.e., indicating a tightening water budget. This paradox is driven by evapotranspiration losses, which increase by 8% (from 7,810 to 8,450 Mm³), likely reflecting climate change impacts such as rising temperatures and altered vegetation water use. Human water abstraction escalates dramatically by 40% (from 245 to 342 Mm³), reflecting growing demand from population increase, agricultural expansion, or economic development. Storage capacity increases by 60% (from 74 to 118 Mm³), suggesting investments in water infrastructure like dams and reservoirs to buffer against declining streamflow. The data underscores that climate change-induced evapotranspiration losses and rising human consumption are eroding water availability faster than precipitation can replenish it, emphasizing the urgency of water conservation and adaptive management strategies.

Table 4: Water Balance Components

Year	Precipitation (Mm3)	Streamflow (Mm3)	Evapotranspiration (Mm3)	Abstraction (Mm3)	Storage (Mm3)
2020	8540	485	7810	245	74
2030	8750	465	8020	285	88
2040	8960	452	8230	312	102
2050	9180	438	8450	342	118

Figure 10 illustrates monthly water balance dynamics across land class inflows and outflows in cubic meters per second. Positive flows above the zero line represent water additions—primarily from precipitation and soil moisture release, along with irrigation and baseflow, while negative flows below represent water losses and storage. April and November display the highest net inflows (~200-235 m³/s), corresponding to rainy seasons, though substantial yellow bars indicate significant water being locked into soil moisture accumulation during these periods. Evapotranspiration (red) consistently depletes water year-round, with losses ranging from approximately 50-100 m³/s. Dry months (June-September) exhibit the smallest net balances, suggesting water stress periods when losses nearly match inputs. The seasonal pattern reveals a system heavily dependent on precipitation pulses during transitional months, with dry season deficits partially buffered by soil moisture releases. The interplay between snow storage (yellow), evapotranspiration losses (red), and precipitation inputs underscores the complex hydrological cycling that governs water availability, highlighting vulnerability periods when demand may exceed natural supply and the critical role of storage mechanisms in maintaining water security.

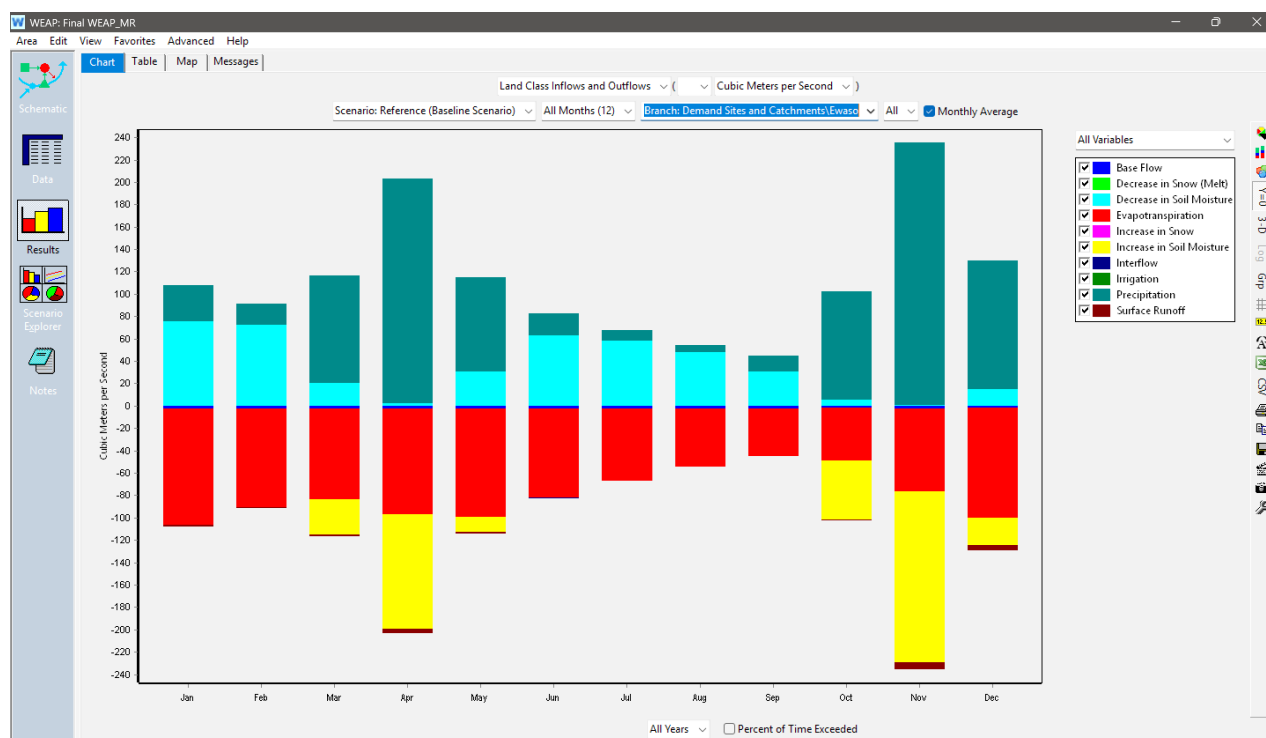


Figure 10: Monthly water balance across land class inflows and outflows

3.3 Annual Water Use Trends by Sector

This section examines water demand across the Ewaso Ngiro North catchment, a region with varied climate zones and evolving water requirements. It analyses five key sectors: domestic, livestock, irrigation (supporting food security and rural economies), industrial/ commercial, Hydropower generation and environmental needs (to maintain ecosystem health). The section also provides an integrated perspective on managing water resources to balance competing sectoral demands.

Figure 11 shows that, domestic water consumption dominates water usage at 43%, making it the single largest sector. Agricultural water use combined—including commercial irrigation (38%) and subsistence irrigation (16%)—accounts for over half of total water consumption at 54%, highlighting the significant role of farming activities. Industrial/commercial and livestock sectors represent minimal shares at 2% and 1% respectively, indicating relatively low water demands from these areas. The data suggests a water use pattern typical of regions where residential needs are substantial and agriculture remains a critical economic activity, though the high domestic percentage may indicate urban population concentration or inefficient household water use that could benefit from conservation measures.

