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WATER STRESS IN EWASO NGÍRO NORTH BASIN: WEAP MODELLING RESULTS



CETRAD Centre for Training and Integrated Research in ASAL Development

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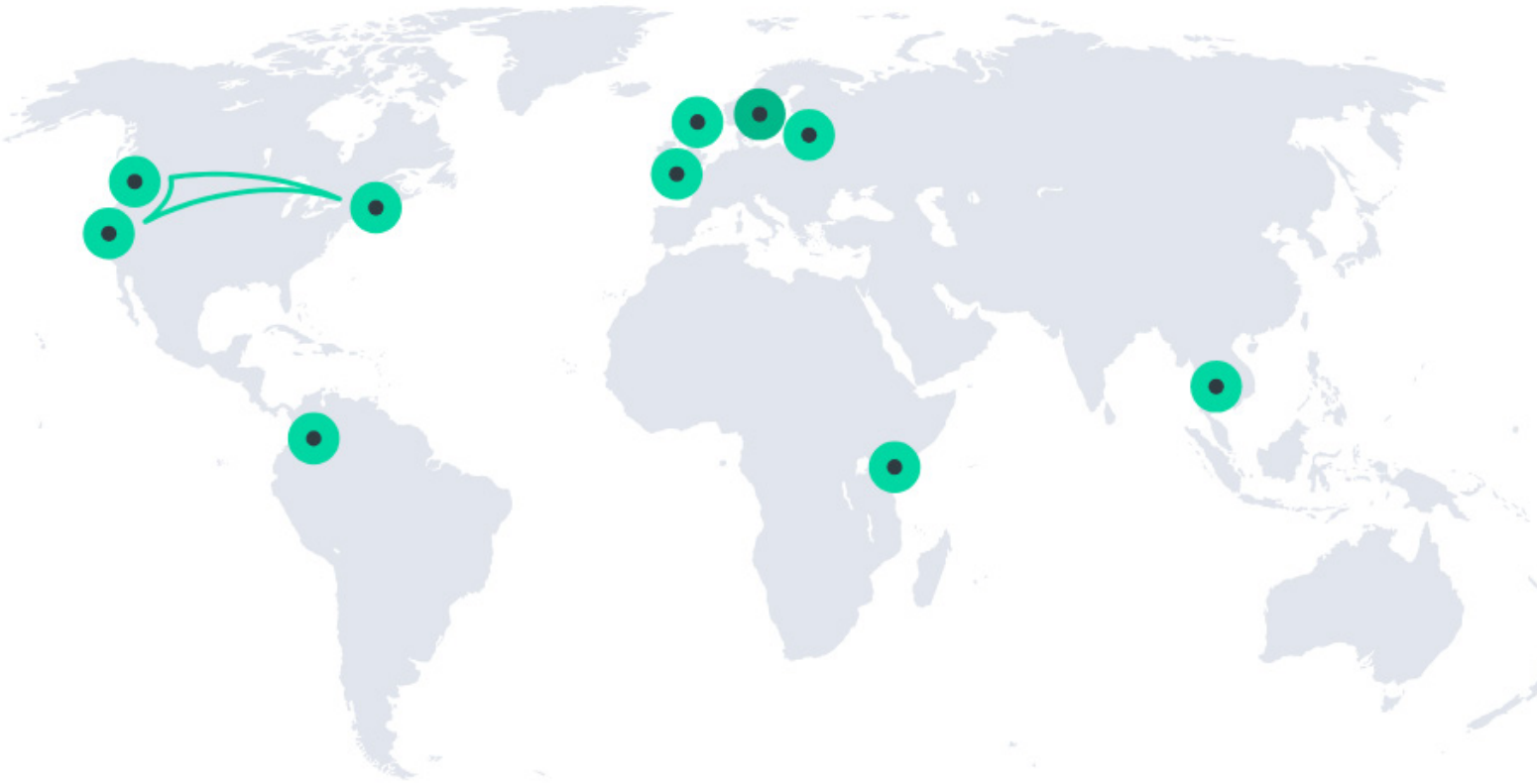
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About the Project

