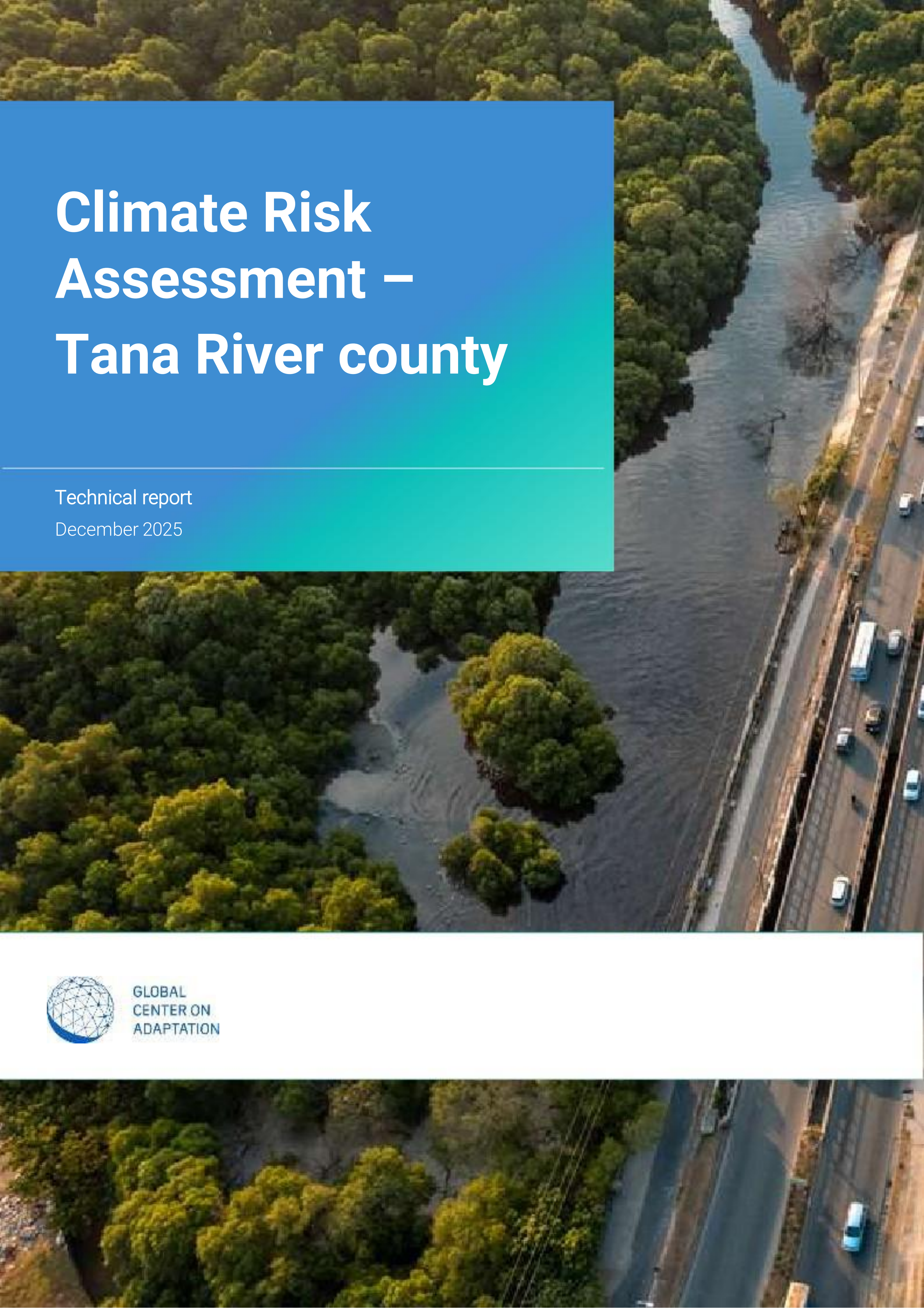

Climate Risk Assessment – Tana River county

Technical report

December 2025

GLOBAL CENTER ON ADAPTATION

AUTHORS & ACKNOWLEDGEMENTS

This report was developed by

Global Center on Adaptation (GCA)

Partnerships :
The World Bank

Consultants :
Groupe Huit, Branded Solution Services

Acknowledgements:

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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
ASL	Above Sea Level
CAAC	Catchment Area Advisory Committee
CBO	Community based organization
CCAP	County Climate Action Plan
CCKP	Climate Change Knowledge Portal (World Bank)
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
CWD	Consecutive Wet Days
CWSSIP	County Water and Sanitation Services Investment Plan
DEM	Digital Elevation Model
DLI	Disbursement Linked Indicator
DRM	Disaster Risk Management
DRS	Department for refugee Services
ENSO	El Niño–Southern Oscillation
ERA5	ECMWF Reanalysis version 5
ESHS	Environmental, Health and Safety
EWS	Early warning systems
FGD	Focus Group Discussions
GAP	Gender action plan
GBV	Gender Based Violence
GCA	Global Center on Adaptation
GCP	Gross County Product
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GoK	Government of Kenya
HCF	Health Care Facility
HI	Heat Index
IDP	Internally Displaced Person(s)
ITCZ	Intertropical Convergence Zone
IVA	Independent Verification Agent

JAS	July–August–September
KEWASNET	The Kenya Water and Sanitation Civil Society Network
KEWI	Kenya Water institute
KMD	Kenya Meteorological Department
K-WASH	Kenya Water, Sanitation and Hygiene Program
LST	Land Surface Temperature
M&E	Monitoring and Evaluation
MAM	March–April–May (Long Rains)
MCA	Multi Criteria Analysis
MJO	Madden–Julian Oscillation
MoWSI	Ministry of Water, Sanitation and Irrigation
MTP	Medium Term Plans
NDMA	National Drought Management Authority
NDOC	National Disaster Operations Centre
NEMA	National Environment Management Authority
NGAO	National Government Administration Officers
NGEC	National Gender and Equality Commission
NGO	Non Governmental Organization
NIB	National Irrigation Board
NRW	Non-Revenue Water
NSWMS	National Solid Waste Management Strategy
NWCPC	National Water Conservation & Pipeline Corporation
NWSS	National Water Service Strategy
OND	October–November–December (Short Rains)
PCRA	Participatory Climate Risk Assessment
PDO	Program Development Objective
PIAP	Performance Improvement Action Plans
PIU	Project implementation unit
PMU	Project Management Unit
PRCPTOT	Total Annual Precipitation
PWD	Person(s) with Disabilities
R20mm	Number of days with rainfall > 20 mm
RA	Result Area
RDLS	Risk Data Library Standard
Rx1day	Maximum 1-day precipitation
Rx5day	Maximum 5-day cumulative precipitation
SCMP	Sub-catchment management plan
SDG	Sustainable Development Goals
SEA/SH	Sexual Exploitation and Abuse / Sexual harassment

SPEI	Standardized Precipitation–Evapotranspiration Index
SRHR	Sexual and Reproductive Health Rights
SSP	Shared Socioeconomic Pathway
SSP5-8.5	Shared Socioeconomic Pathway 5 with radiative forcing of 8.5 W/m² by 2100
SST	Sea Surface Temperature
TA	Technical Assistance
UN	United nations
UNHCR	United Nations High Commissioner for Refugees
WAB	Water Appeal Board
WAPAK	Waste Pickers Association of Kenya
WASH	Water, sanitation and hygiene
WASREB	Water Services Regulatory Board
WB	The World Bank
WHO	World Health Organization
WRMA	Water Resource Management authority
WRUA	Water Resource User Association
WSB	Water Services Boards
WSP	Water Service Providers
WSS	Water supply and sanitation
WSTF	Water Service Trust Fund

EXECUTIVE SUMMARY

The Climate Risk Assessment (CRA) for Tana River County was conducted within the framework of the Kenya Water, Sanitation and Hygiene (K-WASH) Programme. This assessment is directly aligned with the preparation of the Countywide Water Supply and Sanitation Investment Plan (CWSSIP). 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.

Objective and Methodology

The primary objective of the CRA is to systematically **identify and characterize key climate-related hazards** affecting Water Supply, Sanitation, and Hygiene (WSS/WASH) systems. It serves as an **operational decision-support tool** to integrate climate resilience into strategic planning, infrastructure design, and service delivery, ensuring investments are robust against current variability and future climate scenarios. The assessment adopts a risk framework consistent with IPCC AR6, linking hazard, exposure, and vulnerability.

The primary scenario analyzed is the **SSP5-8.5 (Fossil-fuelled Development)**, considered the most conservative pathway, covering planning horizons of **2050** (infrastructure lifespan) and **2100** (long-term resource sustainability).

Key Climate Hazards and Projected Changes

Tana River County primarily experiences a hot semi-arid climate (BSh). Projections indicate several climate signals under SSP5-8.5:

- On main physical parameters:
  - **Temperature:** The average mean surface air temperature is projected to increase by approximately **+1.3°C by 2050**. The number of hot days (Tmax > 30°C) is expected to rise significantly, reaching 355.54 days per year by 2050. The frequency of days with a Heat Index (HI) above 35°C will also increase, particularly during March and April. This intensifies heat stress on people, operational staff, and equipment, while raising evapotranspiration rates.
  - **Precipitation**: Overall, average annual rainfall is projected to increase. Climate projections indicate more intense rainfall and heavy events (Rx1day/Rx5day increasing), reinforcing flood and erosion risks.
- These parameters drive hazard levels as follows:
  - **Floods:** Tana River County is highly prone to flooding (pluvial and riverine), particularly along the Tana River corridor, with the downstream areas of the basin most exposed. Rising water table flooding compounds these effects, especially in flat, poorly drained, or clayey areas. Sublocations such as Kikomo (90%) and Mazuni (88%) show very high exposure to 100-year recurrence interval river flooding.
  - **Heat stress and Droughts:** Despite projected overall increases in precipitation, the county remains an arid and semi-arid zone (ASAL) susceptible to drought, leading to crop failure, food shortages, and mass migrations. Heat stress is already present in the county and is expected to increase especially for the eastern areas of the county.
  - **Coastal erosion:** The 76-kilometer coastline is impacted by coastal erosion, averaging a recession of -0.77m, due to the combination of Sea Level Rise (SLR) and High Tide Flooding (HTF).

- **Salinity** is a key hazard, especially in coastal areas due to seawater intrusion (driven by reduced river flow and SLR) as well as in inland areas due to rising water tables and agricultural practices.

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 (floods, droughts, coastal erosion, salinity).

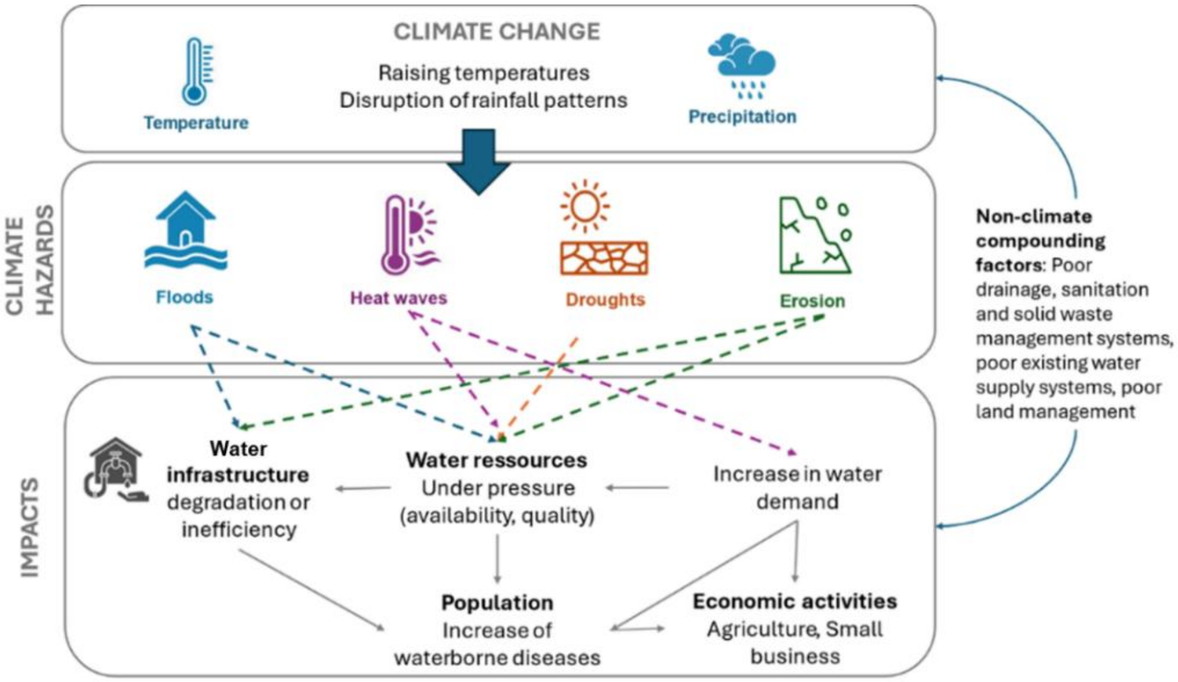


Figure 1: Water sector vulnerability to climate change

Water Resources: During droughts, surface water sources like water pans dry up, forcing communities to dig shallow wells within the pans, which are highly prone to contamination, algae blooms, and poor quality. Groundwater quality is threatened by increased salinity, which constrains borehole development and leads to abandonment. The below table sums these items up.

Table 1: 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

Climate hazard	Impact on water resource
	• 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 2: Links between climate change and water supply services

<table>
<tr><th>Climate hazard</th><th>Global County hazard level</th><th>Water consumption</th><th>Service Quality</th><th>Impacts on infrastructure</th><th>Social impact</th></tr>
<tr><td>Variability of seasonal rainfall patterns</td><td>Moderately exposed</td><td></td><td>▶ Temporary interruption or reduction of service due to lack of available resources</td><td></td><td rowspan="3">▶ Tougher fetching:
▶ 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 during water shortages</td></tr>
<tr><td>Droughts, water shortage</td><td>Highly exposed</td><td rowspan="2">▶ Increasing water requirements and volumes for all uses (domestic agricultural, industrial, etc.).</td><td rowspan="2">▶ 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)
▶ Interruption of service due to damage to installations</td><td rowspan="2">▶ Fragilization of facilities :
▶ over-utilization of equipment during drought period to meet high demand
▶ 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 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.</td></tr>
<tr><td>Heat wave</td><td>Highly exposed</td></tr>
</table>

Climate hazard	Global County hazard level	Water consumption	Service Quality	Impacts on infrastructure	Social impact
Intense and sudden rainfall, flooding	Highly exposed		▶ 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 damage to installations o Inaccessibility to water points (landslides - flooding) o Fragilization of storage by saturation	▶ Fragilization, yield reduction and destruction of 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.	▶ Amplification of migratory phenomena or departure of populations no longer having access to water Reduction of agricultural yields ▶ Health threats due to lower water quality
Storms (including sand and dust storms)	Low exposure				

Climate hazard	Global County hazard level	Water consumption	Service Quality	Impacts on infrastructure	Social impact
Erosion (which can also be induced by floods and water runoff) and landslides	Moderately 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	Highly exposed	▶ 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 3: Links between climate change and wastewater management services

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Droughts, water shortage	Highly 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 which may lead in increased wastewater use, and use of polluted receiving waters. Less water to clean toilets which can become unsanitary
Heat wave	Highly 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). Odour nuisance due to increased nitrogen dioxide (N_2O) emissions

<table>
<tr><th>Climate hazard</th><th>Global County hazard level</th><th>Impacts on infrastructure & Service quality</th><th>Impacts on environment and water resources</th><th>Social impact</th></tr>
<tr><td>Intense and sudden rainfall, flooding</td><td>Highly exposed</td><td rowspan="2">▶ 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 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), mainly collapse of pit latrines during flash floods
▶ Disruption of emptying services (difficulty access, necessary increase in frequency...)</td><td rowspan="2">▶ 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
▶ 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 soakaway or pit from below, increased potential for contamination of groundwater.</td><td rowspan="2">▶ Population without sanitary facilities
▶ Increase in water-borne diseases due to the risk of contact with water containing pathogens
▶ Recourse to open defecation and its multiple negative impact (health, well-being, dignity, safety, etc.)</td></tr>
<tr><td>Storms (including sand and dust storms)</td><td>Low exposure</td></tr>
<tr><td>Sand and dust storms</td><td>Low exposure</td><td>▶ Heavy deposits of sand on solar panels for boreholes and water treatment plants, leading to reduced efficiency in power supply</td><td>Reduced capacities of water treatment plants and borehole pumping systems.</td><td>▶ Less access to clean water by communities</td></tr>
</table>

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Erosion (which can also be induced by floods and water runoff) and landslides	Moderately 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 4: Links between climate change and drainage services

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Intense and sudden rainfall, flooding	Highly 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 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: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (Alain Mailhot et Sophie Duchesne 2005)

CWSSIP Investments: An exposure mapping of the proposed CWSSIP investments confirms that infrastructure along the Tana River faces high combined flood and salinity risks. For example, the proposed Fanjua and Maziwa water supply projects and Idsowe borehole project which are registered the highest final exposure levels.

Social and Gender Impacts:

- Health risks increase due to heat-related illness and water-borne diseases like cholera, linked to contamination from floods and poor sanitation (e.g., collapsing pit latrines). Resource scarcity fuels conflicts between pastoralists and farmers. Flooding leads to mass displacement, loss of property, and disruption of education.
- Climate change exacerbates existing social inequalities among women, children, the elderly, persons with disabilities (PWDs), and marginalized communities. The burden of water collection disproportionately falls on women and children.

Conclusion

The assessment confirms that Tana River County's WASH systems are increasingly exposed to multiple, interacting climate hazards, **flooding, droughts and heat waves** emerge as highest priority hazards compounded by increased soil and water salinity and coastal erosion.

WASH climate risk are not evenly distributed across the county. Indeed**, settlements and urban centres located along the Tana River corridor face the highest overall risk,** due to the convergence of high hazard exposure and high concentration of people and assets, these areas are exposed to multiple flood mechanisms, including river overflow, intense rainfall, and rising groundwater tables.

Water and sanitation infrastructure is closely aligned with population centres, and therefore disproportionately located in flood-prone riverine zones. Urban areas while at risk because they have more assets and population are currently better served than rural areas which rely on weaker WASH systems and are therefore at risk as well. Key exposed assets include latrines, shallow wells, boreholes, water intakes, and distribution networks. **WASH assets most vulnerable and therefore at most risk are latrines which are likely to collapse or overflow but also boreholes, water intakes or pumps which can be damages or stop functioning when submerged. Lastly floods can lead to water resource contamination which thus impacts the whole WASH sector greatly (pest and diseases outbreak).**

Although heat stress and drought are countywide hazards, their impacts are also more severe in riverine and urban areas, where water demand is highest and infrastructure density is greatest. The **main concern during droughts and heat waves is the limited water availability being simultaneous with an increased demand** translating in long water fetching tasks**.** Other concerns on WASH risks in relation with this hazard is the operational stress on infrastructure which has lower efficiency and higher risks of damages/failure (dry pumping, materials expansion, pumps overheating etc.)

Pastoralists face distinct vulnerabilities as, as a mobile population they rely on fewer, more dispersed water points that are highly sensitive to drought and water quality degradation. The nature of such water use (not specific to one settlement) can lead to conflicts over the resource.

Above-mentioned risks are also differentiated depending on social norms and groups (gender, PWDs, pastoralists for instance) and such items should be considered as developed in the social and gender assessment and GAP report.

The above tends to highlight that **priority should be put on**:

- **Flood risk reduction** in both urban and rural settlements in **riverine areas**,
- **Climate-resilient water supply systems** that can withstand drought and heat stress, mostly oriented towards **improvement of water storage and distribution, especially in rural areas to improve their overall adaptative capacity and resilience** (lower water fetching task burden)
- **Protection of water quality through improvement of sanitation and selection of low-salinity areas for boreholes digging**

- **Context-specific WASH solutions for pastoralist communities**, reflecting their mobility and exposure patterns.

While the CWSSIP proposes essential infrastructure investments (boreholes, dams, treatment plants, sanitation facilities) that inherently contribute to resilience, some infrastructure are considered highly exposed to hazards. Therefore, **careful siting and comprehensive climate-proofing** are critical. The strategic guidance provided by the CRA necessitates that **each proposed project undergoes a localized and detailed assessment** to tailor adaptation measures for technical viability, long-term resilience, and social appropriateness.

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 Tana River 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 Objective

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 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

The consultant will use the definitions from the IPCC Fifth Assessment Report (2014), which describes risk as a function of hazard, exposure, and vulnerability (sensitivity and adaptive capacity).

- 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.

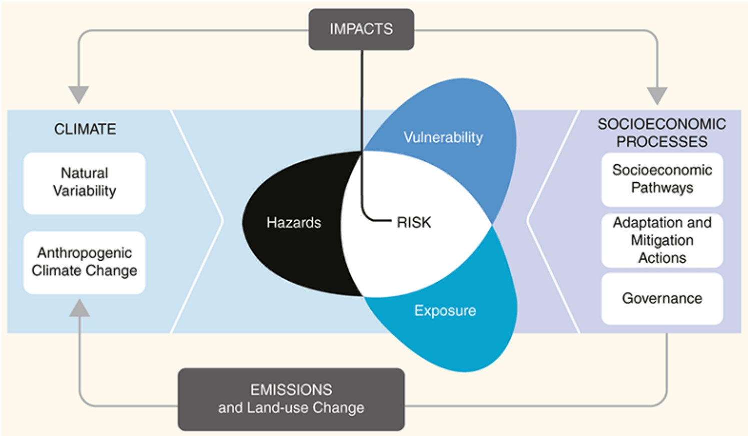


Figure 2: Exposure, Vulnerability, and Hazards as factors of Risks

- Exposure: The presence of people; livelihoods; species or ecosystems; environmental functions, services, and 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. Three tasks are to be carried out: (i) Hazard Assessment, (ii) Impact Assessment: Exposure assessment, Vulnerability assessment, (iii) Climate risk assessment.

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-fuelled Development (Taking the Highway)

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.

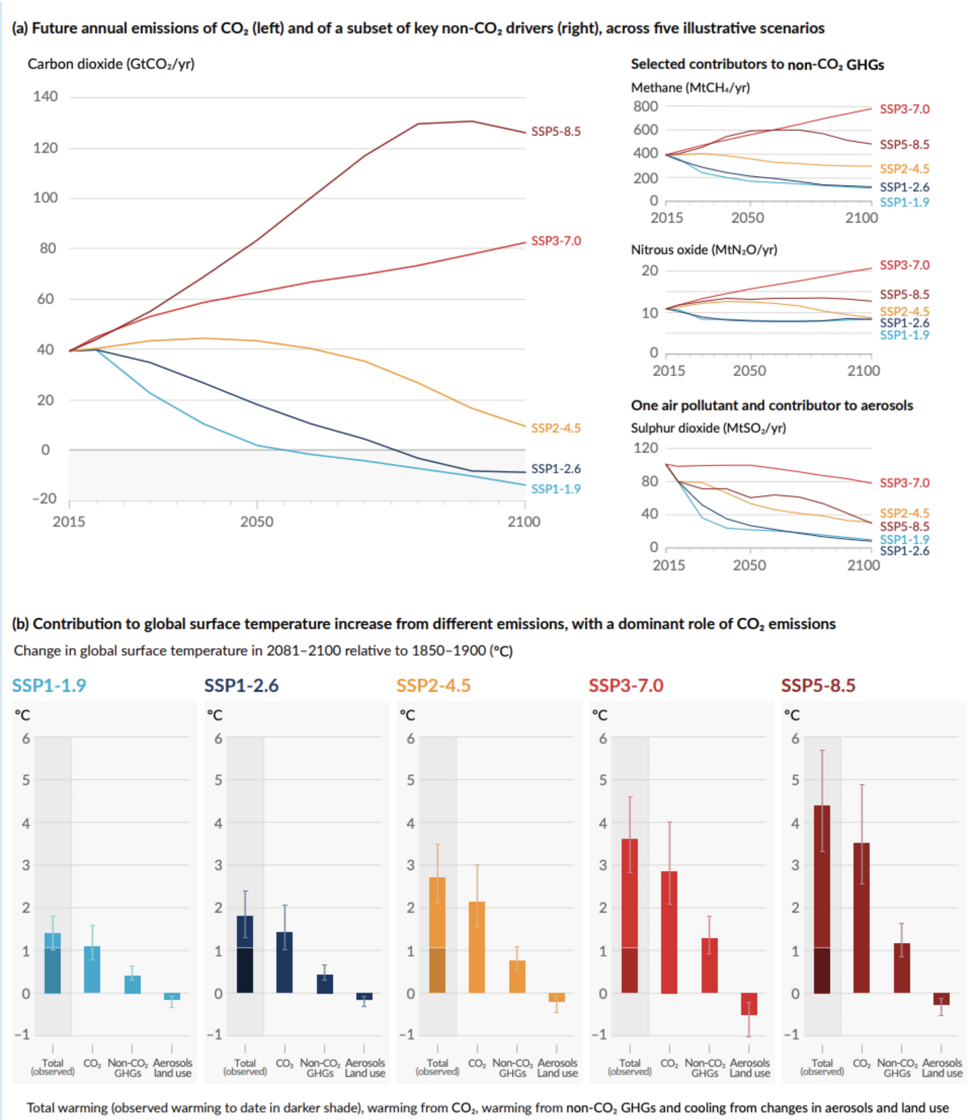


Figure 3: SSP scenarios presentation

Source : (IPCC - Working Group 1: The Physical Science Basis 2021)

2.2.2 Project Horizon

The horizon which was considered was set in accordance with the lifespan of infrastructure (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 Tana River County to 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 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[1] was also used (see annex 2).

[1] 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.

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 and August 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.

Findings from the field mission held in February are presented in Annex 9 while findings from the august field mission are presented in the hotspot analysis which is in Annex 10.

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

3. SOCIAL AND GENDER CONTEXT

3.1 Generalities

Tana River County population was estimated at 315, 943 in 2019 according to the population census of that year. 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 450,000 people.

There are only two areas categorized as urban centers (Hola and Madogo) with a total estimated population of 36,285 people. The settlement patterns are random but are concentrated close to the river.

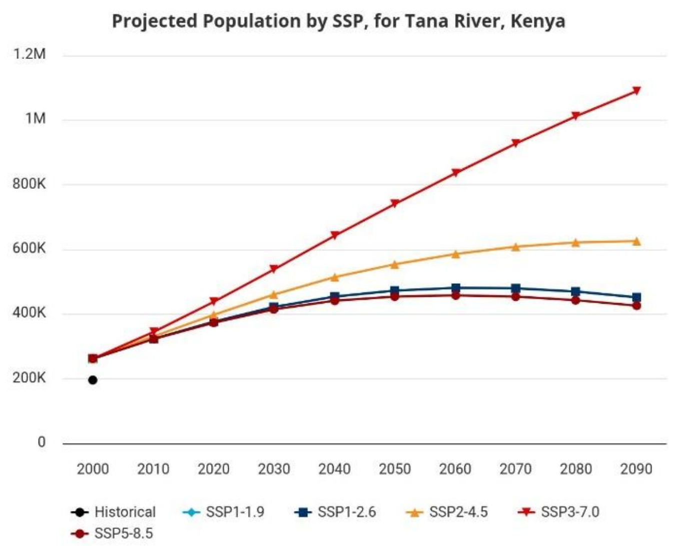


Figure 4: Projected population by SSP, for Tana River County

Source : (The World Bank Group 2025)

3.2 Socio-economic profile

Main economic activities are Pastoralism, Crop Production (Mangoes & Cowpeas), Mining (sand & murram), Indigenous Poultry Keeping and Fishing.

The dominant ethnic groups in the County are the Pokomo, many of whom are farmers, and the Orma and Wardey, who are predominantly nomadic. Other tribes include the Waata and Boni who are culturally Hunters and gatherers, and the Wailwana /Malakote and the Bajuni. It should be noted that the area is home to other Kenyan ethnic groups. These include the Luos, Kambas, Taitas, Giriamas, Kisii and Kikuyus and Somali immigrants among others. A first assessment reveals that the Waata community can be marginalized.

3.3 Socio-economic impacts of climate change

3.3.1 General impacts

Climate change has far-reaching socio-economic consequences in Tana River County. Droughts and soil salinity disrupt water availability and quality which impact livestock and crop yields, as well as drinking water availability 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. The number of urban areas with piped water supply in Tana River are limited, most rural communities are not covered by pipe water distribution (through kiosk of water fountains) which clearly limits their day-to-day well-being, health as well as their resilience to climate shocks.

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. Poor sanitation and particularly open defecation clearly contribute to such disease's outbreaks. 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

Certain inequalities exist at the social level, affecting specific social groups, including women, children, the elderly, people with disabilities, pastoralists, and ethnic minorities.

Both WASH aspects and Climate Change are directly related to these inequalities as the impacts of climate change are not evenly distributed and exacerbate existing inequalities, disproportionately affecting certain groups within the population. This especially when regarding climate change impacts on WASH infrastructures and practices which are already markers of inequalities.

Women and young individuals are among the most vulnerable, with the lowest adoption rates of adaptive strategies (due to hindering factors). Women, who often constitute a significant portion of the population and play a crucial role in food production, face limitations in accessing and utilizing resources despite communal land ownership. They are particularly affected by climate-related hazards, often having to travel long distances to secure water, food, and fuelwood. Local customs can further hinder their ability to inherit property, increasing their vulnerability.

Elderly individuals, children, and persons with disabilities (PWDs) are also highly disadvantaged. Children are especially susceptible to malnutrition, and school dropouts are common as children contribute to water fetching tasks, particularly young boys also search for pasture and water for livestock. Marginalized and indigenous communities, such as those in **Chewele and Bangale**, often live in remote areas, adhere to traditional practices, have large families, and face high illiteracy rates, making them more vulnerable to climate challenges.

Figure 5: Children carrying water over long distances

Source: Fieldwork, August 2025

Resource scarcity, particularly of pasture and water, leads to frequent conflicts between communities, including clashes between farmers and herders, as well as between humans and wildlife. **These conflicts result in loss of life, displacement, destruction of property, and disruption of economic activities, these negative impacts can create vulnerability among displaced groups as well as increase pre-existing inequalities** and therefore some vulnerabilities in the said group.

Low levels of literacy and a lack of technical skills further **hinder adaptation efforts**. Access to training and extension services is insufficient, particularly for women, highlighting the need for education in areas such as medication administration, vaccination, and parasite control.

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 6: 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 Tana River 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.

Tana River mostly falls under the hot semi-arid Climate (BSh) Köppen-Geiger Climate Classification, but also under the tropical savanna climate (As/Aw) one on the coastal part of the county.

Mean average temperature is higher than 27°C from October to May, with March going up to 29°C. Rainfall is low, bimodal, erratic and conventional in nature.

The total annual rainfall ranges between 280mm and 900mm with long rains occurring in April and May, short rains in October and November with November being the wettest month. The observed seasonal precipitation ranging from 213mm in March/April/May to 65.71mm in June/July/August (202.86mm in September/October/November and 101.15mm in December/January/February). The Inter-Tropical Convergence Zone (ITCZ), which influences the wind and non-seasonal air pattern for the river Tana, determines the amount of rainfall along the river line. The dry climate in the hinterland can only support nomadic pastoralism.