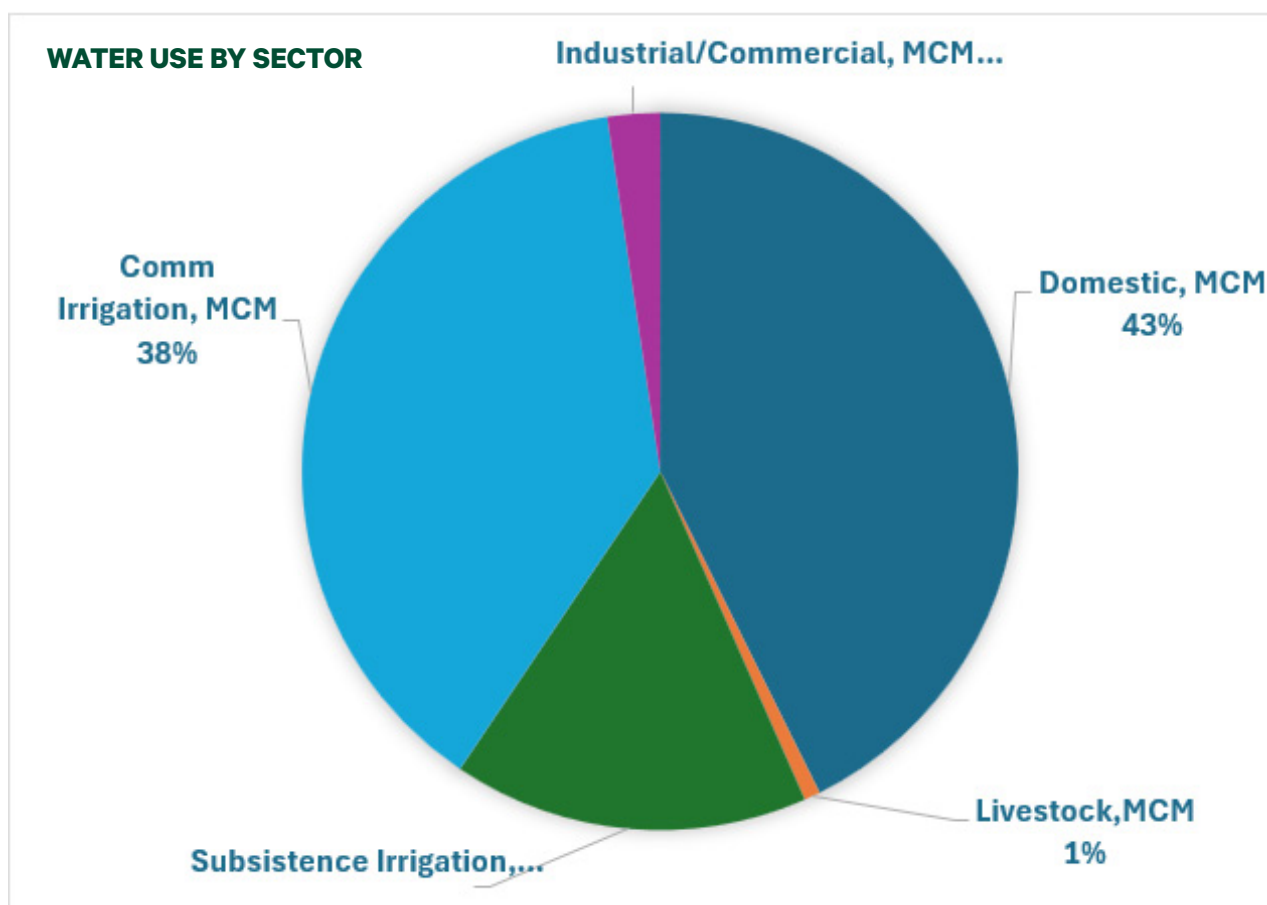


Figure 11: Water use by sector

In **Figure 12**, is the regional variation in water source dependence across five locations. Surface water (green) overwhelmingly dominates in Muranga and Meru, accounting for approximately 99.7% of water use with negligible groundwater extraction. Isiolo demonstrates the most balanced approach, drawing 57% from surface sources and 43% from groundwater. Moving from Isiolo through Rumuruti and Nanyuki shows a progressive shift toward greater surface water reliance, with groundwater use declining from 43% to just 10%. This pattern suggests differing geological conditions, infrastructure availability, or water management strategies across regions. The heavy reliance on surface water in most areas raises concerns about vulnerability to seasonal variations, droughts, and climate change impacts, while also potentially indicating limited aquifer capacity or accessibility in those locations.

