Integrated Water Resources Management (IWRM) Implementation based on a Case Study in the Mara River Basin, Kenya

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DISSERTATION

von

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aus Kericho, Kenia

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Kurzfassung

Die unzureichende Umsetzung von Integriertem Wasserressourcenmanagement (IWRM) in Flusseinzugsgebieten hat, insbesondere in den Entwicklungsländern, zu einer anhaltenden Verschlechterung der bestehenden Initiativen zum Wassermanagement sowie zu einer Eskalation diplomatischer Krisen in grenzüberschreitenden Flusseinzugsgebieten geführt. Wasserknappheit und die zunehmende nicht genehmigte Einleitung von Abwässern sowie die Entsorgung fester Abfälle in Gewässern und auf offenen Feldern haben die Verwirklichung einer guten Wasserbewirtschaftung weiter erschwert. Schlechte Planung, Bau, Betrieb und Wartung der Infrastruktur (wie zum Beispiel Wasserversorgungsnetz, Aufbereitungsanlagen, Wasserspeicher und Systeme zur Wiederverwendung von Wasser) haben zu einem gescheiterten Wasser- und Abwassermanagement beigetragen. Der Einsatz von moderner und innovativer Wasser- und Abwassertechnologie ist von großer Bedeutung für die Verbesserung der aktuellen Situation und die Prognose zukünftiger Entwicklungen.

Planung, Bau, Betrieb und Wartung von „High-Tech“ – Abwasserbehandlungssystemen sind nach wie vor eine Herausforderung für Entwicklungs- und Schwellenländer, insbesondere für diejenigen mit einer großflächigen ländlichen Siedlungsstruktur, die gekennzeichnet ist durch einen Mangel an zuverlässigen Energiequellen, komplexen Schwierigkeiten beim Anschluss von verstreut liegenden Haushalten, Gewerbe und Industrie an die Infrastruktur (z.B. Stromnetz, Leitungen für ungeklärtes und geklärtes Abwasser) und großen landwirtschaftlichen Flächen. Solche Projekte sind insbesondere bei Betrieb und Wartung aufgrund unzureichenden technischen Know-hows fehlender finanzieller Mittel und dem Mangel an Elektrifizierung oder Energiealternativen in ländlichen Gebieten weitgehend gescheitert. Der Fokus dieser Forschungsarbeit liegt daher auf Abwasserstabilisierungsteichen (WPS) und dem Potenzial für die Wiederverwendung des so behandelten Abwassers in ariden und semiariden Gebieten. Die Vorteile von WPS gegenüber anderen Abwasserbehandlungssystemen wurden bereits weltweit erforscht und demonstriert.

Der Kern dieser Arbeit besteht darin, einen Plan zur Wiederverwendung von Wasser innerhalb eines guten Wassermanagements zu entwickeln, das auf die Mikro-Ebene der Wasserwirtschaftung zugeschnitten und mit ihr kompatibel ist, um die unverzichtbare Rolle von Akteuren an der Basis zu veranschaulichen, die nachhaltig gestärkt werden müssen, z.B. technologisch, finanziell, durch aktive Einbeziehung und Kapazitätsaufbau, und deren Funktionsweise und Integrität durch regionale und nationale Interessengruppen geschützt werden muss. In dieser Arbeit werden zwei Fallstudien vorgestellt, nämlich das Mara River Basin (MRB) in Kenia und das Olifants River Basin (ORB) in Südafrika. Ein Vergleich zwischen Fallstudie 1 (MRB) und Fallstudie 2 (ORB) zeigt eine starke Parallele in Bezug auf Landnutzung /wirtschaftliche Aktivitäten sowie auf die Herausforderungen, die sich aus anthropogenen Aktivitäten usw. ergeben, wie insbesondere das Problem des zunehmenden Abwasservolumens und die daraus resultierende Notwendigkeit der Wiederverwendung von Wasser.

Water Governance sollte einen Multiplikatoreffekt auf grenzüberschreitender Ebene haben, wobei der Schwerpunkt auf Mikro-Governance (lokalen Interventionen) liegt. Dies ist ein überschaubarer Ansatz, der zunächst auf lokaler Ebene überprüft werden sollte, bevor er auf regionaler, nationaler und internationaler Ebene angewandt wird. Die Einbeziehung der Akteure in den Mikroeinheiten garantiert ein hohes Maß an Eigenverantwortung und Wertschätzung für die verfügbaren Wasserressourcen und Ökosystemdienstleistungen sowie die Sicherstellung, dass oben genannte Einrichtungen keinen Schaden nehmen. In der Studie wurden die Herausforderungen im Zusammenhang mit der Formulierung, Umsetzung und Überwachung der Leistung eines funktionierenden Wassermanagements im grenzüberschreitenden Flusseinzugsgebiet sowie die Möglichkeiten zur Verbesserung der derzeitigen Ansätze weiter untersucht. Verschiedene Ansätze der Wasserpolitik auf lokaler und internationaler Ebene wurden auf ihre praktische Vereinbarkeit mit den lokalen Gegebenheiten geprüft. Ein neues interaktives Water Governance-Modell, das Umbrella Programm wurde entwickelt. Interessen und Vorlieben verschiedener Wasserverbraucher sind spezifisch, vielfältig und heterogen und sollten daher eine essenzielle Rolle bei der Formulierung der Wasser-Governance-Modelle spielen. Die grenzüberschreitende Wasser-Governance ist daher ein umfassender diplomatischer Diskurs, der von allen Beteiligten innerhalb und außerhalb der Grenzen, einschließlich der lange Zeit ausgeschlossenen und sogenannten „unbedeutenden“ indigenen Gruppen und Minderheiten, geführt werden muss, um ihren Durst nach Wasserressourcen und anderen Umweltdienstleistungen zu stillen. Eine gute Wasser-Governance ist ein hochdynamisches System, das versagt oder ins Stocken gerät, wenn keine Echtzeitüberwachung und tatsächliche Synchronisation seiner Dynamik stattfindet. Es gibt keine Integration des Wasserressourcenmanagements ohne eine gute Wasserbewirtschaftung und keine gute Wasserregierung ohne ein ausgezeichnetes Mikro-Management.

Abwasser wird als vielfältig wiederverwendbare Ressource angesehen, die genutzt und für verschiedene Zwecke wie zur Bewässerung von Pflanzen, als landwirtschaftlicher Dünger, für die Aquakultur und zur Biogasherstellung als Quelle erneuerbarer Energie verwendet werden kann. Die Nutzung der wiederverwendbaren Elemente des Abwassers unter Einhaltung öffentlicher Gesundheitsstandards und -richtlinien zum Schutz der Arbeiter und Verbraucher der Endprodukte sowie der Umwelt ist ein Schritt in Richtung der Verwirklichung des IWRM-Paradigmas. Leider wird der größte Teil des Abwassers aus Abwasserbehandlungsanlagen in Kenia nur teilweise behandelt oder rohes Abwasser wird direkt in offene und ungeschützte künstlich errichtete Becken, auf offenen Felder, in Flüsse und andere aufnehmende Gewässer eingeleitet. Pläne zur Wiederverwendung von Wasser sollten der Weg in die Zukunft sein, um die Herausforderungen sowohl der nicht genehmigten Einleitung von Abwasser oder von Fäkalien als auch der des Wasserstresses zu bewältigen und eine „Win-Win-Situation“ zu erreichen. Das behandelte Abwasser, z.B. aus Abwasserstabilisierungsteichen (WPS) könnte den Landwirten zugeteilt werden, deren Ernte insbesondere in ariden und semiariden Gebieten des Mara River Basin unter Wasserknappheit leidet. Dies könnte durch einen integrierten Plan zur Zuweisung von behandeltem Abwasser und Exkrementen (TEA-Plan) erreicht werden, um die bestehenden Pläne zur Zuteilung von Wasser zu erweitern und in diese zu integrieren, und das Problem des Wasserstresses und der Wasserknappheit insbesondere auf der Ebene von Teileinzugsgebieten anzugehen. Der TEA-Plan beinhaltet ein detailliertes Konzept für die Wiederverwendung des Abwassers, das bestimmte Qualitätsstandards erfüllt, die international oder lokal definiert wurden und weitergehend akzeptiert werden, anstatt es willkürlich in aufnehmende Gewässer abzuleiten, wie dies

weitgehend der aktuellen Situation im Einzugsgebiet des Flusses Mara entspricht. Diese Standards können nicht erreicht werden, ohne ein verbessertes Behandlungssystem sowie örtliche, abgestimmte und genau überwachte Maßnahmen vor und nach der Abwasserbehandlung, die die spezifische Situation vor Ort berücksichtigen. Der TEA-Plan beinhaltet die Maximierung der Wiederverwendung von Abwasser, wodurch ein positiver Beitrag zur Minimierung der Frischwasserentnahme für landwirtschaftliche Tätigkeiten geleistet wird, ohne die Qualität des Endprodukts zu beeinträchtigen. Die Anpassung an und Einbeziehung des TEA-Plans in strategische Pläne für Wasserressourcen in Flusseinzugs- oder Untereinzugsgebieten erfordert eine genaue Beachtung der folgenden wesentlichen Punkte: (i) die typischen Verbreitungswege von Abwasser und Exkrementen, (ii) ein integrierter TEA-Plan-Modellierungsrahmen, (iii) spezifische Ziele des TEA-Plans, (iv) die Bausteine des TEA-Plans, (v) ein Plan zur Überwachung und Bewertung (M & E) für die Wiederverwendung des behandelten Abwassers und der Exkremente, (vi) ein Plan zur Bewertung von Unsicherheitsfaktoren etc.

