

K-WASH – Adaptation options report

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GLOBAL
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LIST OF ABBREVIATIONS

ASL	Above Sea Level
CAAC	Catchment Area Advisory Committee
CBO	Community based organization
CIDP	County Integrated Development Plans
CRA	Climate Risk Assessment
CRVA	Climate risk and vulnerability assessment
CWSSIP	County Water and Sanitation Strategic Investment Plan
DEWATS	Decentralized Wastewater Treatment System
DLI	Disbursement Linked Indicator
DRM	disaster risk management
DRS	Department for refugee Services
ESHS	Environmental, Health and Safety
EWS	Early warning systems
FGD	Focus Group Discussions
FMNR	Farmer Managed Natural Regeneration
GAP	Gender action plan
GBV	Gender Based Violence
GCA	Global Center on Adaptation
GCP	Gross County Product
GDP	Gross Domestic Product
GI	Galvanized Iron
GoK	Government of Kenya
HCF	Health Care Facility
HDPE	High-Density Polyethylene
IVA	Independent Verification Agent
KEWASNET	The Kenya Water and Sanitation Civil Society Network
KEWI	Kenya Water institute
KMD	Kenya Meteorological Department
M&E	Monitoring and Evaluation
MCA	Multi Criteria Analysis
MoWSI	Ministry of Water, Sanitation and Irrigation
MTP	Medium Term Plans
NBS	Nature-Based Solutions
NEMA	National Environment Management Authority
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
O&M	Operation and Maintenance
PDO	Program Development Objective
PIAP	Performance Improvement Action Plans
PIU	Project implementation unit
PMU	Project Management Unit
PCRA	Participatory Climate Risk Assessment
RA	Result Area
RDLS	Risk Data Library Standard
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
TA	Technical Assistance
TDS	Total Dissolved Solids
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
WWTP Wastewater Treatment Plant

1. INTRODUCTION

1.1 Context

This document is developed as part of the K-WASH program led by the Government of Kenya and the World Bank. GCA is providing additional support to the project by bringing in Climate and Gender and social inclusion expertise through the Consultancy services of Groupe Huit.

The K-WASH program will contribute to increase sustainable access to improved water and sanitation services, eliminate open defecation, and improve the financial performance of water services providers in selected counties, including refugee-hosting counties.

Result areas across which these program development objectives (PDO) will be implemented are:

- **Results Area 1:** Increasing sustainable access to improved water services for households in climate vulnerable rural areas.
- **Results Area 2:** Increased sustainable access to improved sanitation services and elimination of open defecation in climate-vulnerable rural areas.
- **Results Area 3:** Improved operational and financial performance of Water Services Providers in participating counties.
- **Results Area 4:** Improving sector reforms, coordination, and M&E Capacity for integrated water management.
- **Results Area 5:** Improving integrated WASH services delivery for refugees and host communities.

As part of the GCA assignment, the Consultant has provided Climate Risk Analysis (CRA) for the Counties of Murang'a and Tana River and support to other counties for them to develop their own CRA. This has been done in parallel with ensuring that climate risk assessment outcomes were properly integrated into the Counties Water Supply and Sanitation Investment Plans (CWSSIP) for the latter to be validated by K-WASH task teams and the World Bank. CWSSIPs are guiding and strategic documentation which also enables to meet the first Disbursement Link Indicators (DLI) of the K-WASH project.

1.2 Objectives

The objective of this report is to **provide guidelines and operational recommendations for enhancing the climate resilience of WASH infrastructure in Kenya**, with a particular focus on infrastructures eligible under the K-WASH program as proposed in the various CWSSIP plans.

This will be achieved through the **identification and recommendation of adaptation options** tailored to the WASH and climate risk contexts of Kenya.

This report is designed to be read in conjunction with the **accompanying Excel tools** (Annex 1). It provides the conceptual and methodological foundation for understanding how climate resilience is assessed and integrated into WASH investment. The report also describes the range of adaptation options and the principles guiding their selection.

The associated Excel sheets (comprising one generic tool and two county-specific versions for Murang'a and Tana River) serve as operational instruments. They translate the methodological approach into practical, investment-oriented guidance, listing adaptation measures that can be considered to climate-proof specific CWSSIP investments. Together, the report and the Excel tools are intended to be used jointly, with the report providing context and justification, and the Excel sheets supporting direct application in planning, design, and prioritisation processes.

2. METHODOLOGY

2.1 Concepts and definitions

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

- **Hazard:** The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- **Exposure:** The presence of people; livelihoods; species or ecosystems; environmental functions, services, 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.

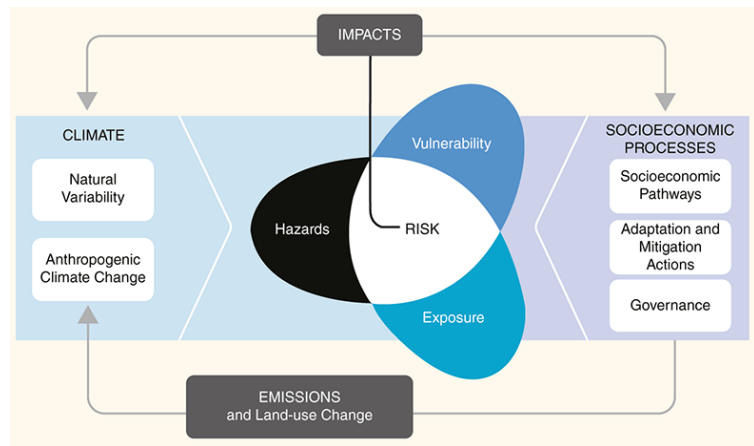


Figure 1 : Hazard - Vulnerabilities - Exposure diagram

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.

2.2 Approach

The overarching objective of this assignment is to support the adaptation of Kenyan WASH systems to projected climate change and to the evolving pressures and constraints this will impose on infrastructure and service delivery. The development of this Adaptation Options Report has followed a structured, multi-layered methodology designed to generate both a broad understanding of climate risks and a detailed, context-specific analysis of vulnerabilities and feasible adaptation measures.

First, the consultant conducted **Climate Risk Assessments (CRAs)** for two counties. These assessments provided a comprehensive understanding of the climatic context, key hazards, and associated exposure and sensitivity of WASH systems. In parallel, an extensive review of planning and strategic documents—especially the **County Water and Sanitation Services Investment Plans (CWSSIPs)**—was carried out. This review helped clarify the nature of proposed WASH infrastructure projects and offered insight into the extent to which climate considerations are (or are not) currently integrated into county-level planning processes.

While the CRAs constitute technical analyses focused on climate dynamics and sector-level vulnerability, they were complemented by a broader, evidence-based assessment drawing from

remote-sensing analyses, literature review, and field-derived information. To deepen the understanding of vulnerability and adaptation practices on the ground, the consultant selected **six hotspots per county**, corresponding to planned WASH infrastructures exposed to different types of climate hazards and representing diverse technological configurations. For each hotspot, a specific analytical process was undertaken that combined:

- remote-sensing–based risk screening,
- field feedback on observed hazards and impacts,
- field feedback on existing or emerging adaptation practices, and
- perspectives gathered from local stakeholders.

The findings from these different layers of analysis—county-level climate risk, hotspot-level assessments, field observations, stakeholder insights, and literature-based good practices—were then consolidated to inform the identification and structuring of **adaptation options**. The report integrates both adaptation measures already observed in Kenya and additional measures drawn from international good practice and internal technical expertise.

All components of the methodology contributed to the logical flow of the report, which includes:

- an assessment of Kenyan WASH vulnerability;
- a comprehensive presentation of adaptation options
- operational sheets designed to support practical implementation.

This integrated methodological approach ensures that the proposed adaptation options are evidence-based, context-appropriate, technically robust, and aligned with county-level planning realities.

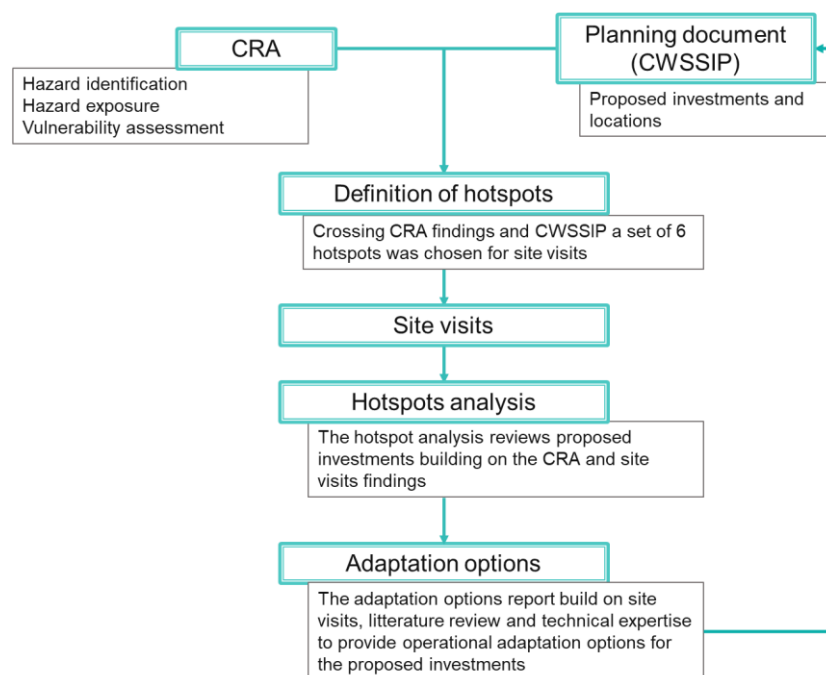


Figure 2: Overall assignment process

3. KENYAN WASH VULNERABILITY

3.1 Exposure to climate hazards in Kenya

3.1.1 Climatology overview

Kenya’s diverse topography results in a wide range of climates. While the coast is typically hot and humid, inland areas are more temperate. The country’s northern and north eastern areas are generally very hot and arid, the central highlands are cooler and are formed of a mix of tropical highlands, which become increasingly arid towards the country’s interior. Kenya’s climate is strongly influenced by the Inter Tropical Convergence Zone (ITCZ),¹² which drives rainfall in the country.

The country’s wide range of climates is reflected through the Köppen-Geiger climate classification which identifies 14 different climate types. Such observation highlights the relevance of undertaking distinct CRAs for each County.

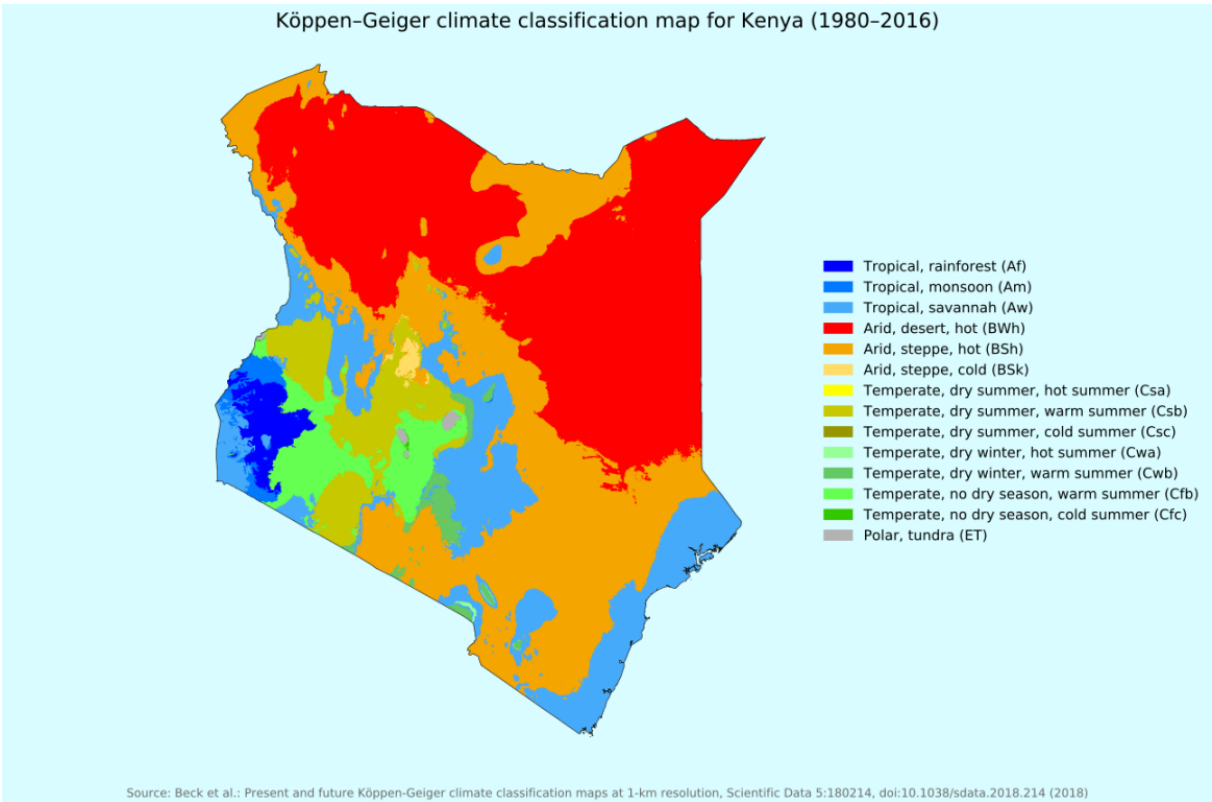


Figure 3: Köppen-Geiger climate classification map for Kenya (1980-2016)

3.1.2 Current climate parameters

Given its diverse topography, temperatures across the country vary significantly, with the highlands experiencing much cooler temperatures than coastal and lowland zones.¹³ Little seasonal variation in temperatures has been observed, with average temperatures ranging between 18°C at the higher elevations to 26°C along the coast. Rainfall varies considerably across the country, with less than 250 millimeters (mm) falling in the arid zones of north, to over 2,000 mm per year in the west annually. Highland areas, where the majority of agriculture takes place, receives approximately 1,000 mm of rainfall each year.

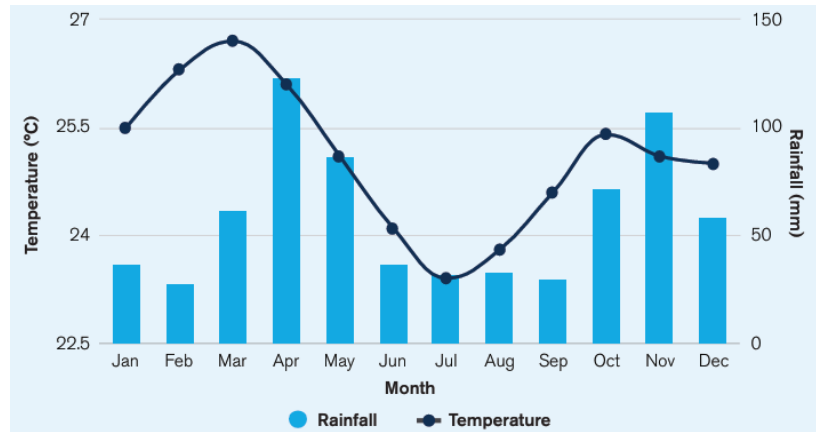


Figure 4: Average monthly temperature and rainfall for Kenya, 1991-2020 (CCKP)

There are four distinct seasons in Kenya, dominated by two rainfall periods: January to March, which is generally considered the 'warm dry season', April to June known as the 'long wet season', July to September the 'cool dry season', and October to December as the 'short wet season'.

3.1.3 Current climate hazards

Overall, in Kenya the main climate hazards that have occurred to-date are **floods, droughts and landslides** as shown in the Figure below. The latter figure also highlights the importance of epidemics which are also linked to climatic events.

Average Annual Natural Hazard Occurrence for 1980-2020

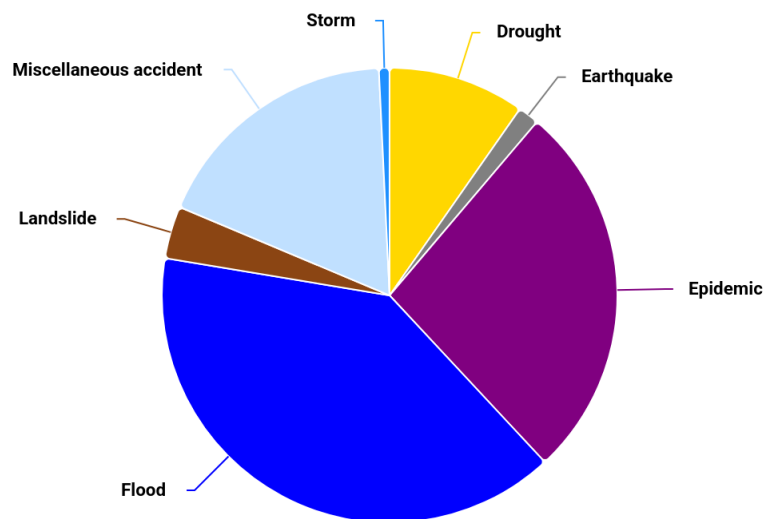


Figure 5: Average Annual Natural Hazard Occurrence for 1980 - 2020 (CCKP)

Key Natural Hazard Statistics for 1980-2020

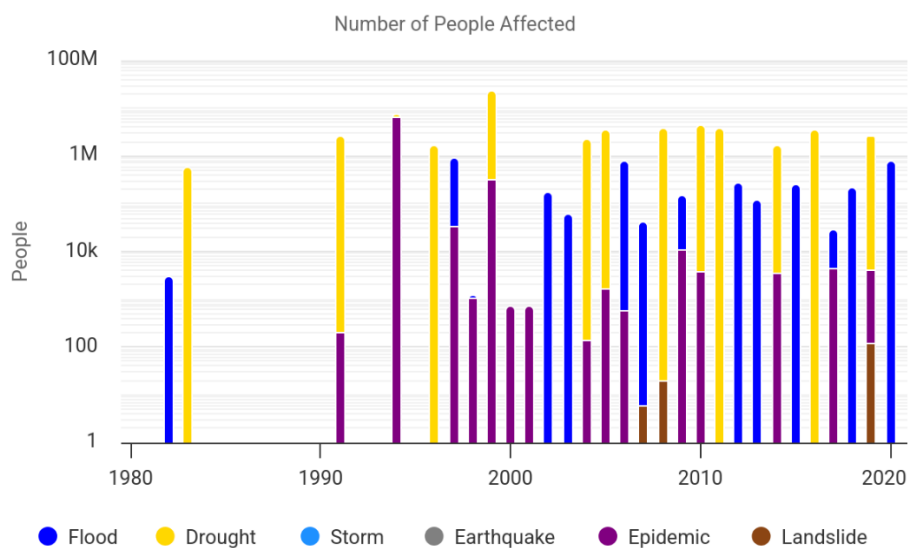


Figure 6: Key Natural Hazard Statistics for 1980 - 2020 (CCKP)

Nonetheless, some differences can be observed between counties, those are presented in the table below for the counties of interest:

Table 1: Main climate hazards preliminary screening for targeted counties

County	Main climate hazards preliminary screening										
	River flood	Urban flood	Coastal flood	Wildfire	Earthquake	Tsunami	Extreme Heat	Volcano	Water Scarcity	Landslide	Cyclone
Murang'a	Low risk	Low risk	N/A	High risk	Low risk	N/A	Low risk	High risk	Moderate risk	High risk	N/A
Tana River	High risk	High risk	High risk	High risk	Moderate risk	Moderate risk	Moderate risk	Low risk	Low risk	Very Low risk	Very Low risk
Makueni	Low risk	Low risk	N/A	High risk	Moderate risk	N/A	Moderate risk	Low risk	Low risk	Very Low risk	Very Low risk
Kericho	Very Low risk	Low risk	N/A	High risk	Moderate risk	N/A	Low risk	High risk	Moderate risk	Moderate risk	Very Low risk
Kwale	High risk	High risk	Moderate risk	Moderate risk	Moderate risk	Low risk	Low risk	N/A	Low risk	Very Low risk	Very Low risk
Samburu	Very Low risk	Very Low risk	N/A	High risk	Low risk	N/A	Moderate risk	Moderate risk	Low risk	Moderate risk	Very Low risk

Legend: High risk, Moderate risk, Low risk, Very Low risk, N/A : non-applicable

Source: ThinkHazard!

3.2 Climate projections in Kenya

3.2.1 Main climate parameters projections

3.2.1.1 Overview

The following maps show the temperature and precipitation anomaly by 2040-2059 and 2080-2099 relative to 1986-2005 baseline under RCP 8.5, it shows that the regions expecting most important climate changes are the ones located in the northwest part of the country.