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

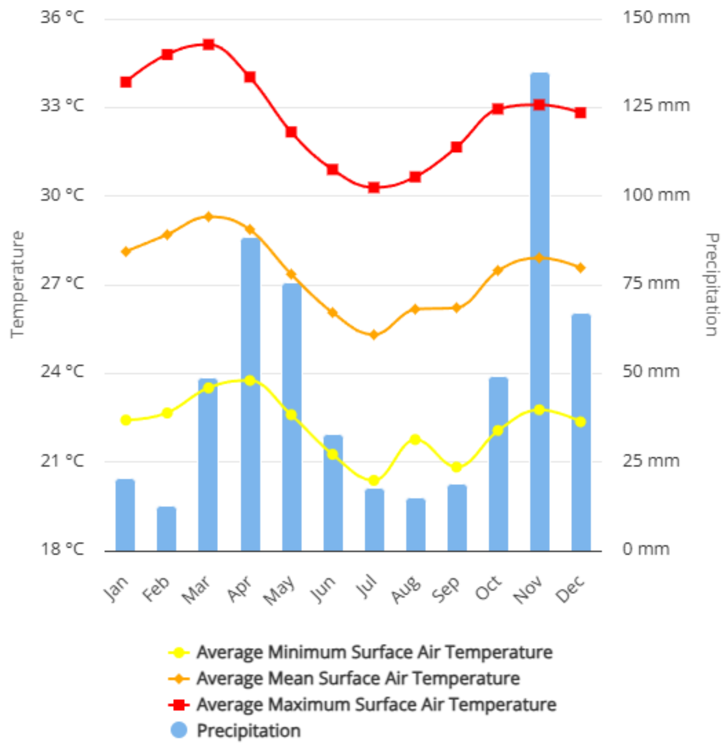


Figure 7: Monthly climatology, 1991-2023; Tana River

Source : (The World Bank Group 2025)

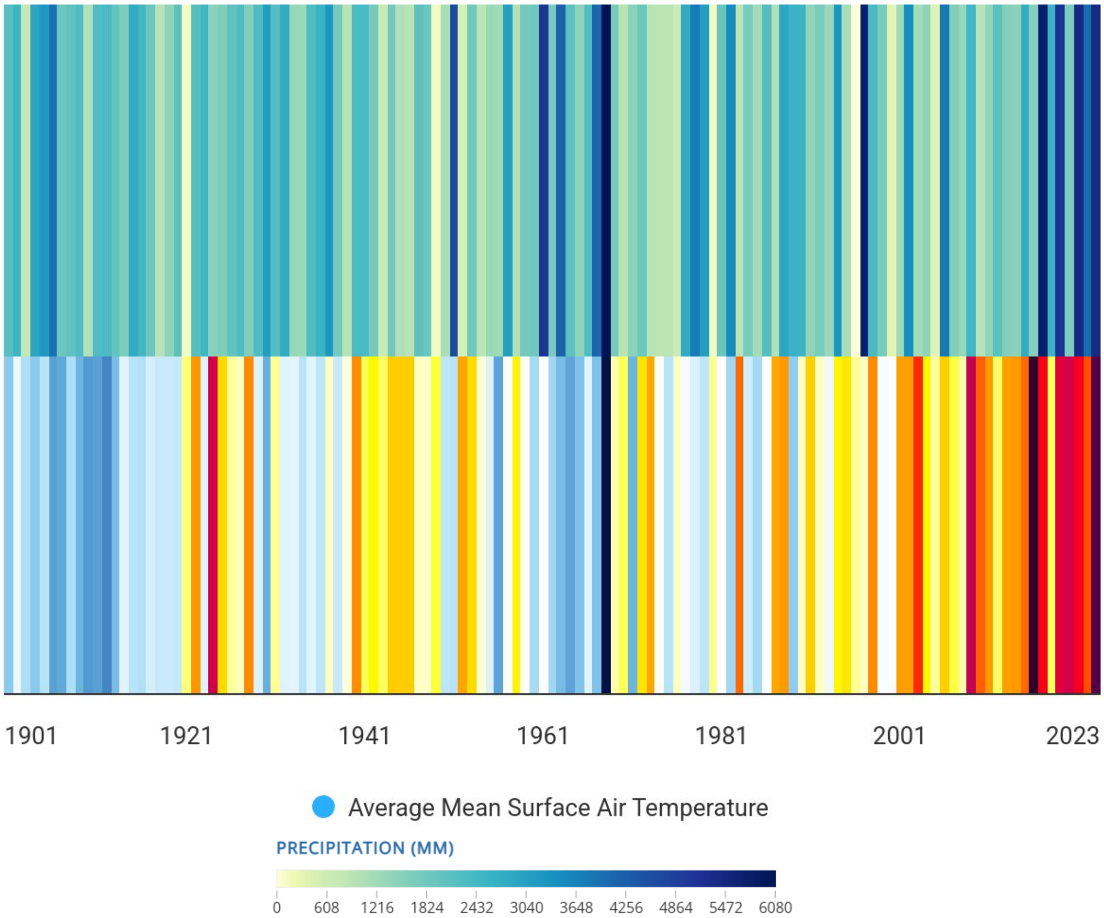


Figure 8: Observed annual average precipitation (top) and mean surface air temperature in Tana River

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."[2] 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 +0.6°C has been noticed since 1901, while for precipitation changes have to be checked seasonally:

- December/January/February: +12.99mm
- March/April/May: -37.89mm
- June/July/August: -8.6mm
- September/October/November: +38.09mm

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 seem to show a change in the usual wet and dry intensity repartition from December to May.

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).

[2] Quote from the CCAP

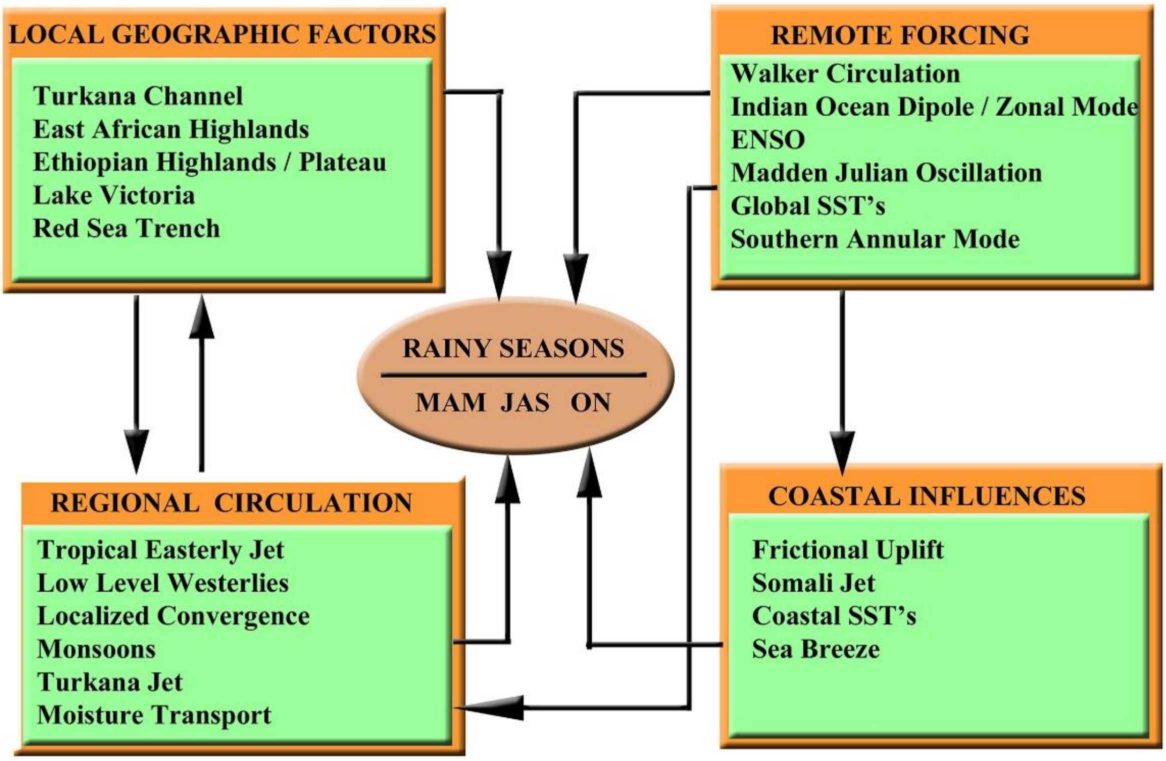


Figure 9: Schematic showing the factors influencing the three rainy seasons (MAM, JAS, and ON) of eastern Africa and the interrelationships among the factors.

Source : (Nicholson 2017)

While multiple rainy season 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).

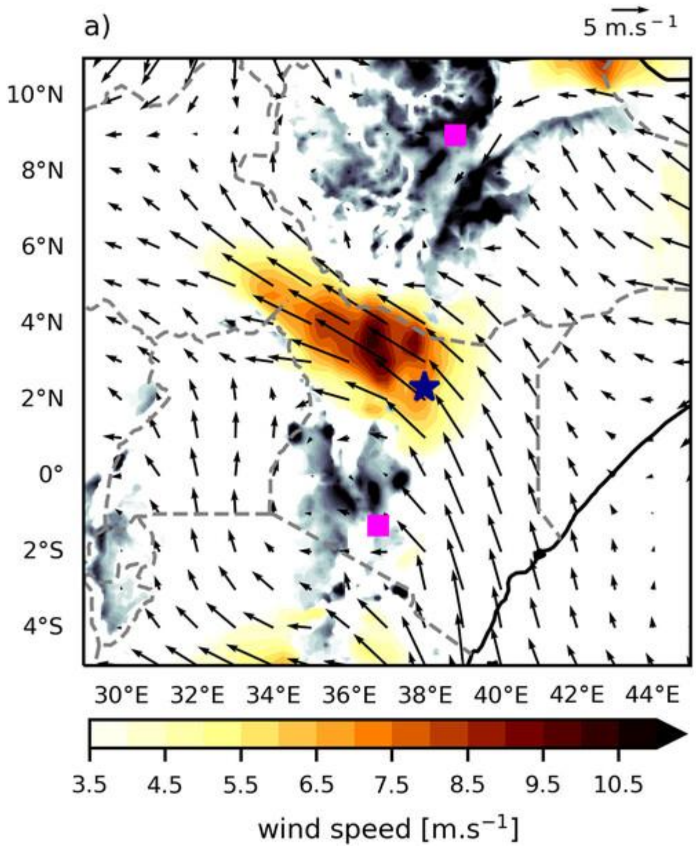


Figure 10: Winds associated with the Turkana Jet and surrounding area

Source : (Nicholson 2017)

4.1.1 Temperature projections

Under the SSP5-8.5 Average Mean Surface Air temperature is expected to increase by +1.25°C in December to up to +1.66°C in May during the 2040-2059 period, over the year the average increase would be of about +1.3°C in 2050 compared to the 5-year smoothed observed temperature of 2023.

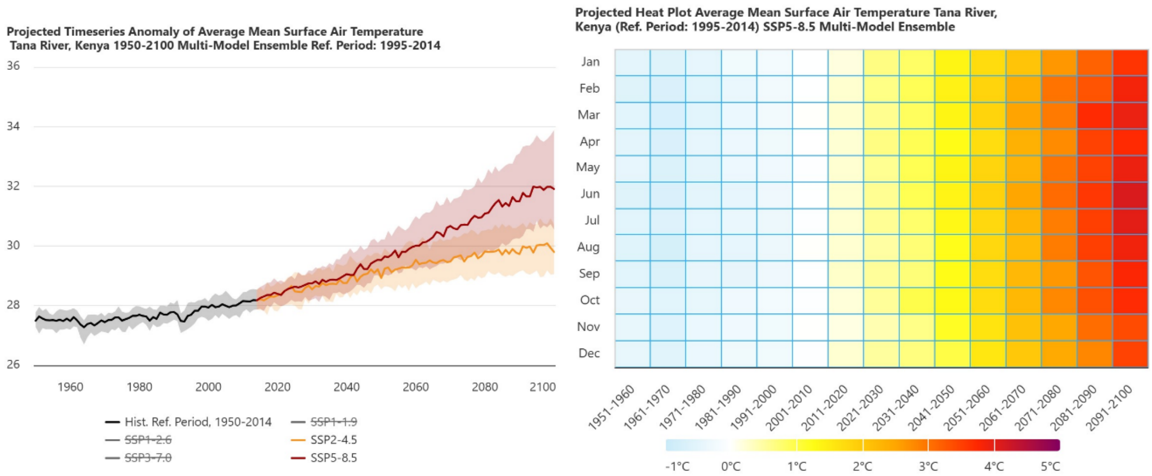


Figure 11: Projections of average mean temperature under SSP5-8.5

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 355.54 days with such characteristic in 2050, which is 10 more days than during the reference period 1995-2014, of these 10 additional days 9 fall during the months of July and august which were the ones with the least number of hot days under the reference period.

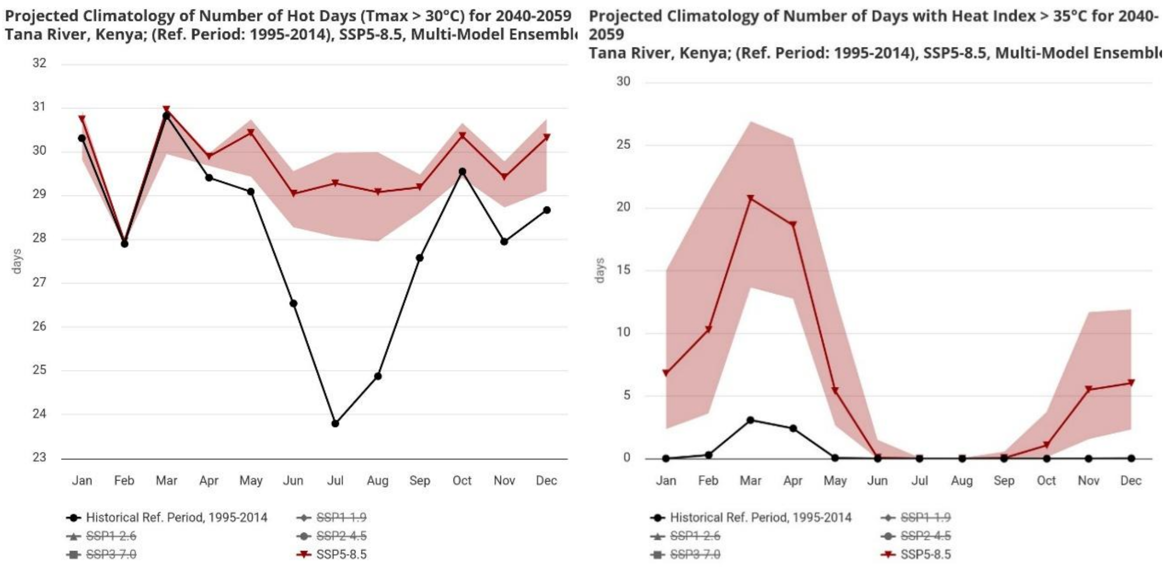


Figure 12: Projected climatology of number of hot days (Tmax>30°C) for 2040-2059) (LEFT) and days with heat index superior to 35°C (RIGHT) in Tana River

Source: (The World Bank Group 2025)

Apart from hot days, an interesting indicator is the number of days with high heat index. Indeed, Heat index is also known as the "apparent temperature" as it corresponds to what the temperature feels like to the human body when relative humidity is combined with the air temperature[3]. Such apparent temperature is also expected to increase from October to May, especially in March and April with +17.67 days in March and April with +16.21 days. This results from the combination of temperature and precipitations projected changes.

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 Tana River

Monthly changes

The most affected months regarding precipitation changes are November to January with an increase of +14.76mm by 2050 and +32.51mm by 2100 in December compared to the 1995-2014 reference.

The largest 5 days cumulative rains are also expected to increase from September to May, with an increase of up to +8mm (27%) in November by 2050 and +25.46 mm (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.

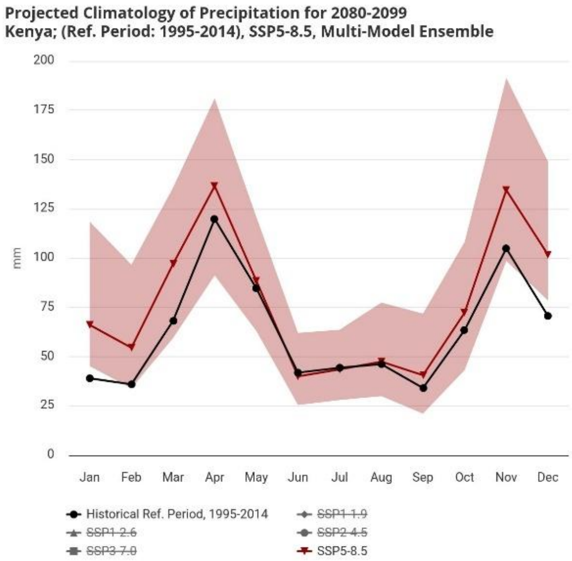


Figure 13: Projected climatology of precipitation for 2100 under SSP5-8.5

Source: (The World Bank Group 2025)

[3] This has important considerations for the human body's comfort. When the body gets too hot, it begins to perspire or sweat to cool itself off. If the perspiration is not able to evaporate, the body cannot regulate its temperature. Evaporation is a cooling process. When perspiration is evaporated off the body, it effectively reduces the body's temperature. When the atmospheric moisture content (i.e. relative humidity) is high, the rate of evaporation from the body decreases. In other words, the human body feels warmer in humid conditions. The opposite is true when the relative humidity decreases because the rate of perspiration increases. The body actually feels cooler in arid conditions. There is direct relationship between the air temperature and relative humidity and the heat index, meaning as the air temperature and relative humidity increase (decrease), the heat index increases (decreases). (National Weather Service s.d.)

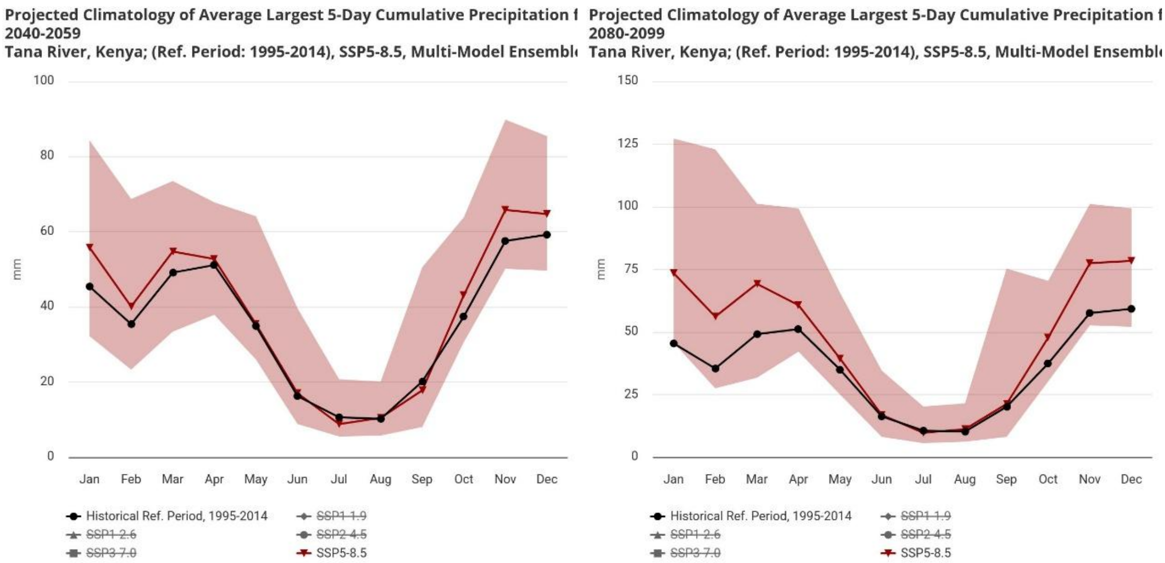


Figure 14: Projected evolution of the largest 5-day cumulative precipitation for 2050 and 2100 under SSP5-8.5

Source: (The World Bank Group 2025)

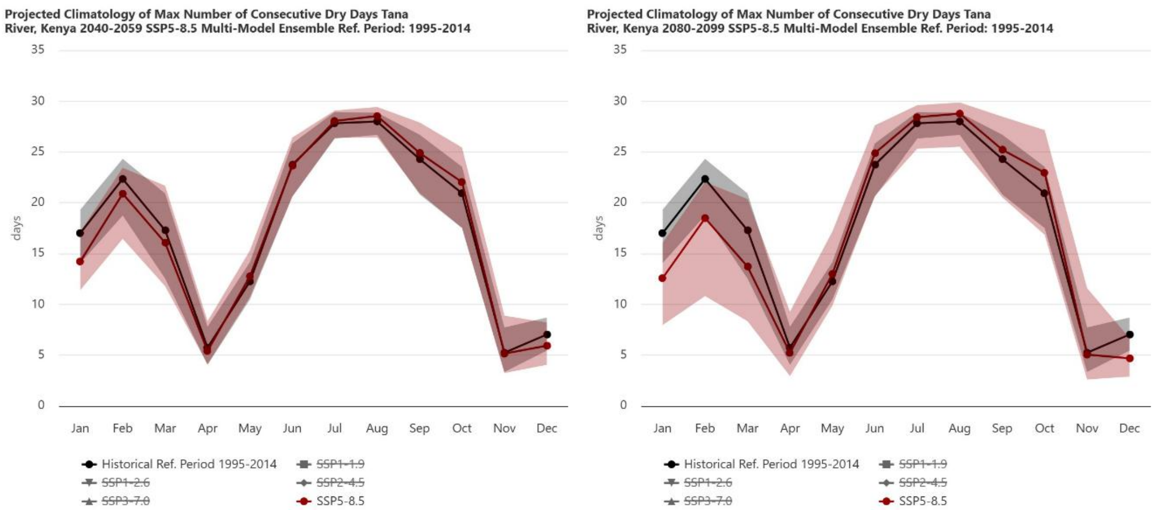


Figure 15: Projected evolution of the number of consecutive dry days for 2050 and 2100 under SSP5-8.5

Source: (The World Bank Group 2025)

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

Interannual changes

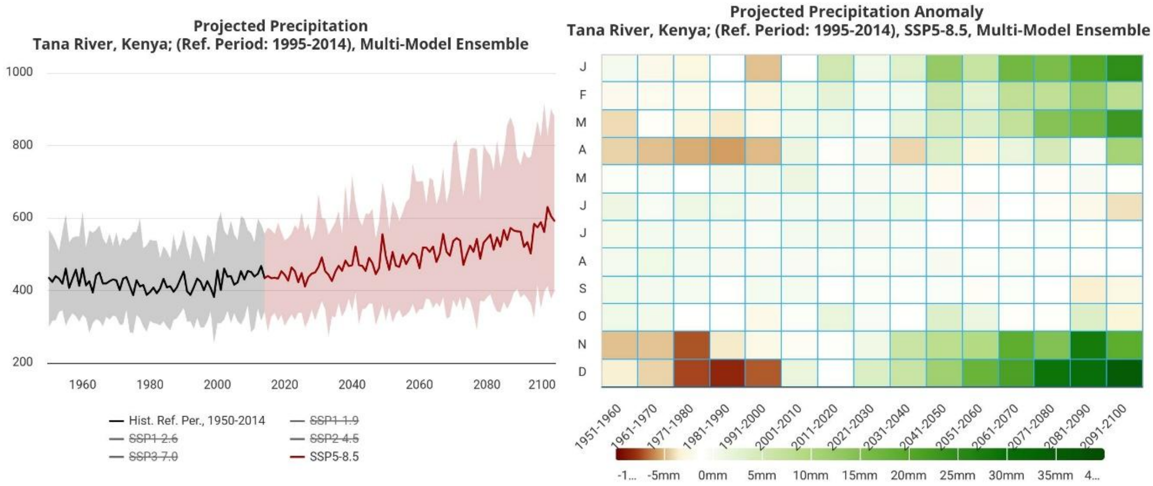


Figure 16 : Interannual precipitation changes projections

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 +0.1 by 2050 and +0.6 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

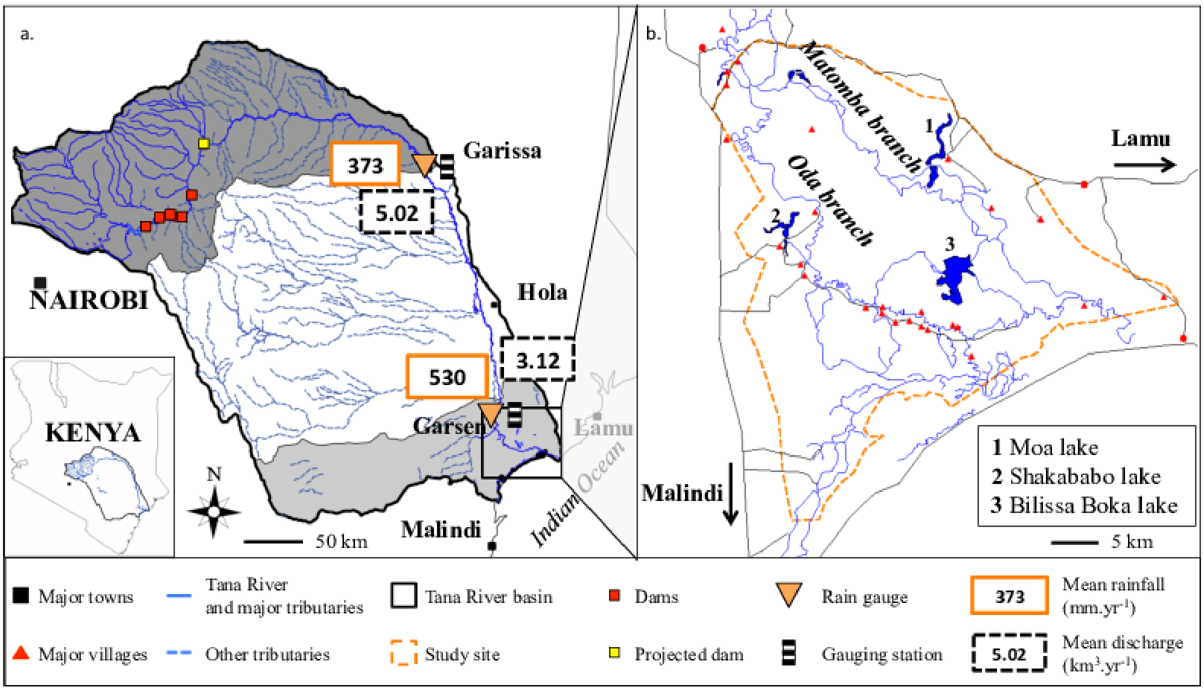


Figure 17: Tana River Water Basin main features and precipitation analysis

Source: (C. Leauthaud et al. 2013)

As much of eastern Kenya experiences tropical semi-arid climate conditions, the water balance and hydrology of the Tana River delta 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).

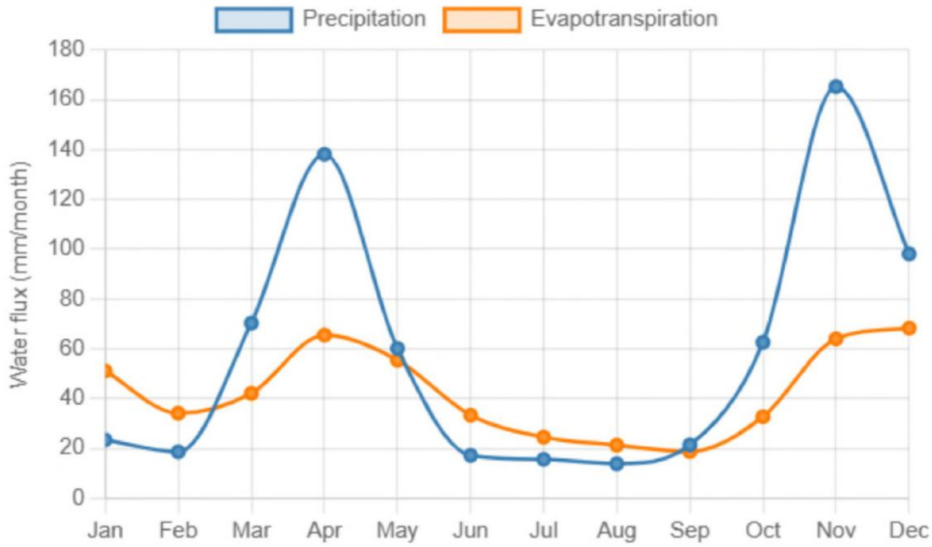


Figure 18: Watershed climatology: monthly average precipitation and evaporation over the watershed.

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).

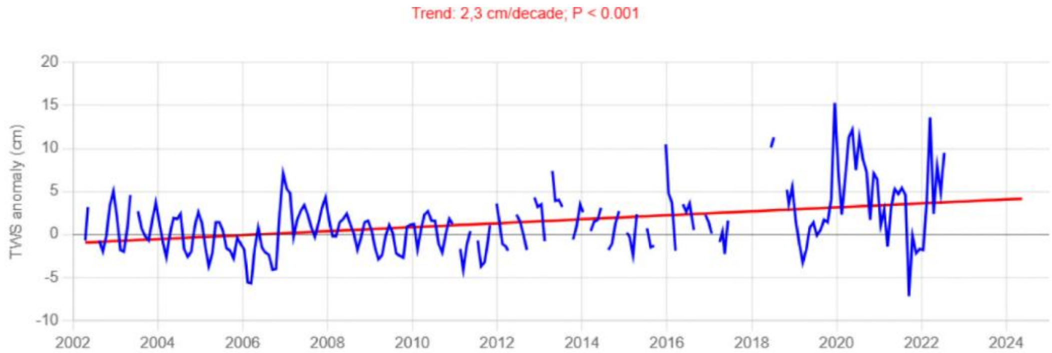


Figure 19: GRACE model, total water storage anomaly from 2002 to 2024

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)

Therefore, while overall precipitation in the county increase according to RCP5-8.5 scenario projections, as well as total water storage either, it should be underlined that on its end surface water flowing through Tana River may be reduced due to upstream dams. The related water availability at county level will then have to be studied considering the distribution of water stored at the dams level (upper Tana River Catchment).

4.1.2.3 Conclusion on precipitation

The analysis at both Tana River County and Tana River Basin scales indicates an overall increase in mean precipitation. However, the projected increase in the maximum 5-day cumulative precipitation during the wet season, combined with a rising number of consecutive dry days during the dry season suggests an intensification of annual rainfall variability. In practical terms, this points to wetter wet seasons and drier dry seasons, this will inform the hazard assessment below, particularly regarding flood and drought risks.

While Figure 18 shows an increase in water storage anomalies, suggesting higher overall water availability in the future, this result requires careful interpretation. The increase is primarily associated with wet-season conditions, while intra-annual variability remains significant and warrants further investigation to assess (i) whether projected flows are sufficient to enable effective groundwater recharge, and (ii) whether dry-season climatic conditions (including temperature and humidity) will allow surface water storage to be sustained without excessive evaporative losses or with a capacity allowing water availability throughout drought periods. In addition, upstream dam operations play a critical role in shaping downstream flows and water availability in Tana River County. As most major dams are located outside the county, this creates a governance and management gap, whereby Tana River County is highly dependent on upstream water management decisions but has limited control or formal involvement in dam operation, flow regulation, and inter-county water allocation.

4.1.3 Topography and soil conditions

Topographic physical parameters can play a significant role in hazard occurrence. Tana River County has a relatively flat topography, corresponding mostly to a "plan" landform classification.

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

- Solonetz, one of the 30 soil groups in the classification system of the Food and Agriculture Organization (FAO). Solonetz soils are defined by an accumulation of sodium salts and readily displaceable sodium ions bound to soil particles in a layer below the surface horizon (uppermost layer).
- Planosols are soils with bleached, light-coloured, eluvial surface horizons that show signs of periodic water stagnation and abruptly overly dense, slowly permeable subsoil with significantly more clay than the surface horizon. They develop mostly on clayey alluvial and colluvial deposits, predominantly in flat lands.
- Vertisols are 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.
- Lixisols are strongly weathered soils with low levels of available nutrients and low nutrient reserves. However, the chemical properties of Lixisols are generally better than of Ferralsols and Acrisols because. of their higher soil-pH and the absence of serious Al-toxicity.
- 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.
- Cambisols are characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides.

