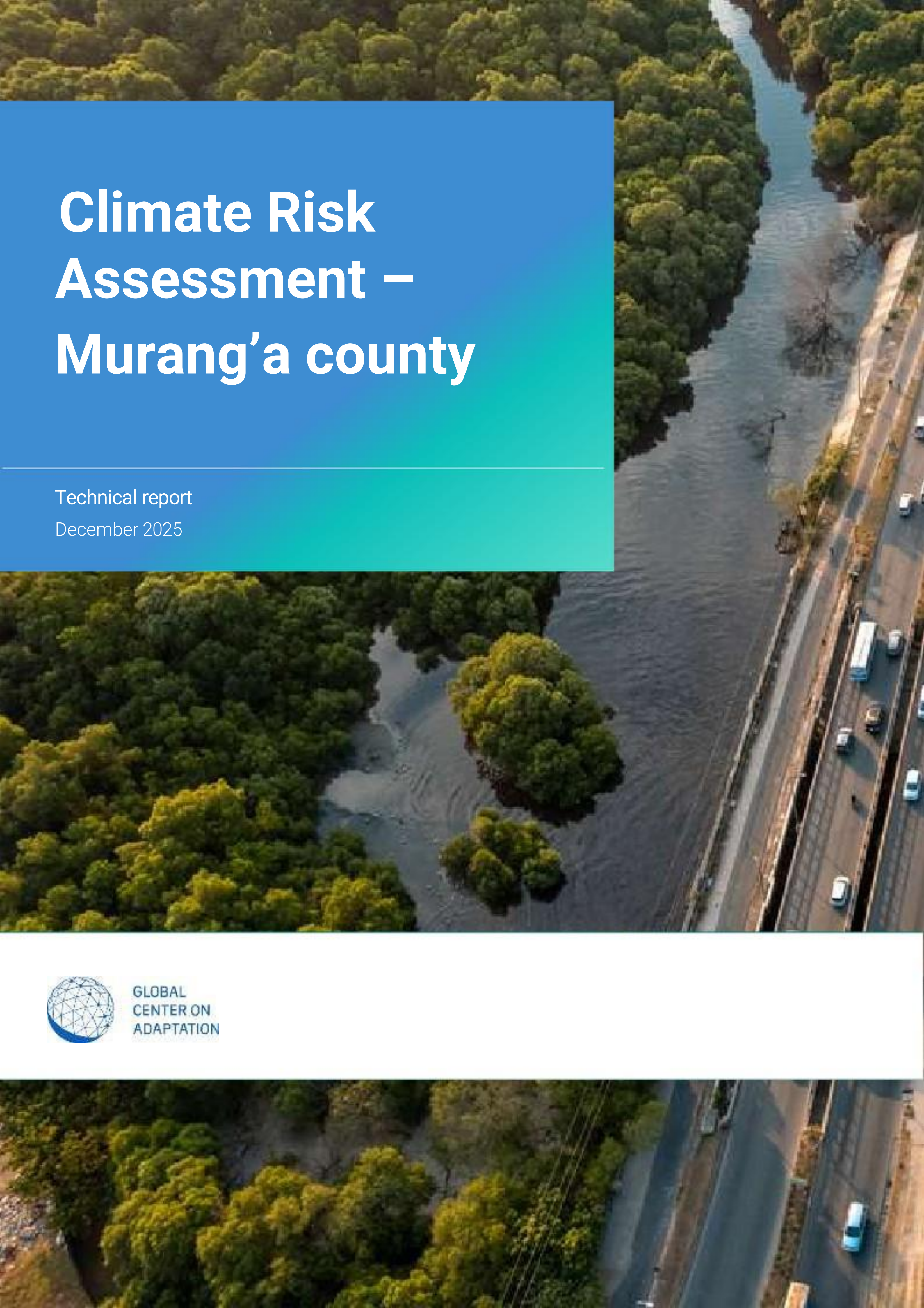

Climate Risk Assessment – Murang’a county

Technical report

December 2025

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ADAPTATION

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AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
AR6	Sixth Assessment Report of the Intergovernmental Panel on Climate Change
ASL	Above Sea Level
CAAC	Catchment Area Advisory Committee
CBO	Community-Based Organization
CCKP	Climate Change Knowledge Portal (World Bank)
CCAP	County Climate Action Plan
CDD	Consecutive Dry Days
CIDP	County Integrated Development Plan
CMIP6	Coupled Model Intercomparison Project Phase 6
CRA	Climate Risk Assessment
CRVA	Climate Risk and Vulnerability Assessment
CWSSIP	County Water and Sanitation Services Investment Plan
CWD	Consecutive Wet Days
DEM	Digital Elevation Model
DLI	Disbursement Linked Indicator
DRM	Disaster Risk Management
ERA5	ECMWF Reanalysis version 5
ENSO	El Niño–Southern Oscillation
FGD	Focus Group Discussion(s)
GBV	Gender-Based Violence
GHG	Greenhouse Gas
GIAVI	Gender- and Inclusion-Adjusted Vulnerability Index
GoK	Government of Kenya
HCF	Health Care Facility
HI	Heat Index
IDP	Internally Displaced Person(s)
ITCZ	Intertropical Convergence Zone
JAS	July–August–September
KMD	Kenya Meteorological Department

K-WASH	Kenya Water, Sanitation and Hygiene Program
LST	Land Surface Temperature
M&E	Monitoring and Evaluation
MCA	Multi-Criteria Analysis
MJO	Madden–Julian Oscillation
MAM	March–April–May (Long Rains)
MoWSI	Ministry of Water, Sanitation and Irrigation
MUWASCO	Murang’a Water and Sanitation Company
NDMA	National Drought Management Authority
NEMA	National Environment Management Authority
NRW	Non-Revenue Water
OND	October–November–December (Short Rains)
PCRA	Participatory Climate Risk Assessment
PRCPTOT	Total Annual Precipitation
PWD	Person(s) with Disabilities
R20mm	Number of days with rainfall > 20 mm
Rx1day	Maximum 1-day precipitation
Rx5day	Maximum 5-day cumulative precipitation
SCMP	Sub-Catchment Management Plan
SDG	Sustainable Development Goal(s)
SPEI	Standardized Precipitation–Evapotranspiration Index
SSP	Shared Socioeconomic Pathway
SSP5-8.5	Shared Socioeconomic Pathway 5 with radiative forcing of 8.5 W/m^2 by 2100
SST	Sea Surface Temperature
UN	United Nations
UNHCR	United Nations High Commissioner for Refugees
WASH	Water, Sanitation and Hygiene
WB	The World Bank
WHO	World Health Organization
WRMA	Water Resources Management Authority
WRUA	Water Resource Users Association
WSP	Water Service Provider

WSS	Water Supply and Sanitation
WSTF	Water Sector Trust Fund

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EXECUTIVE SUMMARY

The Climate Risk Assessment (CRA) of Murang'a County was conducted within the framework of the Kenya Water, Sanitation and Hygiene (K-WASH) Programme and is aligned with the preparation of the Countywide Water Supply and Sanitation Investment Plan (CWSSIP) for Murang'a County. The CRA serves as an operational decision-support tool to ensure climate risks are systematically integrated into strategic planning, infrastructure design, and service delivery in the WASH sector. Conventional planning is increasingly unable to ensure the long-term functionality and reliability of infrastructure due to rising temperatures, changing rainfall, and increased frequency of extreme events.

Objectives and Methodology

The primary objective is to systematically identify and characterize key climate hazards affecting WSS/WASH systems and analyze the drivers of climate exposure and vulnerability. The assessment aims to reduce the vulnerability of planned investments, strengthen institutional and community adaptive capacity, by properly understanding climate hazard exposure and related risks.

The methodology utilizes a risk-based framework consistent with IPCC AR6 and World Bank guidance, defining risk as a function of hazard, exposure, and vulnerability. The assessment uses the SSP5-8.5 scenario as the conservative reference, representative of projected current Greenhouse Gas (GHG) emission levels. The primary time horizon for infrastructure analysis is 2050, with 2100 considered for long-term resource sustainability. Data sources included open source data, and derived indicators (through the use of internal tools: *K'lim*), CMIP6 projections, county documentation (County Climate Action Plan (CCAP), Participatory Climate Risk Assessment (PCRA)), and field missions for ground-truthing. Due to a lack of quantitative data, a qualitative approach drawing on existing documentation and field engagement (including Focus Group Discussions) was used to analyze gender and social vulnerability.

Key Climate Projections and Hazards

Murang'a's climate is characterized by warm conditions and a bimodal rainfall regime. The CRA identified several key hazards linked to climate change that are of importance to the WASH sector. Projections indicate several climate signals under SSP5-8.5:

- On main physical parameters :
    - **Temperature**: Under SSP5-8.5, the average mean surface air temperature is expected to increase by about +1.36°C by 2050 (compared to the 2023 observed temperature). The number of hot days (Tmax > 30°C) is expected to increase significantly (by 9 more days compared to the 1995-2014 reference period).
    - **Precipitation**: Overall annual rainfall is projected to increase, with a shift in the SPEI drought index from "normal" to "Moderate wet" by 2100, suggesting moderation of drought conditions. However, extreme precipitation events, such as the largest 5-day cumulative rainfall (Rx5day), are also projected to increase significantly, rising by up to +34mm (62%) in January by 2100. These changes correspond to more intense floods and landslide triggers.
- These parameters drive hazard levels as follows:
    - **Most concerning hazard : Landslides and Erosion**: Murang'a County is **highly exposed** to landslides, driven by steep slopes (often exceeding 20°), weathered volcanic soils (Andosols and Nitisols), intense and prolonged rainfall, and human factors such as agriculture on steep slopes, deforestation, and road construction. This hazard is concentrated in the Northwest region.
    - **Floods**: The county is prone to flooding. Areas of **high pluvial (heavy rainfall) flood exposure are concentrated in the eastern and south-eastern subcounties**, notably Maragua, due to lower altitudes and concentrated runoff. **River flood exposure, moderate overall**, is highest in Kiharu and Mathioya subcounties along major river valleys.

- **Droughts**: Despite overall wetter projections increased temperatures leading to additional evaporation and evapotranspiration lead to consider **meteorological drought hazard level as moderate**. Socio-economic drought risk remains high as limited water availability (from meteorological drought and salinity) coincides with increasing water demand and strong livelihood dependence on rain-fed agriculture.

An other summary of how the climate parameters projections drive the hazard levels il given below:

The + *boxes indicate that hazard is reinforced by the projected evolution of the climate parameter while the* - *boxes indicate that hazard is reduced.*

Table 1: Relations between climate parameters and hazards

Hazard	Tmean	TXx TNn	PRCPTOT	Rx1day Rx5day	R2mm	CWD	CDD	RH	SPEI	Justification
Floods			+	+	+					Increasing annual rainfall, stronger short-duration rainfall extremes and more frequent heavy-rain days increase runoff and flood triggering.
Heat stress & droughts	+	+					-	+	-	Rising mean and extreme temperatures and higher humidity intensify heat stress, while slightly shorter dry spells and wetter water balance moderate drought intensity.
Landslides			+	+	+					Higher cumulative rainfall and more intense and frequent heavy rains increase soil saturation and slope-failure triggering.
Soil & water salinity			-				-	-	-	Increased rainfall, shorter dry spells, higher humidity and wetter water balance favour salt leaching and reduce evaporative concentration.
Sand & dust storms			-				-	-	-	Wetter and more humid conditions with shorter dry periods reduce soil desiccation and

Hazard	Tmean	TXx TNn	PRCPTOT	Rx1day Rx5day	R2mm	CWD	CDD	RH	SPEI	Justification
			🟩				🟩	🟩	🟩	wind-erosion potential.
Pests & diseases	🟥 +	🟥 +	🟥 +	🟥 +	🟥 +		🟥 +	🟥 +	🟥 +	Warmer, wetter and more humid conditions with more frequent heavy rains expand suitable habitats and favour pest and pathogen development and transmission.

Note: Mean Temperature (**Tmean**), Maximum Temperature (**TXx**), Total Precipitation (**PRCPTOT**), Extreme Rainfall (**Rx1day** / **Rx5day**), Number of Days with Precipitation >20 mm (**R20mm**), Consecutive Wet Days (**CWD**), Consecutive Dry Days (**CDD**), Relative Humidity (**RH**), Drought / Aridity Index (**SPEI**)

Vulnerability and Impacts on WASH

These hazards are tied to the WASH sector as the latter is articulated around water resources and infrastructures which are particularly vulnerable to said hazards (landslide, floods, droughts, salinity).

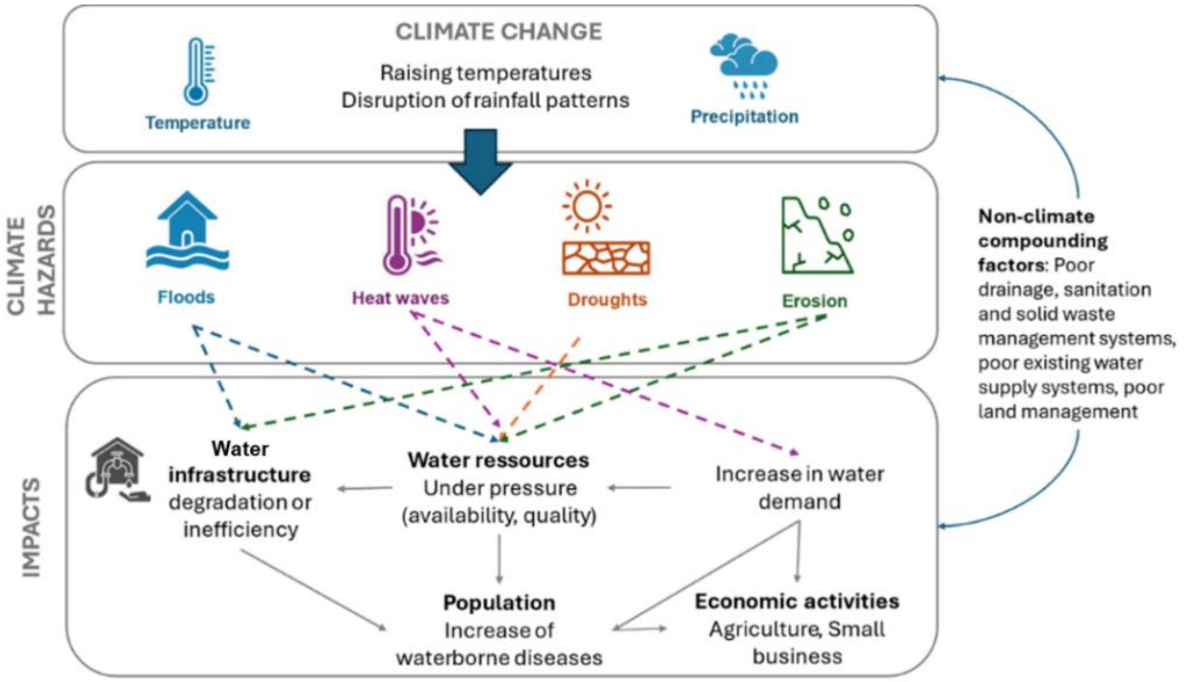

Figure 1: Water sector vulnerability to climate change

In Murang'a the WASH sector is exposed to significant risks as WSS infrastructure are exposed (landslides, floods) and their vulnerability is high, particularly to the combined effects of floods, heavy precipitation, and landslides.

Water Resources: Surface water resources (rivers, shallow wells, water pans) are vulnerable to increased evaporation/evapotranspiration from rising temperatures (meteorological drought) as well as increased water demand leading to potential water depletion. Groundwater quality is at risk from increasing salinity and micropollutant concentrations due to climate disruption, increasing water demand is also one main concern. The below table sums these items up.

Table 2: Links between climate change and water resources

Climate hazard	Impact on water resource
Variability of seasonal rainfall patterns	Weak or even non-existent surface and ground water resources at the end of the dry season
Droughts, water shortage, increased temperatures, heat waves	Decline in quantity and quality of surface and ground water seasonally (large-scale fluctuations) and interannually fluctuations) and on an inter-annual scale (continuous fall in groundwater levels): • Reduced river flow, particularly during low-water periods Increased concentration of various pollutants in water (chemical, organic) due to their reduced dilution • Reduced groundwater recharge • Proliferation of algae disrupting natural processes in water bodies (nitrogen cycle/eutrophication) • Increase in water salinity: ▪ saline upwelling in rivers due to reduced flow, ▪ saline intrusion into coastal groundwater due to reduced recharge, ▪ alteration of geological substrate, releasing elements that generate the formation of soluble salts.
Intense and sudden rainfall, flooding	Pollution of surface water, then groundwater (after infiltration) due to the leaching of pollutants onto the soil, the flooding of latrine pits and the increase in volumes discharged without treatment (saturation of wastewater treatment plants where they exist). Poor infiltration of rainfall into the ground during heavy rainstorms: water no longer infiltrates but runs off, creating areas of flooded areas
Storms (including sand and dust storms)	
Erosion (which can also be induced by floods and water runoff) and landslides	
Sea level rise	Saline intrusions

Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (C. Agudelo-Vera et al. 2020), (Ps-Eau 2018)

Infrastructure and services: The impacts on the WASH sector, which ultimately correspond to impacts on service quality, the infrastructure needed to provide these services, and social impacts, are manifold and vary according to the risks, which are presented in the following tables.

Table 3: Links between climate change and water supply services

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
Variability of seasonal rainfall patterns	Moderately exposed	Weak or even non-existent surface and ground water resources at the end of the dry season		▶ Temporary interruption or reduction of service due to lack of available resources		▶ Tougher fetching: o longer distances to be covered o deeper, less productive water table ▶ Increased diarrheal diseases : o degradation of water quality o use of water points where quality is uncontrolled and questionable by the population when the service is interrupted ▶ Multiplication of usage conflicts
Droughts, water shortage	Moderately exposed	Decline in quantity and quality of surface and ground water seasonally (large-scale fluctuations) and interannually fluctuations) and on an inter-annual scale (continuous fall in groundwater levels): o Reduced river flow, particularly during low-water periods o Increased concentration of various pollutants in water (chemical, organic) due to their reduced dilution o Reduced groundwater recharge o Proliferation of algae disrupting natural processes in water	▶ Increasing water requirements and volumes for all uses (domestic agricultural, industrial, etc.).	▶ Service interruption due to resource unavailability ▶ Degradation of distributed water quality due to inadequate raw water treatment of raw water highly concentrated in pathogenic pathogens, physicochemical pollutants, salt, etc., or high turbidity ▶ Increase in supplied-water temperature above recommended thresholds (WHO's recommendation for maximum drinking water temperature at the tap is 25°C)	▶ Vulnerability and weakening of facilities : o over-utilization of equipment during drought period to meet high demand o risk of dry pumping and damage to pumps o concrete cracking during heat waves o intermittent water supplies and pressure changes in the distribution network lead to	

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
		bodies (nitrogen cycle/eutrophication) o Increase in water salinity: ▪ saline upwelling in rivers due to reduced flow, ▪ saline intrusion into coastal groundwater due to reduced recharge, ▪ alteration of geological substrate, releasing elements that generate the formation of soluble salts.		▶ Interruption of service due to damage to installations	damage of the infrastructure o dams and reservoirs may be weakened by prolonged low storage levels. ▶ Solar panels are less efficient when they become too hot.	during water shortages ▶ Amplification of migratory phenomena or departure of populations no longer having access to water Reduction of agricultural yields
Heat wave	Moderately exposed					
Intense and sudden rainfall, flooding	Moderately exposed	▶ Pollution of surface water, then groundwater (after infiltration) due to the leaching of pollutants onto the soil, the flooding of latrine pits and the increase in volumes discharged without treatment (saturation of		▶ Contamination or degradation of resources by o uncontrolled stormwater runoff o submersion or groundwater flooding of pits	▶ Fragilization, yield reduction and destruction of installations : flooding of wells, wells silting, equipment electrical submerged, erosion of structures,	
Storms (including sand and	Low exposure					

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
dust storms)		wastewater treatment plants where they exist). ▶ Poor infiltration of rainfall into the ground during heavy rainstorms: water no longer infiltrates but runs off, creating areas of flooded areas		containing pollutants o infiltration (through soil or disused boreholes) of flood water in groundwater o rising groundwater mobilizing microbial and chemical contaminants o more rapid transport of subsurface water (rising water tables and soil infiltration) o Interruption of service due to damage to installations o Inaccessibility to water points (landslides - flooding) o Fragilization of storage by saturation	rupture of pipes, network leaks , etc. ▶ Catastrophic failure of dams, leading to reduced storage capacity and potentially damaging releases of water.	

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
Erosion (which can also be induced by floods and water runoff) and landslides	Highly exposed			▶ Degradation of raw water quality due to more polluted run-off, with silt and nutrients ▶ Potential intrusion of contaminants through damaged infrastructure Potential loss of service due to damaged infrastructure	▶ Fragilization and destruction of installations	
Increased water salinity	Moderately exposed	Reduction of water quality	No possibility to consume water containing a certain level of salt, which is no longer fit for drinking	▶ Degradation of raw water quality ▶ Potential intrusion of contaminants through damaged infrastructure ▶ Potential loss of service due to damaged infrastructure	▶ Fragilization and destruction of installations: o leaching of metal o corrosion o increased sediments in pipes	

Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (C. Agudelo-Vera et al. 2020), (Alain Mailhot et Sophie Duchesne 2005), (Ps-Eau 2018)

Table 4: Links between climate change and wastewater management services

Climate hazard	Global county exposure	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Droughts, water shortage	Moderately exposed	▶ Movement and damage of infrastructure related to changes in soil moisture levels	▶ Degradation of resource quality through reduced dilution of pollutants	▶ Reduced water for irrigation may lead to increased wastewater use, and use of polluted receiving waters. Less water to clean toilets which can become unsanitary
Heat wave	Moderately exposed	▶ Dysfunction of biological treatment processes (mortality of certain bacteria). (Ideal WW treatment temperature range being [20 - 35°C] not exceeding 40°C) ▶ Heat-induced degradation of infrastructure and equipment. ▶ Degradation of concrete due to increased production of hydrogen sulfide2 (H_2S)	▶ Degradation of quality of resources through less well treated discharge	▶ Poisoning from inhalation of hydrogen sulfide (H_2S), which is produced more frequently by heat (safety risk for personnel, especially sewage workers). Odor nuisance due to increased nitrogen dioxide (N_2O) emissions
Intense and sudden rainfall, flooding	Moderately exposed	▶ **Submergence failure** of pumps and other electrical systems in treatment plants , rendering out of service. ▶ **Septic tanks filling and backing up; backing up of sewers** ▶ **Fragilization and destruction of installations** o sewers: (scouring or washout of bedding, and flotation	▶ **Increase of untreated water in the natural environment** due to penetration of rainwater into the wastewater network causing overflowing, saturation of pumps and bypass at wastewater treatment plants ▶ **Reduction of pollutants loads and resuspension,** leading to difficulties in treatment process	▶ **Population without sanitary facilities** ▶ **Increase in water-borne diseases** due to the risk of contact with water containing pathogens
Storms (including sand and dust storms)	Low exposure			

Climate hazard	Global county exposure	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
	🟨	leading to cracking of the sewer pipes) o septic tanks flotation ▶ destruction of latrines not built to sustain such hazards (impact on access rates may be significant) ▶ **Disruption of emptying services** (difficulty access, necessary increase in frequency...)	▶ **Treatment process dysfunction** (hydraulic overload) ▶ **Mixed flow of wastewater and rainwater on public roads** as a result of flooding of latrine and toilet pits, with consequent health risks ▶ **Inundation of soak away or pit from below**, increased potential for contamination of groundwater.	
Erosion (which can also be induced by floods and water runoff) and landslides	Highly exposed	▶ Exposing and damaging pipe work, especially simplified sewerage.		

Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (Walchem s.d.), (Ps-Eau 2018)

Table 5: Links between climate change and drainage services

Climate hazard	Global county exposure	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Intense and sudden rainfall, flooding	Moderately exposed	▶ Excessive water and submergence lead to ineffective stormwater management systems which in turn lead to impacts on water and wastewater services: o flooding of equipment, o overflow of wastewater networks, o water contamination	▶ Damage to (or destruction of) buildings including houses ▶ Cascading hazard risk increase (erosion, landslide, water contamination) ▶ Cutting of communication routes and disruption of many other network services (electricity, telephone, etc.) ▶ Disruption/stoppage of economic activities	▶ Displacement of populations whose homes no longer usable ▶ Recurrent damage to private and public property ▶ Accidents, personal injury injuries and drowning due to the risk of being caused by the current, landslides and collapses and traffic accidents ▶ Disease transmission through: o use of contaminated water for domestic purposes o development of disease vectors such as mosquitoes, rats, etc.
Storms (including sand and dust storms)	Low exposure			

Source: (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (Alain Mailhot et Sophie Duchesne 2005)

Proposed Investments: An analysis of proposed CWSSIP investments shows that all mapped projects face moderate to high exposure to **landslide hazard**, this hazard is therefore a main concern to be considered in all projects development. Attention must also be brought **to flood risks in the vicinity of rivers**, as all infrastructures there would be considered moderately to highly exposed. **In this regard flood and landslides hazards were assigned higher weights in the final composite hazard exposure score for proposed investments followed by salinity and erosion which has the lowest weight.**

Social and Gender Impacts: Climate change is intensifying existing social vulnerabilities in the water, sanitation and hygiene (WASH) sector, with impacts on health, livelihoods, and social cohesion. Climate impacts on WASH lead to:

- longer water collection times,
- heightened exposure to diarrhoeal and other water-borne diseases, and
- reduced availability of water for domestic use, sanitation, and irrigation. Limited water for sanitation undermines hygiene practices and the functioning of toilets, increasing public health risks.
- Increase in the competition over resources, contributing to user conflicts and, in some contexts, human–wildlife conflicts.

Reduced water availability for agriculture lowers crop yields and may push communities to rely on untreated wastewater or polluted sources for irrigation, further compounding health and environmental risks. Climate-induced disasters and prolonged water scarcity are also driving displacement and migration, placing additional pressure on host communities and temporary settlements. In such settings, water supply is often reliant on truck delivery rather than resilient piped systems, while sanitation infrastructure is frequently insufficient, unsafe, or poorly maintained.

These impacts disproportionately affect women, children, older persons, persons with disabilities, and marginalized communities. Women and girls bear the primary responsibility for water collection, with scarcity forcing them to wake up as early as 2 a.m. or 5 a.m. to fetch water, increasing their exposure to physical strain and protection risks. Displacement further deepens inequalities, as illustrated by the 2025 landslide in Kiarathe, which forced households into an internally displaced persons (IDP) camp. Overall, climate change acts as a multiplier of existing social and gender inequalities, underscoring the need for inclusive, climate-resilient WASH interventions.

Key Findings

The assessment identifies **landslides as the most critical climate hazard affecting WASH infrastructure in Murang'a County, particularly in the western sub-counties, while pluvial flooding presents higher risks in eastern areas.** Meteorological drought risk is moderate but widespread, driven by rising temperatures, evapotranspiration, and increasing water demand. **Climate change is affecting both the quantity and quality of water resources, with cascading impacts on service continuity, public health, and vulnerable populations.**

Implications for Planning and Investment

The CRA provides a strategic evidence base to inform climate-resilient prioritization under the CWSSIP, highlighting the need for **spatially differentiated interventions, risk-sensitive infrastructure siting and design, and inclusive planning approaches**. While appropriate for county-level decision-making, **the analysis should be complemented by site-specific climate risk screening and detailed design studies for individual investments.**

1. INTRODUCTION

1.1 Context

This Climate Risk Assessment (CRA) has been undertaken within the framework of the Kenya Water, Sanitation and Hygiene (K-WASH) Programme and is closely aligned with the preparation of the Countywide Water Supply and Sanitation Investment Plan (CWSSIP) for Murang'a County. The CRA is designed as an operational decision-support tool to ensure that climate risks are systematically integrated into strategic planning, infrastructure design and service delivery models in the water and sanitation sector.

The CWSSIP provides the strategic framework for identifying priority investments, mobilising financial resources and sequencing projects to achieve universal, safe and sustainable water and sanitation services in line with national sector policies and the Sustainable Development Goals (SDG 6). However, conventional sector planning that does not explicitly account for climate change risks is increasingly unable to ensure the long-term functionality and reliability of infrastructure systems. Rising temperatures, changes in rainfall patterns, increased frequency of extreme events and progressive environmental degradation are already affecting water availability, water quality, infrastructure durability and service continuity.

In this context, the CRA serves to embed climate resilience as a core pillar of the CWSSIP, ensuring that proposed investments are robust under current climate variability as well as plausible future climate scenarios. The assessment adopts a risk-based framework consistent with IPCC AR6 and World Bank guidance, combining hazard, exposure, and vulnerability to identify priority risks and inform climate-resilient design standards, operational practices, and investment prioritisation.

1.2 Objectives

The primary objective of this Climate Risk Assessment is to systematically identify and characterise the key climate-related hazards affecting water supply, sanitation, and hygiene (WSS/WASH) systems, and to analyse the drivers of exposure and vulnerability across populations, infrastructures, and ecosystems. This enables a structured assessment of current and future climate risks to sector assets and services and supports the integration of resilience measures within the CWSSIP.

Specifically, the CRA aims to:

- Assess observed trends and projected changes in temperature, precipitation and extreme events, and their implications for water resource availability, water quality, infrastructure integrity and service delivery.
- Identify and map climate hazards relevant to WSS/WASH, including floods, droughts, heatwaves, landslides, erosion and water quality degradation.
- Analyze the spatial and socio-economic dimensions of exposure, including population growth, settlement patterns, critical infrastructure and ecosystem services.
- Evaluate vulnerability, with particular attention to gender, poverty, disability and displacement, using evidence-based indicators and participatory methods.

Beyond risk reduction, the CRA also seeks to maximise the opportunity for climate co-benefits. Modern WSS and WASH systems are not only essential for public health and environmental protection but can also contribute significantly to climate change mitigation when designed and operated efficiently. Energy-efficient pumping systems, nature-based wastewater treatment, reduction of non-revenue water, and improved sludge management can reduce greenhouse gas (GHG) emissions, in line with international best practice (e.g. WaCCliM and low-carbon water utility frameworks).

The CRA provides strategic guidance to:

- Reduce the vulnerability of planned investments to climate hazards through climate-informed siting, design and operational standards;

- Strengthen the adaptive capacity of institutions and communities responsible for WSS/WASH services; and

By embedding adaptation considerations from the outset of the program, the CRA supports the development of a CWSSIP that is not only technically sound and economically viable, but also climate-resilient, low-carbon and socially inclusive.

2. METHODOLOGY

2.1 Concepts and definitions

This report uses the definitions from the IPCC Fifth Assessment Report (2014), which describes risk as a function of hazard, exposure, and vulnerability (sensitivity and adaptive capacity).

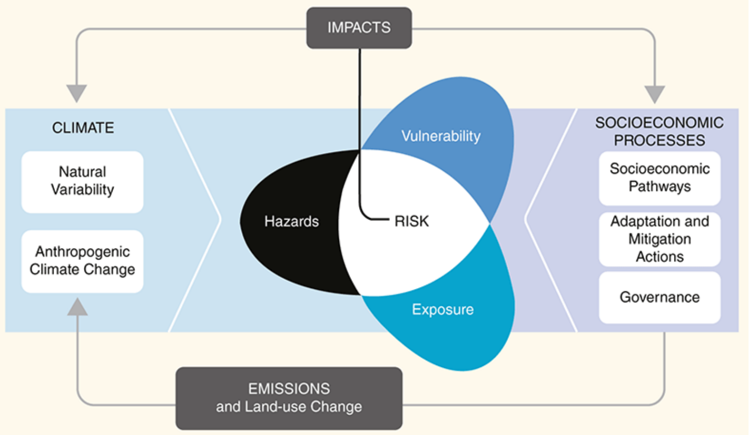

Figure 2: Exposure, Vulnerability, and Hazards as factors of Risks

- Hazard: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- Exposure: The presence of people; livelihoods; species or ecosystems; environmental functions, services, resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
- Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
- Reducing risk of climate change involves adaptation and mitigation measures which are defined as follows:
- Mitigation: A human intervention to reduce emissions or enhance the sinks of greenhouse gases.
- Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

The outcome of the CRA is a comprehensive overview of key climate risks across the regions, including hotspots identification. The following steps will be followed to ensure such assessment: Detailed analysis of the key hazards pre-identified and Analysis of the potential impacts, which depend on the exposure, the sensitivity and the adaptive capacity to the identified hazards.

2.2 Assumptions

2.2.1 Scenarios

The scenarios which were considered to model climate change correspond to Shared Socioeconomic Pathways (SSP) that were defined by IPCC in the framework of the 6th report (AR6, 2021). These Socio-economic scenarios were used by IPCC to derive emissions scenarios without (baseline scenarios) and with climate policies (mitigation scenarios). The following scenarios were defined by IPCC:

- SSP1: Sustainability (Taking the Green Road)
- SSP2: Middle of the Road
- SSP3: Regional Rivalry (A Rocky Road)
- SSP4: Inequality (A Road divided)
- SSP5: Fossil-fueled Development (Taking the Highway)

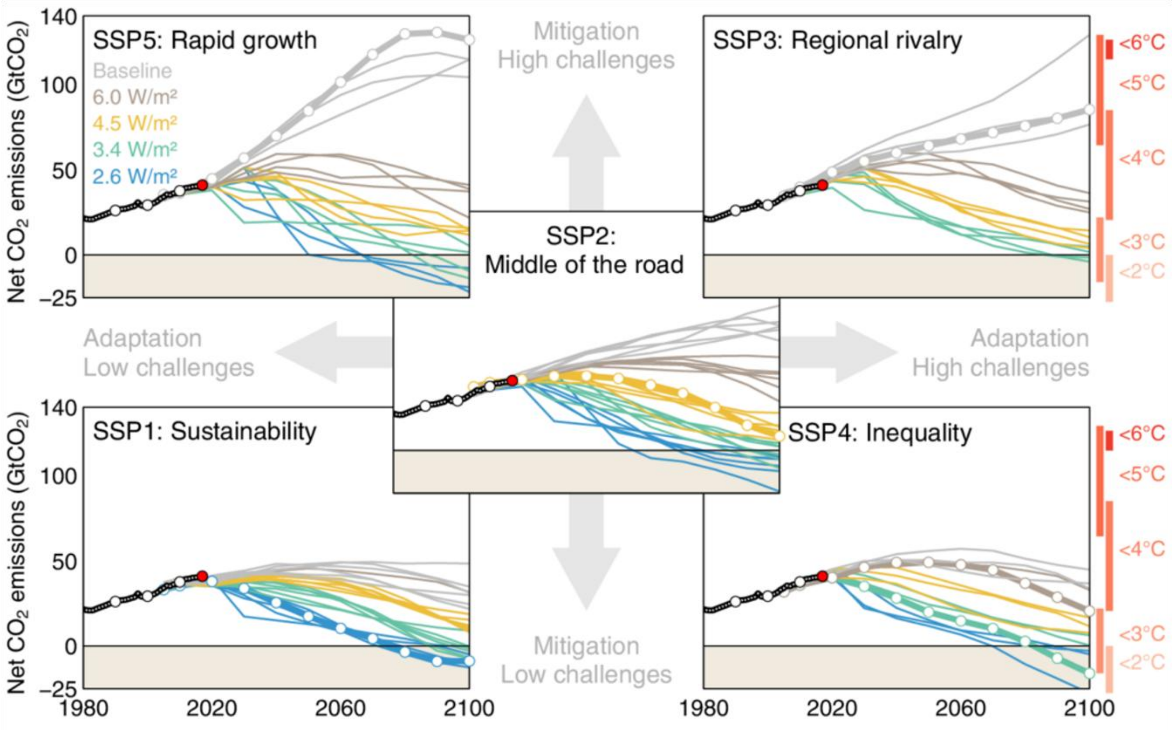

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Figure 3: SSP climatic scenarios from IPCC – 6th report

SSP5-8.5 was considered as the referent scenario, as it is the most conservative scenario, representative of the projected current level of GHG emissions.

2.2.2 Project Horizon

The horizon which was considered was set in accordance with the lifespan of infrastructure planned under the K-WASH project (about 15/20 years for pipes, latrines, boreholes, water intakes) leading to a **2050** horizon. **2100** horizon was also considered for analyzing long-term resource sustainability.

2.3 Climate data and downscaling overview

In order to characterize historical climate, project future trends, and translate these into hazard metrics with relevance for WASH systems, **a robust and transparent methodology was implemented, ensuring scientific consistency, replicability, and alignment with IPCC AR6, World Bank Climate Change Knowledge Portal (CCKP), and county-level documentation**. This methodology is provided in annex 1 of the present report.

Our risk framework followed the IPCC concept of Risk based on cross-analysis of Hazard, Exposure, and Vulnerability, operationalized through hazard indices, sectoral exposure layers, and vulnerability metrics (social and infrastructure).

We used a consistent county-scale workflow for Murang'a and Tana River to preserve comparability.

Regarding data sources, we relied on open and authoritative datasets already mobilized in this report:

- CMIP6 projections / SSPs: temperature, precipitation, and derived indices like Rx5day, CDD, SPEI…
- ThinkHazard for hazard screening.
- County documentation (CCAP, PCRA) for local evidence and historical events.
- Field missions (Feb., Mar., Sept.) for ground-truthing of WASH assets and social dimensions.

Implemented downscaling approach is as follows:

- **Regional extraction & ensemble statistics**. We extract CMIP6 projections (SSP5-8.5 baseline for "stress-test") over Murang'a county compute ensemble means/percentiles and derive monthly/seasonal deltas versus 1995-2014.
- **Delta-change application**. Deltas are applied to observed-climatology baselines to produce county-scale future climatology (temperature, precipitation).
- **Derived indices**. From these fields, we compute hazard-relevant metrics used elsewhere in the report, for the 2050 and 2100 horizons the reference period being 1995-2014:
  - Mean temperature – The average temperature over a specific period.
  - Maximum temperature – The highest temperature recorded during a specific period.
  - Total precipitation (PRCPTOT) – The total amount of rainfall (or snowfall converted to water) over a period.
  - Rx5day (extreme 5-day rainfall) – The highest total rainfall recorded over any 5-day period.
  - CDD (consecutive dry days) – The longest number of days in a row with little or no rain.
  - CWD (consecutive wet days) – The longest number of days in a row with significant rainfall.
  - Relative humidity – How much moisture the air contains compared to the maximum it can hold at that temperature.
  - Seasonal anomalies – How different a season's climate (temperature, rainfall, etc.) is from the long-term average.
  - Heat index – How hot it feels to the human body when temperature and humidity are combined.
  - Number of tropical nights – The number of nights when the minimum temperature stays above a warm threshold (commonly 20–25°C, depending on region).
  - SPEI for wet/dry conditions – An index that measures drought or wetness based on both rainfall and evaporation demand.
- Hazard layers. These metrics feed thematic layers (pluvial/riverine flood propensity, drought, heat-humidity windows, landslide predisposition via coupling with slope/soil) that are then intersected with WASH assets to estimate exposure.

2.4 Gender and social vulnerability methodology

Throughout the assessment, gender and social inclusion (GSI) considerations were **mainstreamed** as a cross-cutting lens rather than treated as a separate quantitative exercise, mainly due to a lack of data. The objective was to understand how climate risks interact with existing social vulnerabilities across **women, youth, the elderly, persons with disabilities (PWDs), and other marginalized groups identified in the PCRA**.

Considering the lack of quantitative data it appeared difficult to compute a full set of quantitative sector indicators, the consultant therefore applied a **qualitative approach**, drawing on existing documentation and field engagement (focus group discussion, interviews on the field):

- **Desk review** of CCAP, PCRA, CIDP, health surveillance records, and other relevant county planning documents.
- **Field missions and stakeholder consultations**, including interviews with water utilities, county officers, community representatives, and focus group discussions.
- **Observation-based assessment** of how climate-related WASH challenges manifest differently across demographic groups.
- **Integration with hotspot analysis findings**, which provided spatial and contextual evidence of differentiated exposure and vulnerability.
- **Consideration for adaptation options report development.**

Main findings are presented in chapter 3 of the present report, which provides a high-level framing of the intersections between climate risk and social vulnerability. The Gender Vulnerability and Action Plan will build on this foundation by presenting:

- group-specific findings,
- refined vulnerability characterizations, and
- actionable recommendations tailored to county WASH systems.