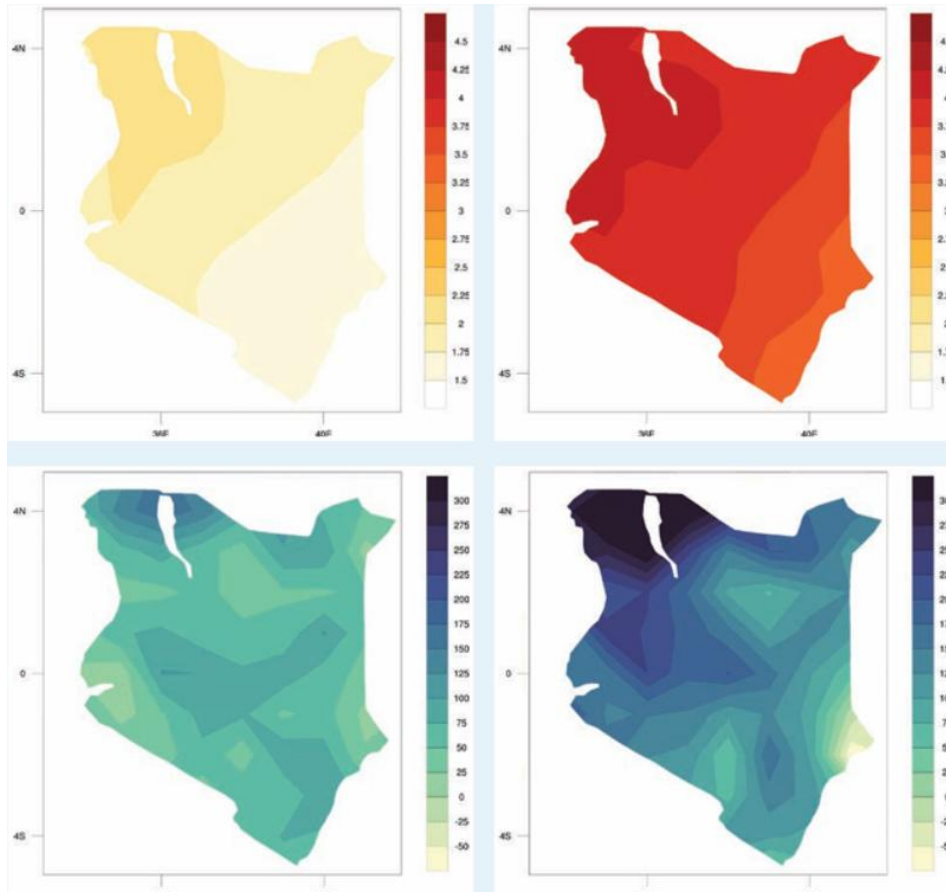


Figure 7: Projected change in annual temperature (top) and precipitation (bottom) by 2040-2059 and by 2080-2099 under RCP8.5

3.2.1.2 Temperature

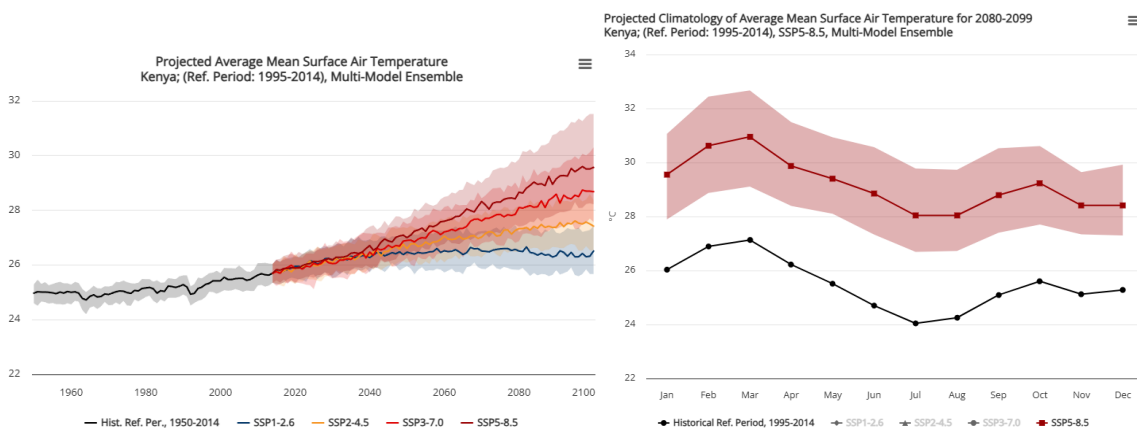


Figure 8: Projected average mean temperature in Kenya

The above graphs, show that regardless of the scenario chosen projected average mean temperature is expected to rise in the future. The graph on the right even shows that under SSP5-8.5 temperature anomaly ranges from +3°C to +4.14°C in June.

In addition to average mean temperature anomalies other data such as the number of hot days (T>30°C) increase throughout the whole year reveal important changes in climate patterns.

3.2.1.3 Precipitation

Regarding precipitation, again regardless of the scenario chosen average mean annual rainfall is expected to increase in Kenya. Under SSP8-8.5 main anomalies are expected to be seen between September and May, with an increase of rainfall going up to 32mm in December.

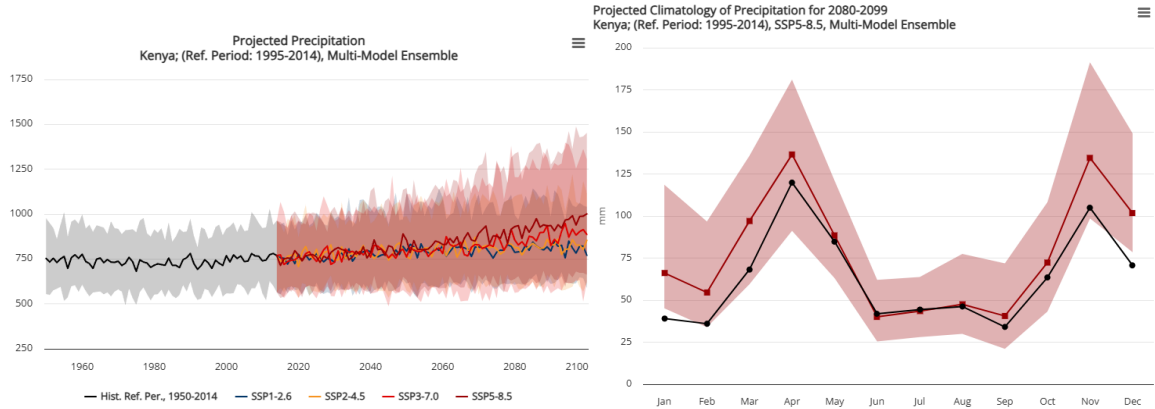


Figure 9: Projected precipitations in Kenya

3.2.2 Main climate hazards projections

It is expected that flood and drought events will be more frequent and intense.

Flooding events combined with increased annual precipitations is likely to trigger mudslides and landslides as well as soil erosion, especially in mountainous areas.

Increasing temperatures are likely to increase periods of aridity, especially in the northwest regions. This combined with increased duration of droughts will probably result in reduction of water storage capacity.

Climate hazards projections also have to be combined with anthropologic actions results such as deforestation, watershed degradation, land use changes, urbanization, pollution and settlements management in order to understand the expected increase in severity of impacts.

3.3 Findings at county scale

It should be noted that further to the ThinkHazard! climate risk screening CRAs should complement the hazard identification and characterization. CRAs should be developed for all counties as they submit their CWSSIPs, the latter enable to decline that current climatology and hazard to counties, as well as the climate projections (as developed at Kenyan scale in the following paragraph).

To ensure a robust climate analysis, it is essential to examine both current and projected climate parameters at the **county scale**, particularly given Kenya's pronounced climatic diversity across regions. Such fine-scale climate assessments is expected to be conducted systematically within each Climate Risk Assessment (CRA), which in turn should inform the development or revision of CWSSIPs or be developed during project-level CRAs. For this assignment, the consultant has carried out detailed CRAs only in Tana River and Murang'a Counties, enabling the mapping of exposure levels

for each major hazard relevant to these areas. These spatially explicit exposure maps made it possible to classify exposure levels by location, including for specific project sites listed in the CWSSIPs, this is what can be seen in the below maps and an extract of the project exposure scores calculated per hazard.

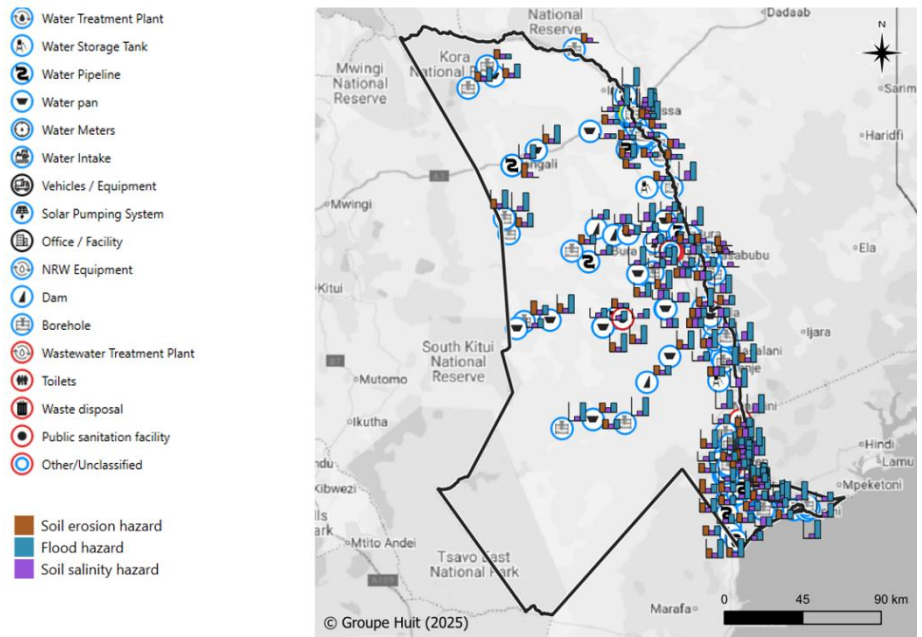


Figure 10: Tana River CWSSIP proposed investments hazard exposure map

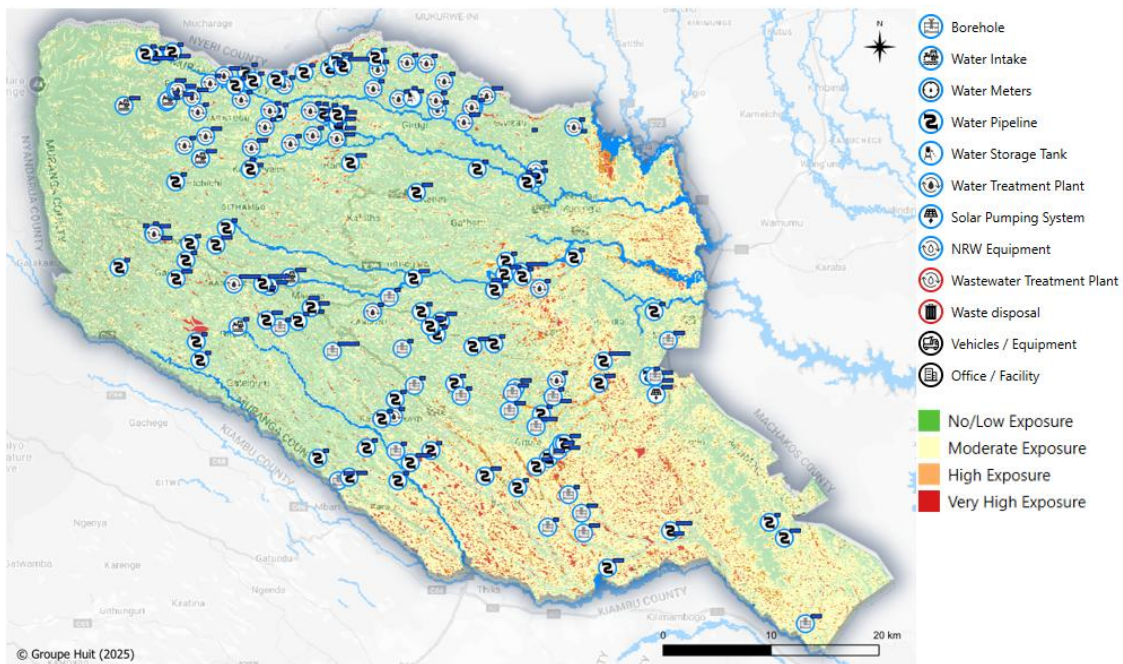


Figure 11: Pluvial and river flooding hazard exposures for proposed investments/ projects in Murang'a County

Table 2: Extract of the hazard exposure scores of some Murang'a proposed investments / projects

Project Description	Type of Network	Works Category	Source	Pluvial Flood Hazard (1-4)	River Flood Hazard (YES/NO)	Flood Hazard (1-4)	Landslide Hazard (1-4)	Erosion Hazard (1-4)	Soil Salinity Hazard (1-4)	Final exposure level
Yakerengo Nyakianga Mainline Water Project -Laying of water distribution pipelines, installation of plastic mold water storage tanks	Water Supply	Water Pipeline	County	1	NO	1	4	1	2	4.00
Bore-Kiahuti-Kinyona W/P-Laying of Gravity water distribution pipeline	Water Supply	Water Pipeline	County	1	NO	1	4	1	1	3.57
Yakarengo-Gitugi W/P 2-Laying of a water mainline 225 mm diameter	Water Supply	Water Pipeline	County	1	NO	1	4	1	2	3.57

3.4 WASH vulnerability

3.4.1 WASH technologies in Kenya

There are numerous technologies in the WASH sector, covering water resource management to sanitation (user interface, storage, collection, treatment, reuse, etc.) passing by water supply (intake, conveying, treatment, household connections, etc.) and hygiene. It can therefore be very extensive to go into all the details. Some compendiums have been developed to provide a comprehensive picture as shown in box 1.

Box.1 WASH-related compendiums

Compendium of accessible WASH technologies, Hazel Jones and Jane Wilbur (2014) – [clickable link](#)

Compendium of Water Supply Technologies in Emergencies, The Global WASH Cluster – [clickable link](#)

Compendium of Sanitation Systems and Technologies, Eawag (2nd revised edition) – [clickable link](#)

Under this assignment only the most used technologies and the ones that are most suited to the Kenyan context (also considering the diversity of Kenyan Counties) will be explored. By context, the following is understood:

- Materials locally available
- Capacity to implement (technical and financial)
- Capacity to support O&M (technical and financial)
- Acceptability from the communities and users, which is related to WASH practices.

In this regard, the specific constitutive components of WASH systems are discussed in the following sections of the report.

WASH sector	Constitutive items of WASH systems
Water Supply	<ul style="list-style-type: none"> • Boreholes • Water intake • Water mains • Water pipes • Water storage • Water Treatment Plant • Solar pumping system • NRW Equipment
Sanitation	<ul style="list-style-type: none"> • Wastewater Treatment Plant • Waste disposal • Vehicles (vacuum trucks) / Equipment
Drainage & Water resource management	<ul style="list-style-type: none"> • Water pan • Dam
Others	<ul style="list-style-type: none"> • Office / Facility

3.4.2 Main findings on WASH systems climate vulnerability

A broad overview of WASH sector vulnerabilities to climate change is presented in Annex 2, offering different perspectives on how hazards affect WASH systems. While Annex 2 takes hazards as the starting point, **this section adopts the Constitutive items of WASH systems defined above as entry points in order to better identify and target adaptation options.**

The tables below highlight a set of key vulnerabilities across WASH system components and are structured to remain anchored in the Kenyan context, drawing on evidence from hotspot analyses conducted in Murang'a and Tana River counties.

3.4.2.1 Climate Vulnerabilities Affecting Water Supply Systems

System impacted	Vulnerability Identified	Description	Evidence Observed From
Water sources (boreholes, shallow wells, springs, river abstraction points, water pans)	Insufficient water yield / unreliable supply. Surface water resources drying up during drought	Boreholes, wells, springs, water pans, and river abstraction systems fail to supply enough water due to drying up, shallow construction, low recharge, or overuse. Includes intermittent piped water supply and rationing in towns.	Mkomani (Tana River), Bura (Tana River), Minjilla (Tana River), Gatanga (Murang'a), Kandara (Murang'a), Wolestokocha (Tana River), , Odole (Tana River), Maragua (Murang'a – seasonal shallow wells)
Intake reservoirs / river abstraction points	Soil erosion & siltation	Upstream agricultural practices accelerate erosion, increasing siltation which reduces reservoir capacity and affects water abstraction.	Irate River intake (Kangema, Murang'a)

System impacted	Vulnerability Identified	Description	Evidence Observed From
Groundwater abstraction (boreholes, wells)	High salinity levels	Groundwater becomes saline during drought or due to seawater intrusion, making water unsuitable for domestic use; pumps corrode due to salinity.	Mkomani (Tana River), Bura (Tana River), Odole (Tana River)
Rivers and surface water	Unsafe river water	River water becomes turbid, contaminated, or unsafe due to floods, pollution, upstream activities, or siltation.	Mkomani (Tana River), Odole (Tana River), Murang'a South (Murang'a)
Access to river water	Human-wildlife conflict at water points	Community members are exposed to attacks from crocodiles and hippos when collecting water; conflicts also occur during drought when people and wildlife compete for limited water.	Mkomani (Tana River), Minjilla (Tana River), Madogo (Tana River)
Water distribution pipelines and fittings	Frequent vandalism and theft	Pipelines, solar panels, valves, and meters vandalized for scrap or to divert water, causing prolonged outages and costly repairs.	Bura (Tana River), Madogo (Tana River), Kandara (Murang'a – meter tampering)
Water supply treatment systems	Declining/inadequate water treatment	Treated water output reduces, or treatment is bypassed, resulting in unsafe piped water.	Bura (Tana River), Murang'a South (Murang'a)
Water infrastructure (wells, boreholes, pans, pipelines)	Damage from floods	Flooding submerges and contaminates water points, washes away pipes, and renders systems non-functional.	Minjilla (Tana River), Odole (Tana River), Madogo (Tana River), Murang'a South (Murang'a – flood-related damage)
	Landslide and slope-failure damage	Landslides, rockfalls and unstable slopes destroy or expose pipelines and intake systems, causing supply interruptions, emergency repairs and high maintenance costs.	Irate River intake (Kangema, Murang'a); Kiarathe (Murang'a); Gatamathi/Gitugi (Murang'a); Kiawambeu intak
Water pans and community reservoirs	Siltation / poor siting	Pans fill with silt after rains or due to erosion, reducing their storage capacity and	Wolestokocha (Tana River), Mkomani (Tana River), Murang'a South

System impacted	Vulnerability Identified	Description	Evidence Observed From
		usefulness. This can also be due to poor siting	(Murang'a – silted small reservoirs)
Water access and collection	Long distances to fetch water	Women, girls and elderly walk long distances due to non-functional or distant water points, causing physical strain and safety risks.	Mkomani (Tana River), Wolestokocha (Tana River), Bura (Tana River), Minjilla (Tana River), Kandara (Murang'a)
Community water points (shallow wells, pans)	Water contamination from surface runoff, animal waste, algae growth	Unprotected shallow wells and pans are contaminated by animals, flooding, algae, silt, and lack of fencing.	Wolestokocha (Tana River), Odole (Tana River), Murang'a South (Murang'a)
Water for consumption	Disease outbreaks linked to unsafe water	Consumption of contaminated water leads to cholera, diarrhea, typhoid, ulcers, bilharzia, Mara Mara, HBP, etc.	Bura (Tana River), Minjilla (Tana River), Wolestokocha (Tana River), Odole (Tana River), Madogo (Tana River), Murang'a South (Murang'a)
Water kiosks and vendor markets	High water tariffs / unaffordable water	High cost for households due to shortages; vendors charge significantly above kiosk rates.	Bura (Tana River), Minjilla (Tana River), Madogo (Tana River), Kandara (Murang'a)
Water project governance	Stalled or incomplete water projects	Community boreholes or water systems remain unfinished due to contractor issues, funding gaps, or administrative delays.	Mkomani (Tana River), Gatanga (Murang'a – incomplete community water schemes)

3.4.2.2 Vulnerabilities Affecting Sanitation

System Impacted	Vulnerability Identified	Description	Evidence Observed From
Household sanitation (pit latrines)	High open defecation levels	Absence or inadequacy of latrines results in widespread open defecation, contaminating water sources and increasing disease risk.	Wolestokocha (Tana River), Minjilla (Tana River), Madogo (Tana River), Parts of Murang'a South (Murang'a)
Latrine structures (pit latrines, VIP latrines)	Latrine collapse during floods	Floods weaken soil structures and inundate pits, leading to collapse, contamination, and unsafe conditions.	Minjilla (Tana River), Madogo (Tana River), Murang'a South (Murang'a)

System Impacted	Vulnerability Identified	Description	Evidence Observed From
Sanitation systems in flood-prone areas	Flood-induced contamination	Floodwaters submerge latrines and carry fecal waste into living areas and water sources.	Minjilla (Tana River), Madogo (Tana River), Murang'a South (Murang'a)
Pit latrines and septic tanks	Overflow and collapse	Septic tanks overflow and cause contamination, pit latrines induce groundwater contamination, pit latrines tend to collapse during of after flooding episodes	Minjilla (Tana River), Kandara (Murang'a)
Septic tanks emptying vacuum trucks	Limited access during floods, landslides, and dense settlements	Roads blocked by floodwater, debris, or landslides prevent vacuum trucks from reaching septic tanks; narrow urban roads further restrict access. Equipment also deteriorates faster under high temperature, humidity, or salinity conditions.	Not discussed during field assessments
Hand pumps/manual emptying	Unsafe emptying practices	Residents empty pits into the environment.	Minjilla (Tana River), Kandara (Murang'a)
Solid waste management systems	Improper waste disposal	Waste—especially diapers—is dumped openly, leading to pollution and runoff contamination during rains.	Minjilla (Tana River), Murang'a South (Murang'a)
Settlement layout / access roads	Limited exhauster access to latrines	Narrow roads and dense settlements limit access for sludge-emptying trucks, leading to prolonged use of full pits.	Minjilla (Tana River), Kandara (Murang'a)
Hygiene practices	Inadequate hygiene due to water scarcity	Water shortages prevent regular washing, cleaning, and latrine maintenance, contributing to disease spread.	Bura (Tana River), Minjilla (Tana River), Madogo (Tana River), Murang'a South (Murang'a)
Public health conditions	Disease outbreaks linked to poor sanitation	Cholera, diarrhea, typhoid, Mara Mara, stomach ulcers, bilharzia, and other outbreaks caused by poor sanitation and contaminated water.	Bura (Tana River), Wolestokocha (Tana River), Minjilla (Tana River), Madogo (Tana River), Murang'a South (Murang'a)
Household and community safety	Safety risks during open defecation (snakes, wildlife, insecurity)	Open defecation areas expose residents to snakebites and insecurity, particularly at night.	Minjilla (Tana River), Murang'a South (Murang'a – wildlife-prone areas)
Health infrastructure	Insufficient health facilities to manage sanitation-related outbreaks	Limited or distant health facilities hinder response to outbreaks caused by poor sanitation.	Wolestokocha (Tana River), Odole (Tana River), Murang'a South (Murang'a)

Drainage & Water resource management

System impacted	Vulnerability identified	Description	Evidence observed from
Surface Water Resources (Rivers)	Overexploitation/competition for the resource	Intensive water abstraction by large companies (such as Delmonte and Kakuzi) during drought periods leads to critical water levels in rivers (such as the Thika River), requiring regulation of allocation.	Rubiro Area (Murang'a), Kwa Mukudi, Ithanga Ward (Murang'a)
Water Pans	Siltation	Upstream agricultural practices accelerate soil erosion, causing siltation and reducing the capacity of water pans, intake reservoirs, and rivers.	Irate River intake (Murang'a); Wolestokocha (Tana River)
	Contamination	Waterpans located in areas with high levels of open defecation, which leads to contamination of water pan sources by fecal matter, especially during the rainy season.	Wolestokocha (Tana River)
Drainage Networks (which can be combined with sewers)	Structural damage and spillages due to flooding	Heavy floods frequently damage sewer pipes, channels (open or closed), and sanitation infrastructure, causing wastewater leaks into rivers and the environment. In addition, toilet bases collapse or sink when flooded.	Kimamo Area (Murang'a); Maragua Town (Murang'a); Rubiro Area, Ithanga (Murang'a)
Water Resources (Rivers/Coastal Areas)	Saltwater intrusion	The drop in water levels of the Tana River during the dry season leads to seawater intrusion caused by tides, contaminating river water and shallow wells, making them unsuitable for consumption and agriculture.	Odole, Kipini West (Tana River)
Surface Water Resources (Quality)	Pollution from effluents and turbidity	Floods and leaks from damaged sewer networks (caused by flooding) pollute rivers with wastewater and increase turbidity. Effluents from upstream coffee plantations can also discolor treated water.	Kimamo Area (River Gathamba, Murang'a); Kwa Mukudi (effluents from coffee plantations); Kiawambeu, Fort Treatment Plant (high turbidity and salinity); Mkomani village (Tana River water often turbid)
Water Resources (Flow Management) (Dam)	External regulation of flows	River flows are influenced by regulation or releases from upstream dams (such as the Maragua Dam or the Masinga Dam), affecting the reliability of downstream water supply.	Irate River intake (Murang'a); Bura (Tana River)

4. ADAPTATION OPTIONS

4.1 Global good practices

There are multiple ways to adapt infrastructures to hazards, the global good practices are listed below and enable to get a checklist of what should be thought of when trying to adapt WASH infrastructures to different kinds of hazards. Such checklist can be used for all types of investments to get a global screening, specific considerations per WASH system and components are developed in section 4.3 below.