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

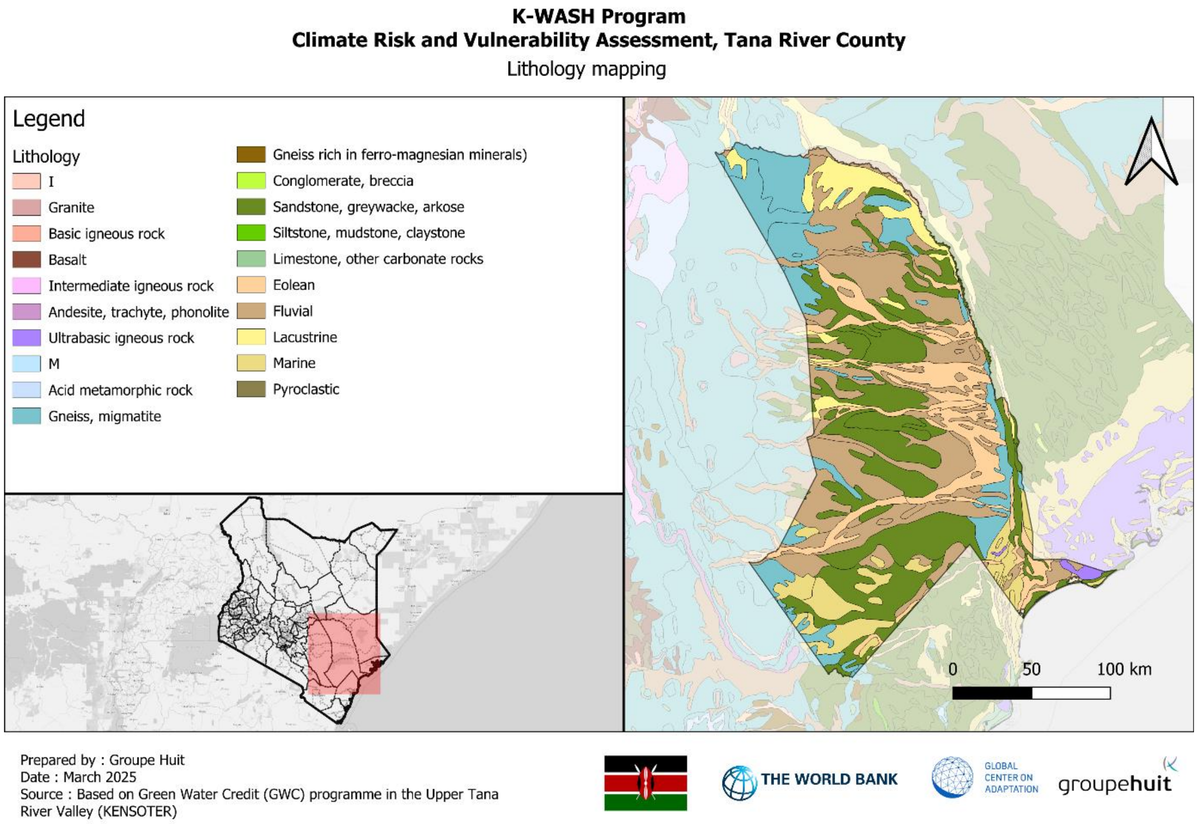


Figure 20: Tana River County lithology mapping

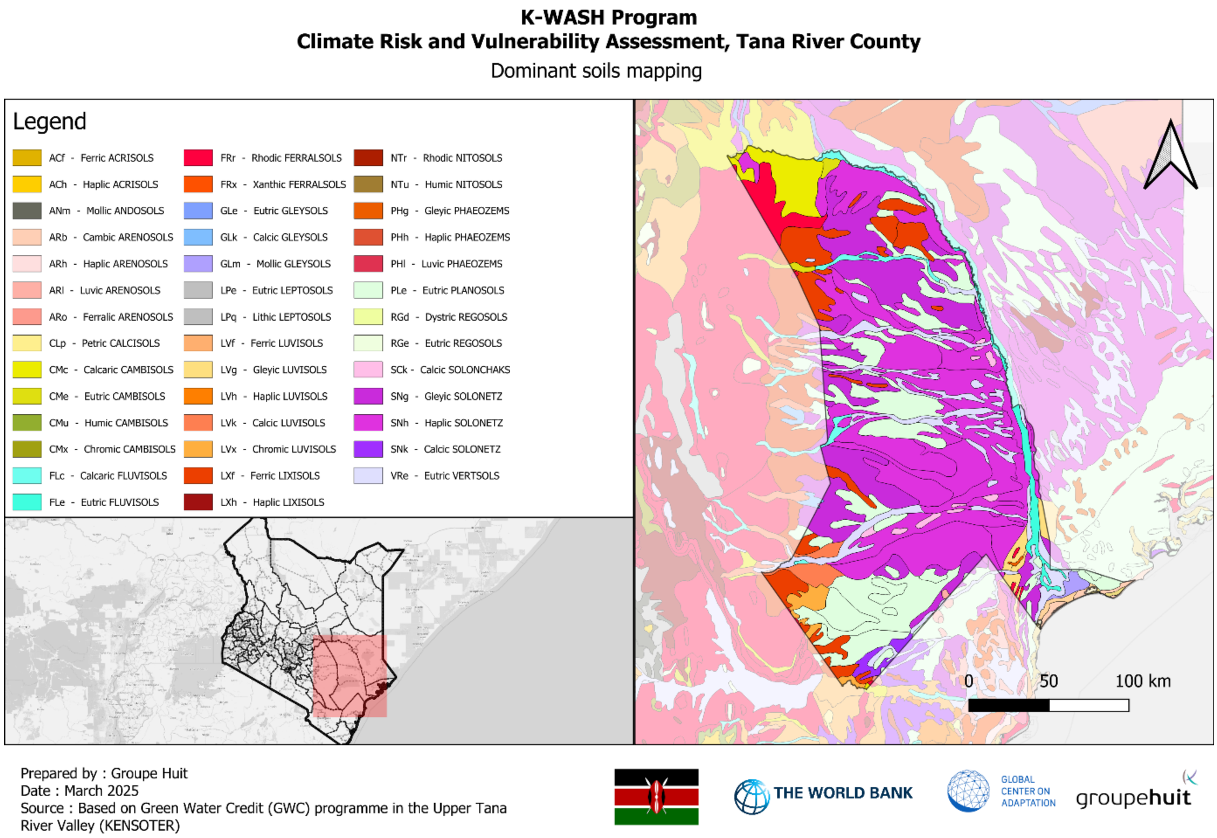


Figure 21: Tana River County dominant soil mapping

4.1.4 Water resources

Tana River County water system falls in the Tana and Athi river basins with Tana basin taking about 90% while Athi takes about 10% (only at the very south west of the County). Apart from the aforementioned river there exist other seasonal rivers (laggas), forming sub catchments which all drain west –east to river Tana basin. These seasonal sub catchments and laggas are Hirimani in Tana North, Galole in Tana River and Kokani in Tana Delta sub counties.

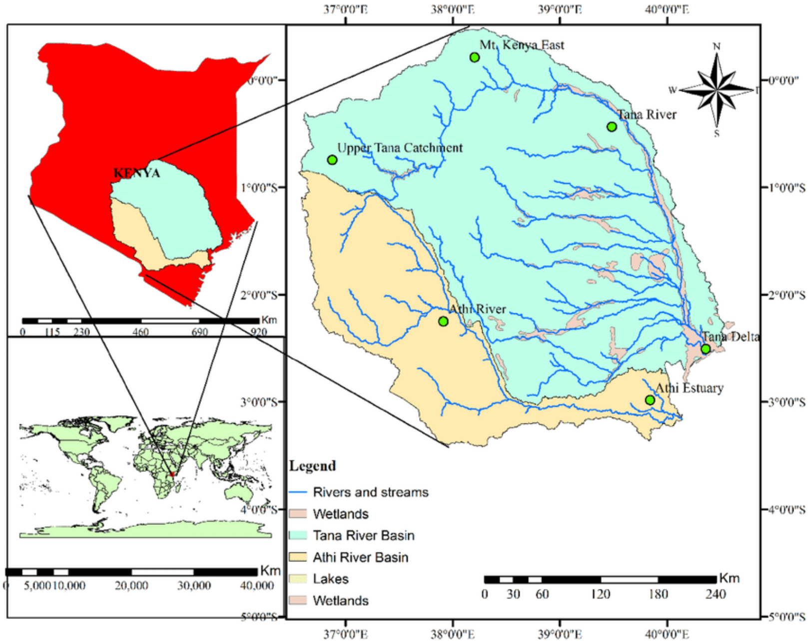


Figure 22: Map of Tana and Athi Catchment Area

Source: (Philip Langat 2019)

As mentioned, the county is mostly located within the Tana Catchment Area (TCA) which is 126,026km² wide, Tana River thus represents 30% of the TCA. The location of the county at the downstream part of the catchment area is to be underlined tu understand surface water flows (developed below).

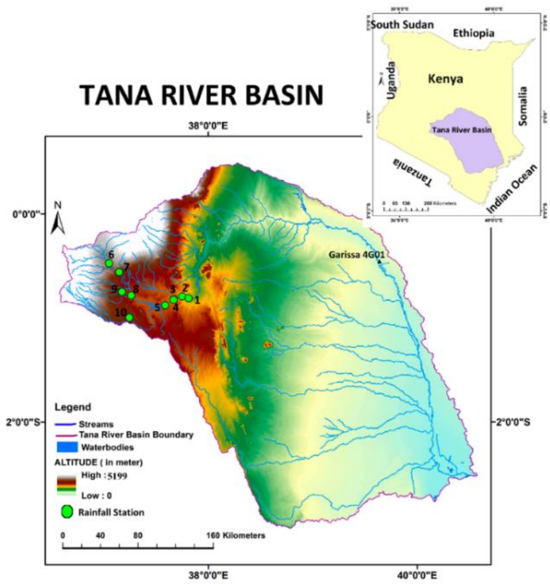


Figure 23: Map of the Tana Catchment Area (TCA)

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

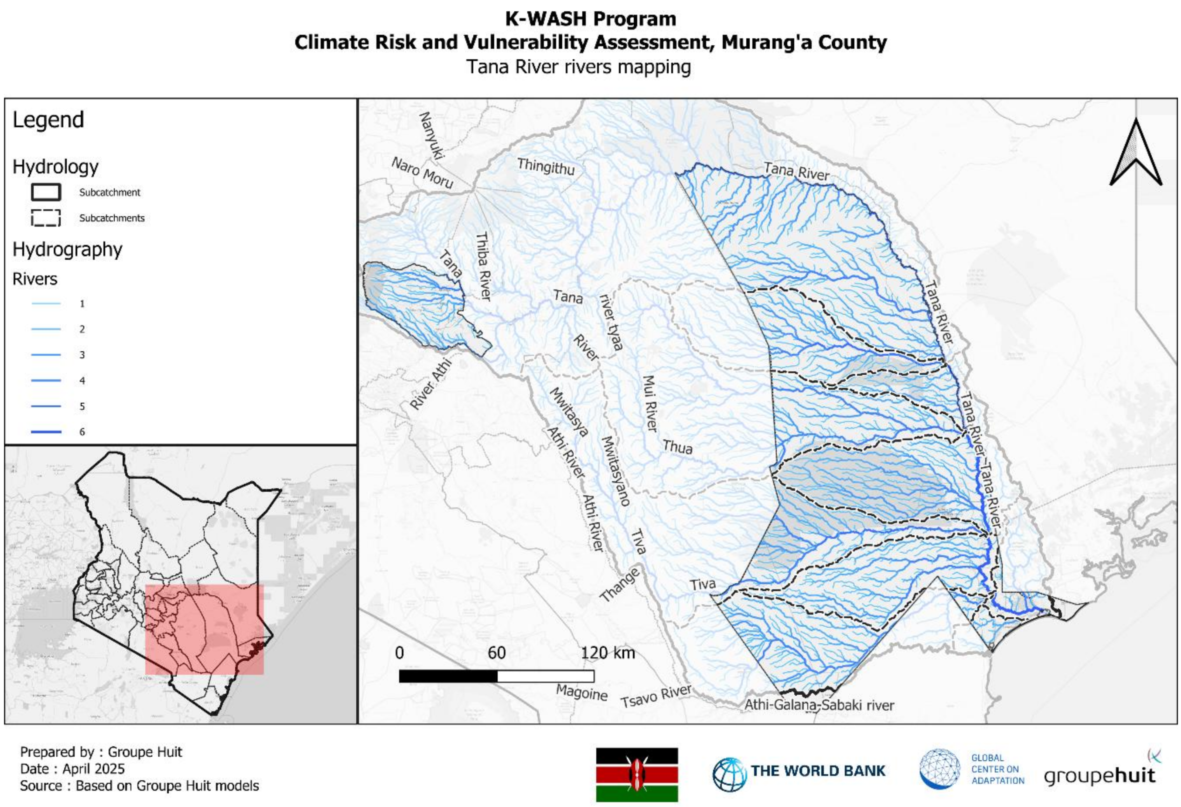


Figure 24: Tana River rivers map

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. It is suspected that Tana River County facing increase in temperatures is likely to lead to important increase of evapotranspiration or modifications of soil characteristics which could therefore enhance this groundwater recharge reduction phenomenon.**

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 Tana River these data have to be analysed cautiously.**

Table 5: 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

4.2.1 Hazard screening

Based on literature review and mostly the PCRA and CCAP documentation of Tana River 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
  - Sea level rise and high tide flooding
- Heat stress and droughts
- Erosion
- Coastal erosion
- 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 2100, and the scenario is SSP5-8.5.

4.2.3 Floods

According to the CCAP and PCRA, Tana River County is highly prone to flooding, especially during the rainy season, with heavy rainfall, overflowing rivers, and inadequate drainage systems being the primary causes.

Intense precipitation, both within the county and upstream areas, significantly contributes to flooding, particularly along the River Tana. Wards such as Kipini East, Kipini West, Garsen North, Garsen South, Garsen West, Garsen Central, Hirimani, Madogo, Chewani, Chewele, Mikinduni, and Kinakomba are among the most affected, with areas like Bura, Gubani, Masabubu, and Tana Delta suffering major damage in recent years.

The county has experienced major flood events in 2002, 2003, 2010, and more recently in 2015, 2016, and 2019, which have led to the displacement of thousands, the loss of lives, and the destruction of infrastructure. These floods have disrupted local economies, particularly agriculture and transportation, while poor drainage systems have exacerbated the situation, leading to further water accumulation and prolonged flooding. The county's vulnerability is compounded by inadequate flood mitigation strategies, highlighting the urgent need for improved drainage infrastructure, flood control measures, and community-based preparedness to reduce the impacts of future floods.

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 soils nor be not drained through pipes or natural drains, especially in low-lying areas. Such floods thus depend on multiple criteria and is 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 6: 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 7: 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 hazard which was assessed through implementing the previous methodology.

The hazard levels are defined through the pluvial flood hazard index (calculated as presented above) and with the following levels:

- Low hazard: Pluvial flood hazard index < 1
- Medium hazard: 1 < Pluvial flood hazard index < 2
- High hazard: 2 < Pluvial flood hazard index < 3
- Very high hazard: 3 < Pluvial flood hazard index

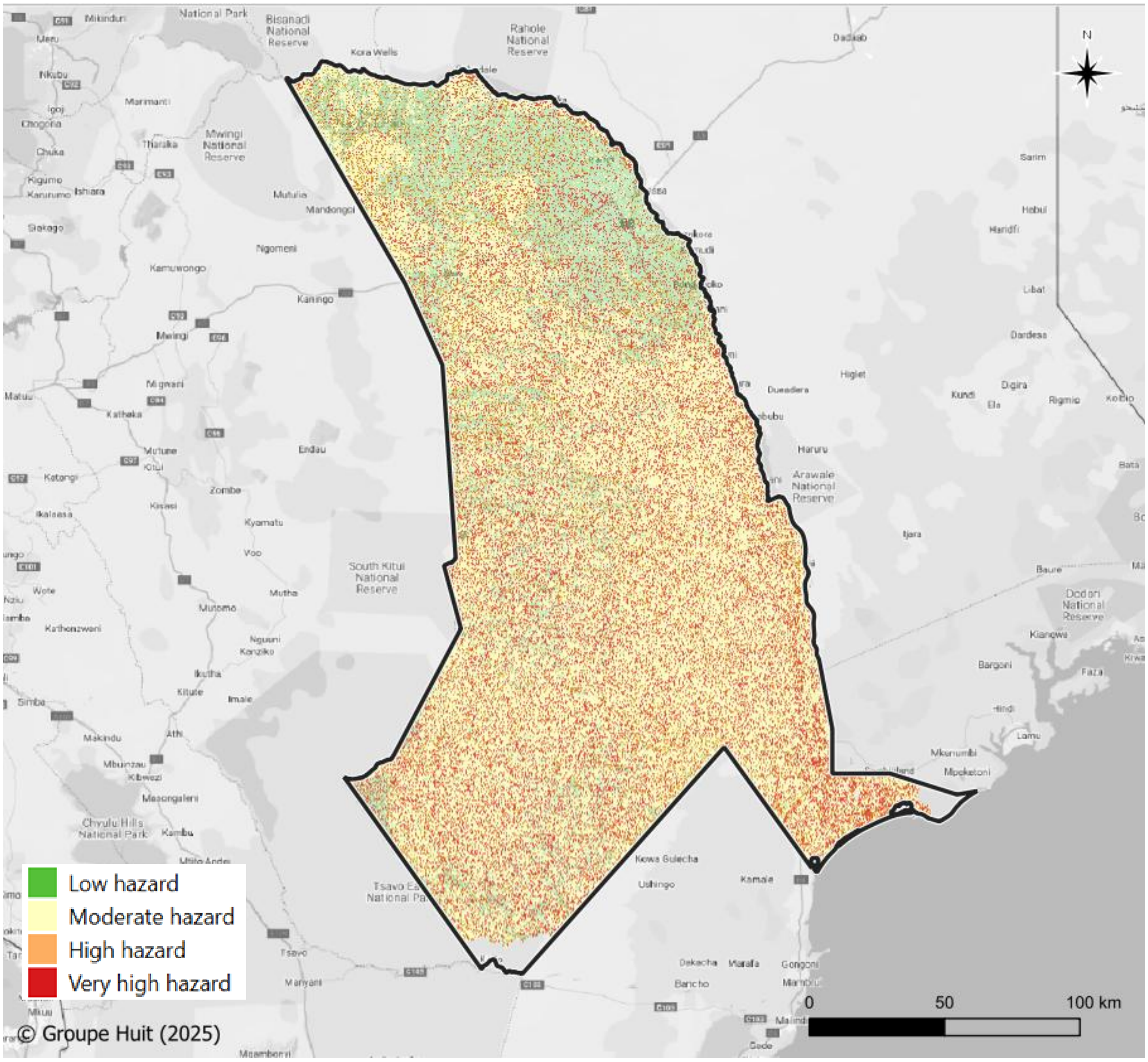


Figure 25: Pluvial flood hazard

A detailed atlas is provided in annex 3 of the present report, it enables to show zoomed-in maps.

At sublocation scale, results are emphasized in the following map

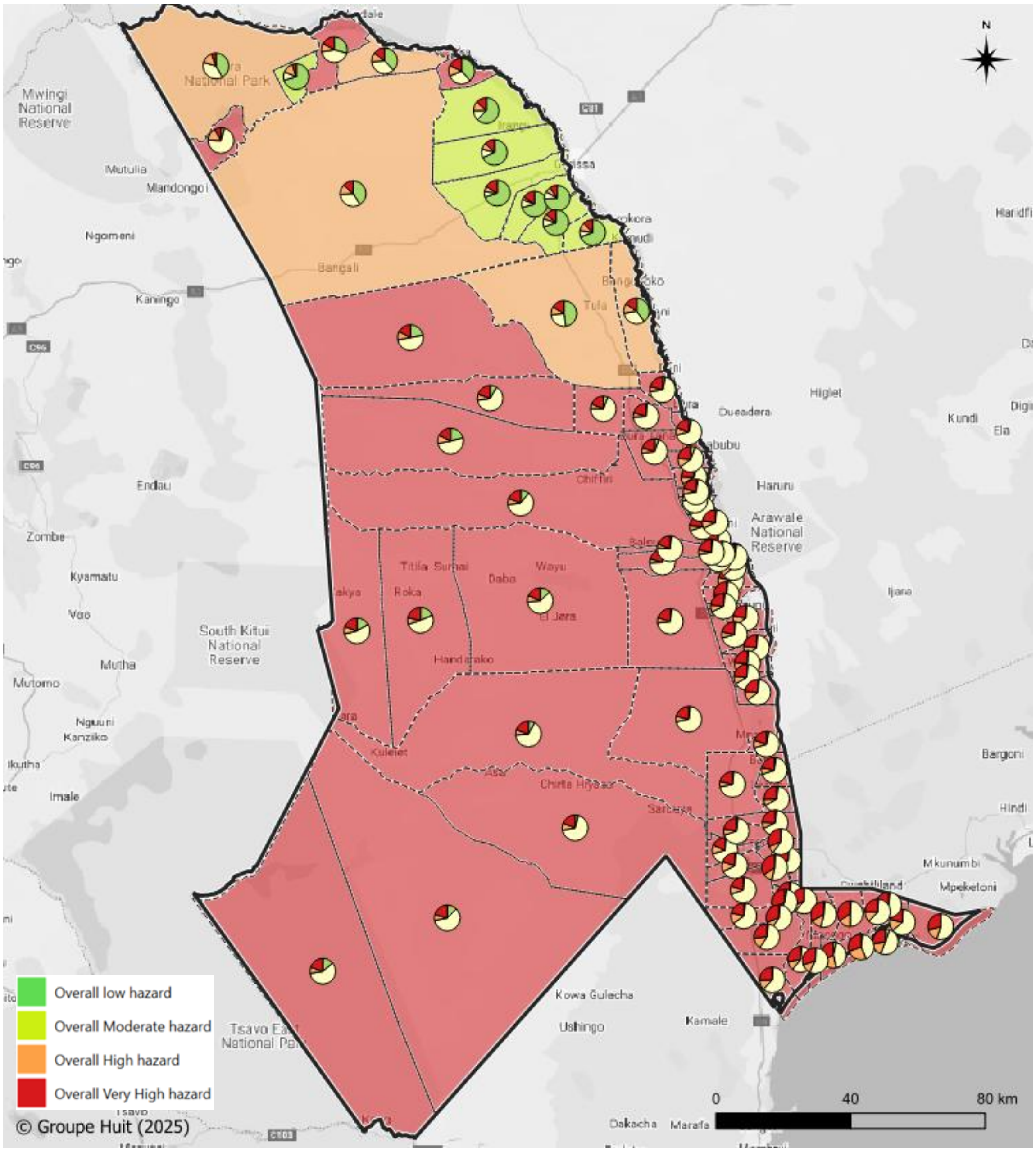


Figure 26: Pluvial flood hazard at sublocations level

The spatial distribution of pluvial flood hazard across Tana River County, as presented in the map, reveals a north–south gradient in hazard levels, reflecting the topographic and hydrometeorological characteristics of the region.

Areas of very high pluvial flood hazard are concentrated in the southern subcounties, notably Galole and Garsen, but the south of Bura subcounty is also has high level of flood hazard. In Bura subcounty hazard also varies between high levels (west) and moderate ones (east). Overall Tana River County corresponds to the lower part of the Tana River basin which is consistent with a higher susceptibility to surface water accumulation during intense rainfall events.

Histograms on the map enable to highlight that the very southern areas of Matangeni, Ozi, Mpeketoni, Chamwuanamuma, Semikaro, Handaraku, Odele, Kikomo, Golbanti, Ongonyo, Ngao, Danisa show very high levels of pluvial hazard flooding on more than 25% of the territory, making them most critical hotspot for pluvial flood hazard. A zoom-in on the territories is presented below.

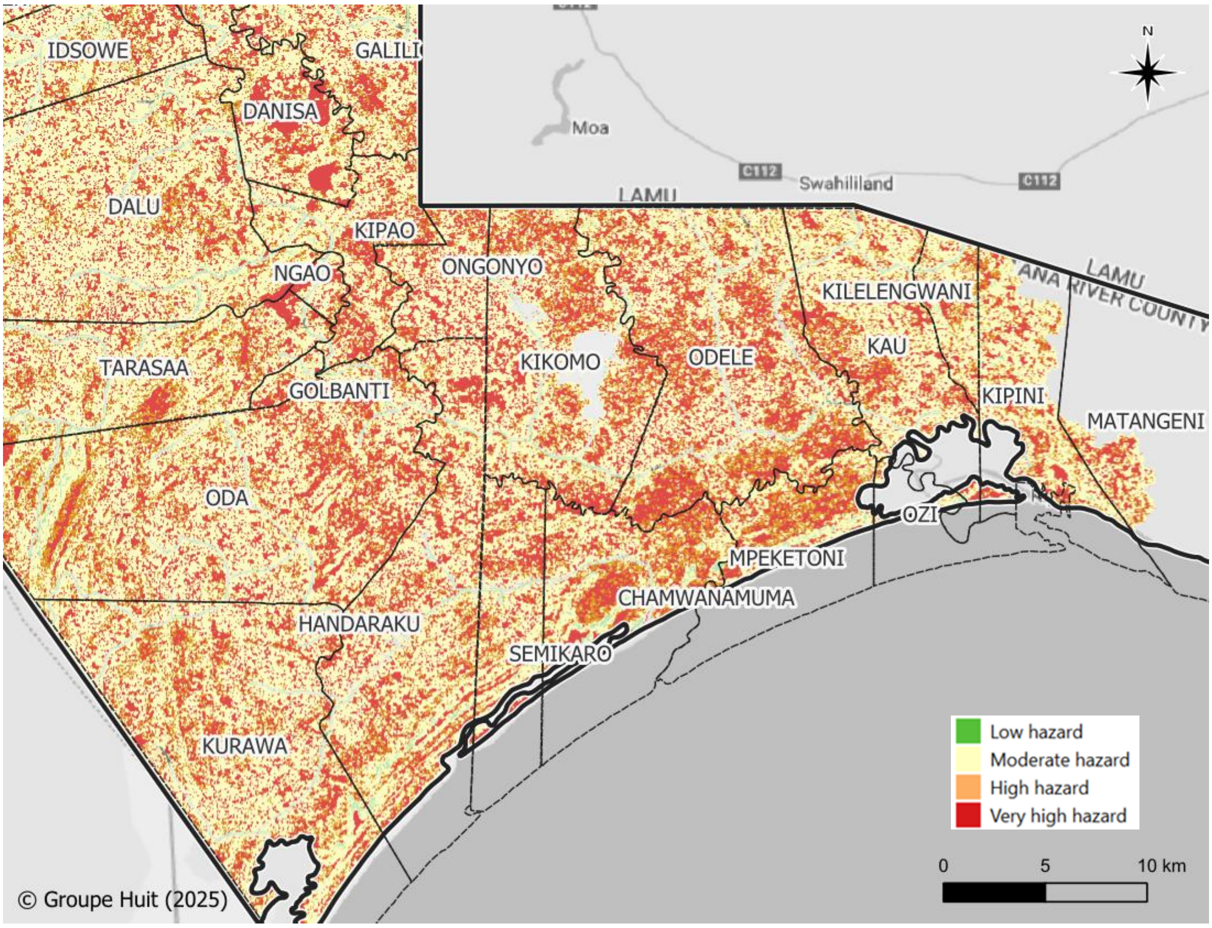


Figure 27: Pluvial flood hazard mapping in the south east area of Tana River county

This spatial diagnosis underscores the necessity to:

- Integrate pluvial flood management into urban development and drainage planning, particularly.
- 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 shows that pluvial flooding in Tana River County is not limited to riverine corridors, but rather represents a widespread hazard associated with the county's position within the larger catchment area. Targeted adaptation measures, informed by local exposure diagnostics, will therefore be essential to build 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 dam release upstream, sending large volumes of water into surrounding floodplains. For instance Madogo often (annualy) experiences flooding related to Masinga and Kindaruma dams.

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. Tana River and its tributaries are highly exposed to such floods. In areas such as Minjila (urban centre located in Shirikisho Location, Garsen Central Ward in Tana Delta) river flash floods are common, with floodwaters reaching heights of 3–5 meters, it can be noted that it is a low lying area (elevation of approximately - 8 meters above sea level).

Despite this recurrent flooding observations, 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 Tana River. 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 hazards in the absence of more detailed hydrodynamic simulations, and for guiding preliminary spatial planning, vulnerability analysis, and prioritization of further detailed studies.

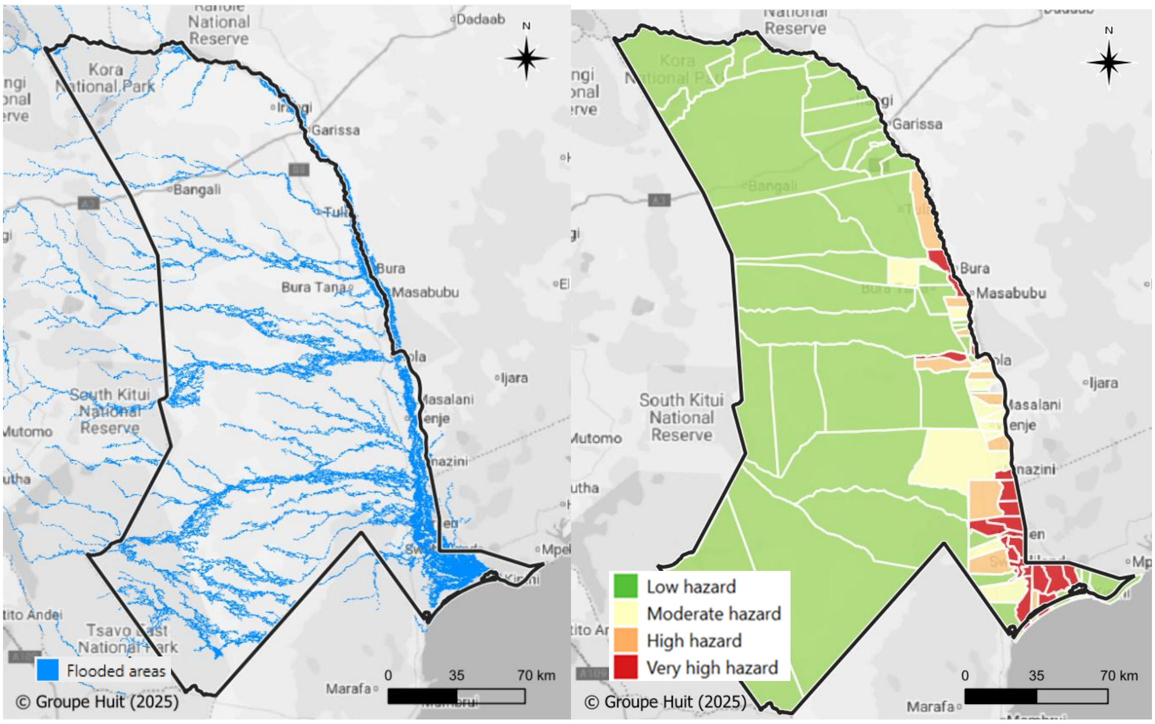


Figure 28: Flood hazard mapping

(left: flood extent of 100-year recurrence interval event ; right: hazard level)

An atlas of River Flood Hazard is provided in Annex 4 to show zoomed-in maps.

The map above illustrates the proportion of each sublocation 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 hydrological connectivity to the Tana River and its tributaries, areas more affected are the ones located in the downstream part of the Tana River, from Garissa city to the Tana River Delta. The sublocations with highest hazard levels are:

- Kikomo (
- 90%),
- Mazuni (88%),
- Odele (87%),
- Ongonyo (82%),
- Kipao (78%),
- Benderani (77%),
- Ngao (74%),
- Danisa (71%),
- Chewele (71%),
- Hola (70%),
- Galili (69%),
- Golbanti (68%),
- 3%).
- Dayate (64%),
- Mikameni (61%),,
- Wema (60%),
- Dumi (59%),
- Mnazini (58%),
- Wadesa (57%),
- Chira (56%),
- Bohoni (56%),
- Handaraku (50%),
- Chamwanamuma (48%),
- Chewani (44%),
- Kau (4

This analysis is confirmed by discussions with county representatives and field observations such as the one in Mkomani village, at the boundary with Mazuni, where the well field area has multiple stagnant water pools indicating frequent flooding which is also linked to its clay soil with poor drainage.

Figure 29: Mkomani Well Field water pooling areas

Source: Fieldwork, August 2025

Considering the mapping exercise, its limitations, and field observations, the results are best interpreted as a screening-level flood susceptibility map, rather than a detailed hydrodynamic floodplain model. This product provides an overview of areas most likely to experience recurrent flood pressures and thus serves as a decision-support tool for prioritizing adaptation and design measures within the investment plan. This, keeping in mind that while most of the county exhibits low fluvial flooding hazard levels, the sublocations with moderate to very high hazard levels (including those identified above) correspond to the most densely populated and economically active areas making the latter all the most exposed.

Because many agricultural zones depend on the Tana River for irrigation, and most major towns are located along its course, high river-flood hazard directly translates into elevated socio-economic exposure when combined with the spatial distribution of population and assets.

From a planning and adaptation perspective, this analysis confirms that river flood hazard management should prioritize riparian protection, the enforcement of buffer zones, and the extension, renewal and maintenance of drainage and river corridor capacity to mitigate future flood risks.

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.

Available information, based on British Geological Survey groundwater depth mapping (5 km resolution) [4], only allows a coarse delineation of potentially affected areas. These data are insufficient for precise hazard levels 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.

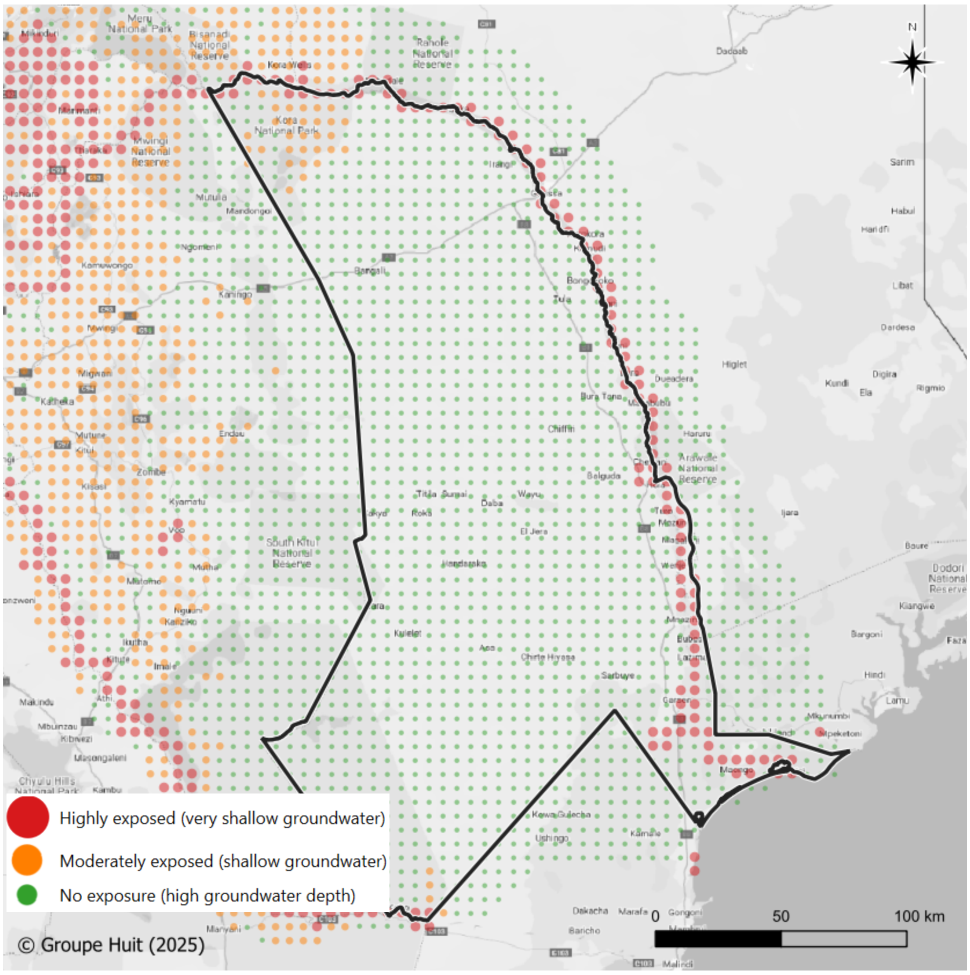


Figure 30: Average groundwater depth in Tana River County and related groundwater flooding hazard

[4] 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

The spatial distribution shows higher potential hazard along the Tana River, where the Tana River's accompanying water table can resurface, filling up when the river is high and serving to recharge the river when it is lower. The risk is therefore particularly high during the two months at the end of the rainy season. All areas located further away exhibit lower hazard levels. This does not rule out the possibility of local risks in the rest of the territory, but these do not appear in this large-scale analysis.