2.5 Steps undertaken to build the CRA

2.5.1 Step 1 – Initial climate risk screening

The Climate Risk Assessment (CRA) was initially developed using open-source data and publicly accessible tools, notably the **Climate Change Knowledge Portal** from the World Bank and the **ThinkHazard!** platform. These sources provided a foundational understanding of climate risks, which was then cross-validated and enriched with county-level documentation, including:

- The County Climate Action Plan (CCAP)
- The Participatory Climate Risk Assessment (PCRA)

2.5.2 Step 2 – Detailed Analysis and Contextual Refinement

To challenge and refine the initial analysis, the **K'lim tool** was also used (see annex 2).

This climate analysis (chapter 4) informed an **exposure assessment**, which was then cross-referenced with the proposed **K-WASH** and **CWSSIP** infrastructure mapping. The goal was to evaluate the exposure of infrastructures to climate hazards, followed by an assessment of their vulnerabilities (chapter 5), ultimately leading to a comprehensive **risk assessment**. This risk assessment serves as the baseline for a separate deliverable: the **Adaptation Option Analysis**, which will be presented as a standalone document.

In addition to the climate analysis, further insights into the vulnerability of the **WSS and WASH sectors** to climate change were gathered through bibliographic research and the Consultant's prior experience in similar contexts.

2.5.3 Step 3 – Integration of Field-Based Evidence

Site visits conducted in **February, March, and September** enabled direct engagement with County water management authorities and on-site observations of WASH infrastructure. These visits provided valuable context on climate-related challenges and the proposed investments to strengthen WASH services. They also facilitated the collection of data on **gender and social vulnerabilities**, which are critical dimensions of climate resilience.

The following chapters of the report are structured in a logical flow that explains, step by step, the approach used to assess climate risks.

2.6 Challenges

It is important to note that the Consultant faced challenges in obtaining accurate location data for the proposed CWSSIP investments. This hindered the early identification of K-WASH sub-projects. It was only during the **September mission** that corrected coordinates were provided, allowing for the identification of **hotspots**—key infrastructure investments selected for in-depth analysis as **case studies**.

3. SOCIAL AND GENDER CONTEXT

3.1 Generalities

Murang'a County is in the center of the Republic of Kenya. It borders Kiambu County to the south, Nyeri County to the north, Nyandarua County to the west and Embu, and Machakos and Kirinyaga counties to the east. Murang'a County occupies a total area of 2,559 km² (Murang'a County Government, 2018).

The main urban centers are Murang'a town and Kenol, but other ones are ditributed along the A2 and C71 roads.

Murang'a County population was estimated at 1,056,640 in 2019 according to the population census of that year. The most populated sub-counties are Gatanga, with 187,989 people, and Murang'a South, with about 184,824 people. Following SSP5-8.5 scenario the population is expected to increase up to a certain threshold approximately corresponding to the 2050 horizon and corresponding to about 2,250,000 people.

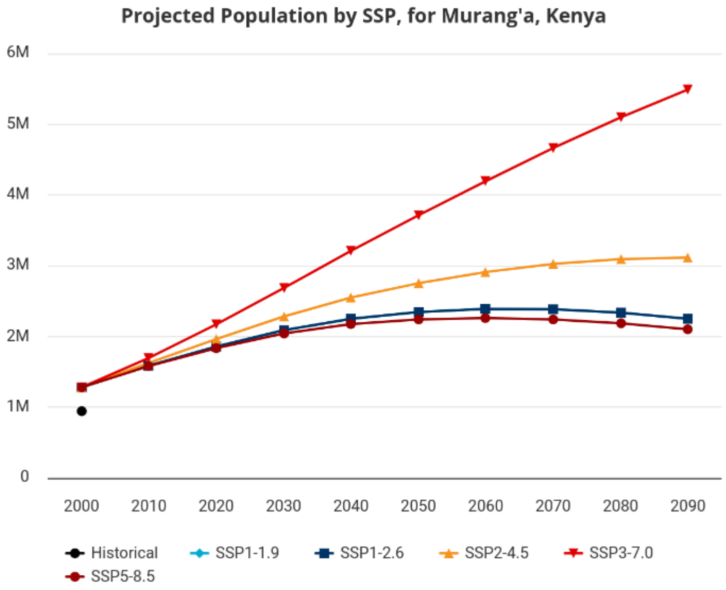

Figure 4: Projected population by SSP, for Murang'a County

Source : (The World Bank Group 2025)

3.2 Socio-economic profile

Murang'a County is heavily dependent on agriculture, which accounts for 60% of its economic activities. More than 70% of Murang'a residents are employed, directly and indirectly, by the sector (Murang'a CIDP 2023-2027). It is estimated that 57% of the county's population is directly employed in the sector (CCAP). The main production activities include tea, coffee, maize, potatoes and dairy farming, which form the most common sources of basic household food consumption and income. The CIDP of Murang'a highlights a will to engage in value in addition to boost incomes in agriculture and diversify its economy from the heavy reliance on primary production.

The dominant ethnic groups in the County are the Bantus and more specifically the Gikuyu, it is even considered that the county is the birthplace of this ethnic group in Kenya.

The county's 2019 Housing Census also gathered data on disabilities counting that the number of persons with disabilities was 102,527, which accounted for 9.7% of the total county population.

3.3 Socio-Economic Impacts of Climate Change

3.3.1 General impacts

Climate change has far-reaching socio-economic consequences in Murang'a County. Droughts and erratic rainfall patterns **reduce crop yields and kill livestock, undermining food security and household incomes**. Women, who control fewer resources and assets, are disproportionately affected during poor harvests and are often the primary borrowers in farming households.

Water scarcity impacts agriculture, domestic use, businesses, and industries. While some areas like Gaturi enjoy near-universal piped water coverage (99% served by MUWASCO and Gatamathi), others such as Ithanga and parts of Kigumo and Kinyona have limited or no access, relying on seasonal rivers. This uneven access deepens regional disparities and limits resilience to climate shocks.

Environmental degradation—driven by sand harvesting, poor waste management, and deforestation—contributes to soil erosion, water pollution, and disease outbreaks. **Human-wildlife conflicts**, involving animals like monkeys, hippos, and porcupines, **are exacerbated by drought and food scarcity, further threatening crops and livelihoods**.

Health outcomes are compromised by waterborne diseases such as cholera, especially during floods or when clean water is unavailable. These health challenges reduce productivity and strain household resources.

Social cohesion is also affected. Migration, family separation, early marriages, and teenage pregnancies are reported in response to economic stress and displacement. **These dynamics weaken community resilience and increase vulnerability.**

3.3.2 Exacerbation of inequalities

3.3.2.1 Background

Murang'a County faces social inequalities that affect specific groups, notably women, children, the elderly, persons with disabilities (PWDs), and marginalized communities. Climate change and WASH (Water, Sanitation, and Hygiene) challenges intersect with these inequalities, amplifying vulnerabilities across the county.

Women and youth are particularly affected by climate-related hazards such as prolonged droughts, which reduce access to water, degrade agricultural productivity, and increase food insecurity. These impacts are not evenly distributed and tend to exacerbate existing inequalities, especially in areas where water infrastructure is limited. In some areas, women are forced to wake as early as 2 a.m. or 5 a.m. to fetch water due to drying water pans and seasonal rivers, increasing their physical and emotional burden.

The county identifies youth, PWDs, the elderly, and marginalized communities as priority vulnerable groups. Household decision-making, traditionally dominated by men, has become more consultative under climate stress, though often driven by desperation rather than genuine empowerment. Men continue to control decisions around cash crops, land ownership, and major investments, while women manage food and domestic responsibilities.

Children are also affected, with drought-induced food insecurity leading to absenteeism and school dropouts, which impair academic performance and concentration. PWDs and the elderly face additional barriers in accessing water, healthcare, and livelihood opportunities.

Inequalities can also be observed in various areas, particularly in terms of representation in decision-making. Despite previous progress in gender representation—Murang'a once had the highest percentage of elected women in the National Assembly (42%)—this figure dropped to 14% following the 2022 general elections. This decline in political representation coincides with alarming rates of gender-based violence: according to the 2022 Kenya Demographic and Health Survey fact sheet, in 2022 54% of women aged 15–49 had experienced physical violence, and 14% had faced sexual violence in the last year, both significantly above national averages (respectively 34% and 7%). These figures underscore the heightened vulnerability of women in Murang'a.

3.3.2.2 Differentiated impacts of climate change

Insights from field discussions with stakeholders and communities—also documented in the Hotspot Analysis—highlighted several recurring patterns of disproportionate impact of climate change on women and vulnerable people:

- **Water collection burden** continues to fall mainly on **women and children**, with climate-driven water scarcity increasing travel times and exposure to risks, including potential human–wildlife conflict.

- **Sanitation accessibility challenges**, particularly for **PWDs, the elderly, and pregnant women**, become more pronounced under climate stress due to damaged infrastructure or longer distances to functional facilities.
- **Dignity and safety concerns** related to **shared sanitation facilities**, especially for **girls in schools** and women in communal settings, are intensified during periods of climate disruption when facilities deteriorate or become overcrowded.
- **Livelihood and health sensitivities** vary across groups, with marginalized households more prone to climate-related income losses and water-borne disease outbreaks.

Differential exposure, sensitivity, and adaptive capacity across social groups mean that climate hazards (drought, floods, heat, and related service disruptions) amplify inequalities already present within the WASH system.

Gender and Water Supply and Sanitation

Biological aspects

Men and women do not urinate in the same way.

Women spend almost 6 years of their lives in menstrual period.

Women have to use sanitary protection like pads, tampons, menstrual cups, etc.

Socio-cultural aspects

Local perception of intimate needs.

Preferential use of certain technologies (standing or not, using paper or water, etc.).

Social construct of dignity, notions of pureness and impureness.

Responsibility of providing water to the family.

Tools and good practices

Making sure both men and women are involved in the project/ decision-making process.

Planning discussions (FGD, GALS*).

Including gender experts in the project team and consider the gender perspective as soon as possible.

Many elements are to be considered when thinking about water supply and sanitation from a gender perspective. Indeed, if women bear the burden of water it is because the situation results from and impacts a complex combination of politics, justice and rights, education, health & security, culture, technologies and economic aspects.
These aspects fall on women negatively all their lives.

Childhood

Having to provide water for the house, a girl will carry heavy loads of water on a long distance, deforming her growth and leaving no time for school.

Adolescence

Inadequate sanitation is particularly crippling during menstruation, this often leads to girls' absenteeism in school and the less education a girl has, the more likely she is to marry young.

Adulthood and Pregnancy

Women income can be lower, for each year of school she missed she lost 10 to 20% of her future potential income.
A mother and her unborn child are subject to dehydration and malnourishment during pregnancy, both can also suffer from carrying heavy loads of water on long distances.

When women are empowered with safe water and toilets at home they are empowered to change their world. No longer burdened by the water crisis, they can care for their families. They can start small businesses, adding to their household income. They have the time and water to garden and cook food for their families. And, they no longer face unsafe situations when defecating in the open or walking to distant sources for water.
Access to safe water at home gives women hope, health and opportunity.

466 M

Women and girls spend 200M hours every day collecting water and 266M hours every day finding a place to go

> **" The needs are clear; the goals are clear. Women and children should not have to spend so much of their time for this basic human right "**
>
> Sanjay Wijesekera - Former UNICEF's global head of water, sanitation and hygiene

*GALS: Gender Action Learning System

Source : Groupe Hult, Voss fondation, MOOC from Eawag and EPFL, water.org
Photo credits: Van Hai

Figure 5: Gender and water supply and sanitation

4. CLIMATE IN THE COUNTY

4.1 Physical parameters

The results presented in this chapter synthesize the outcomes of the climate risk assessment for Murang'a County, drawing upon the downscaled CMIP6 projections (SSP5-8.5), the CCAP and PCRA documents, and the field observations conducted in 2025. The objective is to illustrate the main climatic parameters and hazards relevant to WASH resilience, based on trends and spatial patterns observed at the county scale. The analysis is intended for decision support at planning level rather than detailed engineering design.

Murang'a County experiences a transition between the temperate oceanic (Cfb) and tropical savanna (As/Aw) climatic zones according to the Köppen-Geiger classification. The county's climate is characterized by generally warm conditions and a bimodal rainfall regime typical of central Kenya. Average temperatures exceed 18 °C from October to May, peaking around 20 °C in March, while rainfall remains spatially and temporally variable.

The total annual rainfall ranges between 600mm and 1800mm with long rainfalls in the months of March, April and May. April reliably records the highest amount of rainfall averaging 213mm. The short rains are in October and November averaging about 135mm. The driest month is February with 21mm of rainfall. The Western region, covering Kangema, Gatanga, and higher parts of Kigumo and Kandara, is generally wet and humid due to its proximity to the Aberdare Ranges and Mt. Kenya. (Murang'a CIDP).

There are climate variations between the western and central regions and the eastern areas. Rainfall in western and central regions is reliable, well distributed throughout the year, and is adequate for cultivation. In the eastern areas, the annual temperature ranges from 26 to 30 degrees Celsius, while the mean minimum annual temperature ranges between 14 and 18 degrees Celsius. In the western wetter and colder areas, the mean minimum annual temperatures can be as low as 6 degrees Celsius or less. The temperatures in the central region fall between the minimum and maximum annual mean temperatures.

Current mean surface air temperature and precipitation patterns are outlined in the Figure below.

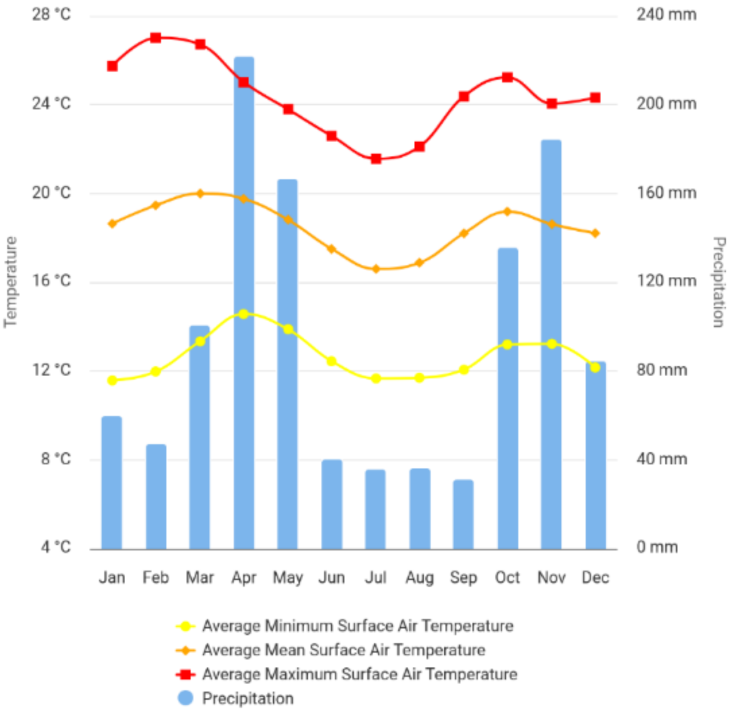

Figure 6: Monthly climatology, mean values of observation made in the 1991-2020 period; Murang'a

Source: (The World Bank Group 2025)

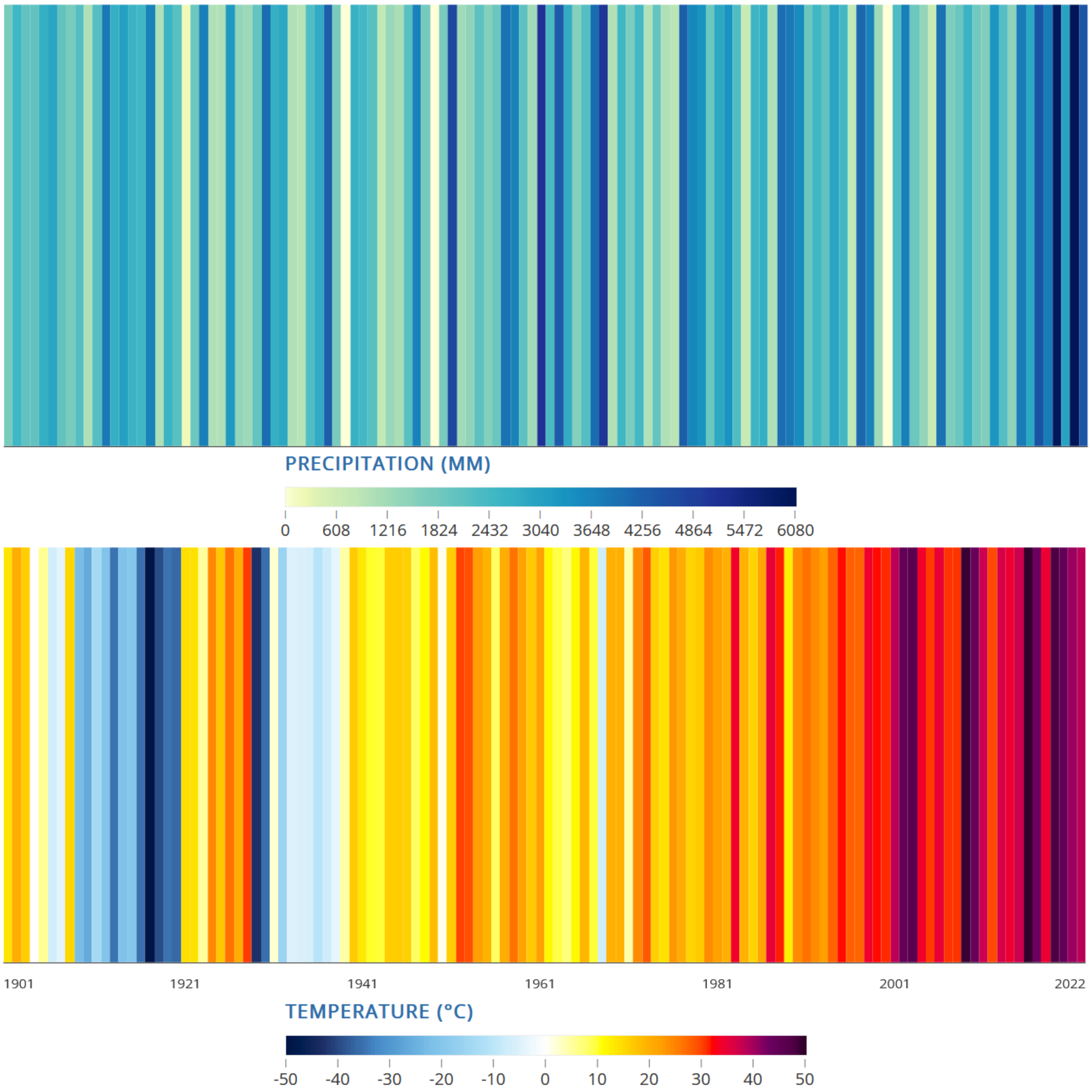

Figure 7: Observed annual average precipitation (top) and mean surface air temperature in Murang'a

Source: (The World Bank Group 2025)

"Experts and farmers alike acknowledge that there have been significant changes and variations in climatic conditions over the past years, affecting agricultural production and livelihoods in the County."[1] Both the observed annual average mean temperature and precipitation have increased over the past century (from 1901 to 2023). For the temperature an increase of +0.84°C has been noticed since 1901, while for precipitation changes are seasonal:

- December/January/February: +43.94mm
- March/April/May: -38.22mm
- June/July/August: -3.79mm
- September/October/November: +62.49mm

Considering that June/July/August was already a dry season this highlights how this tends to be reinforced and September/October/November being a wet period it also shows the increase of that characteristic; the rest of the seasonal analysis seems to show a change in the usual wet and dry intensity repartition from December to May.

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[1] Quote from the CCAP

The pattern of multiple rainy seasons can be explained through multiple factors as detailed in the following figure (Kenya does not have the JAS rainy season but explanations remain similar).

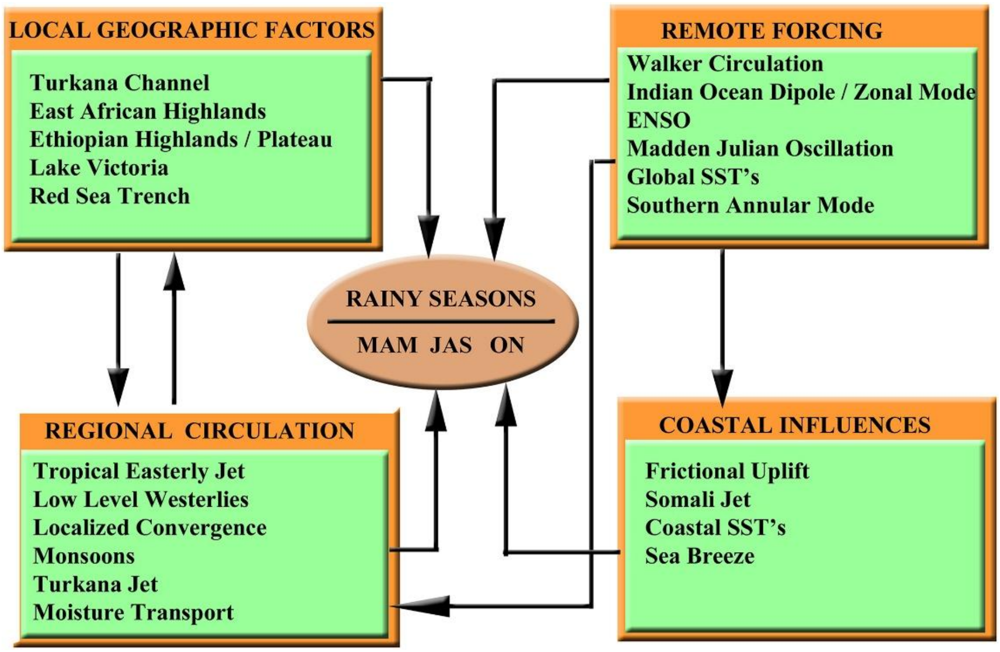


Figure 8: Schematic showing the factors influencing the three rainy seasons (MAM, JAS, and ON) of eastern Africa and the interrelationships among the factors.

Source : (Nicholson 2017)

While multiple rainy seasons are often explained through the seasonal migration of the Intertropical Convergence Zone (ITCZ). A close examination of the wind regime in the region suggests that this explanation is not tenable (Nicholson 2017). However, the changes that enhance precipitation during the two seasons appear to be increases in surface moist static energy and vertically integrated moisture flux, which is generally negative during the year but becomes weakly positive during the rainy seasons. These changes are associated with sea surface temperature (SST) changes in the western Indian Ocean, just off the coast (Yang et al. 2015). Other factors that appear to play a role in creating the seasonal cycle include the low-level Turkana Jet Stream, which appears to suppress rainfall during the boreal summer, and the intensity of the upper level subsidence (Nicholson 2017).

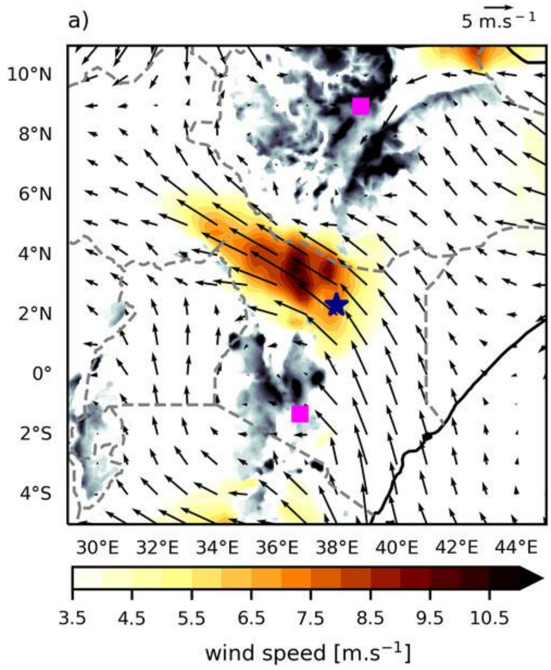


Figure 9: Winds associated with the Turkana Jet and surrounding area

Source : (Nicholson 2017)

4.1.1 Temperature projections

Under the SSP5-8.5 Average Mean Surface Air temperature is expected to increase by +1.23°C in December to up to +1.54°C in May during the 2041-2050 period, over the year the average increase would be of about +1.36°C in 2050 compared to the 5-year observed temperature of 2023.

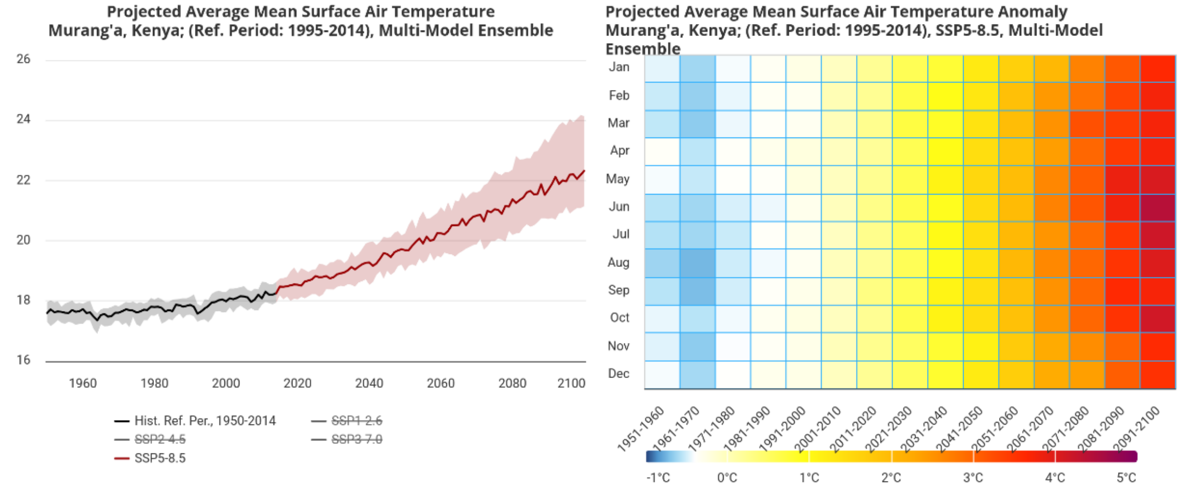


Figure 10: Projections of average mean temperature under SSP5-8.5 at Murang'a

Source: (The World Bank Group 2025)

In addition, the number of hot days, which correspond to days with a maximum temperature above 30°C is expected to greatly increase over the year leading to 9.88 days with such characteristic in 2050, which is 9 more days than during the reference period 1995-2014). However, it can be noted that the combination of temperature and precipitation is not expected to lead to major heat changes as number of days with important heat index (>35°C) will remain null as it is now.

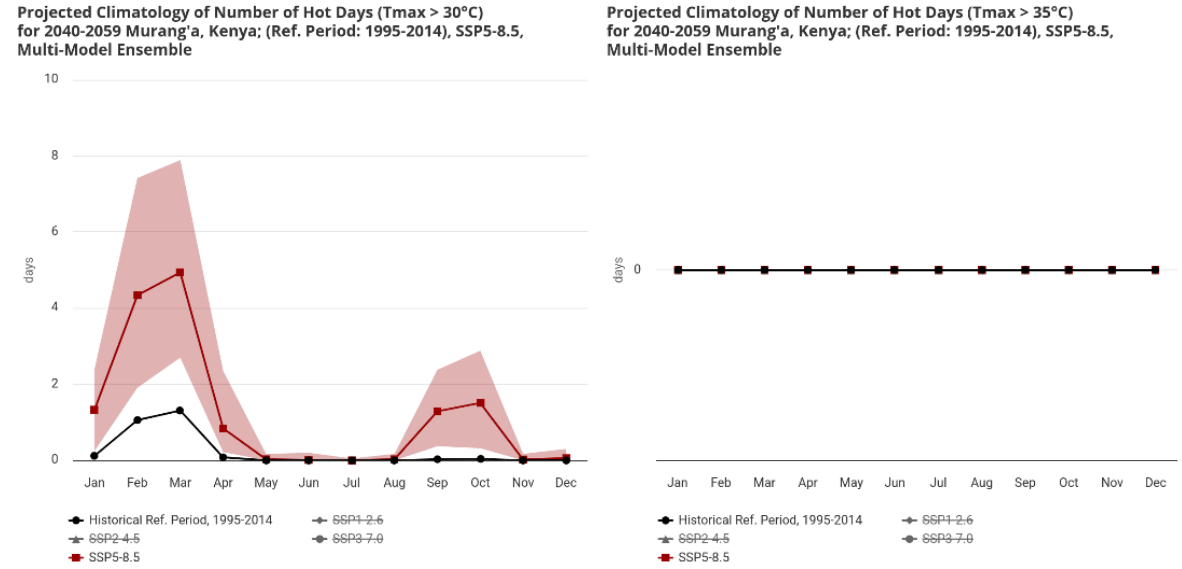


Figure 11: Projected climatology of number of hot days (Tmax>30°C) for 2040-2059) (LEFT) and days with heat index superior to 35°C (RIGHT) in Murang'a

Source: (The World Bank Group 2025)

4.1.2 Precipitation projections

Analysis is based on horizon 2050 (2040-2059 period) and 2100 (2080-2099) as mentioned in the methodological approach, considering that precipitation is the most relevant criteria when checking water resources evolution.

4.1.2.1 In Murang'a

4.1.2.1.1 Monthly changes

The most affected months regarding precipitation changes are November to April with an increase of +12.11mm by 2050 and +27.08mm by 2100 in January compared to the 1995-2014 reference. A lengthening of the rainy season from 2-3 months to 4-5 months has also been reported.

The largest 5-day cumulative rains are also expected to increase from November to February, with a slight increase by 2050 becoming more significant by 2100 increasing of up to +14mm (26%) in January by 2050 and +34mm (62%) in January by 2100 both in comparison with the 1995-2014 reference period.

It is also expected that the maximum number of consecutive dry days will decrease from November to March, especially in January and February which are currently quite dry months, with a reduction of respectively 2.12 and 1.01 days by 2050 and 3.88 and 3.26 days by 2100.

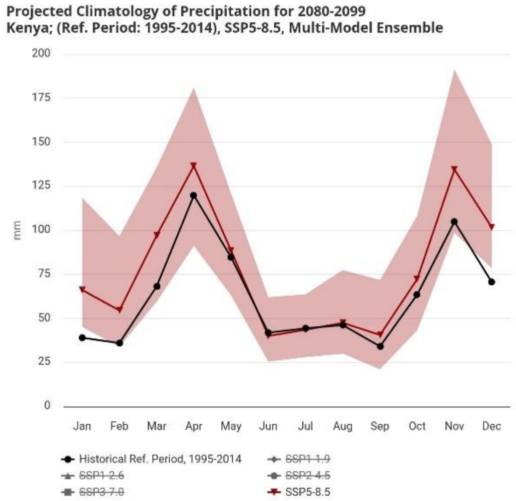


Figure 12: Projected climatology of precipitation for 2100 under SSP5-8.5

Source: (The World Bank Group 2025)

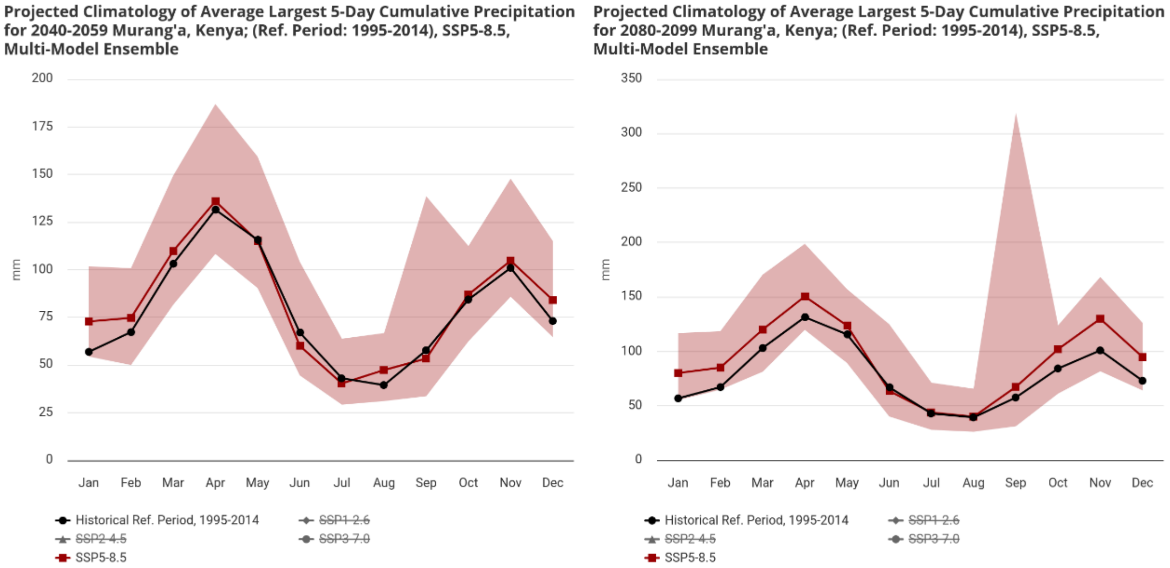
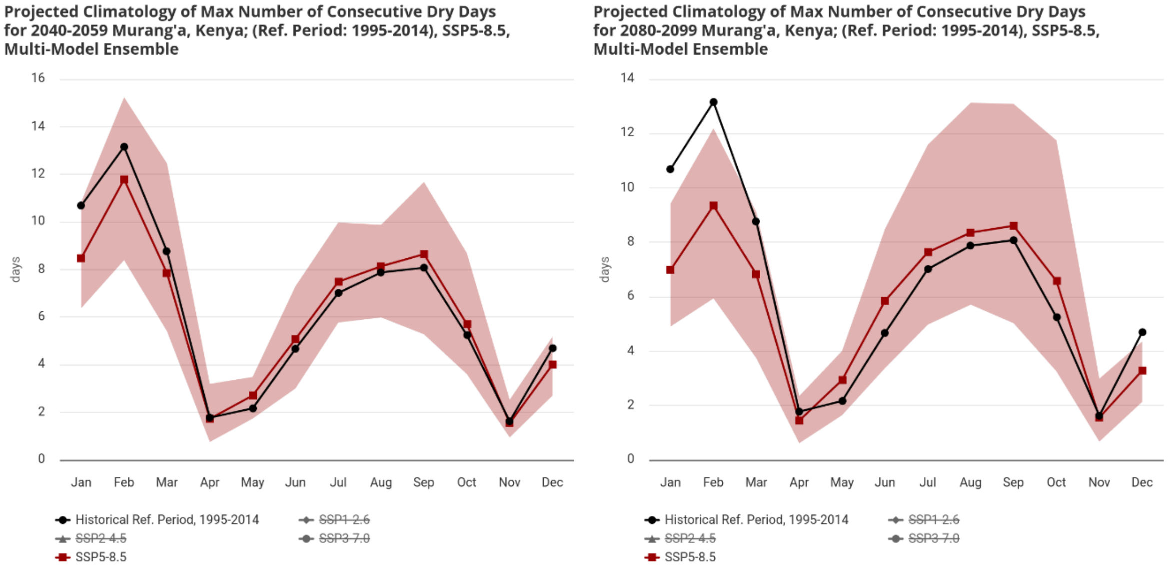


Figure 13: Projected evolution of the largest 5-day cumulative precipitation for 2050 and 2100 under SSP5-8.5

Source: (The World Bank Group 2025)



Projected Climatology of Max Number of Consecutive Dry Days for 2040-2059 Murang'a, Kenya; (Ref. Period: 1995-2014), SSP5-8.5, Multi-Model Ensemble

Projected Climatology of Max Number of Consecutive Dry Days for 2080-2099 Murang'a, Kenya; (Ref. Period: 1995-2014), SSP5-8.5, Multi-Model Ensemble

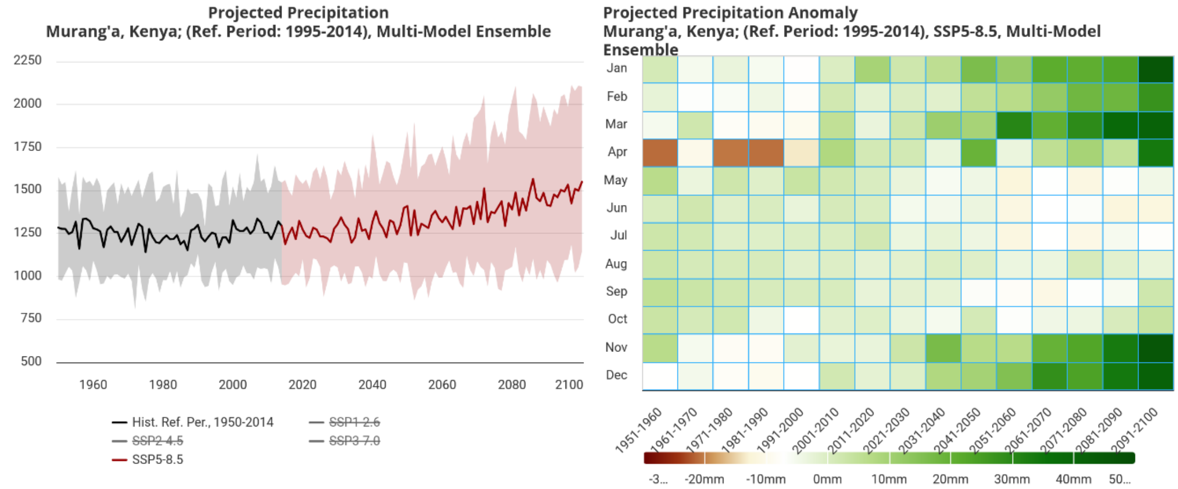
Figure 14: Projected evolution of the number of consecutive dry days for 2050 and 2100 under SSP5-8.5

Source: (The World Bank Group 2025)

Such an increase in precipitation, cumulative rainfall and reduction of dry days can be linked with water resource recharge.

While all the above correspond to global trends it can be underlined that farmers sometimes observe a delay in rainy seasons (in 2019 for instance), **this highlights the need to consider interannual changes in seasons predictability.**

4.1.2.1.2 Interannual changes



Projected Precipitation Murang'a, Kenya; (Ref. Period: 1995-2014), Multi-Model Ensemble

Projected Precipitation Anomaly Murang'a, Kenya; (Ref. Period: 1995-2014), SSP5-8.5, Multi-Model Ensemble

Figure 15 : Interannual precipitation changes projections

Source: (The World Bank Group 2025)

Overall, according to the multi-model ensemble presented in the above Figures it is projected that the average annual rainfall will globally increase over the years.

This also translates into an increase of the annual SPEI drought index from about -0.29 during the reference period (1995-2014) to +0.0 by 2050 and +0.8 by 2100. This corresponds to a shift from a “normal” classification to a “Moderate wet” one.