Der TEA-Plan als Ansatz zur Verbesserung der Wasserresourcenmanagements auf Einzugsgebietsebene und sein Beitrag zu guter Wasser-Governance sind in dieser Arbeit ausführlich dargestellt.

Abstract

Poor performance on Integrated Water Resources Management (IWRM) in the river basins especially in the developing countries has led to continued deterioration of the existing water governance initiatives, as well as escalation of diplomatic crises in the transboundary river basins. Water scarcity and increased unregulated wastewater and solid waste disposal into the receiving water bodies and open fields has further derailed realization of a good water governance. Poor design, construction, operation and maintenance of the infrastructural systems (such as conveyance network, treatment works, storage facilities, and water reuse schemes, etc.) has culminated into a failed or poorly performing water and wastewater management program(s). The use of modern and innovative water and wastewater technology is without a doubt of great importance in the assessment of the current situation and projection of the future scenarios.

Design, construction, operation and maintenance of "*high tech*" wastewater treatment systems have remained a challenge to the developing and emerging economies especially those with vast rural setting characterized with lack of reliable source(s) of energy, complexity in laying down distribution systems (e.g. power gridline, sewer lines, treated effluent conveyances, etc.) to the scattered households, commercial activities, industries, and big tracts of agricultural lands. Such systems have largely failed especially in the operation and maintenance due to the insufficient technical knowhow, financial shortcomings and lack of rural electrification or energy alternatives etc. As a result, a special focus is made in this research on the wastewater ponds systems (WPS) and the subsequent treated effluent for the reuse purposes especially in arid and semi-arid lands. Advantages of WPS over the other wastewater treatment systems have largely been researched on and demonstrated in the world today.

Therefore, the core of this work is to develop a water reuse plan and a good water governance scheme that is customized and compatible with the micro-water-governance levels to illustrate the inevitable role played by the grassroots stakeholders. The role(s) of local stakeholders is achieved through constant empowerment (e.g. technologically, financially, through active engagement and capacity building etc.) and protection of their operation and integrity by the regional and national stakeholders. Two case studies are presented in this work, namely, Mara River Basin (MRB) in Kenya and Olifants River Basin (ORB) in South Africa. A comparison between case study 1 (MRB) and case study 2 (ORB) shows a strong replication of characteristics in terms of land use/economic activities as well as the challenges emanating from anthropogenic activities, etc. and most specifically the pressure originating from the increasing volume of wastewater and the subsequent need for water reuse.

Water governance should mimic the snowball effect at the transboundary scale with an emphasized efforts directed towards micro-governance (local/small-scale interventions). This is a manageable chunk that should first be verified on the local level development before getting to the regional, national and international levels. Engaging the actors at the micro-units guarantees high level if not full ownership and appreciation of the available water resources and eco-services as well as "jealously" guarding aforementioned services from any source of degradation. The research has further evaluated the challenges associated with formulation, implementation and monitoring the performance of water governance at the transboundary river basin as well as possibilities of improving the current approaches. Different water governance principles locally and internationally have been scrutinized on their practical compatibility with the local realities. A new interactive umbrella scheme of water governance model has been developed. Tastes and preferences of different water consumers are so unique, multiplex and heterogeneous and should therefore play an inevitable role in formulating the water governance models. Transboundary water governance, therefore, is an all-inclusive diplomatic discourse that must be addressed by all stakeholders within and beyond borders, including the long excluded and the so called "insignificant" indigenous and minority groups to quench their thirst for water resources and other environmental services. A good water governance is a super dynamic system that is bound to fail or stall if real-time monitoring and actual synchronization of its dynamism is not observed. There is no Integration of Water Resources Management without good water governance and no good water governance without a distinguished micro-governance.

Wastewater is regarded as full of re-usable resources which could be harnessed and re-directed to various uses such as crops irrigation, agricultural manure, aquaculture, and biogas as source of renewable energy among other uses. The extraction of the re-usable elements of wastewater, and subjecting them under public health standards and guidelines in order to protect the handlers, and consumers of the end products as well as the environment is a score towards the realization of the IWRM paradigm. Unfortunately, most of the effluent from wastewater treatment systems in Kenya are more often partially treated or raw sewage is discharged directly into the open and unprotected man-made pools, open fields, rivers and other receiving water bodies. Water reuse plan should be the way forward to alleviate the challenges of both unregulated discharge of wastewater and excreta and water stress so as to attain a "win-win situation." The treated effluent e.g. from wastewater ponds system (WPS) could be allotted to the farmers whose crops suffer water scarcity especially in arid and semi-arid lands of Mara River Basin. This could be achieved through an integrated treated effluent and excreta allocation plan (TEA-Plan) in order to augment and integrate with the existing water allocation plans and to address the water stress and scarcity issue especially at sub-basin levels. The TEA-Plan involves a detailed design on the reuse of the effluent that has acquired certain quality standards – defined internationally or locally and standards that are widely acceptable – instead of haphazardly discharging it to the receiving water bodies as is largely the current situation in Mara river basin. These standards cannot be achieved in the absence of an upgraded treatment system as well as localized, synchronized and closely monitored pre and post treatment measures that will address the unique local situation. The TEA-Plan involves maximization of the wastewater reuse thereby contributing positively towards minimization of freshwater abstraction for agricultural activities without compromising the quality of the end product. Customization and incorporation of the TEA-

Plan in any river basin or sub-basin level water resources strategic plans, requires keen observation of the following essentials; (i) the typical generation and propagation wastewater and excreta routes, (ii) integrated TEA-Plan modelling framework, (iii) specific objective(s) of the TEA-Plan, (iv) the building blocks of the TEA-Plan, (v) monitoring and evaluation (M&E) plan for the reuse of the treated effluent and excreta, and (vi) uncertainty assessment plan among other considerations.

The TEA-Plan as an approach to improving water resource management at the catchment area level and its contribution to good water governance are presented in details in this work.

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Dedication

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Continue experiencing the Perpetual Light in the heavenly *magnificentia* my mother Dr. Beatrice Wangui Githua! You consistently encouraged me through this journey but your curtain fell just before witnessing the light of this tunnel.

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List of Acronyms

Acronym	Meaning
ADCP	Acoustic Doppler Current Profiler
AfDB	African Development Bank
ASALs	Arid and Semi-Arid Lands
ASP	Activated Sludge Process
AWA	Australian Water Association
AWARD	Association for Water and Rural Development
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BOD	Biological Oxygen Demand
BOMWASCO	Bomet Water and Sewerage Company
BWRC	Basin Water Resources Committee
CBD	Central Business District
CBOs	Community Based Organizations
CEAP	County Environment Action Plan
CEC	County Environment Committee
CFU	Colony-forming Unit
CIDP	County Integrated Development Plan
CMAs	Catchment Management Agencies
CMGs	Catchment Management Groups
CMS	Catchment Management Strategies
CSIRO	Commonwealth Scientific and Industrial Research Organization
CWSPs	Cross-County Water Services Providers
CWSS	Community Water Supply Schemes
DMAs	District Meter Areas
DPR	Direct Potable Water Reuse
DWA	Department of Water Affairs
DWRP	Durban Water Recycling Project
DWS	Department of Water and Sanitation
E.coli	*Escherichia Coli*
EDCP	Effluent Discharge Control Plan
EMCA	Environmental Management and Coordination Act
ESR	Effluent Storage Reservoirs
EU	European Union
EWS	eThekwini Water Services
FAO	Food and Agriculture Organization