Water Use by Source

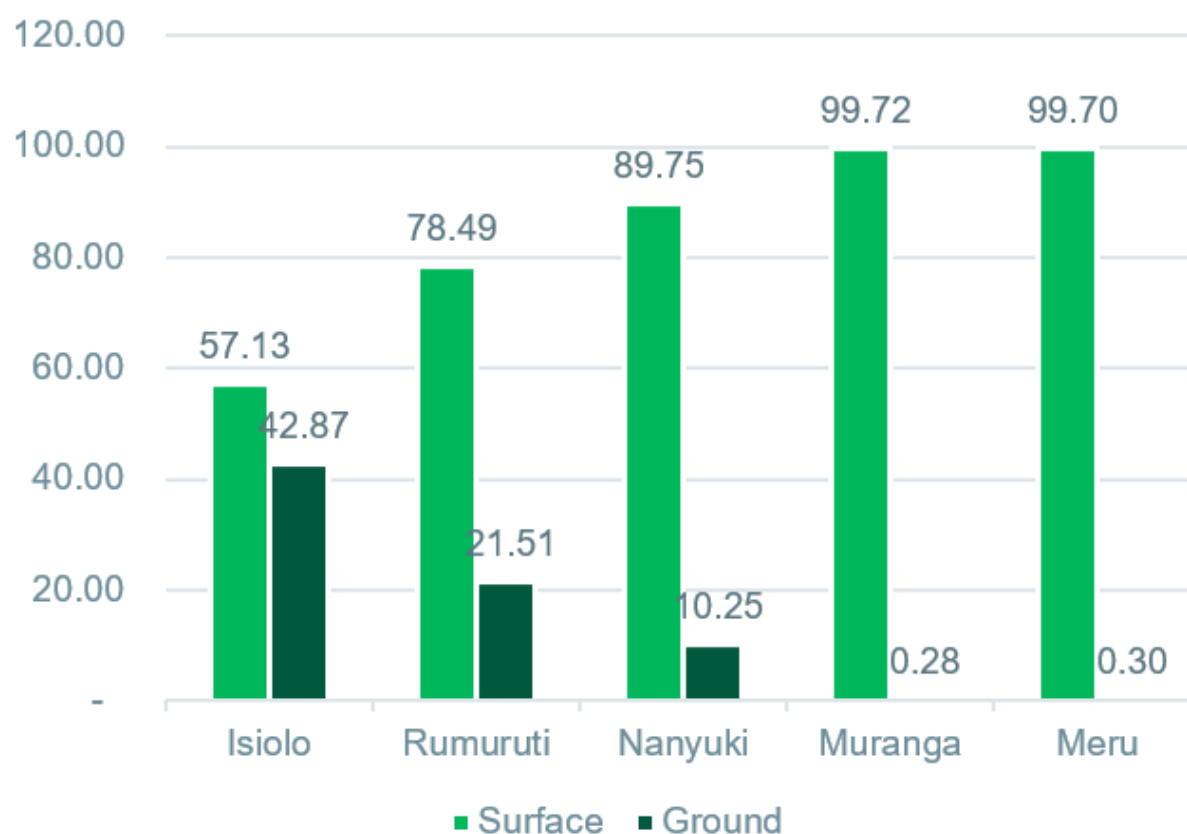


Figure 12: Water use by source

Table 5 compares water supply-demand dynamics across climate variability scenarios for 2030 and 2050, revealing critical insights into water security under different hydrological conditions. Supply (dark blue) fluctuates dramatically based on climate—wet years provide 520-550 MCM while dry years yield only 360-390 MCM, representing a 40% reduction. In contrast, demand (orange) remains relatively stable at 290-350 MCM across all scenarios, reflecting consistent human and agricultural needs regardless of water availability. Unmet demand (green) and water stress percentages (light blue) are most severe during dry periods, with 2030_Dry showing ~100 MCM unmet and 130% stress, indicating demand exceeds supply by 30%. Wet scenarios dramatically improve conditions, reducing unmet demand to just 25-45 MCM and water stress to 40-85%. By 2050, conditions generally improve compared to 2030 equivalents, likely reflecting infrastructure investments or management interventions, though dry year vulnerability persists. This analysis underscores the system's high sensitivity to climate variability and the critical need for adaptive strategies—including storage expansion, demand management, and drought preparedness—to ensure water security across the full range of potential hydrological futures.

Table 5: Irrigated area per crop type

Crop_Type	Total_Area_ha	Percent_Irrigated	Irrigated_Area_ha
Flowers	19611	100	19611
Maize	35649	0	0
Fruits	7974	10	797
Onions	12279	20	2456
Tea_Coffee	587	10	59
Sorghum	20.59	6	1
Vegetables	1031	27	278
Total	397002	5.9	23202

3.4 Water Supply versus demand

Figure 13 reveals a critical temporal mismatch between water supply and demand across the year. Surface runoff (light blue) exhibits dramatic seasonal fluctuations, peaking during the rainy seasons in April-May (~440 MCM) and November-December (~350 MCM), while dropping to minimal levels during dry months like August-September. In contrast, total water demand—combining domestic/industrial needs (dark blue, ~30-40 MCM) and agricultural irrigation (green, ~150-200 MCM)—remains relatively constant year-round at approximately 180-240 MCM. During wet months, supply vastly exceeds demand, creating surplus conditions, while dry months present potential deficits where surface runoff may fall below the red dashed line representing sustainable groundwater yield (~50 MCM). This pattern underscores the urgent need for water storage infrastructure such as dams and reservoirs to capture excess wet-season runoff for use during dry periods, alongside strategic groundwater management to bridge seasonal gaps and ensure year-round water security.

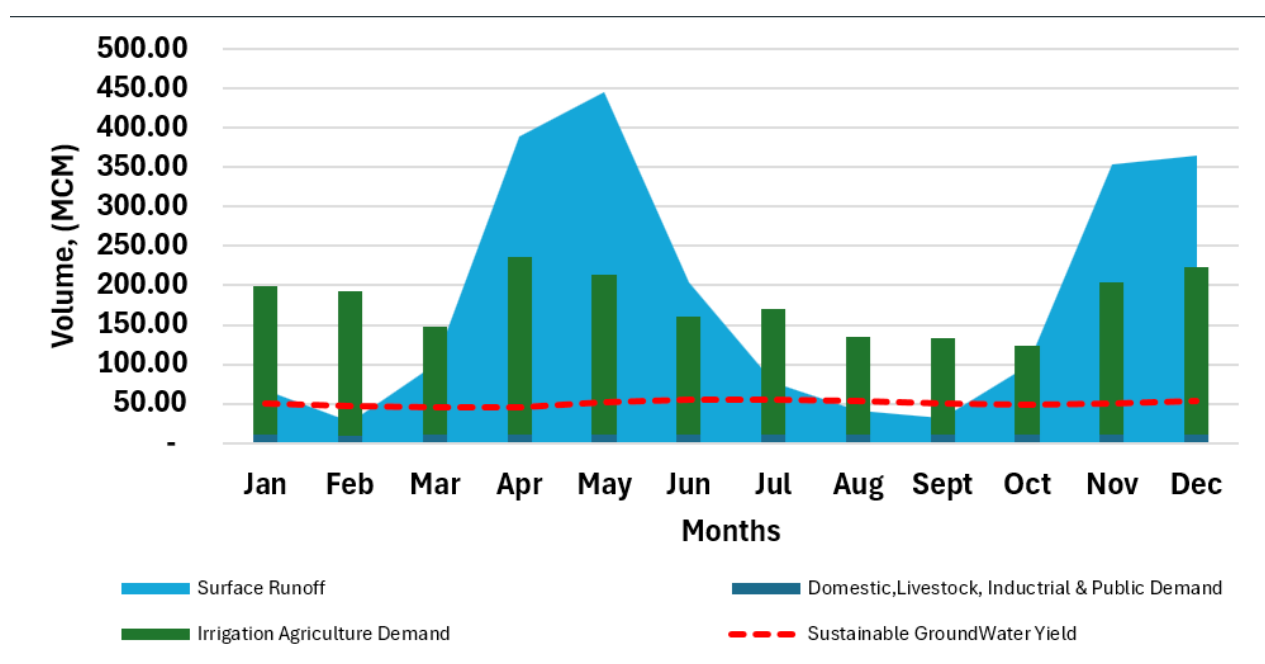


Figure 13: Monthly Water Supply and demand for the Ewaso Ng'iro North Basin

Figure 14 compares six water management scenarios in WEAP, revealing significant trade-offs between water demand and environmental sustainability. The baseline and county focus scenarios (S1, S2) exhibit the highest water demands (292-325 MCM) but achieve only 22-28% of environmental flow requirements, indicating severe ecological stress. In contrast, scenarios S3 through S6 reduce demand to 235-248 MCM through agricultural optimization, energy/climate measures, cooperation, and ecosystem prioritization, resulting in dramatically improved environmental flow metrics (48-88%). Supply remains relatively stable at 465 MCM across most scenarios, with S6 (Ecosystems) achieving the highest at 485 MCM. The water stress percentage (blue line) decreases progressively from baseline to S6, demonstrating that demand management strategies—particularly the ecosystem-focused approach—can substantially reduce pressure on water resources while better protecting environmental flows, suggesting that sustainable water security requires balancing human consumption with ecological needs.