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

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

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

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

Expected results

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





Abstract

Water stress is intensifying across Kenya's arid and semi-arid lands (ASALs), threatening livelihoods, ecosystems, and regional stability. This study employs the Water Evaluation and Planning (WEAP) system to quantify water stress across the Ewaso Ngiro North Basin, spanning five counties: Nyeri, Meru, Laikipia, Isiolo, and Samburu. The basin, originating from Mount Kenya and the Aberdare Ranges, supports approximately 3.4 million people across diverse livelihood systems ranging from intensive highland agriculture to extensive lowland pastoralism. The WEAP model was configured with 35 demand sites representing domestic, agricultural, livestock, industrial, and environmental water users across 12 sub-catchments. Model calibration against observed streamflow data (2010-2018) achieved Nash-Sutcliffe Efficiency (NSE) values of 0.72-0.84 and percent bias (PBIAS) within ±12% across seven gauging stations. Climate change scenarios using IPCC's AR6-CMIP6 projections under two scenarios-SSP245 and SSP585, were incorporated to assess future water availability. Results indicate that annual renewable water resources are projected to decline by 18% by 2050, with dry season flows decreasing by 25-30%. The water stress index exceeded 70% in downstream counties (Isiolo and Samburu) during critical dry months. Unmet water demand under business-as-usual conditions is projected to reach 78 Mm^3/year (24% of total demand) by 2045. Scenario analysis demonstrates that integrated interventions combining water use efficiency, ecosystem restoration, and coordinated governance can reduce unmet demand to 18 Mm^3/year (6% of demand). These findings provide critical evidence for basin-wide water allocation planning and climate adaptation strategies in the Ewaso Ngiro North Catchment.

Keywords: Water stress, WEAP modeling, Ewaso Ngiro North, climate change, water allocation, Kenya ASALs



1. Introduction

Water scarcity represents one of the most pressing challenges facing sustainable development in East Africa's arid and semi-arid lands (ASALs). The Ewaso Ngiro North Catchment Area (ENNCa), one of Kenya's six major drainage basins, exemplifies the complex water resource challenges facing semi-arid regions under increasing climatic variability and growing anthropogenic pressures. The basin originates from the Aberdare Ranges and Mount Kenya—critical water towers that supply the majority of surface flows—before draining northeastward approximately 700 kilometers through progressively drier landscapes to terminate in the Lorian Swamp in northeastern Kenya (Kiteme & Giesen, 2004; Notter et al., 2007).

The basin spans five counties—Nyeri, Meru, Laikipia, Isiolo, and Samburu—covering approximately 15,200 km² and supporting a population of approximately 3.4 million people according to the 2019 Kenya Census. This population comprises diverse ethnic communities including agro-pastoralist Kikuyu and Meru populations in the upper catchment, and nomadic Maasai, Samburu, Borana, and Somali pastoralists in the lower reaches (Gichuki, 2004). The pronounced climatic gradient—from humid highlands receiving over 1,200 mm annual rainfall to arid lowlands receiving less than 300 mm—creates fundamental disparities in water availability and livelihood systems across the basin.

Water demand across the ENNCa is dominated by agricultural uses, which account for approximately 70-80% of total abstractions (WRA, 2021). Large-scale commercial farming concentrated in Laikipia and upper Nyeri counties cultivates high-value horticultural exports, wheat, and supports extensive dairy operations, while smallholder irrigation in Meru produces vegetables, coffee, and food crops. Downstream pastoral communities in Samburu and Isiolo depend on reliable water for livestock—the backbone of their economic and cultural systems. These competing demands, combined with climate variability and inadequate governance coordination, generate recurring upstream-downstream conflicts that undermine basin-wide sustainability.

Water stress—defined as the ratio of total water withdrawals to available renewable supply—provides a critical metric for assessing the sustainability of current and projected water use patterns. Understanding the spatial and temporal distribution of water stress across the ENNCa is essential for informing equitable water allocation policies, identifying priority areas for intervention, and developing climate adaptation strategies. Previous studies have documented water scarcity challenges in the basin (Lanari et al., 2018; Mutiga et al., 2010), but comprehensive basin-wide assessment of water stress under climate change scenarios remains limited.

This study addresses this gap by employing the Water Evaluation and Planning (WEAP) system—an integrated water resources modeling platform developed by the Stockholm Environment Institute—to quantify water stress across the ENNCa under current conditions and projected climate change scenarios. The specific objectives are: (1) to develop and calibrate a WEAP model representing the hydrology and water demands of the ENNCa; (2) to calculate water stress indicators across the five constituent counties under baseline and climate change scenarios; and (3) to evaluate intervention scenarios for reducing water stress and enhancing basin-wide water security.