FDC	Flow duration curve
FDEP	Florida Department of Environmental Protection
FGDs	Focus Group Discussions
FWEA	Florida Water Environment Association's
GDP	Gross Domestic Product
GWRP	Goreangab Biological Wastewater Treatment Project
ICT	Information and communication technology
IEEM	Institute of Environmental Engineering and Management
IEEP	Institute for European Environmental Policy
IoT	Internet of Things
IRWD	Irvine Ranch Water District
IUCN	International Union for Conservation of Nature
iUWG	Interactive Umbrella Scheme of Water Governance
iWaGSS	Integrated Water Governance Support System
IWRM	Integrated Water Resources Management
KENAFF	Kenya National Farmers' Federation
KEWI	Kenya Water Institute
KWCA	Kenya Wildlife Conservancies Association
LLP	Local Level Performance
LVBC	Lake Victoria Basin Commission
LVSCA	Lake Victoria South Catchment Area
M & E	Monitoring and Evaluation
MaMaSe	Mau-Mara Serengeti
MHV	Mouse hepatitis viruses
MMWCA	Maasai Mara Wildlife Conservancies Association
MOSA	Middle Olifants South Africa
MRB	Mara River Basin
MSMEs	Micro, Small to Medium Enterprises
MWI	Ministry of Water and Irrigation
NAIS	Northern Adelaide Irrigation Scheme
NCCAP	National Climate Change Action Plan
NDP	National Development Plan
NEAP	National Environmental Action Plan
NEMA	National Environment and Management Authority
NEP	National Environment Policy
NFNSP	National Food and Nutrition Security Policy
NGOs	Non-Governmental Organizations
NGWRP	New Goreangab Biological Wastewater Treatment Project
NIPF	National Industrialization Policy Framework
NSWMS	Kenya National Solid Waste Management Strategy
NTU	Nephelometric Turbidity Unit
NWA	National Water Act
NWA	National Water Act

NWP	National Water Policy
NWP	National Water Policy
NWR	Non-Revenue Water
NWSA	National Water Storage Authority
NWSMP	National Water and Sanitation Master Plan
O & M	Operation and Maintenance
OECD	Organization of Economic Corporation and Development
ORB	Olifants River Basin
PETRO	Pond Enhanced TReatment and Operation
PPPP	Power of Public-Private Partnership
QGIS	Quantum Geographic Information System
RCMRD	Regional Center for Mapping of Resources for Development
RGS	River Gauging Station
RW	Raw Water
SACCO	Savings and Credit Co-operative
SafiSan	Safi Sanitation
SAPREF	South African Petroleum Refinery
SAR	Sodium Absorption Ratio
SARS	Severe Acute Respiratory Syndrome
SCMP	Sub-Catchment Management Plan
SDGs	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences
STEGRO	Sotik TEa GROwers
SuSanA	Sustainable Sanitation Alliance
SWP	Sustainable Water Partnership
TCTA	Trans-Caledon Tunnel Authority
TEA-Plan	Treated Effluent and Excreta Allocation Plan
TEMS	Treated Effluent Management Strategy
TF	Trickling Filter
TGEV	Transmissible gastroenteritis viruses
TSE	Treated Sewage Effluent
UASB	Up-flow anaerobic sludge blanket reactor
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
US EPA	United States Environmental Protection Agency
USAID	United States Agency for International Development
UV	Ultraviolet
WASREB	Water Services Regulatory Board
WBs	Water Boards
WDC	WRUA Development Cycle
WHO	World Health Organization
WIM	Water Intervention Module
WMAs	Water Management Areas

WoFaAK	Women Farmers Association of Kenya
WPS	Wastewater Ponds System
WRA	Water Resources Authority
WRC	Water Research Commission
WRM	Water Resource Module
WRM	Water Resources Management
WRUA	Water Resources Users Association
WSA	Water Services Act
WSPs*	Water Service Providers
WSS	Water and Sanitation Services
WSTF	Water Sector Trust Fund
WSTR	Wastewater Storage and Treatment Reservoirs
WTE	Water Trading Entity
WUAs	Water Users Associations
WUM	Water Utilization Module
WWDAs	Water Works Development Agencies
WWF-ESARPO	Worldwide Fund for Nature Eastern & Southern Africa Regional Programme Office

List of Symbols

Symbol	Meaning	SI-Unit
$L_{\mathrm{d,COD,IP}}$	Daily load of COD at the influent of the pond	Kg/d
$C_{\mathrm{CSB,EP}}$	Concentration of COD at the effluent of the pond	mg/L
$C_{\mathrm{CSB,IP}}$	Concentration of COD at the influent of the pond	mg/L
f_{Sol}	Factor for consideration of solar radiation	-
ηCSB	Share of degraded COD load in the daily load of COD in the influent	%
T_{A}	Air temperature	°C
T_{W}	Water Temperature	°C
$L_{\mathrm{A,COD}}$	Areal COD loading rate	$g/(m^2 \cdot d)$*
$L_{\mathrm{V,COD}}$	Volumetric COD loading rate	$g/(m^3 \cdot d)$
$Q_{\mathrm{DW,d,aM,IP}}$	Daily wastewater inflow into pond as annual mean	m^3/d
SR	Solar radiation	W/m^2
η_{COD}	COD reduction	%
$L_{\mathrm{v,COD}}$	Permissible COD volume loading	$kg/(m^3.d))$
$C_{COD,EP}$	Effluent COD concentration	mg/L
$V_{\mathrm{P,req.}}$	Required pond volume	m^3
$\mathrm{A}_{\mathrm{P,req}}$	Required area	m^2
$Q_{\mathrm{d_{av}}}$	Average domestic sewage flow	m^3/d or L/s
L_{pcd}	Per capita water consumption	L/inhabitant/day
R	Return Coefficient	%
λ_v	Volumetric organic loading	g BOD_5/m^3
L_i	Influent BOD_5	mg/L
Q	Influent flow rate	m^3/d
V	Pond volume	m^3
t_{an}	Retention time	hours or days
Concin	Concentration in	Mg/L
Concout	Concentration out	Mg/L
N_c	Number of faecal coliforms/100 ml of effluent	coliforms/100ml
N_i	Number of faecal coliforms/100ml of influent	coliforms/100ml
K_b	First-order rate constant for faecal coliform removal	d^{-1}
T	Retention time in any pond	d
$t_{\mathrm{m_n}}$	Retention time in the nth maturation pond	hours or days
ET_c	Crop evapotranspiration	mm d^{-1}
$ET_o\,[t]$	Reference evapotranspiration	mm d^{-1}

K_c	Crop coefficient	-
$K_{C\,ini}$	Initial crop coefficient	-
$K_{C\,mid}$	Mid-crop coefficient	-
$K_{C\,end}$	End crop coefficient	-
$K_s\,[t]$	Dimensionless transpiration reduction factor	-
P_o, P_1, P_2	Population in the years t_o, t_1, t_2	Years
P_t	Population estimated for year t (inhabitants)	Years
P_s	Saturation population (inhabitants)	Years
K_a, K_g, K_d, K_l, i, c, r, s	Regression analysis coefficients	-
H_o	Null hypothesis	
S	Statistical symbol that indicates an upward trend/positive value or downward trend/negative value	
Z	Standard normal variate	
F_N	Standard normal cumulative distribution function	
DALY	Disability-Adjusted Life Years	per person per/yr.
YLL	Years of life lost	Years
YLD	Years lived with a disability or illness	Years
BSB_5	Organic substrate for the growth of microorganisms	mg/L
COD	Chemical Oxygen Demand	mg/L
TOC	Total Organic Carbon	mg/L
PAC	Polialuminium chloride	
GAC	Granular Activated Carbon	

Chemical Symbols

N	Nitrogen	kg/m^3
P	Potassium	mmol/L
K	Calcium	mmol/L
Fe	Iron	µmol/L
Mg	Magnesium	mmol/L
As	Aluminiums	kg/m^3
Cd	Cadmium	
Cr	Chromium	kg/m^3
Cu	Copper	µmol/L
Hg	Mercury	µmol/L
Ni	Nickel	µg/L
Pb	Lead	µmol/L
Zn	Zinc	µmol/L
S	Sodium	mmol/L
$N\text{-}NH_4$	Ammonium	mg/L

$CO(NH_2)_2$	Urea	mmol/L
H_2O	Water	L or m³ or gallons
NH_4^+	Ammonium ion	$g{\cdot}mol^{-1}$
OH^-	Hydroxide	$g{\cdot}mol^{-1}$
HCO_3^-	Hydrogen carbonate	$g{\cdot}mol^{-1}$
H^+	Hydrogen ion	$kJ.mol^{-1}$
NO_2^-	Nitrite ion	$g{\cdot}mol^{-1}$
NO_3^-	Nitrate ion	$g{\cdot}mol^{-1}$

Chapter 1

Introduction

1.1 Background Information

The assessment of the implementation of IWRM involves establishing practical model(s) that are acceptable by all actors and customized to the specific region(s) of interest where water and wastewater management and development is to be executed. Through this, the levels of implementation of IWRM are obtained through active rolling out of the aforementioned models coupled by constant and systemic upgrade and synchronization with the existing relevant policy framework. There are various challenges that have faced such progress in different countries since the conception of IWRM paradigm. These pitfalls span from natural causes (e.g. climate change/global warming) to anthropogenic causes (e.g. land use changes etc.). The water Governance structure and inclusivity in its realization affects IWRM directly.