4.1.2.2 Considerations on the Tana River basin

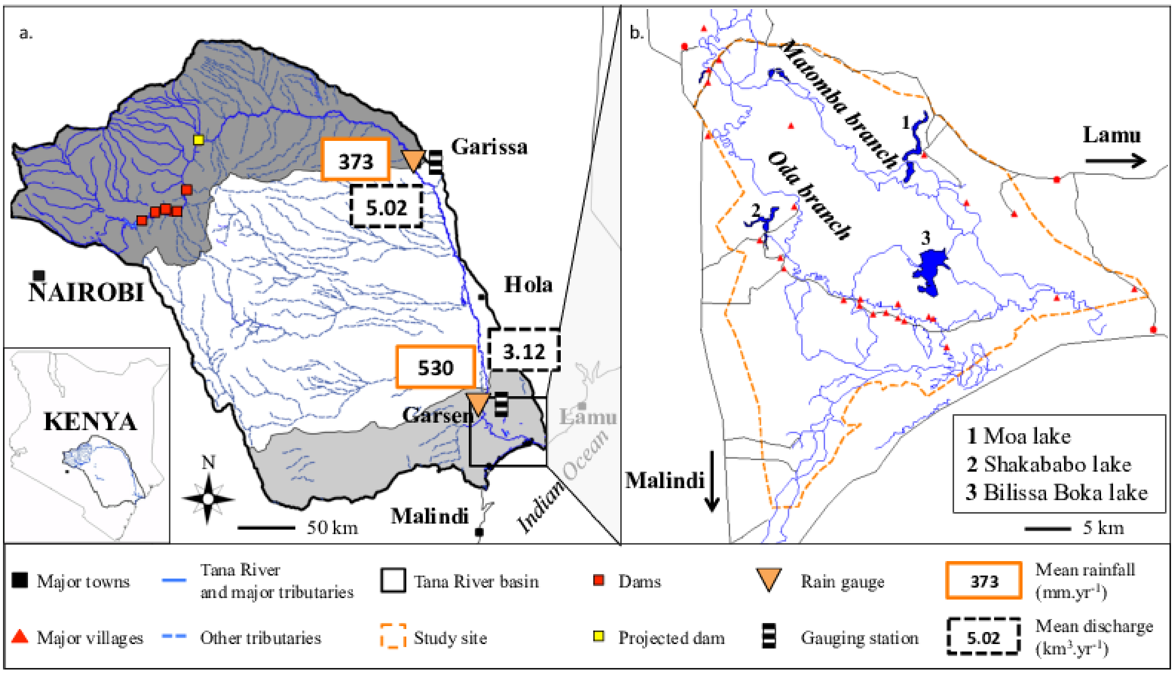


Figure 16: Tana River Water Basin main features and precipitation analysis

Source: (C. Leauthaud et al. 2013)

Murang'a county is located at the very Northwest of the Tana River basin. As much of eastern Kenya experiences tropical semi-arid climate conditions, the water balance and hydrology of the Tana River delta and basin is mainly controlled by precipitation falling in the upper Tana River catchment, especially over the central highlands around Mt Kenya and the Aberdares. Average annual precipitation in the Tana River basin decreases from 2200 mm in this upper section to 350-470 mm in the middle and lower sections, increasing again to about 1000 mm in the deltaic and coastal zones (C. Leauthaud et al. 2013).

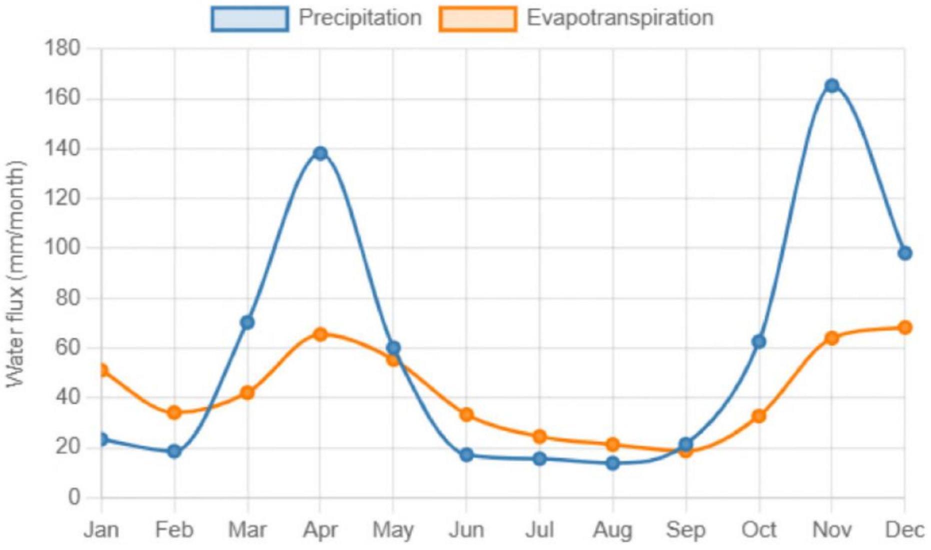


Figure 17: Watershed climatology: monthly average precipitation and evaporation over the watershed.

Source: (Global Watersheds 2025)

Considering the complete watershed, the total amount of water storage appears to be trending upwards at a rate of 2.3 cm per decade (statistically significant trend) (Global Watersheds 2025).

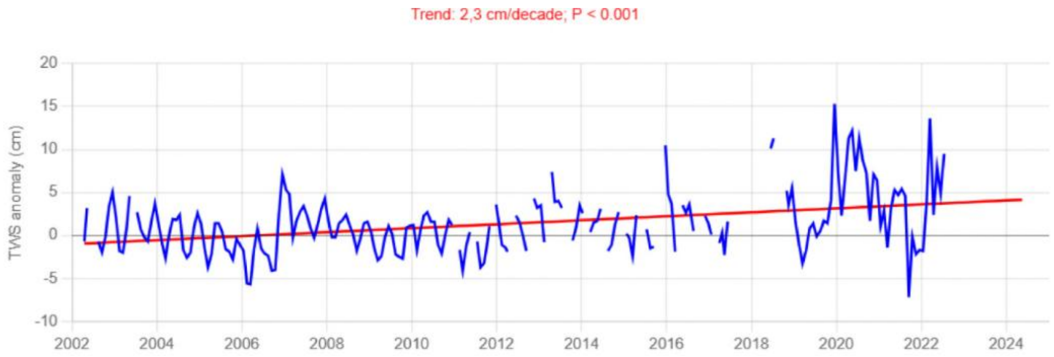


Figure 18: GRACE model, total water storage anomaly from 2002 to 2024

Source: (Global Watersheds 2025)

The Global Dam Watch database identifies 21 dams in the watershed, with a total storage capacity of 2,470 million m^3. Over the past sixty years, five major reservoirs have been built in the upper basin that have significantly modified the hydrological regime of the river, with a 20 % decrease in the peak flows of May. Other projects, particularly those of the Grand Falls Dam, could further impact the downstream flooding processes in the near future. In recent years, many biofuel and large irrigation schemes have also been initiated that will deprive the local communities of essential land and water resources. (C. Leauthaud et al. 2013) The county being located at the upstream it is not expected that it will be the most affected, nonetheless the global vision of watershed management should still be considered.

4.1.3 Topography and soil conditions

The soils from the County are diverse and listed below, along with their definition from the Food and Agriculture Organization (FAO):

- Nitisols, a type of soil found in wet tropical and subtropical regions, originating from more-basic rocks and characterized by shiny, nut-like structural elements and high clay content.
- Andosols are highly porous, dark-colored soils developed from parent material of volcanic origin, such as volcanic ash, tuff, and pumice.
- Cambisols are characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides.
- Fluvisols are very young soils with weak horizon differentiation; they have mostly AC-profiles and are predominantly brown (aerated soils) and/or grey (waterlogged soils) in colour. Their texture can vary from coarse sand in levee soils to heavy clays in basin areas.
- Vertisols are clayey soils that have deep, wide cracks for some time during the year. They shrink as they dry and swell as they become moist. The natural vegetation is predominantly grass, savanna, open forest, or desert shrub.
- Regosol is a deep, well drained, medium textured, non-differentiated mineral soil that has minimal expression of diagnostic horizons (other than an ochric horizon), properties or materials.

A topographical map of the study area is shown below, in addition to soil characteristics maps.

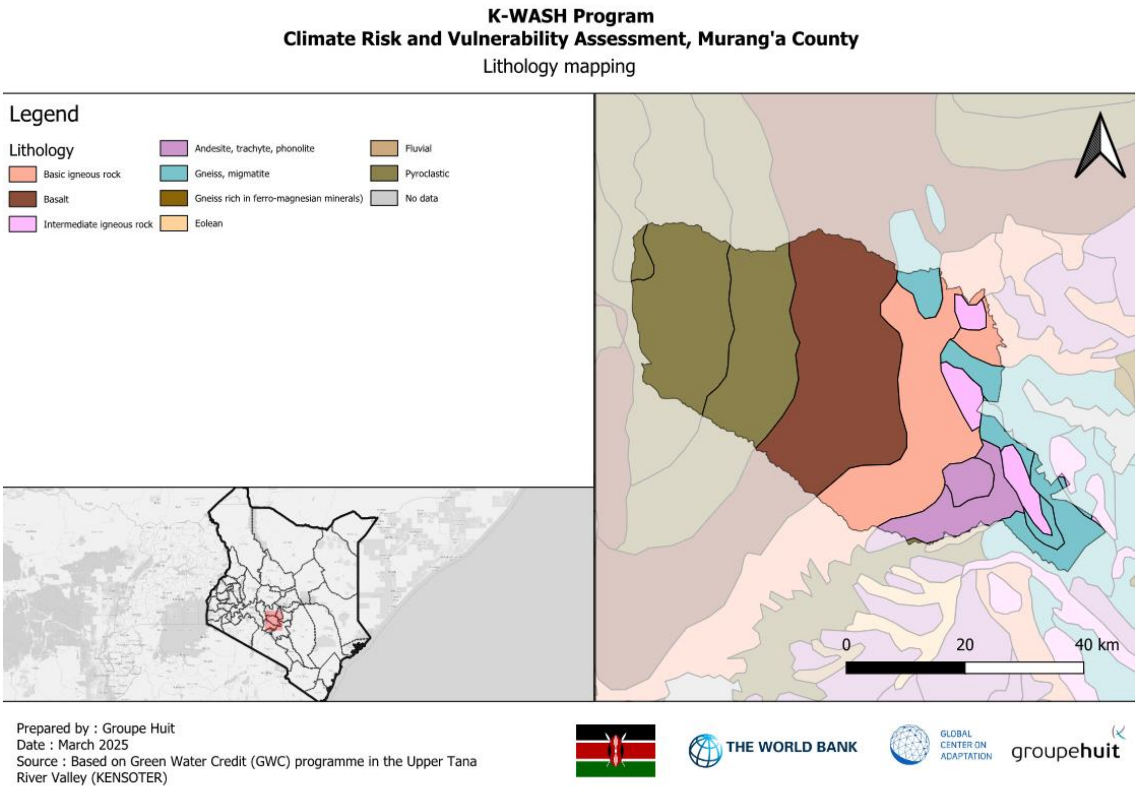


Figure 19: Murang’a County lithology mapping

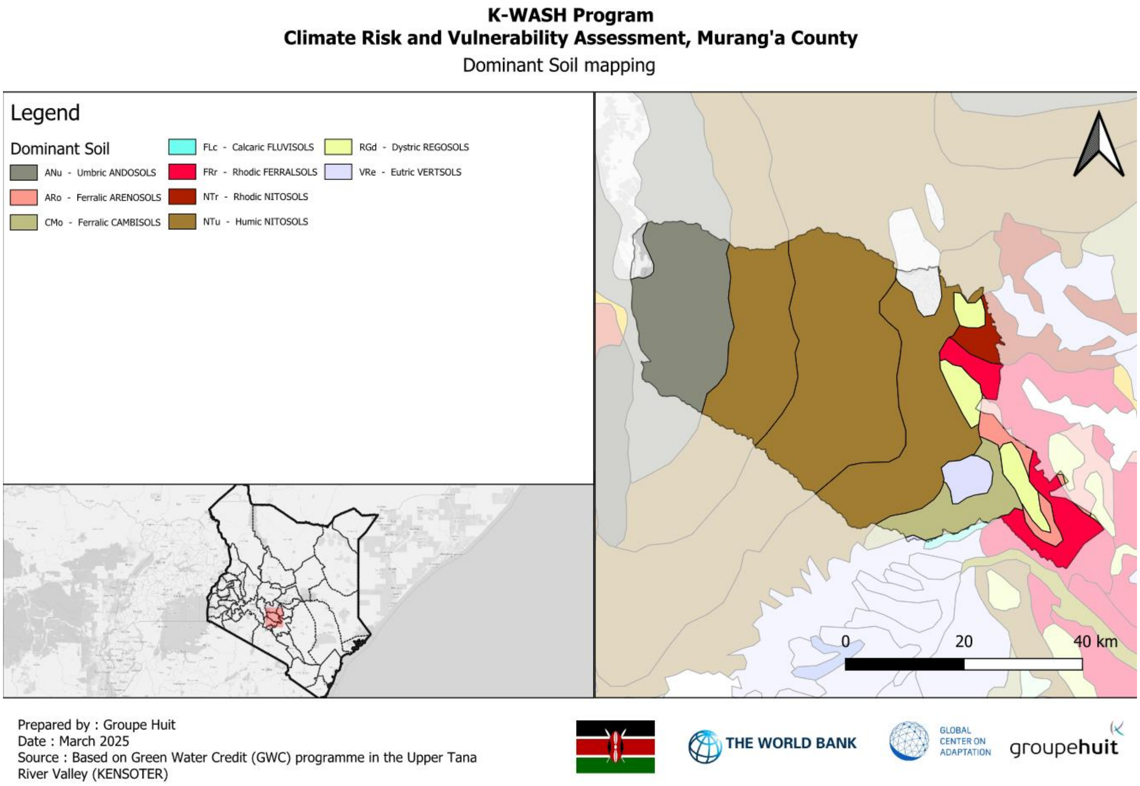


Figure 20: Murang’a County dominant soil mapping

4.1.4 Water resources

Murang'a hosts (partly) one of the five Kenyan main water source which is the Aberdares Range (103,315 ha) a mountains range that forms upper catchments of main perennial rivers flowing eastwards to the Indian ocean. The county is located within the Tana Catchment Area (TCA) which is 126,026km² wide, Murang'a thus only represents 18% of the TCA.

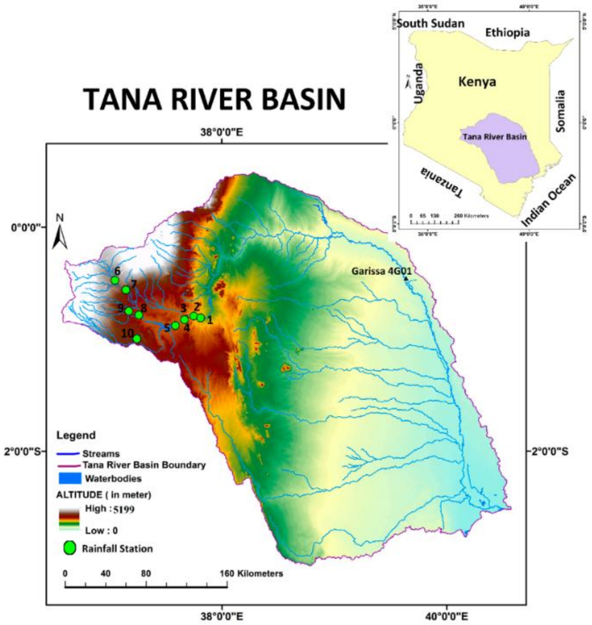


Figure 21: Map of the Tana Catchment Area (TCA)

Source: (Philip Kibet Langat, Lalit Kumar and Richard Koech 2017)

Murang'a main surface water resources are its rivers. The main rivers are Tana River at the very north (northern boundary of the county), rivers Mathioya, Maragua, Mathingeta, and Thaba across the county and Thika River at the very south (southern boundary of the county). There are a lot of tributaries to these rivers.

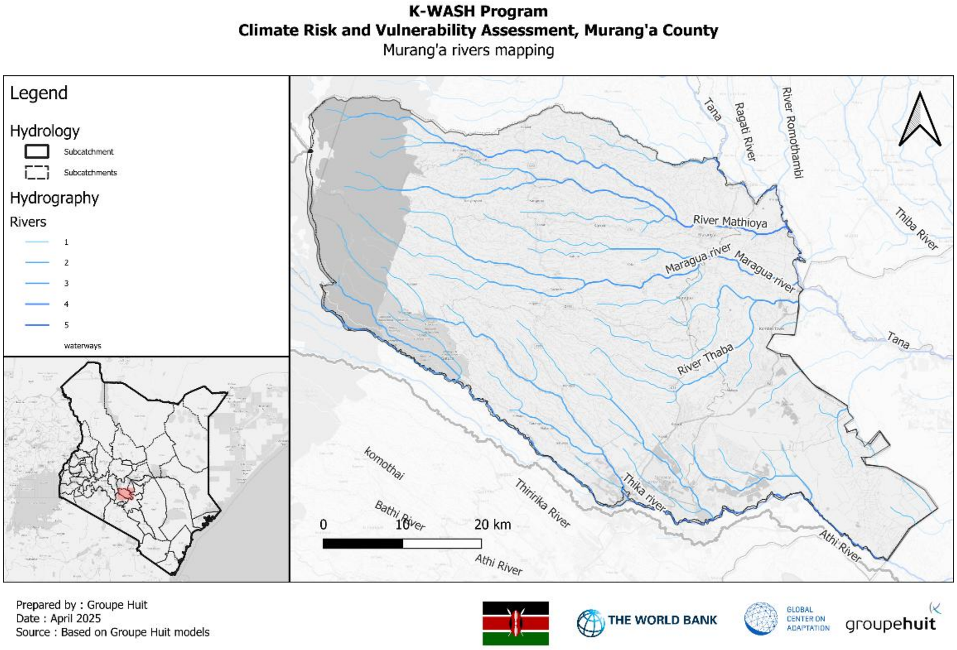


Figure 22: Murang'a Rivers map

Annual surface water runoff in the whole catchment was 5,858MCM/year in 2010 and is projected to be 7,383 MCM/year in 2050 according to the Kenyan National Water Master Plan 2030. This is consistent with the projected increase of precipitation. The same document provides indications on the groundwater recharge estimations: 7,719 MCM/year in 2010, 6,520 MCM/year in 2030 ; 5,840 MCM/year in 2050. **Groundwater recharge is decreasing throughout the years in the TCA. However, it is suspected that this would not apply to Murang'a county where temperature increase is not as important as in other counties and is not likely to lead to important increase of evapotranspiration or modifications of soil characteristics as could be the case in more arid counties of the TCA.**

Water availability corresponds to the addition of total annual surface water runoff and sustainable yield of groundwater (Estimated at around 10% of groundwater recharge amount (with an assumption that the river and riparian areas with 1 km wide are excluded)), this thus leads to an available water resource in the TCA of 6,533 MCM/year in 2010, 7,828 MCM/year in 2030 and 7,891 MCM/year in 2050. **Again, considering that this analysis refers to the whole TCA and not only Murang'a this could even suggest that Muranga's water availability could increase with a greater extent than what is expected at the catchment's scale over the years.**

Table 6: TCA catchment water resource data

TCA water resource (MCM/year)	2010	2030	2050
Annual Surface Water Runoff	5,858	7,261	7,383
Annual Groundwater Recharge	7,719	6,520	5,840
Estimated Sustainable Yield of Groundwater*	675	567	508
Available Water Resources	6,533	7,828	7,891

* Estimated at around 10% of groundwater recharge amount (with an assumption that the river and riparian areas with 1 km wide are excluded)

*The 2030 and 2050 data are based on calculations considering the projected future climates

Source: Kenyan National Water Master Plan 2030

4.2 Hazard assessment (identification and exposure)

4.2.1 Hazard screening

Based on literature review and mostly the PCRA and CCAP documentation of Murang'a the following hazards have been identified to be studies under the CRA which specifically targets the WASH sector, hazards developed below have a direct or indirect link with WASH and are of importance in the county:

- Floods:
- Pluvial floods
- River floods
- Rising water table floods
- Heat stress and droughts
- Landslides
- Soil and water salinity
- Sand and dust storms
- Pest and diseases

4.2.2 Design assumptions

As a reminder of the methodological approach the analysis is based on horizon 2050, and the scenario is SSP5-8.5.

4.2.3 Floods

According to the CCAP and PCRA, Murang'a county is prone to flooding, especially during the rainy season, with **overflowing rivers,** heavy rainfall, and inadequate drainage systems being the primary causes (presented by order of magnitude).

As mentioned before, increase in 5 days cumulative rains and precipitation in the county is expected and has already been observed. This parameter shows an increase in flood hazard as:

- High rainfalls lead to the swelling of rivers (Sagana, Mathioya, Saba, Githanja, Mbaro and Maragua) (this **increasing River Flood hazard**) and
- Increased runoff resulting from increased 5 days cumulative rains can lead to **pluvial floods**. The topography of the county implies a differentiated hazard exposure between the lower and middle ecological zones (more exposed) and the upper one (less exposed).

The county has experienced major flood events in 1998 (related to El-Niño effect) and 2018 (related to heavy rainfall).

4.2.3.1 Pluvial floods

Heavy rainfall floods correspond to when intense or prolonged rainfall lead to the accumulation of rainfall which cannot be absorbed by soil nor be drained through pipes or natural drains, especially in low-lying areas. Such floods thus depend on multiple criteria and are very localized, making it difficult to study at county scale.

For pluvial flood hazard mapping, a QGIS model was implemented, based on a semi-quantitative, multi-criteria approach which is detailed hereafter.

4.2.3.1.1 Methodology

Conceptual Basis

The Pluvial Flooding Hazard model estimates the likelihood and spatial distribution of flooding caused by intense rainfall events that exceed local infiltration and drainage capacity. It relies on a GIS-based, physically informed Multi-Criteria Analysis (MCA) framework. Each input criterion represents a controlling factor of runoff generation or accumulation, and all are combined through weighted aggregation to produce a continuous hazard index.

Input data and preprocessing

Input data to assess pluvial flood hazard exposure are as follows:

Table 7: Input data – Pluvial flood hazard exposure

Input	Role	Hydrological Justification
Basin polygons	Define extent of computation	Ensure hydrological closure and relevance at catchment scale.
Digital Elevation Model (DEM)	Used for slope and flow accumulation	Topography governs flow routing and accumulation.
Stream network	Used for hydrological conditioning (burn-in)	Ensures flow accumulation follows real drainage lines.
Soil/surface map	Provides infiltration and runoff potential	Soil texture, structure, and land cover influence infiltration capacity.

All raster layers are clipped to the watershed mask to ensure consistent extent and resolution before processing.

Computation of Individual Criteria

- **Hydrological Conditioning of the DEM**: The DEM is first hydrologically conditioned using sink filling and stream burning to ensure correct flow routing. This step corrects spurious depressions and enforces real drainage paths, preparing the DEM for hydrological computations.
- **Endorheic Water Depth**: Potential ponding depth is calculated by subtracting the filled DEM from the raw DEM. This raster expresses potential accumulation zones and is reclassified into hazard scores based on predefined depth intervals. Deeper depressions correspond to higher potential for pluvial flooding.
- **Soil Nature Criterion**: The soil map is used to compute two layers: surface and subsurface permeability. Both are reclassified according to their runoff potential, and their average forms the soil criterion. This step accounts for vertical variability in infiltration capacity, crucial in semi-arid or crusted terrains.
- **Topographic Wetness Index (TWI)** : The TWI is computed from the conditioned DEM using the relation $TWI = \ln(A\_s / \tan \beta)$, where A_s is the upslope contributing area and β is the local slope. It represents the potential of a pixel to accumulate moisture: higher values indicate higher saturation and flood potential.

Weighting and Aggregation

Each criterion is assigned a weight reflecting its relative hydrological importance. Default weights are 15% for endorheic water depth (w_endo), 25% for soil (w_soil), and 60% for TWI (w_TWI).

The weighted linear combination used to compute the hazard index is:

$$Hazard = w\_endo \times C\_endo + w\_soil \times C\_soil + w\_TWI \times C\_TWI$$

Each criterion is then normalized to a common 1–4 scale before aggregation, ensuring comparability between units.

Output

Outputs of the processing are as follows:

Table 8: Output data – Pluvial flood hazard exposure

Output	Type	Purpose
Raster hazard map	Continuous raster	Quantitative hazard representation.
Vector hazard map	Polygonised output	Compatible with planning and zoning tools.
Styled outputs	QML style files	Standardized hazard visualization.

Strengths and Limitations

Strengths of the approach are as follows:

- Reproducible, automated in QGIS.
- Physically interpretable criteria (TWI, soil, depressions).
- Adjustable weights and class tables allow local calibration.

Limitations are as follows:

- Static model; does not simulate dynamic rainfall-runoff.
- Sensitive to DEM resolution and accuracy.

- Needs validation with observed or historical flood data.
- Does not explicitly model drainage infrastructure.

This approach is built upon topography-based hydrological modelling (Beven & Kirkby, 1979; Quinn et al., 1995), GIS-based multi-criteria flood susceptibility analyses (Rahmati et al., 2016; Costache et al., 2020), and international flood risk mapping methodologies (e.g., AFD/WB/UNDRR). It represents a scientifically sound yet pragmatic tool for identifying rainfall-driven flood-prone areas.

4.2.3.1.2 Results

The following map emphasizes the pluvial flooding exposure which was assessed through implementing the previous methodology.

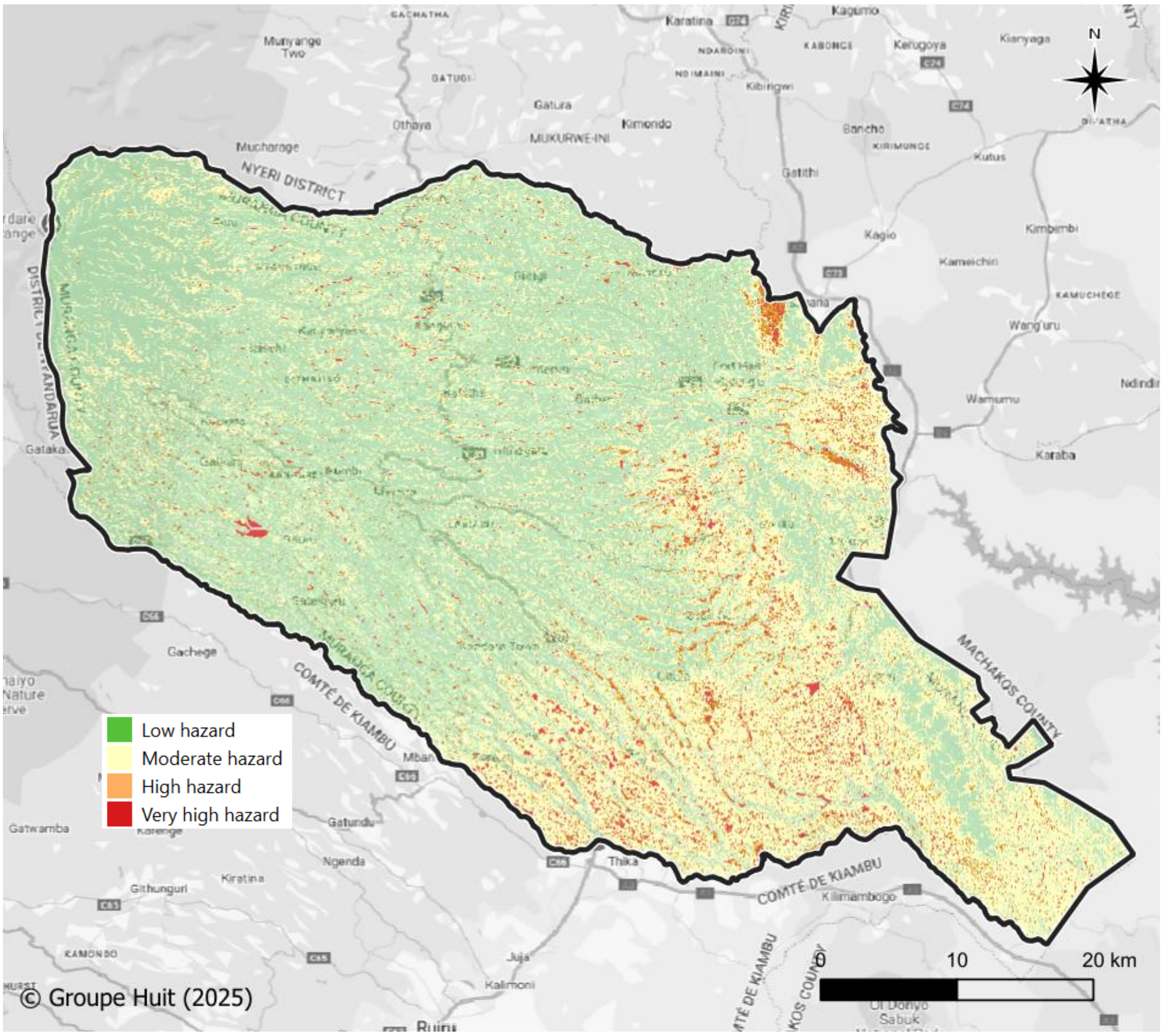


Figure 23: Pluvial flood hazard

A detailed atlas is provided in annex 3 of the present report, enabling to zoom in.

At the scale of subcounties, results are presented in the following map, pie charts also enable to show which proportions of the county are concerned by each level of hazard. This is mainly a map to enable a comparative assessment between subcounties. The global hazard level of the county is calculated as follows: exposure index = (4*surface of subcounty with very high exposure + 3* surface of subcounty with high exposure+ 2* surface of subcounty with moderate exposure + 1* surface of subcounty with low exposure) the exposure index is then normalized from 1 to 4 and these correspond to the overall exposure level of a subcounty.

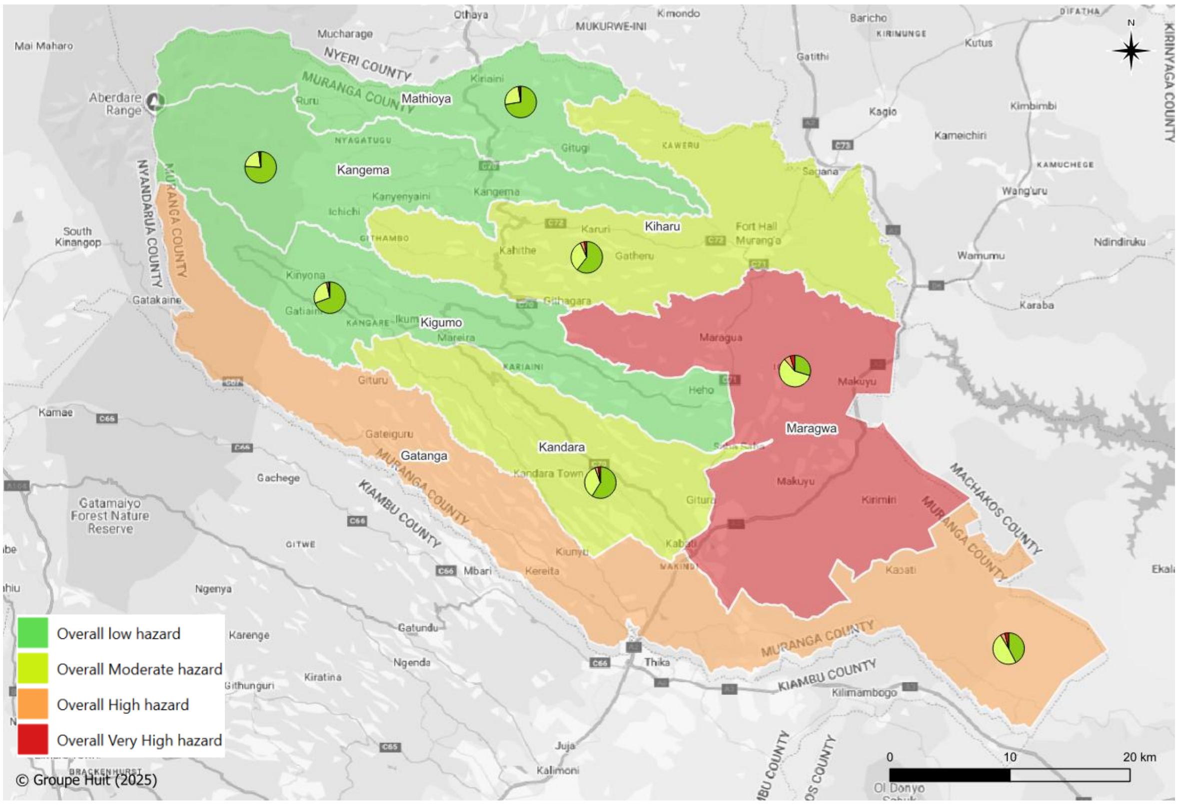


Figure 24: Pluvial flood hazard at subcounty's level

The following figure summarizes the overall exposure level at the scale of Murang'a County.

The spatial distribution of pluvial flood hazard across Murang'a County, as presented in the map, reveals a marked west–east gradient in exposure levels, largely reflecting the topographic and hydrometeorological characteristics of the region.

Areas of high flood hazard are concentrated in the eastern and south-eastern subcounties, notably Maragua (red tone on the map) and the lower parts of Kandara and Gatanga (orange tone on the map). These zones, shown in red and orange, correspond to the lower altitudes and gently undulating terrain draining toward the Tana River basin. The combination of impermeable soils intensified urban and peri-urban development, and concentrated runoff from the upper slopes contributes to a higher susceptibility to surface water accumulation during intense rainfall events.

Conversely, the western and north-western highlands—including Kangema, Mathioya, Kiharu, and Kigumo—exhibit low to moderate hazard level (green to yellow tones). These areas benefit from steeper slopes, denser vegetation cover, and better natural drainage capacity, which tend to limit localized ponding, even under heavy precipitation.

At the subcounty level:

- **Maragua** Subcounty emerges as the **most critical hotspot of pluvial flood hazard**, with both extensive low-lying areas and significant built-up expansion. The spatial coincidence between flood-prone zones and population centers calls for improved urban drainage planning and stormwater management.
- **Kandara** and **Gatanga** also present medium exposure levels, linked to their transitional location between highland runoff generation zones and downstream floodplain accumulation areas.
- **Kangema**, **Mathioya**, and **Kigumo** remain relatively less exposed but should not be considered risk-free, as slope failures and flash floods may still occur during extreme convective storms, especially where land degradation has reduced infiltration capacity.

The observed pattern aligns with findings from regional studies (e.g., World Bank, 2020; SEI, 2021; NEMA, 2018) highlighting Murang'a's vulnerability to short-duration, high-intensity rainfall events linked to changing rainfall extremes under climate variability. The county's steep orographic gradient induces rapid runoff concentration, while land-use transitions—particularly deforestation and conversion of riparian zones to agriculture or settlement—further exacerbate pluvial flood impacts (see Kithiia & Wambua, 2020).

This spatial diagnosis underscores the necessity to:

- Integrate pluvial flood management into urban development and drainage planning, particularly in Maragua and lower Kandara.
- Promote green infrastructure (e.g., infiltration zones, vegetated buffers) to increase retention and reduce surface runoff.
- Strengthen early warning and community awareness systems in identified hotspots.

Overall, the map demonstrates that pluvial flooding in Murang'a County is not confined to riverine corridors but rather constitutes a distributed hazard linked to rapid hydrological responses and anthropogenic changes in land cover. Hence pluvial flooding is to be duly considered even outside of riverine corridors, especially in the eastern part of the county. Targeted adaptation measures, based on local exposure diagnostics, will therefore be essential for building long-term resilience.

4.2.3.2 River floods

A **river flood** happens when a river or stream exceeds its banks due to heavy rainfall or snowmelt upstream, sending large volumes of water into surrounding floodplains. This type of flooding typically affects areas near the river and can cause widespread damage over a longer period as the water levels rise and recede.

Murang'a is quite exposed to such floods, mostly in North-East of the region. However, few data are publicly available to map flood hazard at the scale of the study area.

In the absence of locally calibrated hydraulic or hydrodynamic flood modelling, the 100-year return period flood maps provided by FM Global represent the most suited globally available and methodologically consistent dataset offering a spatial resolution appropriate for county-level analysis in Murang'a. This return period is internationally accepted as a standard benchmark for flood hazard assessment and infrastructure design (e.g. ISO 31010; World Bank, 2020; UNDRR, 2021), allowing meaningful comparison with studies conducted elsewhere.

The **FM Global Flood Map** (available through the NatHaz Toolkit) is a **globally consistent flood hazard dataset** developed for preliminary hazard assessment in areas where detailed hydraulic studies are unavailable. The maps combine **topographic, hydrologic, and satellite data** with **global rainfall statistics and river flow modelling** to estimate areas likely to be inundated under standardized flood scenarios. Using a globally calibrated hydrologic model and digital elevation data (typically derived from SRTM or comparable sources), FM Global delineates the **100-year and 500-year flood extents**, representing high and moderate hazard zones respectively. Although not a substitute for local hydraulic modelling, these maps are recognized as a **reliable global reference for flood screening and comparative hazard assessment**, and have been used in numerous risk analyses and resilience diagnostics led by international organizations (e.g. the World Bank, UNDRR, and OECD).

While such global models cannot capture fine-scale channel processes or local drainage constraints, they provide a **robust first-order estimate of flood-prone areas** by integrating rainfall-runoff relationships, terrain morphology, and hydrological accumulation patterns. Hence, the **100-year FM Global flood hazard layer** serves as a **credible reference baseline** for evaluating exposure in the absence of more detailed hydrodynamic simulations, and for guiding preliminary spatial planning, vulnerability analysis, and prioritization of further detailed studies.

The map illustrates the proportion of each subcounty's area exposed to river (fluvial) flooding, derived from the 100-year return period FM Global flood hazard dataset. The hazard thresholds have been defined considering the proportion of the areas that would be affected by a 10- years-return-period flood hazard, as follows:

- Low hazard: less than 20%
- Moderate hazard: 20% to 30%
- High hazard: 30% to 40%
- Very high hazard: more than 40%

The results show a clear spatial differentiation, closely associated with topography, drainage network configuration, and hydrological connectivity to the Tana River and its tributaries.

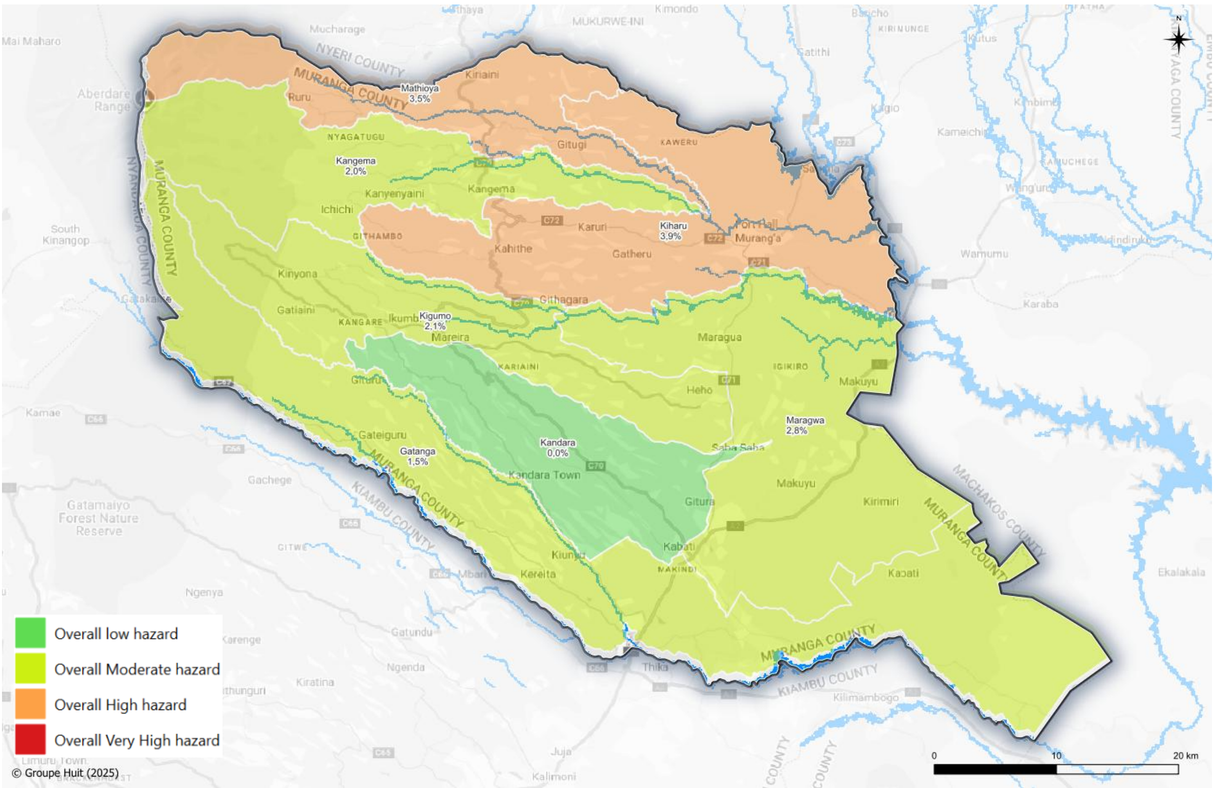


Figure 25: Murang'a County 100-years return period flood mapping

A detailed atlas is provided in annex 4 of the present report.

River flood exposure is **moderate overall** across Murang'a County, with values ranging from **less than 1% to about 4%** of the subcounty area. This range reflects the dominance of **steep, well-drained uplands** in the western part of the county, and **broader alluvial valleys** and **floodplains** toward the east. As expected, exposure is largely concentrated along **major river corridors** such as the Maragua, Mathioya, and Sagana rivers, which drain from the Aberdare slopes toward the Tana basin.