- Avoiding exposure to hazards
 - ▶ Raising
 - Raising the technology or critical components so they are less likely to come into contact with floodwater/groundwater.
 - ▶ Burying
 - Installing the technology or its components underground so that they are less likely to come into contact with wind pressure, fire, or force of flooding.
 - ▶ Portability
 - The ability of the technology to be easily moved to a new location to avoid exposure to a disturbance (Conversely, portability can also enable the technology to be easily deployed to emergency contexts).
 - ▶ No/low Inputs
 - Technologies that require little or no external inputs (e.g. electricity, fuel, water, continuous human operators) to operate, thus reducing the need for inputs that could be exposed to disturbances and the dependence on systems that are vulnerable to disruption during floods, droughts, extreme heat, landslide or other disasters.
- Withstanding exposure to hazards
 - ▶ Armouring and Strengthening
 - Hardening or stiffening the technology or its components against an expected force.
 - ▶ Oversizing
 - Increasing the tolerance or capacity of the technology or its component so that it can accommodate extreme conditions, projected changes in conditions, or changes in number of users."
 - ▶ Shapes that distribute pressure
 - The shape of the technology creates more uniform distribution of stress over its cross-section, thus reducing the risk of failure at weaker points.
 - ▶ Circumvention
 - Technology materials or designs that allow wind or water to pass through so that the stress on the technology or component is reduced.
 - ▶ Sealing and Barriers
 - Integrating seals, barriers or other forms of protection into the technology to protect critical components or processes from being disrupted by a hazard.
- Enabling flexibility
 - ▶ Adaptability
 - The technology design can be adapted or upgraded easily to function better under the changing environmental conditions (e.g. increasingly wet or increasingly dry conditions).
 - ▶ Modular design

- Additional modules can be added (plug-in type model) or removed to increase or decrease capacity of the system to accommodate variability in demand and environmental conditions.
 - ▶ Platform design
 - The technology shares components with other similar technologies, which makes it easier to transition between technologies to suit customer demand or prevailing environmental conditions.
 - ▶ Redundancy and diversity
 - The technology has redundant components that work in parallel, or that act as back-ups to each other, so that if a component(s) fails, the back-up component can take its place and allow the technology to continue functioning. Diversity entails that the redundant / back-up components can perform the same function, but in a different way.
 - ▶ 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.
- Containing failures
 - ▶ Frangibility
 - Less essential components of the technology are designed to breakaway or fail when exposed to a certain level of pressure to protect more essential components of the technology.
 - ▶ Fail-operational
 - The technology can still provide its overall function even when components or processes are damaged/compromised and undergoing repair.
 - ▶ Decentralisation
 - Failures in decentralised systems (small-scale individual or clustered systems) are isolated locally which prevents failures from cascading and causing outages to many users/households.
- Limiting consequences of complete failure
 - ▶ Safe disposal
 - The materials from the destroyed technology are not toxic to the environment or public health and can be safely disposed.
 - ▶ Reusable materials
 - The materials from the destroyed technology can be reused for other purposes (including rebuilding the technology).
 - ▶ Fail-silence
 - The technology stops operating if a critical failure is detected, this can for example prevent the release of human waste into the environment.
- Facilitating fast recovery
 - ▶ Repair speed
 - The technology, its components, processes, or its operations can be quickly replaced, rebuilt or restored if destroyed or disrupted so that performance downtime or degradation is minimised.
 - ▶ Accessibility for rapid flaw detection
 - Components or processes of the technology can be easily accessed for examination.
- Climate adaptation can also be improved through strengthening systems' robustness and reducing cascading climate impacts.
 - ▶ Reciprocity

- By providing its service, the technology produces outputs that build resilience in, or aid, another on-site or off-site system.
- ▶ Hybridising
 - Unrelated systems or technologies share the same physical space or structure, thus saving space and enhancing opportunities for reciprocity.
- ▶ Transformative capacity
 - The technology provides an additional service(s) beyond its usual intent that further aids resilient communities.

4.2 Cross-Cutting social considerations

In addition to good global practices related to design, it is essential to consider cross-cutting social measures. These aspects will be further developed in the Gender and Vulnerable People Assessment Report and the related Gender Action Plan. However, the main considerations to keep in mind include the following:

- Physical Accessibility
 - ▶ Proximity and distance from users
 - ▶ Safe and convenient access routes
 - ▶ Inclusive design features (ramps, handrails, door widths, tactile paving, etc.)
 - ▶ Adequate lighting and signage for all users
- Affordability
 - ▶ Services and facilities should remain accessible to low-income users
 - ▶ Transparent and fair fee structures, if applicable
- Safety and Security
 - ▶ Well-lit and monitored areas, particularly for women and children
 - ▶ Clear evacuation routes and accessible emergency exits
 - ▶ Measures to prevent harassment or violence
- Dignity and Comfort
 - ▶ Cleanliness and regular maintenance
 - ▶ Privacy in use of facilities (e.g., separate and lockable spaces)
 - ▶ Respectful and non-discriminatory service delivery
- Consideration of Diverse Needs
 - ▶ Menstrual hygiene management and adequate disposal facilities
 - ▶ Facilities suitable for children (e.g., lower sinks, child-friendly toilets, safe play areas)
 - ▶ Accessibility for older persons and persons with disabilities (e.g., seating areas, non-slip surfaces)
- Space for caregivers accompanying dependents
 - ▶ Community Participation and Awareness
 - ▶ Engagement of local communities, including women, youth, and marginalized groups, in planning and feedback processes
 - ▶ Awareness and training programs to promote inclusive and respectful use of facilities

4.3 Adaptation options by WASH component

The following paragraphs present the main adaptation options for WASH systems in Kenya, structured around their key components and the primary climate hazards affecting the sector: floods, droughts, erosion and landslides, heat extremes, and salinity.

It is important to note that, although the discussion explores adaptation measures for each component individually, project development should take a holistic view of the system. Accordingly, some measures may need to be integrated or adapted depending on the project’s specific objectives. Examples of how this integration can be achieved are provided in Section 6.

WASH sector	Constitutive items of WASH systems
Water Supply	<ul style="list-style-type: none"> • Boreholes • Water intake • Water mains • Water pipes • Water storage • Water Treatment Plant • Solar pumping system • NRW Equipment
Sanitation	<ul style="list-style-type: none"> • Wastewater Treatment Plant • Waste disposal • Vehicles (vacuum trucks) / Equipment
Drainage & Water resource management	<ul style="list-style-type: none"> • Water pan • Dam
Others	<ul style="list-style-type: none"> • Office / Facility

4.3.1 Water supply systems

4.3.1.1 Water sources

4.3.1.1.1 Use of diversified sources for water supply systems

Use of diversified sources for one water supply system is a climate risk adaptation measure that reduces dependence on one source and enhances the resilience of the system against climate hazards such as floods, droughts, and landslides, ensuring that water supply is maintained even if one source is disrupted. Examples of diversified sources include:

- Mix of borehole sources and a river intake
- Borehole sources and a water pan
- A river intake with reservoir for additional storage
- Rainwater harvesting (gutters, tarpaulin)

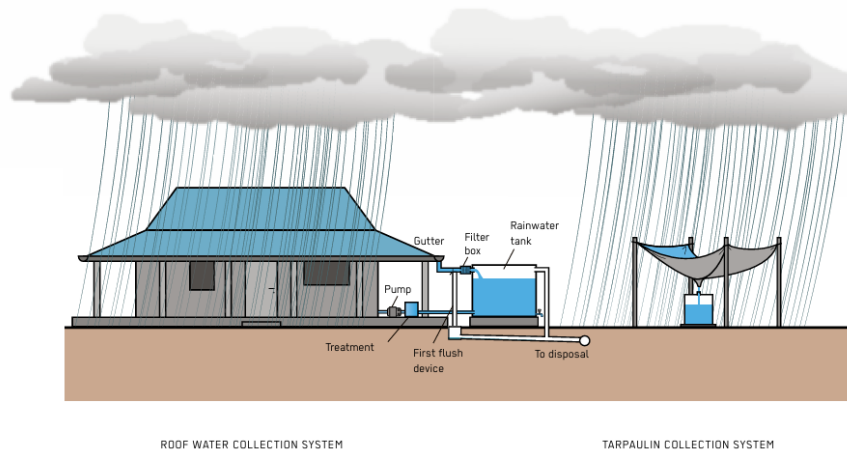


Figure 12: Rainwater harvesting systems

Salt-resistant materials and salinity monitoring

Salinity intrusion and poor water quality present growing challenges for all water supply systems, particularly in coastal and delta regions where over-abstraction and sea-level rise accelerate saline groundwater intrusion. To maintain potable supply, **salt-resistant materials such as uPVC and epoxy-coated metals** should be used in pipelines, borehole casings, and storage tanks to prevent corrosion and leakage. Where feasible, blending saline and fresh water sources can help meet drinking water standards while optimizing limited freshwater availability. The installation of small-scale desalination units, particularly solar-powered systems for kiosks, schools, and health centers, offers a decentralized and climate-resilient solution for communities in saline-affected areas. **Continuous salinity monitoring** of boreholes and surface intakes is also essential to detect changes in water quality early and guide adaptive management of groundwater abstraction and treatment processes.

4.3.1.2 Boreholes and shallow wells

4.3.1.2.1 Boreholes (BH) headworks with elevated concrete floodproof chambers

Most groundwater aquifers in the country are located along river valleys. Thus, many borehole water sources are located in river valleys that are prone to flooding, and exposed to the risk of being flooded or washed away.

To overcome this risk, the boreholes in flood prone areas are designed with their well heads covered in flood proof concrete chambers that are elevated above the flood levels. This ensures the borehole well head fittings and sundries are protected from flood water which could cause damage or malfunction.



Figure 13: Borehole head with elevated concrete chamber

Handpumps for boreholes or shallow wells can also be elevated above flood levels to protect the infrastructure.



Figure 14: Elevated hand pump in Tana River

4.3.1.2.2 Shallow wells

A Protected Dug Well is a large-diameter structure dug by hand that is lined and covered and allows for water abstraction using a pump. Protected Dug Wells are normally around 20 metres deep, although some traditional hand-dug wells are much deeper.

Such shallow wells should see their cover elevated above flood level with accessibility via a ramp or stairs (see picture above) to ensure accessibility and limit risks of flood water infiltration and contamination of the water from the well.

Attention to the lining material should particularly be considered in saline areas and the siting of the well should be far enough from sanitation facilities to avoid any kind of contamination.

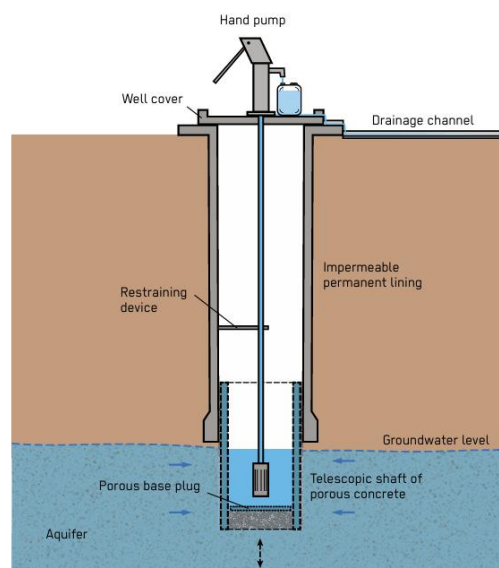


Figure 15: Shallow well scheme

4.3.1.3 Water intake

4.3.1.3.1 River intakes with adjustable intake levels

As rainfall patterns in many areas in the country become more erratic, adjustable intakes on rivers may provide climate resilience to water supplies by ensuring a reliable supply regardless of fluctuating river levels. The adjustable intakes allow utilities to draw water from different depths in a river depending on the flow conditions.

An example is the use of floating pontoons on a river or lake intake, which raises and lowers the level of the intake depending on the level of water flowing the in the river/lake.

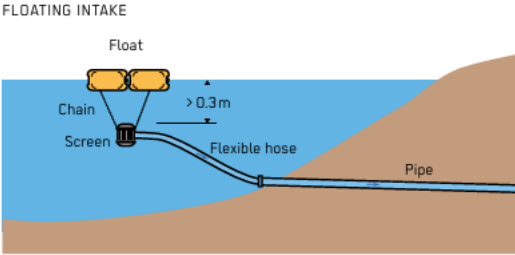


Figure 16: Floating intake scheme

Draw off systems for water supplies using water pans could also be designed with adjustable intake levels to ensure the intake avoids being submerged when the pan fills up, which could lead to failure or draw off of water with sediment or debris.

4.3.1.3.2 Stone and vegetative protections

Riverbanks and intake zones can be safeguarded through gabions, stone pitching, and vegetative reinforcement, which reduce undercutting and protect structures from scouring during high flows. Terracing and vegetation cover around reservoirs and storage tanks also help stabilize surrounding slopes and limit sediment inflow, thereby extending operational life and reducing turbidity challenges at treatment plants.

Vegetated reinforced gabion wall is a good compromise between strength and environmental aspect.

Vegetated gabions are rectangular basket made of heavily galvanized steel or another durable, corrosion resistant wire mesh, filled with stones. Gabions can be reinforced with geotextiles and filled with earth.

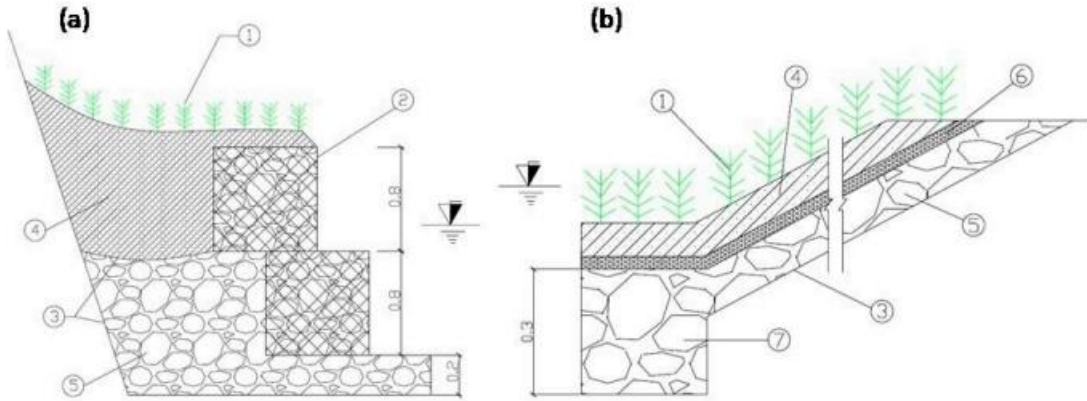


Figure 3. Schematic design of: (a) gabion revetment structure; and (b) riprap revetment structure (1. Vetiver plants; 2. gabion; 3. geotextile; 4. fill soil; 5. limestone; 6. gravel; and 7. base structure).

Figure 17 : Examples of gabion, stone pitching and vegetative reinforcement

Source: An Investigation on Performance and Structure of Ecological Revetment in a Sub-Tropical Area: A Case Study on Cuatien River, Vinh City, Vietnam ; *Water* 2018, 10(5), 636; <https://doi.org/10.3390/w10050636>

Protection can also be ensured thanks to screens and boulders as shown in the scheme below.

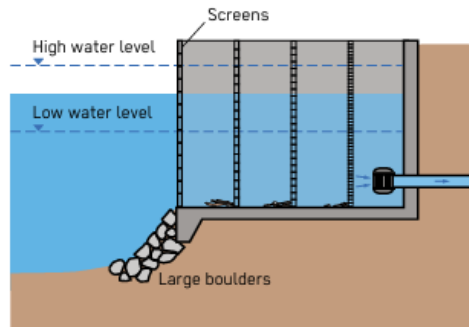


Figure 18: Protected water intake (screens and boulder)

4.3.1.4 Water mains & Water pipes

4.3.1.4.1 Deep buried pipelines

Water supply pipelines in flooding areas can be buried much deeper than normal to protect them from being washed away. In areas prone to heat waves, burying the pipelines deeper could help in temperature regulation. This technology applies to pipelines of all types of material, including steel, GI, DI, HDPE and uPVC. The depth of installation should however be carefully selected depending on the pipe material since some pipe materials such as uPVC may not withstand the high soil overburden pressure if buried too deep.

4.3.1.4.2 Use of HDPE pipes in flooding areas

High Density Polyethylene (HDPE) pipes are constructed using either electro-fusion or butt-fusion joints which are continuous and better at preventing ingress of stormwater in case of flooding hazard.

The joints are also robust and not easily broken, which would make the pipelines better able to cope with flood water and not be easily washed away. The HDPE pipes can also withstand higher overburden pressure when buried deeper to prevent them from erosion by flood water.

4.3.1.5 Water storage

4.3.1.5.1 Use of modular water storage tanks

Modular water storage tanks provide distinct advantages for installation in climate risk prone areas:

- Modular tanks can be expanded or downsized to meet changing storage needs, depending on the storage requirements;
- Panels can be installed in smaller sizes at different locations within the water supply area, creating distributed water reserves that reduce vulnerability to climate hazards;
- After climate disasters (such as floods, droughts and landslides), modular tanks can be easily transported and assembled on-site, providing emergency water storage where it's most needed;
- Tank panels damaged by climate hazards can be replaced, without need for replacing the entire tank;
- Communities can gradually increase capacity as drought risks worsen, instead of replacing tanks entirely.

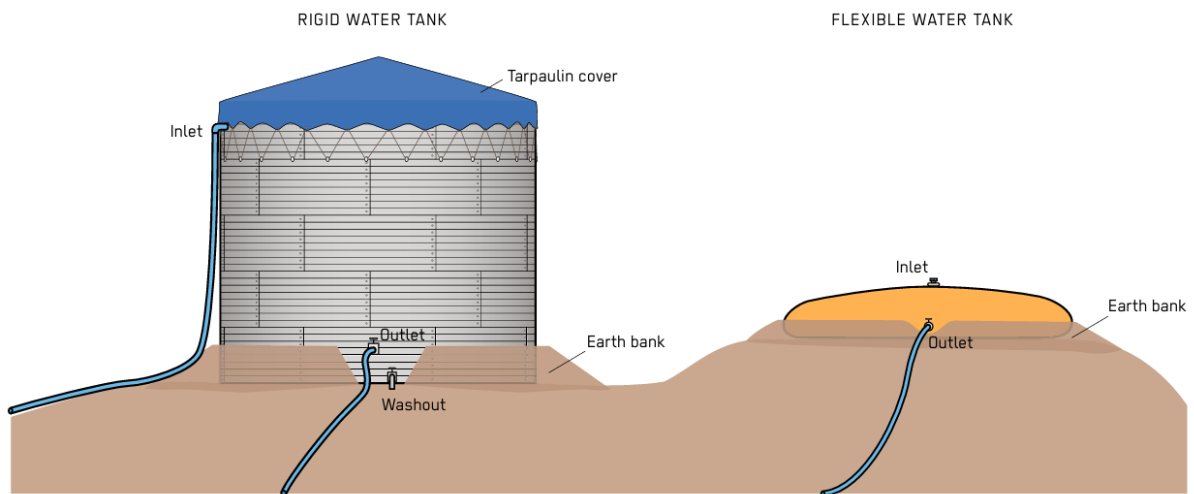


Figure 19: Scheme of water storage tanks



Figure 20: Example of modular water storage system (Photos from iWater company)



Figure 21: Flexible tank for water storage

4.3.1.5.2 Water kiosks with ATMs for low-income communities.

The following adaptation measures could be considered when designing and implementing water kiosks in climate hazard areas:

- Installing water kiosks on raised platforms above flood levels;
- Incorporate adequate stormwater channels around the water kiosk;
- Incorporate an overhead plastic water storage tank for emergency storage in case there is interruption to supply due to flooding;
- Incorporate green spaces at the water kiosk for temperature regulation and to provide shades for water kiosk users and operators;
- Incorporate a roof covering for the overhead water tank for regulation of temperatures inside the tank.