Rising groundwater flooding, has been mentioned multiple times during field works and appear to be an important hazard in Tana River County, it especially appears as a compounding process that can intensify the effects of pluvial and riverine flooding, particularly in flat, clayey, or poorly drained zones which correspond to most of Tana River riverbanks and delta area. 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 Sea level rise and high tide flooding

Considering the 1993-2024 period it is considered that over the past 30 years sea level has risen by 0.11m which corresponds to a 3.4375 mm/year. While sea level rise (SLR) can be considered limited as of now it should be understood that there is a risk of increase in the rate in the future, especially as 40% to 45% of SLR in Kenya results from combined effects of ocean warming and changes in ocean currents, both of which are influenced by climate change. As the ocean absorbs more heat, water expands (thermal expansion), and shifting ocean currents, driven by added freshwater from melting ice and altered heat transport, impact regional sea levels, causing further variability.

Such SLR issue should be considered in parallel with shoreline erosion and tide amplitudes increase which can lead to increased occurrence of high tide flooding. High Tide Flooding (HTF) refers to events where sea levels exceed a specific threshold above the average high tide and can potentially lead to flooding. Three defined thresholds - minor: 40cm (400mm), moderate: 60cm (600mm), and major: 80cm (800mm) - mark increasing levels of high water that may indicate worsening flooding risks. In the case of the Kenyan coastline HTF shows a slight increase over the 1979-2015 period, (increase of about +15 days in minor HTF and about +5 days in major HTF), while no projections is available it could be expected that such figures will increase considering temperature increase projections in the area and melting of Ice Sheet and Glaciers.

It should be noted that 15% of Kenyan SLR is attributed to vertical land motion which can be caused by natural processes like tectonic shifts or human activities such as groundwater extraction, and can either elevate or lower local sea levels, creating regional variations in the overall trend.

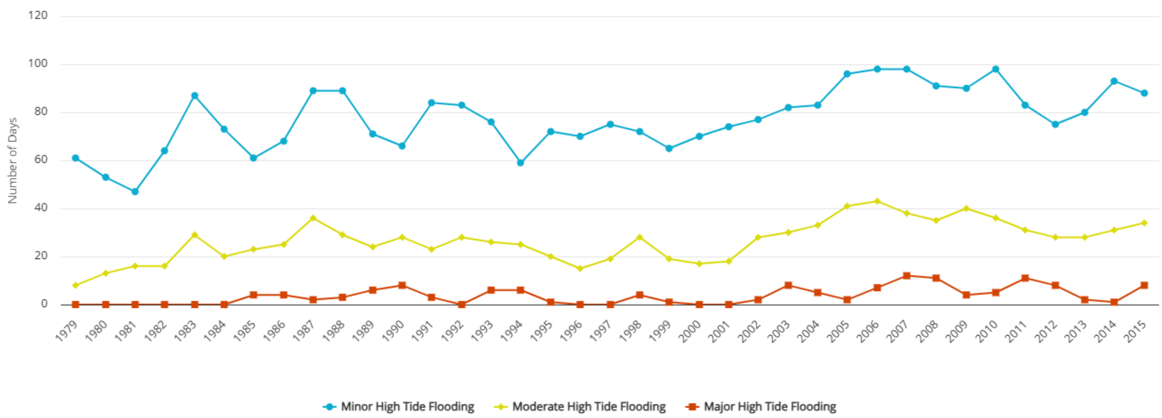


Figure 31: High tide flooding historic trends in Kenya EEZ (1979-2015)

Source: (The World Bank Group 2025)

4.2.5 Heat stress and droughts

4.2.5.1 Droughts

Tana River County is classified as an arid and semi-arid zone (ASAL) and is therefore prone to drought. The frequency and severity of droughts have increased in recent years due to climate change.

A period of drought occurs when rainfall is insufficient for a prolonged period, leading to a hydrological imbalance. In Tana River County, this usually occurs after two consecutive seasons of failed rains. Areas most affected by drought include Bangale, Hirmani, Kamagur, Boka, Konekaliti, Malka Mansa, Lebile and Habaqiq in Tana North sub-county; Wayu, Chifiri, Titila, Daba, Waldena, Gururi, Koticha, Haroresa, Lakole, Kesi and Hakoka in Tana River sub-county; and Hurara, Assa, Kone, Iddi, Odoganda, Ngao, Tarasaa, Kibusu and Gerarsa in Tana Delta sub-county.

Droughts have occurred in Tana River County in 1975, 1976, 1980, 1981, 1983, 2001, 2004 and 2009, mainly affecting the central and northern regions of the county. The most recent drought occurred in 2021, resulting in severe food, water and livestock shortages for around 92,000 people.

The drought is having diverse impacts on the county's pastoral, marginal mixed and mixed livelihood areas. Lack of water leads to crop failure, food shortages and mass migrations of people and livestock, which can result in conflicts over water resources and the spread of disease. The physical condition of livestock deteriorates, market prices fall and milk production declines, affecting the nutrition of young children. Drought has also contributed to the spread of invasive species such as Prosopis juliflora (Mathenge), which dries out watering holes, reduces arable land and impairs road accessibility.

Figure 32: Scenes of the dry Wolestokocha Lagha channels

Source: Fieldwork, August 2025

Discussions held during field activities have shown that the duration of droughts is quite different between areas in the county (according to community feedback) :

- Up to 11 months, with rainfall occurring mainly in April in Bura
- Up to 9 months in Minjilla
- Up to 2 years in Madogo and recurring every two to three years.

4.2.5.2 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 hazard levels also enable to highlight which areas are most concerned by heat waves (only considering temperature for this analysis). The heat risk thresholds presented below combine occupational health stress and WASH infrastructure stress considerations. They are indicative thresholds developed for climate risk screening and planning purposes, rather than definitions of absolute engineering failure limits:

- Low heat– 13-29°C:
  - Normal operating range for most Kenyan regions (especially highlands).
  - Minimal heat stress on staff and infrastructure as the temperature remain within the standard design and operating conditions for most WASH infrastructure (pumps, pipes, storage tanks, etc.)
  - No significant constraints on WASH operations.
- Moderate heat– 30-37°C:
  - Increasing physiological stress for exposed workers.
  - Noticeable impacts on WASH systems (evaporation losses, chlorine decay rates increase, microbial regrowth).
  - Early adaptation measures recommended (shade, schedule adjustments).
- High Heat– 38–44 °C:
  - High risk for heat-related illness with prolonged exposure.
  - Water demand spikes; stress on borehole pumps and solar pumping systems due to higher demand.
  - Borehole pumps and electric motors are usually designed to operate in temperatures below 40°C increasing overheating and failure risk, before/instead of failure efficiency can also be reduced, as is the case with solar panels[5].
  - Increased risk of water quality degradation (microbial growth, algal blooms).
  - Infrastructure materials begin to experience thermal expansion.
- Very high heat– >=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).

[5] For instance solar panels are usually tested at 25°C and offer their best range of efficiency between 15°C and 35°C, it is estimated that too much heat also reduces the efficiency of the solar panel, by 0.5 percentage points for every degree Celsius rise in temperature. (World economic forum 2022)

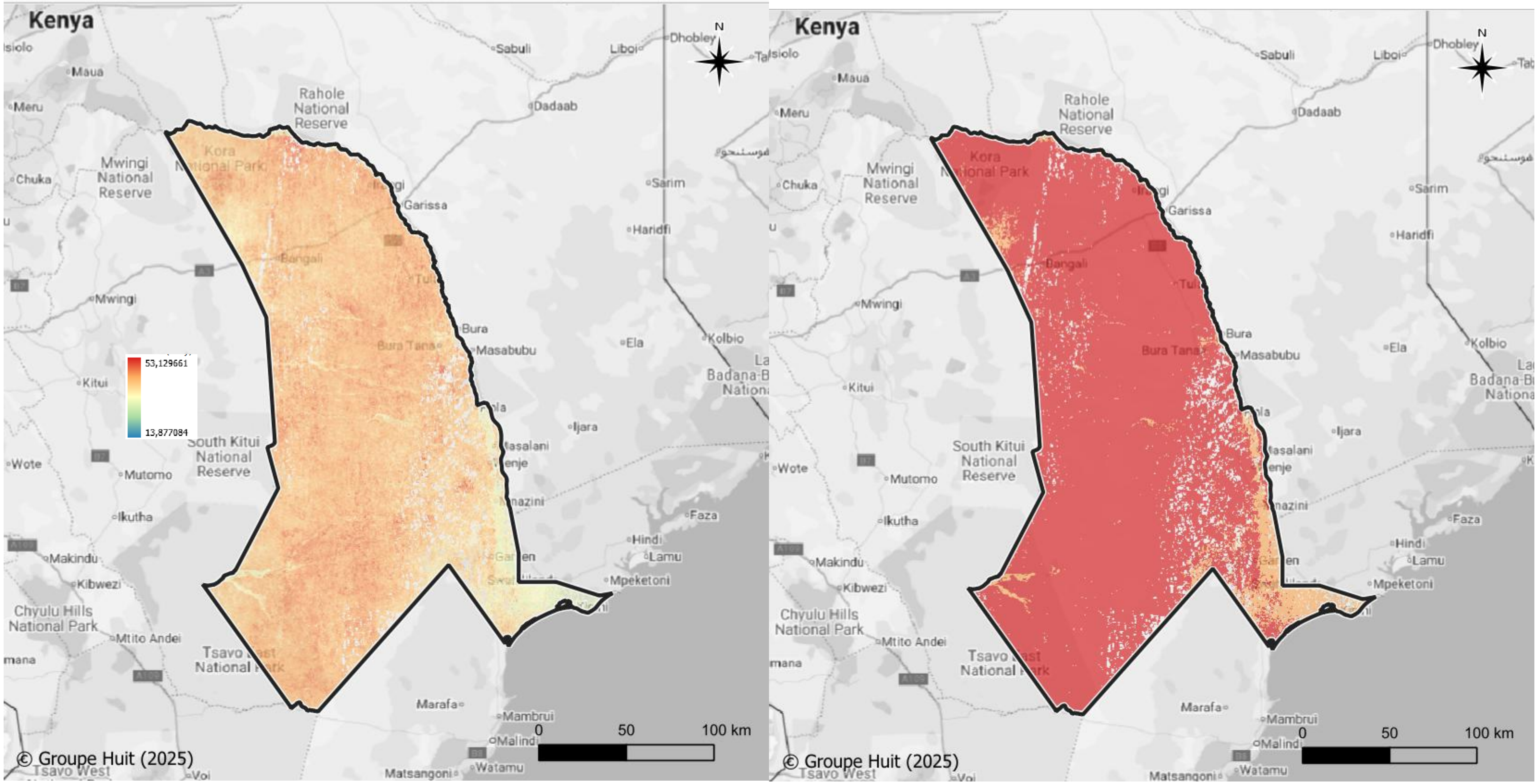


Figure 33: Land surface temperature in °C (left) and derived current heat hazard levels (right)

Source: 2023 LANDSAT/LC08/C02/T1_L2

The following graphs present metrics regarding daytime temperatures and humidity which enable to understand which months are most prone to present a heat risk in the future (heat being a combination of Temperature and humidity).

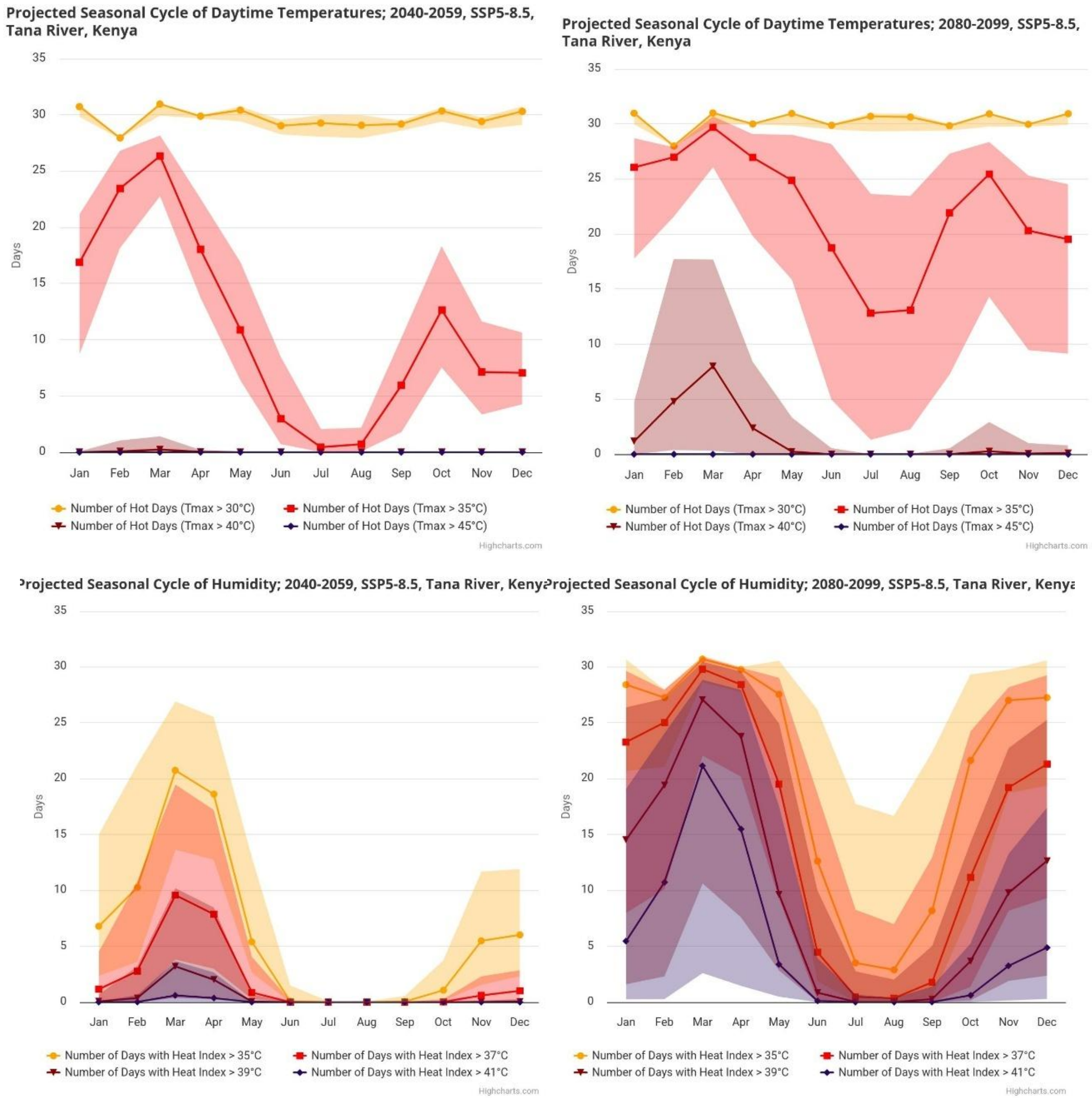


Figure 34: Projected seasonal daytime Temperature (top) and humidity (bottom) metrics for 2025 and 2100 horizons under SSP5-8.5

Source: (The World Bank Group 2025)

This last figure shows the risk factor by month and year, as projected by the multi-model ensemble used by the Climate Change Knowledge Portal.

It shows that the risk of heat is expected to increase from the first to the second or third risk factor. Although the change seems slower from January to April than for the rest of the year in the first half of the century, it is more intense by 2080 with January and April reaching the 3rd risk level.

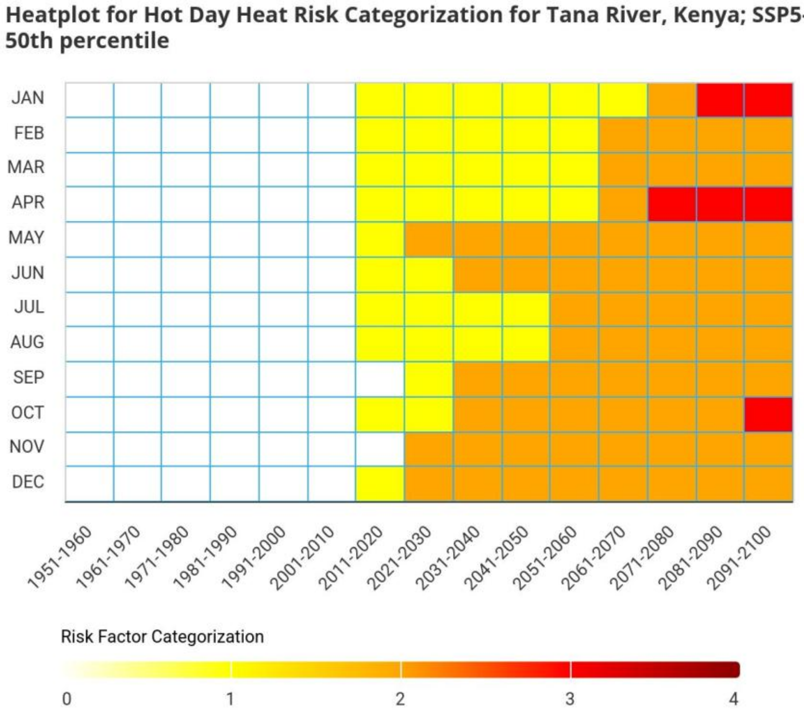


Figure 35: Hot day heat risk monthly and yearly evolution under SSP5-8.5

Source: (The World Bank Group 2025)

Geographically speaking the Eastern areas of the county are the most affected by heat waves. The latter are expected to see up to about 60 days with heat index above 35°C between March and May while the western part of the county will only have about 10 days on the same period.

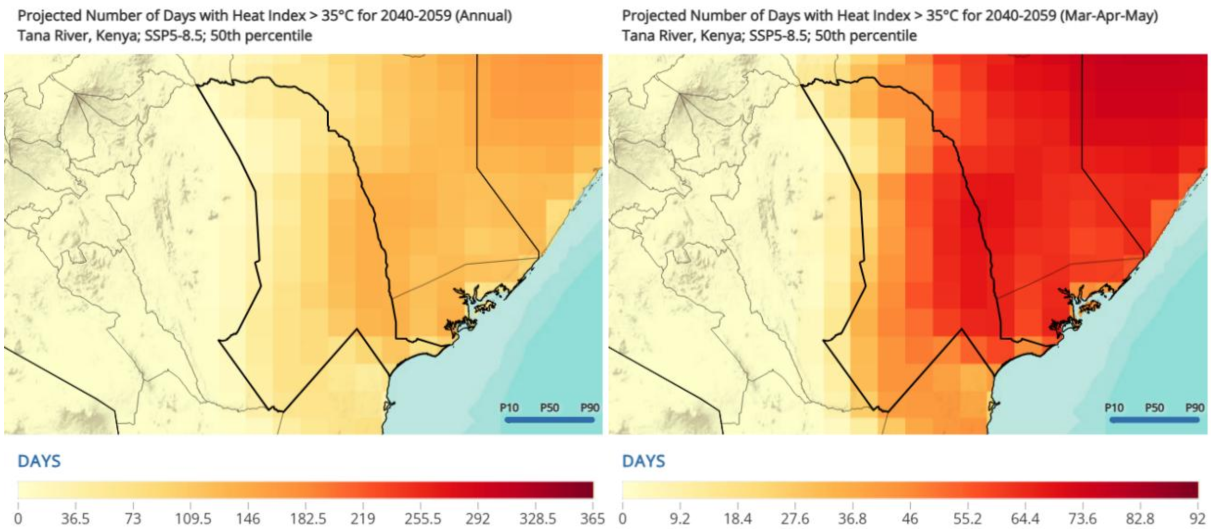


Figure 36: Annual and MAM projected (2050) number of days with heat index > 35°C, under SSP5-8.5

Source: (The World Bank Group 2025)

4.2.6 Soil erosion

Soil erosion is the process by which the upper layer of the soil (surface soil) is detached and transported by erosive agents such as water or wind. It results in a reduction of soil retention capacity, degradation of land structure, and can lead to severe consequences such as mudflows or sedimentation in downstream areas.

Soil erosion reflects the accelerated removal of surface materials beyond the natural rate of soil formation, often intensified by human activities such as deforestation, overgrazing, or poor land management.

The phenomenon can be analyzed through the RUSLE erosion model, which is an empirical model that calculates long-term average annual soil loss due to sheet and rill erosion. The model considers six main factors controlling soil erosion: the erosivity of the eroding agents (water), the erodibility of the soil (including stoniness), the slope length and slope steepness of the land, the land cover and management (or human practices designed to control erosion)[6].

To assess hazard levels, thresholds have been defined as follows:

- Low hazard: < 10 t/ha/year
- Moderate hazard: between 10 and 25 t/ha/year
- High hazard: between 25 and 50 t/ha/year
- Very high hazard: >50 t/ha/year

[6] European Environmental Agency definition, RUSLE soil erosion model structure — European Environment Agency

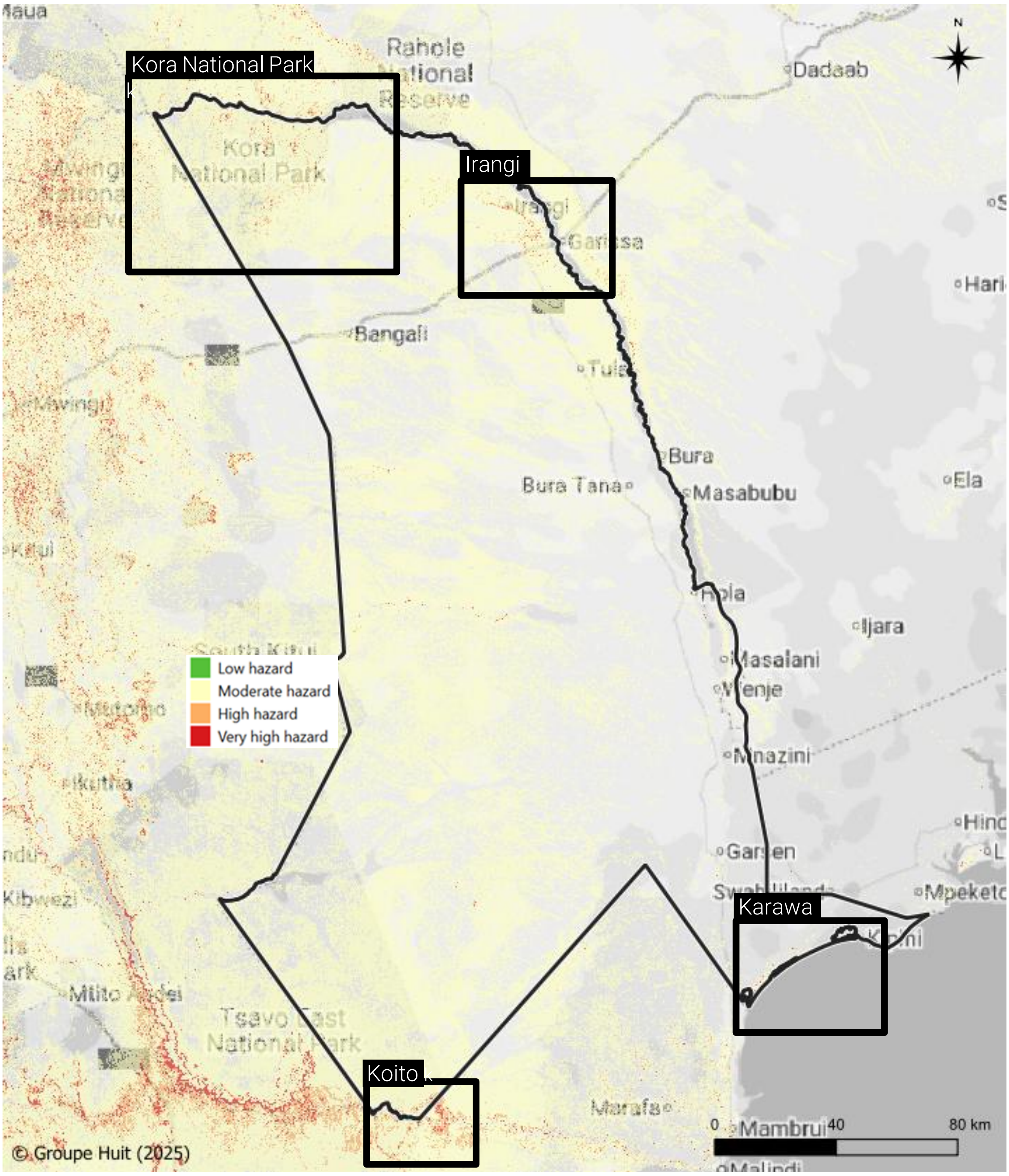
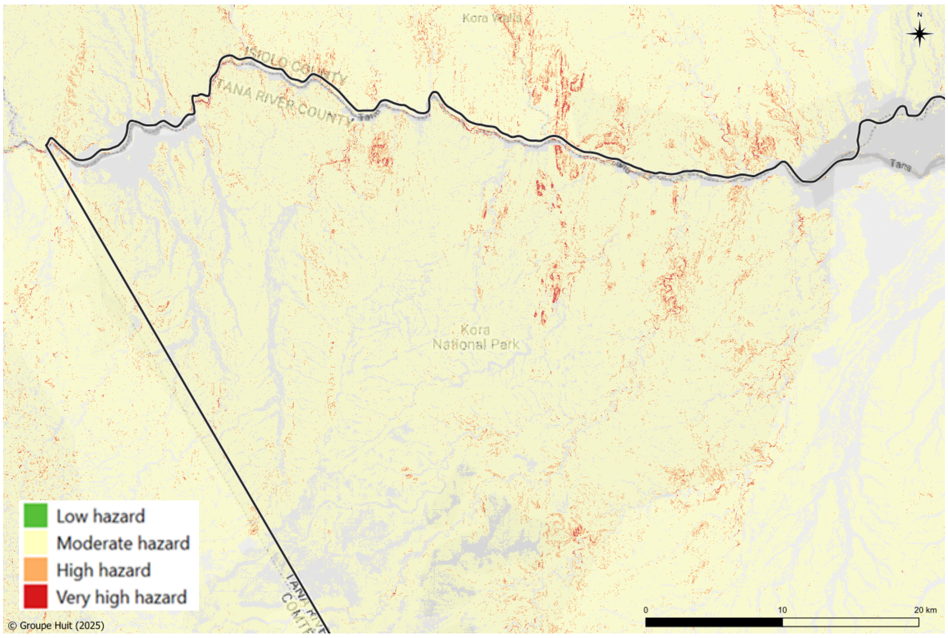


Figure 37: Soil erosion hazard mapping

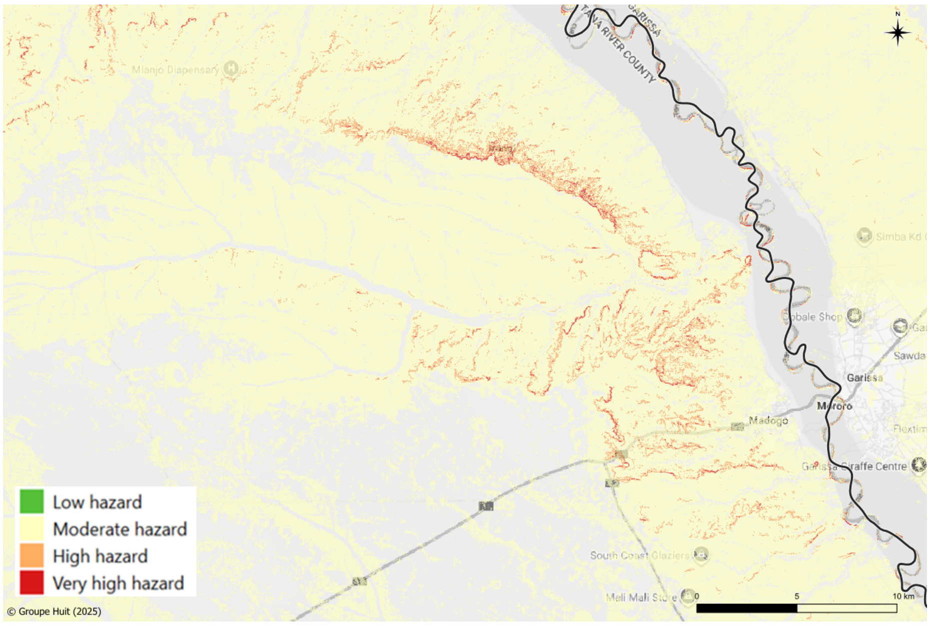
The map reflects an overall moderate erosion hazard, it can be noted that many areas are without data, reflecting either a "soil gain" rather than a "soil loss" as expressed thanks to the rustle erosion, or it can also be water bodies, urban areas or areas with missing input values for the model.

While hazard is mostly moderate when looking at the whole county, there are some specific areas which are more prone to soil erosion, such as:

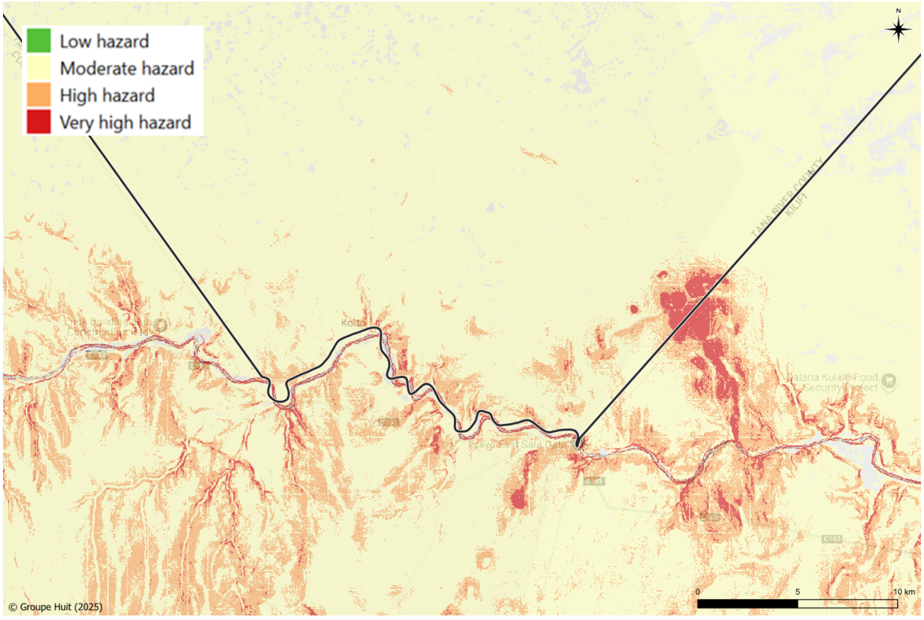
- Kora National Park at the north,



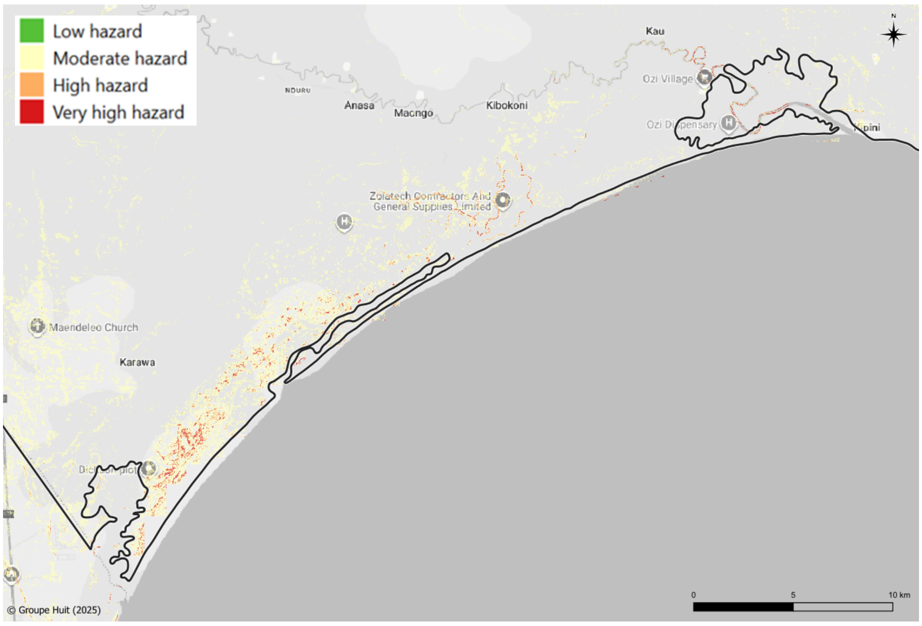
- Irangi area (which is located between Tana River and many of its tributaries), and the western area of Mororo,



- Koito area, at the very southwest of the county,



- Karawa at the southern part of the county's coastal area, and the coastal area in general.