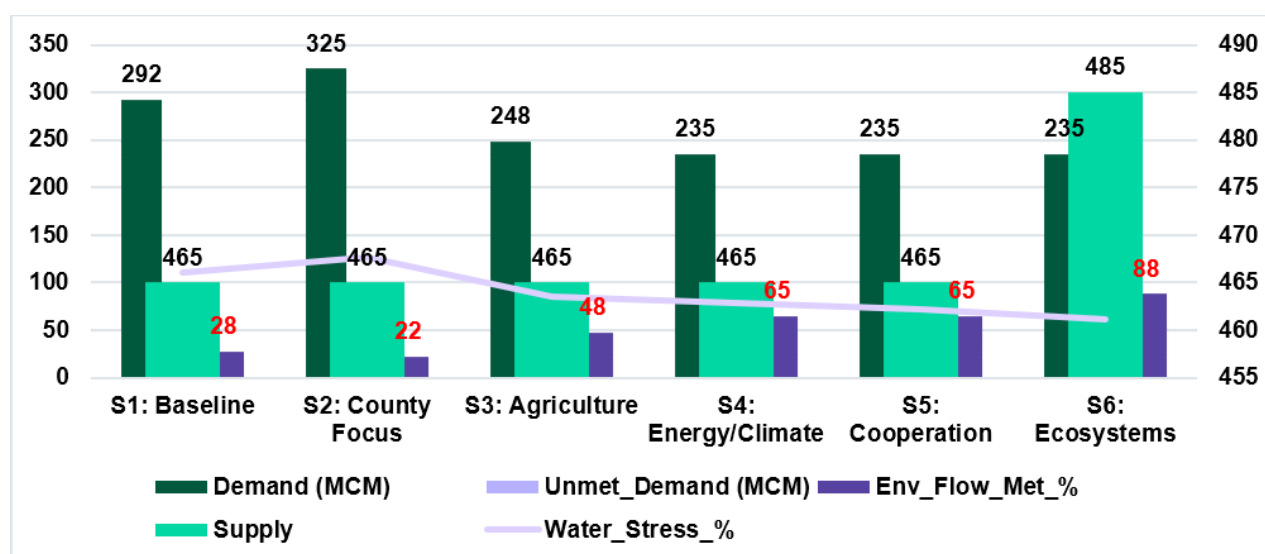


Figure 14: Comparison of Water Demand, Supply, and Environmental Flow Metrics Across WEAP Management Scenarios

Figure 15 illustrates monthly water supply variability under different hydrological conditions compared to demand and environmental flow requirements. Supply during wet years (red line) exhibits extreme seasonality, peaking at ~95 MCM in April and ~88 MCM in November during rainy seasons, while dropping to 40-50 MCM in dry months. In contrast, supply during dry years (dark blue bars) remains consistently low at 15-20 MCM throughout the year, highlighting vulnerability during drought conditions. Average supply (orange bars) fluctuates moderately between 30-70 MCM. The substantial green area representing environmental flow requirements occupies 50-60 MCM for most months, demonstrating that ecological needs consume a major portion of available water. Notably, baseline demand (light blue) and reduced demand (purple line) hover around 20-25 MCM monthly, suggesting that even under dry conditions, basic human needs can be met, though environmental flows would be severely compromised. This underscores the critical importance of water storage infrastructure and demand management to maintain both human and ecological water security across variable climate conditions.

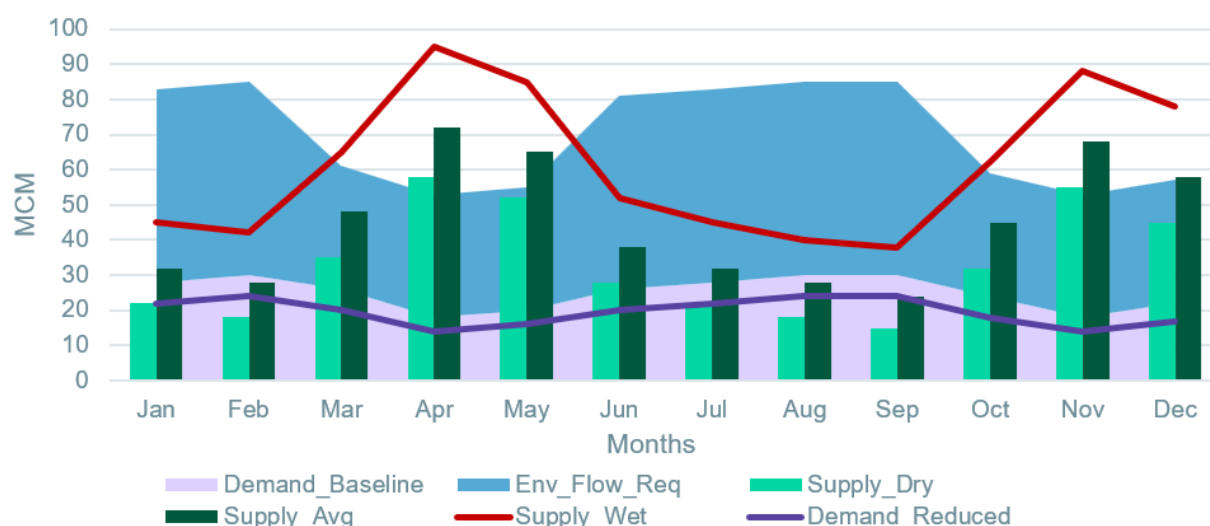


Figure 15: Monthly water supply and demand patterns

This projection chart traces the diverging trajectories of water demand (likely unmet demand or stress) under six management scenarios from 2020 to 2050 (Figure 16). The baseline (S1) and county focus (S2) scenarios demonstrate alarming growth, escalating from approximately 20 units in 2020 to 142 and 174 respectively by 2050, representing business-as-usual pathways with unchecked demand increases. Agriculture-focused (S3), energy/climate (S4), and cooperation (S5) scenarios show moderate growth trajectories, reaching 67, 52, and 38 units respectively, indicating partial mitigation through sector-specific interventions. Most striking is the ecosystem-focused scenario (S6), which maintains demand near baseline levels throughout the projection period at around 20-22 units, suggesting that prioritizing environmental sustainability inherently constrains demand growth. The widening gap between scenarios over time emphasizes that management choices made today will compound significantly by mid-century, with the difference between county focus and ecosystem approaches representing an eightfold divergence in outcomes, underscoring the critical long-term implications of current water policy decisions.