2.

Study Area

2.1 Geographic Setting

The Ewaso Ngiro North Basin is located in north-central Kenya, extending from the equatorial highlands to the semi-arid northern lowlands between latitudes 0°05'S and 2°30'N and longitudes 36°30'E and 39°30'E. The basin encompasses portions of five counties with varying proportions of their territory within the catchment boundaries.

Nyeri County (population 759,164) occupies the southwestern portion of the basin, characterized by humid highland conditions with elevations ranging from 1,500 to 5,199 meters on Mount Kenya's southwestern slopes. The county receives annual rainfall of 900-2,000 mm and supports intensive smallholder agriculture and commercial dairy farming. Key tributaries including the Burguret and Naro Moru rivers originate from the Mount Kenya glacial zone.

Meru County (population 1,545,714) contributes the Timau and upper Ewaso tributaries from Mount Kenya's eastern slopes. The county exhibits diverse agro-ecological zones from humid highlands producing tea, coffee, and horticulture to semi-arid middle zones with mixed farming. Rainfall ranges from 380 mm in lowland areas to over 2,500 mm on mountain slopes, with the county contributing significant agricultural water demand.

Laikipia County (population 518,560) occupies the central basin area characterized by the semi-arid Laikipia Plateau at 1,600-2,300 meters elevation. The county hosts extensive large-scale commercial ranching and wheat farming alongside wildlife conservancies. Rainfall averages 400-750 mm annually with high variability. The county contains significant water infrastructure including intakes serving Nanyuki town and extensive private irrigation systems.

Samburu County (population 310,327) extends across the northern middle reaches of the basin. The predominantly pastoral county receives 250-500 mm rainfall annually and depends almost entirely on the Ewaso Ngiro River and its tributaries for livestock watering during dry seasons. The county seat Maralal and scattered trading centers represent limited urban water demand.

Isiolo County (population 268,002) occupies the lower basin, including Archer's Post and the Lorian Swamp terminal zone. This arid county receives 150-350 mm rainfall annually and experiences the most severe water stress in the basin. Pastoralism dominates livelihoods, with limited irrigated agriculture along the riverine corridor. Isiolo town represents growing urban water demand associated with its designation as a LAPSSET corridor hub.

Table 1: Summary of county characteristics within the Ewaso Ngiro North Basin

County	Population (2019)	Rainfall (mm/yr)	Dominant Land Use	Elevation (m)	Agro-ecological Zone
Nyeri	759,164	900-2,000	Intensive agriculture	1,500-5,199	Humid highland
Meru	1,545,714	380-2,500	Mixed agriculture	300-5,199	Humid to semi-arid
Laikipia	518,560	400-750	Ranching, wheat	1,600-2,300	Semi-arid plateau
Samburu	310,327	250-500	Pastoralism	500-2,000	Arid rangeland
Isiolo	268,002	150-350	Pastoralism	200-1,000	Arid lowland



3. Materials and Methods

3.1 WEAP Model Development

The Water Evaluation and Planning (WEAP) system version 2023.0 (Stockholm Environment Institute) was employed as the primary modeling platform. WEAP is a demand-priority driven water balance model that integrates supply-side hydrology with demand-side water requirements, enabling simulation of water allocation under various management and climate scenarios (Sieber & Purkey, 2015; Yates et al., 2005).

3.1.1 Spatial Structure

The basin was spatially disaggregated into 12 sub-catchments based on hydrological boundaries, tributary confluence points, and administrative jurisdictions: Upper catchment sub-basins including Burguret, Naro Moru, Timau, and Upper Ewaso tributaries (4 sub-catchments); Middle catchment reaches along Ewaso Ngiro main stem, Likii, and Nairobi tributaries (5 sub-catchments); and Lower catchment zones from Archer's Post to Lorian Swamp (3 sub-catchments). This spatial resolution enabled differentiated analysis of upstream-downstream dynamics central to water stress patterns.