It is estimated that a global warming of 2 degrees Celsius could lead to a situation where 1 to 2 billion more people may no longer have enough water to meet their consumption, hygiene and food needs and between 100 million and 400 million more people could be at risk of hunger (AFTHD and DECRG, 2009). Although climate change is the major force behind water scarcity, a significant amount of water stress is caused by pollution from the growth of wastewater and run-off from expanding cities, much of it only partially treated, from the release of agricultural fertilizer, and from the contamination of aquifers from various sources (FAO, 2010). Additionally, the growing of the world population has led to increased water demand hence making more countries to be categorized as water scarce countries. It is estimated that more than 40% of the world's population in the next 50 years will live in countries facing water stress or scarcity (WHO, 2006).

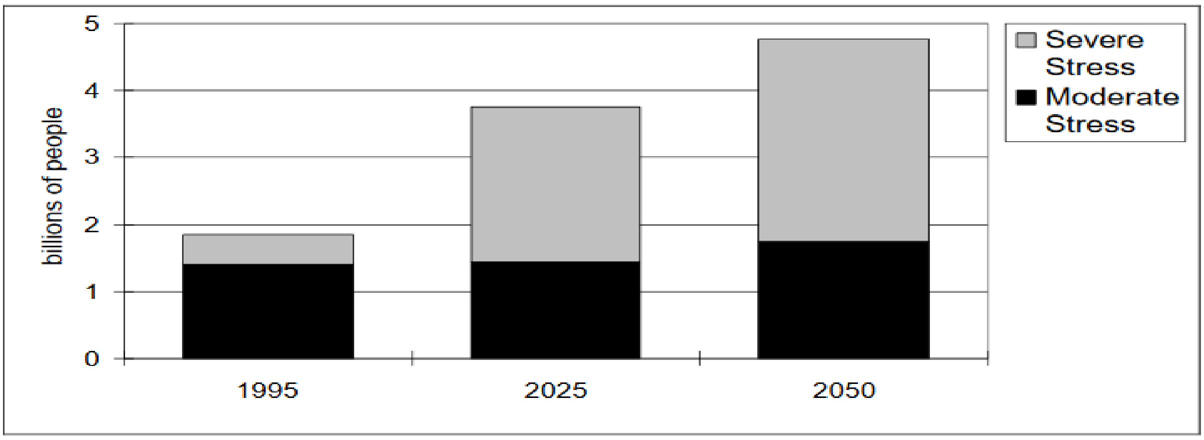

Figure 1.1: World population in water stress, 1995-2050
Source: (Raskin et al., 1998)

The world faces another challenge of both liquid and solid waste that keeps on escalating the issue of poor water quality and the subsequent health risks to the consumers of both water and food grown or obtained from such contaminated water. The world generates 2.01 billion tonnes of municipal solid waste annually, with at least 33 percent of that—extremely conservatively—not managed in an environmentally safe manner and it is globally estimated that, waste generated per person per day averages is 0.74 kilogram but ranges widely, from 0.11 to 4.54 kilograms (World Bank, 2020). Therefore, global waste is expected to grow to 3.40 billion tonnes by 2050, more than double population growth over the same period (World Bank, 2020). Solid waste include all non- liquid wastes generated by human activity and a range of solid waste material resulting from the disaster (WHO, 2011). In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned hence creating serious health, safety, and environmental consequences (World Bank, 2016).

Box 1.1: The escalation of the unregulated wastewater and excessive sediments among other types of solid wastes disposal in the world today is due to the pressure emanating from;

- Human population growth,
- Increased demand on the natural resources such as water, timber, fertile soil for agriculture etc.
- Urbanization,
- Poor and unsynchronized policies,
- Frail stakeholders' linkages,
- Lapses in operationalization of policies as well as action plans,
- Poor or lack of stakeholders' sensitization programs,
- Lack of real-time technological and innovative systems and tools in place, etc.

Unregulated wastewater from both point and non-point sources has increased due to emergence and expansion of commercial centers, open markets, slaughter houses, hospitals, bathing and car washing in and at the banks of water points among others. Poorly managed waste serves as a breeding ground for disease vectors, contributes to global climate change through methane generation, and can even promote urban violence (World Bank, 2016).

Although Kenya has banned the use of plastic bags in the recent past, the rate of non-biodegradable waste generation and disposal is still high as the country moves to the level of a middle income generation state. There is still illegal production of plastic bags in Kenya and the challenge of the already accumulated plastic waste in most of the urban and peri-urban open public gathering places, bushes, by the roadsides, near and in the water bodies etc. is yet to be resolved e.g. through collection and recycling. Waste collection and separation is a critical step in managing waste. Sub-Saharan Africa collects about 44 percent of waste while Europe and Central Asia and North America collects at least 90 percent of waste (World Bank, 2020).

1.2 IWRM paradigm

Integrated Water Resources Management (IWRM) is considered state-of-the-art in water resources management. It is a cross sectoral approach for coordinated management and development of land, water and other related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising ecosystem sustainability (Global Water Partnership, 2000). The cross-sectoral integration involves the three pillars of IWRM, namely, an enabling environment, roles played by institutions and management instruments (Global Water Partnership, 2010). IWRM is based on three principles (3Es) of social equity, economic efficiency and ecological sustainability (Jønch-Clausen, 2004). These principles form a method of analyzing and subsequently managing water resources in a way that leads to a coordinated outcome (Philip et al., 2008).

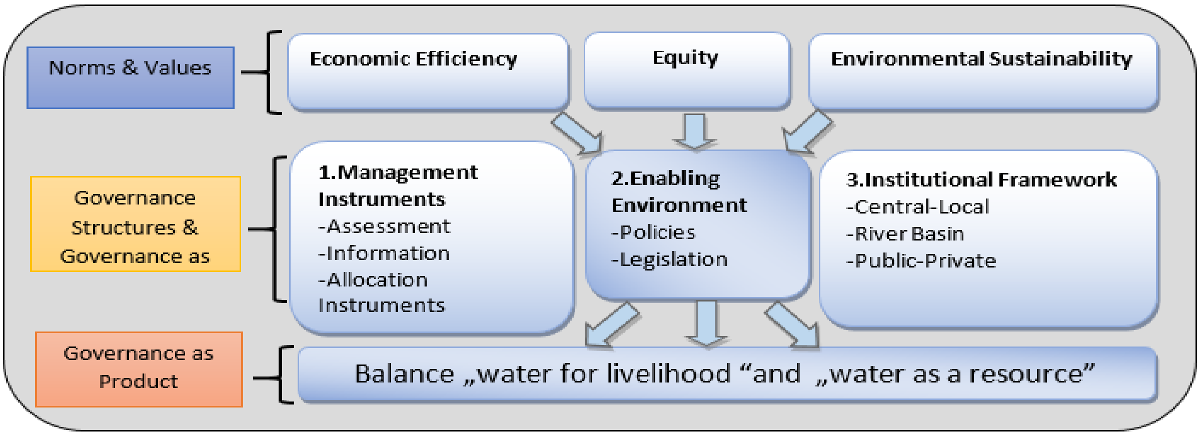

Figure 1.2: The "three pillars" of IWRM
Source: (Jønch-Clausen, 2004; Funke et al., 2007) for Global Water Partnership, (Adapted from (Pahl-Wostl, 2002)

"Integrated" undoubtedly designates that resources management should be approached from an expansive perspective, taking all potential trade-offs and different scales in space and time into account. However, implementation of integrated resources management that fully accounts for the complexity of human-technology-environment systems has yet to be realized (Pahl-Wostl, 2002). The concept of IWRM is essentially a response to the much criticized top-down sectoral approach to water management (Pahl-Wostl et al., 2007). The IWRM ToolBox (*https://www.gwp.org/en/learn/iwrm-toolbox/About_IWRM_ToolBox/*), launched in December 2001, has been designed as an information management system on integrated water resources management to help politicians, water professionals and other stake holders assess their options and decisions based on IWRM approaches (Global Water Partnership, 2003). The IWRM ToolBox combines three main areas of policy tools to form the integrated approach, namely, (1) the enabling environment (A) that establishes the rights and assets of all stakeholders (individuals as well as public and private sector organizations and companies, women as well as men, the poor as well as the better off), while ensuring for environmental quality, (2) institutional arrangements (B) where the current water crisis is mainly a crisis of governance, much more than a crisis of water shortage or water pollution per se, and (3) management instruments (C) which are specific methods that enable decision makers to make rational and informed choices when it comes to water management and to tailor their actions to specific situations (Global Water Partnership, 2018). The IWRM approach in developing countries must be handled very differently from industrialized countries; it should be handled on a case by case basis due to the uniqueness of different regions.