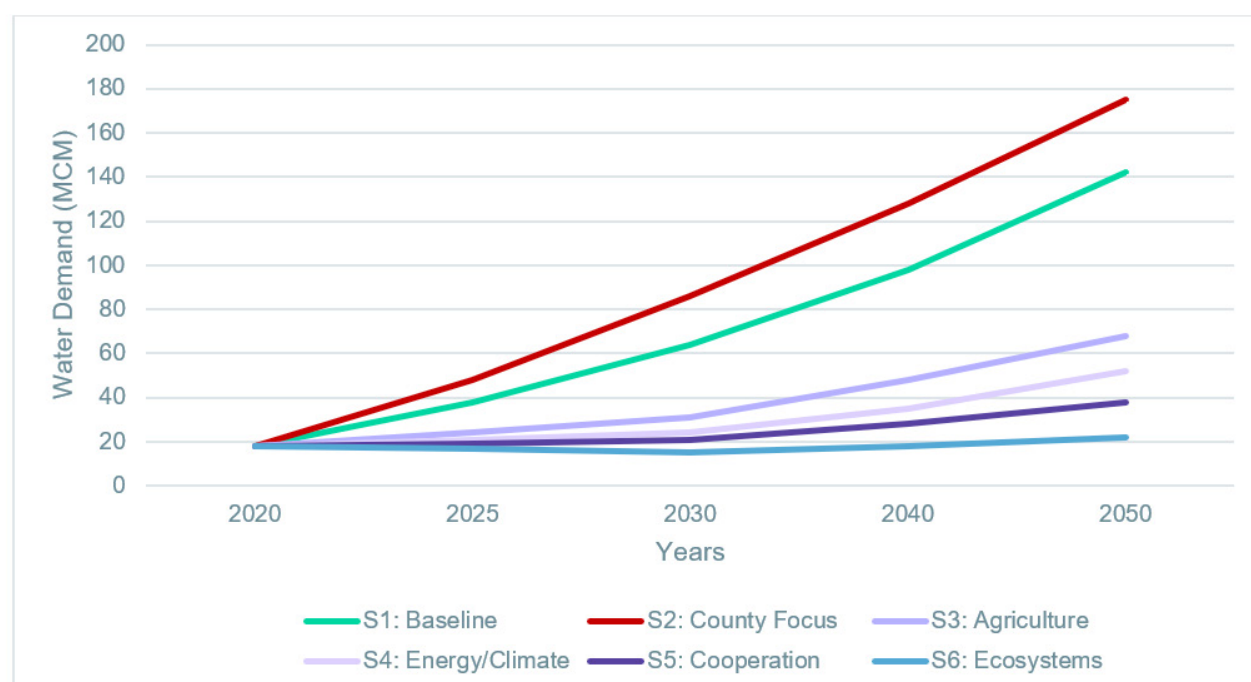


Figure 16: Unmet water demand projections by scenario

Figure 17 compares water supply-demand dynamics across climate variability scenarios for 2030 and 2050, revealing critical insights into water security under different hydrological conditions. Water supply fluctuates dramatically based on climate wet years provide 520-550 MCM while dry years yield only 360-390 MCM, representing a 40% reduction. In contrast, demand remains relatively stable at 290-350 MCM across all scenarios, reflecting consistent human and agricultural needs regardless of water availability. Unmet demand and water stress percentages are most severe during dry periods, with 2030_Dry showing ~100 MCM unmet and 130% stress, indicating demand exceeds supply by 30%. Wet scenarios dramatically improve conditions, reducing unmet demand to just 25-45 MCM and water stress to 40-85%. By 2050, conditions generally improve compared to 2030 equivalents, likely reflecting infrastructure investments or management interventions, though dry year vulnerability persists. This analysis underscores the system's high sensitivity to climate variability and the critical need for adaptive strategies—including storage expansion, demand management, and drought preparedness—to ensure water security across the full range of potential hydrological futures.

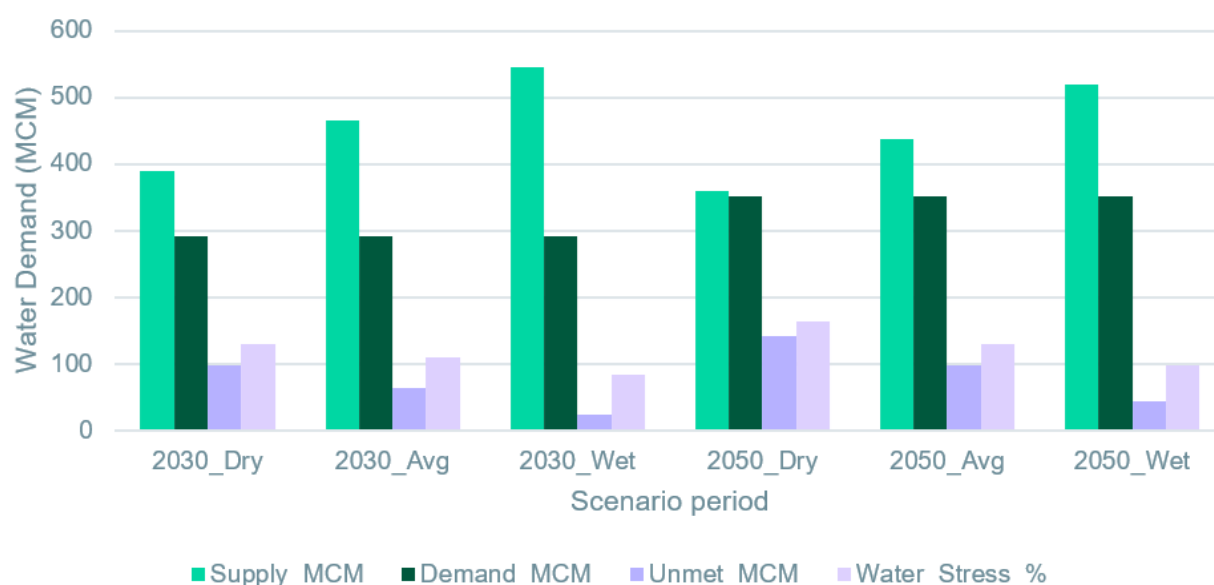


Figure 17: Climate scenario comparison (2030 vs 2050)

Figure 18 compares water stress across seven sub catchments, revealing significant spatial variability in water security. Upper_Ewaso dominates in absolute terms with the highest supply (125 MCM) and demand (85 MCM), yet maintains a moderate stress index of 0.68, suggesting relatively balanced conditions despite high consumption. In contrast, Likii exhibits the highest stress index of 0.88 despite lower absolute demand (48 MCM), indicating that supply barely meets needs and the system operates near capacity. Most sub catchments show stress indices between 0.7-0.8, reflecting moderate to high water pressure across the basin. Unmet demand is relatively low throughout, mostly under 10 MCM except for Ewaso_Main (23 MCM), and this suggests that current demands are largely being met, though the high stress indices warn of minimal buffer capacity. The blue stress index line fluctuates across subcatchments, peaking at Likii and dipping at Upper_Ewaso and Nairobi_Trib, indicating that water security challenges vary geographically and require location-specific management interventions rather than basin-wide uniform approaches.