At the subcounty's level:

- Kiharu (≈3.9%) and Mathioya (≈3.5%) present the highest exposure levels. These subcounties encompass the middle and upper reaches of key river valleys, where narrow floodplains are juxtaposed with steep slopes. Localized flood hazards are likely driven by rapid hydrological response and overbank flows during intense rainfall, compounded by sediment deposition in valley bottoms.
- Maragua (≈2.8%), Kigumo (≈2.1%), and Kangema (≈2.0%) show intermediate exposure levels, mainly confined to riparian corridors and low-lying agricultural zones. These areas face recurrent inundation risks affecting transport and farmland near the riverbeds.

- Kandara (≈0.5%) and Gatanga (≈1.5%) display comparatively low exposure, reflecting their predominance of upland terrain and better natural drainage. However, the presence of river confluences and downstream settlements implies localized vulnerability despite the smaller exposed surface.

Although the overall proportion of land affected by river flooding appears limited, these flood-prone areas are typically densely occupied and economically productive (e.g., agriculture, settlements, and transport corridors). Consequently, even low percentages translate into significant socio-economic exposure when combined with population and asset distribution.

The mapping indicates that flood-prone areas are mainly concentrated along the Mathioya, Maragua, and Sagana Rivers, as well as in low-lying valleys and areas with poor drainage. These findings are consistent with the CCAP and PCRA, which both highlight recurrent flooding along the same corridors, occasionally disrupting access roads and water intakes.

Field observations conducted during the February–March and September missions confirmed these patterns. In Mathioya Sub-County, several water intakes showed signs of scouring and sedimentation; in the lower Maragua and Sagana valleys, residents reported seasonal inundations affecting shallow wells and gravity-fed pipelines. Such evidence validates the general correspondence between the modelled hazard zones and on-site conditions.

The results are thus best interpreted as a screening-level flood susceptibility map rather than a hydrodynamic floodplain model. It provides an overview of where water infrastructure and communities are most likely to experience recurrent flood pressure under current and future conditions, serving as a basis for prioritizing adaptation and design measures within the investment plan.

Moreover, this spatial pattern aligns with regional hydrological studies (e.g., NEMA, 2018; World Bank, 2020; SEI, 2021) highlighting that Murang'a's flood risk arises primarily from short, steep catchments with rapid concentration times. Riverine flooding is particularly sensitive to land-use changes, deforestation, and sedimentation, which modify channel conveyance and increase overbank flow frequency.

From a planning and adaptation standpoint, this analysis confirms that river flood hazard management should prioritize riparian protection, enforcement of buffer zones, and extension, renewal and maintenance of drainage and river corridor capacity, particularly in the Mathioya–Kiharu–Maragua axis.

4.2.3.3 Rising water table flooding

A third, less visible process, rising water table flooding, may also contribute to local flood impacts. This slow-onset phenomenon occurs when groundwater levels rise to the surface, saturating the unsaturated zone, typically following prolonged wet years or exceptional recharge events. While not the dominant flooding mechanism in Murang'a, its occurrence cannot be excluded, especially in valley-bottom zones or areas with shallow aquifers lacking impermeable confining layers.

Available information, based on British Geological Survey groundwater depth mapping (5 km resolution) [2], only allows a coarse delineation of potentially affected areas. These data are insufficient for precise exposure quantification but provide a first indication of zones where groundwater–surface water interactions may exacerbate pluvial or fluvial flooding. Further local hydrogeological investigations would be required to refine this understanding.

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[2] MacDonald, A M, Bonsor, H C, Ó Dochartaigh, B E, Taylor, R G. 2012. Quantitative maps of groundwater resources in Africa. Environmental Research Letters 7, 024009. https://www2.bgs.ac.uk/groundwater/international/africangroundwater/mapsDownload.html

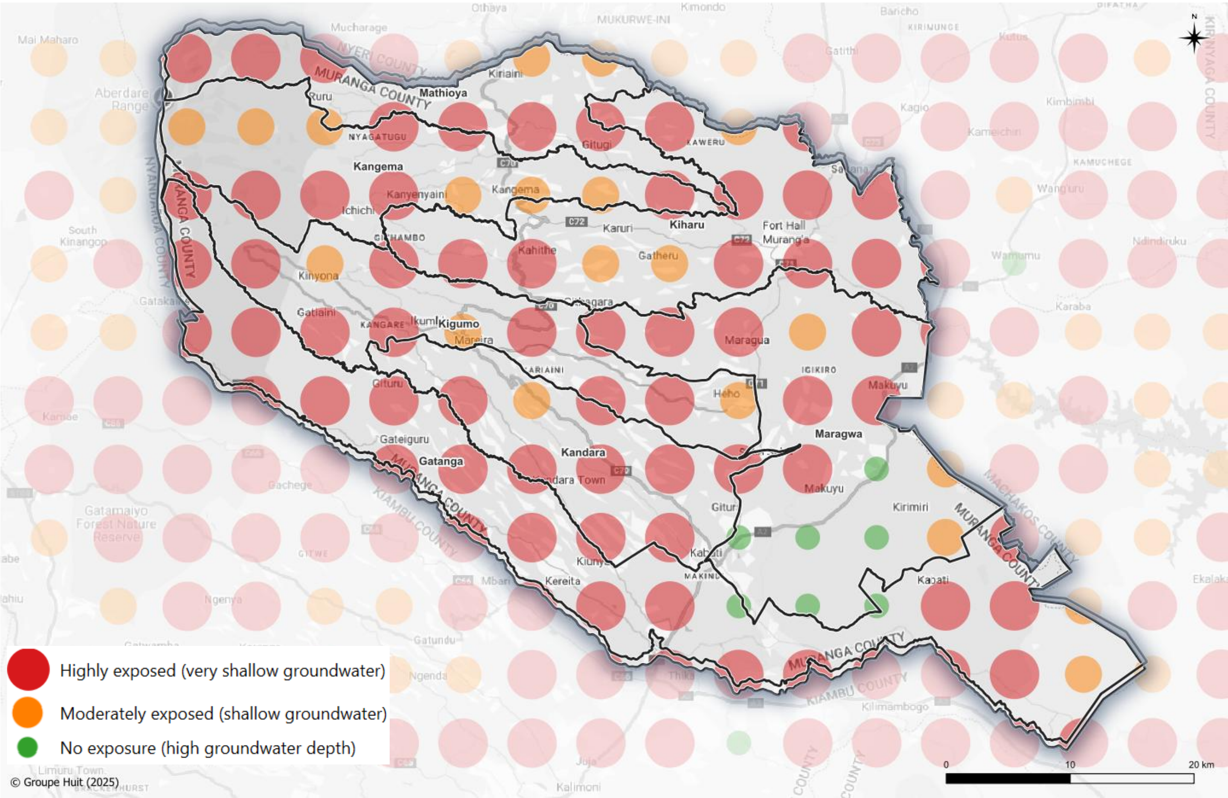


Figure 26: Average groundwater depth in Murang'a County and related exposure

The spatial distribution shows higher potential exposure in the central and south-eastern subcounties—notably Maragua, Kandara, and Gatanga—where shallow groundwater tables and flat topography coincide. These areas are characterized by low hydraulic gradients and finer soils, which limit drainage and favour vertical water table rise during intense or persistent rainfall.

Conversely, the north-western highlands (Kangema, Mathioya, and upper Kiharu) exhibit lower exposure levels, reflecting deeper aquifers and steeper slopes that promote rapid drainage and limited groundwater accumulation. The Kigumo–Maragua corridor shows intermediate conditions where local hydrogeological settings may allow temporary groundwater resurgence in valley bottoms.

While rising groundwater flooding is not the predominant hazard in Murang'a County, it remains a secondary but compounding process that can intensify the effects of pluvial and riverine flooding, particularly in flat, clayey, or poorly drained zones. It can lead to prolonged soil saturation, damage to foundations and roads, and reduced agricultural productivity.

Given the coarse resolution of current groundwater datasets, finer-scale hydrogeological modelling and monitoring would be required to better quantify this hazard. Integrating groundwater-level monitoring with flood early warning systems would also help identify periods of multi-source flood risk.

4.2.4 Heat stress and droughts

4.2.4.1 Droughts

Meteorological projections do not classify Murang'a as one of Kenya's most drought-prone counties; however, existing drought episodes and strong dependence on rainfed agriculture mean that socio-economic drought risk remains significant, especially under rainfall variability and delayed rainy seasons.

Historical drought events show occurrences in 1944 (Mianga), 1984 (Gathirikari), 1992, and 2022-2023 (prolonged drought period), without providing information on the severity of such events.

Projections show an increase in the county's SPEI drought index, which is to be read as a reduction of duration and magnitude of drought conditions.

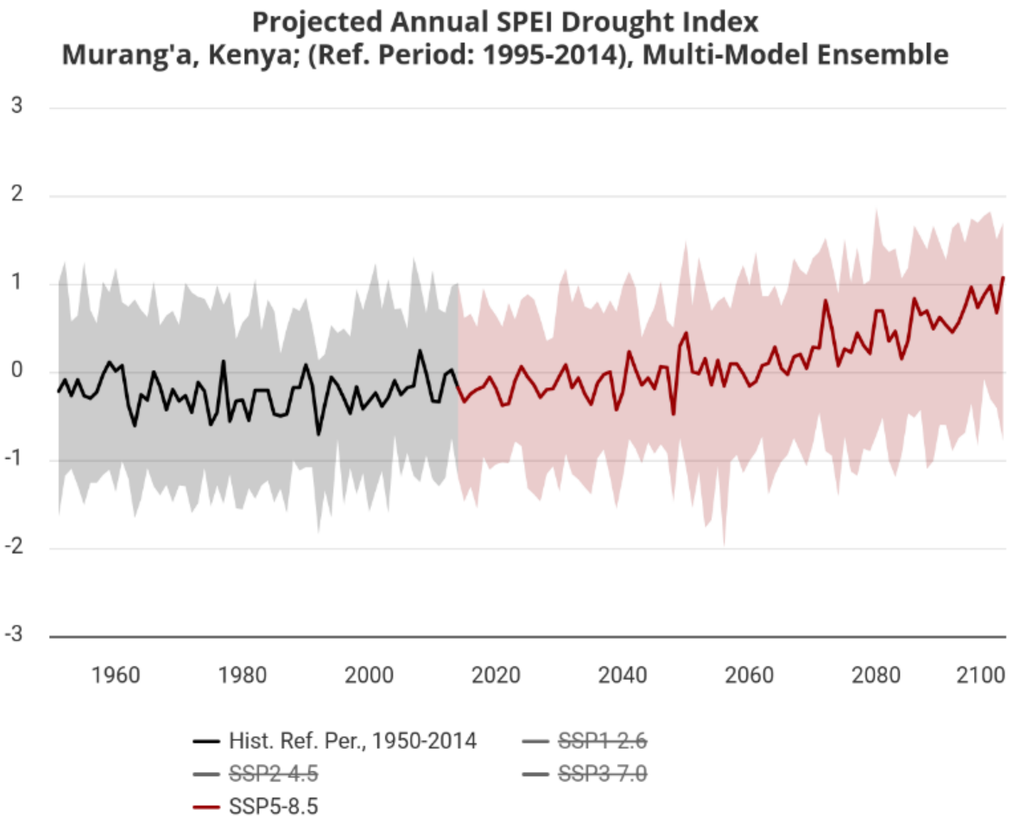


Figure 27: Projected SPEI drought index

Source: (The World Bank Group 2025)

Nonetheless variability on rainfall patterns, especially during the first rainy season (March-May) could increase drought exposure. Indeed, limited precipitations would not allow for groundwater and surface water (rivers, waterpans, ponds) to be recharged enough, especially farmers have reported a prolongation of the dry season and that during the peak dry season, between December and February, water scarcity affects their farms and leads to the premature death of some animals. In extreme cases, water scarcity leads to famine. These communities end up depending on relief food during these months.

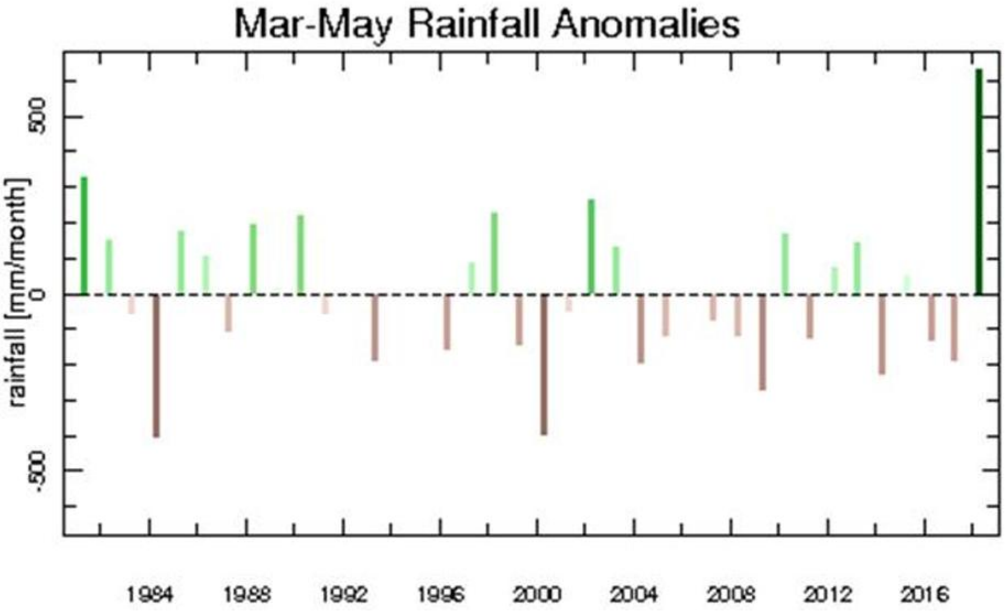


Figure 28: March to May rainfall anomalies

4.2.4.2 Heat Stress

Capturing 'heat risk' in a comprehensive way requires looking across a range of temperature and humidity related conditions that may occur over a 24-hour period, a season, or year. Heat, being a combination of temperature and humidity both parameters have to be looked at.

The current Land Surface Temperature data (extracted from 2023 LANDSAT/LC08/C02/T1_L2) indicates that surface temperature differs geographically within the county, warmer temperatures are experienced in the eastern area compared to the western one. Translating this into thresholds which define exposure also enables to highlight which areas are more exposed to heat waves (only considering temperature for this analysis). The thresholds used are the following:

- Low heat risk – 13-29°C:
    - Normal operating range for most Kenyan regions (especially highlands).
    - Minimal heat stress on staff and infrastructure.
    - No significant constraints on WASH operations.
- Moderate heat risk – 30-37°C:
    - Increasing physiological stress for exposed workers.
    - Noticeable impacts on WASH systems (evaporation losses, chlorine decay rates increase).
    - Early adaptation measures recommended (shade, schedule adjustments).
- High Heat Risk – 38–44 °C:
    - High risk for heat-related illness with prolonged exposure.
    - Water demand spikes; stress on borehole pumps and solar pumping systems.
    - Increased risk of water quality degradation (microbial growth, algal blooms).
    - Infrastructure materials begin to experience thermal expansion.
- Very high heat risk – >=45°C
    - Dangerous for workers even with short exposure.
    - Severe strain on infrastructure (PVC deformation risk, pump overheating, rapid evaporation).
    - Water sources degrade quickly (salinity concentration, surface water temperature rise).

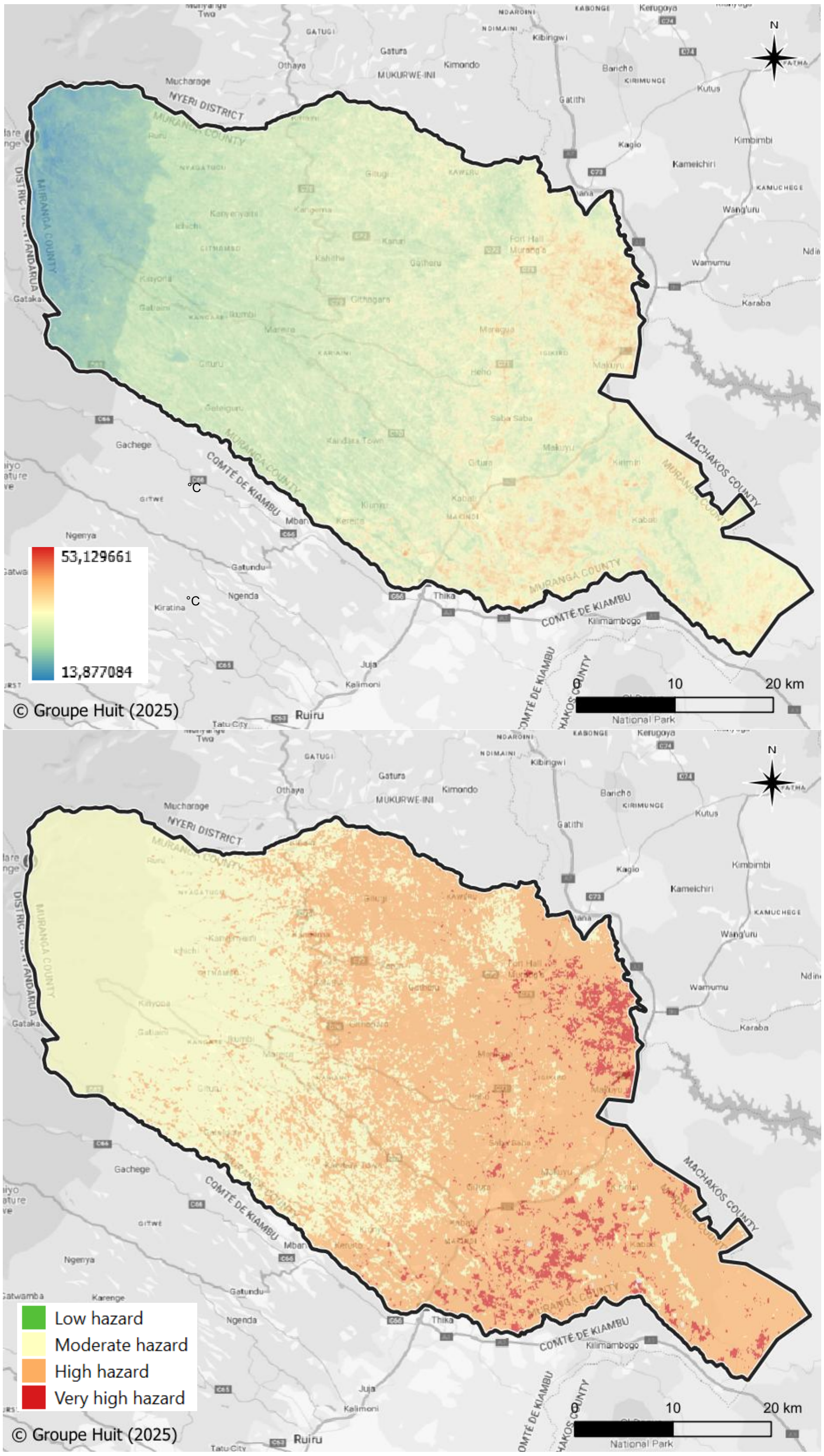


Figure 29: Land surface temperature in °C (top) and derived current heat hazard exposure levels (bottom)

Source: 2023 LANDSAT/LC08/C02/T1_L2

Heat risk increases when temperature increase, and humidity increases during the same period of the year and these parameters projections under SSP5-8.5 both show increasing anomalies between January and April and in September October. Thus, suggesting heat risk will increase under these periods in the future.

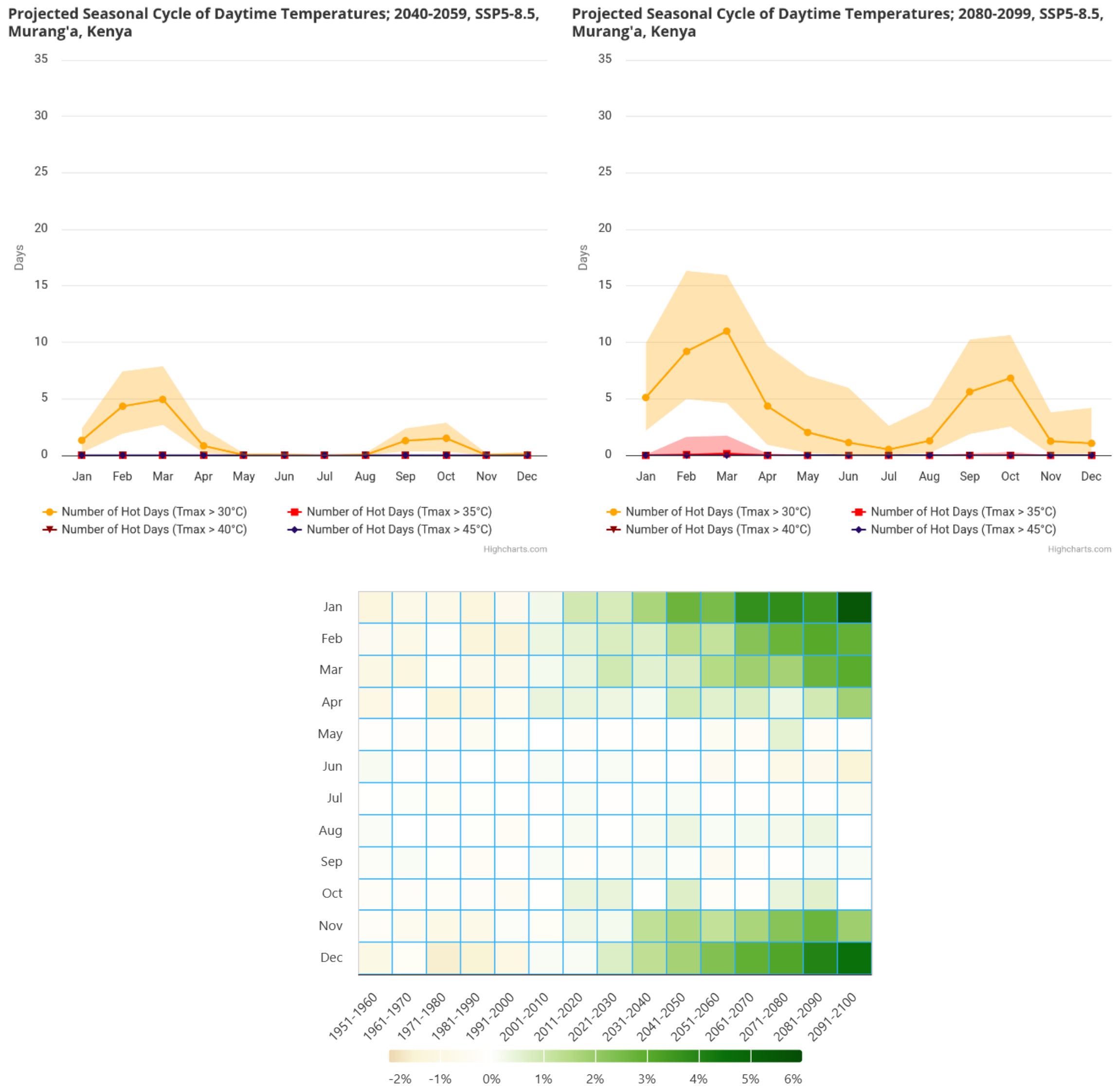


Figure 30: Projected seasonal daytime temperature (top) and humidity monthly anomalies (bottom) metrics for 2050 and 2100 horizons under SSP5-8.5
Source: (The World Bank Group 2025)

The above parameters tend to show that November – April is the period where it will be most likely to observe heat conditions in the future. This is confirmed with the next graph.

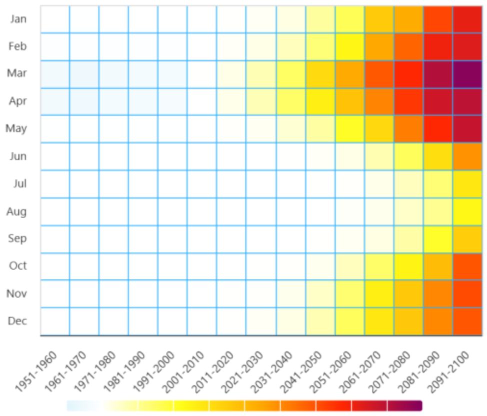


Figure 31: Projected Heat Plot Number of Days with Heat Index > 35°C (Ref period : 1995-2014 ; SSP5-8.5 ; Multi model ensemble)
Source: (The World Bank Group 2025)

4.2.5 Landslides

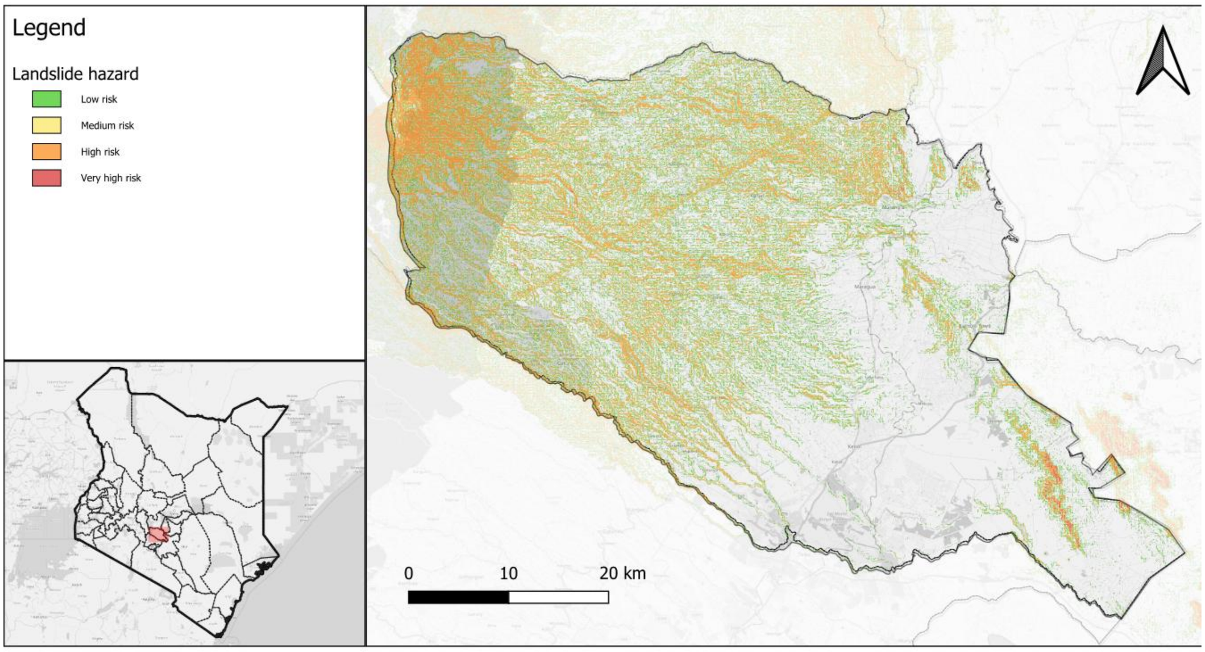
Murang’a County’s landslides are driven both by natural and human factors. The Northwest region’s steep slopes—frequently exceeding 20°—place high gravitational stress on the weathered volcanic soils (Andosols and Nitosols as seen before), which are rich in clay minerals that swell and lose cohesion when saturated. Intense and prolonged rainfall rapidly raises pore-water pressure within these fine-textured soils, reducing their internal friction and triggering slope failure. Additionally, accelerated surface erosion—through sheet and rill processes—strips away protective vegetation and undercuts slope toes, further weakening the soil structure and preconditioning hillsides for collapse.

For the map in figure 30 the hazard level is defined by the slope value, as follows:

- Low hazard: slope < 15°
- Medium hazard: slope 15 - 20°
- High hazard: slope 20 - 30°
- Very high hazard: slope >30°

The subcounties level of hazard on its end was calculated as follows: Exposure index = (4*surface of subcounty with very high exposure + 3* surface of subcounty with high exposure+ 2* surface of subcounty with moderate exposure + 1* surface of subcounty with low exposure) the exposure index is then normalized from 1 to 4 (1 thus being low exposure and 4 very high exposure) and these correspond to the overall exposure level of a subcounty.

K-WASH Program
Climate Risk and Vulnerability Assessment, Murang'a County
Landslide mapping



Prepared by : Groupe Huit
Date : March 2025
Source : Based on Green Water Credit (GWC) programme in the Upper Tana River Valley (KENSOTER)

Figure 32: Murang'a Landslide Mapping

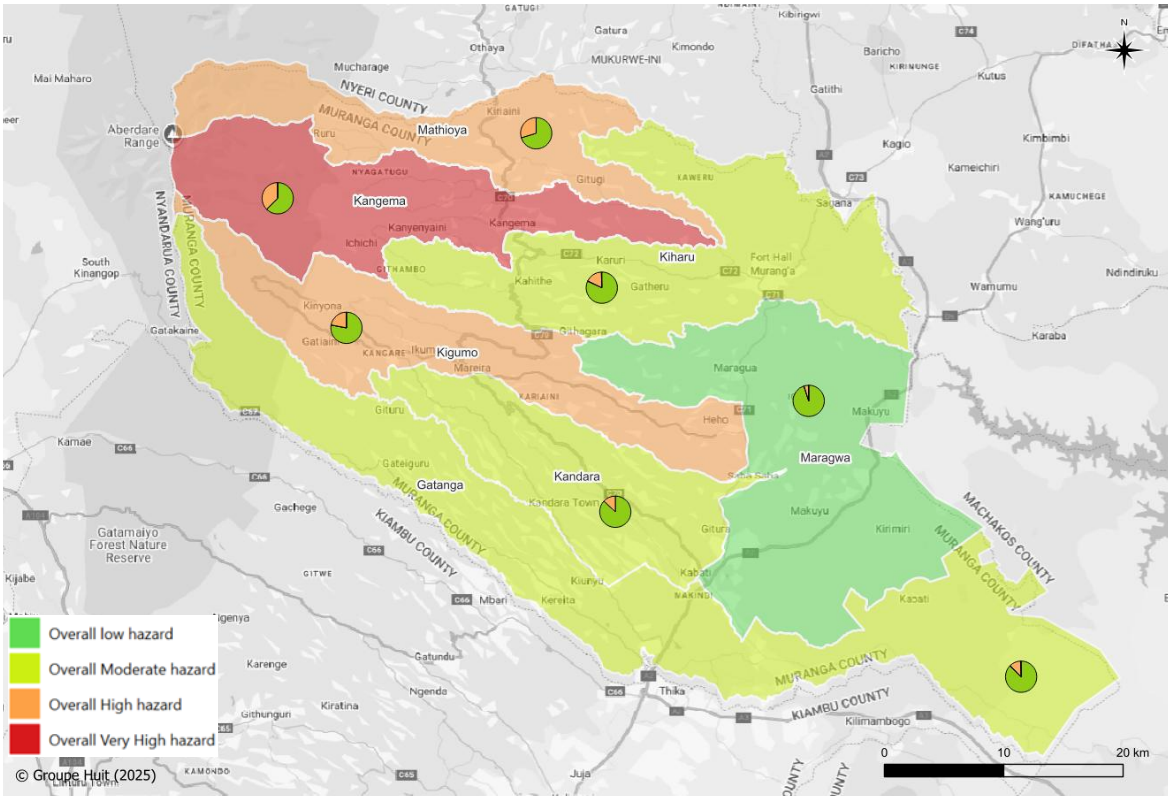


Figure 33: Murang'a Landslide Hazard exposure by subcounty

The high landslide risk here is closely tied to erosion, evident in the graph below, which helps explain why this area is so vulnerable. With rainfall events becoming more frequent and intense, erosion will only accelerate, further amplifying landslide risk and causing conditions to deteriorate over time.

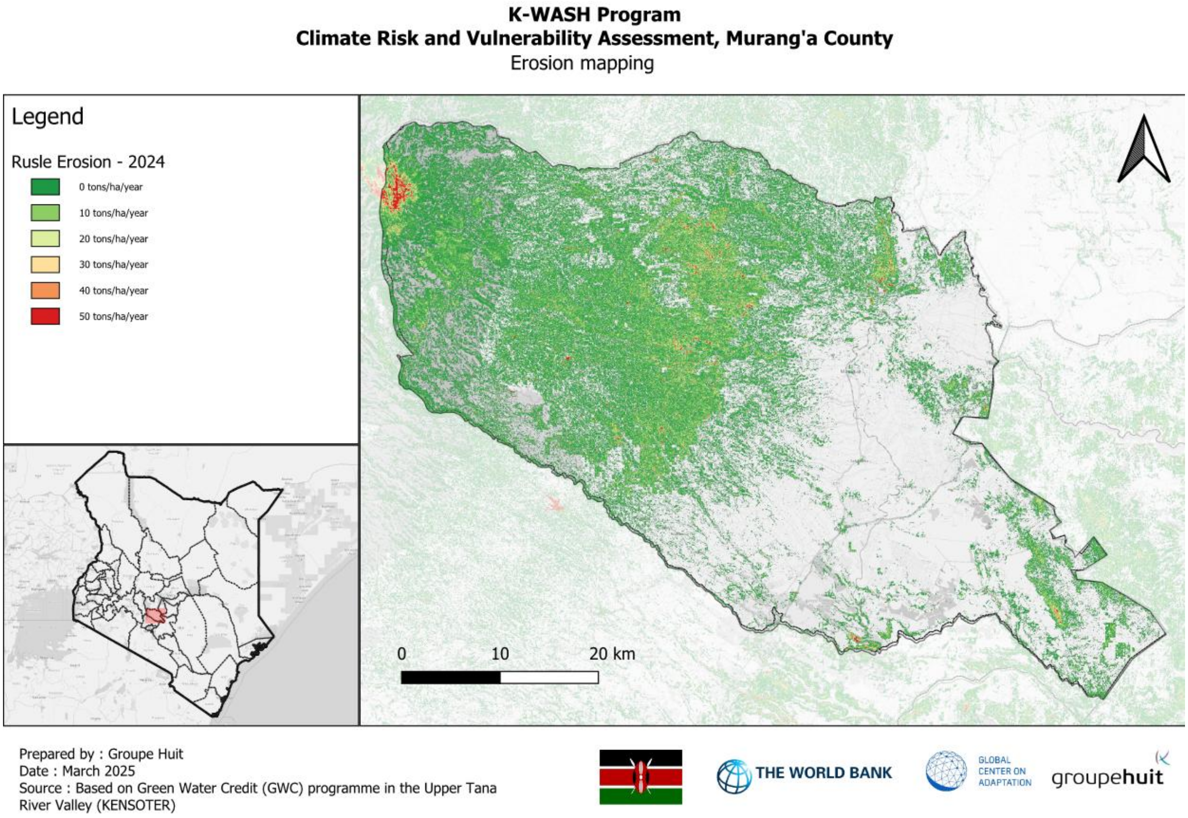


Figure 34: Erosion Mapping

In addition to natural predispositions, human activities further exacerbate landslides. Infrastructure sometimes built on unstable ground—housing developments, buildings, or industrial facilities—can weaken slopes and make them prone to collapse. Likewise, road construction, by altering the terrain or blocking proper drainage, can concentrate water and trigger mass movements. Additionally, deforestation for agriculture or urban expansion, along with quarrying and material extraction, disrupts soil cohesion, while leaks in water networks create localized wet zones. For instance, in Kiarathe (Musoso Village), the continued farming along these steep slopes exposes the areas to landslides. Landslides there have been occurring for a long time but have been considered as severe since 2018 with main occurrences in 2022, 2024 and 2025 especially in the month of May which is the wettest month when soils are waterlogged and saturated resulting to earth movements. The month of May is considered as the one where landslides are most frequent in other areas of Murang'a such as Kiambugi, Mugeka, Gaturi, Kigetuine, Thoithu, and Karengo-Ruiru which are also areas recognized as landslide hotspots, characterized by steep slopes, loose loamy red volcanic soils, and unsustainable farming practices along the hillsides.

Figure 35: illustration of agriculture on steep slopes

Source: Fieldwork, September 2025

Figure 36: Impacts of Landslides in Kiarathe, Crops swept away as mass movement continues downhill

Source: Fieldwork, September 2025

All of these human pressures undermine the natural stability of slopes and can turn even light rainfall into a serious hazard for surrounding communities. Together, these natural and anthropogenic factors create conditions in which minor hydrological events can rapidly evolve into destructive landslide hazards, posing serious risks to communities and infrastructure throughout Murang'a County.

4.2.6 Soil and water salinity

Soil and water salinity hotspots in Kenya are Turkana region, Kitui region, coastal areas and river deltas. Murang'a County is not part of such hotspots, located at the north of Nairobi, the following graphs show a very low probability of soil salinity presence, even with the lowest threshold salinity threshold, the probability is still very low.