Figure 22: Picture of a water kiosk

In addition to these measures, implementing ATMs at water kiosks could be most relevant in some areas for low-income communities.

This within the limits and precautions of not becoming dependent on a banking system.

Indeed, water kiosks with ATMs can be an adaptation mechanism for water supply to communities in water scarce and drought prone areas. The advantage of using water kiosks with ATMs include:

- They dispense water based on the amount that residents are able to pay, thus enabling water access;
- When properly implemented, they can help to avoid wastage or misuse of the water;
- Small affordable payments collected through a customer's water card at the kiosk ensures that the water solution is sustainable because money is easily available to the local water committee.

4.3.1.6 Water Treatment

4.3.1.6.1 Use of commercially available purifiers for water treatment

Currently the water treatments systems in Kenya are diverse and go from community based natural water purification methods such as use of local herbs e.g. Kukube herbs to advanced water treatment plants. In between multiple technologies are used as commercially available water purifiers.

Commercially available water purifiers such as WaterGuard, AquaGuard, Aqualum, PUR, Aquatab, etc., are commonly used by many communities in Kenya. These are chlorine compounds (Calcium hypochlorite or Sodium hypochlorite) which come either in liquid or powder form and can be added to the water to disinfect the water and make it safe for human consumption. They are sold in local shops and chemists but are also supplied freely by non-governmental organisations working within the local communities.



Figure 23 : Some of the locally available chemical water purifiers in Kenya

- They are disinfectants for treatment of contaminants such as coliforms, but may not provide treatment for increased turbidity in the water due to flooding or increased salinity due to sea water intrusion into water sources;
- Lack of adequate understanding on usage could lead to overdose or misuse which could have significant health effects on the communities;

The proposed climate change adaptations for this form of water treatment include the following:

- Combined use of chemical purifiers with natural plants additives to provide better water purification;
- Separating storage for treated water and untreated one (including harvested water) Mixing of chemically treated water with clean harvested water such as rain water from roofs to dilute the effect of the chemicals.

4.3.1.6.2 Water Purification through locally available natural herbs

This kind of water treatment is commonly used by different communities for purification of their domestic water. The highly turbid water collected from rivers and water pans is placed in a jerry can in which the selected natural herbs (either their extracted roots, leaves, barks, stems or seeds) are added and left to stay for a while. For instance the Kukube tree seeds are used in some areas of Kenya (for instance in Bura, Mkomani and Wolstokocha in Tana River County). The turbid water ends up being clear, with all the suspended solids settling at the bottom. While the decantation of the water can be verifiable by a simple physical inspection, **this method's treatment efficiency has not yet been confirmed by scientific research, and no studies have been undertaken to confirm if the water is adequately treated to achieve the required drinking water quality.**

The associated climate risks for this water treatment method include the following:

- Repeated droughts and heat waves in the affected areas may lead to reduced availability of these plants in the short-term, and a threat to the long-term survival of these plants' species among the communities;
- Increased salinity in the water due to sea water intrusion or contamination of water sources through flooding may have an impact on the plants' capacity to purify the water¹;
- Invasive species such as the *Prosopis juliflora* (or Mathenge plant) pose an existential threat to these plant species;
- Forced migration of the communities from their homes to safer areas due to flooding means the communities may not have easy access these beneficial plants;

¹ No studies have been undertaken at the moment, this is an hypothesis

- Increased soil salinity may limit the growth of the plants and pose a long-term threat to their survival.

Nevertheless, this method of water purification appears to be quite resilient to climate change considering its multiple benefits:

- Communities make use of locally available and naturally occurring resources;
- It requires little or no technical capacity for operation and maintenance and has no financial implications on the communities;
- It builds on local knowledge and can be passed on future generations for a long time;
- Studies have shown that some of these naturally occurring plants and herbs are very resilient and highly adaptive to climate change hazards such as droughts, floods and storms;

Acceptability from the communities and users should be high as this is based on local knowledge. Nevertheless, it can be anticipated that some communities would not trust such a natural process if it has not been used in their communities beforehand.

While such water treatment solutions could be seen as an adaptation option in itself, the following recommendations are necessary towards further improvements on the use of these methods:

- To assess the effectiveness of purification by use of these natural additives, especially with increased pollutants such as salinity from sea water intrusion and presence of coliforms due to flooding;
- To assess the viability of introducing such natural solutions in areas where communities do not use it as yet.

4.3.1.7 NRW Equipment

By reducing NRW, service operators not only improve overall water resources management (through lower physical losses, more efficient distribution, and increased revenue) but also strengthen climate resilience. Lower water losses reduce pressure on available water resources, thereby limiting the amplification of water scarcity during droughts and dry periods. At the same time, improved financial and operational performance enhances the institutional robustness of water service providers, increasing their capacity to anticipate, prepare for, and cope with climate change impacts, including slow-onset trends, increased climate variability, and extreme events. District metering areas (DMAs)

District Metering Areas (DMAs) are one of the most effective tools water utilities use to control Non-Revenue Water (NRW) and reduce wastage. Such improved NRW and wastage management can be achieved through the following:

- DMAs can be used to monitor inflows and consumption within a particular zone, making it easy to identify unusual water losses (through hidden leaks and bursts).
- Pressure and night-flow monitoring within a DMA can help to pinpoint underground leaks much faster than system-wide monitoring.
- DMAs make it easy to regulate and maintain optimal pressure per zone, reducing stress on pipes and minimizing water losses.
- DMAs allow utilities to track how much water is produced, delivered, billed, and lost in each zone. This improves accountability and helps prioritize maintenance where losses are highest.
- By comparing inflow to customer meter readings within a DMA, utilities can detect unauthorized connections, faulty meters, or under-registration of consumption.

The following adaptation measures could be considered for DMAs in climate hazard areas:

- Use of pipe materials that are resistant to corrosion due to sea water intrusion;
- Separate DMAs for areas with critical consumers (e.g., hospitals), allowing continuous supply even during times of scarcity;

- Equip DMAs with solar-powered data loggers and backup batteries, to withstand possible power interruptions during flooding and storms;
- DMAs planning, design and installation should be overlaid with flood risk maps, drought vulnerability zones and landslide hotspots, with early warning systems incorporated as appropriate.

4.3.1.7.1 Smart metering for bulk and individual water meters

Smart metering is the use of digital water meters that automatically record the consumption and transmit this data in real time to both the water service provider and the customer. The smart meters may be connected remotely through one of the available communication technologies (e.g., GSM, GPRS, LoRaWAN, NB IoT, Wi-Fi, or satellite) that allow two-way data exchange.

Smart meters are a necessary tool for water companies better manage the water resources and services:

- Smart metering improves water efficiency and demand management the most critical adaptation need during droughts or prolonged dry spells.
- By detecting leaks and illegal connections, it reduces non-revenue water (NRW), helping utilities maintain service continuity when supplies are limited.
- Prepaid or quota-based systems allow equitable allocation during water shortages episodes, reducing social tensions and ensuring minimum supply to all.

While smart metering can improve water management and thus adaptation, smart meters themselves are also vulnerable to hazards and need to be adapted themselves:

- Technical adaptations (elevated installations, waterproof chambers, remote reading) directly improve system resilience during floods, when access to meters or infrastructure is constrained.
- Flood-proofing of meter chambers and remote data transmission prevent service interruption and damage in inundated areas. Flood-proofing can be done through:
 - ▶ Strengthen sealing: waterproof sealant or tape.
 - ▶ Install drainage pipes around the meter box to timely drain accumulated water and prevent it from seeping into the meter box.
 - ▶ Regular maintenance to identify potential damages or poor waterproofing performance (aging sealant or tape, etc.)

4.3.2 Sanitation systems

4.3.2.1 Wastewater Treatment Plant

4.3.2.1.1 Constructed wetlands for enhanced effluent treatment before disposal into rivers

Constructed wetlands are nature-based adaptations that are very common with Decentralized Treatment Facilities (DTFs) in Kenya. They provide further treatment of the effluent before the water is discharged into rivers. Their key benefits in the treatment process include the following:

- Pathogen reduction in the effluent through removal of E. coli and other harmful microbes.
- Removal of nutrients such as nitrogen and phosphorus by being absorbed by plants and transformed by microbes.
- Further reduction of BOD and COD levels before discharge into the natural water courses.
- **They are resilient under fluctuating inflows, thus providing a buffer against flooding and water quality deterioration.**

4.3.2.1.2 Re-use of treated effluent for irrigation

Wastewater reuse represents a **practical and climate-resilient strategy** to alleviate water scarcity and enhance local greening in semi-arid and peri-urban areas. Properly treated effluent from decentralized or conventional wastewater treatment plants can be safely **reused for irrigation of public spaces, tree planting, and small-scale agriculture**, thereby reducing pressure on freshwater sources. In Tana River County, such reuse could support school or health-centre gardens and roadside vegetation, improving microclimates and community aesthetics. To ensure safety and sustainability, effluent quality must **comply with KEBS and WHO standards**, and simple treatment technologies such as **constructed wetlands, waste stabilization ponds, or biofiltration units** can be integrated into existing systems.

While wastewater reuse could serve as an effective and practical strategy to anticipate and mitigate future drought conditions, most effluents from **treatment systems in Kenya** currently **do not meet the National Environmental Management Authority (NEMA) discharge standards**, posing risks to both human health and the environment.² Consequently, large-scale implementation remains limited, and **the approach is still at a pilot and research stage**. Developing **demonstration projects** under upcoming WASH or climate adaptation initiatives, accompanied by **robust monitoring** frameworks, institutional coordination, and regulatory oversight, would provide valuable insights for **scaling up safe and sustainable wastewater reuse across the country**.

4.3.2.1.3 Adjust aeration systems and biological process monitoring

Operationally, aeration and process monitoring systems should be adjusted during heat waves to maintain treatment efficiency and effluent quality. Improved ventilation, shading, and odor control mechanisms should also be incorporated into the design of drying beds and sludge handling units. **Regular monitoring of temperature**-dependent parameters—such as chlorine decay, aeration efficiency, and biological oxygen demand—helps maintain treatment performance during heat waves.

4.3.2.1.4 Green buffers and ventilation systems

At the planning and management level, **green buffers, shading and ventilation systems** should be integrated into plant layouts to reduce ambient heat around critical equipment, particularly for sludge drying beds and aeration units.

4.3.2.2 Latrines

4.3.2.2.1 Low-flush or pour flush toilets in water scarce areas

In water scarce areas which are drought prone, water-borne sanitation systems should ensure minimum water usage, and thus ordinary flush toilets are not ideal. The proposed adaptation for these areas is to use pour flush toilets which ensure that households minimise water use per toilet flushing session. The toilets could also be designed with mini cisterns with highly effective flushing mechanisms.

4.3.2.2.2 Raised latrines above flooding levels

Ventilated improved pit latrines (VIPs) in flood prone areas should be constructed on raised platforms to ensure the pits are protected from filling with water during flooding periods. The height of elevation should be selected based the known highest flood mark in the areas or where this is not known, could be modelled for a 1–10-year flood level.

However, the design should include access ramps to make them disability friendly.

² Kilingo, Flory & Bernard, Zulu & Bin, Chen & Mkangombe, Kilingo. (2021). The Analysis of Wastewater Treatment System Efficiencies in Kenya: A Review Paper. International Journal of Scientific and Research Publications (IJSRP). 11. 204-215. 10.29322/IJSRP.11.05.2021.p11322.

4.3.2.2.3 Latrines with masonry lined and separated single or multiple pits

In areas which are prone to flooding or sea level rise, communities could design and implement **ventilated improved pit latrines (VIPs) with lined pits** which reduce the incidences of collapse when the soils become waterlogged. The pits are excavated to about 6-8m deep and the pit walls lined with plastered masonry work using waterproof cement. The technology ensures that the pits are waterproof and therefore do not allow ingress of water from the surrounding waterlogged areas.

To ensure further resilience, the lined pit is located a few feet away from the pit latrine structure so that the weight of the pit latrine structure does not rest on the pit directly below it. The lined pit is connected to the latrine via a wastewater pipe and the waste directed to the pit through pour flushing.

In case the cost of lining the pits becomes a hindrance, a further resilience mechanism could involve having more than one pit connected to the latrine so that in case one pit collapses, the other pit will ensure the latrine continues to operate normally.

The pit latrine floor slabs should also be raised above the flooding level to protect the pits from filling with water during flooding.

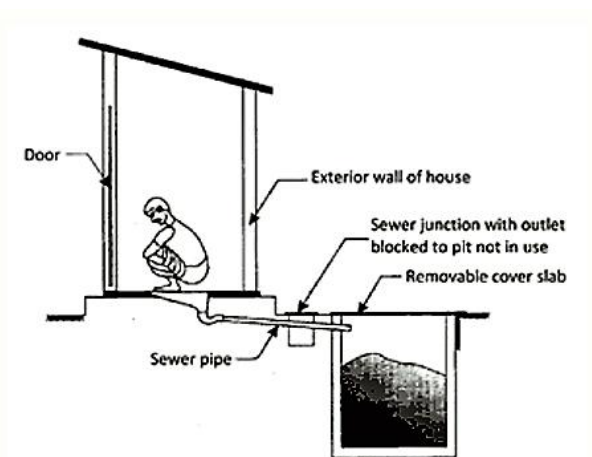


Figure 24: Schematic of a pit latrine with lined and separated multiple pits

4.3.2.2.4 Relocation and reinforced masonry

In erosion-prone and unstable areas, latrines and septic tanks should be carefully sited away from steep slopes, floodplains, and riverbanks to avoid collapse and contamination risks. Where relocation is not possible, pit foundations should be reinforced using masonry lining or concrete rings to enhance structural stability. These preventive measures ensure continuity of sanitation services during extreme weather while protecting groundwater quality from contamination due to pit failures.

4.3.2.3 Container based sanitation systems

Container Based Sanitation (CBS) systems can be adopted by households in climate hazard areas such as flooding and landside prone areas. CBS systems use sealable containers to collect excreta, which are then safely transported to waste treatment sites. The CBS systems have the following advantages:

- ▶ CBS toilets are located above ground, sealed, and portable, thus reducing cases of filling with flood water and causing contamination risks.
- ▶ They can either be waterless or low-water use systems, making them ideal where climate change reduces water availability.
- ▶ CBS units are compact and mobile, so they can be relocated if settlements are displaced by climate hazards such as flooding or landslides.
- ▶ In informal settlements where space is limited and climate hazards disrupt traditional infrastructure; CBS avoids the need for deep excavation and large sewer systems.

To be fully effective such CBS methods deeply rely on effective management of collecting and prevention from emptying container in the environment without treatment.

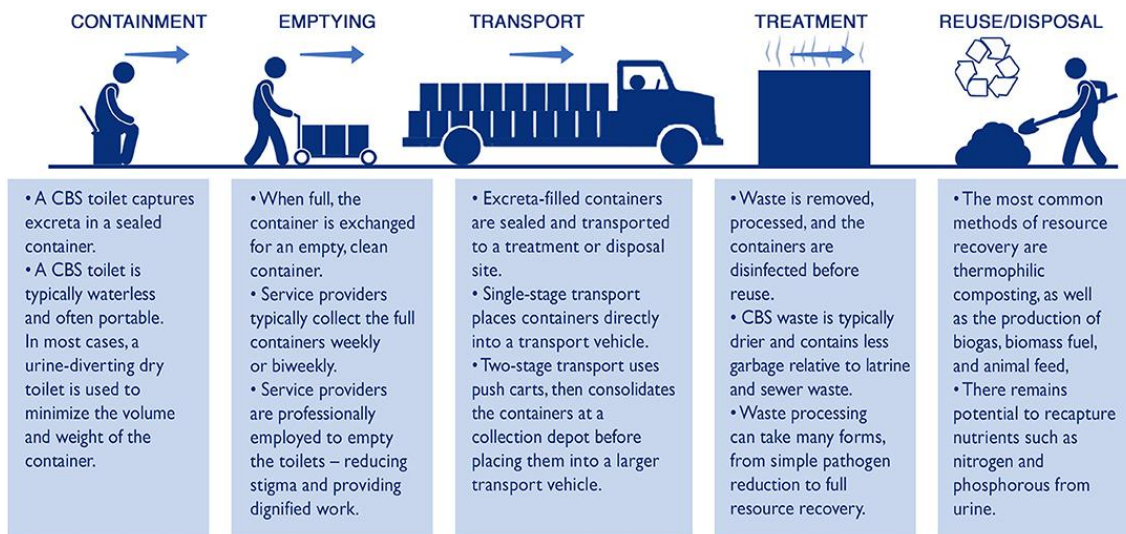


Figure 25: Container Based Sanitation scheme

4.3.2.4 Emerging sanitation technologies

In emergencies or when permanent sanitation facilities are unavailable, Peepoo bags could be used as a temporary solution. They are single-use bags with two layers: the inner layer, coated with urea to disinfect the feces, and the outer layer, which is tied shut after use. The bags are biodegradable and can be transported to a composting facility, where they break down into water, carbon dioxide, and biomass, contributing to the composting process. They remain odor-free for at least 24 hours, are safe to handle, lightweight, and can hold up to 800 mL of excreta. Peepoo bags are not intended to replace permanent sanitation technologies but are useful for people without access to facilities, including in emergency situations or when safety prevents access to toilets. This solution was piloted in Kibera, Nairobi, between 2012 and 2014.



Figure 26: Peepoo bag

4.3.2.5 Sludge emptying and transport

Apart from sewer pipes septic tanks can be emptied through 2 main methods (i) Vacuum trucks or (ii) Hand pumps and jerricans filling

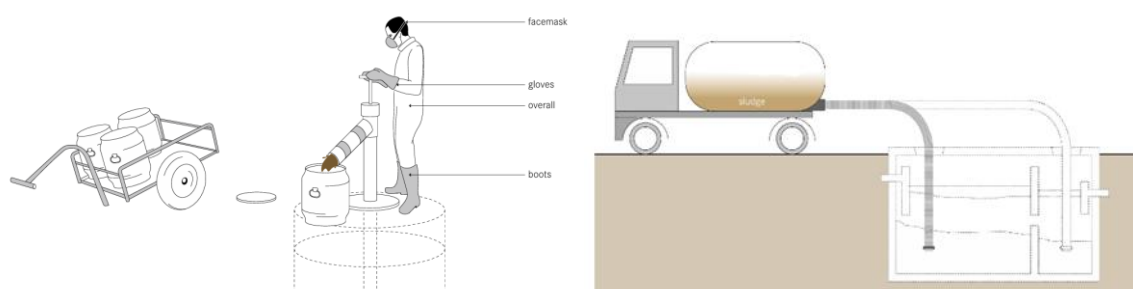


Figure 27: Illustration of emptying (left: manual ; right: using vacuum trucks)

To reduce their respective vulnerabilities the following adaptation measures can be considered:

- For vacuum trucks:
 - ▶ Parking, maintenance, and storage areas for trucks should be located outside flood-prone or landslide-risk zones to avoid damage during extreme events.
 - ▶ Fleet design should balance capacity and manoeuvrability, ensuring trucks can carry sufficient sludge to minimize multiple trips, while remaining compact enough to navigate narrow or debris-blocked roads in dense settlements or after extreme weather events.
 - ▶ Regular maintenance of vacuum trucks, including checks on engines, hoses, and hydraulic systems, improves reliability under heat, salinity, and humidity stress, while also reducing fuel consumption and emissions.
- For manual and jerrycan-based emptying:
 - ▶ Training operators on safe handling techniques.
 - ▶ Providing protective equipment.
 - ▶ Improving pit design (e.g., reinforced walls, access points above flood level) can reduce labor risks, improve efficiency, and limit contamination during adverse conditions.

For both it could be considered that planning for more frequent tank emptying is recommended in order to prevent overflow, reduce operational risks for trucks and manual emptiers, and protect public health during climate-related stresses.

4.3.2.6 Sewers salinity management

Salinity can significantly affect the performance and lifespan of sanitation systems by **corroding metallic components**, damaging concrete, and allowing **saline infiltration into sewers**.

Sewer networks and pumping stations should **incorporate corrosion-resistant materials**, such as **HDPE pipes** and protective coatings for metallic parts, to **extend service life and reduce maintenance costs**. Where wastewater treatment is practiced, operators should also **monitor salinity levels** in influent streams, as high salt concentrations can disrupt biological treatment processes and affect sludge stabilization.

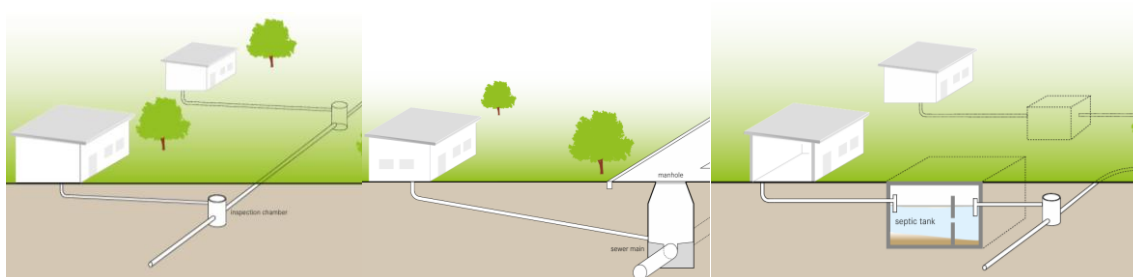


Figure 28: Illustration of sewer systems (left to right: simple, gravity, solid-free sewers)

4.3.3 Drainage & water resource management

4.3.3.1 Water pan

4.3.3.1.1 Water pans for rainwater harvesting

Households in water scarce areas can enhance resilience in water supply by constructing water pans or lined ponds for harvesting stormwater run-off during rain seasons and using the water during dry periods. The water pans can also be used for roof rainwater harvesting.