Regional and national institutions must develop their own IWRM practices with regard to the relevant context (Global Water Partnership, 2000). Therefore, in order to customize the IWRM concept and enhance its practicality, various models have been conceived by various institutions and researchers e.g. a modular IWRM model (Figure 1.3) developed during Phase 1 of Middle Olifants South Africa, MOSA project (Rudolph et al., 2011) etc. The model consists of three intertwined modules, namely, (i) Water Resource Module, WRM, to calculate the available yield, (ii) Water Utilization Module, WUM, to derive technical, economic and institutional measures, and (iii) Water Intervention Module, WIM, to improve the water situation and secure a sustainable management of the water resources (Hilbig et al., 2016a).

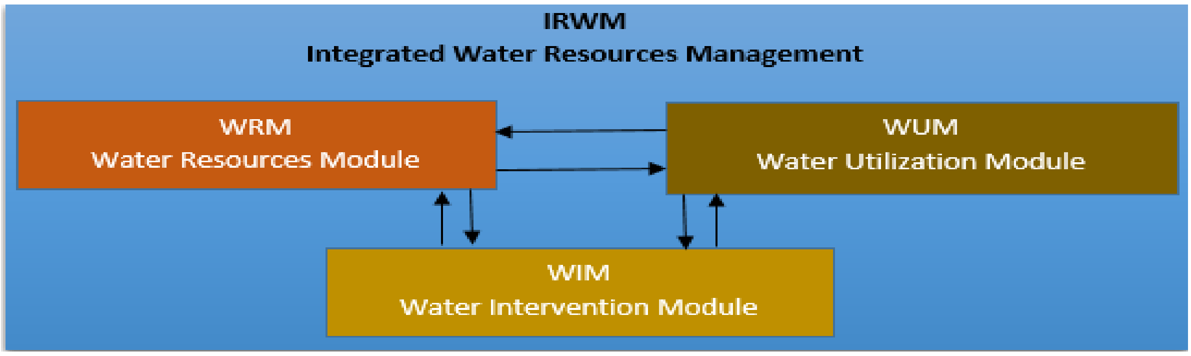

Figure 1.3: Modular IWRM Concept
Source: (Hilbig et al., 2016a)

Many of the world's socio-economic systems are becoming linked at an unprecedented rate. The impacts of extreme climates in flood and drought conditions are increasingly witnessed (Easterling et al., 2000). It is within this setting that water managers need to manage an increasingly scarce resource that varies greatly in space and time. The pressures and complexity that water managers face are huge. IWRM processes will therefore need to be responsive to change and be capable of adapting to new economic, social and environmental conditions as well as to changing human values (Pahl-Wostl et al., 2007). The large uncertainties usually connected to water management with respect to the physical settings, climate, socio-economic and political environment make it difficult to develop a consistent water management strategy (Van der Keur et al., 2008). UN-Water, 2018 shows that IWRM implementation on SDG 6.5.1 ranges between very low to medium high in most of the developing countries where both Kenya and South Africa performance is "medium high" (Figure 1.4). Poor performance in IWRM is the main reason contributing towards poor water governance nationally and locally. The implementation of sustainable IWRM measures is a necessary step towards an economic, social and environmental sustainable management of scarce water resources (Hilbig et al., 2016b). The issue of water stress in river basins and escalating pollution (e.g. from untreated wastewater and excreta, agrochemicals, excessive sedimentation etc.) of the water bodies requires very strong water governance especially micro-water-governance, to enhance the performance of various institutions and stakeholders vertically and horizontally.

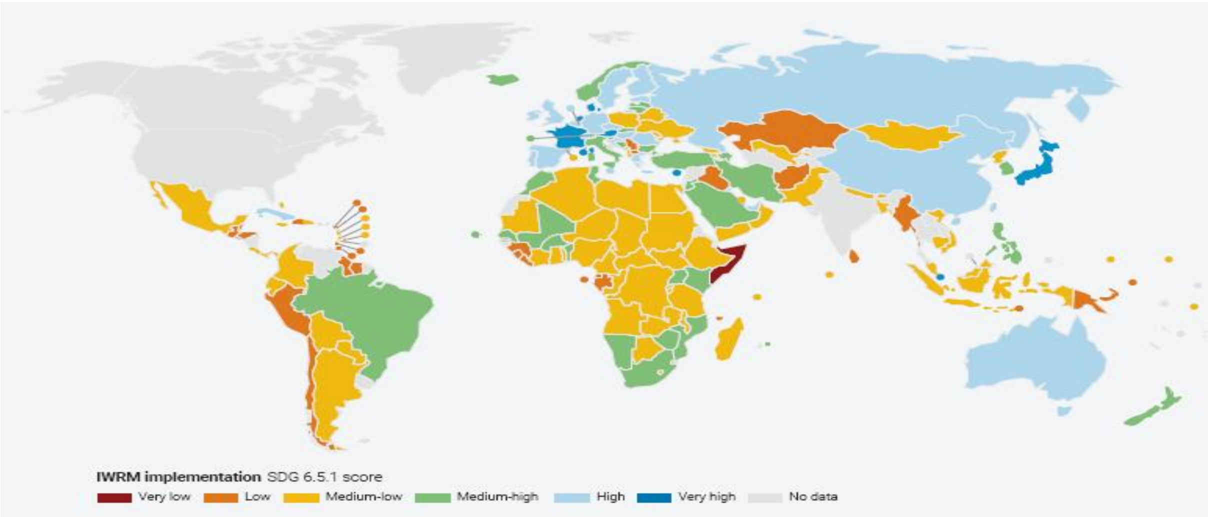

Figure 1.4: Country implementation of IWRM
Source: (UN-Water, 2018)

1.3 Goal Setting and Approach

This research is geared towards developing tools for the assessment and implementation of IWRM paradigm in the river basins. This is fueled by a current list of uncertainty and slow implementation of IWRM, which has led to continued poor performance on the water governance and increased unregulated wastewater and poor management in the receiving water bodies, etc. The poor performance on the water governance is characterized mainly by discontent among the local stakeholders, transboundary water diplomatic crises, and poor water and wastewater management. In order to achieve the target of this study, there has been (I) establishment and assessment of the current IWRM paradigm level of implementation vis-à-vis its performance in the case study areas, and (II) a possibility to disseminate these findings to another river basin with the same or almost the same underlying challenges and potentials. There are several drivers that could be explored in order to unlock the current stalemate that has led to poor performance and slow implementation of IWRM. This research zeroed in on two essential drivers that could be instrumental towards unlocking the existing stalemate, namely, (i) micro-water-governance, and (ii) water reuse.

1.3.1 Motivation Towards Micro-Water-Governance

Global Water Partnership, 2000 recommended that, "*regional and national institutions must develop their own IWRM practices with regard to the relevant context*." This context should reflect local conditions and foster coordination between different scales (OECD, 2015). Local stakeholders are the bottom water governance stronghold due to the fact that they directly interact with the water and wastewater situation on the ground and therefore are in a better position to either protect or destroy these resources. The local stakeholders' natural strategic position at the bottom and the most important segment in the water governance hierarchy should positively be capitalized to enhance water governance at the local realms. There are several milestones that should still be explored to enhance micro-water-governance e.g. "*Seven Sins in Local Water Management*" (Rudolph et al., 2020) or the seven success factors in local water management.