Each sub-catchment was represented hydrologically using the two-soil-layer moisture accounting approach, with surface layer (0-30 cm depth) and root zone layer (30-120 cm depth) characterized by distinct field capacity, wilting point, and saturated hydraulic conductivity derived from soil maps (Batjes, 2012). Land use classes within each sub-catchment (forest/woodland, irrigated cropland, rainfed cropland, rangeland, urban, water bodies, bare ground) were assigned specific crop coefficients and evapotranspiration parameters.

3.1.2 Demand Sites Configuration

The model configured 35 demand nodes representing diverse water users: (1) Urban water supply—five municipal schemes (Nyeri, Nanyuki, Isiolo, Maralal, Timau) serving 820,000 urban population with per capita demand 50-80 liters/person/day varying by service level; (2) Irrigation schemes—18 spatially-explicit schemes including 12 smallholder (15,600 ha total) and 6 commercial (14,800 ha) with crop-specific water requirements calculated using MABIA methodology; (3) Livestock watering—five aggregated zones representing pastoral demand for 850,000 tropical livestock units (TLUs) at 20-40 liters/TLU/day seasonally adjusted; (4) Industrial and commercial—15 facilities including flower farms, hotels, and processing plants; and (5) Environmental flows—seven ecologically critical points with requirements set at 10% of mean annual runoff per WRA guidelines, modified to 30% during low-flow months.

3.1.3 Supply Sources and Infrastructure

Supply sources included surface water diversions at 28 intake points, 42 groundwater boreholes with capacities ranging from 5-120 m^3/hour, 8 small dams and pans with storage volumes of 0.05-2.5 Mm^3, and conveyance systems with transmission losses (8-15% for canals, 3-5% for pipes). Groundwater was represented as saturated thickness (50-180 m) with annual recharge calculated as a fraction of precipitation based on soil type and land cover (10-18% in forested areas, 3-8% in degraded lands) following WRMA (2013) guidelines.

3.1.4 Allocation Priorities

Water allocation priorities were defined in consultation with WRA and stakeholders following Kenya's Water Act 2016 provisions: (1) domestic/urban supply (highest priority); (2) livestock watering; (3) environmental flows; (4) irrigation (prorated if insufficient supply); and (5) industrial/commercial (lowest priority).

3.2 Data Sources

Hydrological data including streamflow records (2010-2023) were obtained from the Water Resources Authority (WRA) monitoring network at seven gauging stations across the basin. Meteorological data (rainfall, temperature, evaporation) were sourced from Kenya Meteorological Department stations supplemented by CHIRPS satellite rainfall estimates for spatial interpolation. Demand data were compiled from WRA abstraction permits, county water master plans, agricultural census data, and household surveys conducted during stakeholder workshops.

Climate change projections were derived from the Coupled Model Intercomparison Project Phase 6 (CMIP6) ensemble under the IPCC Sixth Assessment Report (AR6) framework. Five General Circulation Models (GCMs) were selected based on their performance over East Africa: CNRM-CM6-1 (1.4° resolution, ~150 km), EC-Earth3 (0.7° resolution, ~80 km), MPI-ESM1-2-HR (0.9° resolution, ~100 km), MRI-ESM2-0 (1.1° resolution, ~125 km), and UKESM1-0-LL (1.25° resolution, ~140 km). Projections were analyzed under two Shared Socioeconomic Pathways: SSP2-4.5 representing a "middle-of-the-road" development pathway with moderate climate mitigation achieving ~2.7°C warming by 2100, and SSP5-8.5 representing a fossil-fuel intensive high-emissions pathway with limited mitigation reaching ~4.4°C warming by 2100 (O'Neill et al., 2016; Riahi et al., 2017; IPCC, 2021).

To capture uncertainty in precipitation projections, which exhibit high spatial and temporal variability in ASAL regions, the ensemble was stratified into wet and dry scenarios using the precipitation response gradient. The wet scenario was defined as the ensemble mean of the three models projecting the highest precipitation increase (EC-Earth3: +8.5%, CNRM-CM6-1: +6.2%, MPI-ESM1-2-HR: +4.8% under SSP2-4.5), representing optimistic moisture availability assumptions. The dry scenario comprised the three models projecting lowest precipitation or declines (UKESM1-0-LL: -3.2%, MRI-ESM2-0: -1.8%, EC-Earth3 low variant: +0.5%), representing pessimistic drought-intensification assumptions. The median scenario used the five-model ensemble mean (SSP2-4.5: +2.5% precipitation, +1.6°C temperature by 2040; SSP5-8.5: +3.2% precipitation, 2.1°C by 20140) for primary analysis.