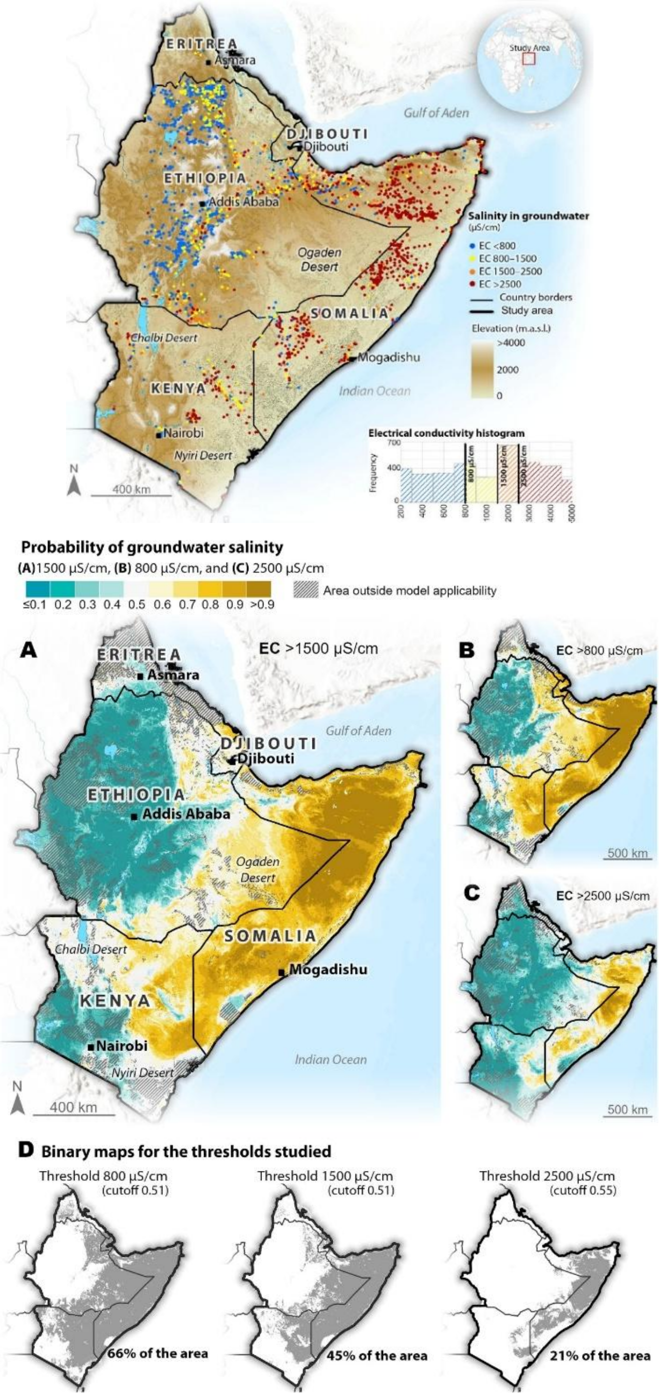


Figure 37: Groundwater salinity maps for East Horn of Africa

Source: (D. Araya et al. 2023)

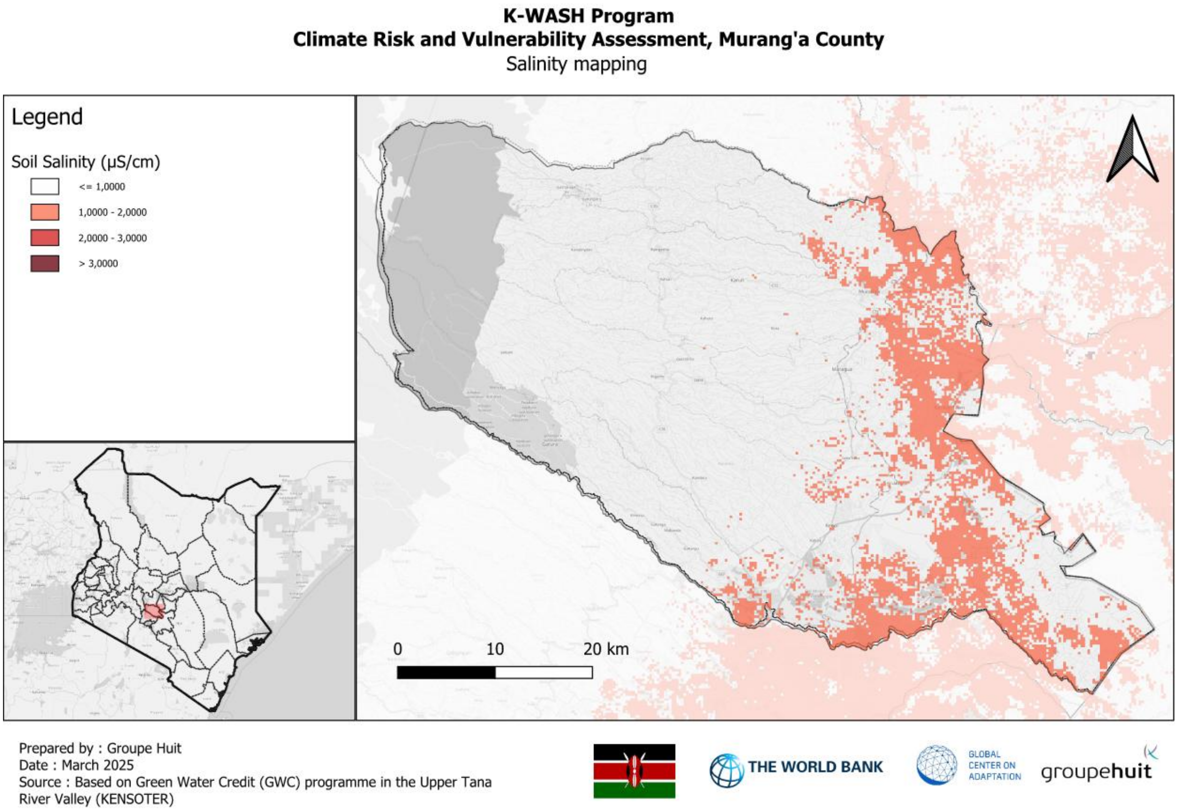


Figure 38: Murang'a Soil Salinity Mapping

Inland soil salinity that is observed in Murang'a County is not very documented. Nonetheless its location is close to the southern rift valley in which salinity can be explained through multiple factors (Mugai 2003):

- Insite accumulation of salts: This means salts that build up directly in the soil over time, often due to dry conditions.
- Remnants of dried-up soda lakes: These are areas where once there were lakes with highly saline water, but now they are dry.
- Overflowing of soda lakes (Lakes like Bogoria, Magadi, Nakuru, and Elmenteita have very salty water due to springs rich in carbon dioxide.). When these lakes overflow or when salt particles blow onto the surrounding soil during rainy and dry seasons, it can make the soil even more saline.
- Irrigation of agricultural plots (this factor appears to be a bit more limited in Murang'a), the following analysis are drawn from Turkana County studies (J. Smaoui et al. 2024):
- It is most likely that non-irrigated fields with shallow-rooted pastures for livestock have low surface salinity, with salt concentration peaks could be at little depth (0.20m in Turkana) due to salt deposition from evaporation, declining to a non-saline level a little bit deeper (0.60m in Turkana)
- Intensively irrigated fields are expected to have low salinity enabling them to support vegetable production, with salt leached by frequent irrigation (Ndegwa & Kiiru, 2010).

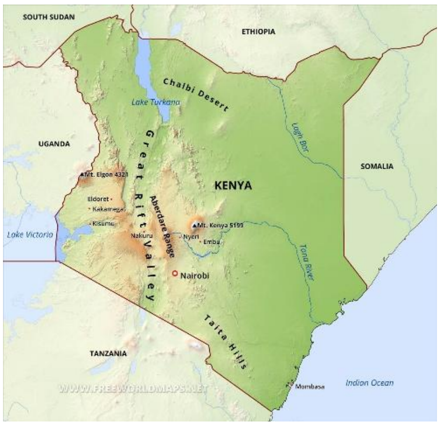


Figure 39: Great Rift valley location in Kenya

Source: Free World Maps

- Periodically irrigated fields are expected to have a saline soil surface due to salt translocation from the shallow groundwater table. Over-irrigation and inadequate drainage can cause rising groundwater levels, leading to soil salinization (Ndegwa & Kiiru, 2010).

4.2.7 Sand and dust storms

Sand and dust storms (SDS) are common meteorological hazards in arid and semi-arid regions that generate large amounts of airborne mineral dust particles. (World Meteorological Organization 2022)

SDS present a formidable, widespread threat to health and hinder the achievement of sustainable development in its economic, social and environmental dimensions. Originating from the land, these particles of various sizes and composition get lifted in the air, creating storms. The activity of a sand or dust source depends on the fraction of surface winds exceeding the erosion threshold defined by the local surface properties. Most major dust sources are dominated by inland drainage basins in arid areas, due to the wind-erodible nature of their surface materials, exacerbated by the dry conditions, and the limited vegetation due to aridity (deserts and agricultural land impacted by drought). Removal of vegetation, loss of biodiversity, and disturbance of the sediment or soil surface, will increase susceptibility to dust generation in these areas. (UNEP, WMO, UNCCD 2016)

Their wide impact goes beyond human health and air quality, as it also impacts agriculture, environment, industry, transport and water quality. (WHO 2024)

SDS information remain limited for Tana River County. Nevertheless, considering soil characteristics (dry soils, prone to erosion in some areas as: Kora National Park, Irangi, Karawa, Koito) and wind parameters in the area sand and dust storms remain a hazard to be considered at the County level although not yet considered as a concern by the local autorities. Most SDS prone areas are considered to be Kora national Park area and Irangi area considering

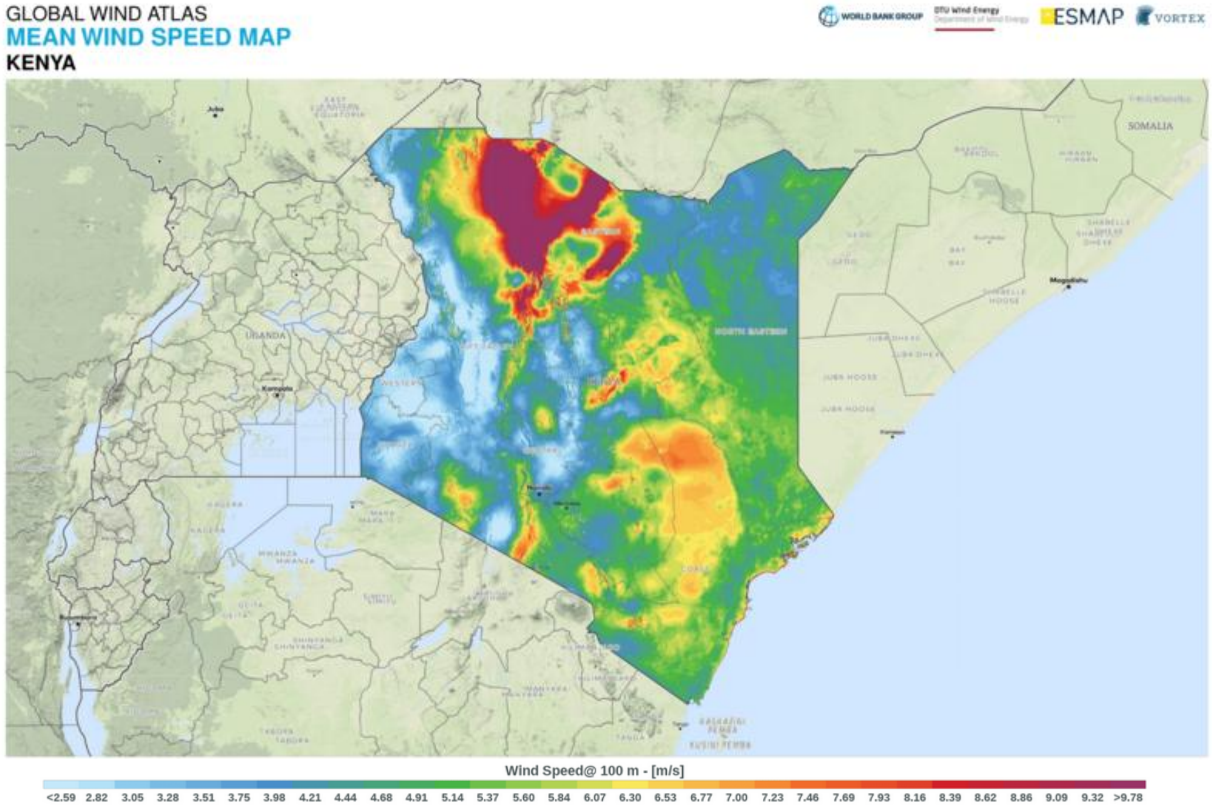


Figure 40: Mean wind speed in Kenya

Source: (Global Wind Atlas 2024)

4.2.8 Pest and diseases

Climate change effects have increased the prevalence and occurrence of pest and diseases in humans, livestock and crops.

Pest and disease outbreaks are considered a negative effect associated with the combination of drought and flooding.

During floods, waterborne disease outbreaks tend to increase in frequency. In Murang'a disease which outbreak recently were Anthrax, Cholera and Malaria. The PCRA also highlighted an increase in post-harvest pests and diseases on the maize and other cereals which had to be stored in improvised storage bags to reduce losses, farmers even directly linked this issue to climate change, especially in the lower midland agro-ecological zones.

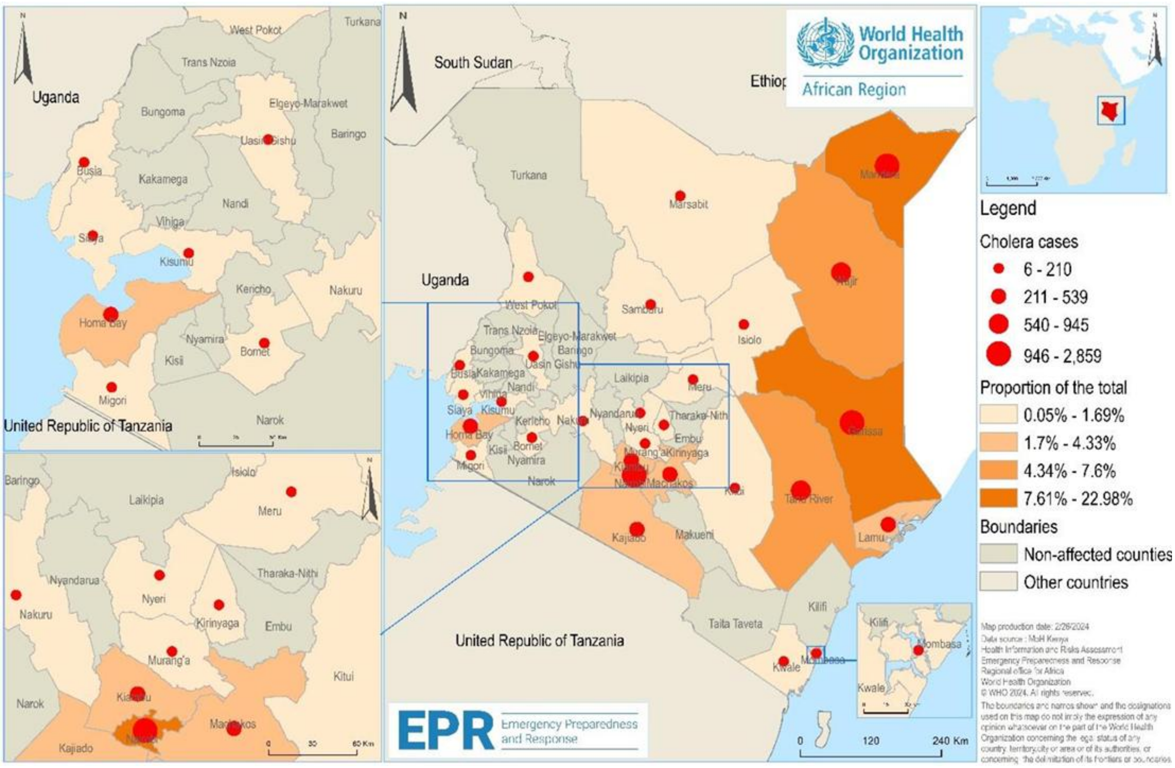


Figure 41: Map for cholera outbreak in Kenya, October 2022 – 18 February 2024

Source : (WHO 2024)

Generally speaking, high temperatures are reported to have led to an increase in cases of pests and diseases such as Rift Valley Fever (RVF), ECF and CCP in livestock in the lower and middle zones of the county (Ithanga, Kambiti, Kimorori-wempa, Kakuzi Mitumbiri, Makuyu, Mbiri, Kamahuha, Gaturi, Mbiri, Township, Wangu, Muguru, Mugoiri, Murarandia, Gitugi, Kamacharia, Muthithi, Kahumbu, Ichagaki, Nginda, Ithiru, Gatanga, Kahumbu-ini, Ichagaki, Gaichanjiru, Muruka, Ng'araria, Mugumoini wards).

On the other hand, drought and rising temperatures have led to an increase in hunger and malnutrition due to crop failures and livestock mortality.

Adaptation strategies are proposed to control pests and diseases:

- Adoption of disease-tolerant crops.
- Leveraging Indigenous Technical Knowledge (ATK) for crop and livestock pest and disease management.
- Acquisition of improved breeds and disease-tolerant crops.
- Support for extension services at the local level.
- Strengthening links with research institutes such as KALRO.
- Training and capacity building of community groups in integrated pest and crop management.

- Raising awareness of pests and diseases through radio programs and community meetings.
- Vaccination and immunization of livestock.
- Adoption of Integrated Pest Management (IPM).
- Adoption of disease-resistant crop breeds and varieties.
- Disposal of deadstock by burial or incineration.
- Treatment with plant species for medicinal use.
- Crop rotation.
- Agricultural monitoring and prospecting.
- Application of pesticides and inorganic miticides.
- Creation of livestock migration areas to disease-free areas.
- Quarantine.

The County Climate Action Plan (CCAP) 2023-2027 includes specific actions to improve pest and disease control, including **:**

- Adopting the county one health strategy in control of zoonosis
- Adopting the national rabies eradication strategy
- Adopting common approach of providing resources for prevention, early detection and response to zoonotic disease
- The establishment of a strategic pest and disease control unit.

4.2.9 Climate variability

Climate and weather conditions, including storms, are affected by global modes of variability (MoV) that form global teleconnections (see annex 5). This internal climate variability is always present. A climatology, therefore, must be understood as a mean with variability around it.

In the case of Kenya, research have shown that the specific modes considered are:

- Madden-Julian Oscillation and Pacific and Indian Ocean anomalies (intraseasonal variability – wet and dry spells that occur within the rainy season, and interannual variability) mainly, and
- El Nino-Southern Oscillation (ENSO) (interannual variability of the contrast between the two rainy seasons and the zonal winds). (Nicholson 2017)

In contrast to natural variability, anthropogenic emissions of greenhouse gases and resulting changes in atmospheric concentrations (i.e., CO2, methane) together with land surface changes and aerosol impose a different forcing on the climate system.

The search for climate change signals tries to separate their effects from the natural background variability. That signal can show changes in the magnitude of the variability as well as through a systematic trend overtime.

4.2.10 Conclusion on hazards

The above paragraphs have shown that while the county can experience multiple types of hazards (floods, heat stress and droughts, landslides, soil and water salinity, sand and dust storms, pest and diseases and global climate variability) the hazards showing the highest levels of intensity are:

- Landslides (critical hazard)
- Flood hazard (mainly pluvial) (critical hazard)
- Meteorological droughts (moderate but widespread hazard)

Hence, the county should be particularly focused on those, while not completely overlooking the other.

4.3 Impact of climate change

Impact of climate change on considered hazards requires first to analyze the projected evolution of forcing climate parameters which can impact these hazards. The considered parameters are as follows, all based on annual aggregation:

- Mean Temperature (Tmean) represents the overall thermal background of a climate system. It controls baseline evaporation and evapotranspiration rates, influences crop growth, ecosystem functioning, and pest and disease life cycles. It is a key driver of heat stress and gradual aridification trends.
- Maximum Temperature (TXx) represents the upper and lower thermal extremes of the climate system. They control the intensity of heatwaves and cold events, influence human and livestock thermal stress, determine crop damage thresholds, and regulate the survival, reproduction, and geographical expansion of pests and disease vectors.
- Total Precipitation (PRCPTOT) represents the cumulative water input from rainfall over a defined period. It controls soil moisture recharge, surface runoff, river discharge, and groundwater replenishment. It is a fundamental driver of water availability, flood potential, and drought development.
- Number of days with heat index above 35°C / 37°C represents the frequency of days when the combined effect of air temperature and humidity exceeds thresholds associated with marked human heat stress. The heat index integrates temperature and relative humidity to approximate how hot conditions *feel* to the human body and is widely used in occupational and public-health guidance to characterize dangerous heat exposure. An increase in the number of days with HI >35–37°C signals higher risks of heat exhaustion and heat stroke, reduced outdoor labor capacity, and elevated mortality and morbidity—especially for vulnerable groups (elderly people, children, outdoor workers, informal sector). It also increases thermal stress on livestock, constrains safe working hours, and can exacerbate energy demand peaks for cooling, with implications for power system reliability and urban heat-island impacts.
- Number of tropical nights with minimum temperature above 20°C / 23°C represents the frequency of nights when temperatures remain unusually high and fail to provide relief from daytime heat. This index is an ETCCDI-type indicator (TR) capturing nights with minimum temperatures above 20°C (or a higher threshold such as 23°C in already warm climates) and is closely linked to the health impacts of heatwaves. Persistent or more frequent tropical nights prevent the human body from recovering from daytime heat stress, significantly increasing heat-related mortality and hospital admissions, particularly in dense urban areas and poorly ventilated housing. Rising tropical-night frequencies also stress livestock, affect crop and tree physiology (e.g. higher respiration losses, phenology shifts), intensify urban heat-island effects, and can reinforce nocturnal ozone and pollution episodes, compounding health risks.
- Extreme Rainfall (Rx1day / Rx5day) represents the intensity of short-duration precipitation events. These parameters control the triggering of flash floods, urban flooding, and rainfall-induced landslides. They are critical indicators of climate-related changes in hydrological extremes and infrastructure stress.
- Number of Days with Precipitation >20 mm (R20mm) represents the frequency of heavy rainfall days. In Murang'a, the number of >20 mm days increases in the projections, indicating more frequent heavy-rain events. This reinforces flood and landslide risks and provides more frequent high-moisture windows that can favour certain crop and vector-borne diseases.
- Consecutive Wet Days (CWD) represents the persistence of wet conditions over time. It controls soil saturation, slope instability, prolonged flooding, and the development of moisture-dependent crop and plant diseases. It is a key indicator of long-lasting wet spells and drainage pressure.
- Consecutive Dry Days (CDD) represent the persistence of rainfall deficits. It controls soil desiccation, vegetation stress, crop water deficits, increased wildfire susceptibility, dust

mobilization, and soil salinization processes. It is a core indicator of drought intensity and landscape drying.

- **Relative Humidity (RH)** represents the moisture content of the air relative to its saturation capacity. It controls evaporation rates, plant transpiration, fungal and bacterial disease development, and human and livestock thermal comfort. It strongly influences the transmission potential of airborne and vector-borne diseases.
- **Drought / Aridity Index (SPEI)** represents anomalies in the climatic water balance by integrating precipitation and atmospheric evaporative demand. It controls the severity, duration, and spatial extent of drought conditions. It is a robust indicator of climate change–driven drying trends and water stress.

Considering these definitions of parameters, they can be understood as hazard key climate drivers as per the following table. (↑ means an increase in the parameters value, while ↓ means a decrease in the parameters' value), for instance the first item of the table should be read as "*an increase (↑) in the total precipitation parameter (PRCPTOT) tends to lead to an increase of flood hazard level*".

Table 9: Relation between parameters and key hazards

	Increase hazard level	Decrease hazard level
Floods	↑ PRCPTOT, ↑ R20mm, ↑ Rx1day/Rx5day, ↑ CWD, ↑ SLR, ↑ HT	↓ PRCPTOT, ↓ R20mm, ↓ Rx1day/Rx5day, ↓ CWD, ↓ SLR, ↓ HT
Heat stress and droughts	↑ Tmean, ↑ TXx, ↑ Number of days with heat index above 35°C / 37°C, ↑ Number of tropical nights with minimum temperature above 20°C / 23°C, ↑ RH, ↓ SPEI	↓ Tmean, ↓ TXx, ↓ Number of days with heat index above 35°C / 37°C, ↓ Number of tropical nights with minimum temperature above 20°C / 23°C, ↓ RH, ↑ SPEI
Erosion and sedimentation	↑ PRCPTOT, ↑ Rx1day/Rx5day, ↑ R20mm, ↑ CWD, ↑ SLR, ↑ HT	↓ PRCPTOT, ↓ Rx1day/Rx5day, ↓ R20mm, ↓ CWD, ↓ SLR, ↓ HT
Soil and water salinity	↑ PRCPTOT, ↓ CDD, ↓ SPEI, ↑ SLR, ↑ HT	↓ PRCPTOT, ↑ CDD, ↑ SPEI, ↓ SLR, ↓ HT

The following figures emphasize the projected evolution of these annual parameters up to 2100 for SSP5-8.5 (SSP2-4.5 were also represented for comparison).

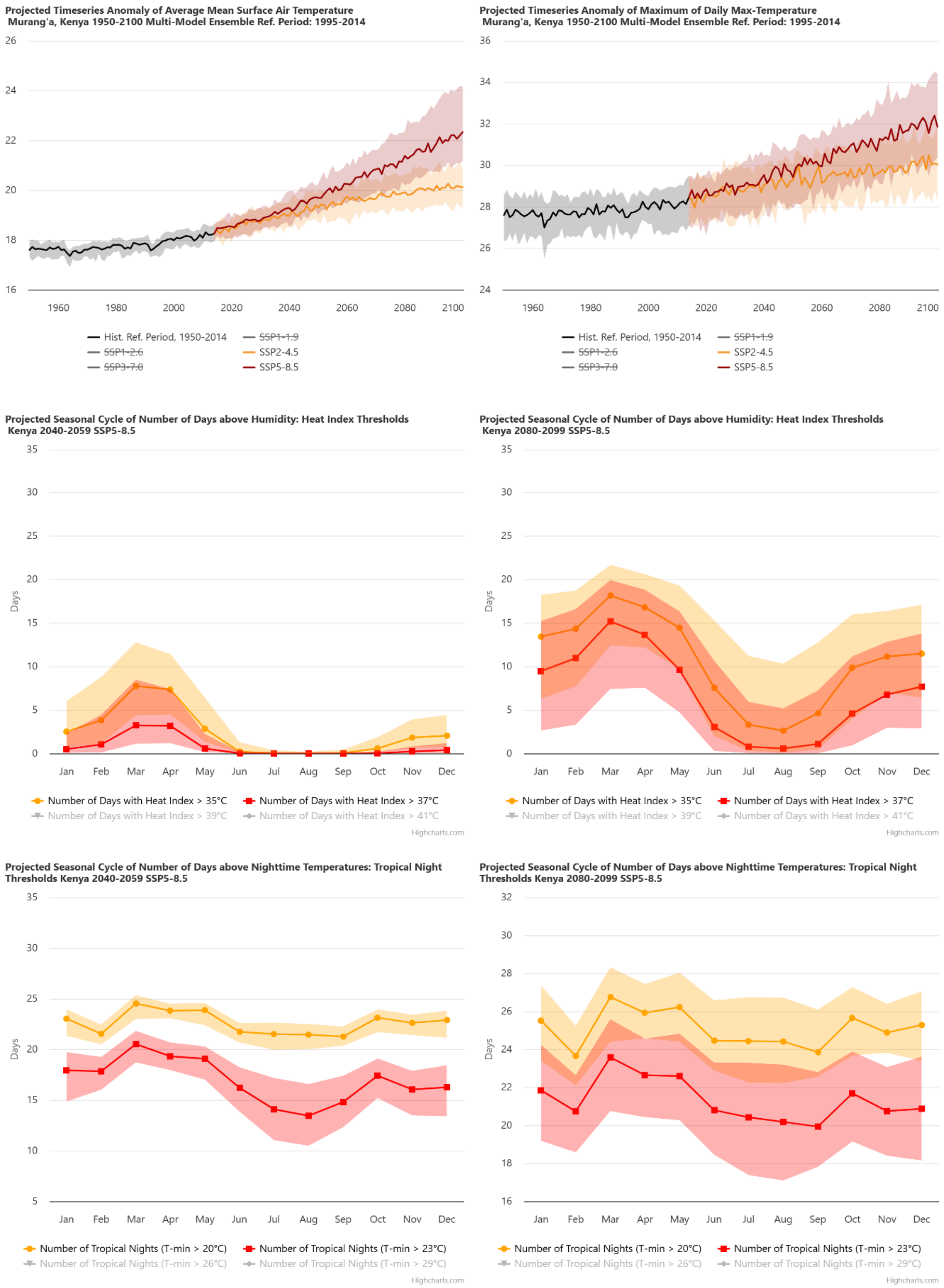
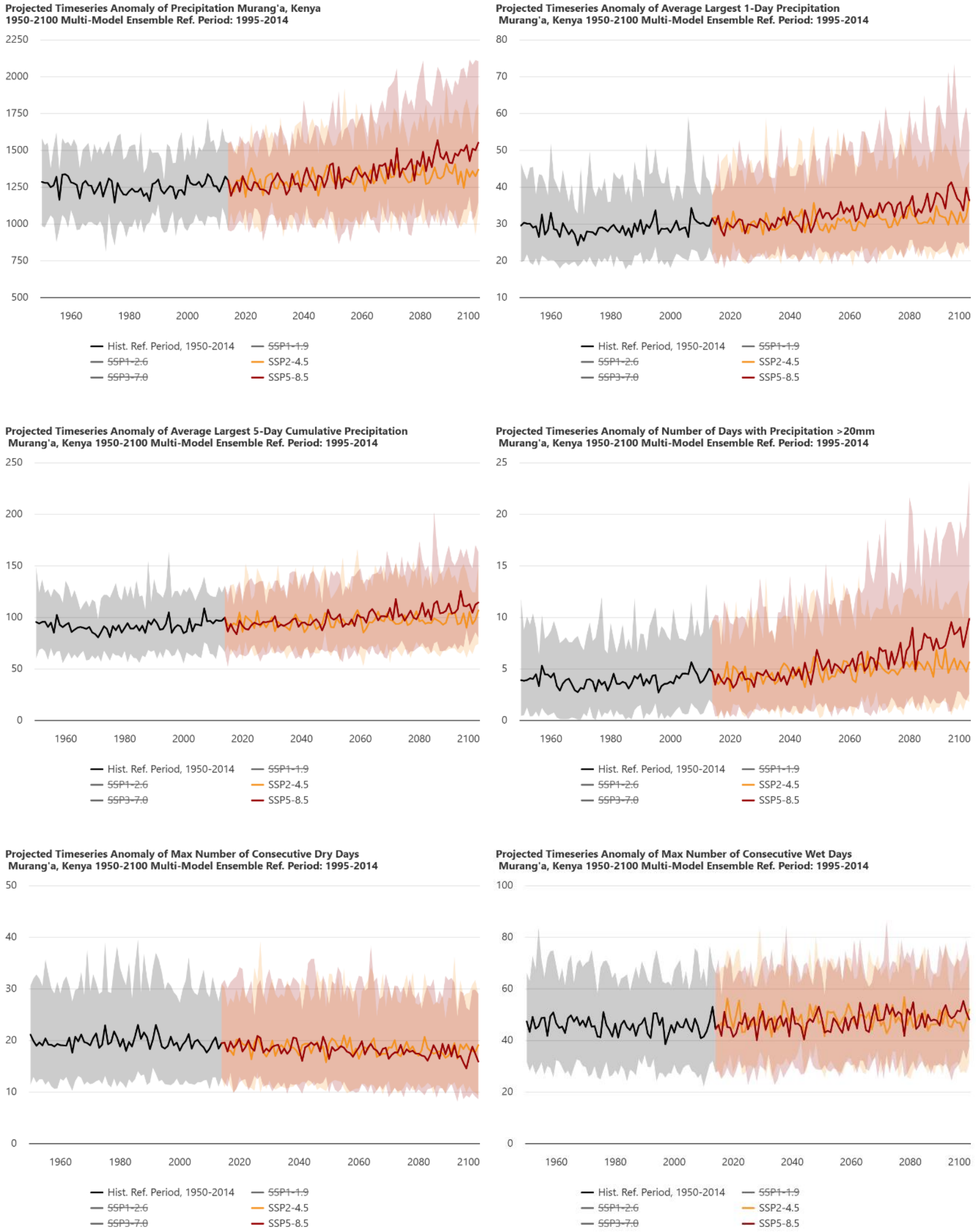


Figure 42: Projection of temperature-related parameters up to 2100 (SSP2-4.5 and SSP5-8.5)



Projected Timeseries Anomaly of Precipitation Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Projected Timeseries Anomaly of Average Largest 1-Day Precipitation Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

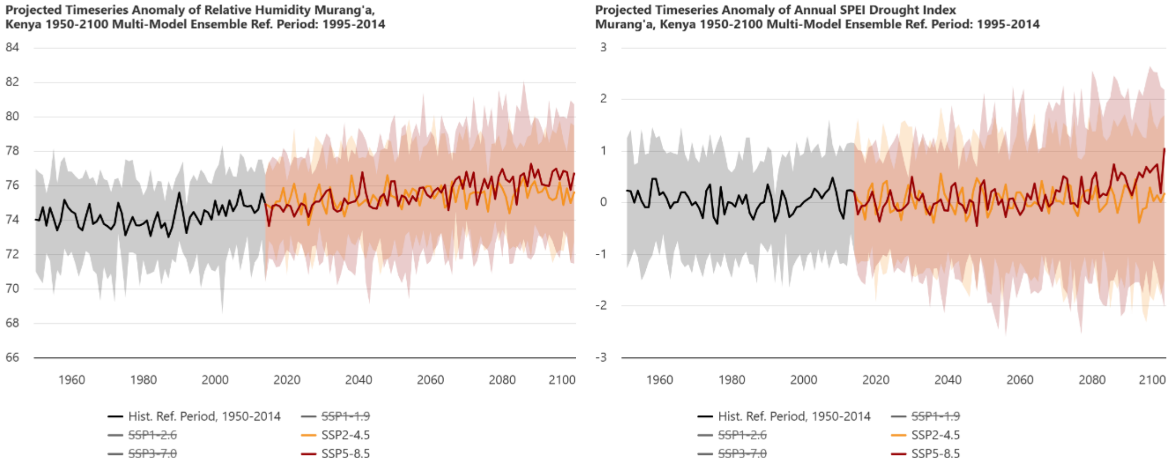
Projected Timeseries Anomaly of Average Largest 5-Day Cumulative Precipitation Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Projected Timeseries Anomaly of Number of Days with Precipitation >20mm Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Projected Timeseries Anomaly of Max Number of Consecutive Dry Days Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Projected Timeseries Anomaly of Max Number of Consecutive Wet Days Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Figure 43: Projection of precipitation-related parameters up to 2100 (SSP2-4.5 and SSP5-8.5)


Projected Timeseries Anomaly of Relative Humidity Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Projected Timeseries Anomaly of Annual SPEI Drought Index Murang'a, Kenya 1950-2100 Multi-Model Ensemble Ref. Period: 1995-2014

Figure 44: Projection of other parameters up to 2100 (SSP2-4.5 and SSP5-8.5)

These figures enable to derive the relations between these projections and the hazard levels, which is presented in the table hereafter.

The + boxes indicate that hazard is reinforced by the projected evolution of the climate parameter while the - boxes indicate that hazard is reduced.

Table 10: Relations between climate parameters and hazards

Hazard	Tmean	TXx TNn	PRCPTOT	Rx1day Rx5day	R2mm	CWD	CDD	RH	SPEI	Justification
Floods			+	+	+					Increasing annual rainfall, stronger short-duration rainfall extremes and more frequent heavy-rain days increase runoff and flood triggering.
Heat stress & droughts	+	+					-	+	-	Rising mean and extreme temperatures and higher humidity intensify heat stress, while slightly shorter dry spells and wetter water balance moderate drought intensity.
Landslides			+	+	+					Higher cumulative rainfall and more intense and frequent heavy rains increase soil saturation and slope-failure triggering.
Soil & water salinity			-				-	-	-	Increased rainfall, shorter dry spells, higher humidity and wetter water balance favour salt leaching and reduce evaporative concentration.
Sand & dust storms			-				-	-	-	Wetter and more humid conditions with shorter dry periods reduce soil desiccation and wind-erosion potential.
Pests & diseases	+	+	+	+	+		+	+	+	Warmer, wetter and more humid conditions with more frequent heavy rains expand suitable habitats and favour pest and pathogen development and transmission.

Note: Mean Temperature (**Tmean**), Maximum Temperature (**TXx**), Total Precipitation (**PRCPTOT**), Extreme Rainfall (**Rx1day** / **Rx5day**), Number of Days with Precipitation >20 mm (**R20mm**), Consecutive Wet Days (**CWD**), Consecutive Dry Days (**CDD**), Relative Humidity (**RH**), Drought / Aridity Index (**SPEI**)

These impact levels will be used to assess the future hazard exposure of planned WASH infrastructure (see next chapter).

5. HAZARD VULNERABILITY

5.1 WASH sector vulnerability

The diagram overleaf illustrates how climate impacts end up affecting people in different and unequal ways especially through a WASH sector lens. The framework may be understood as having a "physical side" - the climate hazards and physical systems, and a "social side" - the psycho-social equity and inclusion factors and the WASH actions that people take. Livelihoods comprise both physical materials and social actions.

In addition to the above, the relationship between climate change and WASH can be seen from two perspectives: on the one hand, poor WASH management can exacerbate the impacts of climate change (for instance mismanaged drains will increase flooding impacts), and on the other hand impacts of climate change can make WASH more complicated, as it is shown in the scheme below.

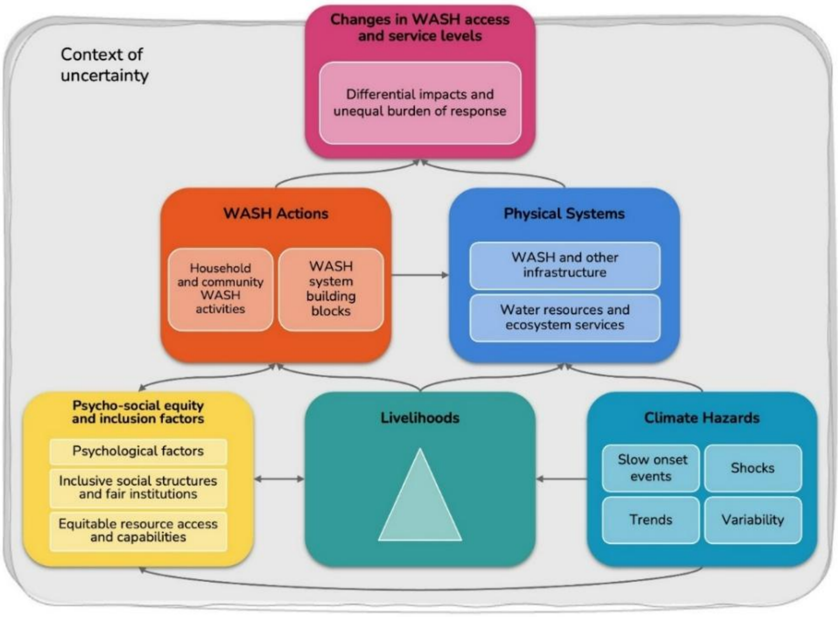


Figure 45: WASH sector framework and relation to climate change

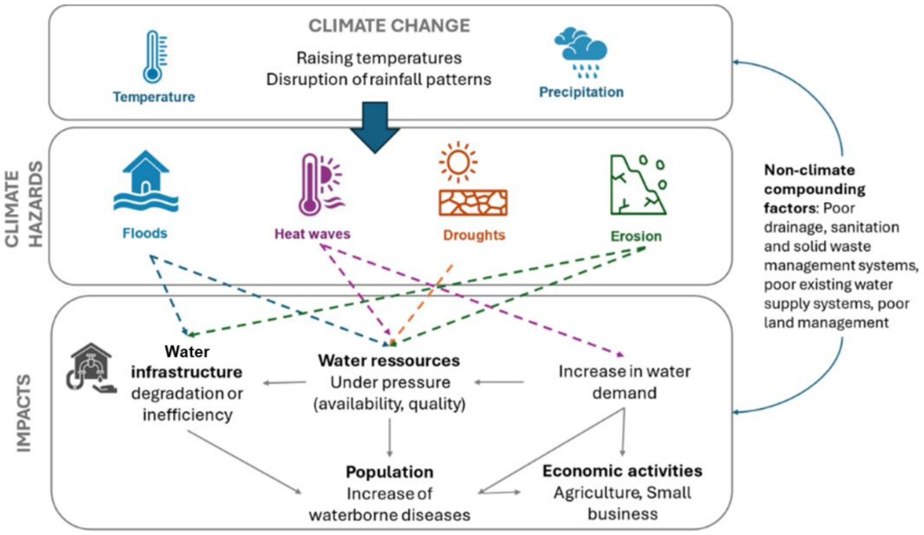


Figure 46: Water sector vulnerability to climate change

The following sub-chapters will elaborate on specific impacts in order to point out specific vulnerabilities of Murang'a County.

5.1.1 Water resources

The following table provides an overview of climate change impacts on water resources, while the next paragraphs will provide additional details.

Table 11: Links between climate change and water resources

Climate hazard	Impact on water resource
Variability of seasonal rainfall patterns	▶ Weak or even non-existent surface and ground water resources at the end of the dry season
Droughts, water shortage, increased temperatures, heat waves	▶ Decline in quantity and quality of surface and ground water seasonally (large-scale fluctuations) and interannually fluctuations) and on an inter-annual scale (continuous fall in groundwater levels): o Reduced river flow, particularly during low-water periods o Increased concentration of various pollutants in water (chemical, organic) due to their reduced dilution o Reduced groundwater recharge o Proliferation of algae disrupting natural processes in water bodies (nitrogen cycle/eutrophication) o Increase in water salinity: ▪ saline upwelling in rivers due to reduced flow, ▪ saline intrusion into coastal groundwater due to reduced recharge, ▪ alteration of geological substrate, releasing elements that generate the formation of soluble salts.
Intense and sudden rainfall, flooding	▶ Pollution of surface water, then groundwater (after infiltration) due to the leaching of pollutants onto the soil, the flooding of latrine pits and the increase in volumes discharged without treatment (saturation of wastewater treatment plants where they exist). ▶ Poor infiltration of rainfall into the ground during heavy rainstorms: water no longer infiltrates but runs off, creating areas of flooded areas
Storms (including sand and dust storms)	
Erosion (which can also be induced by floods and water runoff) and landslides	
Sea level rise	▶ Saline intrusions

Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (C. Agudelo-Vera et al. 2020), (Ps-Eau 2018)

5.1.1.1 Surface Water Resources

As mentioned earlier, Murang'a main surface water resources are its rivers, as there are no major lakes in the county.

Murang'a CIDP's indicates that Murang'a County's water resources are **rivers, shallow wells, springs, dams, boreholes and roof catchment**. There are 15 permanent rivers, 2740 shallow wells, 95 protected springs, 345 unprotected springs, 85 water pans, 12 dams and 250 boreholes that supply water for domestic and agricultural use in the county. All these sources supply 60% of the county population with clean and safe drinking water.

Figure 47: Irate Intake on River Irate in Gachocho area.

Source: Fieldwork, September 2025

In addition to those water resources, it has been noticed that farmers build up water pans to capture runoff water as shown in the picture.

Figure 48: Example of a water pan built by farmers in Murang'a

Source: Kenya News Agency

Surface water resources are crucial for agriculture and livestock but are heavily impacted by climate-related hazards.