It can be noted that this phenomenon was not clearly mentioned during field works, this can be explained by the fact that it is not a readily visible phenomenon. Erosion processes often occur gradually and are therefore less perceptible to local communities.

However, some impacts of erosion are more tangible and likely to be felt through other land and water degradation, for instance through increased water turbidity, mudflows, sedimentation of water infrastructure and rivers, potentially leading to shifts in river courses and drainage patterns.

Strengthening community awareness and integrating erosion control measures into land management and investment planning could therefore reduce water degradation and enhance water resources management.

4.2.7 Coastal erosion

The 76-kilometer coastline of Tana River County is located in Kipini East Ward. Such coastline includes the Tana River Delta area. Multiple causes have led to an erosion process along the Kenyan coastline, including in Tana River County :

- Degradation of mangrove forests
- Increased tidal variations
- Sea level rise phenomenon
- Modifications in sediment fluxes, turbidity and siltation related to:
  - Changes in land used for agriculture
  - Modifications of hydrodynamics of the Tana River related to water abstraction, modification of flood regimes and overall flow changes which impact sedimentation deposits in the Tana River Delta
  - extreme events such as the El Niño event of 1997/1998, which led to devastating effects such as an increase in sediment fluxes and turbidity, coral bleaching and mortality and substantial sea level rise

In other areas of the Kenyan coastline other activities such as coral harvesting, seawall construction, urbanization and lack of regulations on the construction of structures along of the coastline can be linked to the coastal erosion processes, these items do not seem to be predominant in Tana River County coastline nevertheless erosion has to be considered as global process along the coastline with the phenomenon in one area affecting the others directly or indirectly.

The following map highlights the coastline recession which is of -0.77m on average, and the more intense rates affecting river mouths areas changes of +/-14m per year.

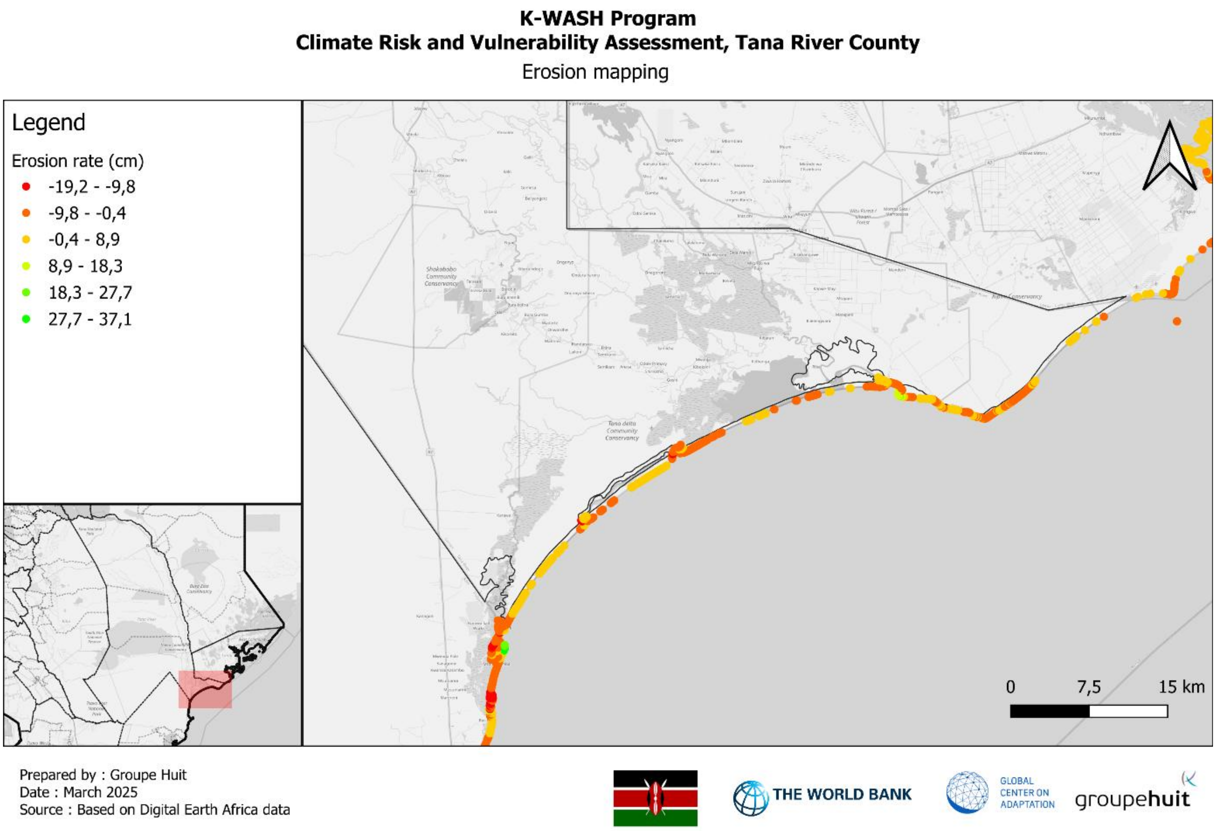


Figure 38: Tana River coastline erosion

4.2.8 Soil and water salinity

Soil and water salinity hotspots in Kenya are Turkana region, Kitui region, coastal areas and river deltas. Tana River County is part of such hotspots, the issue has indeed been observed in the county with mentions of the necessity to drill deeper to reach certain salinity levels compared to earlier periods.

Such salinity increase corresponds to two major types detailed in the following paragraphs.

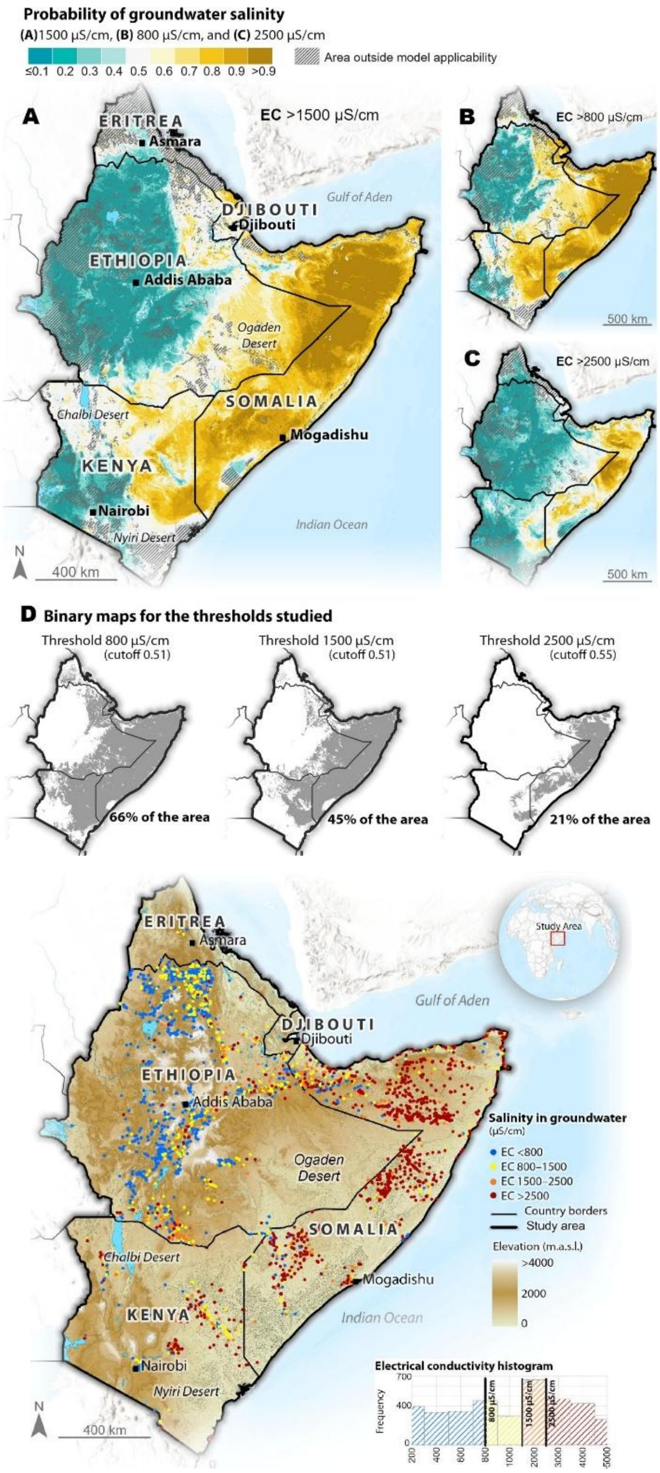


Figure 39: Groundwater salinity maps for East Horn of Africa

Source: (D. Araya et al. 2023)

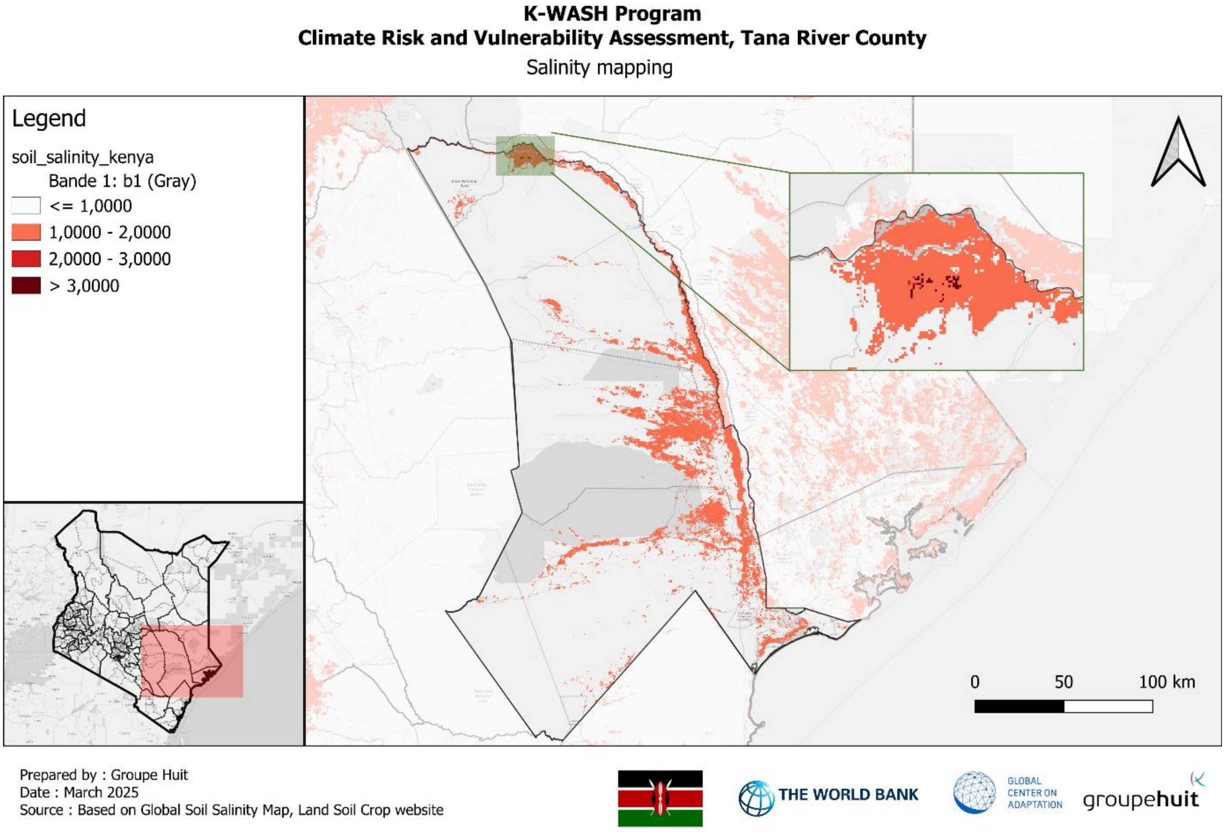


Figure 40: Tana River Salinity Mapping

4.2.8.1 Coastal Sea Water Intrusion and soil salinity

As presented above the Tana River Delta is located along the county's coastline. Over the past decades climate change has led to a reduction in the amount of river water flowing into the Indian Ocean. In parallel, the melting of icebergs from the North and South Arctic regions has contributed to an increase in sea levels. As a result, the reduction of water levels from River Tana flowing into the Indian Ocean and the rise in sea water levels have caused the intrusion of seawater.

In parallel, soil salinity is increased due to in situ salt accumulation.

4.2.8.2 Inland soil salinity

Inland soil salinity rising that is observed in Tana River County can be explained through multiple factors (Mugai 2003):

- Mineral alteration related to arid climate,
- Irrigation of agricultural plots, 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).
- 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).

4.2.9 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 size 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

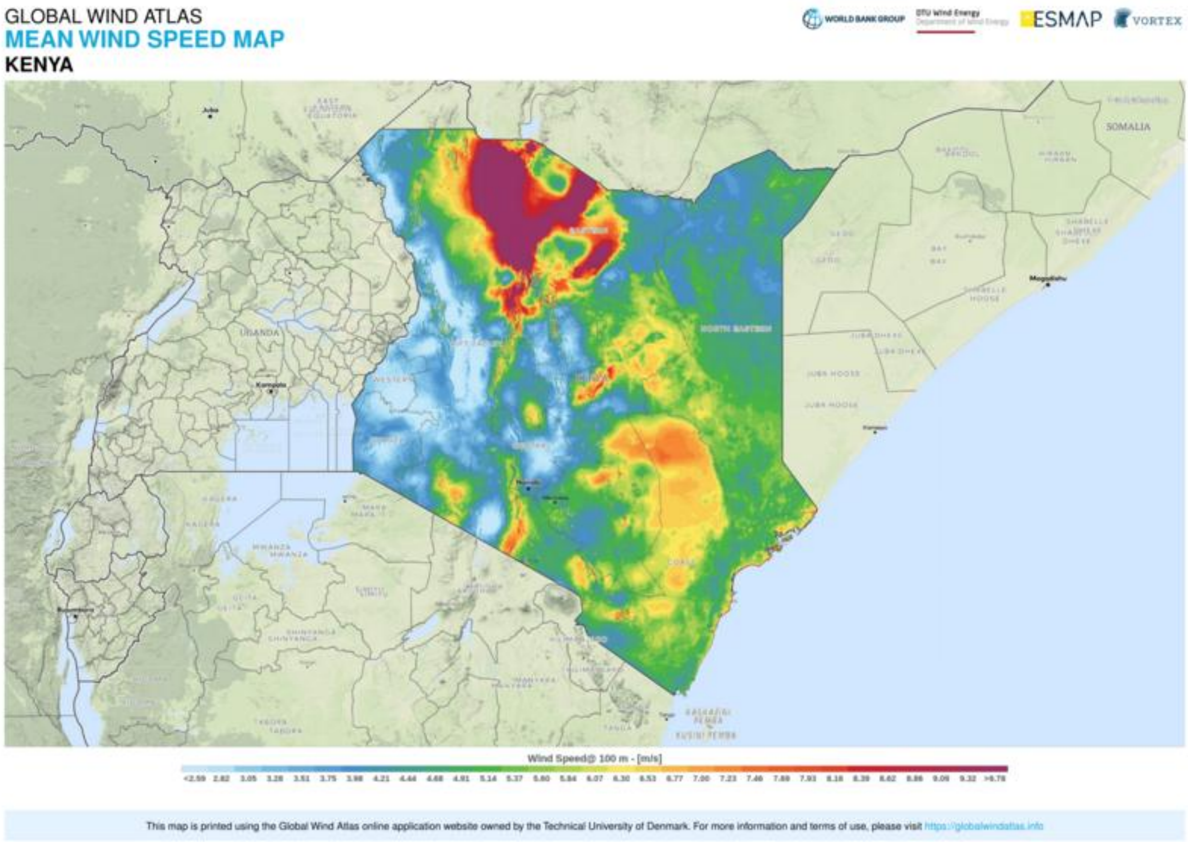


Figure 41: Mean wind speed in Kenya

Source : (Global Wind Atlas 2024)

4.2.10 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. However, even if the recent climatic conditions have reduced the occurrence of floods and thus reduction in water borne disease outbreaks, a recent episode of cholera outbreak was signalled in North Tana subcounty in February 2023. (WHO 2024)

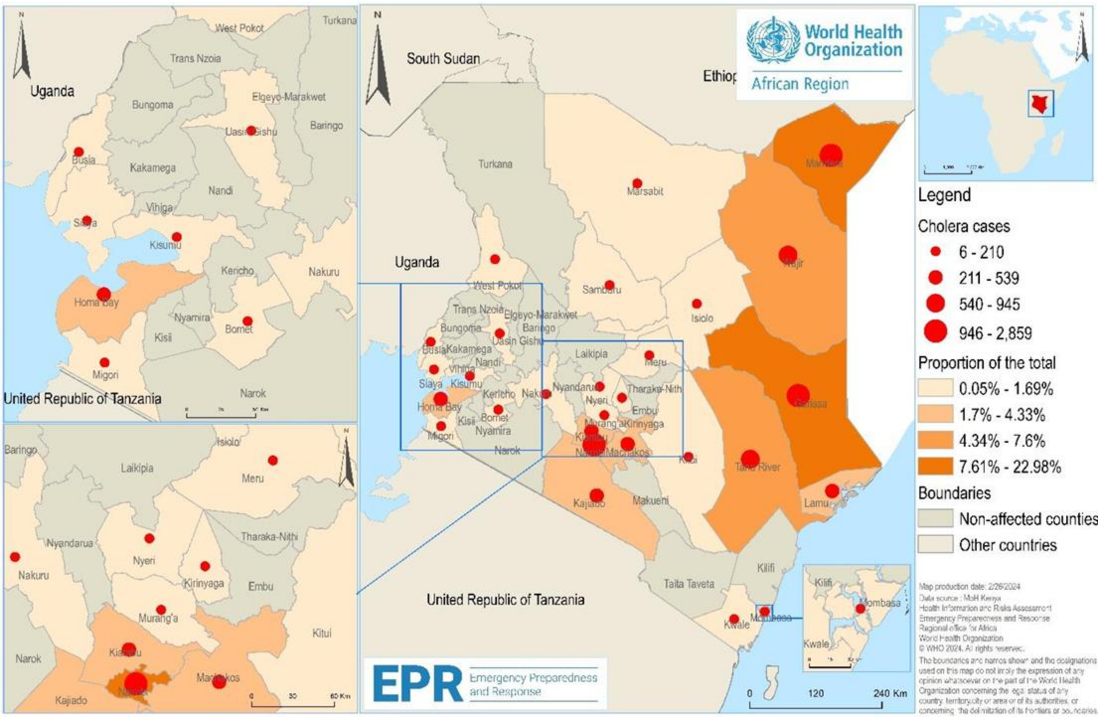


Figure 42: Map for cholera outbreak in Kenya, October 2022 – 18 February 2024

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, with the areas of Garsen, Assa, Nanighi and Kone being the most affected.

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

It can be noted that pest and diseases resulting from flooding and droughts can also be indirect, for instance in Minjila (urban centre located in Shirikisho Location, Garsen Central Ward in Tana Delta) it was reported that some residents empty their pit latrines into the nearby environment and septic tanks overflowing (which mostly happens during flooding) into neighboring lands hence propagating diseases.

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 training and capacity building, creating awareness, adopting disease-tolerant crops and improved livestock breeds, carrying out vaccination and immunization programs, disease surveillance, and investing in livestock and crop insurance.

4.2.11 Climate variability

Climate and weather conditions, including storms are affected by global modes of viariability (MoV) that forms 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 as changes in the magnitude of the variability as well as through a systematic trend overtime.

4.2.12 Conclusion on hazards

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

- Heat Waves and droughts
- Flood hazard (mainly pluvial and river floods)
- Soil and water salinity hazard
- Soil erosion

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

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. Each parameters highlights specific trends regarding hazards, the latter are developed in table 8 below.

The parameters considered 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 (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 and urban flooding. 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 Tana River, the number of >20 mm days increases in the projections, indicating more frequent heavy-rain events. This reinforces flood and 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.
- **Sea Level Rise (SLR)** is driven by the expansion of warming ocean waters and the melting of glaciers and polar ice sheets and represents the anomaly of sea level compared to 1995-2015 average.
- **High Tide (HT)** reflects the number of projected days that exceed one thresholds above the average high tide, from 1983-2001.

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 8: 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).

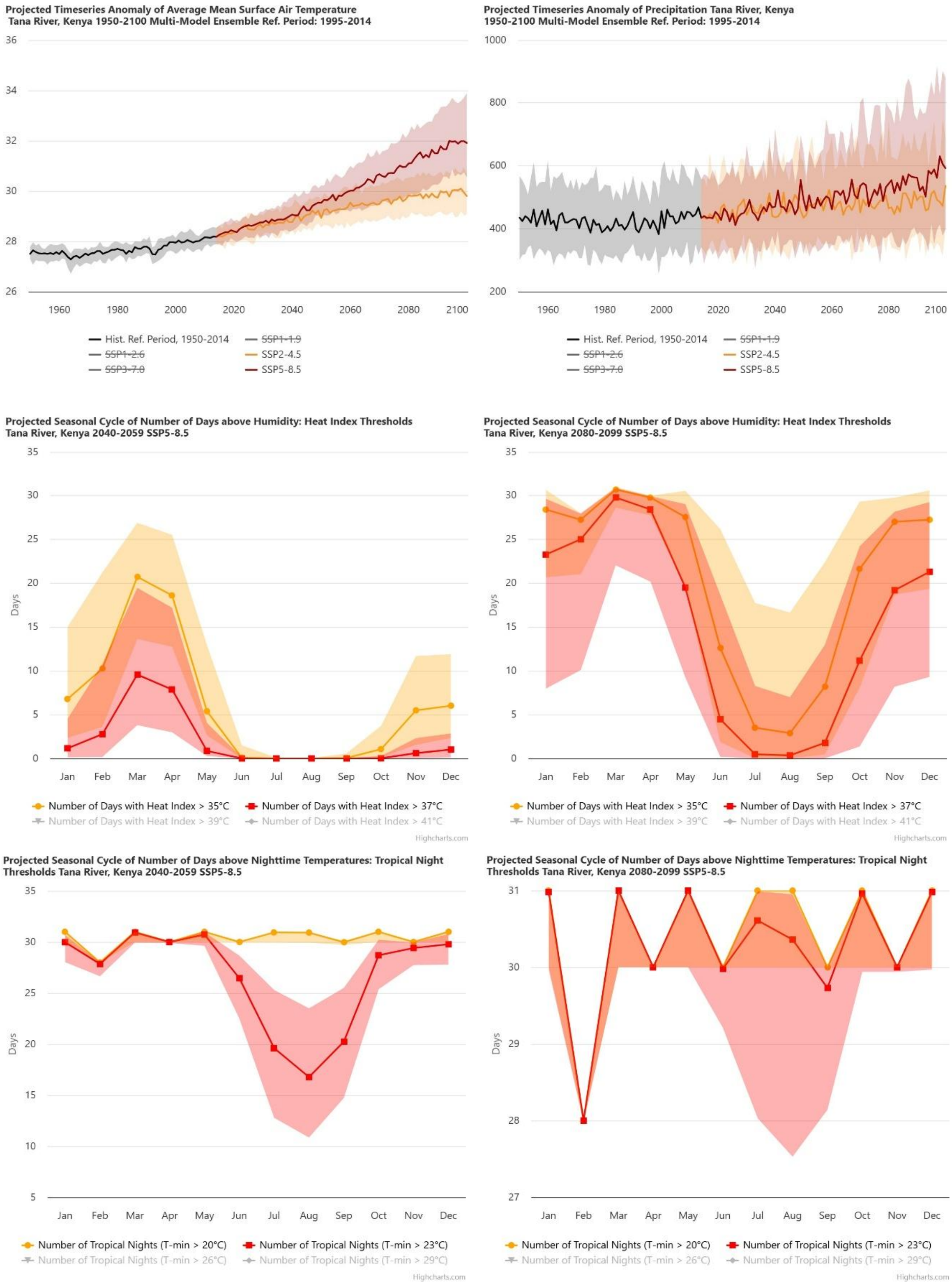


Figure 43: Projection of temperature-related parameters up to 2100 (SSP2-4.5 and SSP5-8.5)

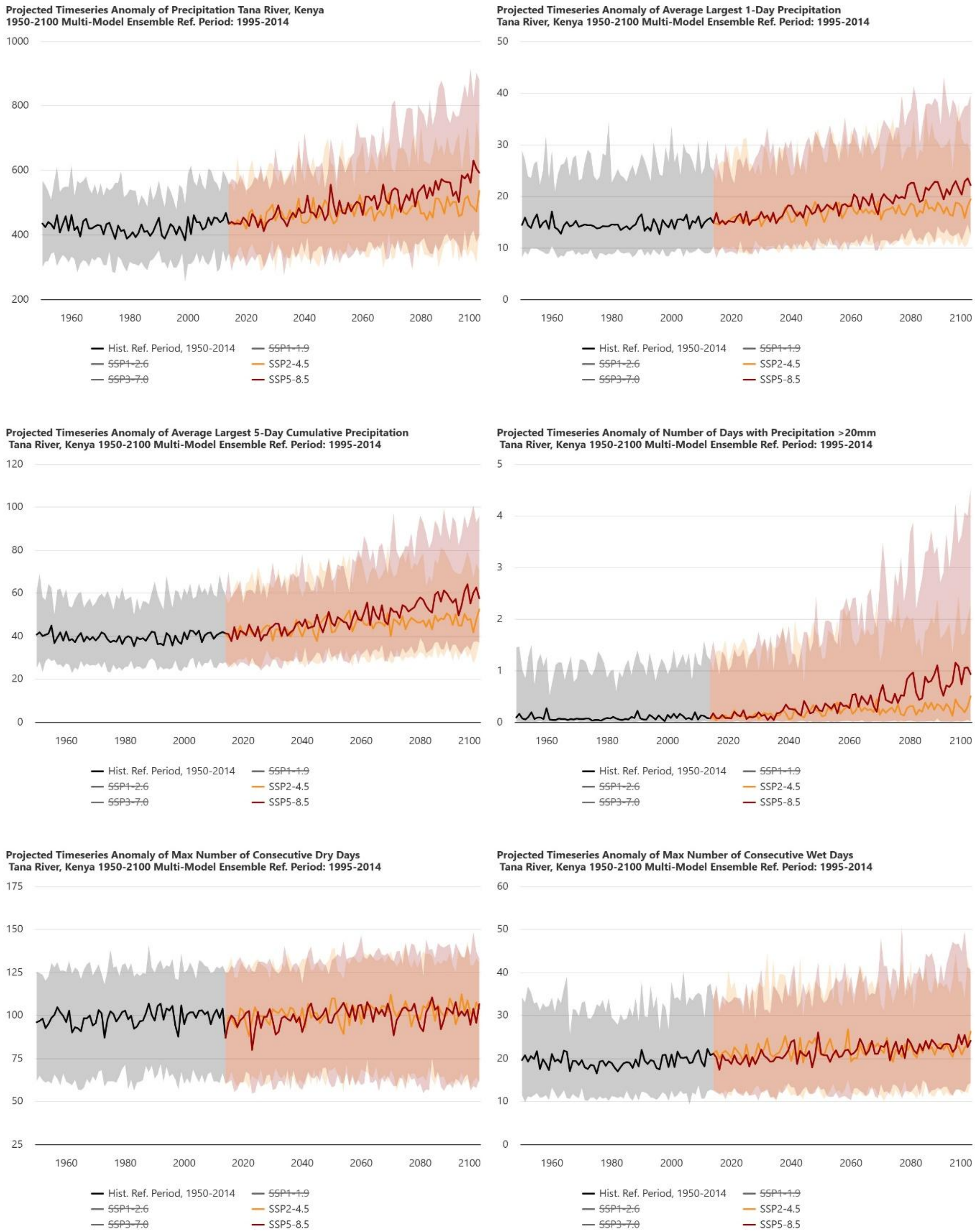


Figure 44: Projection of precipitation-related parameters up to 2100 (SSP2-4.5 and SSP5-8.5)

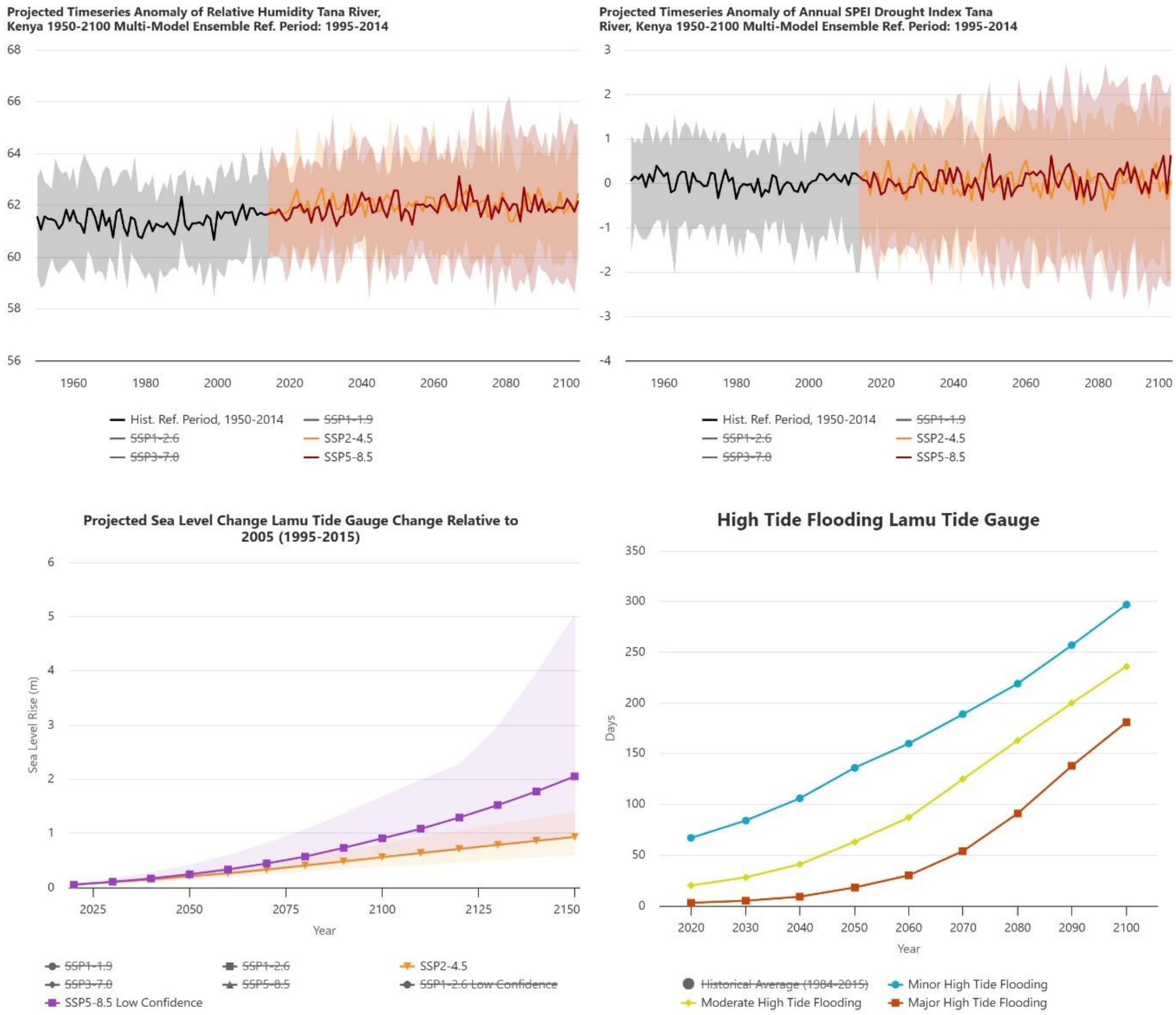


Figure 45: Projection of other parameters up to 2100 (SSP2-4.5 and SSP5-8.5)

These figures enable to derive the relations between these projections and the hazards 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 9: Relations between climate parameters and hazards

Hazard	Tmean	TXx TNn	PRCPTOT	Rx1day Rx5day	R2mm	CWD	CDD	RH	SPEI	SLR	HT	Justification
Floods			+	+	+	+				+	+	Increasing annual rainfall, stronger short-duration rainfall extremes, more frequent heavy-rain days as well as long period of rains increase runoff and flood. In parallel, both SLR and high tide issues should be considered leading to an increase in occurrence of flooding, exacerbating in coastal regions, doubling the danger if both high tide and rainfall events occur.
Heat stress & droughts	+	+				-		+				Rising mean and extreme temperatures and higher humidity intensify heat stress, while longer rainy periods moderate drought intensity.
Soil & water salinity			-			-		-		+	+	Increased rainfall and rainfall duration and higher humidity favour salt leaching and reduce evaporative concentration.
Coastal erosion										+	+	SLR and increased occurrence of high tides increase coastal erosion processes
Sand & dust storms			-			-		-				Wetter and more humid conditions with longer wet periods reduce soil desiccation and wind-erosion potential.
Pests & diseases	+	+	+	+	+	+		+				Warmer, wetter and more humid conditions with more frequent heavy rains and long 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**); Sea Level Rise (**SLR**); High Tide (**HT**).