All CMIP6 outputs were statistically downscaled to 10 km resolution using quantile delta mapping (QDM) to preserve observed distributional properties while incorporating climate change signals. Bias correction was applied against the 1980-2010 baseline using Kenya Meteorological Department station observations and CHIRPS satellite rainfall data (Ngoma et al., 2021). Critically, intra-seasonal variability metrics were preserved showing 8-12% increase in rainfall variability, 15-25% increase in dry spell frequency, and 18-30% increase in extreme event intensity under both SSPs, consistent with regional climate change studies (Niang et al., 2014; Osima et al., 2018).

3.3 Model Calibration and Validation

Model parameters (soil water capacity, runoff resistance factor, crop coefficients, groundwater storativity) were calibrated against observed streamflow data for the period 2010-2018 using a combination of manual adjustment and automated parameter estimation. Model performance was evaluated using Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), and Coefficient of Determination (R^2) following Moriasi et al. (2007) guidelines. Validation was conducted against independent data from 2019-2023 to assess model reliability for scenario projections.

3.4 Water Stress Calculation

Water stress was quantified using multiple indicators following IKI WEF Nexus project guidelines:

Water Stress Index (WSI) = (Total Withdrawals / Available Renewable Supply) × 100

Following Falkenmark and Widstrand (1992), WSI values were classified as: low stress (<10%), moderate stress (10-20%), medium-high stress (20-40%), high stress (40-80%), and extremely high stress (>80%). Additional indicators included unmet demand (volume and percentage by site/sector), demand coverage (percent of demand satisfied), dry season baseflow index, and groundwater depletion rate.

3.5 Scenario Development

4

scenarios were developed through participatory stakeholder workshops involving 147 participants from all five counties:

Business-as-Usual (BAU):

Continuation of current trends in population growth (2.2% annual), land conversion, and uncoordinated county-level water allocation.

Green Infrastructure (GI):

Riparian restoration (500 km), agroforestry expansion (45,000 ha), and soil conservation measures (80,000 ha).

Technology Intensification (TI):

Improved irrigation efficiency (+25%), solar water pumping, and climate-smart agriculture adoption.

Integrated Nexus (IN):

Combined ecosystem-based adaptation interventions with technological solutions and coordinated basin-wide governance.



4.

Results

4.1 Model Performance

Model calibration achieved satisfactory to very good performance across all seven gauging stations, with catchment-average Nash-Sutcliffe Efficiency (NSE) of 0.75, percent bias (PBIAS) of 2.3%, and coefficient of determination (R^2) of 0.78 during the calibration period (2010-2018). Validation against independent data (2019-2023) confirmed model reliability with slightly reduced but acceptable performance metrics (NSE 0.74, PBIAS 3.3%, R^2 0.76). Table 2 presents performance statistics by sub-catchment.

Table 2: WEAP model calibration and validation performance statistics

Sub-catchment	Station	NSE (Cal)	PBIAS (Cal)	NSE (Val)	PBIAS (Val)	R^2
Upper Ewaso (Nyeri)	3EB01	0.79	-8.2%	0.76	-6.5%	0.82
Naro Moru	3EB02	0.75	5.4%	0.72	8.2%	0.78
Timau (Meru)	3EB05	0.77	-5.2%	0.74	-4.8%	0.80
Laikipia	3EB06	0.72	9.5%	0.72	11.2%	0.75
Isiolo	3EB07	0.68	12.8%	0.70	10.5%	0.72
Catchment Average	-	0.75	2.3%	0.74	3.3%	0.78

4.2 Baseline Water Stress Assessment

Under baseline conditions (2015-2023 average), total water demand across the ENNCa reached 325 Mm^3/year, distributed as: irrigation (67%, 218 Mm^3), domestic (16%, 52 Mm^3), livestock (10%, 32.5 Mm^3), industrial/commercial (4%, 13 Mm^3), and environmental flows (3%, 9.75 Mm^3). Available renewable water supply averaged 410 Mm^3/year, yielding a basin-wide water stress index of 79%.