Drought can represent a threat to surface water resources, as it leads to the **drying up of shallow wells, small springs, and water points**, including water pans, and reduces the global water levels.

The specific case of Murang’a suggests a **rise in rainfall and in the SPEI droughts index**. **Those two items show a lower risk of meteorological droughts.** Nevertheless, the impact of temperature with related **evaporation and evapotranspiration impacts** should not be overlooked as it plays a major role in the year-round loss of surface water stocks. Especially, the increased number of hot days (Tmax>30°C) under RCP5-8.5 from January to April and September and October could lead to increase loss rates. **This shows a higher risk of meteorological drought**.

The balance between parameters must be assessed at the county level in order to evaluate the risk of meteorological drought. Historical events and PCRAs show that the risk of meteorological drought is indeed increasing and that evaporation and its effects linked to rising temperatures outweigh the increase in precipitation, tipping the balance toward a higher risk of meteorological drought. Droughts should therefore duly be considered as a hazard for Murang’a County, with an overall hazard exposure considered moderate (in comparison with landslide for with high exposure is considered).

Such balance between rainfall patterns changes and evaporation rates should be closely considered for surface water quantities annual evolution estimates to be given quantitatively. While FAO models have been run at Country and TCA scale (see National Water Master Plan) and enable to get an overview of agricultural droughts the analysis should be refined and downscaled at county scale especially considering the different topography, soil conditions, crop typologies and meteorological parameters of Murang’a compared to the rest of the TCA, such downscaling requires hydrologic modelling and in depth crop analysis to identify quantities of each crop and their vulnerability to changing climate parameters.

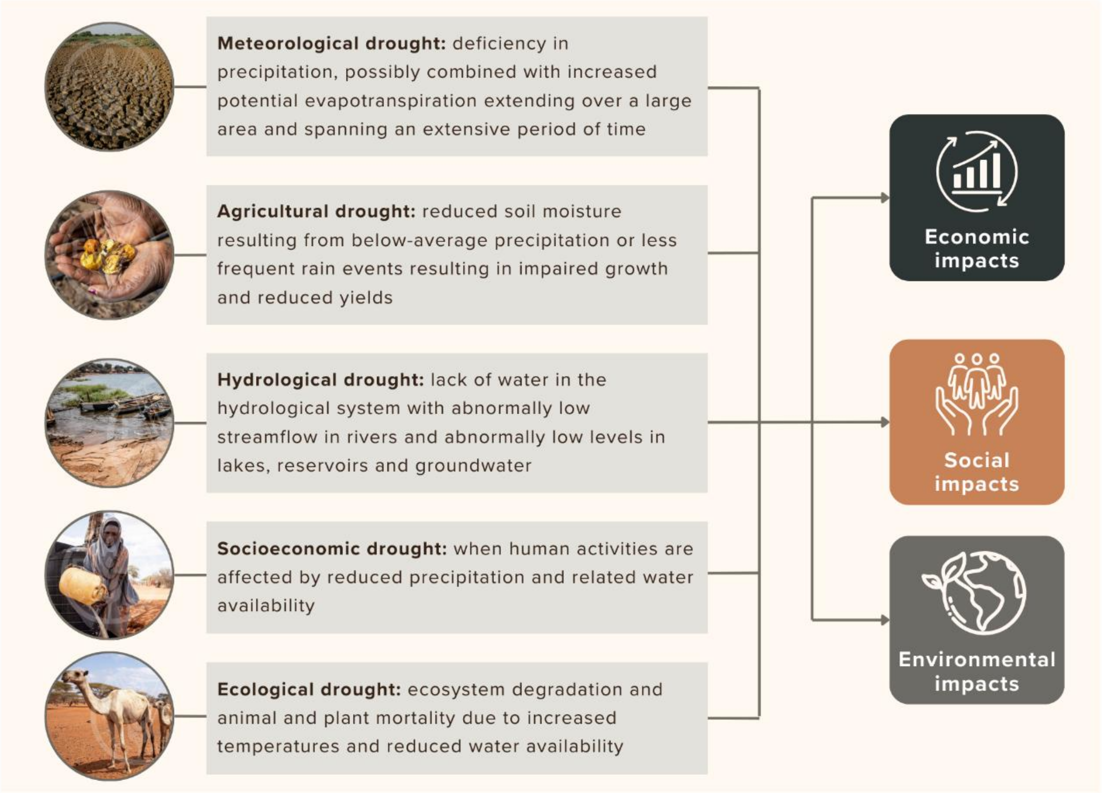


Figure 49: Decription of drought types

Other challenges are (i) the increase of groundwater salinity which may lead to water availability decrease but also threaten fertile lands and (ii) dust storms as they would lead to deposits in surface water and thus quality reduction.

These surface water resources are regarded as **vulnerable assets** to climate hazards, including drought, floods, and salinity increase. **Watershed degradation** is another factor that contributes to the vulnerability of these resources.

To mitigate these risks, various adaptation strategies are proposed in the CIDP and are reported below, such as:

- Regarding investment in irrigation schemes:
  - training on efficient utilization and management of irrigation which is expected to improve global water resource management and hence enhance adaptative capacity
  - disaster management in irrigation schemes, which is expected to reduce vulnerability of irrigation schemes an related water resources
- Development of water harvesting and storage infrastructure for irrigation.
- Enhancing compliance with environmental, statutory and legal requirements
- Construction of small dams and water pans to collect flood water flows.
- Use of climate smart agriculture by use of water conserving irrigation methods such as drip irrigation, digging of terraces, planting water friendly trees along the riverbanks.
- Reduction of water wastage through modern technology measures.
- Capacity building of water stakeholders on climate change mitigation measures

5.1.1.2 Groundwater Resources

Groundwater is an essential resource in areas where surface water is scarce or unreliable, which is not the case in most parts of Murang'a, nevertheless groundwater remains a water resource to be considered. Limited information is available regarding location and capacities of water tables in the County. This limits the evaluation of the quality and quantity of groundwater in the county. In most cases, these resources also under strain due to over-extraction, pollution, and the effects of climate change, especially in the case of shifts of the rainfall patterns which can lead to a decline in groundwater levels and reduced recharge rates, but **in Murang'a no data enables to study such items, the only parameter with reported change is the salinity of groundwater resource which seems to have increased and is expected to keep increasing by the county.**

It is more difficult to study the impact of climate disruption on groundwater resources than on surface waters, due to the great variability of the contexts in which they are found:

- type of geological formations (aquifers)
- degree of confinement
- hydraulic interactions with nearby watercourses and neighboring aquifers (or with seawater in the case of coastal aquifers)
- scale of abstraction

In addition, withdrawal volumes are subject to change (increased domestic consumption during periods of drought, increased irrigation withdrawals, diminishing availability of certain surface resources).

However, it has been established that climate change is having an impact on the rate of groundwater recharge, notably through changes in rainfall and evapotranspiration. This has to be linked with the annual hydrologic cycle. As developed above, the total water storage of the watershed follows an upwards trend. Hence, compared to existing situation, groundwater availability should not be reduced by climate change, especially considering Murang'a's location within the TCA. Then, if adequate management practices are put in place, water resources should not be reduced.

Regarding groundwater quality, rising water and surface soil temperatures also lead to a reduction in micropollutant absorption and complexation with Natural Organic Matter (NOM), sediments and soils, which release micropollutants.

As a result, there is a potential risk of an increase in micropollutant concentrations considering climate projections. However, it is impossible to quantify this increase.

Increased salinity should also be considered as a risk regarding groundwater quality.

To safeguard groundwater resources, it is crucial to implement efficient management practices. This includes gathering additional data improving the operation of boreholes, promoting sustainable extraction methods, and enhancing the management of existing wells. Additionally, strategies to recharge groundwater, such as restoring wetlands and catchment areas, and managed aquifer recharge (MAR) systems will help maintain groundwater reserves.

As with surface water, the conservation of forests and the protection of natural recharge zones are essential to ensuring the long-term availability of groundwater. Regular monitoring and data collection are vital, as well as establishing comprehensive water management plans to protect these resources from the challenges posed by climate change. Effective management will help ensure that groundwater remains a reliable resource for the population in Murang'a County.

5.1.2 Infrastructure

5.1.2.1 General considerations

WSS infrastructures are affected differently by the different climate slow onset trends and hazards, the following tables aim at presenting how so.

Table 12: Links between climate change and water supply services

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
Variability of seasonal rainfall patterns	Moderately exposed	Weak or even non-existent surface and ground water resources at the end of the dry season		▶ Temporary interruption or reduction of service due to lack of available resources		▶ Tougher fetching: o longer distances to be covered o deeper, less productive water table ▶ Increased diarrheal diseases : o degradation of water quality o use of water points where quality is uncontrolled and questionable by the
Droughts, water shortage	Moderately exposed	Decline in quantity and quality of surface and ground water seasonally (large-scale fluctuations) and interannually fluctuations) and on an inter-annual scale (continuous fall in groundwater levels): o Reduced river flow, particularly during low-water periods o Increased concentration of various pollutants in water (chemical, organic) due to their reduced dilution	▶ Increasing water requirements and volumes for all uses (domestic agricultural, industrial, etc.).	▶ Service interruption due to resource unavailability ▶ Degradation of distributed water quality due to inadequate raw water treatment of raw water highly concentrated in pathogenic pathogens, physicochemical pollutants, salt, etc., or high turbidity ▶ Increase in supplied-water temperature above recommended	▶ Vulnerability and weakening of facilities : o over-utilization of equipment during drought period to meet high demand o risk of dry pumping and damage to pumps o concrete cracking during heat waves o intermittent water supplies	

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
		o Reduced groundwater recharge o Proliferation of algae disrupting natural processes in water bodies (nitrogen cycle/eutrophication) o Increase in water salinity: ▪ saline upwelling in rivers due to reduced flow, ▪ saline intrusion into coastal groundwater due to reduced recharge, ▪ alteration of geological substrate, releasing elements that generate the formation of soluble salts.		thresholds (WHO's recommendation for maximum drinking water temperature at the tap is 25°C) ▶ Interruption of service due to damage to installations	and pressure changes in the distribution network lead to damage of the infrastructure o dams and reservoirs may be weakened by prolonged low storage levels. ▶ Solar panels are less efficient when they become too hot.	population when the service is interrupted ▶ Multiplication of usage conflicts during water shortages ▶ Amplification of migratory phenomena or departure of populations no longer having access to water ▶ Reduction of agricultural yields
Heat wave	Moderately exposed					
Intense and sudden	Moderately exposed	▶ Pollution of surface water, then groundwater (after infiltration) due to			▶ Fragilization, yield reduction and destruction of	

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
rainfall, flooding		the leaching of pollutants onto the soil, the flooding of latrine pits and the increase in volumes discharged without treatment (saturation of wastewater treatment plants where they exist). ▶ Poor infiltration of rainfall into the ground during heavy rainstorms: water no longer infiltrates but runs off, creating areas of flooded areas		▶ Contamination or degradation of resources by o uncontrolled stormwater runoff o submersion or groundwater flooding of pits containing pollutants o infiltration (through soil or disused boreholes) of flood water in groundwater o rising groundwater mobilizing microbial and chemical contaminants o more rapid transport of subsurface water (rising water tables and soil infiltration) o Interruption of service due to	installations : flooding of wells, wells silting, equipment electrical submerged, erosion of structures, rupture of pipes, network leaks , etc. ▶ Catastrophic failure of dams, leading to reduced storage capacity and potentially damaging releases of water.	
Storms (including sand and dust storms)	Low exposure					

Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
				damage to installations o Inaccessibility to water points (landslides - flooding) o Fragilization of storage by saturation		
Erosion (which can also be induced by floods and water runoff) and landslides	Highly exposed			▶ Degradation of raw water quality due to more polluted run-off, with silt and nutrients ▶ Potential intrusion of contaminants through damaged infrastructure Potential loss of service due to damaged infrastructure	▶ Fragilization and destruction of installations	
Increased water salinity	Moderately exposed	Reduction of water quality	No possibility to consume water containing a certain level of salt, which is no longer fit for drinking	▶ Degradation of raw water quality ▶ Potential intrusion of contaminants through damaged infrastructure ▶ Potential loss of service due to	▶ Fragilization and destruction of installations: o leaching of metal o corrosion o increased sediments in pipes	

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Climate hazard	Global county exposure	Water Resource	Water consumption	Service Quality	Impacts on infrastructure	Social impact
	🟧			damaged infrastructure		

Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (C. Agudelo-Vera et al. 2020), (Alain Mailhot et Sophie Duchesne 2005), (Ps-Eau 2018)

Table 13: Links between climate change and wastewater management services

Climate hazard	Global county exposure	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Droughts, water shortage	Moderately exposed	▶ Movement and damage of infrastructure related to changes in soil moisture levels	▶ Degradation of resource quality through reduced dilution of pollutants	▶ Reduced water for irrigation may lead to increased wastewater use, and use of polluted waters. ▶ Less water to clean toilets which can become unsanitary
Heat wave	Moderately exposed	▶ Dysfunction of biological treatment processes (mortality of certain bacteria). (Ideal WW treatment temperature range being [20 - 35°C] not exceeding 40°C) ▶ Heat-induced degradation of infrastructure and equipment. ▶ Degradation of concrete due to increased production of hydrogen sulfide2 (H_2S)	▶ Degradation of quality of resources through less well treated discharge	▶ Poisoning from inhalation of hydrogen sulfide (H_2S), which is produced more frequently by heat (safety risk for personnel, especially sewage workers). ▶ Odor nuisance due to increased nitrogen dioxide (N_2O) emissions
Intense and sudden rainfall, flooding	Moderately exposed	▶ **Submergence failure** of pumps and other electrical systems in treatment plants , rendering out of service. ▶ **Septic tanks filling and backing up; backing up of sewers** ▶ **Fragilization and destruction of installations** o sewers: (scouring or washout of bedding, and flotation	▶ **Increase of untreated water in the natural environment** due to penetration of rainwater into the wastewater network causing overflowing, saturation of pumps and bypass at wastewater treatment plants ▶ **Reduction of pollutants loads and resuspension,** leading to difficulties in treatment process	▶ **Population without sanitary facilities** ▶ **Increase in water-borne diseases** due to the risk of contact with water containing pathogens
Storms (including sand and dust storms)	Low exposure			

Climate hazard	Global county exposure	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
	🟨	leading to cracking of the sewer pipes) ○ septic tanks flotation ▶ destruction of latrines not built to sustain such hazards (impact on access rates may be significant) ▶ **Disruption of emptying services** (difficulty access, necessary increase in frequency...)	▶ **Treatment process dysfunction** (hydraulic overload) ▶ **Mixed flow of wastewater and rainwater on public roads** as a result of flooding of latrine and toilet pits, with consequent health risks ▶ **Inundation of soak away or pit from below**, increased potential for contamination of groundwater.	
Erosion (which can also be induced by floods and water runoff) and landslides	Highly exposed	▶ Exposing and damaging pipe work, especially simplified sewerage.		

Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (Walchem s.d.), (Ps-Eau 2018)

Table 14: Links between climate change and drainage services

Climate hazard	Global county exposure	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Intense and sudden rainfall, flooding	Moderately exposed	▶ Excessive water and submergence lead to ineffective stormwater management systems which in turn lead to impacts on water and wastewater services: o flooding of equipment, o overflow of wastewater networks, o water contamination	▶ Damage to (or destruction of) buildings including houses ▶ Cascading hazard risk increase (erosion, landslide, water contamination) ▶ Cutting of communication routes and disruption of many other network services (electricity, telephone, etc.) ▶ Disruption/stoppage of economic activities	▶ Displacement of populations whose homes no longer usable ▶ Recurrent damage to private and public property ▶ Accidents, personal injury injuries and drowning due to the risk of being caused by the current, landslides and collapses and traffic accidents ▶ Disease transmission through: o use of contaminated water for domestic purposes o development of disease vectors such as mosquitoes, rats, etc.
Storms (including sand and dust storms)	Low exposure			

Source: (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (Alain Mailhot et Sophie Duchesne 2005)

While the tables above enable to get a good grasp of infrastructures vulnerability to climate hazards in Murang'a, additional items from field visits can highlight the issues that are already faced in the County:

5.1.2.1.1 Flood and heavy precipitation

During field visits, flooding and heavy rainfall were not mentioned extensively as having a direct impact on infrastructure, but their impact on increasing landslides was raised on several occasions.

5.1.2.1.2 Droughts and water shortages

Again, droughts have not been mentioned during fieldworks, however water availability reduction during dry seasons was highlighted. Indeed, during prolonged dry periods, water levels in the Irate River drop significantly. To sustain downstream flows, outfalls at the intake reservoir must be opened, which in turn limits the volume of water available for abstraction.

5.1.2.1.3 Landslides and erosion

In Gachocho area of Kigumo Sub-county, an area characterized by hilly and steep slopes landslides and rock falls have already led to damages on infrastructures. Discussions undertaken in august enables raised the point that unstable slopes along the pipeline corridor have repeatedly damaged nearly 1 km of the transmission line hence cutting of water supply and leading to increased maintenance costs. The May 2018 landslide was particularly destructive, damaging key infrastructure including the NIB pipe, Murang'a pipes, and the Maragua line. Ongoing rockfalls, compounded by explosions and blasting activities in the area, continue to threaten the system's stability. Similar threats to HDPE pipes were observed in Kiarathe requiring relocating pipes.

Figure 50: Water Supply HDPE pipes anchored by reinforced concrete anchors along the foot of the slopes to deter impacts of landslides and rock fall at Irate Intake. Second photo also shows evidence of poor slope clearance and cultivation.

Source: Fieldwork, September 2025

Figure 51: Relocated pipes running along River South Mathioya valley in Kiarathe with river crossing fitted with GI pipes from the joint chambers and also firmly anchored by concrete reinforced anchors.

Source: Fieldwork, September 2025

Agricultural activities practiced on upstream slopes can drive erosion and landslides, which can in turn, as mentioned above, result in direct damage but also in siltation of specific areas. This has been observed with the Kangema upstream slopes that are being used for agriculture and lead to siltation of the intake reservoir of Irate Intake, reducing its storage capacity and limiting the efficiency of water abstraction.

Figure 52: Shrinking Irate Intake reservoir capacity as a result of siltation caused by soil erosion

Source: Fieldwork, September 2025

These hazard's impacts on infrastructure not only cut off water supply for residents and damage the materials but also force the water company to divert resources from planned activities to emergency response and customer relocation, disrupting budget estimates. This not only inflates operational costs but also delays or limits expansion projects, constraining the company's overall progress.

This was particularly raised by Gatamathi Water Supply company.

Figure 53: Gathamati water and sanitation company visit

5.1.2.2 Understanding of proposed investments

At the time of writing this report, the information provided on the investments proposed by Murang'a County and their typology is very limited. The following steps will therefore give an overall idea of the analysis process that will need to be carried out in greater depth as the investment projects are implemented.

The only investment type on which the Consultant has received information on the location is "water distribution" which can cover Water supply intake/treatment/main and distribution pipes/meters/water-kiosk or connection (construction and expansion). The following activities can be undertaken for such investment development:

- Feasibility study including surveys, planning, and design
- Environmental and social impact assessment (ESIA)
- Improvement and expansion of intake work at water treatment facilities
- Solarization of water intake systems
- Construction of pipelines (rising mains and distribution lines)
- Construction and rehabilitation of elevated steel and plastic water tanks
- Construction of boreholes and equipping them with solarized pumps
- Construction of water kiosks and provision of automated systems
- Installation of water meters (consumer meters, zonal meters)
- Drilling and equipping of boreholes to supplement water supply
- Rehabilitation and expansion of treatment works
- Installation of pumps and auxiliary systems
- Installation of last mile water supply connections
- Site clearance, fencing, and de-silting of water pans and silt traps
- Construction of water draw-off systems
- Construction of livestock troughs and VIP toilets
- Supply and installation of rising mains and distribution pipelines
- Construction of water kiosks with automated features
- Rehabilitation of existing water infrastructure
- Procurement and installation of smart zoning meters
- Construction of auxiliary structures (e.g., perimeter fences, latrines)
- Construction and rehabilitation of auxiliary works at water facilities
- Automation of water kiosks for efficient operation
- Supply and installation of storage tanks and other infrastructure components
- Supply and installation of distribution and transmission pipelines
- Construction of water treatment and filtration systems
- Implementation of water security measures (e.g., fencing and perimeter security)
- General construction and installation of essential infrastructure for water supply

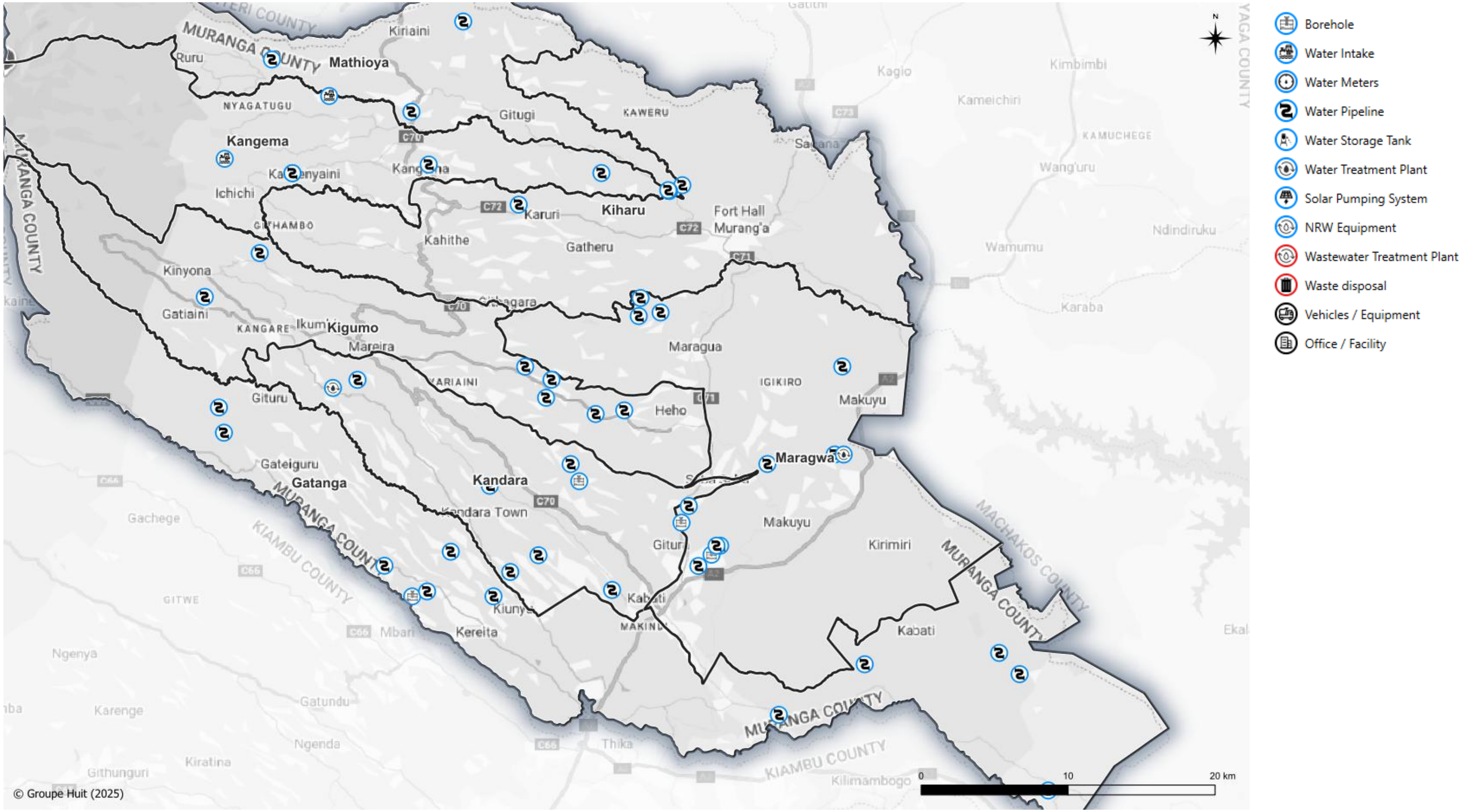

Figure 54: Murang'a County proposed investments map

Figure 55: Gatamathi proposed investments map

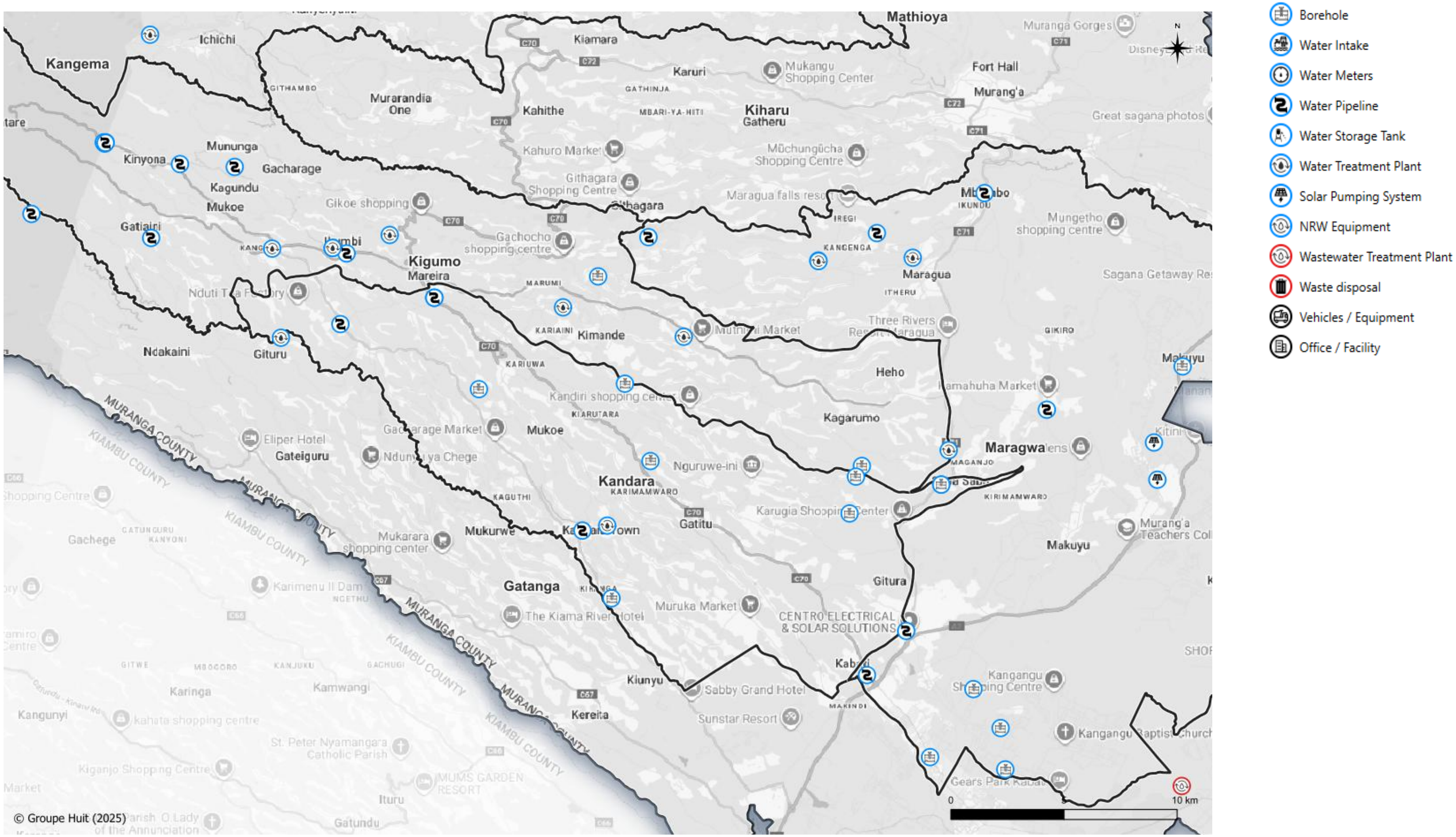

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Figure 56: MUWASCO proposed investments map

5.1.2.3 Exposure of proposed investments

5.1.2.3.1 Overall exposure

The following maps show the hazard exposure of proposed investments. Only main hazards with an intensity that can be geographically differentiated have been presented on the map. Indeed, sand and dust storms, pest and diseases, heat stress and drought hazards are considered to be present in all areas of the county and are thus not reported on the mapping, they will nonetheless have to be duly considered for adaptation of proposed investments.

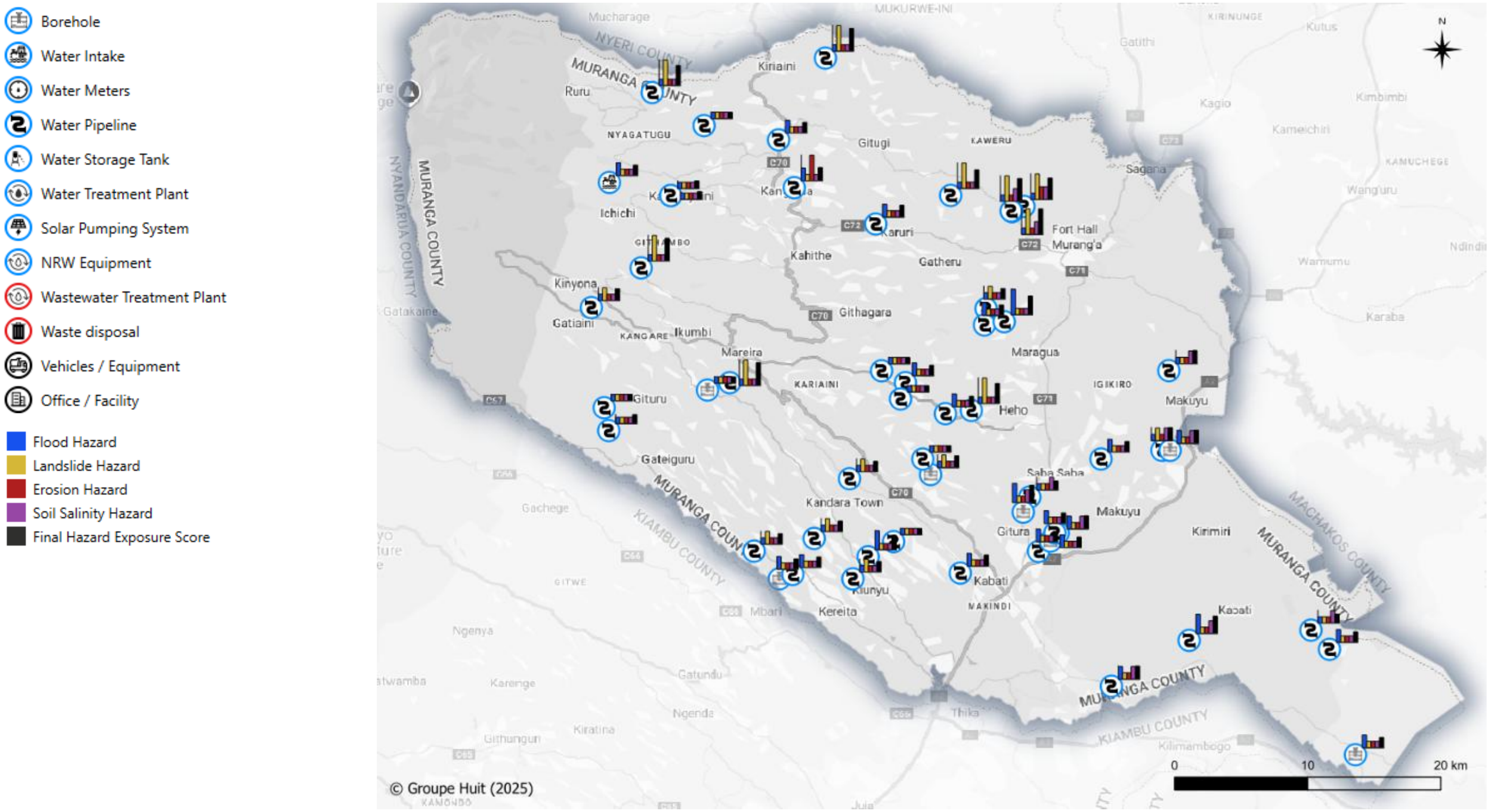

Figure 57: Murang'a County proposed investments hazard exposure map

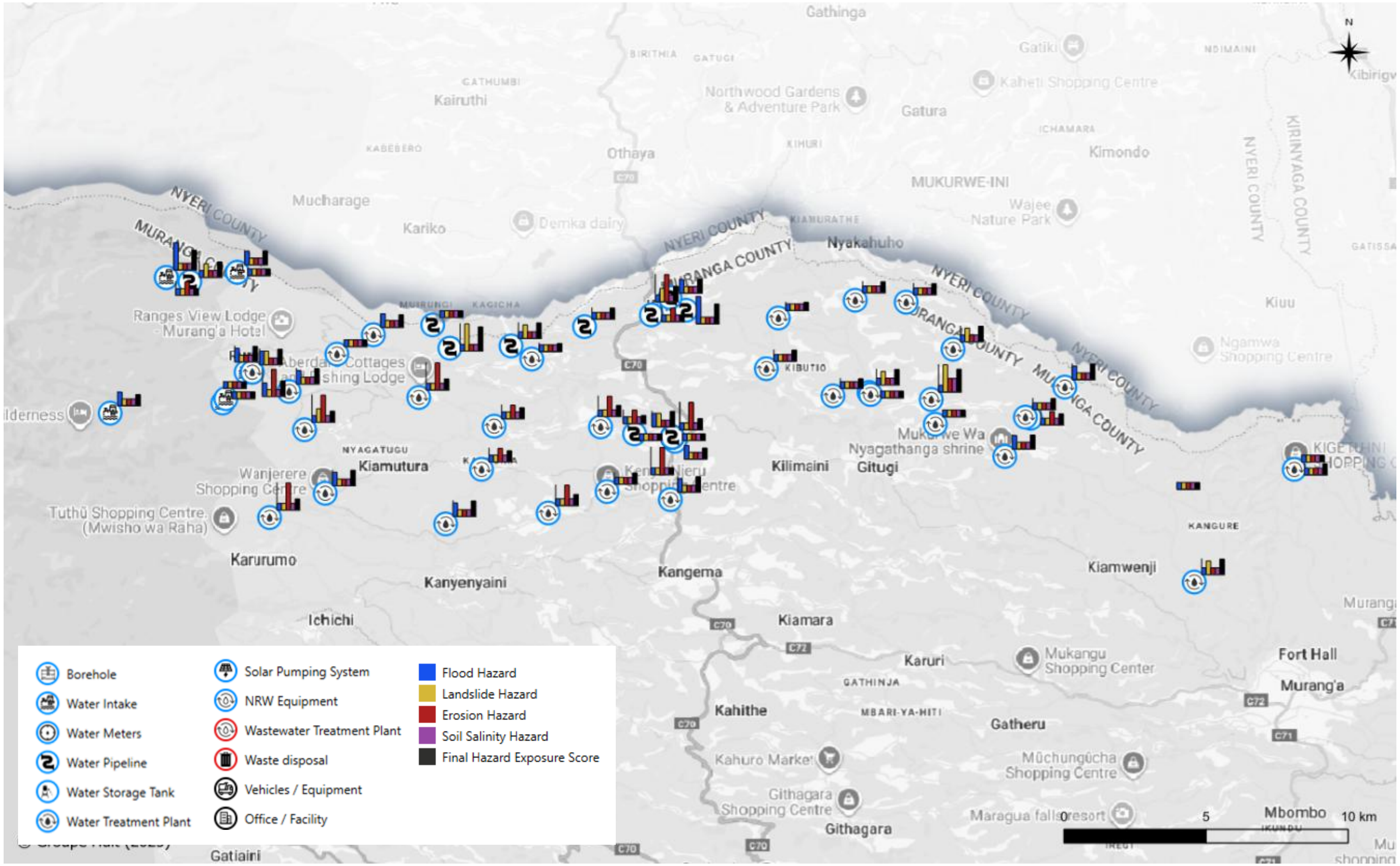

Figure 58: Gatamathi proposed investments hazard exposure map

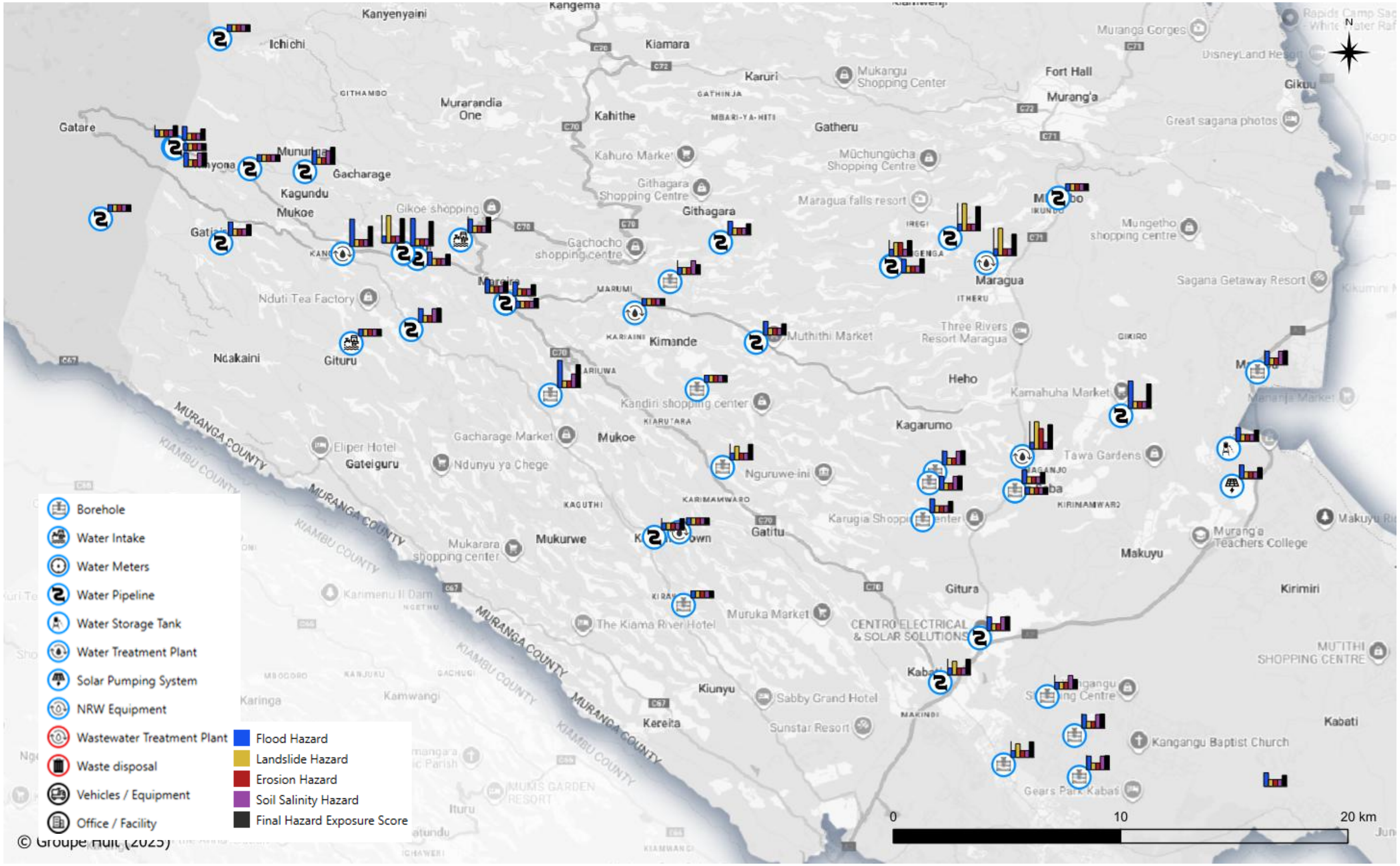

Figure 59 : MUWASCO proposed investments hazard exposure map

The following table emphasizes the planned projects which are the most impacted by hazards. The overall analysis was consolidated into a single climate hazard exposure score (*final exposure level*), assigning higher weights to flood and salinity hazards, as these emerged as the primary concerns raised during field consultations.

The composite score is defined as:

Final exposure level = 3*Flood hazard + 3*Landslide hazard + 2* salinity hazard + 1*Soil Erosion hazard

To ensure comparability across hazards, each individual hazard layer was normalized to a common scale prior to combination, and the resulting final exposure level was subsequently normalized to range from 1 (very low exposure) to 4 (very high exposure).