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.

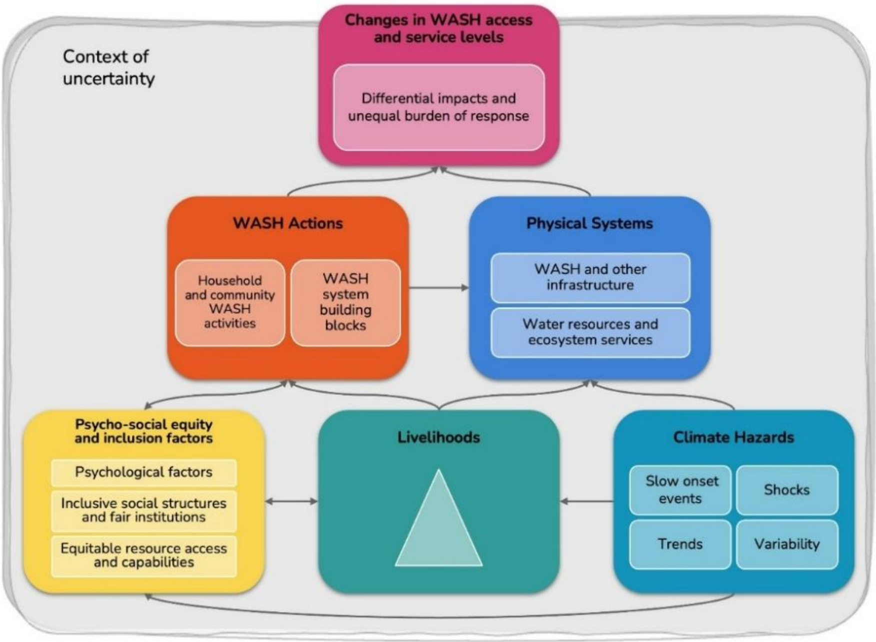


Figure 46: WASH sector framework and relation to climate change

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.

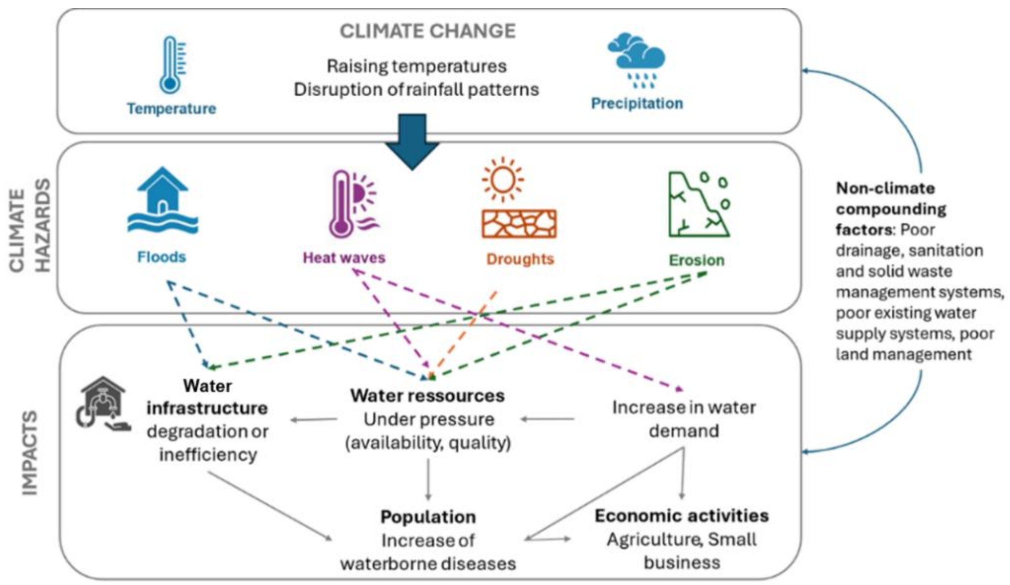


Figure 47: Water sector vulnerability to climate change

The following sub-chapters will elaborate on specific impacts in order to point out specific vulnerabilities of Tana River 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 10: 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)

5.1.1.1 Surface Water Resources

Surface water resources are crucial for the livelihoods in Tana River County but are heavily impacted by climate-related hazards. The **Tana River** is the primary source of surface water in the county and is often linked to flooding, particularly during heavy rains upstream or within the county itself. The riverbanks are especially vulnerable to these floods. In addition to the Tana River, the county also relies on other surface water sources such as **water pans**, **oxbow lakes**, **marshes**, and **river channels**, notably in the Garsen Central area. In the Wayu region, water is sourced primarily from boreholes, shallow wells, and **water pans**, with **laggas** (temporary rivers) occasionally filling with water.

Drought represents a significant threat to surface water resources, as it leads to the **drying up of water points**, including water pans, and reduces the water levels in the Tana River. During drought conditions, areas such as Chewele, Hirimani, Madogo, and Sala experience the near-total drying of their **earth pans**.

During prolonged droughts water pans drying up lead the communities to dig shallow wells within the pan. These wells are highly prone to contamination from animal waste, and algae blooms frequently develop, rendering the water unsafe for consumption with poor quality and taste. Figure 9 illustrates this contrast, with an algae-infested shallow well on the left and a relatively clean, algae-free well on the right, both located within the same water pan. The water from water pans can be used for livestock but in the case of the Wolestokocha waterpan (Figure below) below it is used for domestic use (drinking, cooking, washing) and watering of animals.

Figure 48: Different water quality Shallow Wells in the same water pan in Wolestokocha

Source : Fieldwork, August 2025

The specific case of Tana River suggests a rise in rainfall and in the SPEI droughts index, showing a lower risk of droughts. As a primary approach this is thus reassuring regarding the renewal of water resources, especially as the changes between months' rainfall tends to smooth along the year.

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 May to December (mainly JJA) could lead to increase loss rates.

Such balance between rainfall patterns changes and evaporation rates should be closely considered for surface water quantities annual evolution estimates.

Other challenges are **saltwater intrusion**, which affects coastal regions like Kipini East and Kipini West, threatening rivers and fertile lands and dust storm could also be considered 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 saltwater intrusion. **Watershed degradation** is another factor that contributes to the vulnerability of these resources.

To mitigate these risks, various adaptation strategies are proposed such as:

- Desilting and constructing water pans, silted lakes, and earthen dams.
- Building hydraulic structures on laggas.
- Building waterpans
- Restoring sources, such as the Boka spring.
- Restoring water flow in diversions.
- Restoring wetlands (lakes, laggas, and riparian zones).
- Investing in climate-resilient infrastructure, such as mega-dams, underground dams, control weirs, and barkards.
- Implementing rainwater harvesting techniques.
- Improving water filtration systems in water pans.
- Reforestation along critical water catchment areas with indigenous trees.

5.1.1.2 Groundwater Resources

Groundwater is an essential resource in areas where surface water is scarce or unreliable. In regions such as Wayu, groundwater sources like boreholes and shallow wells are vital for providing water. However, these resources are 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.

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. 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 sorption and complexation with Natural Organic Matter (NOM), sediments and soils, which releases 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. For instance in Bura it was highlighted that borehole development is constrained by low water tables, slow recharge rates during droughts, and high salinity levels, which have led to the abandonment of many boreholes.

To safeguard groundwater resources, it is crucial to implement efficient management practices. This includes 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 Tana River 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 11: Links between climate change and water supply services

<table>
<tr><th>Climate hazard</th><th>Global County hazard level</th><th>Water consumption</th><th>Service Quality</th><th>Impacts on infrastructure</th><th>Social impact</th></tr>
<tr><td>Variability of seasonal rainfall patterns</td><td>Moderately exposed</td><td></td><td>▶ Temporary interruption or reduction of service due to lack of available resources</td><td></td><td rowspan="3">▶ Tougher fetching:
▶ 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</td></tr>
<tr><td>Droughts, water shortage</td><td>Highly exposed</td><td rowspan="2">▶ Increasing water requirements and volumes for all uses (domestic agricultural, industrial, etc.).</td><td rowspan="2">▶ 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)</td><td rowspan="2">▶ Fragilization of facilities :
▶ over-utilization of equipment during drought period to meet high demand
▶ 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 damage of the infrastructure
o dams and reservoirs may be weakened by</td></tr>
<tr><td>Heat wave</td><td>Highly exposed</td></tr>
</table>

Climate hazard	Global County hazard level	Water consumption	Service Quality	Impacts on infrastructure	Social impact
			▶ Interruption of service due to damage to installations	prolonged low storage levels. ▶ Solar panels are less efficient when they become too hot.	▶ 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 ▶ Health threats due to lower water quality
Intense and sudden rainfall, flooding	Highly exposed		▶ 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 damage to installations	▶ Fragilization, yield reduction and destruction of 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 hazard level	Water consumption	Service Quality	Impacts on infrastructure	Social impact
			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	Moderately 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	Highly exposed	▶ 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 12: Links between climate change and wastewater management services

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Droughts, water shortage	Highly 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 which may lead in increased wastewater use, and use of polluted receiving waters. Less water to clean toilets which can become unsanitary
Heat wave	Highly 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). Odour nuisance due to increased nitrogen dioxide (N_2O) emissions

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Intense and sudden rainfall, flooding	Highly 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 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), mainly collapse of pit latrines during flash floods ▶ Disruption of emptying services (difficulty access, necessary increase in frequency...)	▶ 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 ▶ 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 soakaway or pit from below, increased potential for contamination of groundwater.	▶ Population without sanitary facilities ▶ Increase in water-borne diseases due to the risk of contact with water containing pathogens ▶ Recourse to open defecation and its multiple negative impact (health, well-being, dignity, safety, etc.)
Storms (including sand and dust storms)	Low exposure			
Sand and dust storms	Low exposure	▶ Heavy deposits of sand on solar panels for boreholes and water treatment plants, leading to reduced efficiency in power supply	Reduced capacities of water treatment plants and borehole pumping systems.	▶ Less access to clean water by communities

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Erosion (which can also be induced by floods and water runoff) and landslides	Moderately 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 13: Links between climate change and drainage services

Climate hazard	Global County hazard level	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Intense and sudden rainfall, flooding	Highly 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 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: Groupe Huit, (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 Tana River, additional items from field visits can highlight the issues that are already faced in the County:

5.1.2.2 Flood & heavy precipitations

Water from the River Tana is often turbid and discoloured, especially during floods, rendering it unsafe for domestic use ; this is an observation made in Mkomani village and confirmed in most placed along Tana River.

In Wolestocha the siltation of the water pans which often occurs after the rainy season reduces the facilities capacity to hold more water.

In Minjila it was reported that flooding submerges boreholes and damages water infrastructure, reducing access to safe water and contaminating available sources. Water contamination during floods was also reported in Odole when shallow wells are inundated, such situations increases pest and diseases outblreaks (see below). Same situation has been addressed through borehole and hand pumps raising in Madogo.

Figure 49: Elevatad borehole platforms in Madogo

Source: Fieldwork, August 2025

Regarding sanitation : in Minjila it was observed that during flash floods, pit latrines often collapse and become unsafe for use as floodwaters inundate them. This challenge is further compounded by the unstable soils in the area, which weaken the structures. Such statement can be enlarged to areas with unstable soils and prone to flooding. In Minjila and in Odoloe where similar problems were faced (due to high groundwater levels leading to frequent collapse of pit latrines) a few residents have managed to construct lined pit litrines while other have pit latrines with the superstructure separated from the pit, some residents have also managed to invest in septic tanks and some households have reinforced and raised the latrine pits with concrete to reduce the risk of inundation and collapse during floods.

5.1.2.3 Drought, water shortage

During drought season salinity levels of water tables are high requiring to take water from greater depth (Mkomani village).

In Bura water shortages are also due to increasing demand and as the Bura Water Works cannot meet the latter. Within Bura town, water rationing occurs up to three days per week, with some periods extending to a full week without piped water, rationing has also been observed in Minjilla and is a reality in many sub-counties.

In addition, in Bura borehole development is constrained by low water tables, slow recharge rates during droughts, and high salinity levels, which have led to the abandonment of many boreholes.

5.1.2.4 Salinity

In Odole (Kipini West), many issues related to salinity were reported. During the dry season, when water levels in the Tana River drop, the tributary passing through Odole is affected by seawater intrusion. Saline water pushed inland by high ocean tides contaminates both the river water and surrounding soils, making them unsuitable for domestic use and agriculture. Shallow wells become saline and water from these wells becomes unsafe for human consumption. Seawater intrusion also kills freshwater fish especially at Kalota, which supports the livelihood of residents of Odole. In addition, because of seawater intrusion, manual water pumps rust and pose health threats to continued use of water from such boreholes.

5.1.2.5 Pest and diseases

Disease outbreaks have been observed in Bura, indeed because of consuming contaminated untreated water and stress associated to water scarcity within Bura, the residents have suffered from Ulcers, High Blood Pressure, Diabetes, Cholera and Bilharzia outbreaks in the past. In wolestokocha as well an outbreak of stomach diseases (Mara Mara) and Constipation due to drinking of contaminated untreated water from the water pan was observed.

Another aspect is that prolonged drought conditions leads to food shortages, as the community largely depends on milk for sustenance. This results in malnutrition among children and increased health complications for both people and livestock. In some areas like Wolestokocha the situation is further worsened by the absence of a health facility.

Similar things are observed in Minjilla and Odole where water scarcity contributes to outbreaks of diseases such as influenza, diarrhea, typhoid and cholera, particularly among pastoralist communities in Shake, due to limited water for sanitation and hygiene. Cases of children suffering from stomach ulcers because of consuming contaminated water have also been reported like in Wolestokocha.

5.1.3 Understanding of proposed investments

Based on the CWSSIP table of proposed investments, as well as discussions and a mapping exercise undertaken with the County, it has been possible to map out most of the different actions proposed as part of the CWSSIP. Linear items are located through a punctual location (or multiple points) to highlight the area in which they will be developed or rehabilitated although it has not been considered necessary to map out the exact layout as of now.

Some items have not yet been precisely located such as:

- Villages in which Community Led Total Sanitation programs will be implemented,
- School and health facilities in which WASH activities and infrastructure will be implemented

The following map displays the proposed investments according to different categories, which correspond to the following:

- Borehole, which includes the following activities:
  - Drilling and equipping of a borehole
  - Flushing of the borehole
  - Test pumping of the borehole
  - Installation of a new pump
  - Reinstatement of the distribution pipeline
  - Solarization of the borehole system
  - Construction of a rising main pipeline
  - Construction of an online chlorine dosing system
  - Construction of water kiosks
  - Automation of the water kiosks
  - Fencing of intake infrastructure
    - Installation of an elevated water tank

- Hydrogeological survey for borehole site
- Surveying and design for borehole and water supply system
- Construction of toilets with biogas digesters
- Installation of a pump house
- Installation of genset for pump operation
- Supply and installation of plastic water tanks on concrete bases
- Construction of cattle troughs

- Dam, which includes the following activities:

  - Construction of a new dam
  - Construction of a silt trap
  - Construction of auxiliary works
  - Construction of a draw-off system
  - Construction of a perimeter fence
  - Construction of a VIP toilet
  - Site clearance
  - De-silting of silt trap

- Excavation of water pan
  - Solarization of the system
  - Construction of cattle troughs
  - Construction of a latrine

- Water pan, which includes the following activities:

  - Site clearance
  - Excavation of water pan
  - Construction of a perimeter fence
  - Construction of a silt trap
  - Construction of a draw-off system / Installation of a solarized draw-off system with a floating pontoon
  - Construction of a VIP toilet
  - De-silting of silt trap
  - Solarization of the system
  - Extension of pipeline to nearby village
  - Repair of auxiliary works
- Water supply intake/treatment/main and distribution pipes/meters/water-kiosk or connection (construction and expansion), which includes the following activities:
  - Feasibility study including surveys, planning, and design
  - Environmental and social impact assessment (ESIA)
  - Improvement and expansion of intake works 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

- Water supply pipe (repair and replacement)
  - Excavation and replacement of old pipelines with HDPE pipes
  - Upgrading and replacement of existing pipelines (e.g., UPVC, GI, and Cast Iron)
  - Procurement and supply of HDPE pipes and fittings
  - Overhaul and upgrade of existing pipeline systems
  - Installation of zonal district metering areas (DMAs)
  - Repair and maintenance of water supply distribution lines
  - Improvement works for water supply systems
  - Installation of new distribution lines to connect households
  - Construction and installation of water kiosks for public access
  - Connection of water pipelines to local communities or centres
  - General civil works related to water supply infrastructure upgrades
  - Enhancement of water supply system capacity and efficiency

- Public sanitation facility
  - Public sanitation facilities (trading centers and markets)
  - VIP toilets construction
  - Hygiene promotion
  - Declaration of ODF free villages

- Decentralized treatment facility
  - Survey and mapping, Civil design, Process design, structural design, architectural design, electrical design
  - Construction of DTF
- Construction of households' toilets
- CLTS activities
- School and health center WASH
  - Construction of (VIP) latrines
  - Provision of WASH infrastructure

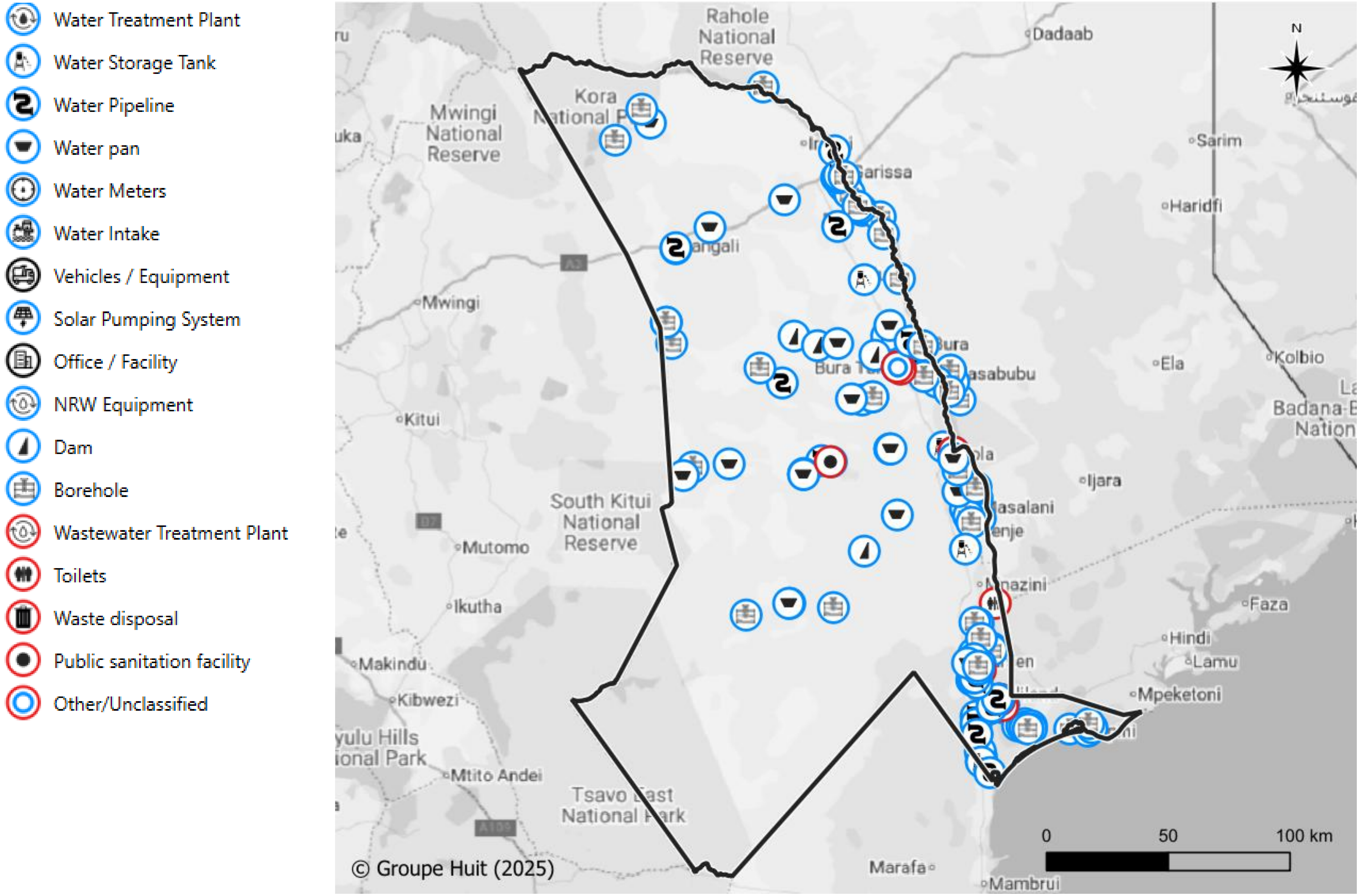


Figure 50: Tana River CWSSIP proposed investments map

Figure 51: Bura CWSSIP proposed investments map

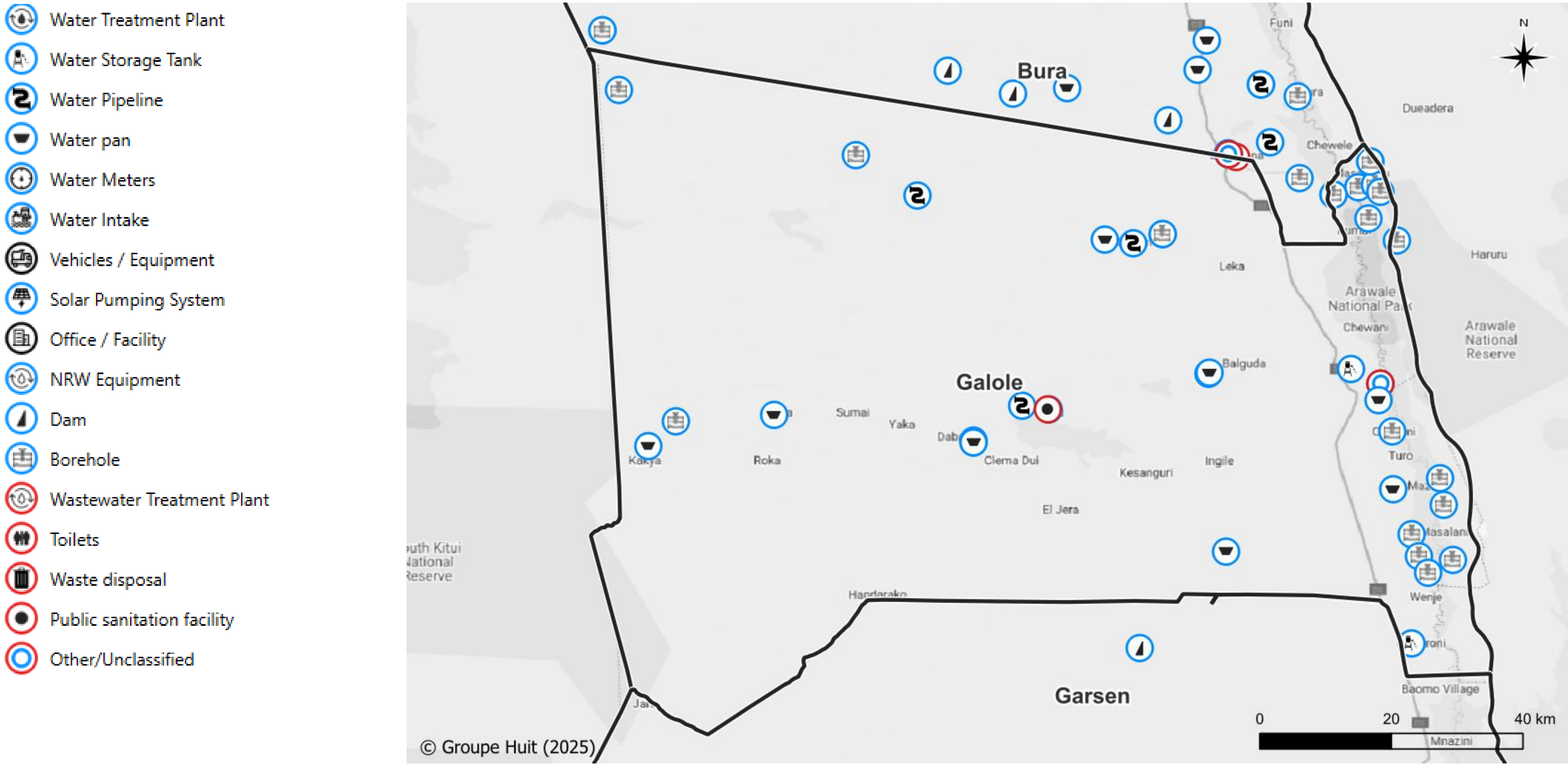


Figure 52: Galole CWSSIP proposed investments map

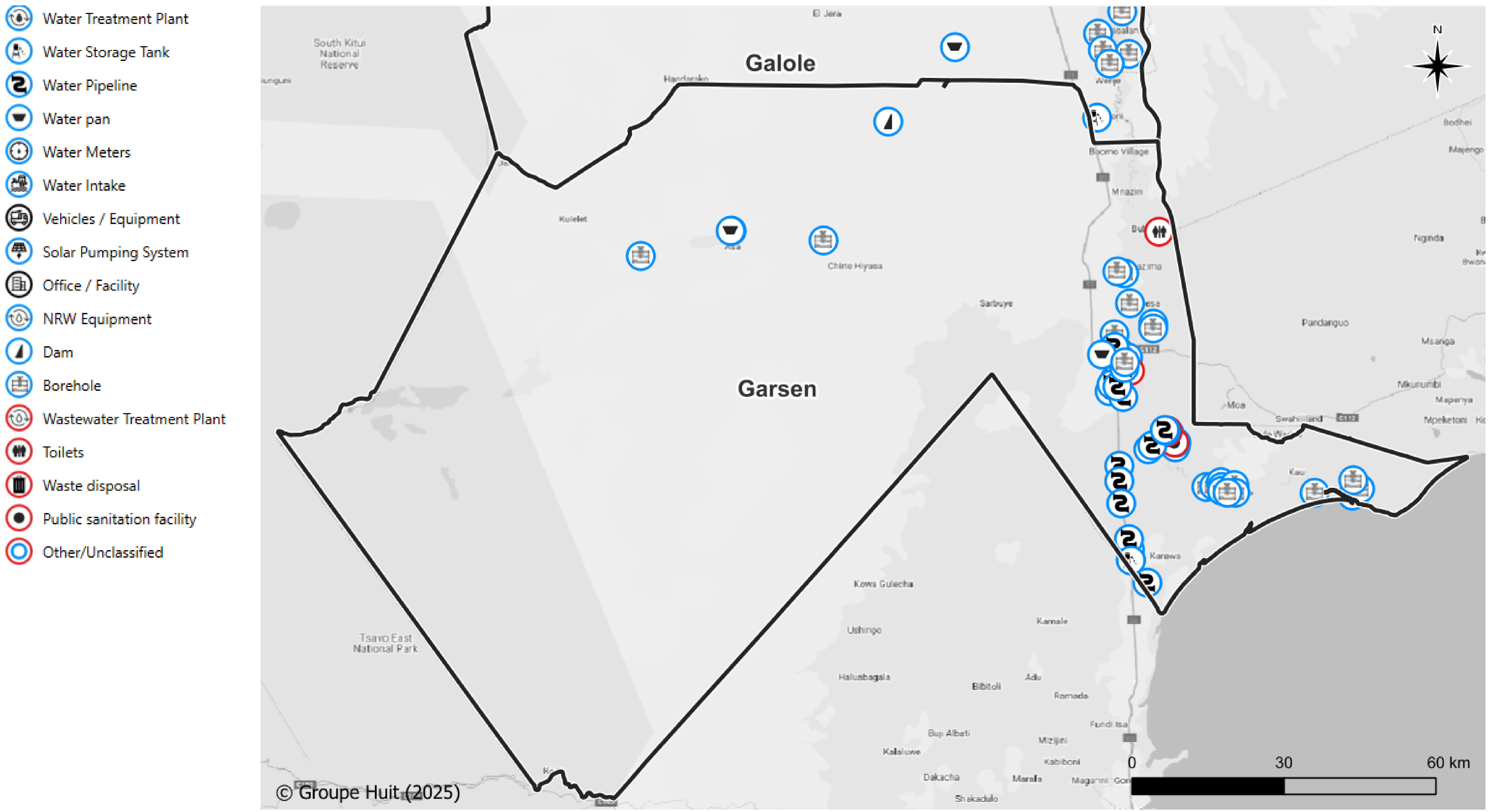


Figure 53: Garsen CWSSIP proposed investments map

5.1.4 Exposure mapping of proposed investments

The following map shows the hazard exposure of proposed investments of the CWSSIP. Only main hazards with an intensity that can be geographically differentiated have been presented in the map, that is to say that hazards considered are:

- Flood hazard (pluvial and river floods combined)
- Soil and water salinity hazard
- Soil erosion

Indeed, 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. Coastal erosion hazard does not concern any of the proposed infrastructure and finally pest and diseases, is considered as either an aggravating factor or a cascading impact of other hazard, thus not considered on the mapping.

The following table and map emphasize the planned projects which are the most impacted by hazards. The overall analysis was consolidated into a single climate hazard exposure score, 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:

Exposure = 2*Flood 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 exposure score 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 salinity hazards while still accounting for soil erosion as a contributing factor to overall vulnerability.