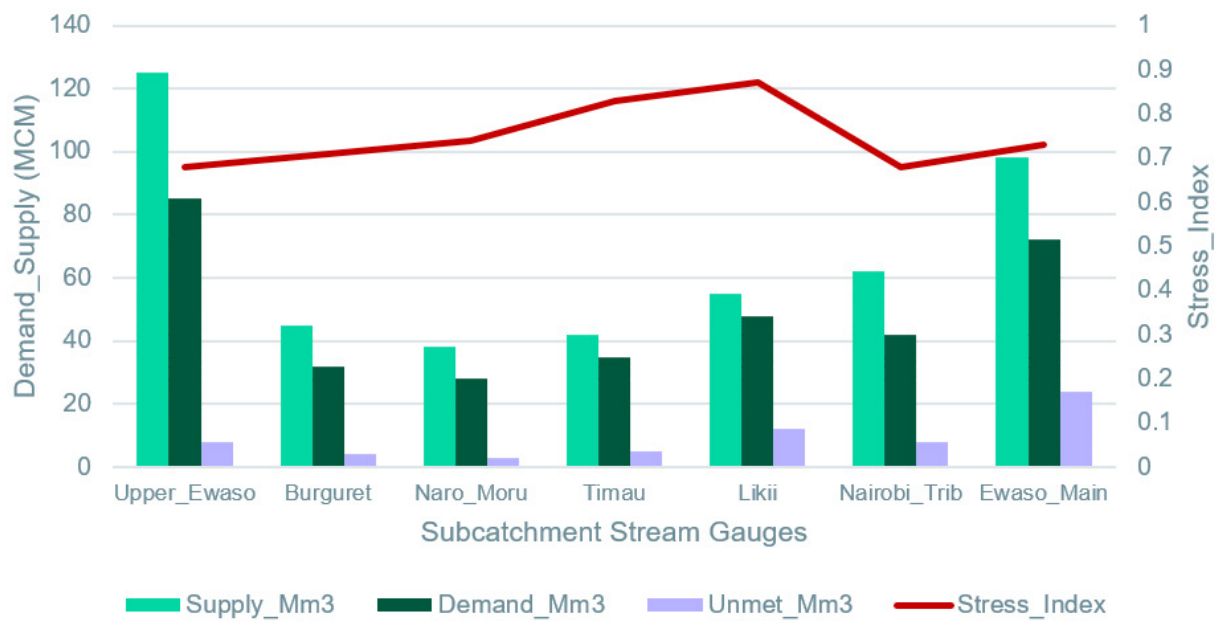


Figure 18: Sub_catchment water stress index (2030)

This scenario analysis for the Ewaso Ngiro basin illustrates the evolution of water management strategies from historical conditions to future intervention scenarios (**Figure 19**). Historical periods (2010, 2015–2020) show minimal water stress with low demands around 500–1,000 million m³ and abundant surface water availability. The National Water Master Plan projects dramatically increased surface water availability (~9,000 million m³ in wet years), yet irrigation demands surge to ~4,500 million m³ (yellow), while environmental flows and other demands remain modest, suggesting an ambitious expansion of irrigated agriculture. Progressive intervention scenarios—irrigation efficiency, climate-smart agriculture, and combined approaches demonstrate potential demand reductions of 13%, 24%, and 33% respectively, cutting irrigation requirements from 4,500 to 2,500 million m³.

The analysis reveals that even with optimistic water availability projections, unchecked irrigation expansion under the Master Plan would consume the majority of resources, leaving minimal buffer for droughts and potentially compromising environmental flows. The combined intervention scenario achieving 33% demand reduction appears critical for sustainability, as it brings total water use closer to historical wet-year availability (dashed line at 6,200 million m³) while maintaining environmental allocations. This underscores that future water security depends not on supply expansion alone, but on aggressive demand management through agricultural efficiency and climate adaptation to prevent over-extraction and ecological degradation.

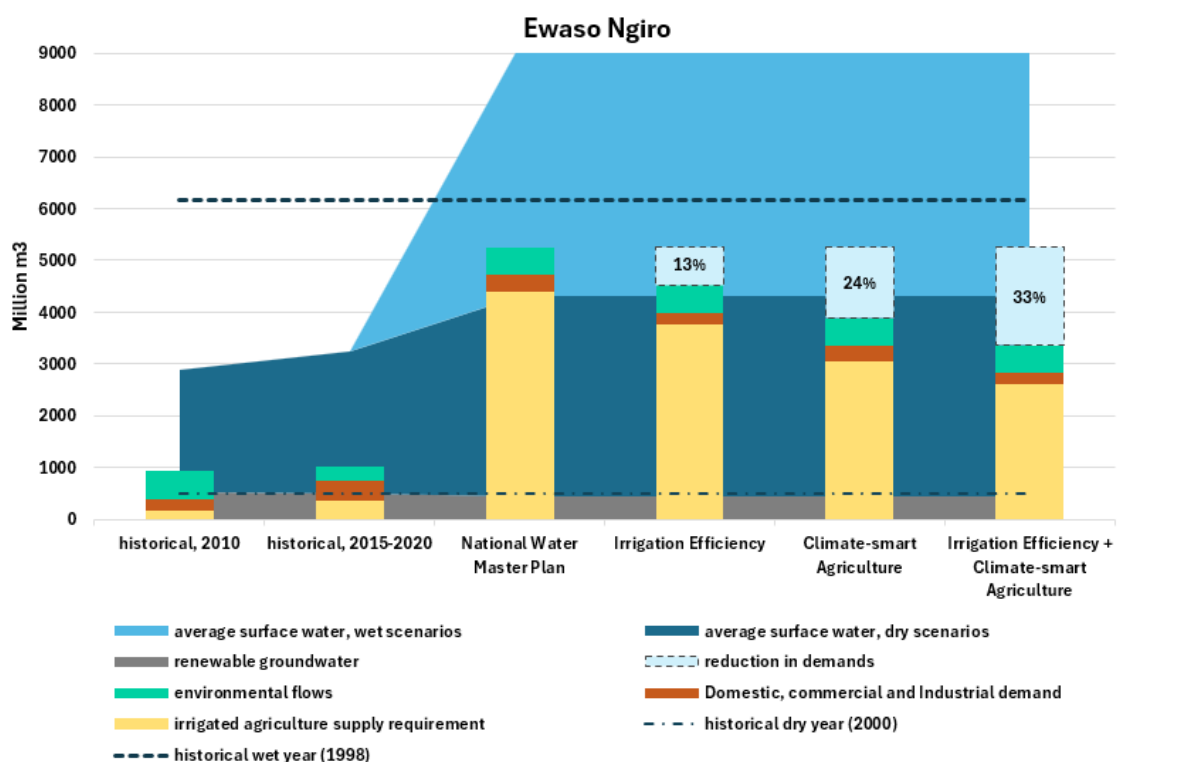


Figure 19: Trends in Water Demand and Supply in the Ewaso Ng'iro North River Catchment for scenarios in Agriculture