This approach provides an integrated representation of multi-hazard exposure, emphasizing the relative influence of flood and landslide exposure while still accounting for salinity and soil erosion as a contributing factor to overall vulnerability.

Table 15: Most impacted planned projects by hazards

Project Description	Type of Network	Works Category	Source	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Landslide Hazard (1-4)	Erosion Hazard (1-4)	Soil Salinity Hazard (1-4)	Final exposure level
Yakerengo Nyakianga Mainline Water Project - Laying of water distribution pipelines, installation of plastic mold water storage tanks	Water Supply	Water Pipeline	County	1	NO	1	4	1	2	4.00
Bore-Kiahuti-Kinyona W/P- Laying of Gravity water distribution pipeline	Water Supply	Water Pipeline	County	1	NO	1	4	1	1	3.57
Yakarengo-Gitugi W/P 2- Laying of a water mainline 225 mm diameter	Water Supply	Water Pipeline	County	1	NO	1	4	1	2	3.57
Gikindu-Kandabibi Kamacharia w/p- Laying of gravity water distribution pipelines	Water Supply	Water Pipeline	County	1	NO	1	4	1	1	3.57
Kianduguri-Karangi -Ruch W/P- Laying of gravity water distribution pipelines	Water Supply	Water Pipeline	County	1	NO	1	4	1	1	3.57
Completion of the Kamagoko-Kiria-ini Main line and connection to existing 3 number tanks (Muriga,Gatundu,Kagiri) and extension of 160mm pipeline from Kagicha junction to Texas and from Kiria-ini Equity bank to Ngurwe-ini shopping center	Water Supply	Water Pipeline	Gatamathi	1	NO	1	4	1	1	3.57
Rehabilitation of Chathanda intake, CFU and system rehabilitation	Water Supply	Water Intake	MUSWASCO	1	NO	1	4	1	1	3.57

Project Description	Type of Network	Works Category	Source	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Landslide Hazard (1-4)	Erosion Hazard (1-4)	Soil Salinity Hazard (1-4)	Final exposure level
Construction of Gaichanjiru water project for Gaichanjiru ward and Kenol from Chathanda river	Water Supply	Water Pipeline	MUSWASCO	1	YES	4	1	1	1	3.57
Construction of Maragua ridge water project of 250mm diameter HDPE Pipeline for 25Km	Water Supply	Water Pipeline	MUSWASCO	1	NO	1	4	1	1	3.57
Makuyu water distributions	Water Supply	Water Pipeline	MUSWASCO	1	YES	4	1	1	1	3.57
Construction of Sewerage treatment infrastructure in Sabasaba	Water Supply	Water Treatment Plant	MUSWASCO	1	NO	1	4	3	1	3.57
Kiambugi-Mugecha-Guri W/P- Laying of Gravity water distribution pipeline	Water Supply	Water Pipeline	County	1	NO	1	4	2	2	3.36
Cold water meters (DN15mm,DN20mm,DN25mm)	Water Supply	Water Meters	Gatamathi	1	NO	1	4	4	1	3.36
54 number Decentralized Treatment Facility at 25,000,000.00	Water Supply	Water Treatment Plant	Gatamathi	1	NO	1	4	2	2	3.36
Kibage Borehole	Water Supply	Borehole	MUSWASCO	4	NO	4	1	1	2	3.36

The full project's list with detailed hazard exposure scores is provided in annex 6 of the present report.

Main outcome of the global view of hazard exposure is the fact that all the county is exposed to the landslide hazard with a moderate to high exposure. Vulnerability of infrastructure can be considered high as landslides tend to lead to complete destruction of water supply and sanitation infrastructure, this will have to be duly considered in infrastructure design.

Concerning soil erosion hazard exposure is medium, when crossing this with above analyses it remains a hazard to be duly considered, especially as its combination with floods can also reveal landslide risks. Considering that the sensitivity of water supply and sanitation infrastructure to such hazard (erosion) is not great it is expected that the hazard is considered in the design of investments while not being a main area of focus, landslide on its end will have to be considered in the selection of investments location as designs cannot be adapted easily to landslides.

Salinity hazard exposure is considered low to inexistent, in areas where the proposed investments have been mapped, nonetheless the Eastern area of the county is exposed and if investments are to be made there it will have to be considered, especially considering high sensitivity of water supply and sanitation infrastructure to such hazard.

As mentioned therebefore flood mapping based on opensource data appears a bit weak for Murang'a and a complete model would be needed to better assess the risk. The Consultant has refined mapping[3] to highlight that some infrastructures are exposed (low exposure). It should be underlined that all

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[3] Reviewed flood exposure scoring manually to improve the analysis.

infrastructures in the vicinities of rivers would be exposed to floods, we would consider them moderately to **highly exposed to flood risk**. As not all proposed investments are mapped it is hard to assess which ones would be exposed exactly at this stage. Here again vulnerability of proposed infrastructure to floods is quite important and combined with a high exposure it will lead to a great risk; therefore, attention will be specifically brought on this topic for the definition of adaptation options.

Exposure scoring is based on hazard intensity, allowing for a relative comparison of risk levels across the county. Nonetheless, as mentioned before, the county's proposed investments are also **moderately exposed to droughts and heat waves** to which water supply and sanitation are quite sensitive but to which they can also be a means of adaptation. This duality will have to be duly considered in the adaptation options and climate proofing of proposed investments. It is also understood that some investments already fulfil the purpose of increasing adaptation to such hazards (water pans, water tanks, water storage, etc.).

5.1.2.3.2 Specific exposure mapping – Present situation

While the above maps display a summary version of the exposure analysis of proposed investments in Murang'a County it is based on hazard-per-hazard exposure mapping. Such mapping is available in GIS format and maps are provided below.

In order to ensure proper climate proof of each proposed investment it will be most useful for design teams to take a closer look at each hazard exposure layer regarding the specific investment being studied. Indeed, the above analysis was developed at county scale which, considering the size of the county, may lead to some approximation, also as it is based on satellite data and does not always consider local knowledge it can lack relevant information on past events.

Landslide exposure

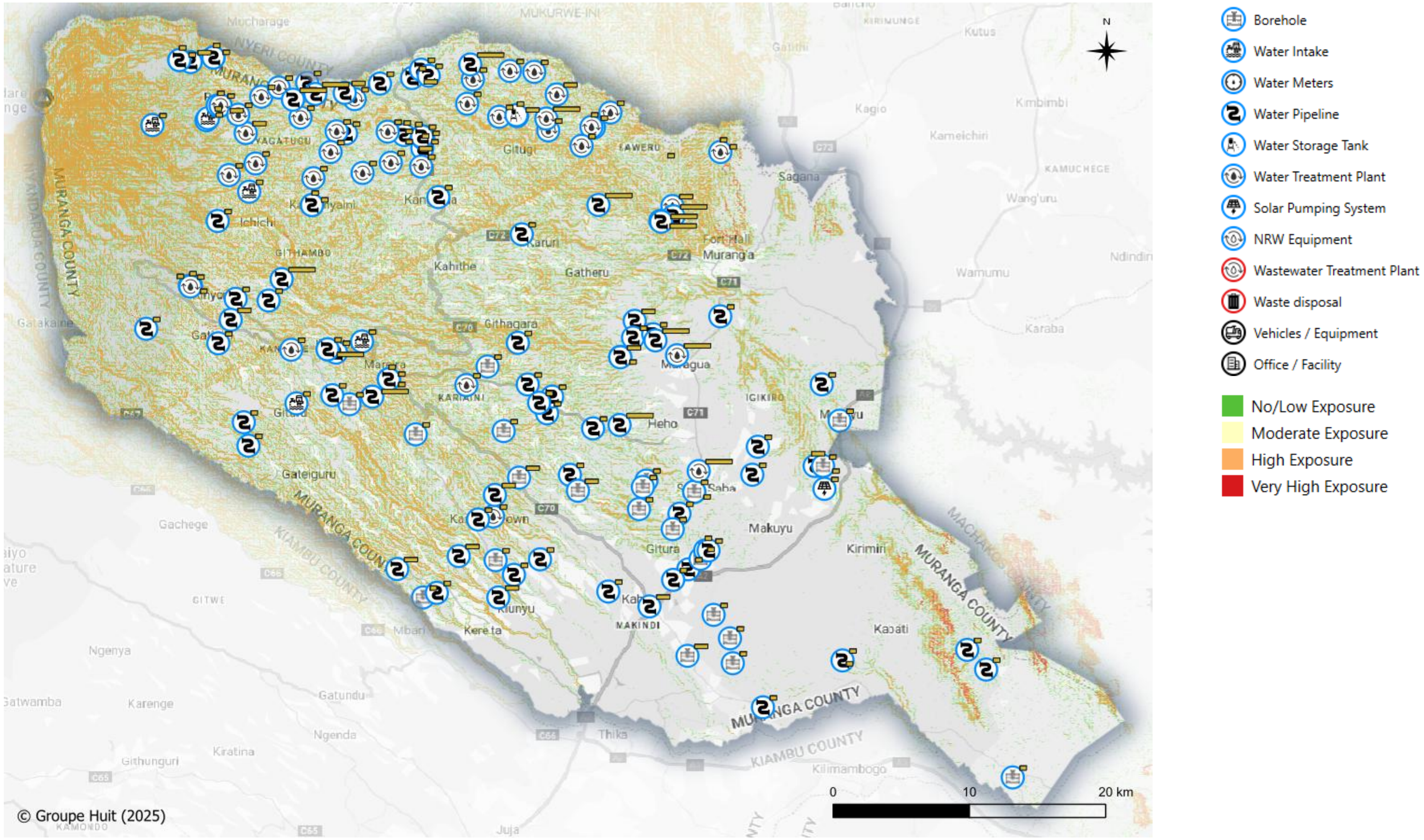

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Figure 60: Murang'a proposed investments exposure to landslide hazard

Erosion exposure

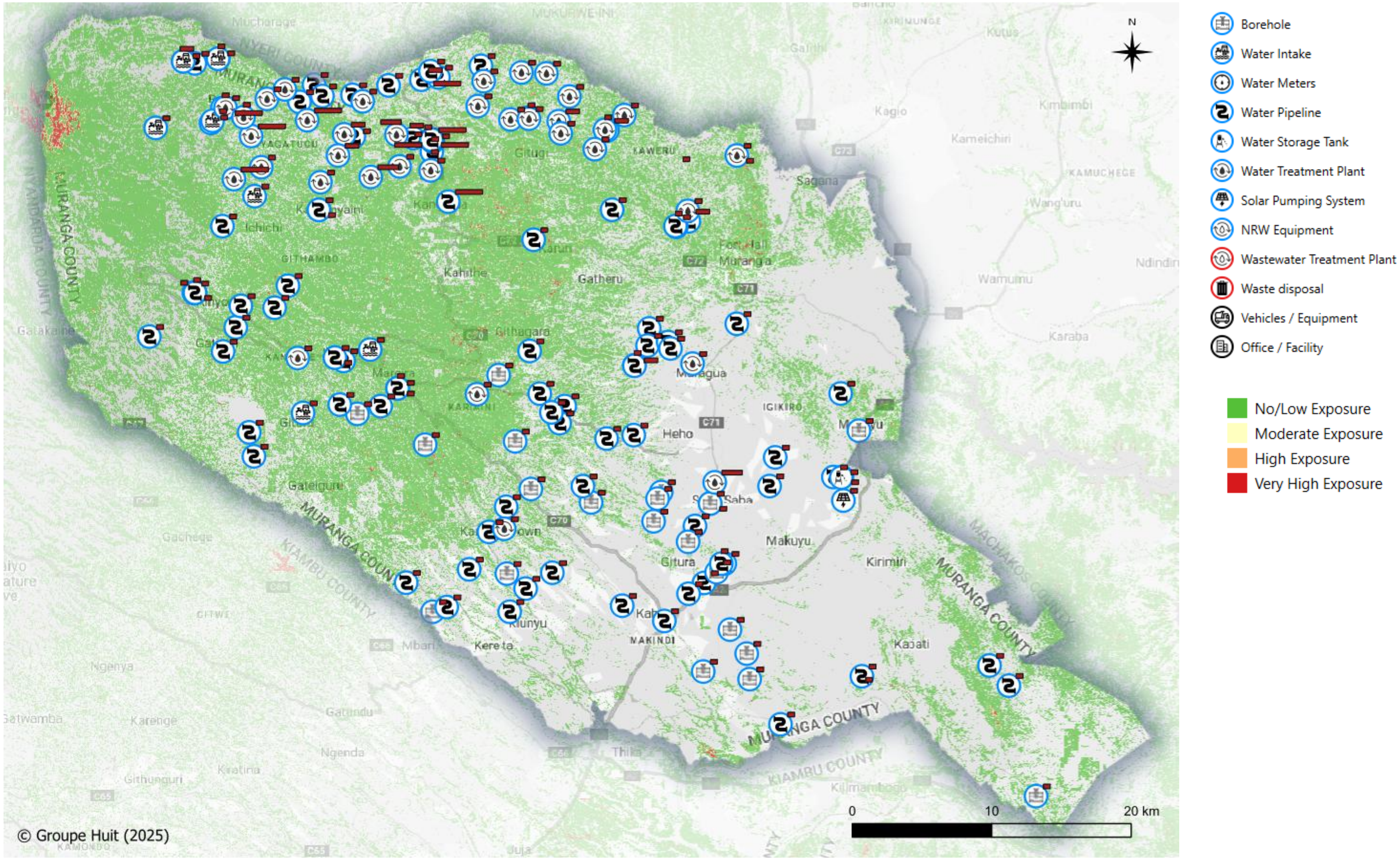


Figure 61: Murang'a proposed investments exposure to erosion hazard

Pluvial and river flooding hazard exposure

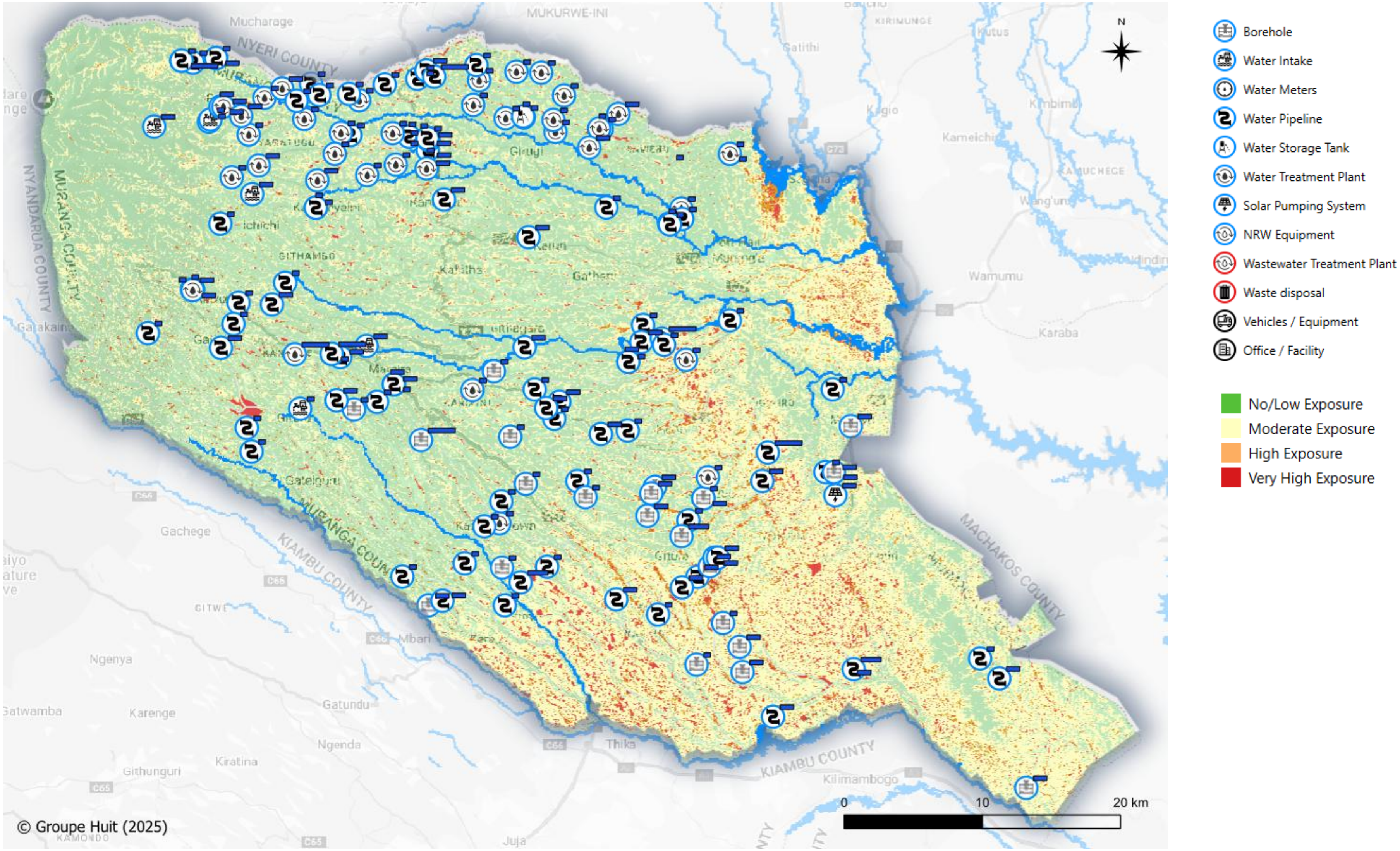


Figure 62: Murang'a proposed investments exposure to flood hazard

Salinity exposure

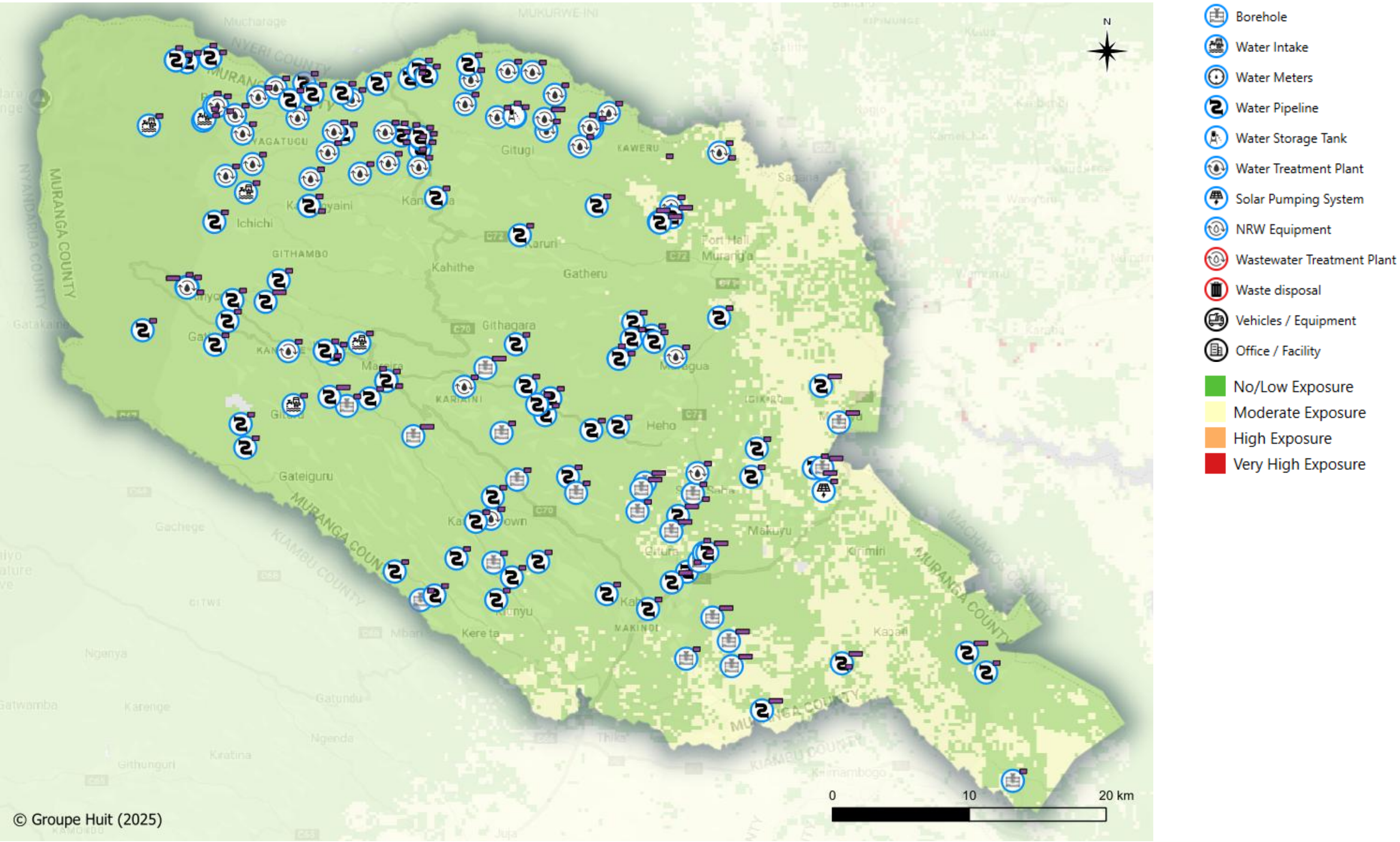


Figure 63: Murang'a proposed investments exposure to soil salinity hazard

5.1.2.4 Impact of climate change

5.1.2.4.1 Climate signal for Murang’a to 2050

Observed records and projections point to three robust signals:

- **Rising temperatures**: Kenya is projected to warm by around **2–3°C by mid-century** under intermediate/high emissions scenarios, with stronger warming in central highlands.
- **More intense rainfall and heavy events**: IPCC AR6 and regional studies indicate that **heavy precipitation frequency and intensity will increase across East Africa**, including central Kenya. Recent seasons already show record MAM rainfall and flash floods in central Kenya and the Upper Tana.
- **Slightly wetter annual balance in central Kenya**: Climate profiles for Kenya suggest a **modest increase in annual rainfall and wetter climatic water balance** in the central highlands, albeit with strong interannual variability and more intense short-duration storms.

When translated into our indicators, this means for Murang’a by ~2050:

- **Tmean, TXx, tropical nights, heat-index days: increasing** → more heat stress (people, O&M staff, equipment) and higher evapotranspiration.
- **PRCPTOT, Rx1day/Rx5day, R20mm, CWD: increasing** → more frequent and more intense flood and landslide triggers; stronger erosion and sediment transport.
- **CDD: slightly decreasing** and **SPEI: generally wetter**, especially in the mid- and upper catchment → tendency to reduce salinization risks, though local groundwater salinity can remain high.
- **RH: increasing** → higher discomfort, more corrosion and biological fouling in infrastructure.

5.1.2.4.2 Specific climate impacts on WASH infrastructure in Murang’a

The table in the next page presents the specific impacts of climate change on projected infrastructure.

A preliminary list of recommendations for adaptation to climate change is provided in annex 7 of the present report, further recommendations will be provided in the following adaptation options report.

Hazard	Key Climate Drivers	Asset Type	Main Impact Mechanisms	Typical Physical Consequences	Operational / Service Impacts
Floods	↑ PRCPTOT, ↑ R20mm, ↑ Rx1day/Rx5day, ↑ CWD	Gravity & bulk pipelines	Riverbank and gully erosion at crossings; scour at culverts and bridge supports; slope wash-out	Pipe exposure, sagging, rupture; loss of bedding and backfill; burial or collapse of pipe sections	Increased leakages; higher NRW; repeated emergency repairs; longer service interruptions
Floods	↑ PRCPTOT, ↑ R20mm, ↑ Rx1day/Rx5day, ↑ CWD	Intakes, weirs, small dams	Higher flood peaks causing overtopping and structural loading; debris and sediment surges	Structural cracking; scour of foundations; blockage of intake screens and grit chambers	Frequent shutdowns; increased desilting and maintenance costs; reduced raw water reliability
Floods	↑ PRCPTOT, ↑ R20mm, ↑ Rx1day/Rx5day, ↑ CWD	Treatment plants, storage tanks, DTFs	Inundation from riverine and pluvial flooding; surcharge of sewers and drains	Damage to electro-mechanical equipment; short-circuiting; water ingress into control panels; access road washouts	Emergency plant shutdowns; risk of untreated discharges; public-health incidents; higher downtime
Floods	↑ PRCPTOT, ↑ R20mm, ↑ Rx1day/Rx5day	Boreholes & headworks	Pluvial flooding around wellheads; surface run-off ponding	Compromised sanitary seals; infiltration of turbid or contaminated water	Deterioration in water quality; need for shock chlorination; potential well abandonment
Landslides	↑ Rx1day/Rx5day, ↑ PRCPTOT, ↑ CWD	Mountain pipelines and last-mile extensions	Saturation of slope materials; shallow and deep-seated slope failures	Exposed, bent, displaced or buried pipes; trench collapse	Long outages, expensive rerouting and slope stabilization works; isolation of upstream communities
Landslides	↑ Rx1day/Rx5day, ↑ PRCPTOT, ↑ CWD	Intakes and weirs in steep channels	Bank failures; debris flows impacting structures	Undermining of anchor blocks and foundations; damage to access paths	Increased maintenance frequency; reduced reliability during rainy seasons
Landslides	↑ Rx1dayCons/Rx5day, ↑ PRCPTOT, ↑ CWD	Access roads and service tracks	Slope failures and cut-slope collapses	Road blockages; edge failures; loss of shoulder support	Delayed emergency repairs; higher O&M costs;

Hazard	Key Climate Drivers	Asset Type	Main Impact Mechanisms	Typical Physical Consequences	Operational / Service Impacts
					extended service interruptions
Erosion & Sedimentation	↑ PRCPTOT, ↑ Rx1day/Rx5day, ↑ R20mm, ↑ CWD	Catchments upstream of intakes	Accelerated sheet, rill and gully erosion; bank erosion	Higher sediment yield; bank retreat; bed aggradation	Need for catchment interventions; more frequent dredging and desilting
Erosion & Sedimentation	↑ PRCPTOT, ↑ Rx1day/Rx5day, ↑ R20mm	Intakes, reservoirs, desilting basins	Sediment deposition and deposition surges	Siltation of reservoirs; reduced storage volume; clogged grit chambers	Reduced water availability; higher O&M burden; reduced asset life
Erosion & Sedimentation	↑ PRCPTOT, ↑ Rx1day/Rx5day, ↑ R20mm	Treatment plants	Elevated raw-water turbidity; higher suspended solids	Abrasion of pumps and valves; higher sludge volumes	Increased chemical and energy costs; more frequent backwashing; faster wear of equipment
Soil & Water Salinity	↑ PRCPTOT, ↓ CDD, ↓ SPEI (wetter balance)	Irrigated command areas and recharge zones	Enhanced salt leaching	Lower salinity accumulation in topsoil and shallow aquifers	Lower medium-term risk of secondary salinization
Soil & Water Salinity	Local geology and abstraction dominate	Boreholes in saline aquifers (e.g. Sabasaba, Karugia)	Upconing of saline groundwater; geogenic salt release	Persistently high EC and TDS in pumped water	Need for desalination, blending or abandonment
Soil & Water Salinity	High ET + poor drainage in lowlands	Low-lying irrigated areas	Localized salt build-up during dry spells	Patchy salinity hotspots	Local restrictions on use of groundwater for WASH

Note: Mean Temperature (Tmean), Maximum Temperature (TXx), Total Precipitation (PRCPTOT), Extreme Rainfall (Rx1day / Rx5day), Number of Days with Precipitation >20 mm (R20mm), Consecutive Wet Days (CWD), Consecutive Dry Days (CDD), Relative Humidity (RH), Drought / Aridity Index (SPEI)

Cross-cutting service and health implications are as follows:

- **More frequent service interruptions** from flood- and landslide-related damage, especially for long gravity systems with limited redundancy.
- **Higher treatment complexity and costs** due to turbidity peaks, more variable raw water quality, and occasional contamination of boreholes and springs.
- **Public-health risks** from combined flooding and sanitation failures (DTFs, sewers, septic systems), with increased potential for diarrheal disease outbreaks following storm events.
- Operational challenges in extreme heat and humidity for staff and equipment (e.g. derating of pumps, more frequent overheating of electrical components, shorter lifespan of some plastics).

5.1.3 WSS / WASH sector contribution to climate change

It should be understood that the WSS/ WASH sector is not only impacted by climate change but also contributes to it, either by:

- Emission of GHG gases (see annex 8)
- Anthropogenic shift of hydrologic patterns (dams, groundwater extraction, modification of water runoff etc.) which can itself lead to other phenomena such as subsidence, floods, erosion, etc.

Infrastructure should then be designed to both adapt to climate change but also mitigate it.

5.1.4 Conclusion

Climate change poses a broad range of risks to water, sanitation, and drainage infrastructure, impacting both service delivery and the physical resilience of systems in Murang'a County. **Key hazards such as landslides, erosion, droughts, heatwaves, flooding, and salinity lead to service interruptions, degraded water quality, and increased strain on equipment.** These effects are compounded by rising water demand across domestic, agricultural, and industrial sectors, while fragile infrastructure faces heightened risks of damage—such as cracked concrete, corroded pipes, and equipment failures. Social impacts include longer water-fetching distances, increased disease outbreaks, and population displacement, particularly during water shortages or floods. Wastewater and drainage systems are equally vulnerable, with flooding often leading to system overflows, contamination of water sources, and exposure to untreated sewage, all of which threaten public health and environmental quality.

In response, the CWSSIP which proposes a wide range of infrastructure investments aimed at improving climate resilience across Murang'a County also has to be adapted for its proposed investments to be able to face these challenges as well.

These proposed investments include the construction of treatment facilities (water supply and sewerage treatment, including DTF)), dams, last mile connectivity (could be water kiosk or household connection, not specified), the purchase of vacuum trucks, consumer meters, alongside the repair and upgrading of existing water supply pipelines and rehabilitation of boreholes and water intakes (going solar for some boreholes).

While the CWSSIP provide information on broad location (sub-county or companies' scope) they do not provide exact location considered. Therefore, as these investments have not all been specifically located on hazard exposure maps it will be needed to refine the analysis once the county has more information regarding its investments. It is also a way to avoid implementing these in highly exposed areas. Generally, the hazard exposure mapping should help guiding investment siting and design, though **final decisions must also consider infrastructure sensitivity and local social contexts.** Many proposed interventions—like water storage systems and decentralized treatment facilities—not only require climate-proofing but also serve as adaptive responses to climate stressors such as drought and water scarcity.

5.2 Social and Sectoral Vulnerability

5.2.1 Human health

5.2.1.1 General

Climate change through both its slow onset trends and the related extreme events present climate-sensitive health risks such as mortality and injuries from extreme weather events, heat related illness, respiratory illness, water-borne related illness, vector-borne diseases, malnutrition, etc.

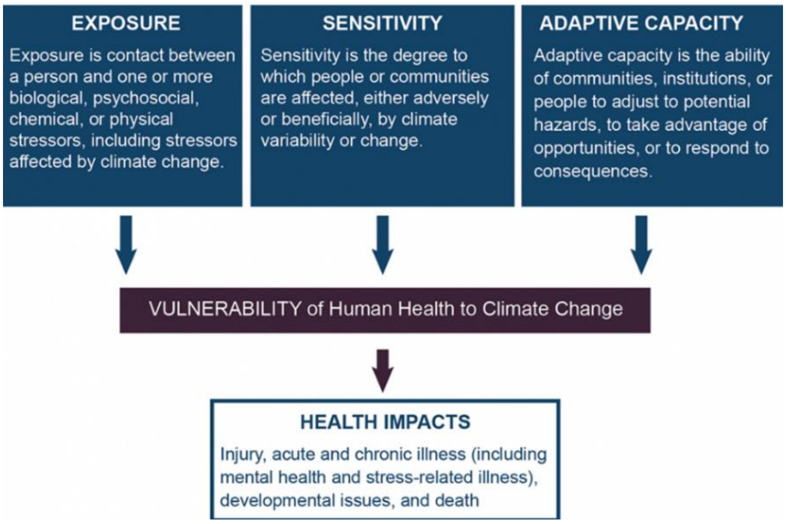


Figure 64: Determinants of Vulnerability

Source: adapted from Turner et al. 2003 in (People Who Are Vulnerable to Climate Change 2024)

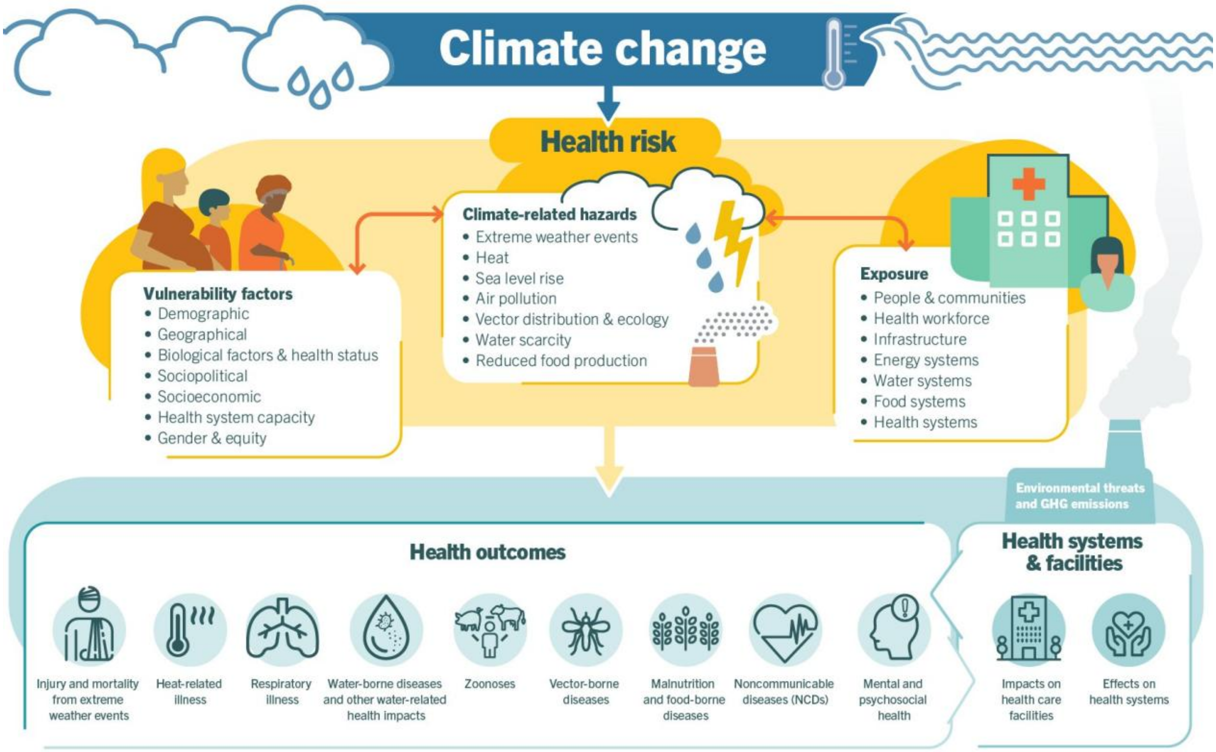


Figure 65: An overview of climate-sensitive health risks, their exposure pathways and vulnerability factors. Climate change impacts health both directly and indirectly, and is strongly mediated by environmental, social and public health determinants.

Source: World Health Organization

5.2.1.2 WSS and WASH sector specifics

The impacts of climate change on the water and sanitation sector affect human health in many ways, mainly through water quality and quantity. These effects are mainly linked to food-borne, water-borne and vector-borne diseases, as well as malnutrition in the event of crop failure.

5.2.1.3 Vulnerable groups

Health impacts can be disproportionately felt by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions.

In the project case it should be underlined that informal workers are usually part of one or more of the above-mentioned groups and therefore not only are the occupational health and safety risks they are facing increasing due to climate change, but they also face general/community climate-sensitive health risks mentioned therebefore. In the WSS sector some of the most exposed workers are desludgers.

5.2.2 Agriculture

Agriculture is an important activity for 70% portion of the county's population, directly or indirectly employed by the sector. The success of agricultural activities, especially crops and livestock, is highly dependent on climate, especially rainfall.

The main hazards related to climate change in the county (flooding, landslides and erosion and heat stress and drought) have a negative impact on agriculture, which can lead to an increase in poverty and hunger.

- Flooding leads to the loss or poor productivity of crops and livestock and changes crop patterns.
- Soil and water salinity increase in fertile farms lead to reduced productivity of crops and fruit trees.
- The reduction in the amount of rain and the total failure of rainfall leads to droughts, which in turn increase the prevalence of pests and diseases, negatively affecting crops. Water scarcity during droughts in marginal pastoral and mixed areas leads to crop failures and food shortages.

The CCAP states that “The establishment of a Kenya Climate Smart Agriculture Strategy (KCSAS) (2017-2026) in Murang’a County is a forward-thinking initiative. It not only promotes economic growth and job creation but also contributes to reducing post-harvest losses, a critical climate action. By incorporating climate-smart agriculture and improving market linkages, it enhances food security and reduces greenhouse gas emissions associated with food wastage.” Which shows that adaptation capacity is built through the implementation of KCSAS, nevertheless the clear adaptation strategy for the county is not highlighted. The KCSAS main items are:

- Specific objectives:
- Enhance the adaptive capacity and resilience of farmers, pastoralist, and fisher-folk to the adverse impacts of climate change,
- Develop mechanisms that minimize greenhouse gas emissions from agricultural production systems,
- Create an enabling regulatory and institutional framework, and
- Address cross-cutting issues that adversely impact climate smart agriculture.
- Four broad strategic areas have been identified for KCSAS;
- Adaptation and building resilience by addressing vulnerability to changes in rainfall and temperature, extreme weather events, and unsustainable land/water management and utilization,
- Mitigation of greenhouse gas emissions from key and minor sources in the agriculture sector,
- Establishment of an enabling policy, legal, and institutional framework for effective implementation of climate smart agriculture,

- Minimizing the effects of underlying cross-cutting issues, such as human resource capacity and finance, which would potentially constrain the realization of climate smart agriculture objectives.

While not clearly tagged agricultural adaptation strategies in the CIDP some items or challenges mentioned in that document will also result in an increased agricultural adaptative capacity if they are addressed such as:

- “A need to incorporate nutrition sensitive agriculture in all projects and programmes addressing food and nutrition security. This will reduce incidences of nutrition related diseases in the county, such as diabetes, hypertension and malnutrition.”
- “Indigenous technical Knowledge (ITK) if incorporated in the extension system can improve planning for farm operations.”

Multiple items derived from the lessons learnt from the First CIDP Plan Period, including the covid outbreak, will also enable to increase adaptation capacity.

5.2.3 Biodiversity and Ecosystems

Environmental degradation, changes in water resources, and the loss of biodiversity and ecosystem services pose significant challenges to the country’s development, particularly affecting the tourism sector. Rising temperatures will also negatively impact key sectors such as forestry, agriculture, and livestock. Shifts in precipitation patterns could have widespread effects on ecosystems, biodiversity, food production, and the water industry.

5.2.4 Energy and infrastructure

The energy sector in Kenya is vulnerable to climate change, particularly due to the impacts of extreme weather events and temperature fluctuations. While Kenya has diversified its energy mix, with nearly 90% from clean sources like geothermal, wind, and solar, the sector faces risks from rising temperatures, heatwaves, and storm surges. Extreme weather events, such as heavy rains, could damage infrastructure and disrupt supply lines, while rising temperatures could lead to higher cooling demands, putting stress on power plants. Additionally, sea level rise and salinity threaten coastal energy infrastructure. These climate-induced changes may affect the reliability, efficiency, and capacity of Kenya's energy generation and distribution systems, especially as cooling demands increase in urban centers.

Considering the WSS specifically the use of solar panels to operate pumps and other systems should consider the reduced efficiency of the panels in case of temperature considered too high.

5.2.5 Displacement

Hazard occurrences lead to displacement as infrastructures (households) and services (including water supply) can be disrupted in some areas. For instance, in May 2025, a landslide in Kiarathe swept away approximately 200 meters of GI pipes, disrupting water supply to the area. The disaster also displaced residents, forcing them to seek temporary shelter at an IDP camp established at Kiarathe Academy, which is managed by the local church.