1.3.2 Motivation Towards Water Reuse

It is estimated that around 90% of all wastewater in developing countries is discharged untreated directly into receiving water bodies e.g. rivers, lakes or the oceans etc. (UN-Water, 2008) and less than 1% of wastewater is treated in sub-Saharan Africa (Keraita et al., 2010), yet wastewater in 3 out of 4 cities in developing countries is used for irrigation without any effective treatment (Jiménez and Asano, 2008; Keraita et al., 2008). In many West African cities, more than 90% of vegetables consumed are grown within the cities, which implies that a high proportion are grown using untreated urban wastewater (FAO, 2010). At least 10% of the world's population is thought to consume food irrigated by wastewater (WHO, 2019) and around 2·8 billion people, mostly in developing countries, currently lack adequate sanitation (Mara and Broome, 2008) though there has been a positive trend with (WHO, 2019) reporting 2.0 billion people without basic sanitation facilities. More billions of people therefore faces outbreak of waterborne diseases and deaths due to the consumption of contaminated food and water. United Nations, 2015 in sub-section 6.3 of its SDG 6 aims at, improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally by 2030. This is also expected to reduce high transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid and polio brought by poor sanitation (WHO, 2019). In many cities of Asia, Africa, and Latin America, engineered wastewater collection systems and wastewater treatment facilities are nonexistent (Metcalf et al., 2007).

Box 1.2: Sanitation is defined as access to and use of facilities and services for the safe disposal of human urine and faeces. A safe sanitation system is defined as a system that separates human excreta from human contact at all steps of the sanitation service chain from toilet capture and containment through emptying, transport, treatment (in-situ or off-site) and final disposal or end use (WHO, 2018)

There are various components of the sanitation service chain as illustrated by e.g. (WHO, 2018), (see Figure 1.5).

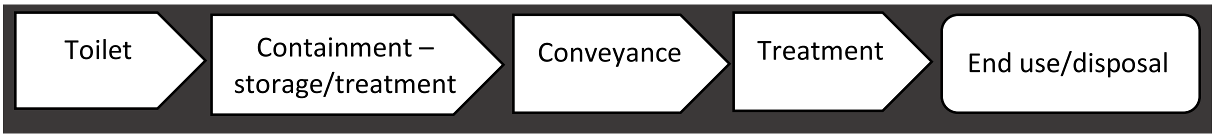

Figure 1.5: Sanitation service chain
Source: (WHO, 2018)

Increased interest in wastewater reuse in many parts of the world is occurring in response to growing pressures for high quality, dependable water supplies by agriculture, industry and the public (Asano and Levine, 1996), due to increasing water scarcity affected by climatic changes as well as the overwhelming water consumption demand for human activities, wildlife and ecosystem at large. Arid and semi-arid sections of the river basins of the world could utilize the opportunity of harnessing wastewater for reuse in crop farming activities etc. in their respective regions. Transboundary river basins like Mara and the Olifants in Kenya and South Africa respectively – which forms our area of focus – are even more water and wastewater stressed. This is due to their highly populated and complex network of stakeholders that have different cultural backgrounds, and tastes and preferences that affect their water consumption behavior. Both basins have a far reaching impacts – positive and/or negative – to the countries downstream as well as other intertwined river basins and water bodies. As such, a clear, participative, comprehensive and equitable treated effluent and excreta allotment plan will act as one of the vital driver towards improving the current trend of unregulated and direct wastewater discharge to the receiving water bodies by cultivating a positive behavior of harnessing nutrients-rich and reusable wastewater and sludge etc.

Impact of wastewater discharges to water bodies include pollution by organic matter (dissolved oxygen consumption), contamination by pathogenic microorganisms (bacterial die-off), and pollution of lakes and reservoirs (eutrophication, caused by nitrogen and phosphorus) (Von Sperling, 2007). Water resources planners have come to realize that there are great values of wastewater reuse ranging from water conservation, nutrients recycling, and as a prevention mechanism for the surface and ground water (WHO, 1989). The "Big Five R's" namely, recycling, reuse, reclamation, recovery and renovation (Shelef, 1991) are still "*alive*" – but not "*kicking*" as expected – in the efforts of addressing the ever growing volumes of wastewater and excreta. There are some countries mostly those dominated by arid and semi-arid regions – e.g. Saudi Arabia, Israel, Jordan, Peru etc. – which have government policies to reuse all treated effluent for crop irrigation etc.(WHO, 1989). These countries should be emulated by Kenya, South Africa and other countries with similar challenges.

This research therefore sought;

- To elaborate approaches for the good water governance to enhance Local Level Performance (LLP) in the Transboundary Mara River Basin, Kenya
- To evaluate the value of reuse water as a driver towards IWRM implementation in the Transboundary Mara River Basin, Kenya.
- To demonstrate symbiotic transfer of technology and concepts such as innovative water governance concept from lower Olifants River Basin through Integrated Water

Governance Support System (iWaGSS) project in South Africa and transfer water reuse plan from Mara River Basin, Kenya to the Olifants River Basin, South Africa

The literature review on water issues in Kenya and most specifically the case study area is geared towards demonstrating the current state of art and so therefore present a benchmark from which this research is pegged on. This involves establishing (1) present development on principles, guidelines and procedures for the allocation of water resources and the failures thereof, (2) whether the monitoring systems and reassessment of the national water resources management strategy is done time to time, (3) whether there are proper regulations in place and protection of water resources quality from adverse impacts, (4) whether all stakeholders are involved for the better regulation and management of water resources, (5) political good will and societal support towards realization of IWRM, and (6) whether or not there is available information in terms of relevant data for the implementation of IWRM within the case study area, among other issues.

1.4 The Integrated Water Governance Support System (iWaGSS) Project

iWaGSS project operated under the auspices of the Bundesministerium für Bildung und Forschung, BMBF (funding number: 02WGR1424; Duration: May 01, 2017 to June 30, 2021) and was coordinated by Institute of Environmental Engineering and Management (IEEM gGmbH) at the Witten/Herdecke University, Germany.

The objective of the research project was the development and practical pilot implementation of an innovative water governance system basing on new technologies and tools for mitigating water stress and for a sustainable management of the water resources in the lower Olifants sub-catchment as the primary iWaGSS demonstration area including the Phalaborwa pilot zone in South Africa. This included cross-border dissemination to other regions with overstressed water resources in Africa and worldwide. There were 10 iWaGSS work packages, namely, (AP1) Water Governance, (AP2) Risk Assessment and Hydrological Modelling, (AP3) Storage Space Modelling, (AP4) Real-time Water Quality Monitoring, (AP5) Data Management and Data Integration, (AP6) Optimised Operating and Management Concepts, (AP7) Transboundary Water Governance, (AP8) Remote Sensing, (AP9) Cross-border Dissemination and (AP10) Capacity Development.

The project partners in Germany included Bundesministerium für Bildung und Forschung (BMBF), Institute of Environmental Engineering and Management (IEEM gGmbH) at the Witten/Herdecke University, Institut für Umwelttechnik & Ökologie (U+*Ö*) in Bauwesen Bochum, Institut für Wasser und Gewässerentwicklung (IWG) at Karlsruhe Institute of Technology, Fördermaßnahme Globale Resource Wasser (GRoW), Forschung für Nachhaltigkeit (FONA), the Center for Development Research (ZEF) at University of Bonn, LAR Process Analysers AG Berlin, Disy Information System GmbH Karlsruhe, Global Water Franchise Agency (GWFA) Berlin, and DIE GEWÄSSER-EXPERTEN!, Lohmar, while those in South Africa included Association for Water and Rural Development (AWARD), Council for Scientific and Industrial Research (CSIR), Department of Science and Technology (DST), Department of Water and Sanitation (DWS), LEPELLE, South African Environmental

Observation Network (SAEON), South African National Parks (SANPARKS), and Water Research Commission (WRC).

1.5 The Structure of the Work

This dissertation is structured into nine (9) chapters, all revolving around the main topic on the assessment of the IWRM implementation.

Chapter 1 addresses the general background information on IWRM paradigm, as well as motivation towards micro-water-governance and towards water reuse. This chapter also introduces the Integrated Water Governance Support System (iWaGSS) project; a partner project in the Olifants River Basin, South Africa.

Chapter 2 deals with water scarcity especially agricultural water, in different levels e.g. globally, in the sub-Saharan Africa, and in Kenya and South Africa etc. Additionally, this chapter looks keenly on the transboundary water governance in Kenyan and in the South African context based on policy and regulation framework as well as the water governing institutions. Finally, a comparison is made between current water and wastewater mitigation measures and regulatory framework in Kenya and South Africa.