The water pans can be on small scale done by individual households or groups of households, or on a larger scale, constructed by government agencies or non-governmental actors.

Water from water pans can be used directly for watering animals and for irrigated agriculture or can be further treated for domestic consumption.

4.3.3.1.2 Silt traps on water pans inlets to control siltation

Water pans tend to fill up with sediment over time due to large volumes of silt deposited by inflowing stormwater. This challenge is attributed to soil erosion which is a climate hazard in many arid and semi-arid areas with little or vegetation cover.

To overcome this challenge, the water pans can be designed and constructed with a silt trap at the inlet section to ensure the sand and silt is deposited upstream before the water reaches the water pan.

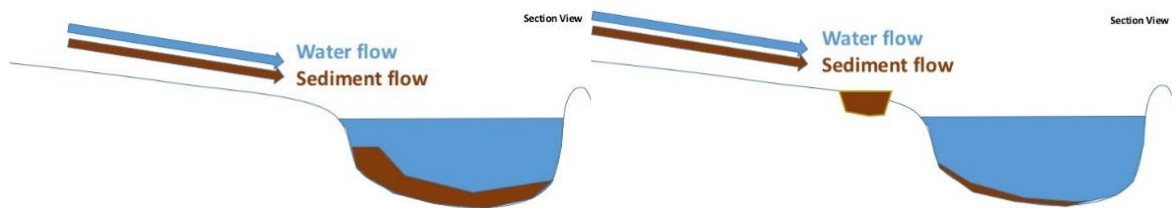


Figure 29: Silt trap mechanism, views without (left) and with (right) silt trap

Source: TreeYo

A nature-based adaptation for silt traps may be in form of a constructed wetland upstream of the water pan, that slows the flow of water stormwater, allowing the sand and silt to be deposited before the water reaches the water pan.

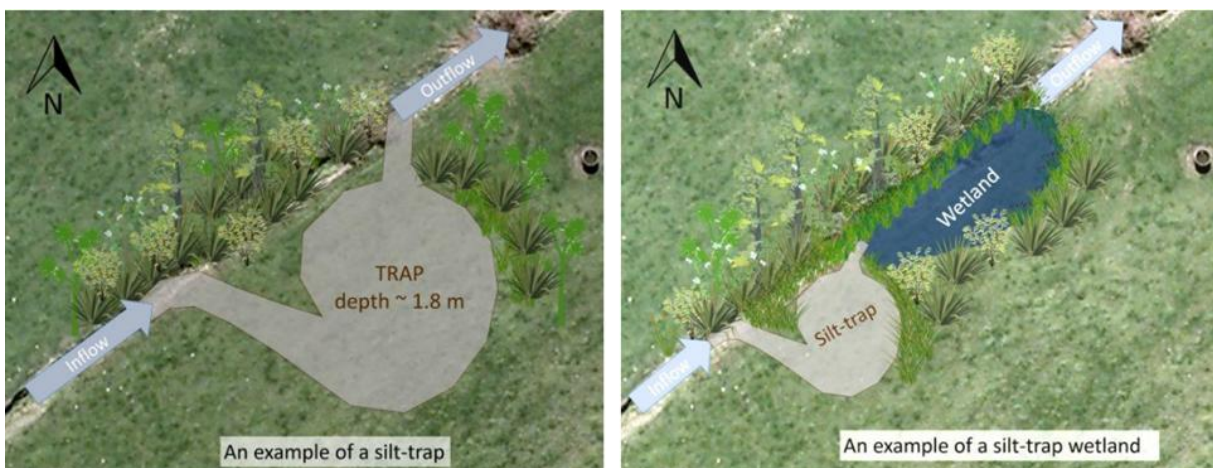


Figure 30: Example of wetland silt trap

4.3.3.2 Drainage & stormwater

4.3.3.2.1 Rehabilitation of existing drains with silt traps

Rehabilitation of existing drains with silt traps is a critical and cost-effective flood adaptation strategy for Kenya, where clogged and inefficient drainage systems frequently exacerbate urban and rural flooding.

In urban areas like Nairobi and Mombasa, where rapid urbanization and poor waste management often overwhelm drainage infrastructure, silt traps help maintain drain functionality, extend the lifespan of the system, and reduce maintenance costs.

In rural regions, these traps prevent soil erosion and agricultural runoff from clogging natural waterways, thereby protecting both farmland and downstream communities. Implementation can be achieved through community-led initiatives, leveraging local materials and labor to ensure affordability and sustainability.

For example, the Nairobi River Regeneration Project includes drain rehabilitation and silt management as key components, demonstrating how targeted interventions can restore drainage capacity and enhance urban resilience. By adopting this approach, Kenya can avoid the risks of infrastructure damage, waterborne diseases, and economic losses associated with recurrent floods, while also improving water quality and public health.

4.3.3.2.2 Green Corridors, Bioswales, and Permeable Surfaces

These nature-based solutions work by slowing, filtering, and infiltrating rainwater, reducing surface runoff and the strain on overburdened drainage systems.

In **urban areas** like Nairobi and Mombasa, where impermeable surfaces and inadequate infrastructure exacerbate flooding, **green corridors along rivers and roads**, combined with bioswales in public spaces, can restore natural water absorption, improve water quality, and enhance urban resilience.

In **rural regions**, **permeable surfaces and vegetated swales** help mitigate soil erosion and recharge groundwater, addressing both flood and drought vulnerabilities. Implementation can be achieved through partnerships with county governments, NGOs, and local communities, using indigenous plants and locally sourced materials to ensure cost-effectiveness and sustainability. By adopting these measures, Kenya can avoid the risks of infrastructure damage, waterborne diseases, and economic losses caused by recurrent floods, while also delivering co-benefits such as improved air quality, urban cooling, and biodiversity conservation.

Notably, the Nairobi River Regeneration Project already integrates elements of green infrastructure, such as rehabilitating riparian zones and improving stormwater management, demonstrating the feasibility and impact of these approaches.

- **Green Corridors:** Linear strips of vegetation (trees, shrubs, grasses) along waterways or roads, designed to slow, filter, and infiltrate stormwater.
- **Bioswales:** Shallow, vegetated channels that collect, slow, and filter runoff, removing pollutants and reducing flood risk.
- **Permeable Surfaces:** Pavements, roads, or open spaces made of materials (porous asphalt, permeable concrete, gravel) that allow water to seep into the ground, reducing surface runoff.

4.3.3.3 Water resource management

4.3.3.3.1 Managed aquifer recharge (MAR) and wetland restoration

MAR has been proven to produce a wealth of benefits from integrated management of a wide range of conventional and un-conventional water resources, paving the way for global adoption to achieve sustainable development goals for water

Managed aquifer recharge (MAR) technologies offer a powerful adaptation strategy to combat drought and water scarcity in Kenya, where erratic rainfall and prolonged dry spells increasingly threaten water security. By capturing and storing excess surface water—such as seasonal rains or treated wastewater—in underground aquifers, MAR systems act as natural reservoirs, buffering communities against water shortages during droughts. This approach not only replenishes depleted groundwater supplies but also protects against saltwater intrusion in coastal regions and minimizes evaporation losses compared to surface storage.

In Kenya's arid and semi-arid lands (ASALs), where groundwater is often the only reliable water source, MAR can be tailored to local conditions using low-cost, scalable methods **like infiltration basins, sand dams, or recharge wells**. For example, pilot projects in Laikipia and Makueni counties have shown how MAR can stabilize water availability for both domestic use and small-scale agriculture, even in areas prone to recurrent droughts. Additionally, integrating MAR with wetland restoration—such as **rehabilitating degraded catchments** in the Tana or Athi River basins—further enhances water retention and ecosystem resilience.

4.3.3.2 Construction of sand dams on seasonal rivers

This is highly effective climate adaptation measure for enhancing water security in arid and semi-arid areas. Built across seasonal rivers that flow only during rains, the sand dams accumulate sand behind the dam over time, which can store huge volumes of water for use during dry periods when the river is no longer flowing. The stored water is protected from evaporation and contamination and can be accessed by hand dug wells or by use infiltration galleries during the dry season.

4.4 Conclusion on adaptation options

All the adaptation measures are summed up in a main table which also enables to highlight which system's component the measures apply to and the hazard exposure thresholds that triggers the measure (1- Low exposure; 2- Moderate exposure; 3- High exposure; 4- Very high exposure).

These threshold levels, which guide the identification and selection of relevant adaptation measures, have been defined based on expert judgement and practical experience. This includes the experts' background in water and sanitation governance support, their involvement in feasibility and design studies, and operational feedback on the performance, successes, and limitations of climate-proofing measures implemented in WASH infrastructure projects. The thresholds have been defined in a conservative manner, meaning that the trigger levels for certain measures are set slightly below expected impact levels. This approach is intended to ensure that adaptation options are systematically reviewed during the feasibility and design phases, thereby reducing the risk of overlooking relevant measures and strengthening overall climate resilience.

The table is accessible in an Excel format (see Annex 1). An extract of the table is shown below.

Table 3: Adaptation options table extract

#	Measure	Floods	Landslides	Erosion	Heat waves & droughts	Soil Salinity	Justification	BH	Water intake	Water mains	Water pipes	...
1	Raise wellhead on a drained mound with sealed apron; flood-resistant kiosk and elevated controls	2					Cost-effective for mod floods; essential for H/VH to avoid submersion and contamination.	X				
2	Perimeter drain and all-weather access within fenced protection zone	2					Basic drainage needed even for mod events; critical in H/VH catchments.	X				
3	Instrument static/dynamic level & EC/turbidity; set abstraction rules to limit drawdown/up-coning					3	Only justified in saline-prone areas (coastal/arid); monitoring prevents irreversible salinization (H/VH risk). *Not needed for low/mod salinity.*	X				
4	Install deep sanitary seal and grout to prevent surface infiltration	3					Recommended only in H/VH flood zones (e.g., flash-flood valleys); over-engineering for mod isolated sites.	X				
5	Site selection outside floodways; relocate if recurrent flooding observed	3					Relocation is costly → justified only for H/VH flood recurrence (>1:10 yr).	X				
6	Site intake outside floodplain; if unavoidable, raise platform above design flood	2					Raising platform is standard for mod (1:25 yr); full avoidance only feasible for new H/VH sites.		X			
7	Debris/sediment management: coarse screens & sluicing points	3		3			Required only in H/VH flood/erosion zones (e.g., high-sediment rivers); mod sites may use basic screens.		X			
...

5. MITIGATION OPTIONS

5.1 Global Good Practices

Across all WASH components, several mitigation principles apply universally:

- **Transition to Renewable Energy.** Many WASH facilities—pumping stations, treatment plants, boreholes, offices, fleets—still depend on grid electricity or diesel generators. Replacing these with solar PV, micro-hydro, hybrid PV-battery systems, or generator hybridization significantly reduces direct (Scope 1) and indirect (Scope 2) emissions.
 - ▶ Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)
 - ▶ Solar pumping systems (PV + battery or gravity storage)
 - ▶ Install solar PV and hybrid operation
 - ▶ Use high-efficiency inverters and tracking systems
 - ▶ Hybridize generators with PV-battery systems
 - ▶ Solar rooftops and net metering
- **Improve Energy Efficiency.** Highly efficient motors, pumps, treatment processes, and buildings reduce electricity demand.
This includes VFDs, high-efficiency motors, optimized pump sizing, high-efficiency aeration, and thermal insulation.
- High- buildings (LED, HVAC, free cooling)
- **Reduce Water Losses and Non-Revenue Water (NRW).** Energy is embedded in every cubic metre produced. Therefore, leakage reduction, pressure management, DMA systems, AMI and analytics indirectly reduce emissions by lowering the volume that must be pumped or treated.
- Pressure management and leakage control (DMA, NRW programs)
- Leak detection and proactive maintenance
- Advanced analytics, AMI, pressure zoning
- **Sustainable Resource Management.** Managing groundwater levels and rehabilitating natural resources reduces pumping lifts, protects recharge, and optimizes system resilience.
 - ▶ Groundwater level management (sustainable abstraction)
 - ▶ Reuse treated effluent
- **Reduce Embodied Carbon in Construction.** The choice of materials—particularly cement and steel—has major lifecycle emissions. Using **low-carbon concrete, blended cement, recycled steel**, and hydraulic design that minimizes concrete volumes lowers overall embodied emissions.
- **Optimize Fleet and Logistics.** An electrified fleet or well-maintained thermic one, route optimization and generator-fuel reduction strategies significantly reduce Scope 1 emissions. This can be considered for vacuum trucks .
- A robust **Measurement, Reporting, and Verification (MRV) system for energy and GHG tracking** ensures continued improvement and quantification of mitigation gains.

5.2 Mitigation Options by WASH Component

5.2.1 Water Supply Systems

5.2.1.1 Boreholes

The main objective is to reduce diesel use, optimize pumping efficiency, protect groundwater levels. While this enables to lower GHG emissions it can also lower dependence on grid electricity which can be unreliable in some remote areas.

The key measure for boreholes is solar electrification and hybrid systems to replace diesel generator use; reduce operating costs. This is already something being implemented in some areas of Kenya and therefore appears to be very feasible.

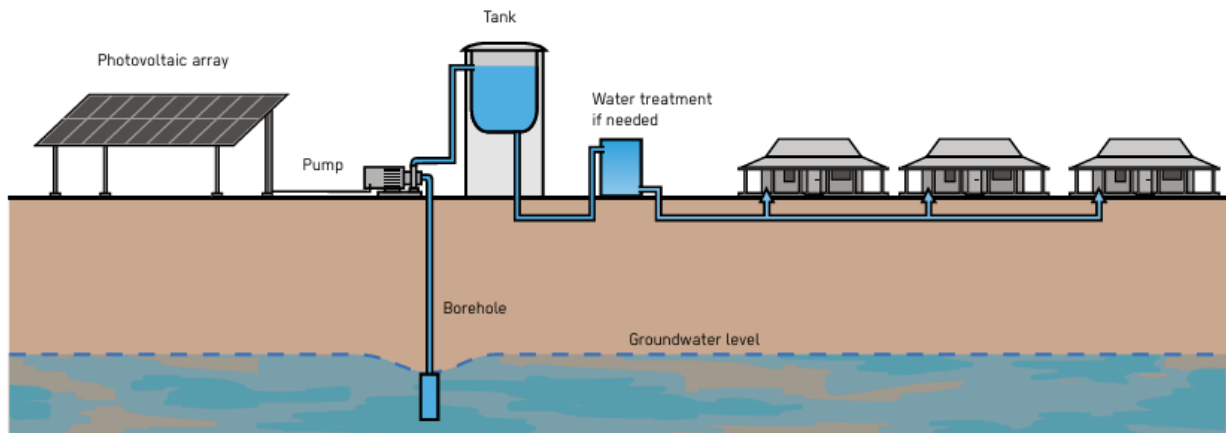


Figure 31: Solar electrification of a borehole

Other potential measures are listed below:

- Efficient motors and VFDs which match pump speed to varying well yields to reduce kWh/m³.
- Pressure and leakage reduction in distribution from boreholes to minimize volumes pumped.
- Hydraulic optimization. Larger pipes or gravity distribution where possible.
- Low-carbon materials in borehole construction.
- Electrification of maintenance fleet or good maintenance of existing thermic fleet.
- Low-global-warming-potential (GWP) refrigerants in control rooms/equipment.
- MRV system.
- Ensure groundwater level management as sustainable abstraction ensures lower pumping depth and energy use.

5.2.1.2 Water Intake Structures

Mitigation of emissions for water intake structures can be achieved through the use of renewable energy sources, such as **solar electrification**, which directly reduces reliance on fossil fuels. **Micro-hydro electrification** is also a viable option, utilizing elevation drops or pressure in raw-water pipelines to generate energy through small turbines (PAT turbines).

Effective debris management, including self-cleaning intake screens, reduces head loss and improves pump efficiency.

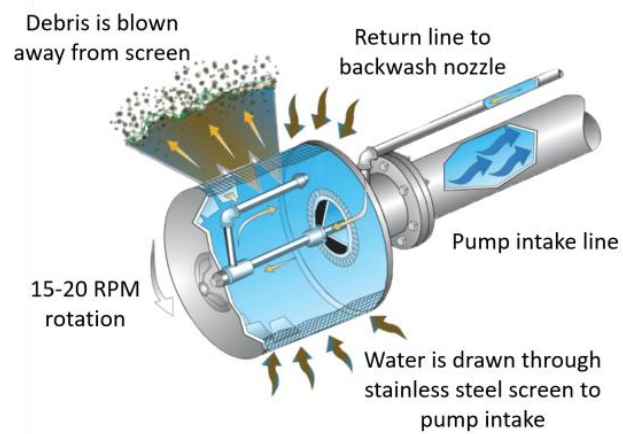


Figure 32: Example of a self cleaning intake screen

Source: Lakos filtration solutions

Pressure regulation with energy recovery allows excess pressure in pipelines to be converted into usable energy rather than wasted, reducing the overall energy demand of the system.

Additionally, **leak detection and proactive maintenance** enable targeted interventions, extending infrastructure lifespan and minimizing emissions associated with full replacement or inefficient operation.

5.2.1.3 Water Mains and Transmission/Distribution Pipes

Mitigation of emissions in water mains and distribution networks can be achieved through a combination of hydraulic and operational strategies.

Effective pressure and non-revenue water (NRW) management reduces energy losses and improves system efficiency, the following equipment and operations serve this purpose:

- including district metered areas (DMAs),
- advanced metering infrastructure (AMI),
- pressure zoning, and
- predictive maintenance

Hydraulic optimization further decreases the need for pumping and can be done through:

- Proper pipe sizing minimizes friction losses and lowers pumping energy requirements.
- Locating reservoirs at elevation allows gravity-driven flow.

Exposed pipes and tanks can be thermally insulated or shaded to reduce heat-related losses.

Finally, hydraulic energy storage systems offer a more efficient alternative to batteries for managing energy intermittency.

5.2.1.4 Water Storage Tanks

The **use of hydraulic energy storage**, as highlighted right before in the water mains and distribution context, **reduces reliance on batteries and improves overall energy efficiency**, in that regard water storage tanks themselves can be regarded as mitigation measures.

Solar photovoltaic (PV) systems installed at storage sites, potentially in **hybrid configurations** with other energy sources, can further decrease emissions by supplying renewable electricity for pumping and auxiliary operations.

Thermal insulation and shading of tanks are particularly important in hot regions, as they minimize evaporation and reduce make-up pumping, contributing both to water conservation and energy savings.

5.2.1.5 Water Treatment Plants (WTP)

Mitigation of emissions at water treatment plants can be achieved through a combination of process optimization, renewable energy, and infrastructure management. The following measures enable to do that:

- **Energy-efficient process design** reduces electricity consumption they correspond to the following measures:
 - ▶ including high-efficiency aeration,
 - ▶ dissolved oxygen control, and
 - ▶ optimized filtration cycles.
 - ▶ Again, solar photovoltaic (PV) installations and hybrid energy systems further decrease reliance on fossil fuels.
- **Sludge minimization and optimized chemical dosing** reduce haulage and treatment-related emissions.
- WTP are built using lots of concrete material, the consideration on **low carbon-concrete and other materials** should especially be thought-through.
- **Implementation of monitoring, reporting, and verification (MRV) systems** for energy and greenhouse gas tracking, support sustainable operations.
- **Debris management upstream** of the plant lowers treatment load and associated energy use. It can also limit repair and maintenance requirements.

5.2.1.6 Solar Pumping Systems

Emission mitigation in solar pumping systems relies on maximizing the efficiency of renewable energy, to do so the following measures can be implemented:

- **High-efficiency inverters and solar tracking systems** to increase energy capture and system performance.
- **Combining solar PV with battery or hydraulic storage** to alloc energy to be stored and used as needed, reducing reliance on backup generators.
- **Hybrid generator-PV configurations** to further minimize diesel runtime while maintaining reliable water supply.

5.2.1.7 Non-Revenue Water (NRW) Equipment

Reducing non-revenue water contributes directly to energy and emissions savings by **optimizing system operation**. Key measures to improve NRW management include

- The creation of district metered areas (DMAs): to monitor flows and identify leaks (zonal meters) and to control flows (valves),
- Pressure management to reduce leakage and stress on the network, and
- The use of advanced analytics or advanced metering infrastructure (AMI) to detect leaks and inefficiencies.