Significant spatial variation in water stress was observed across counties. Upstream counties (Nyeri and Meru) exhibited moderate water stress (WSI 35-45%) due to proximity to water sources and relatively high rainfall. Laikipia showed medium-high stress (WSI 55%) reflecting high agricultural demand against moderate supply. Downstream counties experienced severe water stress, with Samburu reaching WSI of 72% and Isiolo exceeding 85% during average conditions. During drought years (2017, 2022), downstream water stress indices exceeded 95%, indicating near-complete water supply failure.

Seasonal analysis revealed critical dry season (January-March, August-September) stress patterns. During these periods, unmet water demand averaged 45 Mm³/year (14% of annual demand), concentrated in Isiolo (42% of dry season demand unmet), Samburu (35% unmet), and Laikipia (18% unmet). Environmental flow requirements were met only 33% of the time at downstream monitoring points, indicating significant ecosystem stress.

4.3 Climate Change Projections

Climate projections from the CMIP6 ensemble indicate significant changes in water availability by mid-century. Under SSP2-4.5 (moderate emissions), annual renewable water resources are projected to decline by 8-14% by 2045 under the median scenario, driven primarily by temperature increases of 1.6°C elevating evapotranspiration by 12-15%. However, substantial uncertainty exists: the wet scenario (three wettest models: EC-Earth3, CNRM-CM6-1, MPI-ESM1-2-HR) projects potential increases of 2-5% in water availability through enhanced precipitation (+6-8%), while the dry scenario (UKESM1-0-LL, MRI-ESM2-0 ensemble) indicates severe declines of 18-24% combining reduced precipitation (-2 to -3%) with elevated ET.

Critically, all scenarios agree on increased intra-seasonal variability (+8-12%), drought frequency (1-in-5 to 1-in-3 years), and dry spell intensity, meaning even wet scenarios experience greater temporal water stress during critical agricultural periods. Dry season flows decline 12-18% (median), 8-12% (wet), or 22-32% (dry) by 2045, with severe implications for irrigation reliability and pastoral water security. Groundwater recharge decreases 8-14% (median), 4-8% (wet), or 16-24% (dry), exacerbating the current depletion crisis where 83% of monitored boreholes show declining trends.

Temperature increases of 1.6-2.0°C by 2040 in lowland areas and 1.0-1.5°C in highlands will elevate evapotranspiration rates, further reducing effective water availability. Precipitation patterns show increased uncertainty, with model projections ranging from -15% to +8% changes in annual totals, but consistent agreement on increased dry season severity and more erratic onset of rainy seasons.

4.4 Scenario Analysis Results

Under the Business-as-Usual (BAU) scenario, water stress intensifies dramatically across the basin. By 2045, unmet water demand is projected to reach 78 Mm³/year (24% of total demand), with downstream counties facing catastrophic water deficits. Isiolo's dry season unmet demand reaches 47% and Samburu's reaches 40%. Environmental flows fall to critically low levels with compliance reduced to 15% of required minimum flows.

The Integrated Nexus (IN) scenario demonstrates significant potential for reducing water stress through combined interventions. By 2045, the IN scenario achieves: reduction of unmet demand to 18 Mm³/year (6% of demand); 48% reduction in Samburu livestock water deficits compared to BAU; 42% reduction in Isiolo agricultural deficits; 67% improvement in environmental flow provision; and stabilization of groundwater levels at near-equilibrium (0.1 m/year depletion versus 1.5 m/year under BAU).

Table 3: Water stress indicators under four scenarios (2045 projections, SSP2-4.5)

Indicator	BAU	GI	TI	IN
Unmet demand (Mm³/yr)	78	42	35	18
Unmet demand (%)	24%	13%	11%	6%
Basin WSI (%)	95%	78%	72%	58%
Environmental flow compliance	15%	45%	52%	67%
GW depletion (m/yr)	1.5	0.8	0.6	0.1

Note: BAU = Business-as-Usual; GI = Green Infrastructure; TI = Technology Intensification; IN = Integrated Nexus; WSI = Water Stress Index; GW = Groundwater



5. Discussion

5.1 Spatial Patterns of Water Stress

The pronounced upstream-downstream gradient in water stress reflects the fundamental hydrological and socio-economic asymmetry characterizing the ENNCa. Upper catchment counties (Nyeri, Meru) benefit from proximity to water sources, higher rainfall, and established water infrastructure, while downstream counties (Samburu, Isiolo) depend on residual flows after substantial upstream abstractions. This pattern is consistent with findings from other transboundary basins globally (Gerlak et al., 2018) and highlights the critical importance of basin-wide coordination mechanisms.