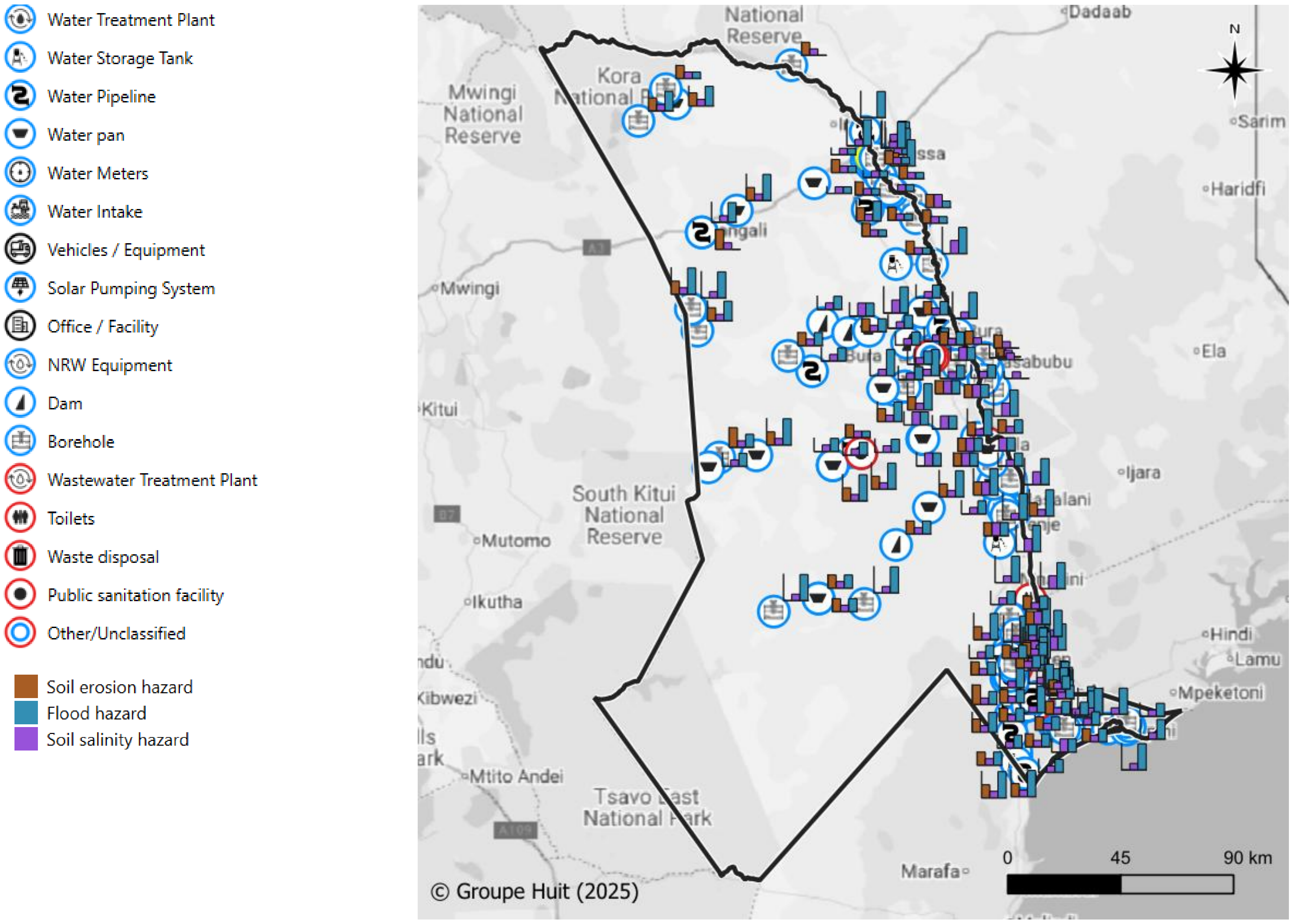


Figure 54 : Tana River CWSSIP proposed investments hazard exposure map

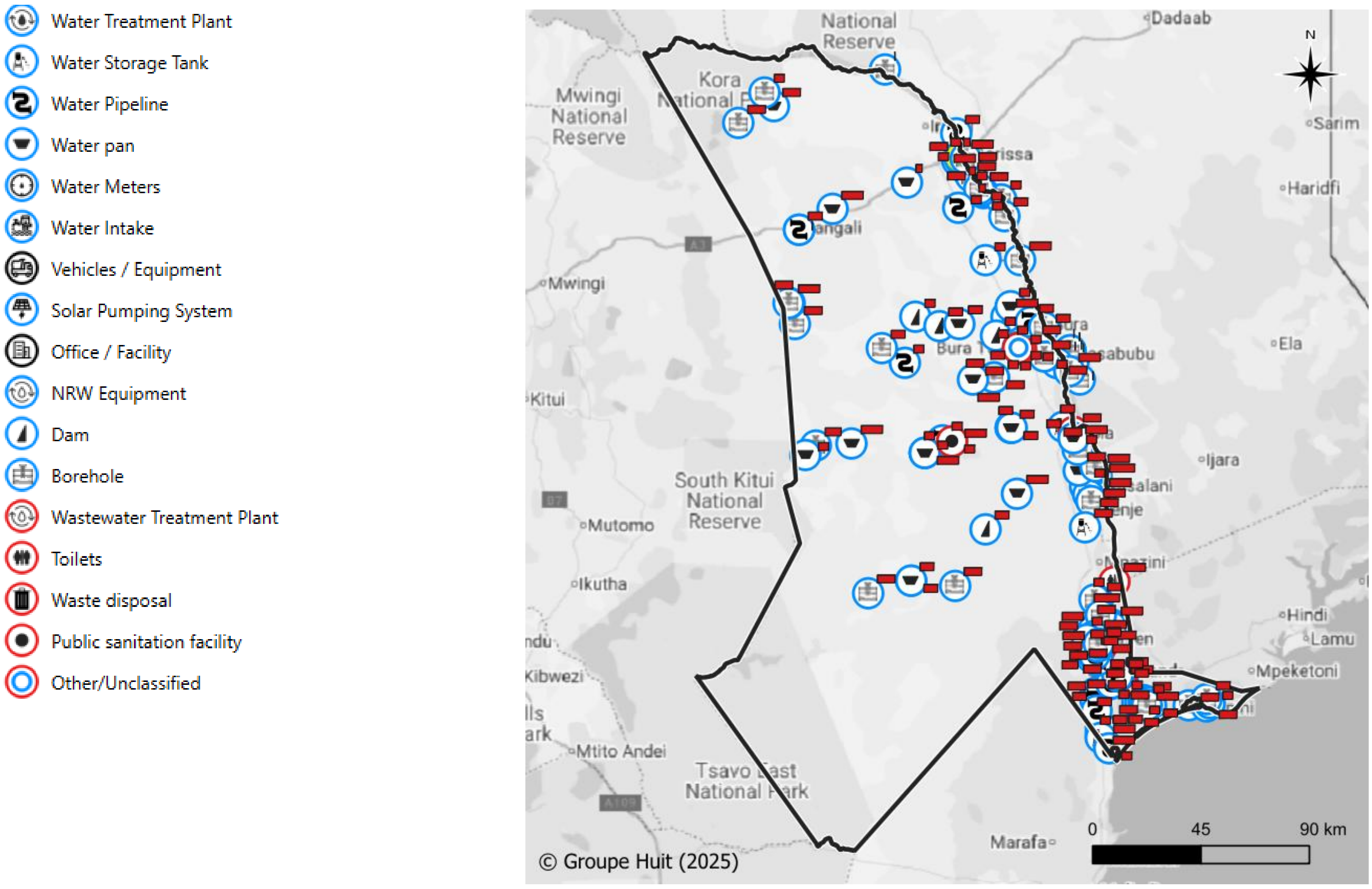


Figure 55: Tana River proposed investments overall exposure to climate hazard

Table 14: Most impacted planned projects by hazards

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Proposed construction of Fanjua water supply in Kinakomba ward	Water Supply	Borehole	2	YES	4	2	2	4.0000
Construction of Maziwa water supply and sanitation supply project	Water Supply	Borehole	2	YES	4	2	2	4.0000
Drilling and Equipping of a borehole at Idsowe	Water Supply	Borehole	2	YES	4	2	2	4.0000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	1	YES	4	1	2	3.4000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	2	YES	4	1	2	3.4000
Proposed construction of Kipao water supply	Water Supply	Borehole	2	YES	4	2	0	3.4000
Construction of Kaniki - Gurujo water supply project in Galedertu SC	Water Supply	Borehole	4	NO	4	1	2	3.4000
Construction of larger diameter boreholes in Feji, Bilisa to Garsen Market Water Project	Water Supply	Borehole	2	YES	4	2	0	3.4000
Construction of Daba strategic borehole in Wayuward	Water Supply	Borehole	2	YES	4	1	2	3.4000
Proposed Construction of Hewani, Wema, Kulesa, Sailoni and Vumbwe water supply project	Water Supply	Borehole	4	YES	4	2	0	3.4000
Proposed construction of Anasa water supply in Kipini West ward	Water Supply	Borehole	2	YES	4	2	0	3.4000
Proposed construction of Jararodi water supply in Kinakomba ward	Water Supply	Borehole	2	YES	4	1	2	3.4000
Construction of Bilbil water pan project in Chewele ward	Water Supply	Water pan	2	YES	4	2	0	3.4000
Proposed drilling of borehole and construction of water kiosk at Masabubu	Water Supply	Borehole		YES	4	2	0	3.4000
Proposed drilling of Mkomani borehole and construction of 3 water kiosks	Water Supply	Borehole	1	YES	4	2	0	3.4000
Proposed rehabilitation and desilting of Haroresa water pan	Water Supply	Water pan	4	NO	4	1	2	3.4000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Proposed construction of Bububu water supply	Water Supply	Borehole	3	YES	4	2	0	3.4000
Proposed construction of Chira Village water supply	Water Supply	Borehole	4	YES	4	1	2	3.4000
Construction of a borehole water supply project in Darime village, sala ward	Water Supply	Borehole	4	NO	4	1	2	3.4000
Rehabilitation/desilting of Titla Galole water pan in Wayu ward	Water Supply	Water pan	2	YES	4	1	2	3.4000
Rehabilitation/desilting of Bultobanta water pan in Bangale ward	Water Supply	Water pan	2	YES	4	1	2	3.4000
Construction of Mlima Abo cluster water and sanitation supply project	Sanitation	Toilets	2	YES	4	2	0	3.4000
Consultancy services for Energy Audit for Garsen Water scheme	Water Supply	Other/Unclassified	2	YES	4	2	0	3.4000
Replacement of Tarasaa Police - Shakababo to 3" HDPE (2KM)	Water Supply	Water Pipeline	2	YES	4	1	2	3.4000
Upgrading of the Ma Mainline from Intake to Ma Palace 12" HDPE (4Km)	Water Supply	Water Pipeline	2	YES	4	2	0	3.4000
Desilting of Majengo mapya water pan in Mikinduni ward	Water Supply	Water pan	2	YES	4	1	2	3.4000
Rehabilitation of Nanighi borehole	Water Supply	Borehole	2	YES	4	2	0	3.4000

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 **soil erosion hazard** with a **low** exposure, except for a few specific points. Considering that the sensitivity of water supply and sanitation infrastructure to such hazard is not great it is expected that the hazard is considered in the design of investments while not being a main area of focus.

Salinity hazard exposure on its end mostly concerns infrastructure located in the vicinity of the Tana River or its tributaries, again this exposure is considered **low to medium**, but considering high sensitivity of water supply and sanitation infrastructure to such hazard this will need close consideration.

The same pattern is observed with **flood hazard** exposing most infrastructure along the Tana River and in this case some infrastructure can be considered **highly exposed** to flood risk, 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 brough 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 **highly 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 fulfill the purpose of increasing adaptation to such hazards (water pans, water tanks, water storage, etc.).

5.1.4.1 Specific exposure mapping – Present situation

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

In order to ensure proper climate proofing 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.

5.1.4.1.1 Pluvial and river flooding hazard exposure

- Water Treatment Plant
- Water Storage Tank
- Water Pipeline
- Water pan
- Water Meters
- Water Intake
- Vehicles / Equipment
- Solar Pumping System
- Office / Facility
- NRW Equipment
- Dam
- Borehole
- Wastewater Treatment Plant
- Toilets
- Waste disposal
- Public sanitation facility
- Other/Unclassified

- No/Low exposure
- Moderate exposure
- High exposure
- Very high exposure

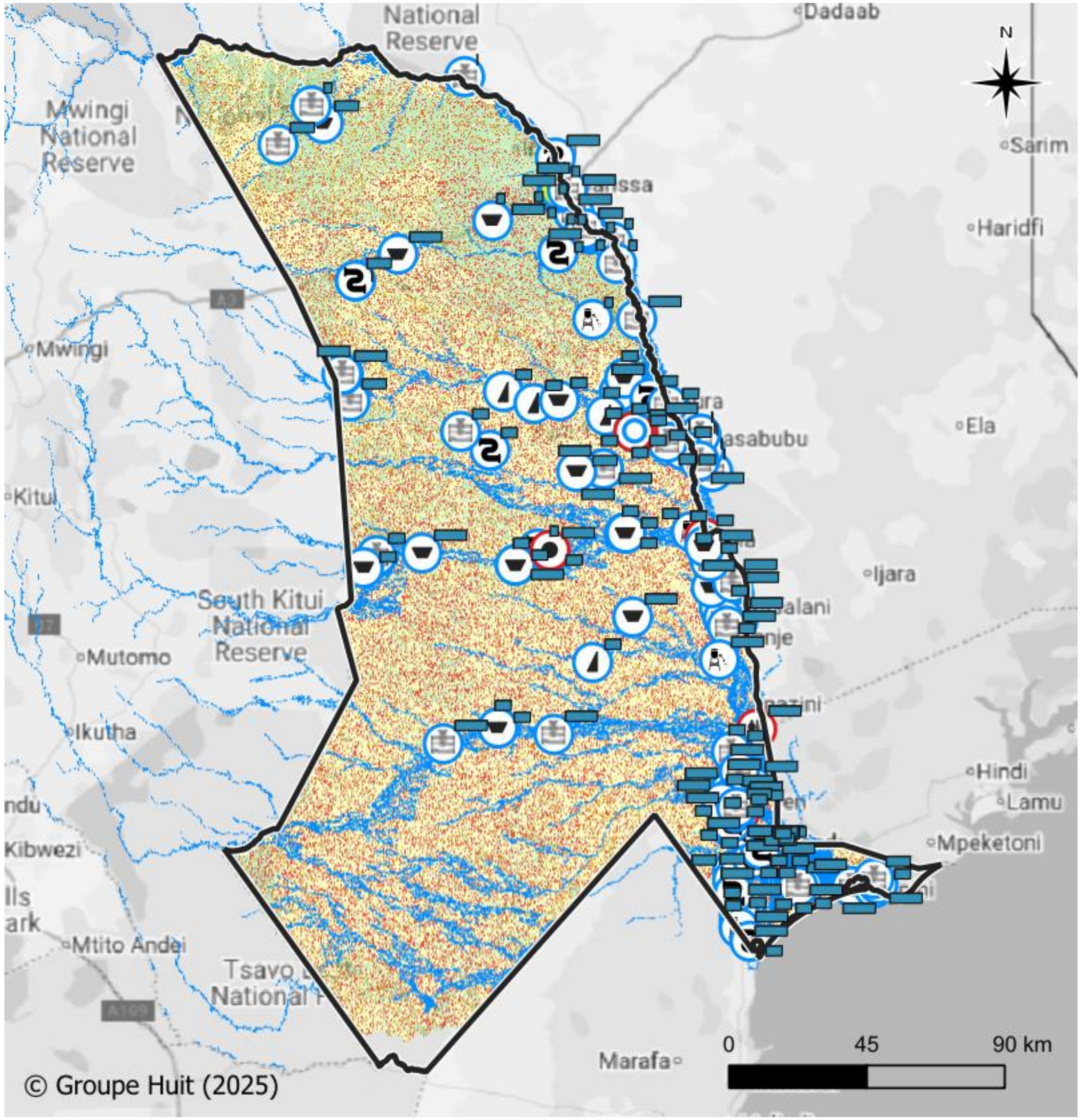


Figure 56: Tana River proposed investments exposure to flood hazard

5.1.4.1.2 Erosion exposure

- Water Treatment Plant
- Water Storage Tank
- Water Pipeline
- Water pan
- Water Meters
- Water Intake
- Vehicles / Equipment
- Solar Pumping System
- Office / Facility
- NRW Equipment
- Dam
- Borehole
- Wastewater Treatment Plant
- Toilets
- Waste disposal
- Public sanitation facility
- Other/Unclassified

- No/Low exposure
- Moderate exposure
- High exposure
- Very high exposure

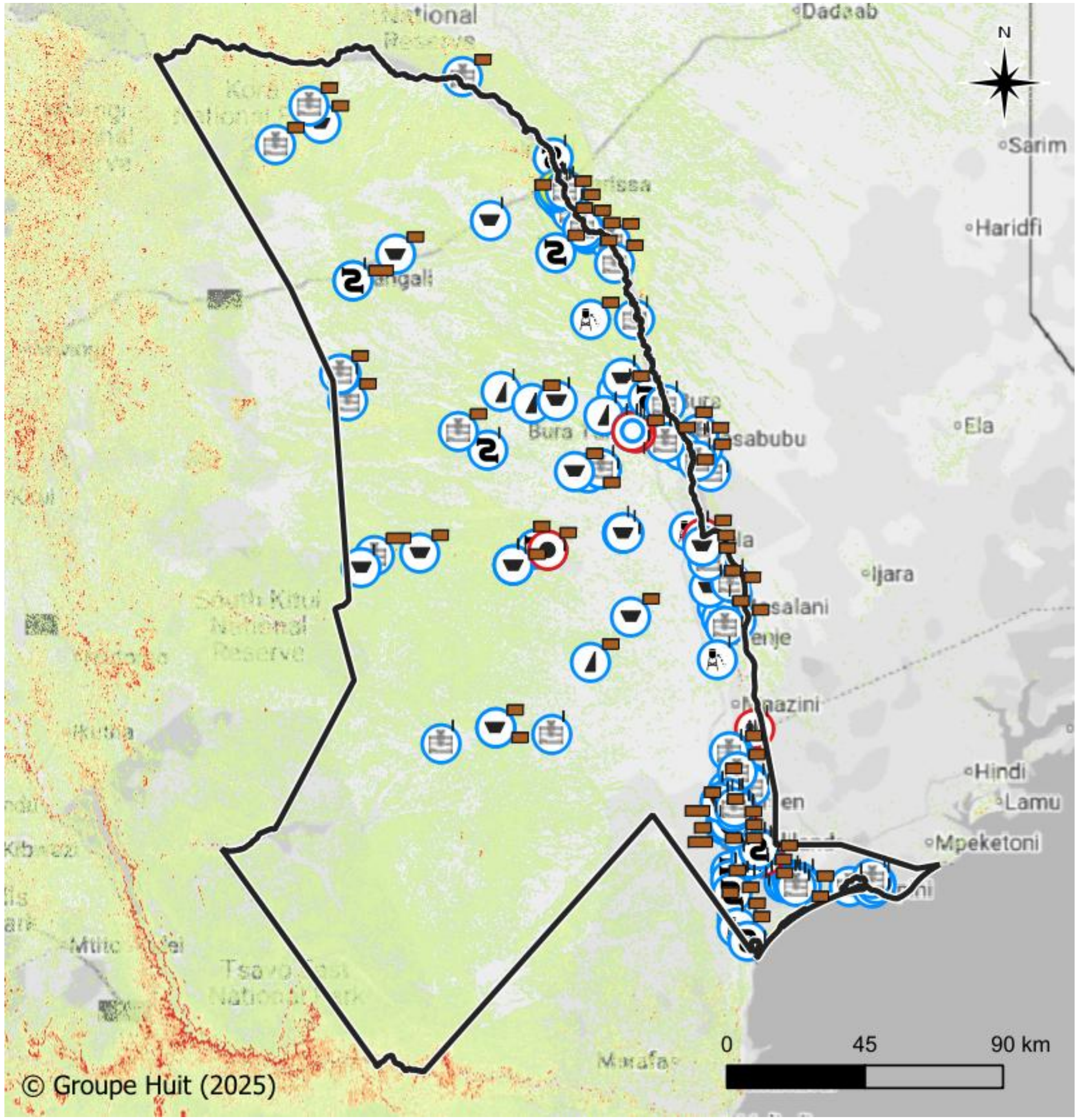


Figure 57: Tana River proposed investments exposure to soil erosion hazard

5.1.4.1.3 Salinity exposure

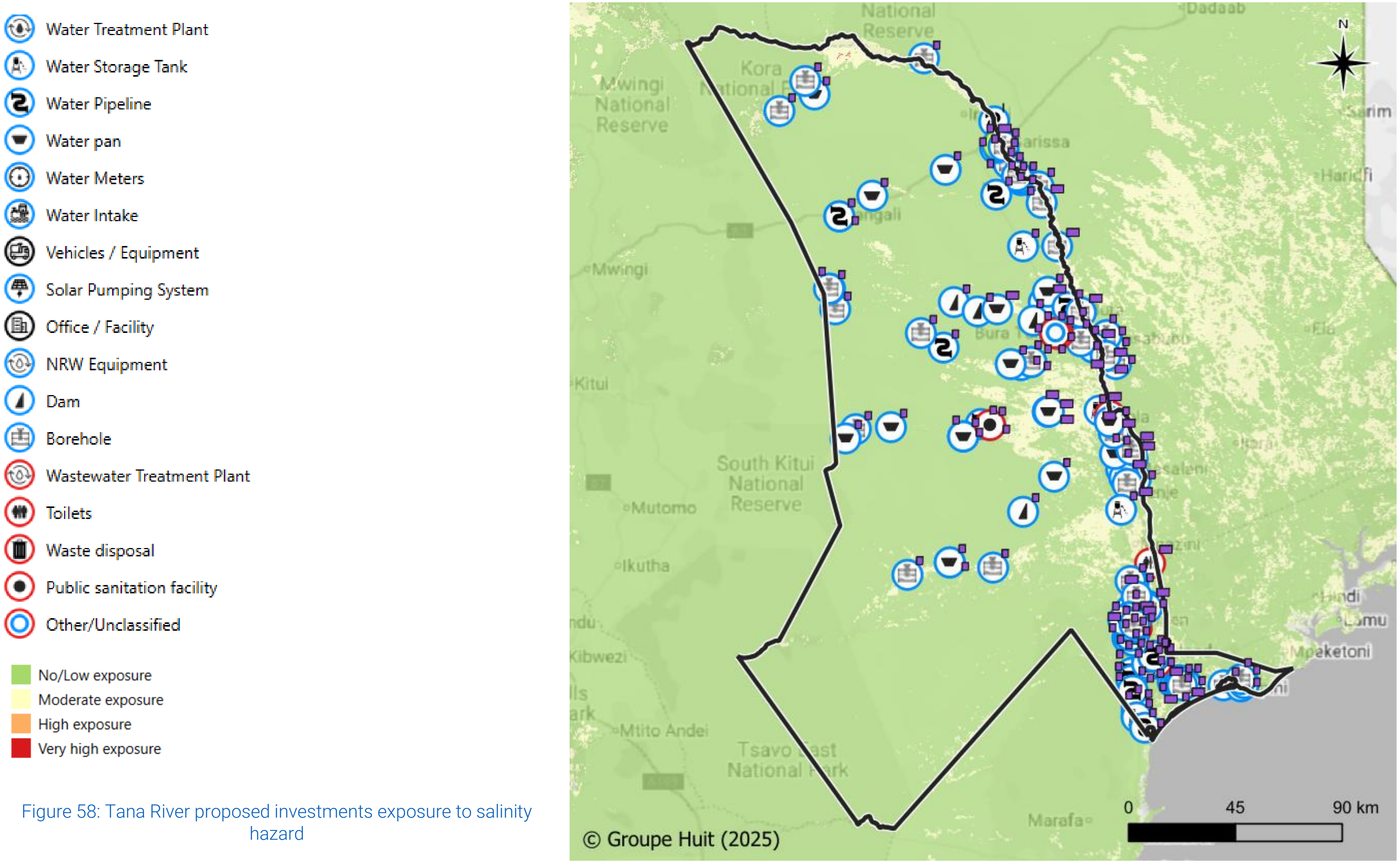


Figure 58: Tana River proposed investments exposure to salinity hazard

5.1.5 Impact of climate change

5.1.5.1 Climate signal for Tana River at horizon 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.
- More intense rainfall and heavy events: IPCC AR6 and regional studies indicate that heavy precipitation frequency and intensity will increase across East Africa.
- Sea level rise presents a risk to coastal counties including Tana River.

When translated into our indicators, this means for Tana River 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; stronger erosion and sediment transport.
- PRCPTOT, CWD, RH: increasing and CDD and SPEI : stable → tendency to slightly reduce salinization risks.
- RH: increasing → higher discomfort, more corrosion and biological fouling in infrastructure.
- SLR and HT: increasing → more coastal erosion and coastal flooding also driving saline water intrusion.

5.1.5.2 Specific climate impacts on WASH infrastructure in Tana River

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
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

Hazard	Key Climate Drivers	Asset Type	Main Impact Mechanisms	Typical Physical Consequences	Operational / Service Impacts
Soil & Water Salinity	Local geology and abstraction dominate	Boreholes in saline aquifers	Upcoming 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

Cross-cutting service and health implications are as follows:

- More frequent service interruptions from flood-related damage, especially for water intakes boreholes and 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).

5.1.6 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.

5.1.7 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 Tana River county. Key hazards such as 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 Tana River 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 and solarization of boreholes, dams, water pans, water kiosks, treatment plants, and sanitation facilities, alongside the repair and upgrading of existing water supply pipelines.

While most areas are moderately exposed to erosion and salinity, infrastructure along the Tana River faces high flood risk, requiring careful adaptation planning. Hazard exposure maps help guide 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.

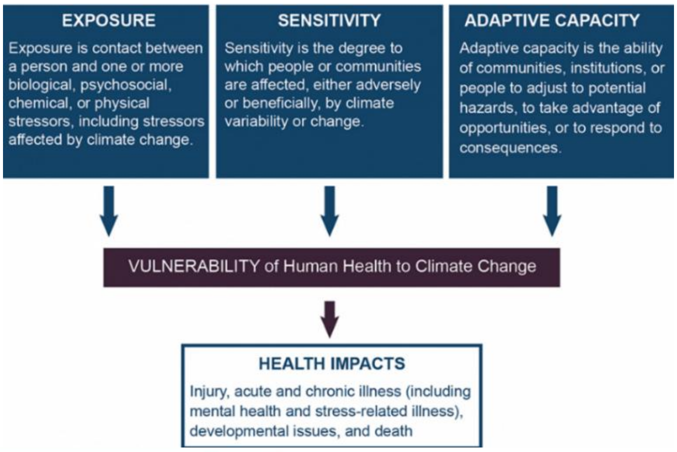


Figure 59: Determinants of Vulnerability

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

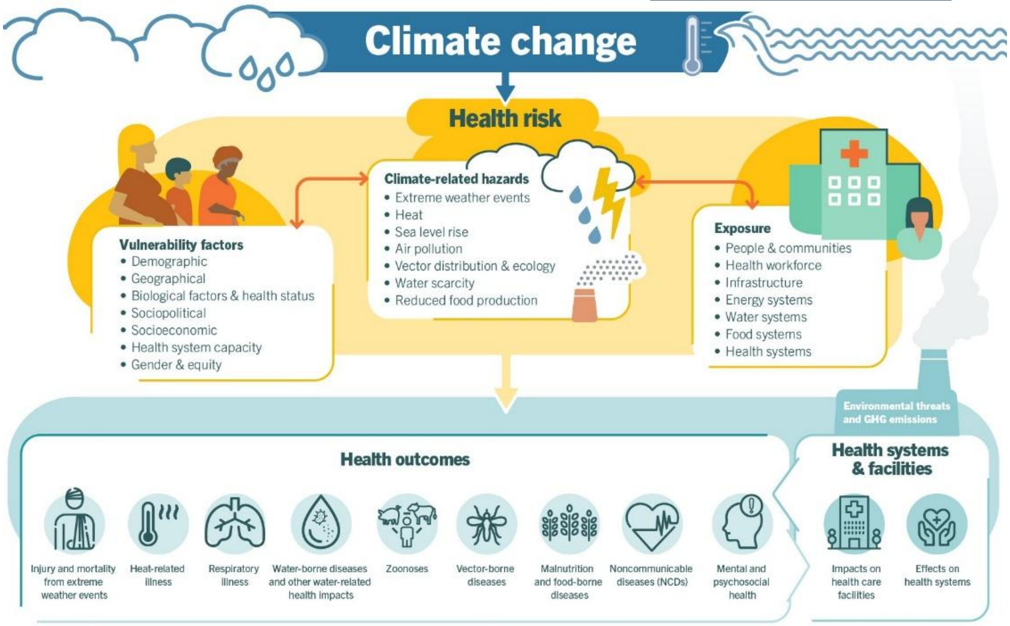


Figure 60: An overview of climate-sensitive health risks, their exposure pathways and vulnerability factors. Climate change impacts health both directly and indirectly, and is strongly mediated by environmental, social and public health determinants.

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 a key sector in Tana River County on which the livelihoods of communities depend heavily, but it is heavily affected by climate change.

Agriculture, especially **mixed subsistence farming**, is a primary activity for a large portion of the county's population. Other agricultural activities are carried out in various **irrigation projects**. The success of agricultural activities, especially crops and livestock, is highly **dependent on climate, especially rainfall**.

The three main hazards related to climate change in the county (flooding, drought and salinity of water and soil) have a negative impact on agriculture, leading to an **increase in poverty and hunger**.

- Flooding leads to the loss or poor productivity of crops and livestock and changes crop patterns.
- Seawater intrusions into 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.

Pastoralist communities are affected differently by changing their movements and livestock migrations to find water.

Adaptation strategies are put in place such as:

- The county has developed specific irrigation schemes and water pans to adapt to the changes
- Communities affected by climate hazards are turning to activities such as charcoal mining and manual labour, which are often insufficient or lead to **further land degradation**, affecting their ability to adapt.
- In marginal mixed livelihood areas (along the Tana River). Farmers are resorting to the purchase of fuel and the rental of water pumps to increase production.
- Targeted **research on drought-tolerant crops and soil health**, improving water resource management through irrigation and water storage, adopting appropriate crop sequences, improving marketing systems, improving early warning systems, implementing sustainable land management practices, encouraging the use of water-efficient agricultural technologies and more resilient crop varieties, encouraging food storage, diversifying livelihoods (including mixed farming), and strengthening local institutions.
- Adaptive investments for agriculture in response to drought include **crop production through irrigation**, establishing new irrigation systems, purchasing drought-tolerant seeds, subsidizing agricultural inputs, training farmers in climate-smart agriculture, improving crop insurance initiatives, establishing food storage facilities, promoting improved storage technologies, improved aflatoxin control, and the adoption of appropriate and diversified companies and value chains.
- In the face of floods, adaptive strategies for agriculture include the promotion of aquaculture and mixed farming.
- Measures to reduce post-harvest losses are also being considered, such as promoting improved storage technologies and creating awareness.
- The County Climate Action Plan (CCAP) 2023-2027 highlights priority actions for drought-faced agriculture, including crop production through irrigation, procurement of drought-

tolerant seeds, input subsidies, climate-smart agriculture training, creation of new irrigation systems, improved crop insurance, the establishment of food storage facilities, the promotion of improved storage technologies, improved crop processing, cash transfers to vulnerable groups, and the diversification of livelihoods.

- Objective 1 of the CCAP aims to improve food and nutrition security by diversifying crops, improving farmers' access to inputs, promoting organic farming, improving soil testing, developing irrigation, promoting solar-powered irrigation systems, investing in research, promoting added valorization, investing in early warning systems, promoting indigenous knowledge, improving the adoption of certified seeds, engaging youth and women in commercial agriculture, creating awareness, and promoting agroforestry and water conservation techniques.

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 Coastal zones

Kenya's coastal zone is highly vulnerable to climate change, particularly due to rising sea levels and increasing storm surges. Coastal ecosystems, including coral reefs, estuaries, and beaches, are at risk, along with critical sectors such as fisheries, tourism, and infrastructure. Key areas like Mombasa and other low-lying coastal regions face severe flooding, saltwater intrusion into freshwater aquifers, and waterlogging, which threatens agriculture and freshwater supply. The coastal economy, heavily reliant on tourism, shipping, and small-scale fishing, could suffer substantial losses. Additionally, infrastructure like ports and agricultural production (e.g., mango, cashew nuts, and coconuts) is at risk, with potential economic losses reaching $472.8 million due to a one-meter sea level rise. (The World Bank Group 2021)

5.2.5 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.

5.2.6 Socio-economic impacts

In some areas, such as Odole, flooding causes widespread displacement of residents. During severe flood events, the entire community is forced to migrate to Golicha Cluster to seek relief. In these temporary shelters, men, women, and children are accommodated together in single rooms, resulting in limited privacy and compromised dignity.

Flooding also disrupts education. School-going children are often sent to stay with relatives in safer areas until floodwaters recede. This leads to interrupted learning, absenteeism, increased school dropouts, and early marriages among girls. This also interferes with family cohesion as children are separated from their families.

5.2.7 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.

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).

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

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 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.

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 Hult
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 61: Women and disaster vulnerability

Similar observations to the ones made on gender can be made for other marginalized 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.

6. CONCLUSION

The assessment confirms that Tana River County's WASH systems are increasingly exposed to multiple, interacting climate hazards, **flooding, droughts and heat waves** emerge as highest priority hazards compounded by increased soil and water salinity and coastal erosion. These hazards directly and indirectly undermine water resource management, supply, sanitation, and drainage, leading to service disruptions, equipment failures, and reduced efficiency, while rising water demand and low socio-economic development intensify the magnitude of impacts. Communities face heightened social consequences such as disease outbreaks, longer water-fetching distances, and displacement during extreme events, revealing uneven resilience across the county.

WASH climate risk are not evenly distributed across the county. Indeed**, settlements and urban centres located along the Tana River corridor face the highest overall risk,** due to the convergence of high hazard exposure and high concentration of people and assets, these areas are exposed to multiple flood mechanisms, including river overflow, intense rainfall, and rising groundwater tables.

Water and sanitation infrastructure is closely aligned with population centres, and therefore disproportionately located in flood-prone riverine zones. Urban areas while at risk because they have more assets and population are currently better served than rural areas which rely on weaker WASH systems and are therefore at risk as well. Key exposed assets include latrines, shallow wells, boreholes, water intakes, and distribution networks. **WASH assets most vulnerable and therefore at most risk are latrines which are likely to collapse or overflow but also boreholes, water intakes or pumps which can be damages or stop functioning when submerged. Lastly floods can lead to water resource contamination which thus impacts the whole WASH sector greatly (pest and diseases outbreak).**

Although heat stress and drought are countywide hazards, their impacts are also more severe in riverine and urban areas, where water demand is highest and infrastructure density is greatest. The **main concern during droughts and heat waves is the limited water availability being simultaneous with an increased demand** translating in long water fetching tasks. Other concerns on WASH risks in relation with this hazard is the operational stress on infrastructure which has lower efficiency and higher risks of damages/failure (dry pumping, materials expansion, pumps overheating etc.)

Pastoralists face distinct vulnerabilities as, as a mobile population they rely on fewer, more dispersed water points that are highly sensitive to drought and water quality degradation. The nature of such water use (not specific to one settlement) can lead to conflicts over the resource.

Above-mentioned risks are also differentiated depending on social norms and groups (gender, PWDs, pastoralists for instance) and such items should be considered as developed in the social and gender assessment and GAP report.

The above tends to highlight that priority should be put on:

- Flood risk reduction in both urban and rural settlements in riverine areas,
- Climate-resilient water supply systems that can withstand drought and heat stress, mostly oriented towards improvement of water storage and distribution, especially in rural areas to improve their overall adaptative capacity and resilience (lower water fetching task burden)
- Protection of water quality through improvement of sanitation and selection of low-salinity areas for boreholes digging
- Context-specific WASH solutions for pastoralist communities, reflecting their mobility and exposure patterns.

While the CWSSIP proposes essential infrastructure investments (boreholes, dams, treatment plants, sanitation facilities) that inherently contribute to resilience, some infrastructure are considered highly exposed to hazards (see hazard exposure maps and exposure index for proposed infrastructures). Therefore, **careful siting and comprehensive climate-proofing** are critical. The strategic guidance provided by the CRA necessitates **that each proposed project undergoes a localized and detailed assessment** to tailor adaptation measures for technical viability, long-term resilience, and social appropriateness.

7. ANNEXES

ANNEX 1. DETAILED METHODOLOGY FOR CLIMATE HAZARD AND VULNERABILITY ASSESSMENT

1. 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 (which appeared irrelevant for Tana River County)

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 Tana River, 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 or national 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.

2. Vulnerability assessment

Exposure of WASH Assets

Geospatial overlay of:

- Proposed CWSSIP assets
- 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

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.