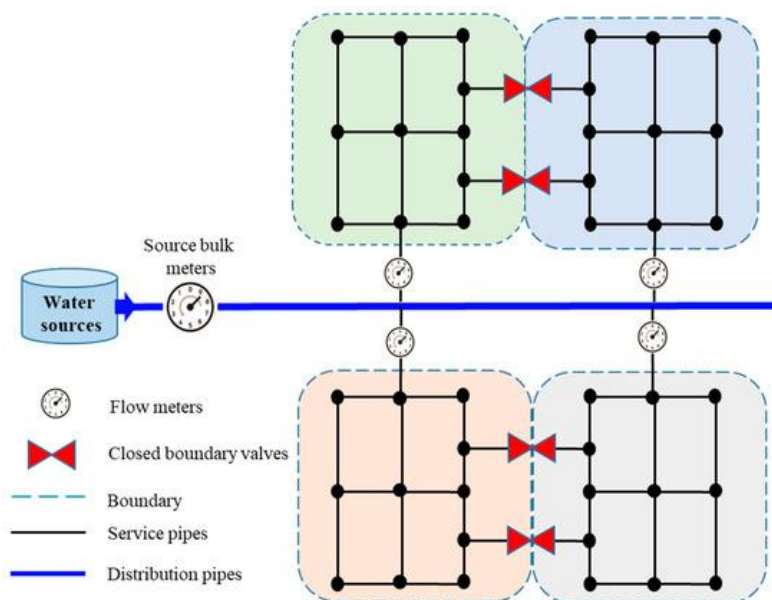


Figure 33: DMA scheme

5.2.2 Sanitation Systems

5.2.2.1 Wastewater Treatment Plants

Mitigation in wastewater treatment processes can mainly be driven by the following measures:

- **Optimized aeration efficiency**, as aeration (the process used to supply oxygen to biological reactors) is the most energy-intensive step in most wastewater treatment plants:
 - ▶ Variable Frequency Drives have become an indispensable tool in modern wastewater treatment facilities. By allowing operators to precisely control pump speed and flow, VFDs help reduce energy consumption, improve system reliability, and extend equipment life.
 - ▶ Using Dissolved Oxygen (DO) sensors and automatic controls, plants can match oxygen supply to biological demand, significantly reducing blower energy consumption.
- **Low-N₂O biological processes** such as shortcut nitrification and anammox, substantially reduce nitrous oxide emissions.
- **Biogas capture and utilization** through combined heat and power (CHP) or flaring prevents uncontrolled methane release while generating usable energy.
- **Covering basins and collecting off-gas**
- **Effluent reuse** offsets the need for pumping additional raw water, resulting in system-wide energy savings.
- **Sludge minimization** strategies and **solar drying** reduce treatment and transport emissions
- WWTP are built using lots of concrete material, the consideration on **low carbon-concrete and other materials** should especially be thought-through.

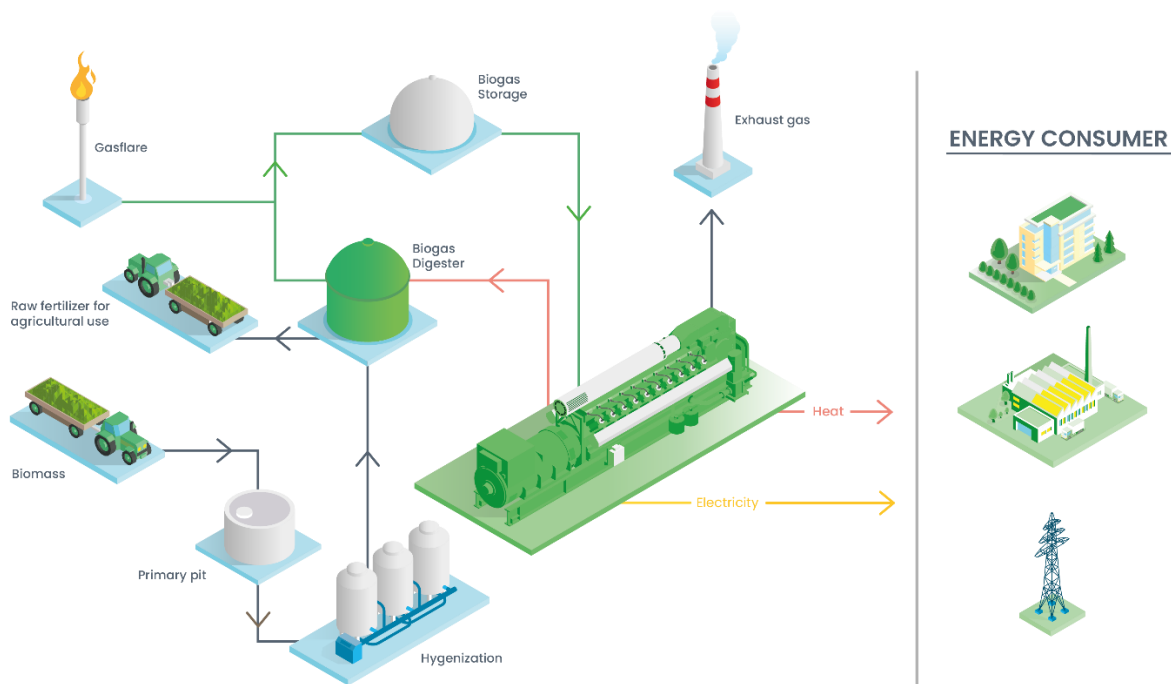


Figure 34: Biogas capture and utilization

5.2.2.2 Waste Disposal Systems

Waste disposal systems can reduce emissions through improved treatment processes and low-carbon logistics.

- **Controlled composting or solar drying** lowers the energy required for sludge or waste stabilization.
- **Co-processing or incineration with energy recovery** provides an opportunity to offset fossil fuel use.
- Transitioning to **electrified transport fleets** for sludge and waste hauling further contributes to emission reductions while maintaining operational reliability. The **maintenance of existing fleet** is also a major consideration.

5.2.2.3 Latrines and Sanitation Facilities

Mitigation for on-site sanitation facilities centers on construction practices, energy use, and desludging efficiency:

- **Low-carbon construction materials** and methods reduce embodied emissions in new latrines and sanitation blocks.
- **Efficient desludging logistics** help reduce fuel consumption across service chains.
- **Small-scale solar installations can power lighting or low-lift pumps**, reducing dependence on grid electricity or diesel.
- **Composting or solar drying options for waste treatment** provide low-energy alternatives suited to remote or decentralized contexts.

5.2.3 Drainage and Water Resource Management

Mitigation opportunities in drainage and water resource management mainly target **energy efficiency**, reduced material-related emissions, and **system-wide optimization**:

- **Hydraulic optimisation** (particularly in combined drainage systems) reduces unnecessary pumping requirements, lowering electricity demand and associated emissions.
- **Leak detection and preventive structural maintenance** further support mitigation by extending asset life and preventing major rehabilitation works that carry significant embodied emissions.
- **Using low-carbon concrete and alternative materials** contributes to reducing construction-related GHG emissions across drainage infrastructure.
- **Electrifying fleets** used for drain clearing also displaces diesel combustion and improves local air quality.
- **Effluent reuse** provides an additional mitigation pathway by reducing the need for raw water abstraction and the related energy consumption for pumping and conveyance—regardless of whether the system is powered by grid electricity or solar.

5.2.3.1 Water Pans

Mitigation in water pans primarily focuses on reducing evaporative losses and lowering embodied carbon in construction. Shading structures, floating covers, and windbreaks are effective measures to limit evaporation, thus reducing the frequency of water extraction and the energy used for replenishment pumping. Complementing this, the use of low-carbon materials for embankments and lining helps minimise emissions associated with construction and rehabilitation works.

Conclusion on mitigation options

All the mitigation measures are summed up in a main table which also enable to highlight which system's component the measures apply to. An extract of the table is shown below.

Table 4: Mitigation options table extract

#	Measure	Boreholes	Water intake	Water mains	Water pipes	...
1	Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)	X	X	X	X	
2	High-efficiency motors and variable frequency drives (VFDs)	X	X	X	X	
3	Pressure management and leakage control (DMA, NRW programs)	X	X	X	X	
4	Hydraulic optimization (gravity-based systems, large diameters)	X	X	X	X	
5	Low-carbon construction materials (blended cement, recycled steel)	X	X	X	X	
6	Electrified fleet and logistics optimization	X	X	X	X	
7	Low-GWP refrigerants and proper maintenance	X	X	X	X	
8	MRV system for energy and GHG tracking	X	X	X	X	
9	Optimize pump sizing and duty cycles	X	X	X	X	
10	Solar pumping systems (PV + battery or gravity storage)	X	X	X	X	
11	Groundwater level management (sustainable abstraction)	X				
12	Micro-hydro on raw-water pipelines or falls		X	X		
13	Debris management and self-cleaning screens		X			
14	Pressure regulation with energy recovery (PATs)			X	X	
15	Leak detection and proactive maintenance			X	X	
16	Locate reservoirs at elevation					
17	Thermal insulation and shade					

...
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6. OPERATIONAL SHEETS ON INFRASTRUCTURE ADAPTATION

To facilitate the implementation of measures and the operational aspects of all the above recommendations, these have been summarized in fact sheets, which are easier to use and provide a better tool for disseminating information.

Two approaches are possible:

- on the one hand, **generic WASH system components' fact sheets** have been developed for use in any Kenyan context, they present the general considerations for adaptation measures depending on hazards, the measures of course have to be reviewed based on the area's exposure to different hazards. This is what is shown in section 6.1.
- on the other hand, for counties for which the consultant has a list of CWSSIP projects and their locations, and for which he has carried out a CRA to determine the levels of exposure to various hazards, specific **project fact sheets** have been developed.






The former have the advantage of considering the measures to be applied to all components of the project (e.g., water intake + pipes + kiosks) where the generic sheets cover the systems' components individually.

The sheets give the names of the measures to be implemented, but for reasons of readability, the exact justification and explanations relating to the measures are not developed in the sheets. It will be up to the implementing entities to seek the information in the paragraphs above (section 4 and 5), from literature, from their peers or from consultants.

6.1 WASH system components' general climate measures fact sheets

6.1.1 Water supply

6.1.1.1 Boreholes

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)	
System component	
Boreholes	
Adaptation Measures	
<p>Floods</p> 	<p>Landslides</p> 
<p>Raise wellhead on a drained mound with sealed apron; flood-resistant kiosk and elevated controls Perimeter drain and all-weather access within fenced protection zone Install deep sanitary seal and grout to prevent surface infiltration Site selection outside floodways; relocate if recurrent flooding observed</p>	<p>None</p>
<p>Erosion</p> 	<p>Soil Salinity</p> 
<p>None</p>	<p>Instrument static/dynamic level & EC/turbidity; set abstraction rules to limit drawdown/up-coning Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes</p>
<p>Heat waves & droughts</p> 	
<p>Re-use of treated effluent for irrigation</p>	
Mitigation Measures	
<p>Electrification via renewable energy (solar PV, micro-hydro, hybrid systems) High-efficiency motors and variable frequency drives (VFDs) Pressure management and leakage control (DMA, NRW programs) Hydraulic optimization (gravity-based systems, large diameters) Low-carbon construction materials (blended cement, recycled steel) Electrified fleet and logistics optimization Low-GWP refrigerants and proper maintenance MRV system for energy and GHG tracking Optimize pump sizing and duty cycles Solar pumping systems (PV + battery or gravity storage) Groundwater level management (sustainable abstraction) Hybridize generators with PV-battery systems</p>	








6.1.1.2 Water Intake

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water intake

Adaptation Measures	
<p>Floods </p> <p>Site intake outside floodplain; if unavoidable, raise platform above design flood Debris/sediment management: coarse screens & sluicing points Bank protection (gabions/rip-rap), non-constricting Diversion of hillside runoff (cut-off drains/berms) Elevate & seal electrical/controls (watertight) High-clearance vehicles + snorkels Adjustable intake for river intakes</p>	<p>Landslides </p> <p>None</p>
<p>Erosion </p> <p>Debris/sediment management: coarse screens & sluicing points Bank protection (gabions/rip-rap), non-constricting Diversion of hillside runoff (cut-off drains/berms)</p>	<p>Soil Salinity </p> <p>Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes</p>
<p>Heat waves & droughts </p> <p>Adjustable intake for river intakes Re-use of treated effluent for irrigation</p>	

Mitigation Measures

Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)
 High-efficiency motors and variable frequency drives (VFDs)
 Pressure management and leakage control (DMA, NRW programs)
 Hydraulic optimization (gravity-based systems, large diameters)
 Low-carbon construction materials (blended cement, recycled steel)
 Electrified fleet and logistics optimization
 Low-GWP refrigerants and proper maintenance
 MRV system for energy and GHG tracking
 Optimize pump sizing and duty cycles
 Solar pumping systems (PV + battery or gravity storage)
 Micro-hydro on raw-water pipelines or falls
 Debris management and self-cleaning screens
 Hybridize generators with PV-battery systems







6.1.1.3 Water Mains

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water mains

Adaptation Measures

Floods		Landslides		
<p>Sleeves + scour aprons at road/river crossings Seal & elevate valve/air-valve chambers Sleeves/ducts + anchor blocks at crossings/direction changes Seal & elevate valve chambers DMAs + surge relief valves Data loggers: battery backup + flood-secure chambers Rehabilitate valves/hydrants; sealed chambers Use of HDPE pipes</p>		<p>Realign routes to avoid unstable slopes/gullies Deeper burial + concrete anchors on steep slopes Post-storm patrols on sensitive slopes</p>		
	Erosion		Soil Salinity	
	<p>Realign routes to avoid unstable slopes/gullies Deeper burial + concrete anchors on steep slopes Sleeves + scour aprons at road/river crossings Post-storm patrols on sensitive slopes</p>		<p>Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes</p>	
	Heat waves & droughts			
None				

Mitigation Measures

Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)
 High-efficiency motors and variable frequency drives (VFDs)
 Pressure management and leakage control (DMA, NRW programs)
 Hydraulic optimization (gravity-based systems, large diameters)
 Low-carbon construction materials (blended cement, recycled steel)
 Electrified fleet and logistics optimization
 Low-GWP refrigerants and proper maintenance
 MRV system for energy and GHG tracking
 Optimize pump sizing and duty cycles
 Solar pumping systems (PV + battery or gravity storage)
 Micro-hydro on raw-water pipelines or falls
 Pressure regulation with energy recovery (PATs)
 Leak detection and proactive maintenance







6.1.1.4 Water Pipes

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water pipes

Adaptation Measures

<i>Floods</i>		<i>Landslides</i>	
<p>Sleeves + scour aprons at road/river crossings</p> <p>Seal & elevate valve/air-valve chambers</p> <p>Sleeves/ducts + anchor blocks at crossings/direction changes</p> <p>Seal & elevate valve chambers</p> <p>DMAs + surge relief valves</p> <p>Data loggers: battery backup + flood-secure chambers</p> <p>Rehabilitate valves/hydrants; sealed chambers</p> <p>Use of HDPE pipes</p>		<p>Realign routes to avoid unstable slopes/gullies</p> <p>Deeper burial + concrete anchors on steep slopes</p> <p>Post-storm patrols on sensitive slopes</p>	
	<i>Erosion</i>		<i>Soil Salinity</i>
	<p>Realign routes to avoid unstable slopes/gullies</p> <p>Deeper burial + concrete anchors on steep slopes</p> <p>Sleeves + scour aprons at road/river crossings</p> <p>Post-storm patrols on sensitive slopes</p> <p>Avoid erosion gullies in routing; stabilize as needed</p> <p>Sleeves/ducts + anchor blocks at crossings/direction changes</p> <p>Increase burial depth for plastic pipes</p>		<p>Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes</p>
	<i>Heat waves & droughts</i>		
None			

Mitigation Measures

Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)

High-efficiency motors and variable frequency drives (VFDs)

Pressure management and leakage control (DMA, NRW programs)

Hydraulic optimization (gravity-based systems, large diameters)

Low-carbon construction materials (blended cement, recycled steel)

Electrified fleet and logistics optimization

Low-GWP refrigerants and proper maintenance

MRV system for energy and GHG tracking

Optimize pump sizing and duty cycles

Solar pumping systems (PV + battery or gravity storage)

Pressure regulation with energy recovery (PATs)

Leak detection and proactive maintenance

Advanced analytics, AML, pressure zoning



6.1.1.5 Water Storage

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water storage

Adaptation Measures

Floods



Safe access (non-slip, rails, lighting) during heavy rain
Separate wastewater/stormwater; raise embankments + emergency bypass
Cover systems + stormwater diversion around storage
Modular water storage tanks

Landslides



Site on stable high ground, outside landslide polygons
Deep foundations/ground improvement
Stabilize embankments (geogrids, toe drains, veg)
Modular water storage tanks

Erosion



Peripheral drainage & surface erosion protection
Stabilize embankments (geogrids, toe drains, veg)
Cover systems + stormwater diversion around storage
Modular water storage tanks

Soil Salinity



Lined storage for sludge/screenings + leachate control
Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes

Heat waves & droughts



Adjust aeration systems and biological process monitoring

Mitigation Measures

Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)
High-efficiency motors and variable frequency drives (VFDs)
Pressure management and leakage control (DMA, NRW programs)
Hydraulic optimization (gravity-based systems, large diameters)
Low-carbon construction materials (blended cement, recycled steel)
Electrified fleet and logistics optimization
Low-GWP refrigerants and proper maintenance
MRV system for energy and GHG tracking
Locate reservoirs at elevation
Thermal insulation and shade
Prefer hydraulic storage over batteries



6.1.1.6 Water Treatment Plant

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water Treatment Plant

Adaptation Measures

Floods



Safe access (non-slip, rails, lighting) during heavy rain
 Pre-works flood assessment & platform elevation per return period
 Complete stormwater management (grading, swales, outfalls)
 Elevate/relocate equipment; watertight doors
 Controlled overflow/holding capacity
 Separate wastewater/stormwater; raise embankments + emergency bypass
 Rainwater/stormwater management (gutters, drains)
 Passive cooling + emergency power

Landslides



Site on stable high ground, outside landslide polygons
 Deep foundations/ground improvement
 Stabilize embankments (geogrids, toe drains, veg)

Erosion



Peripheral drainage & surface erosion protection
 Complete stormwater management (grading, swales, outfalls)
 Stabilize embankments (geogrids, toe drains, veg)
 Rainwater/stormwater management (gutters, drains)

Soil Salinity



Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes

Heat waves & droughts



Adjust aeration systems and biological process monitoring

Mitigation Measures

Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)
 High-efficiency motors and variable frequency drives (VFDs)
 Pressure management and leakage control (DMA, NRW programs)
 Hydraulic optimization (gravity-based systems, large diameters)
 Low-carbon construction materials (blended cement, recycled steel)
 Electrified fleet and logistics optimization
 Low-GWP refrigerants and proper maintenance
 MRV system for energy and GHG tracking
 Optimize pump sizing and duty cycles
 Solar pumping systems (PV + battery or gravity storage)
 Micro-hydro on raw-water pipelines or falls
 Optimize process design and aeration efficiency
 Install solar PV and hybrid operation
 Sludge minimization and optimized dosing
 Optimize aeration (VFD, DO control)
 Hybridized generators with PV-battery systems








6.1.1.7 Solar Pumping System

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Solar pumping system

Adaptation Measures






<p>Floods</p>  <p>Perimeter drain and all-weather access within fenced protection zone Array mounting for wind/storm loads; surge protection Fenced compound + all-weather access</p>	<p>Landslides</p>  <p>Panel drainage to avoid local erosion Stabilize dikes/slopes; maintain wet-season access</p>
<p>Erosion</p>  <p>Panel drainage to avoid local erosion Stabilize dikes/slopes; maintain wet-season access</p>	<p>Soil Salinity</p>  <p>None</p>
<p>Heat waves & droughts</p>  <p>None</p>	

Mitigation Measures

Electrification via renewable energy (solar PV, micro-hydro, hybrid systems)
 High-efficiency motors and variable frequency drives (VFDs)
 Pressure management and leakage control (DMA, NRW programs)
 Hydraulic optimization (gravity-based systems, large diameters)
 Low-carbon construction materials (blended cement, recycled steel)
 Electrified fleet and logistics optimization
 Low-GWP refrigerants and proper maintenance
 MRV system for energy and GHG tracking
 Optimize pump sizing and duty cycles
 Solar pumping systems (PV + battery or gravity storage)
 Use high-efficiency inverters and tracking systems
 Prefer hydraulic storage over batteries








6.1.1.8 NRW equipment

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)	
System component	
NRW Equipment	
Adaptation Measures	
<p>Floods </p> <p>DMAs + surge relief valves Data loggers: battery backup + flood-secure chambers Rehabilitate valves/hydrants; sealed chambers</p>	<p>Landslides </p> <p>None</p>
<p>Erosion </p> <p>None</p>	<p>Soil Salinity </p> <p>None</p>
<p>Heat waves & droughts </p> <p>None</p>	
Mitigation Measures	
<p>Electrification via renewable energy (solar PV, micro-hydro, hybrid systems) Leak detection and proactive maintenance Advanced analytics, AMI, pressure zoning</p>	








6.1.2 Sanitation

6.1.2.1 Wastewater Treatment Plant

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)	
System component	
Wastewater Treatment Plant	
Adaptation Measures	
<p>Floods </p> <p>Separate wastewater/stormwater; raise embankments + emergency bypass Inlet screening & grit removal sized for storm peaks Cover systems + stormwater diversion around storage</p>	<p>Landslides </p> <p>Stabilize dikes/slopes; maintain wet-season access</p>
<p>Erosion </p> <p>Stabilize dikes/slopes; maintain wet-season access Cover systems + stormwater diversion around storage</p>	<p>Soil Salinity </p> <p>Lined & drained sludge beds; leachate collection Lined storage for sludge/screenings + leachate control Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes</p>
<p>Heat waves & droughts </p> <p>Re-use of treated effluent for irrigation Adjust aeration systems and biological process monitoring Green buffers and ventilation systems</p>	
Mitigation Measures	
<p>Electrification via renewable energy (solar PV, micro-hydro, hybrid systems) High-efficiency motors and variable frequency drives (VFDs) Pressure management and leakage control (DMA, NRW programs) Hydraulic optimization (gravity-based systems, large diameters) Low-carbon construction materials (blended cement, recycled steel) Electrified fleet and logistics optimization Low-GWP refrigerants and proper maintenance MRV system for energy and GHG tracking Optimize pump sizing and duty cycles Solar pumping systems (PV + battery or gravity storage) Optimize process design and aeration efficiency Install solar PV and hybrid operation Sludge minimization and optimized dosing Capture and use biogas for energy (CHP, flare) Optimize aeration (VFD, DO control) Apply low-N₂O processes (shortcut nitrification, anammox) Cover emitting basins and collect off-gas Reuse treated effluent Anaerobic digestion of sludge Controlled composting or solar drying Hybridize generators with PV-battery systems</p>	