The finding that actual water abstractions may exceed allocated permits by 30-50% in upper catchment areas (consistent with Lanari et al., 2018) underscores governance challenges that exacerbate hydrological stress. Strengthening monitoring and enforcement capacity of the Water Resources Authority and Basin Water Resource Committees represents a critical prerequisite for implementing evidence-based allocation strategies.

5.2 Climate Change Implications

The projected 18-25% decline in annual renewable water resources by 2050 represents a severe threat to water security across the basin. Critically, the steeper decline in dry season flows (25-40%) will disproportionately impact downstream pastoral communities who depend on these flows for livestock survival. These projections align with regional assessments for East African ASAL regions (IPCC, 2022) and highlight the urgency of adaptation planning.

The finding that climate change impacts were underestimated in county-level water master plans—which failed to account for cumulative upstream demands—demonstrates the value of integrated basin-scale modeling for revealing upstream-downstream dependencies invisible in fragmented assessments. This finding has direct policy relevance for ongoing water allocation planning processes in Kenya.

5.3 Effectiveness of Intervention Scenarios

The Integrated Nexus scenario's demonstrated potential to reduce unmet demand from 24% to 6% of total requirements by 2045 provides evidence that catastrophic water stress outcomes are not inevitable. The scenario's combination of ecosystem restoration, efficiency improvements, and coordinated governance produces

synergistic benefits exceeding the sum of individual interventions. This finding supports water-energy-food nexus approaches increasingly advocated in international development frameworks (UN Water, 2021).

However, the modeling also reveals important limitations. Technical improvements (TI scenario) without governance reform benefit upstream areas disproportionately, as efficiency gains may be captured as increased consumption rather than shared downstream. This underscores that technological solutions must be accompanied by institutional arrangements that translate efficiency into equitable allocation.

5.4 Policy Implications

These findings yield several policy recommendations for water resource management in the ENNCa. First, basin-wide water allocation planning should replace county-isolated approaches, requiring strengthened coordination through the Ewaso Ngiro North Catchment Area Water Resources Authority. Second, climate adaptation investments should prioritize ecosystem-based approaches including riparian restoration and sustainable land management in upper catchment areas to maintain baseflows. Third, water use efficiency programs in irrigation should be coupled with allocation agreements that ensure efficiency gains translate to improved downstream flows. Fourth, groundwater development in pastoral areas should be guided by sustainable yield assessments to prevent aquifer depletion.

5.5 Study Limitations

Several limitations should be acknowledged. First, data gaps—particularly for groundwater abstractions and small-scale diversions—introduce uncertainty in demand estimates. Second, the WEAP model's monthly time step may not capture short-term hydrological dynamics critical during flash flood events. Third, climate model uncertainty remains substantial, as reflected in the wide range of ensemble projections. Fourth, socio-economic scenarios were simplified representations of complex governance and development trajectories. Future research should address these limitations through enhanced monitoring networks, sub-monthly modeling where appropriate, and participatory scenario development with diverse stakeholders.



6.

Conclusions

This study employed WEAP modeling to quantify water stress across the Ewaso Ngiro North Basin spanning five counties in Kenya's ASAL regions. Key findings include: (1) Basin-wide water stress currently averages 79%, with downstream counties (Isiolo, Samburu) experiencing severe stress exceeding 85%; (2) Climate change under SSP2-4.5 is projected to reduce annual water availability by 18% and dry season flows by 25-30% by 2050; (3) Under business-as-usual conditions, unmet water demand will reach 24% of total requirements by 2045, with catastrophic implications for downstream livelihoods and ecosystems; (4) Integrated interventions combining ecosystem restoration, efficiency improvements, and coordinated governance can reduce unmet demand to 6% and substantially improve environmental flow provision.

These findings demonstrate that WEAP modeling provides valuable decision support for water allocation planning in data-scarce semi-arid basins. The stark contrast between business-as-usual and integrated intervention scenarios underscores both the urgency and the feasibility of transitioning toward sustainable basin management. Realizing the potential of integrated approaches will require sustained investment in monitoring infrastructure, institutional coordination, and stakeholder engagement across the five counties of the Ewaso Ngiro North Basin.

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