Figure 20 indicates deep contrasts in food security, livelihoods, and vulnerability across five counties. Meru and Nyeri exhibit agricultural-dominated economies with high crop production (35 and 25 MT/year respectively), large populations (~1.5M and 750K), and superior food security—Nyeri achieves 95% food self-sufficiency with only ~20% food poverty, while Meru reaches 80% self-sufficiency with ~30% poverty. These counties demonstrate successful crop-based food systems supporting dense populations. Conversely, pastoral counties Samburu and Isiolo rely heavily on livestock (45 and 25 TLU) with minimal crop production (under 5 MT/year), resulting in elevated food poverty rates (~60% and 35%) despite moderate food self-sufficiency (50-60%), indicating that livestock-based livelihoods face greater vulnerability to market shocks, droughts, and price volatility. Laikipia presents a mixed economy with moderate livestock (30 TLU), limited crops, yet maintains 70% self-sufficiency and 35% food poverty.

This implies that pastoral systems, while culturally important and ecologically adapted, face systemic food insecurity requiring targeted interventions such as livestock market development, drought-resistant feed systems, and social protection programs. Agricultural counties benefit from stable crop production but must manage water resources sustainably to maintain their advantage. The disconnect between self-sufficiency and poverty rates in pastoral areas suggests that diversification strategies—integrating crops where feasible, strengthening value chains, and improving market access—are essential for building resilience beyond subsistence production alone.

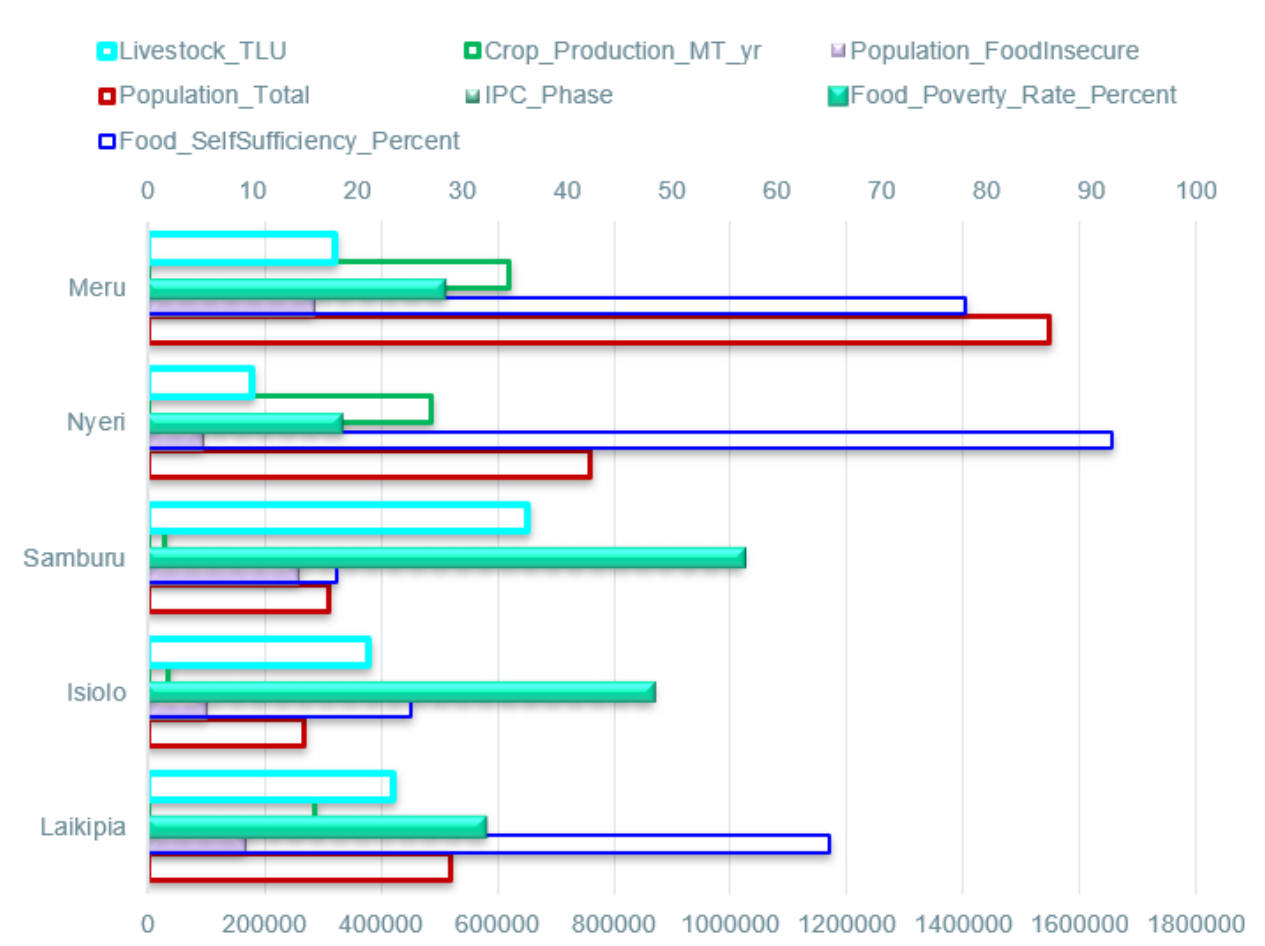


Figure 20: comparison between food security, livelihoods, and vulnerability across counties

3.5 Gap Analysis and Strategic Areas for Interventions

The WEAP modeling and stakeholder consultation processes revealed critical gaps across technical, institutional, infrastructure, and policy dimensions that constrain sustainable water management.

1.

Governance and Institutional Coordination Gaps

Critical Gaps:

Absence of legally binding inter-county water allocation agreements; weak enforcement resulting in abstractions exceeding allocations by 30-50%; limited basin-level coordination mechanisms.

Strategic Interventions include:

- Establish Basin Water Allocation Framework through ENNDA with legally enforceable county entitlements
- Strengthen WRA enforcement capacity through satellite-based monitoring systems
- Institutionalize WEF nexus planning requiring WEAP/LEAP consistency reviews

2.

Infrastructure and Storage Deficits

Critical Gaps:

Total storage capacity (74 Mm³) represents less than 16% of annual demand; aging conveyance systems experiencing 40-50% losses; limited groundwater development in downstream areas.

Strategic Interventions include:

- Accelerate storage expansion targeting 500 Mm³ additional capacity by 2035
- Rehabilitate conveyance systems achieving 25-30% loss reduction
- Scale managed aquifer recharge programs increasing groundwater availability by 15 Mm³/year

3.