6.1.2.2 Waste Disposal

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)	
System component	
Waste disposal	
Adaptation Measures	
<p>Floods </p> <p>Cover systems + stormwater diversion around storage</p>	<p>Landslides </p> <p>None</p>
<p>Erosion </p> <p>Cover systems + stormwater diversion around storage</p>	<p>Soil Salinity </p> <p>Lined & drained sludge beds; leachate collection Lined storage for sludge/screenings + leachate control</p>
<p>Heat waves & droughts </p> <p>None</p>	
Mitigation Measures	
<p>Electrification via renewable energy (solar PV, micro-hydro, hybrid systems) High-efficiency motors and variable frequency drives (VFDs) Pressure management and leakage control (DMA, NRW programs) Hydraulic optimization (gravity-based systems, large diameters) Low-carbon construction materials (blended cement, recycled steel) Electrified fleet and logistics optimization Low-GWP refrigerants and proper maintenance MRV system for energy and GHG tracking Controlled composting or solar drying Co-incineration or co-processing</p>	



6.1.2.3 Latrines

System component	
Latrines and sanitation	
Adaptation Measures	
<p>Floods</p> 	<p>Landslides</p> 
<p>Raised latrines above flooding levels Latrines with masonry lined and separated single or multiple pits Relocation and reinforced masonry Container based sanitation systems</p>	<p>Latrines with masonry lined and separated single or multiple pits Relocation and reinforced masonry</p>
<p>Erosion</p> 	<p>Soil Salinity</p> 
<p>Latrines with masonry lined and separated single or multiple pits Relocation and reinforced masonry</p>	<p>None</p>
<p>Heat waves & droughts</p> 	
<p>Low-flush or pour flush toilets in water scarce areas</p>	
Mitigation Measures	
<p>Low-carbon construction materials (blended cement, recycled steel) Leak detection and proactive maintenance Thermal insulation and shade Capture and use biogas for energy (CHP, flare) Anaerobic digestion of sludge</p>	








6.1.2.4 Vehicles / Equipment

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)	
System component	
Vehicles / Equipment	
Adaptation Measures	
<p>Floods</p> <p>High-clearance vehicles + snorkels On-board spill kits for adverse weather</p>	<p>Landslides</p> <p>None</p>
<p>Erosion</p> <p>Wet-season driver training + maintenance plans</p>	<p>Soil Salinity</p> <p>None</p>
<p>Heat waves & droughts</p> <p>None</p>	
Mitigation Measures	
<p>Electrification via renewable energy (solar PV, micro-hydro, hybrid systems) High-efficiency motors and variable frequency drives (VFDs) Pressure management and leakage control (DMA, NRW programs) Hydraulic optimization (gravity-based systems, large diameters) Low-carbon construction materials (blended cement, recycled steel) Electrified fleet and logistics optimization Low-GWP refrigerants and proper maintenance MRV system for energy and GHG tracking Electrify fleet; efficient logistics</p>	



6.1.3 Drainage & water resource management

6.1.3.1 Drainage and stormwater

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)	
System component	
Drainage and stormwater	
Adaptation Measures	
<p><i>Floods</i></p>  <p>Silt traps to control siltation</p>	<p><i>Landslides</i></p>  <p>None</p>
<p><i>Erosion</i></p>  <p>Silt traps to control siltation</p>	<p><i>Soil Salinity</i></p>  <p>None</p>
<p><i>Heat waves & droughts</i></p>  <p>None</p>	
Mitigation Measures	
<p>Hydraulic optimization (gravity-based systems, large diameters) Low-carbon construction materials (blended cement, recycled steel) Debris management and self-cleaning screens</p>	













6.1.3.2 Water resources management

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water resources management

Adaptation Measures	
<p><i>Floods</i></p>  <p>Green Corridors, Bioswales, and Permeable Surfaces</p>	<p><i>Landslides</i></p>  <p>None</p>
<p><i>Erosion</i></p>  <p>None</p>	<p><i>Soil Salinity</i></p>  <p>None</p>
<p><i>Heat waves & droughts</i></p>  <p>Re-use of treated effluent for irrigation Low-flush or pour flush toilets in water scarce areas Green Corridors, Bioswales, and Permeable Surfaces Construction of sand dams on seasonal rivers Managed aquifer recharge and wetland restoration</p>	
Mitigation Measures	
None	

6.1.3.3 Water Pans

Climate Resilience Support for Kenya Water, Sanitation, and Hygiene Program (K-WASH)

System component

Water pan

Adaptation Measures






	<i>Floods</i>	<i>Landslides</i>
Silt traps to control siltation		
		None
	<i>Erosion</i>	<i>Soil Salinity</i>
Silt traps to control siltation		
		None
	<i>Heat waves & droughts</i>	
		
None		

Mitigation Measures

Low-carbon construction materials (blended cement, recycled steel)
 Debris management and self-cleaning screens
 Leak detection and proactive maintenance
 Thermal insulation and shade



6.1.4 Offices and facilities

System component	
Office / Facility	
Adaptation Measures	
<p>Floods</p>  <p>Site office outside floodplain or raised floor Rainwater/stormwater management (gutters, drains) Passive cooling + emergency power Relocation and reinforced masonry</p>	<p>Landslides</p>  <p>Relocation and reinforced masonry</p>
<p>Erosion</p>  <p>Rainwater/stormwater management (gutters, drains) Relocation and reinforced masonry</p>	<p>Soil Salinity</p>  <p>None</p>
<p>Heat waves & droughts</p>  <p>None</p>	
Mitigation Measures	
<p>Electrification via renewable energy (solar PV, micro-hydro, hybrid systems) High-efficiency motors and variable frequency drives (VFDs) Pressure management and leakage control (DMA, NRW programs) Hydraulic optimization (gravity-based systems, large diameters) Low-carbon construction materials (blended cement, recycled steel) Electrified fleet and logistics optimization Low-GWP refrigerants and proper maintenance MRV system for energy and GHG tracking Install solar PV and hybrid operation Hybridize generators with PV-battery systems Energy-efficient buildings (LED, HVAC, free cooling) Solar rooftops and net metering Digitalization / paperless systems</p>	



6.2 Projects climate measures fact sheets

Project-specific sheets enable to identify, for each subproject, the necessary actions based on:

- Exposure level to each hazard, assessed previously,
- Components of the subproject (pipes, boreholes...)
- Previous decision matrix which enables to relate each component of the subproject to necessary adaptation and mitigation options given the exposure level for each considered hazard. Indeed, each measure is triggered only above a certain exposure threshold, which explains why not all measures listed above are recommended for every project—many sites are simply not exposed enough to justify them.

Only one project sheet is presented as an example but all of them are available in Appendix 1.

Moreover, in case of additional subprojects, the tool can be used to assess necessary measures, which requires first to extract the various exposure levels from exposure raster layers packed in the QGIS project which will be delivered to the Client.

Project Selection

Development of 50M high Dam for Muranga South at Irati river for Kenol and Sabasaba water supply

Project location

Latitude: -0,778

Longitude: 36,918

Hazards Levels

Floods: Moderate

Landslides: Low

Erosion: Low

Soil Salinity: High

Heat waves & droughts: High

Adaptation Measures

Floods	Landslides
<p>Site intake outside floodplain; if unavoidable, raise platform above design flood</p> <p>Elevate & seal electrical/controls (watertight)</p> <p>Safe access (non-slip, rails, lighting) during heavy rain</p> <p>Adjustable intake for river intakes</p>	<p>None</p>
Erosion	Soil Salinity
<p>None</p>	<p>Lined storage for sludge/screenings + leachate control</p> <p>Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes</p>
Heat waves & droughts	
<p>Adjustable intake for river intakes</p> <p>Re-use of treated effluent for irrigation</p> <p>Adjust aeration systems and biological process monitoring</p>	

Mitigation Measures

Site intake outside floodplain; if unavoidable, raise platform above design flood ; Debris/sediment management: coarse screens & sluicing points ; Bank protection (gabions/rip-rap), non-constricting ; Diversion of hillside runoff (cut-off drains/berms) ; Elevate & seal electrical/controls (watertight) ; Site on stable high ground, outside landslide polygons ; Deep foundations/ground improvement ; Peripheral drainage & surface erosion protection ; Safe access (non-slip, rails, lighting) during heavy rain ; Stabilize embankments (geogrids, toe drains, veg) ; Separate wastewater/stormwater; raise embankments + emergency bypass ; Lined storage for sludge/screenings + leachate control ; Cover systems + stormwater diversion around storage ; High-clearance vehicles + snorkels ; Adjustable intake for river intakes ; Modular water storage tanks ; Water kiosks with ATMs ; Salt-resistant materials such as uPVC and epoxy-coated metals or HDPE pipes ; Re-use of treated effluent for irrigation ; Adjust aeration systems and biological process monitoring



7. CONCLUSION

This study has demonstrated that Kenya’s WASH systems are highly exposed to climate hazards, including droughts, floods, and changing rainfall patterns. Vulnerabilities were identified across water supply, sanitation, and drainage systems, with impacts ranging from overexploitation of water resources and saline intrusion to structural damage of infrastructure and pollution risks. Social inequalities, particularly affecting women, children, and marginalized communities, further exacerbate these vulnerabilities.

7.1 Strategic Implications

The findings underscore the urgent need to integrate climate resilience into WASH sector planning and investment. County-level assessments reveal that localized vulnerabilities require tailored responses, while national-level strategies must ensure coherence and coordination. The adaptation and mitigation options identified in this report provide a roadmap for strengthening infrastructure, improving service continuity, and safeguarding public health.

The options have been presented individually so that practitioners can easily refer to them and understand the measures. These undertakings can—and should—be refined at the design stage to ensure full consistency with project needs and local context (in some cases, a more detailed Climate Risk Assessment may be required).

For ease of use, the measures have also been compiled into tables and operational sheets. It should be noted that:

- Both climate adaptation and mitigation options are presented in the report.
- Climate measures are organized under two perspectives: the **system components entry point** and the **project entry point**.

7.2 Cross-Cutting Considerations

Beyond technical measures, the study highlights the importance of addressing social equity and inclusion. Climate-resilient WASH systems must not reinforce existing inequalities; instead, they should actively contribute to reducing them. Gender-sensitive approaches, stakeholder participation, and community ownership are essential to ensure that interventions are both effective and equitable.

7.3 Recommendations for Next Steps

- **Prioritize implementation** of pilot adaptation measures with high replicability potential.
- **Strengthen institutional capacity** for climate risk management within the WASH sector.
- **Enhance monitoring and evaluation** frameworks to track progress and adjust strategies.
- **Promote knowledge sharing** of global good practices adapted to Kenyan contexts.
- **Mobilize resources and partnerships** to support long-term resilience building.

Building climate-resilient WASH systems is not only a technical necessity but also a social imperative. By investing in adaptation and mitigation measures today, Kenya can protect its water and sanitation services, reduce vulnerability to climate change, and promote sustainable development. The path forward requires collaboration, foresight, and commitment to equity—ensuring that resilience benefits all communities.

ANNEXES

ANNEX 1. CLIMATE MEASURES TABLES

Parallel to this report 3 Excel files are shared:

- Climate measures generic tables or “global matrix”
- Murang’a projects climate measures
- Tana River projects climate measures

The last 2 files include the generic sheets from the “climate measures generic table”.

Prior to sharing the tool with counties, the following preparatory steps were undertaken:

- **The Excel workbook was structured to allow counties to list their WASH investments**, organised by WASH system categories (e.g. water supply, sanitation, energy, drainage).
- **A comprehensive list of adaptation and mitigation measures relevant to WASH systems was compiled**, and **hazard exposure thresholds were associated with each adaptation measure**.
 - ▶ When **hazard exposure is low**, no adaptation measures are triggered.
 - ▶ When **hazard exposure is moderate**, a subset of adaptation measures is triggered.
 - ▶ When **hazard exposure is very high**, all relevant adaptation measures are triggered.
 - ▶ **Mitigation measures are triggered systematically**, regardless of exposure level.

This preparation is what has allowed to develop the tools which can be used by the counties in two complementary ways:

- **System-level screening** : Counties may use the tool to obtain a **global overview of adaptation measures** that should be considered when planning a given type of WASH system (e.g. boreholes, piped networks, solar pumping).
In this case, **the Global Matrix file and the “Fiche système” sheet are sufficient**, as the objective is to support early planning and option identification.
- **Project-level assessment (recommended for investment planning)**: Counties may also use the tool to **assess adaptation measures at project level**, which is particularly important where a single project includes **multiple WASH components** (e.g. borehole, distribution pipes, and solar panels).

When using the tool for project-level assessment, counties should proceed as follows:

A. Complete the “Project Sheet”

- List all projects under consideration.
- Indicate the **main system type** (Column D) and the **main type of works** (Column E).
- Identify any **additional system components included in the project** (Columns O to AD).
- Provide the **project location** (Columns AE and AF).

B. Assign hazard exposure levels

- For each project, assign **hazard exposure levels** based on available **Climate Risk Assessment (CRA) maps** or, where these are not available, a **rapid hazard screening**.

C. Review results in the “Fiche projet” sheet

- The tool automatically compiles and displays the **adaptation and mitigation measures to be considered** for each project, based on its components and hazard exposure levels.

Used in this way, the tool supports **systematic, transparent, and risk-informed identification of climate-proofing measures**, while remaining flexible enough to accommodate different project types and levels of data availability.

ANNEX 2. WASH SECTOR VULNERABILITY

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

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

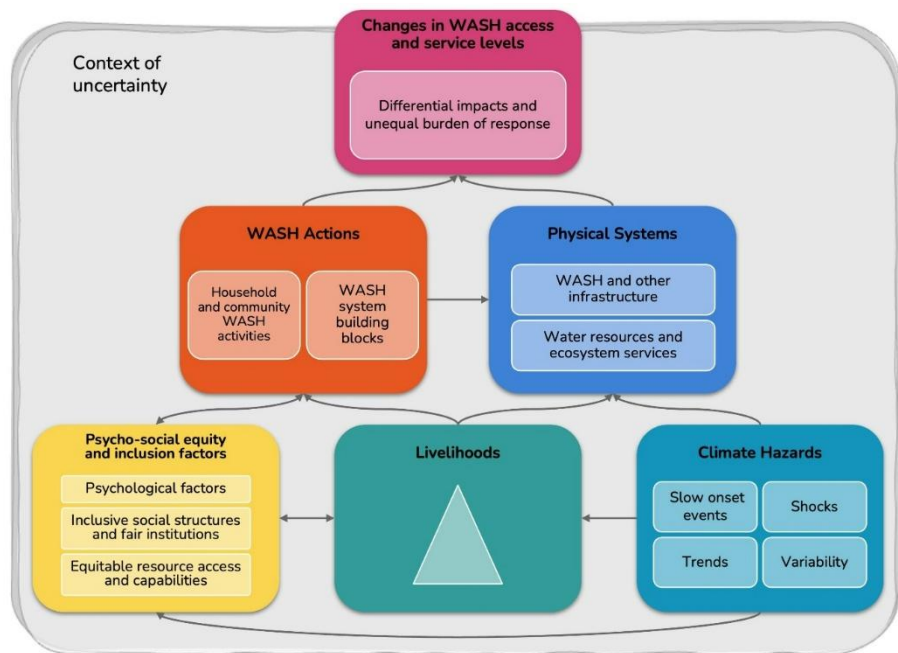


Figure 35 : WASH sector framework and relation to climate change

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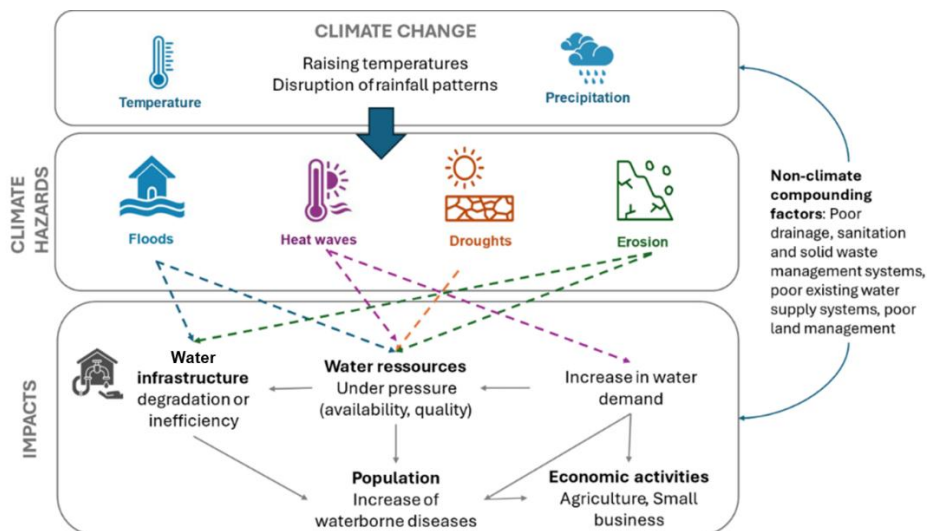


Figure 36 : Water sector vulnerability to climate change

The following sub-sections will elaborate on specific vulnerabilities to the WASH sector through the water resources entry point and then the infrastructure one. As the WASH sector is not only a sector vulnerable to climate change but also one that is a driver of climate change a section will highlight these aspects.

In line with the IPCC definition, the risks faced by WASH systems results from the combined effect of exposure to climate hazards, the physical and operational sensitivity of water and sanitation infrastructure, and the limited adaptive capacity at institutional and community levels.

Water resources

According to the World Bank's Climate Risk Country Profile developed for Kenya the country's water scarcity index has worsened since 1992 and is expected to fall from approximately 586 m³ per capita in 2010 to as low as 293 m³ per capita by 2050, this is much below the international acceptable threshold of 1,000 m³. Kenya is thus critically exposed to the adverse effects of climate change. Freshwater resources in Kenya are already highly subject to the large inter-and intra-annual rainfall variability, including the extremes of floods and droughts. As rainfall patterns are further altered, and rising temperatures increase soil moisture deficits and lower lake levels. All these climate patterns, which are expected to be reinforced by climate change led to diverse impacts on all stages of water ecosystem services as presented in the Figure below.

Water ecosystem service	Changes in temperature, precipitation and CO2 concentration can result in...
Storage and retention of water	changes in riparian and aquatic vegetation, soils and biogeochemistry which affect quantity and quality of surface water and groundwater
Groundwater recharge	changes in topography and vegetation which affect runoff, flood patterns and groundwater dynamics
Water purification and waste treatment	changes in riparian and aquatic vegetation, soils and biogeochemistry which may limit the environment's capacity to break down compounds and dilute waste
Flood mitigation	changes in wetland extent and distribution, aquatic vegetation, and topography which influence patterns of flooding

Adapted from Capon, S. J., & Bunn, S. E. (2015). Assessing climate change risks and prioritising adaptation options using a water ecosystem services-based approach. *Ecosystem Services: A Global Perspective*, eds J. Martin-Ortega, RC Ferrier, JJ Gordon, and S. Khan Cambridge: Cambridge University Press, 17-25.

Figure 37: Climate change impacts on water ecosystem services

The ecosystem services approach is necessary to understand the interconnection between the various impacts on water resources as a whole (groundwater, surface water, precipitation, evapotranspiration, etc.). This should be kept in mind. However, to facilitate analysis and adopt a more direct approach, it was decided to examine the impacts of climate change from another angle, namely through the prism of hazards.

Hazards can be classified under different categories as presented in the Figure below. Only the most relevant hazards regarding the present study have been considered in the following of the report, namely : Variability of seasonal rainfall patterns ; Droughts, water shortage, increased temperatures, heat waves ; Intense and sudden rainfall, flooding ; Storms (including sand and dust storms) ; Erosion (which can also be induced by floods and water runoff) and landslides ; Sea level rise.





Hazard category	Description	Examples
 Slow onset	Events that gradually emerge over extended periods of time. They may not be noticeable to people at first, but eventually start being felt deeply	Drought; sea-level rise; salinization; erosion
 Shocks	Events that occur acutely within a short timeframe (but effects may be felt long after)	Cyclones; flash floods; storm surges; extreme heat waves; landslides; wildfires
 Trends	Long-term (i.e. over decades) changes in climate variables. These refer to statistical changes in climate variables that are often measured quantitatively	Increasing average annual temperature; increasing average annual rainfall
 Variability and unpredictability	Increases in the variability of climate variables, and increased unpredictability of climate and weather	Increasing contrast in rainfall between wet and dry seasons; irregular start and finish time of seasons

Figure 38: Hazards categories

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

Table 5: 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): <ul style="list-style-type: none"> ○ 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: <ul style="list-style-type: none"> ▪ 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).
Storms (including sand and dust storms)	

Climate hazard	Impact on water resource
Erosion (which can also be induced by floods and water runoff) and landslides	▶ Poor infiltration of rainfall into the ground during heavy rainstorms: water no longer infiltrates but runs off, creating areas of flooded areas
Sea level rise	▶ Saline intrusions

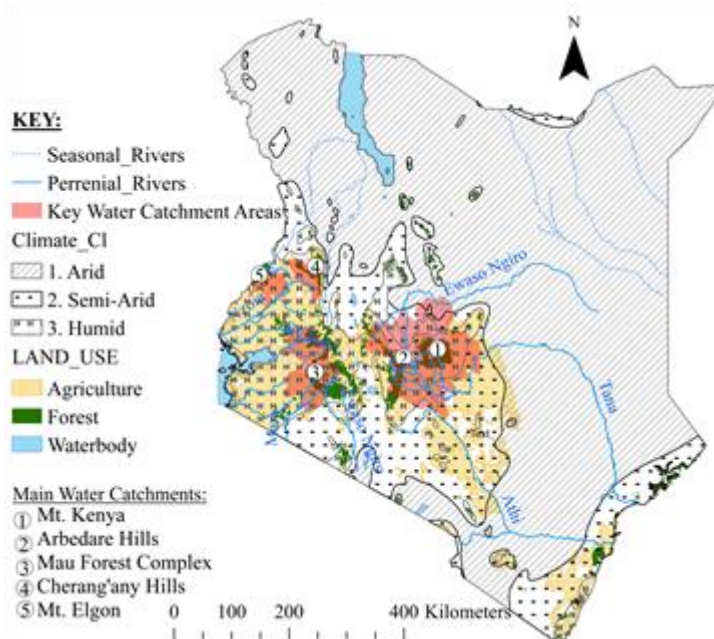
Source: Groupe Huit, (pS-Eau 2016), (Robens Centre for Public and Environmental Health, University of Surrey 2022), (C. Agudelo-Vera et al. 2020), (Ps-Eau 2018)

Surface Water Resources

Kenya's natural renewable water resources heavily depend on the few and fragile catchments covered by montane forests in the country's highland areas where humid climate zone is prevalent. Headwater catchments of Kenya's main rivers make up the five basin areas in the country namely: **Lake Victoria, Rift Valley, Athi, Tana and Ewaso Ng'iro North**. It is estimated that the catchments contribute over 75% of the nation's surface water resources.