Figure 66: IDP Camp housing at Kiarathe Academy

Source: Field Survey, 2025

Such displacement can lead to social negative impacts. First, displacement can be an emotional burden and threat for mental health, but it can also lead to restrictions and social tensions. In the IDP camp housing in Kiarathe : IDPs, particularly men, are subject to an 8 p.m. curfew imposed by the church, which weakens social cohesion and limits interactions. Families are also required to seek church permission to host guests, further restricting freedom. Another aspect is that some families have been separated, as siblings or relatives who lived outside the landslide zone were not enumerated and therefore excluded from housing and support within the IDP camp.

5.2.6 Disproportionately impacted groups

It is already highlighted in the human health section that some groups are more vulnerable to climate change health risks. However, cascading impacts of climate change are also expected to affect some groups differently. The level of impacts and coping strategies of populations depends heavily on their socio-economic status, socio-cultural norms, access to resources, poverty as well as gender.

Research has also provided more evidence that the effects are not gender neutral, as women and children are among the highest risk groups. Key factors that account for the differences between women's and men's vulnerability to climate change risks include gender-based differences in time use; access to assets and credit, treatment by formal institutions, which can constrain women's opportunities, limited access to policy discussions and decision making, and a lack of sex-disaggregated data for policy change.

Similar observations to the ones made on gender can be made for other undeserved groups such as disabled people, the elderly and ethnic minorities. Overall, informal workers and precarious workers are also more vulnerable as mentioned regarding health risk but also regarding financial coping mechanisms or their lack of integration into climate change strategies.

An integrated social inclusion approach is therefore also needed in climate change considerations.

Women and Disaster Vulnerability

During a disaster

Women are often involved in helping children and people with limited mobility, which delays their evacuation.

The low incomes of some women and girls do not allow them to own clothing that protects them properly (strong and covering), which can slow them down to get over barriers, into fields, etc.

Because girls often have less access to education, they are often less prepared for evacuation (e.g., in the case of floods, they may not know how to swim).

After a disaster

The women's role in managing the daily life of the household leads them to spend a lot of time collecting food and emergency supplies, fetching water, cooking, etc. preventing them to have time to hold a job or go to school.

In addition, if one of the people responsible for income or household management is missing, it is the girls who are most likely to be pulled out of school to perform these functions.

Following a natural disaster, women are more likely to be victims of domestic violence and sexual abuse, which is facilitated by proximity to shelters and increased alcohol consumption following a disaster.

They then avoid the shelters provided to the population in the disaster areas for fear of the violence they experience there and find themselves in even more precarious situations.

Women often have less social protection and access to credit and savings to absorb shocks.

Gender inequality is both a driver and a consequence of disasters impacts.

Events of extreme intensity and danger such as tsunamis, earthquakes, floods or other natural disasters highlight the vulnerability of women.

This has an impact on preparedness, evacuation, response, death toll and recovery.

This vulnerability is often linked to the role women play in society and to the cultural and gender norms in force in their country.
Women's vulnerability increases when they belong to a lower socio-economic group, especially in the South.

70% of the people who perished in the 2004 tsunami in Asia were women

Women & Resilience

Women can help identify disaster risks for themselves and girls (not always understood by male planners). They can also help increase the security of their families (by increasing their income or raising awareness of disaster preparedness).

Empowering women and including them in disaster planning creates resilience.

Including women in recovery reduces stereotypes and discrimination about women's roles.

Example: After the earthquake in Ecuador in 2016, the United Nations coordinated programs to increase women's participation in camp management; (traditionally, dominated by men). This reduced violence and gave women more control over their space. The design of small projects to change traditional gender roles and improve women's participation led to women engaging in non-traditional activities.

Source : Groupe Huit
The World Bank "What social inclusion mean for a resilient city ?",
UN "Gender responsive disaster risk reduction",
Center for Disaster Philanthropy
Photo credits: Van Hai

Figure 67: Women and disaster vulnerability

6. CONCLUSION

The Climate Risk Assessment for Murang'a County highlights a WASH system that is increasingly constrained by climate-related pressure. While the county benefits from comparatively well-developed water infrastructure and active sector stakeholders, there are vulnerabilities across water resource management, service delivery, and governance structures. Considering the exposure of the County to **erratic rainfall patterns, rising temperatures, soil salinity and increasing frequency of extreme events such as droughts, heat waves, floods, and localized landslides it can be underlined that the WASH sector is at risk from Climate Change**.

Landslides represent the most critical hazard, particularly in the western sub-counties, **while pluvial flooding** poses higher risks in the eastern areas. **Meteorological drought risk is moderate but widespread**, driven by higher evapotranspiration and increasing demand.

The water resource itself is affected by climate change both in terms of quantity (droughts) and quality (salinity, contamination) and **key WASH assets, notably transmission and distribution pipelines, latrines and water abstraction points, are highly vulnerable to these hazards**, with cascading impacts on water quality, service continuity, and public health.

Beyond physical risks, climate change has multiple **social impacts** (fetching water burden, water-borne diseases, migration, relocation and displacement) and it is **amplifying existing social and gender inequalities,** disproportionately affecting women, children, persons with disabilities, and marginalized communities. These impacts reinforce the need for climate-resilient and inclusive planning approaches that integrate technical, social, and institutional dimensions.

This assessment provides a strategic baseline to inform climate-resilient investment planning under the CWSSIP. While appropriate for county-level prioritization**, the analysis must be complemented by site-specific climate risk screening and detailed design-level assessments for each proposed investment**. The forthcoming adaptation options will translate these findings into actionable measures, enabling Murang'a County to strengthen the resilience of its WASH systems and safeguard long-term water security under current and future climate conditions.

7. ANNEXES

ANNEX 1. DETAILED METHODOLOGY FOR CLIMATE HAZARD AND VULNERABILITY ASSESSMENT

Hazard assessment

Data Sources and Rationale

Historical Climate Data

To characterize baseline climatic conditions (temperature, precipitation), the methodology relies on:

- Observed climatology (1991–2020) from the World Bank CCKP,
- Historical time series (1901–2023) for long-term trend detection,
- Local evidence from CCAP and PCRA (farmers' observations, rainy-season delays, water stress, etc.).

Historical analysis provides:

- The reference baseline against which projections are compared.
- A direct link between observed trends and local hydrological/landscape responses affecting WASH.

Climate Projections (CMIP6 / SSPs)

The methodological choice of SSP5-8.5 as reference scenario is guided by:

- Its conservative nature (upper-bound risk)
- Its alignment with current global emissions trajectories
- Its widespread adoption in resilience planning

Projections are extracted from CMIP6 multi-model ensemble (MME) for temperature, precipitation, and derived indices.

Extracted hazard relevant indices are as follows:

- Mean temperature (Tmean): Controls baseline evapotranspiration and long-term aridification trends; influences crop growth, ecosystem functioning, and pest and disease dynamics.
- Maximum temperature (TXx): Captures thermal extremes driving heatwaves, human and livestock heat stress, crop damage thresholds, and expansion of pests and disease vectors.
- Total precipitation (PRCPTOT): Determines water availability by controlling soil moisture recharge, runoff, river discharge, groundwater replenishment, and overall flood and drought potential.
- Heat Index exceedance days (>35–37 °C): Measure the frequency of dangerous combined heat and humidity conditions, indicating risks of heat-related illness, reduced labor productivity, and higher cooling demand.
- Tropical nights (Tmin >20–23 °C): Track nights without thermal relief, linked to increased heat-related mortality, reduced physiological recovery, and stress on crops and livestock.
- Extreme rainfall (Rx1day/Rx5day): Represent short-duration rainfall intensity, directly linked to flash floods, urban flooding, landslides, and infrastructure stress.
- Heavy rainfall days (R20mm): Reflect the frequency of intense rain events, increasing flood, landslide, and moisture-related disease risks.
- Consecutive wet days (CWD): Indicate persistence of wet spells, driving soil saturation, prolonged flooding, slope instability, and moisture-driven crop diseases.

- Consecutive dry days (CDD): Reflect drought persistence, influencing soil drying, vegetation stress, wildfire risk, dust mobilization, and salinity build-up.
- Relative humidity (RH): Influences evapotranspiration, plant water use, fungal and bacterial development, thermal comfort, and vector-borne disease transmission.
- SPEI (Drought/Aridity Index): Integrates rainfall and evaporative demand to characterize drought severity, duration and spatial extent, and long-term water stress trends.

Regional & Local Contextual Data

To contextualize projections, the methodology integrates:

- **Various geographic datasets, such as topography and soil texture** (DEM, lithology, soil types).
- **County field observations** from the 2025 missions (water intakes, erosion, landslides, WASH operations).

Hazard Spatialization and downscaling Procedure

Pluvial Flood Hazard Mapping

The QGIS semi-quantitative model used in the report is anchored in hydrology and MCA approaches:

- DEM conditioning (sink filling + stream burning).
- Computation of endorheic depressions, Topographic Wetness Index, soil infiltration capacity.
- Weighted combination: TWI (60%) + Soil (25%) + Depressions (15%).

It produces continuous hazard rasters and polygonised maps.

This approach (inspired by Beven & Kirkby 1979, Rahmati 2016) is suitable for areas lacking detailed hydrodynamic data, which is the case in the study area.

River Flood Hazard

Given the absence of local hydraulic models, the methodology uses:

- **FM Global 100-year return period maps**, an internationally accepted first-order hazard reference (UNDRR, WB).
- Extraction of flood extents per subcounty and intersection with river corridors.

Groundwater Rise Hazard

Assessment relies on:

- British Geological Survey groundwater depth maps (5 km resolution).
- Hydromorphology cross-analysis (flat valleys, clayey soils).
- Identification of potential compounding zones with pluvial and river floods.

Heat Stress

Heat-humidity exposure assessment is based on:

- Future TAS + humidity anomalies
- Heat Index exceedances (threshold: **HI >35°C**)

Landslide Susceptibility

It is calculated through the combination of:

- Slope (>20°)
- Soil types (Andosols, Nitisols)
- Rainfall intensification

- Field observations of erosion and mass movement
- Anthropogenic pressures (farming on steep slopes, deforestation, infrastructure cuts)

The mapping guides hotspot identification.

Salinity Risk

Though low in Murang'a, methodology includes:

- Probabilistic salinity mapping (Araya et al., 2023).
- Soil/groundwater cross-interpretation with rift valley geology.

Pests & Diseases

Hazard assessment is based on:

- Flood/drought interactions
- Temperature-driven pathogen/pest proliferation
- CCAP/PCRA outbreak records (cholera, anthrax, malaria)

Climate Variability

Interpreting projections requires understanding interannual and intraseasonal variability:

- ENSO (El Niño/La Niña)
- MJO
- Indian/Western Pacific anomalies

These are essential for contextualizing year-to-year irregularities even under long-term climate change.

Vulnerability assessment

Exposure of WASH Assets

Geospatial overlay of:

- Proposed CWSSIP assets (corrected September coordinates)
- Hazard layers: floods, drought, landslides, salinity, groundwater rise

This determines which infrastructures are spatially exposed.

Sensitivity Assessment

For each asset type (intakes, pipelines, treatment plants, WWTWs, boreholes), sensitivity is assessed through engineering and operational criteria:

Hazard	Sensitivity Dimension
Floods	erosion of intakes, pipeline scour, latrine overflows
Drought	reduced yield, reduced recharge, water trucking
Landslides	pipeline breaks, intake burial, access disruption
Heat	increased biological treatment stress, demand spikes
Salinity	corrosion, groundwater suitability issues
Pests/diseases	contamination, public health burden

Social Vulnerability (Gender, Age, Disability, Livelihoods)

The Gender- and Inclusion-Adjusted Vulnerability Index (GIAVI) developed earlier was used:

- Indicators normalized (0–1)
- Weighted (rationale based on literature + stakeholder inputs)
- Mapped to identify “social hotspots”
- Combined with hazards to identify multi-dimensional risk areas.

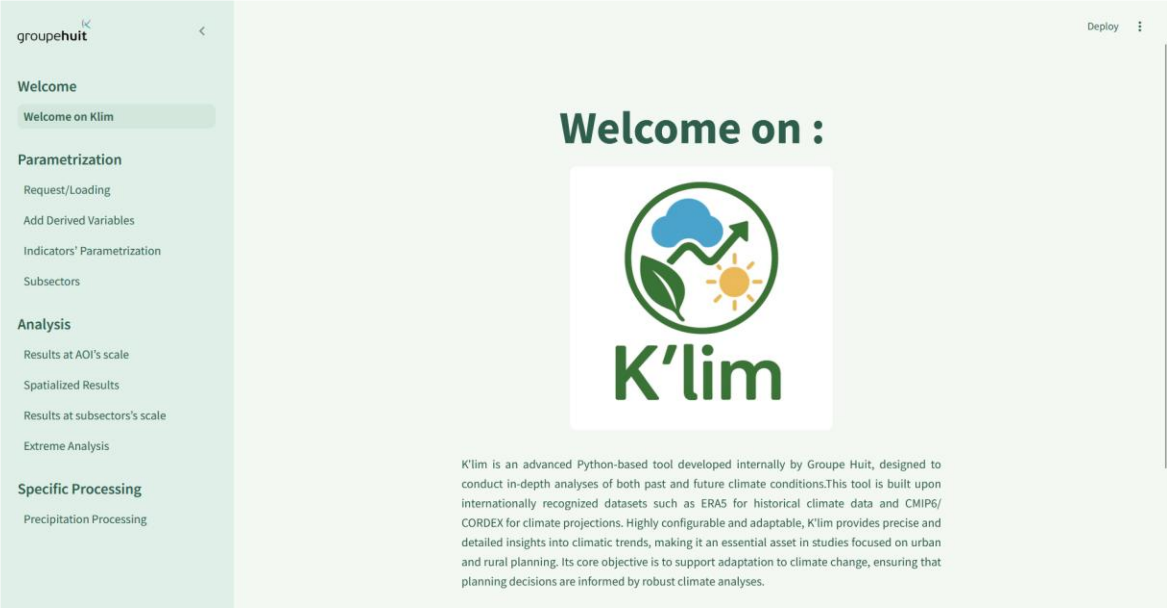
Cross-Analysis and Synthesis

Combining hazard exposure and sensitivity, we then produce a **graded risk level** for each WASH subsystem and each subcounty.

This is the basis for the Adaptation Options Analysis.

ANNEX 2. K'LIM TOOL

K'lim Tool is an advanced (Python) tool, developed in-house by Groupe Huit, designed to perform in-depth analyses of past and future climate conditions, including the derivation of climate indicators, the analysis of extreme events, and the analysis of seasonal cycles.



K'lim is an advanced Python-based tool developed internally by Groupe Huit, designed to conduct in-depth analyses of both past and future climate conditions.This tool is built upon internationally recognized datasets such as ERA5 for historical climate data and CMIP6/ CORDEX for climate projections. Highly configurable and adaptable, K'lim provides precise and detailed insights into climatic trends, making it an essential asset in studies focused on urban and rural planning. Its core objective is to support adaptation to climate change, ensuring that planning decisions are informed by robust climate analyses.

Figure 68 : K'Lim tool

K'lim Tool is based on internationally recognized climate data, such as ERA5 for historical observations, and projections from climate models developed as part of the CMIP6 program.

ERA5 is a climate database produced by the European Center for Medium-Range Weather Forecasts (ECMWF) as part of the Copernicus Climate Change Service (C3S) program. It is a climate reanalysis: a historical reconstruction of the global climate combining observations (satellites, ground stations, radiosondes, etc.) with a numerical weather prediction model. This produces consistent, comprehensive, and regular estimates of atmospheric and surface conditions. The historical data in K'lim covers the period from 1950 to 2014.

As for projected data, the data available via the tool are all derived from models developed as part of the IPCC's 6th Assessment Report (AR6), and more specifically as part of CMIP6 (the latest generation of coupled ocean-atmosphere models). All models developed as part of AR6 with sufficient resolution are available via the tool for all available SSPs. The projected data corresponds to the period 2014-2099.

ANNEX 3. ATLAS OF PLUVIAL FLOOD HAZARD

ANNEX 4. ATLAS OF RIVER FLOOD HAZARD

ANNEX 5. DESCRIPTION OF MODES OF VARIABILITY

Madden Julian Oscillation

The Madden-Julian Oscillation (MJO) is an atmospheric event primarily observed over the Indian and Pacific Oceans. It was discovered in 1971 by Roland Madden and Paul Julian, making it one of the more recent climate drivers to be studied. The phenomenon is characterized by two areas: one of suppressed rainfall and one of enhanced rainfall. These regions move eastward as the oscillation cycle unfolds. Each cycle of oscillation lasts 30 to 60 days and is split into eight phases of equal length.

The phenomenon usually first becomes apparent over the Western Indian Ocean and remains evident as it moves over the very warm ocean waters of the western and central tropical Pacific. This pattern of tropical rainfall then generally becomes nondescript as it moves over the cooler ocean waters of the Eastern Pacific, except over the region of warmer water off the west coast of Central America. Occasionally, it reappears at low amplitude over the Tropical Atlantic and at higher amplitude over the Indian Ocean. Most of the rain in the tropics comes from convective clouds, a type of cloud that sits high in the atmosphere and emits little longwave radiation. Because of this, satellites with infrared sensors are easily able to detect and track the propagation of the region of unusually enhanced or suppressed rainfall.

The breakdown of the phases is as follows:

- Phase 1: Enhanced rainfall develops over the Western Indian Ocean.
- Phase 2 and 3: The enhanced rainfall region moves slowly eastward over Africa, the Indian Ocean, and parts of the Indian subcontinent.
- Phase 4 and 5: Enhanced rainfall reaches the maritime continent, including Indonesia and the West Pacific.
- Phase 6, 7, and 8: Enhanced rainfall moves further eastward over the Western Pacific, eventually dying out in the Central Pacific.

The MJO affects global weather in several ways. Both the onset and breaks in summer monsoons are linked to the MJO phase, especially in the case of the Indian and Australian monsoons. There is also a strong link between the MJO and tropical cyclones. The region of increased rainfall is favorable for the development of cyclones; this does not concern Kenya.

However, there's a connection between the MJO phase and the intensity of rainfall in Africa as well as winter precipitation in the western USA. Evidence suggests the MJO can also contribute to the speed of development and intensity of El Niño and La Niña episodes, as well as influencing the onset of sudden stratospheric warming events.

The MJO not only enhances the predictability of tropical weather, but the teleconnections to the middle latitudes can also enhance the predictability of mid-latitude weather systems to several weeks ahead. All in all, the MJO is an important driver of global weather and can influence the North Atlantic Oscillation.

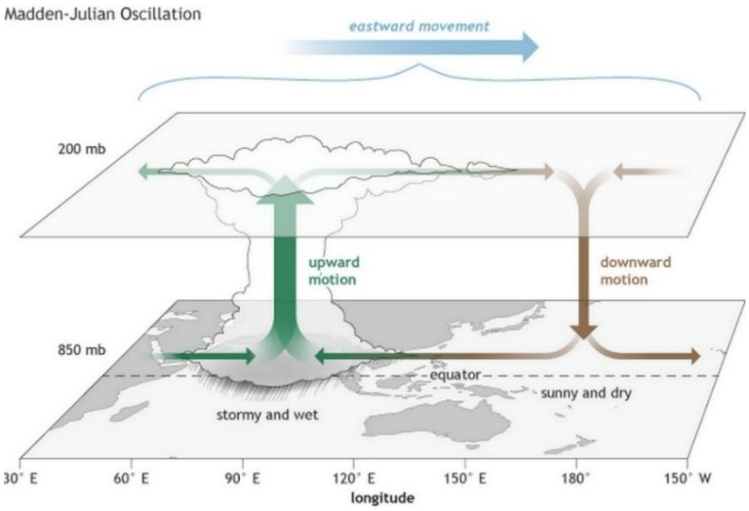


Figure 69: MJO scheme

El Niño–Southern Oscillation (ENSO)

El Niño and La Niña are the warm and cool phases of a natural climate pattern across the tropical Pacific known as the El Niño-Southern Oscillation, or "ENSO" for short. The pattern shifts back and forth irregularly every two to seven years, bringing predictable changes in ocean temperature and disrupting the normal wind and rainfall patterns across the tropics. These changes in the seasonal climate of the world's biggest ocean have a cascade of global side effects. ENSO is one of the most important climate phenomena on Earth due to its ability to change the global atmospheric circulation, which in turn influences temperature and precipitation across the globe.

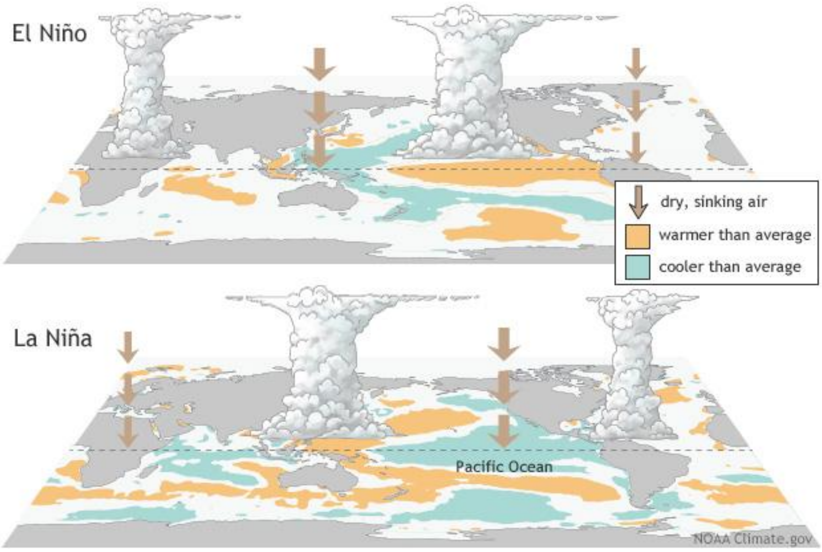


Figure 70: ENSO scheme

Though ENSO is a single climate phenomenon, it has three states, or phases, it can be in. The two opposite phases, "El Niño" and "La Niña," require certain changes in both the ocean **and** the atmosphere because ENSO is a *coupled* climate phenomenon. "Neutral" is in the middle of the continuum.

1. El Niño: A warming of the ocean surface, or above-average sea surface temperatures (SST), in the central and eastern tropical Pacific Ocean. Over Indonesia, rainfall tends to become reduced while rainfall increases over the tropical Pacific Ocean. The low-level surface winds, which normally blow from east to west along the equator ("easterly winds"), instead weaken or, in some cases, start blowing the other direction (from west to east or "westerly winds").

2. La Niña: A cooling of the ocean surface, or below-average sea surface temperatures (SST), in the central and eastern tropical Pacific Ocean. Over Indonesia, rainfall tends to increase while rainfall decreases over the central tropical Pacific Ocean. The normal easterly winds along the equator become even stronger.

3. Neutral: Neither El Niño nor La Niña. Often tropical Pacific SSTs are generally close to average. However, there are some instances when the *ocean* can look like it is in an El Niño or La Niña state, but the atmosphere is not playing along (or vice versa).

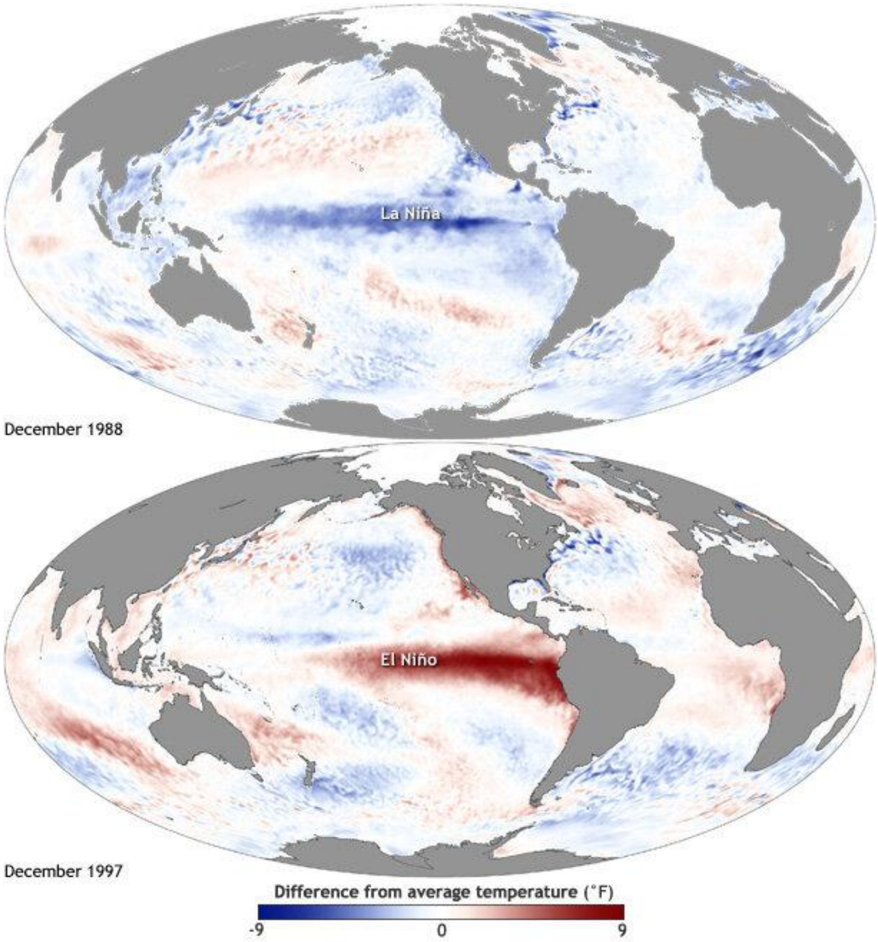


Figure 71: Maps of sea surface temperature anomaly in the Pacific Ocean during a strong La Niña (top, December 1988) and El Niño (bottom, December 1997).

Source: Maps by NOAA Climate.gov

ANNEX 6. LIST OF PROJECTS CLASSIFIED BY EXPOSURE LEVEL

ANNEX 7. WASH ADAPTATION OPTIONS

An adaptation options recommendations deliverable is expected as part of this assignment and will be provided in another document, some guidance tables are already reported to provide an initial idea.

Table 16: Guidelines for climate change adaptation and mitigation in WSS sector

Category	Example design feature	Example applied to sanitation
Avoid exposure to hazards: Design features that reduce the likelihood that critical components and processes of the sanitation technology become directly exposed to a climate hazard	**Portability:** The ability of the technology to be easily moved to a new location to avoid exposure to a hazard. *Other design features: Raising, Burying, No/low inputs*	Container-based sanitation units or other forms of portable toilets that can be easily transported if needed to avoid flooding.
Withstanding exposure to hazards: Design features that enable the sanitation technology to continue functioning "as normal" (i.e. no changes in hardware or operations) even when exposed to climate hazards.	**Oversizing:** Increasing the tolerance or capacity of the technology or its component so that it can accommodate extreme conditions or projected changes in conditions. *Other design features: Armouring and strengthening, Shapes that distribute pressure, Circumvention, Sealing and barriers*	Buffer containment units that can hold peak flows temporarily when large inflows occur.
Enabling flexibility: Design features that enable the sanitation technology to have its hardware components adapted or reconfigured, or their processes or operation changed, in order to continue providing services when exposed to climate hazards	**Signalling:** The technology, by the nature of how it functions or by intentional design, has a way of signalling to operators or users when the technology requires modification to prevent failure or to enhance its performance. *Other design features: Adaptability, Modular design, Platform design, Redundancy and diversity*	Flow meters to signal changes in flow rate that may require changes to operations.
Containing failures: Design features that enable the sanitation technology to continue providing services (albeit potentially degraded) that meet user needs, despite damage to the sanitation technology caused by climate hazards.	**Frangibility:** Less essential components of the technology are designed to breakaway or fail when exposed to a hazard to protect more essential components of the technology. *Other design features: Fail-operational, Decentralisation*	Manholes, in defined locations, on sewers that are designed to burst when pressure from high flows in sewers become too great, hence protecting pipes from bursting.
Limiting consequences of complete failure: Design features that minimise the negative consequences of a sanitation technology failing due to a climate hazard.	**Reusable materials:** The materials from the destroyed technology can be reused for other purposes (including rebuilding the technology). *Other design features: Safe disposal, Fail-silence*	Prefabricated septic tanks (if not damaged) can be used for other sanitation systems.
Facilitating fast recovery: Design features that enable the sanitation technology to be quickly rebuilt or restored if they are damaged, disrupted or destroyed by a climate hazard.	**Accessibility for rapid flaw detection and repair:** Components or processes of the technology can be easily accessed for examination and repairs. *Other design feature: Repair speed*	Above ground tanks that can be easily repaired in case of leakage (compared to an underground tank).
Providing benefits beyond resilience: Design features may also strengthen the resilience of other systems or communities in which they are located.	**Reciprocity:** Through its operations, the sanitation technology also builds resilience in, or aids, another on-site or off-site system. *Other design features: Hybridising, Transformative capacity*	Treated sludge or wastewater can be used to aid in agricultural production.

Table 17: Best practices for water infrastructure climate-proofing

	Floods	Erosion	Extreme heat
River Intakes	✓ Protect sensitive structures (electrical cabinets) from flooding ✓ Use submersible pumps ✓ Protection of exposed structures in the riverbed ✓ Intake design must not reduce the river's flow capacity	✓ Progressive silting up of the water intake: Compartmentalize the water intake so that one compartment can be maintained while the other is still in service (redundancy). ✓ Provide a self-cleaning system ✓ For sudden silting (after a flood): sediment study/field surveys to locate the intake ✓ Provide O&M resources for sand removal (backhoe loaders, etc.) ✓ Protection of exposed structures in the riverbed ✓ Protective device for bank on which structures are installed (gabions)	✓ Pumps stop at low level (pump safety sensors)
Drinking water production plant	✓ Move plant to a non-flood zone ✓ If the area is subject to flooding, protect sensitive structures (electrical cabinets) from flooding (elevation) ✓ Watertight access doors to sensitive structures ✓ Secure access roads (embankment access with rainwater diversion)	✓ Rainwater detour (to avoid runoff onto the site) ✓ Soil stabilization (vegetation and geogrid, gabions) ✓ Secure access roads (embankment access with rainwater diversion) ✓ Prefer deep pile foundations (no shallow foundations)	✓ Evaluate the need for air conditioning in the electrical room ✓ Special treatment required in the event of micro-algae growth in the settling tank
Boreholes	✓ If the area is subject to flooding, protect sensitive structures (electrical cabinets) from flooding.	✓ Place drilling head in embankment and divert rainwater ✓ Secure access roads (embankment access with rainwater diversion) ✓ Equip the drilling head with an enclosure with a concrete wall with deep foundations	✓ Anticipate the risk of lowering the water table and install the pump at sufficient depth (leeway). ✓ Anticipate the risk of lower production (planning of resources to be mobilized must include a margin) ✓ Installation of sensors and regular monitoring of borehole water quality and levels (static and dynamic)
Water storage / tanks	✓ To be installed on high points	✓ Limited risk at high points ✓ Rainwater drainage ✓ Deep pile foundations preferred (no shallow foundations) ✓ Secure access roads (embankment access with rainwater diversion)	✓ Special treatment in case of micro-organism development (adapt chlorination)

	Floods	Erosion	Extreme heat
Water networks	✓ Leak tight pipes, limited risk ✓ Transfer/transport pipes: e.g. between water intake and plant and between plant and water tower, larger pipes, suction cups in non-flooding manholes	✓ Heat-welded HDPE (polyethylene) pipes (no risk of dislocation) ✓ Bury them deeper	✓ Bury them deeper, especially plastic pipes

ANNEX 8. CONTRIBUTIONS OF THE WSS SECTOR TO THE GHG EMISSIONS

While being concerned about CC effects, the WSS facilities themselves contribute to the already aggravated problem of climate change by producing GHG emissions:

- Lack of sanitation or unsustainable water management causes the degradation of water-dependent ecosystems that consequently stop functioning as carbon sinks.
- Pumping, water distribution, treatment processes, sludge disposal practices, etc. are consuming energy and producing greenhouse gases like CO_2, CH_4 and N_2O.

The following figure presents the main sources of GHG from the water and sanitation sectors but also highlights the potential for improvement.

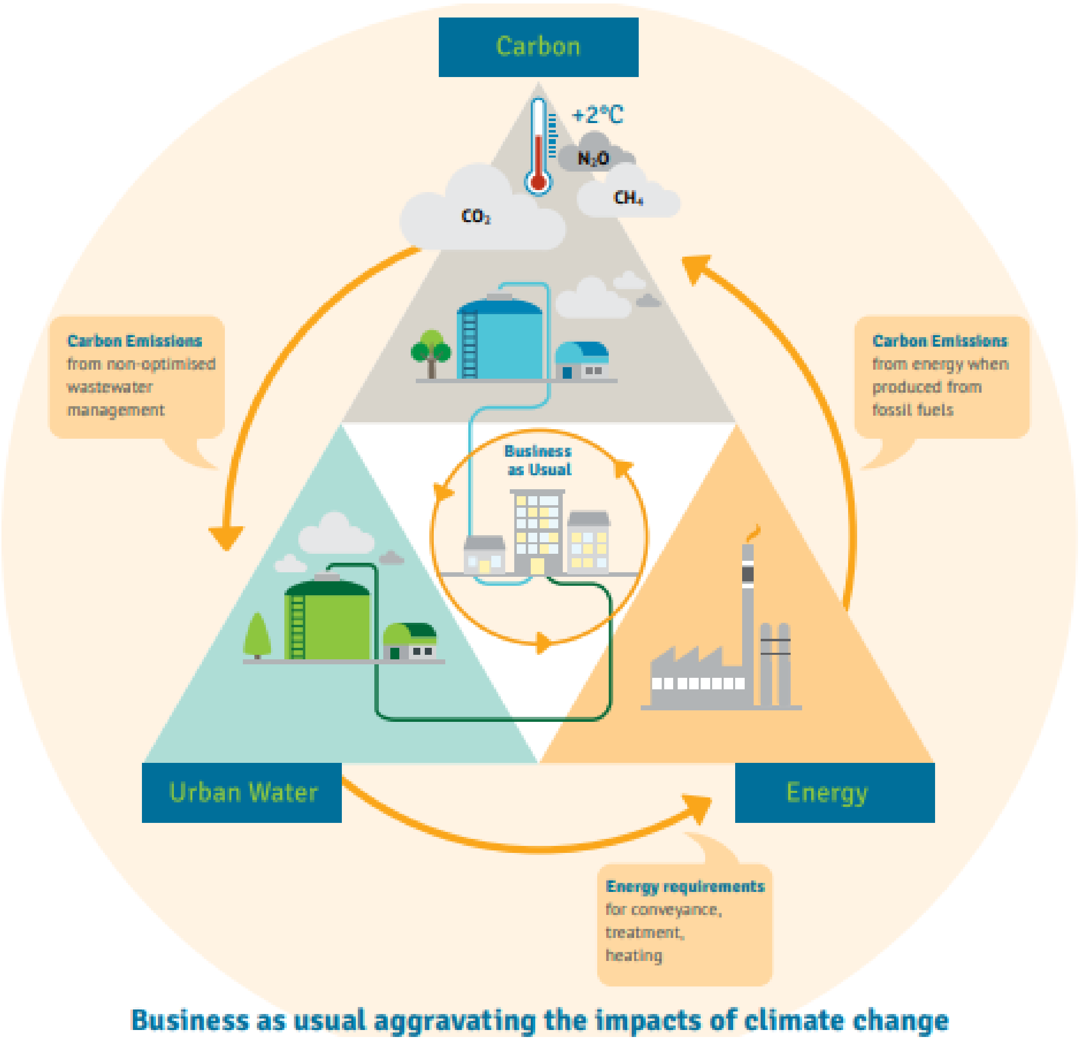
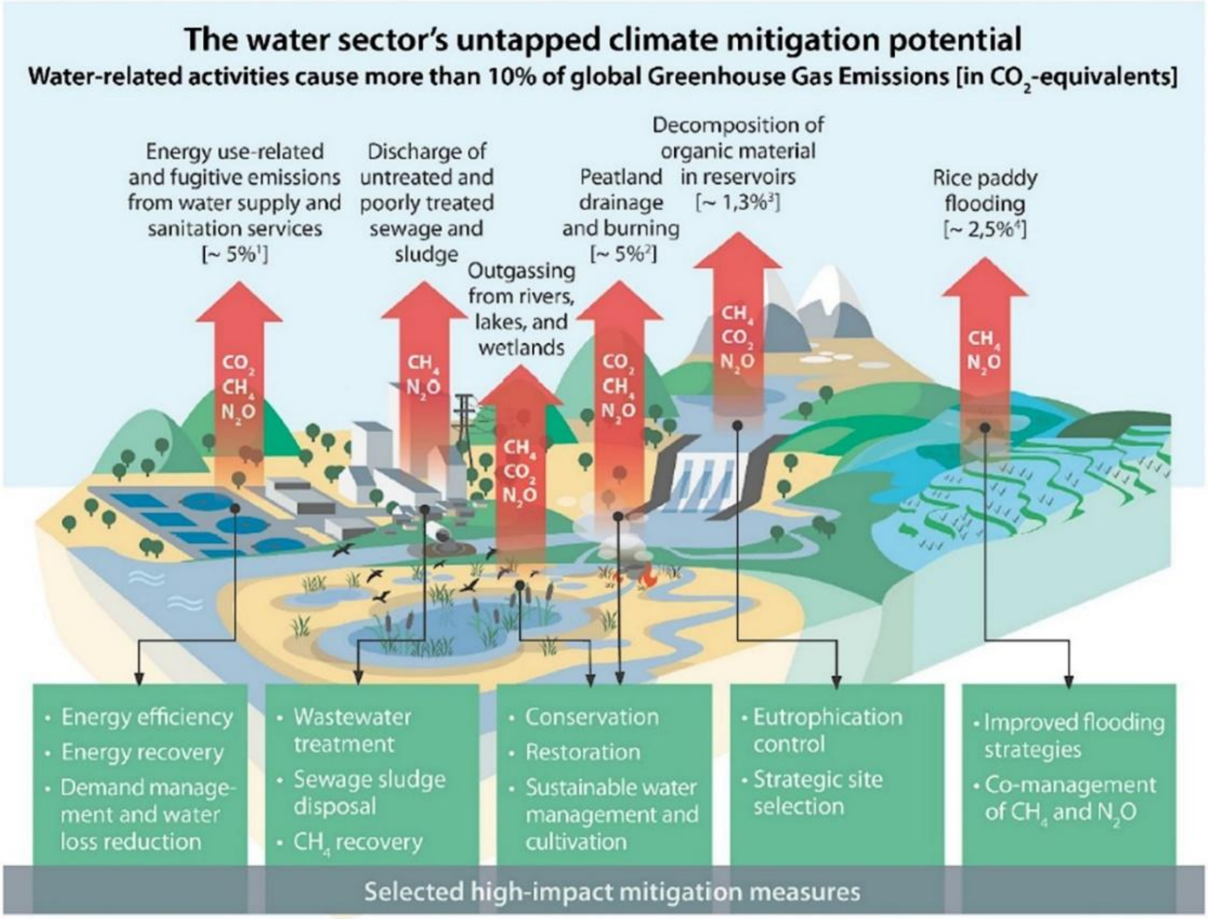


Figure 72: WSS business as usual aggravating the impacts of climate change



The water sector's untapped climate mitigation potential

Water-related activities cause more than 10% of global Greenhouse Gas Emissions [in CO_2-equivalents]

Note: Percentage values for global estimates of GHG emission sources partly stem from single studies and may require further validation. Recent research indicates that some values may be higher since not all GHG emissions are adequately accounted for. Estimations for GHG emissions from disposal of wastewater and sewage as well as freshwater ecosystems are currently not available. The measures are not exclusive, but represent a selected suite with a high mitigation impact.

Sources: [1]Michels and Saravanja, 2017; [2]Joosten, 2015; [3]Deemer et al., 2016; [4]Kritee et al., 2018

Figure 73: The water sector's untapped climate mitigation potential

According to the WaCCliM Project and the Roadmap to a Low-Carbon Urban Water Utility, the urban water sector could contribute the equivalent of 20% of the sum of committed reductions by all countries in the Paris Agreement (the Nationally Determined Contributions).

ANNEX 9. HOTSPOT ANALYSIS

ANNEX 10. BIBLIOGRAPHY

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