Agricultural Water Efficiency Gaps

Critical Gaps:

Dominance of flood irrigation (>85%) with efficiencies below 40%; limited adoption of water-efficient crops; low yields in downstream counties.

Strategic Interventions include:

- Deploy modern irrigation systems targeting 30,000 ha achieving 60-70% efficiency
- Implement climate-smart crop diversification shifting 50% of wheat to cassava/sorghum
- Strengthen agricultural value chains increasing farm gate prices by 30-50%

4.

Climate Resilience and Ecosystem Protection Gaps

Critical Gaps:

Environmental flows met at only 22% under baseline; ongoing water tower degradation; limited integration of climate projections.

Strategic Interventions include:

- Enforce environmental flow requirements achieving 60-80% of natural flows
- Accelerate water tower restoration through 50,000 ha reforestation programs
- Mainstream climate-smart water management using WEAP-derived scenarios

5.

Data and Monitoring Gaps

Critical Gaps:

Only 3 of 10 gauging stations operational; groundwater abstraction unmonitored; agricultural data based on outdated 2010-2015 surveys.

Strategic Interventions include:

- Rehabilitate hydrometric network expanding to 15 operational stations with telemetry
- Establish comprehensive water accounting system integrating all sources and uses
- Institutionalize WEAP model maintenance through dedicated basin modeling unit

4.

Policy Implications and Recommendations

The WEAP modeling exercise for the Ewaso Ngiro North catchment reveals that current fragmented, county-focused water management approaches will significantly increase water stress, threatening food security and livelihoods across all five counties. Six scenarios were analyzed: Business as Usual (S1), which perpetuates uncoordinated practices and current conditions; County focus (S2), where counties in the ENNCA region implement county plans for WRM; Water and Agricultural Improvements (S3), which emphasizing water conservation and technological improvements in agriculture; energy and climate change efficiency (S4) focusing on hydropower expansions; Integrated Cooperation (S5), promoting basin-wide coordination and Ecosystem restoration (S6) based on the environmental health of the ecosystem. Results demonstrate that siloed planning substantially underestimates cumulative water stress and misses synergistic opportunities, while efficiency measures combined with inter-county cooperation can reduce unmet water requirements by 15-25%, lower greenhouse gas emissions, and generate lasting positive impacts on agricultural productivity and GDP through 2050.

The WEAP modeling analysis reveals that business-as-usual approaches will significantly intensify water stress. Seven strategic policy recommendations emerge:

Establish Inter-County Water Allocation Framework: Operationalize basin-wide water allocation agreements through ENNDA, establishing legally enforceable county water entitlements; Establish benefit-sharing mechanisms including upstream conservation payments, strengthen enforcement through satellite monitoring, and create Inter-County Water Allocation Committee with quarterly compliance reviews.

Prioritize Water and Agricultural Efficiency Investments: Deploy agricultural water efficiency programs across 30,000 hectares achieving 13-33% demand reduction. Launch County Irrigation Modernization Programs providing 50% subsidies for drip/sprinkler systems, implement climate-smart crop diversification shifting wheat to drought-tolerant crops, and rehabilitate aging conveyance infrastructure achieving 25-30% loss reduction.

Integrate WEF Nexus Principles into Planning: Mandate Water-Energy-Food nexus consistency reviews for all County Integrated Development Plans. Establish County WEF Nexus Task Forces, require CIDP basin-consistency certification from ENNDA before budget approval, develop integrated investment plans, and institutionalize joint planning workshops convening all five counties biennially.

Strengthen Climate Resilience: Mainstream climate projections through continuous WEAP scenario updating. Establish Basin Drought Management Protocol with tiered response actions, expand storage capacity by 500 Mm³, deploy climate-smart infrastructure including solar-powered systems, and institutionalize seasonal forecasting services.

Protect Critical Water Towers: Implement ecosystem restoration targeting 50,000 ha reforestation in Mt. Kenya and Aberdare water towers. Enforce environmental flow requirements achieving 60-80% of natural flows, launch Water Tower Restoration Program planting 10 million trees annually, establish Payment for Ecosystem Services scheme, and strengthen protected area management.

Enhance Data Collection and Monitoring: Rehabilitate and expand hydrometeorological monitoring from 3 to 15 operational gauging stations. Deploy comprehensive monitoring network with telemetry, establish Basin Water Accounting System, create ENNDA Basin Modeling Unit, and institutionalize data-sharing protocols.

Build Capacity for Integrated Management: Launch comprehensive capacity building programs targeting county water officials and develop decision-support tools and guidance materials.

Implementation Considerations: Establish Basin Water Forum convening annually with 200+ participants, ensure inclusive participation (minimum 40% women), and implement results framework tracking water security, efficiency, equity, and ecosystem health indicators.

4.1 Conclusion and Recommendations

4.1.1 Conclusion

The WEAP modeling study provides compelling evidence that current fragmented water management is unsustainable. Despite projected 7.5% precipitation increases by 2050, streamflow will decline by 10% while abstractions surge 40%, creating chronic deficits where supply (360 Mm³ dry years) falls 100 Mm³ short of demand. However, integrated interventions combining efficiency improvements, infrastructure investments, and cooperative governance can reduce unmet requirements by 78-88%, achieve 60-80% environmental flow compliance, and generate sustained livelihood benefits. Critical is addressing upstream-downstream inequity where upper catchment counties command 99.7% of surface water while downstream pastoral counties face 60% food poverty rates.

The calibrated WEAP model (NSE=0.72, R²=0.85) provides robust decision-support for adaptive management. It should be institutionalized within ENNDA for annual water balance assessments, drought planning, and climate adaptation.

Priority Actions

Urgent (2025-2026): Operationalize inter-county allocation agreements; launch irrigation efficiency (10,000 ha); rehabilitate priority monitoring; establish Inter-County Committee.

Near-Term (2026-2028): Advance storage projects (+200 Mm³); scale efficiency to 30,000 ha; implement PES schemes; deploy climate-smart infrastructure; establish Basin Water Academy.

Medium-Term (2028-2030): Complete storage expansion (500 Mm³); achieve 60-80% environmental flows; scale restoration (50,000 ha); institutionalize WEF nexus planning; establish water accounting system.

Sustained (2025-2050): Maintain WEAP as living tool; conduct biennial basin forums; ensure 40% women representation; leverage climate finance (KES 5-7B); implement results tracking framework.

Closing Statement

The path forward is clear: integrated, cooperative basin management can achieve water security for 2.5 million people while protecting ecosystems. The alternative leads to escalating conflicts and humanitarian crises. The window for action is narrowing—decisions made in the next 3-5 years will determine basin outcomes for 30-50 years.

Water security is achievable through cooperation recognizing shared basin dependence. Technical solutions exist; economic case is compelling; social imperative is urgent. The question is whether we will act with required speed and scale.

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