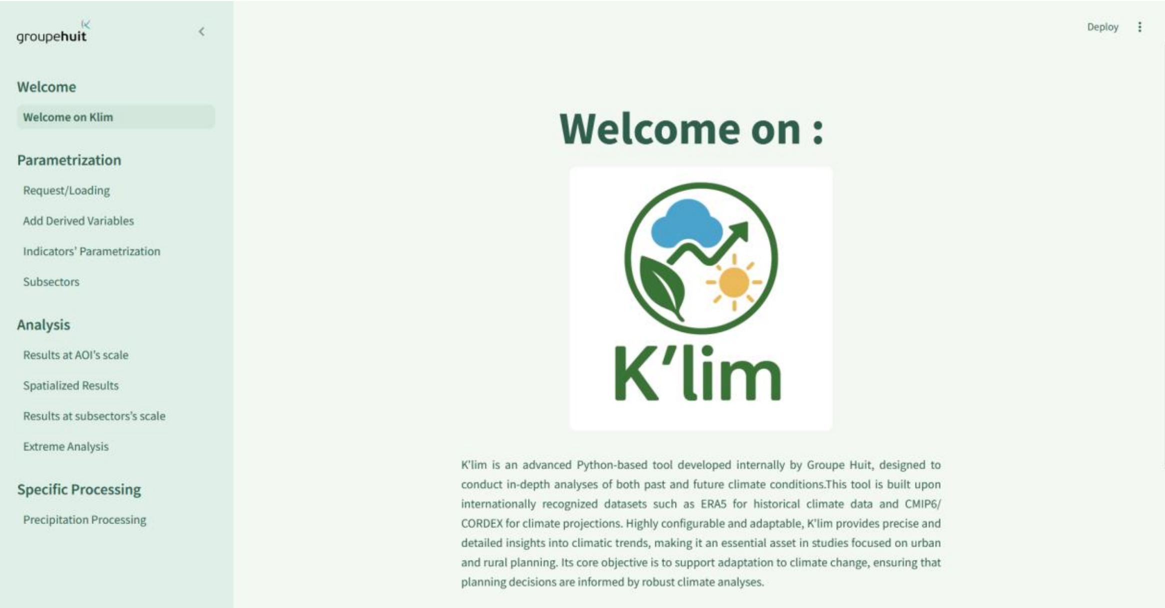


Figure 62 : K'Lim tool

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 correspond 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

1. Madden Julian Oscilation

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 the 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 up to several weeks ahead. All in all, the MJO is an important driver of global weather and can influence the North Atlantic Oscillation.

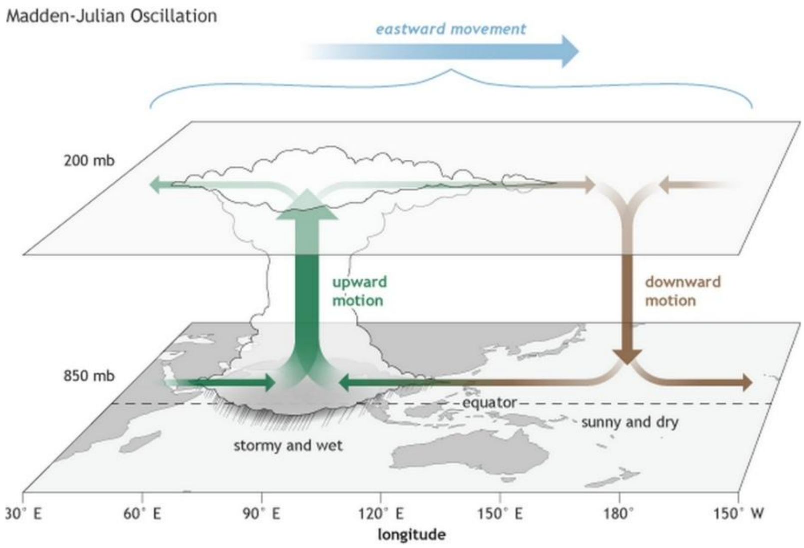


Figure 63: MJO scheme

2. 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.

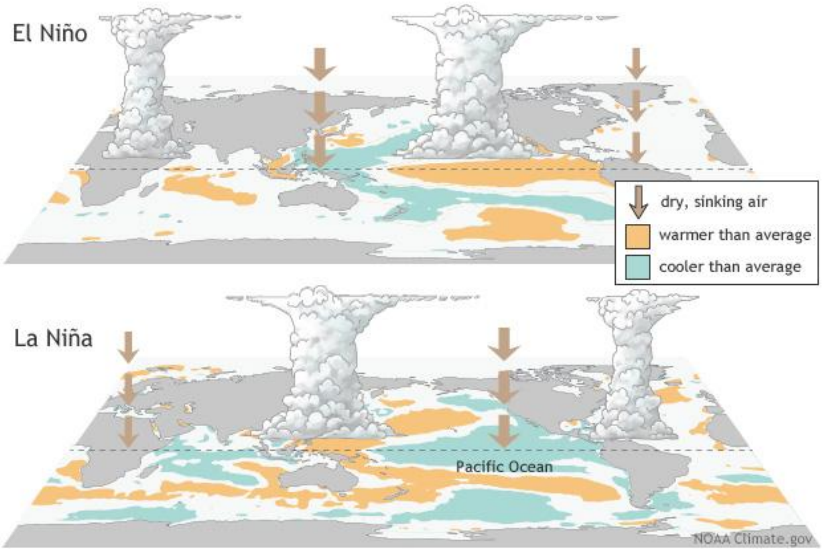


Figure 64: ENSO scheme

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 or 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).

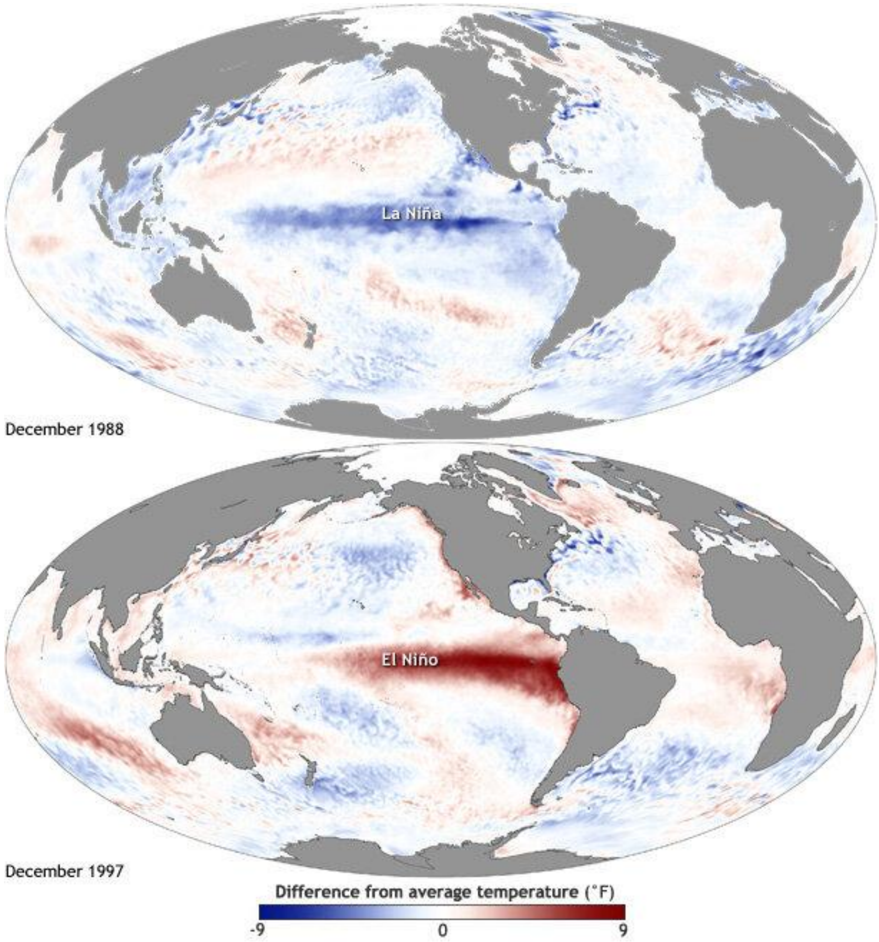


Figure 65: Maps of sea surface temperature anomaly in the Pacific Ocean during a strong La Niña (top, December 1988) and El Niño (bottom, December 1997).

Source: Maps by NOAA Climate.gov

ANNEX 6. LIST OF PROJECTS CLASSIFIED BY EXPOSURE LEVEL

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Proposed construction of Fanjua water supply in Kinakomba ward	Water Supply	Borehole	2	YES	4	2	2	4.0000
Construction of Maziwa water supply and sanitation supply project	Water Supply	Borehole	2	YES	4	2	2	4.0000
Drilling and Equipping of a borehole at Idsowe	Water Supply	Borehole	2	YES	4	2	2	4.0000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	1	YES	4	1	2	3.4000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	2	YES	4	1	2	3.4000
Proposed construction of Kipao water supply	Water Supply	Borehole	2	YES	4	2	0	3.4000
Construction of Kaniki - Gurujo water supply project in Galedertu SC	Water Supply	Borehole	4	NO	4	1	2	3.4000
Construction of larger diameter boreholes in Feji, Bilisa to Garsen Market Water Project	Water Supply	Borehole	2	YES	4	2	0	3.4000
Construction of Daba strategic borehole in Wayuward	Water Supply	Borehole	2	YES	4	1	2	3.4000
Proposed Construction of Hewani, Wema, Kulesa, Sailoni and Vumbwe water supply project	Water Supply	Borehole	4	YES	4	2	0	3.4000
Proposed construction of Anasa water supply in Kipini West ward	Water Supply	Borehole	2	YES	4	2	0	3.4000
Proposed construction of Jararodi water supply in Kinakomba ward	Water Supply	Borehole	2	YES	4	1	2	3.4000
Construction of Bilbil water pan project in Chewele ward	Water Supply	Water pan	2	YES	4	2	0	3.4000
Proposed drilling of borehole and construction of water kiosk at Masabubu	Water Supply	Borehole		YES	4	2	0	3.4000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Proposed drilling of Mkomani borehole and construction of 3 water kiosks	Water Supply	Borehole	1	YES	4	2	0	3.4000
Proposed rehabilitation and desilting of Haroresa water pan	Water Supply	Water pan	4	NO	4	1	2	3.4000
Proposed construction of Bububu water supply	Water Supply	Borehole	3	YES	4	2	0	3.4000
Proposed construction of Chira Village water supply	Water Supply	Borehole	4	YES	4	1	2	3.4000
Construction of a borehole water supply project in Darime village, sala ward	Water Supply	Borehole	4	NO	4	1	2	3.4000
Rehabilitation/desilting of Titla Galole water pan in Wayu ward	Water Supply	Water pan	2	YES	4	1	2	3.4000
Rehabilitation/desilting of Bultobanta water pan in Bangale ward	Water Supply	Water pan	2	YES	4	1	2	3.4000
Construction of Mlima Abo cluster water and sanitation supply project	Sanitation	Toilets	2	YES	4	2	0	3.4000
Consultancy services for Energy Audit for Garsen Water scheme	Water Supply	Other/Unclassified	2	YES	4	2	0	3.4000
Replacement of Tarasaa Police - Shakababo to 3" HDPE (2KM)	Water Supply	Water Pipeline	2	YES	4	1	2	3.4000
Upgrading of the Madogo Mainline from Intake to Madogo Palace 12" HDPE (4Km)	Water Supply	Water Pipeline	2	YES	4	2	0	3.4000
Desilting of Majengo mapya water pan in Mikinduni ward	Water Supply	Water pan	2	YES	4	1	2	3.4000
Rehabilitation of Nanighi borehole	Water Supply	Borehole	2	YES	4	2	0	3.4000
Construction of Kaniki water supply project in Galedertu SC	Water Supply	Borehole	3	NO	3	1	2	2.8000
Construction of Gurujo water supply project in Galedertu SC		Dam	4	NO	4	1	0	2.8000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Last mile connectivity (Sala village and its environs)	Water Supply	Borehole	3	NO	3	1	2	2.8000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao, Lakole and Gururi)	Water Supply	Borehole	4	NO	4	1	0	2.8000
Construction of boreholes at Roka, Daku and Wachakone	Water Supply	Borehole	2	NO	2	2	2	2.8000
Construction of Boka strategic borehole in Bangale ward	Water Supply	Borehole	3	NO	3	1	2	2.8000
Construction of Odoganda strategic borehole in Wayu ward	Water Supply	Borehole	4	NO	4	1	0	2.8000
Proposed Construction of Hewani, Wema, Kulesa, Sailoni and Vumbwe water supply project	Water Supply	Borehole	2	YES	4	1	0	2.8000
Proposed construction of Kikomo water supply in Garsen Central ward	Water Supply	Borehole		YES	4	1	0	2.8000
Proposed construction of Odole water supply in Kipini West ward	Water Supply	Borehole	4	YES	4	1	0	2.8000
Proposed construction of Bububu water supply in Kinakomba ward	Water Supply	Borehole	2	NO	2	2	2	2.8000
Proposed drilling of borehole at Wadesa	Water Supply	Borehole	4	NO	4	1	0	2.8000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao	Water Supply	Borehole	4	NO	4	1	0	2.8000
Construction of boreholes at Roka, Daku and Wachakone	Water Supply	Borehole	2	NO	2	2	2	2.8000
Proposed Desilting and bush clearing of Gafuru dam	Water Supply	Water pan	4	NO	4	1	0	2.8000
Proposed drilling and equipping of Danisa borehole	Water Supply	Borehole	2	YES	4	1	0	2.8000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Prooposed expansion of Hara Village water supply	Water Supply	Water Storage Tank	4	NO	4	1	0	2.8000
Proposed construction of Kone water supply	Water Supply	Borehole	2	YES	4	1	0	2.8000
Proposed construction of Mpeketoni Water Supply	Water Supply	Borehole		YES	4	1	0	2.8000
Upgrading of 1No. Borehole in Ziwani village in sala ward	Water Supply	Borehole		YES	4	1	0	2.8000
Rehabilitation and expnsion of the Kipini water supply project operated by Kipwa CBO	Water Supply	Water Pipeline	4	NO	4	1	0	2.8000
Expansion of Kipao sanitation project in Tana Delta sub-county	Sanitation	Public sanitation facility	2	YES	4	1	0	2.8000
Rehabilitation/desilting of Kesi water pan in wayu ward	Water Supply	Water pan	3	NO	3	1	2	2.8000
Rehabilitation/desilting of Elrar water pan in Bangale ward	Water Supply	Water pan	3	NO	3	1	2	2.8000
Construction of Mnjila decentralized treatment facility	Water Supply	Toilets	3	YES	4	1	0	2.8000
Construction of Ngao decentralized treatment facility	Water Supply	Toilets	4	NO	4	1	0	2.8000
Solarization of Hola water works in Tana River SC	Water Supply	Solar Pumping System	2	NO	2	2	2	2.8000
Consultancy services for Energy Audit for Madogo Water scheme	Water Supply	Other/Unclassified	3	YES	4	1	0	2.8000
Replacement of Tarasaa Bridge - AIC Church Distribution line 3" HDPE	Water Supply	Water Pipeline	2	YES	4	1	0	2.8000
Replacement of Minjila - CDF 3" HDPE	Water Supply	Water Pipeline	3	NO	3	1	2	2.8000
Replacement of Minjila - Kibusu 4" HDPE (6Km)	Water Supply	Water Pipeline	4	NO	4	1	0	2.8000
Replacement of Garsen - Konkona 3" (3Km)	Water Supply	Water Pipeline	2	YES	4	1	0	2.8000
Upgrading of DO - Al Aqsa Mosque -	Water Supply	Water Pipeline	4	NO	4	1	0	2.8000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Health Center 4" (2Km)								
Chanani water supply project in Mikinduni ward	Water Supply	Borehole	2	NO	2	2	2	2.8000
Desilting of Garsen ya juu water pan in Garsen west ward	Water Supply	Water pan	2	YES	4	1	0	2.8000
Rehabilitation of 2No. Boreholes at Madogo	Water Supply	Borehole		YES	4	1	0	2.8000
Construction of Water Supply to Cluster Villages. Kalalani-Waldena, Mbalambala - Maderte, Masalani - Mkomani- Vumbwe, Bainani	Water Supply	Borehole	2	NO	2	1	3	2.5000
Replacement of Minjila - Law Courts 3" HDPE (4Km)	Water Supply	Water Pipeline	2	NO	2	1	3	2.5000
Distributions lines at Minjila Center 2" (4Km)	Water Supply	Water Pipeline	2	NO	2	1	3	2.5000
Bangale Intergrated Water Supply	Water Supply	Water Pipeline	3	NO	3	1	0	2.2000
Phase II of Kipao integrated water supply	Water Supply	Water Treatment Plant	2	NO	2	1	2	2.2000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao, Lakole and Gururi)	Water Supply	Borehole	2	NO	2	2	0	2.2000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao, Lakole and Gururi)	Water Supply	Borehole	3	NO	3	1	0	2.2000
Construction of Diram strategic borehole in Chewele ward	Water Supply	Borehole	1	NO	1	2	2	2.2000
Proposed construction of Semikaro water supply in Kipini West ward	Water Supply	Borehole	2	NO	2	2	0	2.2000
Proposed construction of Shirikisho water supply in Kipini West ward	Water Supply	Borehole	2	NO	2	1	2	2.2000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Proposed construction of Mbelezoni water supply in Kipini West ward	Water Supply	Borehole	2	NO	2	1	2	2.2000
Proposed excavation of dam at Dukanotu	Water Supply	Dam	2	NO	2	1	2	2.2000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao	Water Supply	Borehole	2	NO	2	2	0	2.2000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao	Water Supply	Borehole	3	NO	3	1	0	2.2000
Proposed drilling of Korati borehole	Water Supply	Borehole	2	NO	2	1	2	2.2000
Proposed rehabilitation of Walesorhea borehole and desilting of dam		Dam	2	NO	2	1	2	2.2000
Proposed construction of Matanya village water supply	Water Supply	Water Storage Tank	2	NO	2	2	0	2.2000
Proposed rehabilitation (desilting and excavation) of Gururi water pan	Water Supply	Water pan	2	NO	2	2	0	2.2000
Construction of wolestokocha water pan project	Water Supply	Water pan	2	NO	2	2	0	2.2000
Expansion of Kipao water and sanitation water project in Tana Delta sub-county	Water Supply	Borehole	2	NO	2	1	2	2.2000
Construction of Sera water and sanitation supply project	Water Supply	Borehole	2	NO	2	1	2	2.2000
Construction of Bura decentralized treatment facility	Water Supply	Water Treatment Plant	2	NO	2	1	2	2.2000
Construction of Public Sanitaion Facility (PSF) at Ngao hospital	Sanitation	Public sanitation facility	2	NO	2	1	2	2.2000
Solarization of Ngao water works in Tana Delta SC	Water Supply	Solar Pumping System	3	NO	3	1	0	2.2000
Consultancy services for Energy Audit for Hola Water scheme	Water Supply	Other/Unclassified	2	NO	2	1	2	2.2000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Consultancy services for Energy Audit for Ngao Water scheme	Water Supply	Other/Unclassified	3	NO	3	1	0	2.2000
Replacement of Tarasaa Stage - Tarasaa Sec School line to 3" HDPE	Water Supply	Water Pipeline	3	NO	3	1	0	2.2000
Replacement of Idsowe tank - Bahamas 3" HDPE	Water Supply	Water Pipeline	2	NO	2	1	2	2.2000
Replacememnt of Minjila - Garsen Cluster 4" HDPE (4Km)	Water Supply	Water Pipeline	2	NO	2	1	2	2.2000
Replacement of Kurumutu - Team & Team 3" HDPE (3Km)	Water Supply	Water Pipeline	2	NO	2	1	2	2.2000
Replacement of Malakoteni distribution 3" (3Km)	Water Supply	Water Pipeline	3	NO	3	1	0	2.2000
Uppgrading Madogo Palace - Hargarsot 3" (1.5Km)	Water Supply	Water Pipeline		YES	4	0	0	2.2000
Rehabilitation/Desilting of Chirfa water pan in Garsen west ward	Water Supply	Water pan	2	NO	2	1	2	2.2000
Pipeline extension to Waldesa village	Water Supply	Water Pipeline	2	NO	2	1	2	2.2000
Construction of wadesa water supply	Water Supply	Borehole	2	NO	2	2	0	2.2000
Rehabilitation of 2No. Ziwani boreholes in Kipini East ward	Water Supply	Borehole	3	NO	3	1	0	2.2000
Fencing of Assa water pan	Water Supply	Water pan	2	NO	2	1	2	2.2000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000
Construction of Pahse II of Bura-Chifiri-Wayu water pipeline	Water Supply	Water Pipeline	1	NO	1	1	2	1.6000
Construction of distribution lines, Repair of 5No. elevated steel tanks at the irrigation	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
scheme and last mile connectivity								
Construction of distribution lines, Repair of 5No. elevated steel tanks at the irrigation scheme and last mile connectivity	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000
Proposed Construction of sala water supply and sanitation projects	Water Supply	Borehole	1	NO	1	1	2	1.6000
Last mile connectivity (Sala village and its environs)	Water Supply	Borehole	1	NO	1	1	2	1.6000
Bura domestic water supply project	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000
Bura domestic water supply project PHASE II	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao, Lakole and Gururi)	Water Supply	Borehole	2	NO	2	1	0	1.6000
Construction of Maramtu strategic borehole in Sala ward	Water Supply	Borehole	1	NO	1	1	2	1.6000
Proposed construction of Nduru water supply in Kipini West ward	Water Supply	Borehole	2	NO	2	1	0	1.6000
Proposed construction of Chamwanamuma water supply in Kipini West ward	Water Supply	Borehole	2	NO	2	1	0	1.6000
Proposed construction of Duwayo water supply in Kipini West ward	Water Supply	Borehole	2	NO	2	1	0	1.6000
Drilling of drought emergency boreholes across the County (2NO. Boreholes at Ngao	Water Supply	Borehole	2	NO	2	1	0	1.6000
Proposed Drilling of borehole at Garagareti	Water Supply	Borehole	1	NO	1	1	2	1.6000
Proposed extension of Kurawa, Hurara	Water Supply	Water Storage Tank	2	NO	2	1	0	1.6000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/ NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Katsangani water pipeline								
Proposed rehabilitation (excavation and desilting) of Sabukia dam		Dam	2	NO	2	1	0	1.6000
Proposed rehabilitation (desilting and excavation) of Halo dam		Dam	2	NO	2	1	0	1.6000
Proposed rehabilitation of borehole and construction of Meti water kiosk	Water Supply	Borehole	2	NO	2	1	0	1.6000
Construction of a borehole water supply project in Bawama village, sala ward	Water Supply	Borehole	1	NO	1	1	2	1.6000
Rehabilitation/desilting of Daba water pan in Wayu ward	Water Supply	Water pan	2	NO	2	1	0	1.6000
Rehabilitation/desilting of Hara water pan in Kinakomba ward	Water Supply	Water pan	2	NO	2	1	0	1.6000
Rehabilitation/desilting of Bilbil water pan in Chewele ward	Water Supply	Water pan	2	NO	2	1	0	1.6000
Rehabilitation/desilting of Haboye water pan in Wayu ward	Water Supply	Water pan	2	NO	2	1	0	1.6000
Construction of Galma water and sanitation supply project	Water Supply	Borehole	2	NO	2	1	0	1.6000
Construction of Madogo decentralized treatment facility	Water Supply	Water Treatment Plant	1	NO	1	1	2	1.6000
Construction of Public Sanitation Facility (PSF) at Bura hospital	Sanitation	Public sanitation facility	2	NO	2	1	0	1.6000
Construction of Public Sanitaion Facility (PSF)at Wayu dispensary	Sanitation	Public sanitation facility	2	NO	2	1	0	1.6000
Construction of Public Sanitaion Facility (PSF)at Garsen health centre	Sanitation	Public sanitation facility	2	NO	2	1	0	1.6000
Solarization of Bura water works in Tana North SC	Water Supply	Solar Pumping System	2	NO	2	1	0	1.6000

Project description	Type of project	Works Category	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Soil Salinity Hazard (1-4)	Erosion Hazard (1-4)	Final exposure level
Consultancy services for Energy Audit for Bura Water scheme	Water Supply	Other/Unclassified	2	NO	2	1	0	1.6000
Drilling , Equipping and construction of a water supply pipeline to Tana Kurole School	Water Supply	Water Pipeline	2	NO	2	1	0	1.6000
Drilling and Equipping of a borehole for Gatundu Village	Water Supply	Borehole	2	NO	2	1	0	1.6000
Construction of Dukanotu water kiosk	Water Supply	Water Storage Tank	1	NO	1	1	2	1.6000
Completion of Hamaresa water project	Water Supply	Water Pipeline	1	NO	1	1	2	1.6000
Proposed drilling of Odowan Borehole	Water Supply	Borehole	1	NO	1	1	2	1.6000
Construction of a borehole water supply project in Anole village, sala ward	Water Supply	Borehole	1	NO	1	1	0	1.0000
Rehabilitation/desilting of Habaki water pan in Chewele ward	Water Supply	Water pan	1	NO	1	1	0	1.0000
Upgrading of Life Frontier School - Citizen 3" (1.2Km)	Water Supply	Water Pipeline	1	NO	1	1	0	1.0000
Upgrading of Samira Mosque - Adele Primary Sch 4" (2Km)	Water Supply	Water Pipeline	1	NO	1	1	0	1.0000

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 15: 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 16: 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 on 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 by 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.

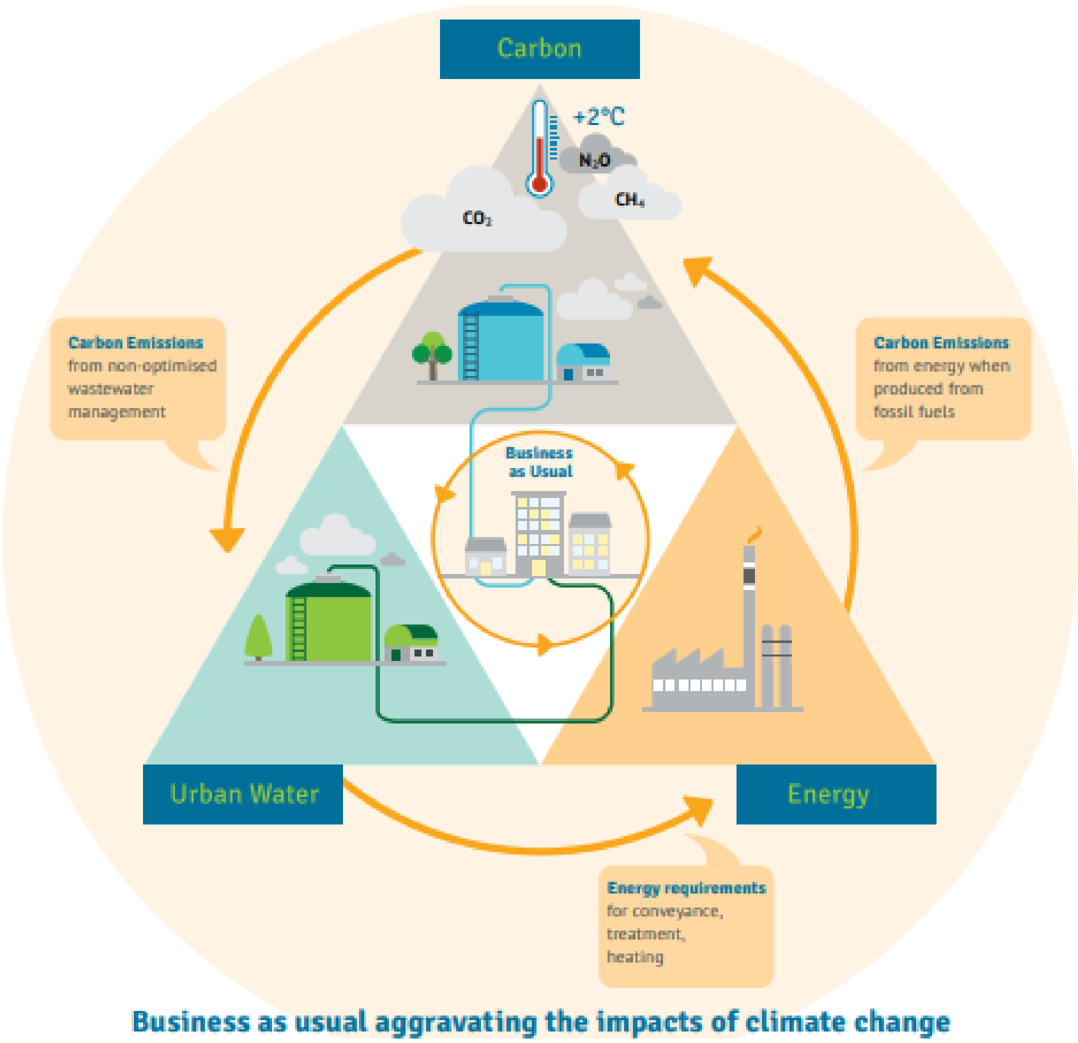


Figure 66: WSS business as usual aggravating the impacts of climate change

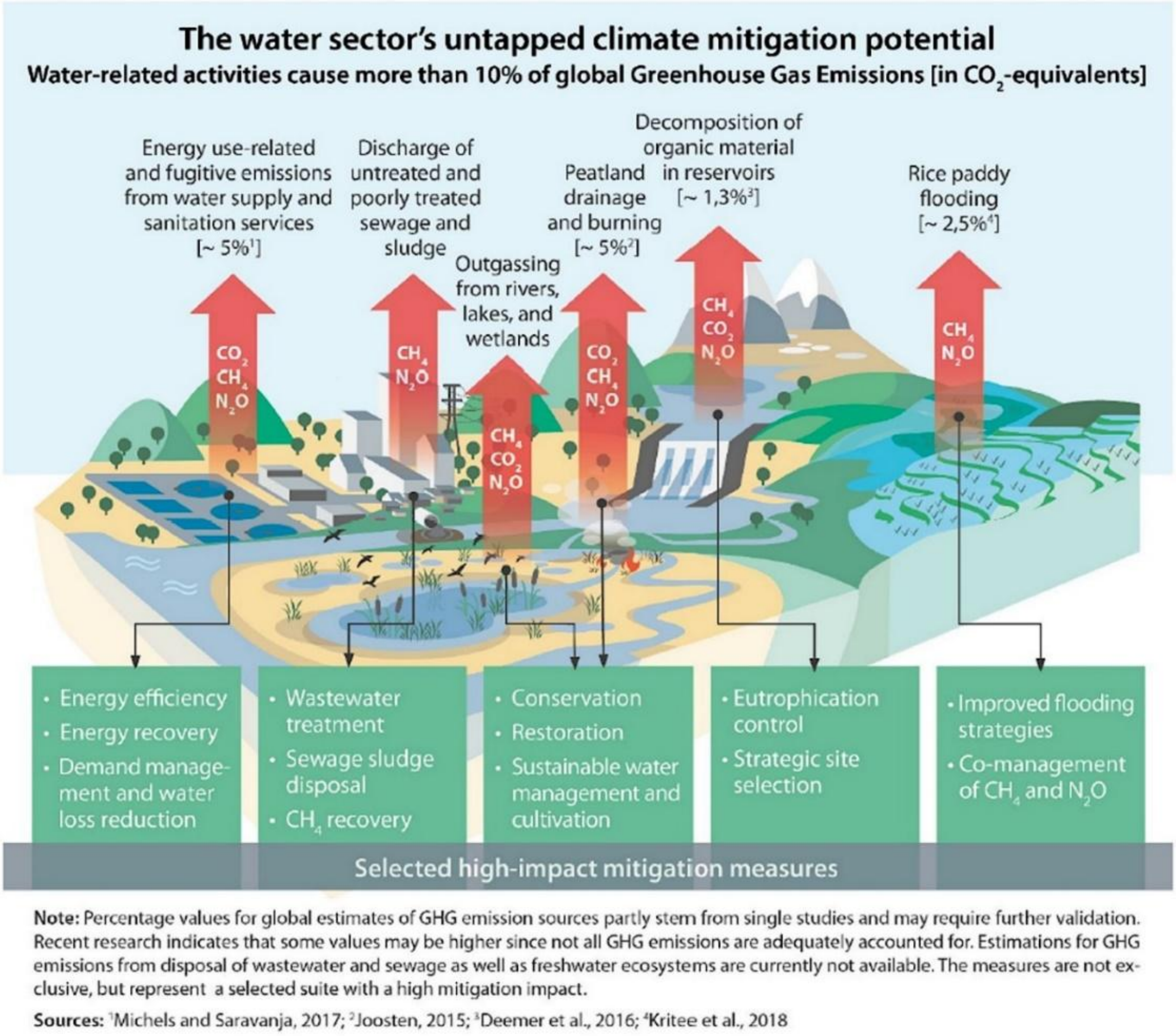


Figure 67: The water sector's untapped climate mitigation potential

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. FINDINGS FROM THE FIELD MISSION HELD IN FEBRUARY

ANNEX 10. HOTSPOT ANALYSIS

ANNEX 11. BIBLIOGRAPHY

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