Chapter 3 explores on wastewater treatment and reuse with a special focus on wastewater ponds system. On the wastewater treatment, a comparison between different technologies based on the reduction rates of pathogens and other indicator organisms is done. The use of treated effluent and excreta for agriculture with a strict consideration of the relevant health guidelines, assessment of health risks, and planning for the treated effluent and excreta reuse is presented. This is followed by demonstrating the fertilizer content in the wastewater and excreta, the general benefits of wastewater and excreta reuse, treated effluent and excreta recommended time of application, and proper infrastructural planning for the treated effluent and excreta reuse. This chapter also illustrates steps necessary towards monitoring the system performance. Finally, the chapter cites out some exemplary examples of water reuse in the world e.g. Namibia, Israel, South Africa, Singapore and Australia etc.

Chapter 4 deals with materials and methods, and the description of the study areas e.g. Case Study 1: The transboundary Mara river basin, Kenya and Case Study 2: The transboundary Olifants River Basin, South Africa. This is followed by the problem statement of both case studies, and the vulnerability levels, and protected areas (e.g. the wildlife reserves/parks and their level of deterioration etc.) in both cases. This chapter also explains the focus of the study, namely, (i) Enhancing local level performance using micro-water-governance, and (ii) evaluation of the water reuse value as a driver towards IWRM implementation. This is achieved through performing an analysis of different cases within the river basins e.g. the Water Resources Users Associations (WRUAs), the Maasai Mara wildlife conservancies Association (MMWCA) and other water management activities within the case study areas. Data analysis methods have been explained e.g. use of QGIS, and SPSS etc. Finally, a closer look at Water Demand (e.g. domestic, agricultural, industrial, environmental etc.) in Mara River Basin has been done.

Chapter 5 expounds on the micro-water-governance especially the micro-based strategies (e.g. WRUA Development Cycle and Sub-Catchment Management Plan) and the crucial and indivisible role played by the youth and women in the water governance. The chapter further recommends a comprehensive sub-catchment sustainable management and development, incentive-driven water service performance, and the enhancement of the communication channels. Finally, an interactive umbrella scheme of water governance and the 5-Stars of a good water governance are developed and explained.

Chapter 6 demonstrates the role of local stakeholders in the Water Reuse and the necessity for public consultation and active engagement in the water management and development initiatives; including formulation of necessary policies.

Chapter 7 takes a look at the effects of wastewater and excreta to the receiving water bodies and the environment at large.

Chapter 8 explores widely on the Water Reuse Plan, the principles and criteria for sharing water, and typical generation and propagation wastewater and excreta routes. These forms the foundation of the Integrated Treated Effluent Allocation Plan (TEA-Plan) including the analysis and the establishment of the TEA-Plan objectives. The Integrated TEA-Plan modelling framework further navigates through various essential and unavoidable water reuse stages required to maximize the output and protect the health of the public and the environment at large. There are various key requirements of the TEA-Plan categorized into three main segments, namely, (i) the design stage (measures to be taken before the commencement of wastewater allocation plan), (ii) the implementation stage (measures to be taken during the actual execution of the wastewater and excreta allocation plan), and (iii) the post allocation stage (measures to be taken after the actual execution of the wastewater and excreta allocation plan). The final issue handles water reuse quality assurance, the costs and benefits of the water reuse, the possible TEA-Plan customization strategy in the micro-governance water level, and the probable challenges of Integrated TEA-Plan.

Chapter 9 finalizes this work by drawing all the necessary conclusions and recommendations obtained from the micro-water-governance and the water reuse.

Chapter 2

Water Scarcity and Water Governance

2.1 Chapter Overview

This Chapter provides a comprehensive discussion on the water scarcity especially agricultural water, in different levels e.g. globally, in the sub-Saharan Africa, and in Kenya and South Africa etc. Additionally, this chapter looks keenly on the transboundary water governance in Kenyan and in the South African context based on policy and regulation framework as well as the water governing institutions. Finally, a comparison is made between current water and wastewater mitigation measures and regulatory framework in Kenya and South Africa.

2.2 Water Scarcity Globally

Water scarcity is one of the greatest challenges of the twenty-first century (FAO, 2016) and the situation is skyrocketing in different countries due to both natural and anthropogenic dynamics. Water scarcity can mean scarcity in availability due to physical shortage, or scarcity in access due to the failure of institutions to ensure a regular supply or due to a lack of adequate infrastructure (UN-Water, 2021). Steduto et al., 2012 defines water scarcity as a gap between available supply and expressed demand of freshwater in a specified domain, under prevailing institutional arrangements (including both resource 'pricing' and retail charging arrangements) and infrastructural conditions.

Water scarcity = an excess of water demand over available supply (Steduto et al., 2012).

Water scarcity affects directly water consumption per capita per day and it generally influences the water consumption behavior. A constant decline on the availability and the supply of the water resources in any given river basin amounts to surging difficulties in satisfying the water demand. Therefore, water scarcity is characterized by low per capita water consumption per day.

Scarcity is signaled by unsatisfied demand, tensions between users, competition for water, over-extraction of groundwater and insufficient flows to the natural environment (Steduto et al., 2012). Although climate change is the major force behind water scarcity, a significant amount of water stress is caused by pollution from the growth of wastewater and run-off from expanding cities, much of it only partially treated, from the release of agricultural fertilizer, and from the contamination of aquifers from various sources (FAO, 2010). Additionally, the growing of the world population has led to increased water demand hence making more countries to be categorized as water scarce countries. It is estimated that more than 40% of the world's population in the next 50 years will live in countries facing water stress or scarcity

(WHO, 2006) and between 75–250 million people in Africa will be living in areas of high water scarcity by 2030 (*www.ais.unwater.org*, UNCCD, 2013). About two-thirds of the global population – which is approximately 4.0 billion people – live under conditions of severe water scarcity at least 1 month of the year and half a billion people in the world face severe water scarcity all year round (Mekonnen and Hoekstra, 2016).

Water scarcity in the face of exponentially increasing demand demonstrates the potential for disputes and conflict both within and among states (*www.ais.unwater.org*, UNCCD, 2013). Also, there is a strong link between drought, food insecurity, poverty and water scarcity (*www.ais.unwater.org*, UNCCD,2013). Different sectors are currently facing water scarcity in the world and in the case study areas, namely, drinking and other domestic purposes, agricultural, environmental, industrial, commercial (e.g. hotels, tourism activities etc.), among other water uses. This research zeroes in on agricultural water uses and the underlying water scarcity, so as to find the necessity and the applicability of the harvested wastewater to augment the irrigation activities.

2.2.1 Agricultural Water Scarcity

Of all the sectors of the economy, agriculture is the most sensitive to water scarcity (Steduto et al., 2012). Although the agricultural sector is sometimes viewed as a 'residual' user of water, after domestic and industrial sectors, it accounts for 70 percent of global freshwater withdrawals, and more than 90 percent of consumptive use (Steduto et al., 2012). Agriculture, encompassing crops, livestock, fisheries, aquaculture and forestry, is both a cause and a victim of water scarcity and it accounts for the bulk of global water withdrawals (FAO, 2016). With rising temperatures intensifying demand, in combination with more frequent and severe weather extremes impacting production, the need to address water scarcity in agriculture is apparent (FAO, 2016). FAO, 2020 reports that 3.2 billion people live in agricultural areas with high to very high levels of water shortages (affecting rainfed agriculture) or scarcity (affecting irrigated agriculture), of whom 1.2 billion people – about one-sixth of the world's population – live in severely water-constrained areas. Water withdrawals increased at almost twice the rate of the population in the twentieth century, and a 50 percent surge in food demand is expected by 2050 (FAO, 2016). These matters most severely affect water-scarce regions, as well as areas where a lack of infrastructure or capacity prevents sufficient access to water. It is clear that there is an urgent need to address water scarcity (FAO, 2016).

2.3 Water Scarcity in Kenya

Kenya is a chronically water scarce country (United Nations, 2012) and has one of the world's lowest water replenishment rates per capita (Mogaka et al., 2005). The average renewable supply of freshwater resources in Kenya has dramatically reduced from around 650m^3 per capita per year in 2007 (World Bank, 2007) to around 449m^3 in 2018; a decline from 2393m^3/c/y in 1962 (World Bank, 2021). This is further projected to reduce to 250m^3/c/y by the year 2025. This amount is far below the recommended freshwater benchmark of 1,000m^3 per capita (Falkenmark, 1989). Between 80 to 85% of the Kenya physical areas consists of arid and semi-arid lands (ASALs) (Kenya Ministry of Health, 2016; IUCN, 2020). Water scarcity has heavy economic, social and political costs (FAO, 2010). The drought in Kenya in 1998-2000 is estimated to have reduced GDP by 16% over this period, falling with particular severity on industrial output, hydropower, agriculture and livestock (FAO, 2010). Despite Kenya being also categorized as a water scarce country (United Nations, 2012), there has been a rapid human population growth of 9.9 Million in the last 10 years (Kenya National Bureau of Statistics, 2019a). The arid and semi-arid regions of Kenya are more water stressed especially the middle region of the transboundary Mara River Basin, specifically the Maasai Mara National Park which is connected with Serengeti Wildlife reserve on the Tanzanian side.