The dilemma facing the government has been to balance between the expanding agriculture,

Figure 39: Kenya water resource map



which thrives in the region of the catchments and supports the country's economy, vis-à-vis managing the water resources and conserving the forests. Such challenge is quite consistent across the country with increasing demand over surface water resources which are crucial for the agriculture and livestock but are heavily impacted by climate-related hazards.

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

The rise in the Standardised Precipitation-Evapotranspiration Index (SPEI) at Kenyan scale shows a higher risk of droughts. It should be noted that there are differences between counties regarding the projected evolution of droughts intensity and frequency, some being more exposed than others.

Apart from droughts aspects the impact of temperature on evaporation and evapotranspiration should not be overlooked as it plays a major role in the year-round loss of surface water stocks.

Such balance between rainfall patterns changes and evaporation rates should be closely considered for surface water quantities annual evolution estimates. While the Food and Agriculture Organization models (FAO models) have been run at Country and some catchment areas scale (see National Water Master Plan) the analysis should be refined at county scale.

Other hazards that bring challenges are (i) the increase of soil salinity³ which in the end also leads to surface water salinity and then may lead to water availability decrease, but also threaten fertile lands and

³ Driven by groundwater abstraction (see below), sea level rise and intensive agriculture and related irrigation as well as the use of pesticides.

(ii) dust storm could also be considered as they would lead to deposits in surface water and thus quality reduction.

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

To mitigate these risks, various adaptation strategies are proposed in the County Integrated Development Plans (CIDP) such as:

- Investment in irrigation schemes
- Development of water harvesting and storage infrastructure for irrigation.
- Enhancing compliance with environmental, statutory and legal requirements
- Construction of small dams and water pans to collect flood water flows.
- Use of climate smart agriculture by use of water conserving irrigation methods such as drip irrigation, digging of terraces, planting water friendly trees along the river banks.
- Reduction of water wastage through modern technology measures
- Capacity building of water stakeholders on climate change mitigation measures

It was also observed that farmers develop coping mechanisms for instance building small waterpans (see Figure below.)

Groundwater Resources

Groundwater is an essential resource in areas where surface water is scarce or unreliable. Limited information is available regarding location and capacities of water tables in the country of the quality and quantity of groundwater is therefore complicated. In most cases, 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.



Figure 40 : Example of a waterpan built by farmers in Murang'a (source : Kenya news agency)

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.

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.

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

As with surface water, the conservation of forests and the protection of natural recharge zones are essential to ensuring the long-term availability of groundwater. Regular monitoring and data collection are vital, as well as establishing comprehensive water management plans to protect these resources from the challenges posed by climate change.

Infrastructure

WSS infrastructures are affected differently by the various climate slow-onset trends and hazards, and the following tables aim to present how. While both sets of tables begin with the hazard entry point, **the first set applies the primary lens of Service Continuity & Social Vulnerability**, with high social and contextual detail (health, migration, conflicts). Its end focus is on human and social impacts for communities, making it **particularly suited for use by policy makers, social professionals, and in social vulnerability assessments**. In contrast, **the last table adopts an Engineering & Asset Resilience perspective**, with high technical specificity on mechanisms and asset types. Its end focus is on operational and service impacts for utilities, making it mainly **developed for engineers, planners, and asset managers concerned with infrastructure risk and resilience**.

Lens of Service Continuity and Social Vulnerability

Table 6: Links between climate change and water supply services

Climate hazard	Water consumption	Service Quality	Impacts on infrastructure	Social impact
Variability of seasonal rainfall patterns		<ul style="list-style-type: none"> ▶ Temporary interruption or reduction of service due to lack of available resources 		<ul style="list-style-type: none"> ▶ Tougher fetching: <ul style="list-style-type: none"> ○ longer distances to be covered ○ deeper, less productive water table ▶ Increased diarrheal diseases : <ul style="list-style-type: none"> ○ degradation of water quality ○ use of water points where quality is uncontrolled and questionable by the population when the service is interrupted
Droughts, water shortage	<ul style="list-style-type: none"> ▶ Increasing water requirements and volumes for all uses (domestic agricultural, industrial, etc.). 	<ul style="list-style-type: none"> ▶ 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 	<ul style="list-style-type: none"> ▶ Fragilization of facilities : <ul style="list-style-type: none"> ○ over-utilization of equipment during drought period to meet high demand ○ risk of dry pumping and damage to pumps ○ concrete cracking during heat waves ○ intermittent water supplies and pressure changes in the distribution network lead to damage of the infrastructure ○ dams and reservoirs may be weakened by prolonged low storage levels. 	
Heat wave		<ul style="list-style-type: none"> ▶ 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 		

Climate hazard	Water consumption	Service Quality	Impacts on infrastructure	Social impact
			▶ Solar panels are less efficient when they become too hot.	▶ Multiplication of usage conflicts during water shortages
Intense and sudden rainfall, flooding		▶ Contamination or degradation of resources by <ul style="list-style-type: none"> ○ uncontrolled stormwater runoff ○ submersion or groundwater flooding of pits containing pollutants ○ infiltration (through soil or disused boreholes) of flood water in groundwater ○ rising groundwater mobilizing microbial and chemical contaminants ○ more rapid transport of subsurface water (rising water tables and soil infiltration) ○ Interruption of service due to damage to installations ○ Inaccessibility to water points (landslides - flooding) ○ 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
Storms (including sand and dust storms)				
Erosion (which can also be induced by floods and water runoff) and landslides		▶ Degradation of raw water quality due to more polluted run-off, with silt and nutrients ▶ Potential intrusion of contaminants through damaged infrastructure	▶ Fragilization and destruction of installations	

Climate hazard	Water consumption	Service Quality	Impacts on infrastructure	Social impact
		Potential loss of service due to damaged infrastructure		
Increased water salinity	<ul style="list-style-type: none"> ▶ No possibility to consume water containing a certain level of salt, which is no longer fit for drinking 	<ul style="list-style-type: none"> ▶ Degradation of raw water quality ▶ Potential intrusion of contaminants through damaged infrastructure ▶ Potential loss of service due to damaged infrastructure 	<ul style="list-style-type: none"> ▶ Fragilization and destruction of installations: <ul style="list-style-type: none"> ○ leaching of metal ○ corrosion ○ 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 7: Links between climate change and wastewater management services

Climate hazard	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Droughts, water shortage	<ul style="list-style-type: none"> ▶ Movement and damage of infrastructure related to changes in soil moisture levels 	<ul style="list-style-type: none"> ▶ Degradation of resource quality through reduced dilution of pollutants 	<ul style="list-style-type: none"> ▶ 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

Climate hazard	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Heat wave	<ul style="list-style-type: none"> ▶ 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 (H₂S) 	<ul style="list-style-type: none"> ▶ Degradation of quality of resources through less well treated discharge 	<ul style="list-style-type: none"> ▶ Poisoning from inhalation of hydrogen sulphide (H₂S), which is produced more frequently by heat (safety risk for personnel, especially sewage workers). Odour nuisance due to increased nitrogen dioxide (N₂O) emissions
Intense and sudden rainfall, flooding	<ul style="list-style-type: none"> ▶ 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 <ul style="list-style-type: none"> ○ sewers: (scouring or washout of bedding, and flotation leading to cracking of the sewer pipes) ○ septic tanks flotation ▶ destruction of latrines not built to sustain such hazards (impact on access rates may be significant) ▶ Disruption of emptying services (difficulty access, necessary increase in frequency...) 	<ul style="list-style-type: none"> ▶ 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. 	<ul style="list-style-type: none"> ▶ Population without sanitary facilities ▶ Increase in water-borne diseases due to the risk of contact with water containing pathogens
Storms (including sand and dust storms)			

Climate hazard	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	<ul style="list-style-type: none"> ▶ 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 8: Links between climate change and drainage services

Climate hazard	Impacts on infrastructure & Service quality	Impacts on environment and water resources	Social impact
Intense and sudden rainfall, flooding	<ul style="list-style-type: none"> ▶ Excessive water and submergence lead to ineffective stormwater management systems which in turn lead to impacts on water and wastewater services: <ul style="list-style-type: none"> ○ flooding of equipment, ○ overflow of wastewater networks, ○ water contamination 	<ul style="list-style-type: none"> ▶ 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 	<ul style="list-style-type: none"> ▶ 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: <ul style="list-style-type: none"> ○ use of contaminated water for domestic purposes ○ development of disease vectors such as mosquitoes, rats, etc.
Storms (including sand and dust storms)			

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

Engineering and Asset Resilience perspective

Table 9: Climate Hazards and Their Impacts on WSS Infrastructure Assets and Operations

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

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

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.
- 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.

Additional elements on the contributions of the WSS sector to the GHG emissions are given below.

The WSS facilities themselves contribute to 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 CO₂, CH₄ and N₂O.

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

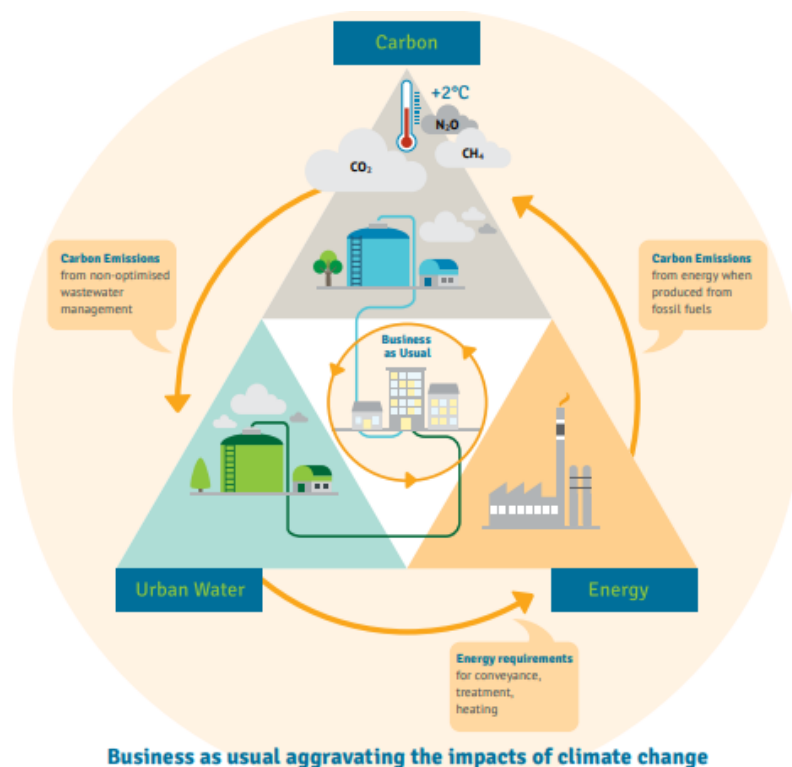


Figure 41: WSS business as usual aggravating the impacts of climate change

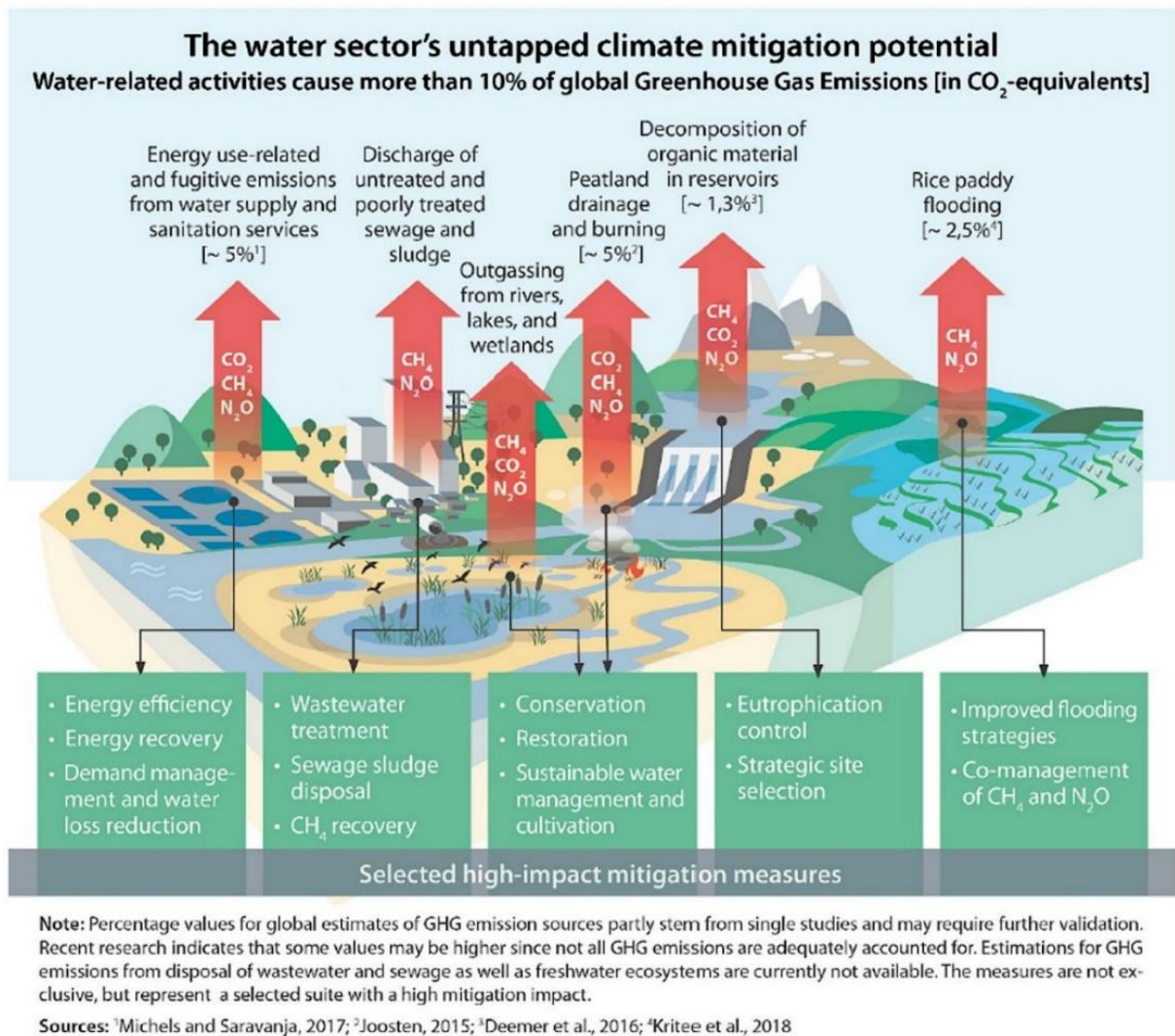


Figure 42: The water sector's untapped climate mitigation potential

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 3. REFERENCES

- Alain Maillhot et Sophie Duchesne. «Impacts et enjeux liés aux changements climatiques en matière de gestion des eaux en milieu urbain.» *Vertigo*, 2005.
- C. Agudelo-Vera et al. «Drinking Water Temperature around the Globe: Understanding, Policies, Challenges and Opportunities.» *Water - Water Quality in Drinking Water Distribution Systems*, 2020.
- C. Leauthaud et al. «Characterizing floods in the poorly gauged wetlands of the Tana River Delta, Kenya, using a water balance model and satellite data.» *Hydrology and Earth System Sciences*, August 2013.
- Chemeril Chepyegon, Daisuke Kamiya. «Challenges Faced by the Kenya Water Sector Management in Improving Water Supply Coverage.» *Journal of Water Resource and Protection*, 2018: Vol.10 No.1.
- Coastal Erosion Devastates Kenya's Kipini Village*. 15 August 2024. <https://evrimagaci.org/tpg/coastal-erosion-devastates-kenyas-kipini-village-19285?srsId=AfmBOonaw2BA6y9X2P8Sz47sC76ik1opsKhKSMJ487gEvapZMTsbUqW>.
- County Government of Tana River. *About Us*. 2024. <https://tanariver.go.ke/about-us/>.
- D. Araya et al. «Groundwater salinity in the Horn of Africa: Spatial prediction modeling and estimated people at risk.» *Environment International*, June 2023.
- Global Watersheds. *Watershed Data Report*. 20 March 2025.
- Global Wind Atlas. *Kenya*. 2024. <https://globalwindatlas.info/en/area/Kenya>.
- Government of Makueni County. *About Makueni County*. 2024. <https://makueni.go.ke/>.
- Groupe Huit. s.d.
- IPCC - Working Group 1: The Physical Science Basis. «IPCC Sixth Assessment Report - Summary for Policymakers.» 2021.
- J. Smaoui et al. «Salinity in African Countries: From Local Challenges to Global Solution.» 2024.
- Kamau, Faith. *Exploring Gender Dynamics in Decision-Making, Resource Access, and Labour among Agro-Pastoralists in Tana River, Kenya*. 29 January 2025. <https://clareprogramme.org/update/exploring-gender-dynamics-in-decision-making-resource-access-and-labour-among-agro-pastoralists-in-tana-river-kenya/>.
- Kenya News Agency. *Elderly persons in Kenya continue to face abuse*. 16 June 2023. <https://www.kenyanews.go.ke/elderly-persons-in-kenya-continue-to-face-abuse/>.
- Ministry of Gender, Culture, the Arts and Heritage. *Sanitary Towels Program*. 2024. <https://gender.go.ke/sanitary-towels-program/>.
- Mugai, Elisha Njue. «Salinity Characterization of the Kenyan Saline Soils.» *Soil Sci. Plant Nutr.*, 2003: 181-188.
- Murang'a County. «CIDP 2023-2027.» s.d.
- NEMA - GoK. «The National Solid Waste Management Strategy.» 2015.
- Nicholson, Sharon E. «Climate and climatic variability of rainfall over eastern Africa.» *Reviews of Geophysics*, 28 April 2017.
- People Who Are Vulnerable to Climate Change*. 09 04 2024. https://www.niehs.nih.gov/research/programs/climatechange/health_impacts/vulnerable_people#:~:text=In%20general%2C%20children%20and%20pregnant,events1%20%2C2%20%2C3%20
- Philip Kibet Langat, Lalit Kumar and Richard Koech. «Temporal Variability and Trends of Rainfall and Streamflow in Tana River Basin, Kenya.» *Sustainability*, 2017.
- Ps-Eau. «Les services d'eau face au changement climatique.» 2018.

- pS-Eau. «Services d'eau et d'assainissement face au changement climatique.» 2016.
- Robens Centre for Public and Environmental Health, University of Surrey . «The resilience of water supply and sanitation in the face of climate change - Technology fact sheets.» 2022.
- S. Oiro & J-C. Comte. «Drivers, patterns and velocity of saltwater intrusion in a stressed aquifer of the East African coast: Joint analysis of groundwater and geophysical data in southern Kenya.» *Journal of African Earth Sciences*, 2019: 334-347.
- State Department for Devolution. *General information - Background to Counties*. 2024. <https://www.devolution.go.ke/county-information>.
- T.E. Idowu & K.H. Lasisi. «Seawater intrusion in the coastal aquifers of East and Horn of Africa: A review from a regional perspective.» *Scientific African*, 2020.
- The World Bank Group. «Climate Risk Profile: Kenya.» 2021.
- . *Kenya*. 2025. <https://climateknowledgeportal.worldbank.org/country/kenya>.
- UNHCR. *Kenya*. 2024. <https://reporting.unhcr.org/operational/operations/kenya>.
- United Nations - UN Water. *SDG 6 Data*. 12 2024. https://www.sdg6data.org/en/country-or-area/kenya#anchor_6.2.1a.
- Walchem. *WALCHEM*. s.d. <https://www.walchem.com/managing-wastewater-temperature-in-the-water-treatment-process/>.
- WHO. «Cholera in the WHO African Region, weekly regional cholera bulletin: 1 April 2024.» 2024.
- . *Sand and dust storms*. 11 July 2024. <https://www.who.int/news-room/fact-sheets/detail/sand-and-dust-storms>.
- World Meteorological Organization. *New sand and dust forecast website launch*. 21 January 2022. <https://wmo.int/media/news/new-sand-and-dust-forecast-website-launched>.
- Yang et al. «The Annual Cycle of East African Precipitation.» *Journal of Climate*, 15 March 2015: 2385 - 2404.
- The promise of replenished aquifers in two Kenyan coastal cities, *13 January, 2023* <https://wsup.com/news/the-promise-of-replenished-aquifers-in-two-kenyan-coastal-cities/>
- Zheng, Y., Ross, A., Villholth, K.G. and Dillon, P. (eds.), 2021. *Managing Aquifer Recharge: A Showcase for Resilience and Sustainability*. Paris, UNESCO.