Agriculture accounts for around 70% of global water use, mainly in the growth of crops for food and raw materials and for processing agricultural products (FAO, 2010). When rainfall is insufficient to sustain crops, irrigation is necessary and adds to the cost of agricultural operations (FAO, 2010). Unfortunately, the irrigation water has also been declining tremendously making some irrigation farms to perform poorly in the case study area and others to terminate their operations altogether. Treated wastewater and excreta offers a chance to revive some of the failed irrigation projects and also to the small scale farmers in arid and semi-arid lands. Kenya is not only a water scarce country but a net importer of major cereals (20 % of domestic production), and prevalence of undernourishment is ranked at 31% of its population (FAO, 2008).

2.4 Global Situation on Water Governance

Although at present, there is no universally agreed upon definition for water governance (Tortajada, 2010), more and more definitions keep on emerging from different institutions and researchers. Global Water Partnership, 2003 defined water governance as the "*range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society*." Another definition of water governance by the (OECD, 2015) states that it is the "*range of political, institutional and administrative rules, practices and processes (formal and informal) through which decisions are taken and implemented, stakeholders can articulate their interests and have their concerns considered, and decision makers are held accountable for water management*." The result is that different people and institutions are using water governance concept in different ways, and within varying cultural, economic, social, legal and political contexts (Tortajada, 2010).

Gaps in water governance hinders water policy design and implementation. The water governance situation changes with context and is case-by-case basis (OECD, 2015). There is need to implement an innovative water policy framework through process analysis over time as well as connecting the process attributes of the water governance system to functional performance (Pahl-Wostl, 2015). "*Good governance frameworks refer to new processes and methods of governing and changed conditions of ordered rule on which the actions and inactions of all parties concerned are transparent and accountable*" (Tortajada, 2010). It embraces the relationships between governments and societies, including laws, regulations, institutions, and formal and informal interactions which affect the ways in which governance systems function, stressing the importance of involving more voices, responsibilities, transparency and accountability of formal and informal organizations associated in any process (Tortajada, 2010). Pahl-Wostl, 2015 suggests that multi-level governance should be characterized through a process analysis over time.

Figure 2.1: Multi-level Governance Framework: Mind the Gaps, Bridge the Gaps
Source: (OECD, 2011)

Therefore, governance is not synonymous with government but a complex process that considers multi-level participation beyond the state, where decision making includes not only public institutions, but also the private sector, civil society and society in general (Tortajada, 2010). On the conceptualization of governance systems, its structural complexity could be analyzed in a systematic fashion according to (Pahl-Wostl, 2009, 2015), where a four classes of structural elements – though not entirely independent but capture important characteristics that influence functional performance – is distinguished, namely, (i) institutions and the relationship and relative importance of formal and informal institutions, (ii) actor networks and power structures with emphasis on the role and interactions of state and none-state actors, (iii) governance modes – bureaucratic hierarchies, markets, networks, and (iv) multi-level interactions across administrative boundaries and vertical integration.

The OECD principles on water governance expected to contribute towards improving the "Water Governance Cycle" from policy design to implementation (OECD, 2015). Policy responses will only be viable if they are coherent, if stakeholders are properly engaged, if well-designed regulatory frameworks are in place, if there is adequate and accessible information, and if there is sufficient capacity, integrity and transparency (OECD, 2015). The water governance will unlikely take into account the needs of the less powerful and the environment, if the principles of good governance are neglected (Pahl-Wostl, 2015).

On the reasons for the good water governance, (OECD, 2018) emphasizes that (i) water connects across sectors, places and people as well as geographical and temporal scales, (ii) freshwater management is of global and local concern and involve the entire spectrum of stakeholders in decision making, policy and project cycles, (iii) water is a highly capital-intensive and monopolistic sector with important market failures where coordination is essential, (iv) water policy is inherently complex and strongly linked to domains that are critical for development e.g. health, environmental, agriculture, energy, spatial planning, regional development and poverty alleviation, and (v) allocation of complex and resource-intensive responsibilities to subnational governments to varying degrees by countries has led to interdependencies across levels of government that require coordination to mitigate fragmentation.

Effective water governance aims to facilitate communication between politicians and other decision makers, water managers and users in an effort to address water governance issues; highlight good practices and lessons learned in implementing IWRM and use case studies to illustrate progress in improving water governance and demonstrate IWRM as a practical process using the IWRM ToolBox (Global Water Partnership, 2003). There are suggestions to develop a balance between the techno-scientific, socio-economic, political, and cultural aspects of water management activities, which may help in superseding the artificial separation of water research and practice in disciplinary and corporatist feuds (Castro, 2007). Mara and the Olifants river basins are unique cases as enumerated in this research (*see the subsequent chapters*) and must be approached in a unique water governance mechanism.

2.4.1 Transboundary Water Governance

Transboundary water governance of an international river basin ought to go beyond national interests of riparian states (Hirsch et al., 2006). This is because, transboundary water governance is the mechanism in which cross-border water resources are governed by different stakeholders who have complex interests regarding the use and utilization of the limited water resources that flow across borders (Mirzabaev et al., 2019). Transboundary water governance is a social process of dialogue, negotiations and decision-making to achieve a pre-determined objective regarding the transboundary water allocations and quality of water (Dore et al., 2012) and it involves different institutional arrangements between co-riparian countries such as treaties, agreements, conventions, charters, declarations and protocols (Boadu, 2016). The utilization of transboundary waters is a potential source of conflict among riparian states and competing water users within the countries (Conca et al., 2006; Paisley and Henshaw, 2013). Efficient and equitable management of transboundary water resources is essential for the achievement of practically all Sustainable Development Goals, SDGs (United Nations, 2015). The significance of focusing on the transboundary basin is further demonstrated by the fact that, at least 276 transboundary surface water basins and 592 transboundary groundwater aquifers are in the world (IGRAC, 2015; Paisley and Henshaw, 2013) with more transboundary aquifers yet to be mapped. An estimated half of the world's terrestrial area is occupied by the transboundary water basins (Paisley and Henshaw, 2013). These basins provide 60% of the world's freshwater (Paisley and Henshaw, 2013). More than half of the global rivers flows across international borders and with 40% of the world's population reside within these transboundary water basins (Shrestha and Ghate, 2016). The water crisis is mainly a crisis of governance (Castro, 2007; OECD, 2015). However, there is no shared understanding of what "governance" means, how it works, and who are its actors (Castro, 2007).

Working towards effective water governance requires an enabling environment and appropriate institutional structures that allow stakeholders to work together for effective water management (Global Water Partnership, 2000). Water governance deficiencies include failure to provide sufficient water for poor and marginalized areas, lack of attention to water legislation and infrastructure, and inability to balance competing demands between socio-economic needs and the environment (Global Water Partnership, 2000). This is due to failure on the political, social, economic and administrative systems to develop and manage water resources and water services delivery (Global Water Partnership, 2000). There have to be radical changes in the governance processes and the institutions responsible for water to cope with the immediate challenges, potential future changes and uncertainties both from within the sector and around the sector (Biswas and Tortajada, 2010). Transboundary water governance, therefore, is an all-inclusive diplomatic discourse that must be addressed by all stakeholders within and beyond borders, including the long excluded and the “insignificant” indigenous and minority groups to quench their thirst for water resources and other environmental services. These minor and marginalized groups of stakeholders are indeed and in most cases the traditional custodians of not only the water resources but also the entire natural resources spectrum within their area of influence. An example of such a minority and vulnerable group in the Mara river basin include the Ogiek and the Maasai communities that have largely been residing in Mau Forest for centuries and Maasai Mara regions respectively. These communities have attempted in many ways to protect the upstream of Mara river basin where the forest complex is situated as well as downstream in the arid and semi-arid region where Maasai Mara is situated.

A good water governance is the top priority for the human security as it enhances water quality and quantity (Falkenmark et al., 2007) and it motivates peoples’ active participation in decision making (WHO, 2014). A good water governance system – that is functional – should be able to manage water quantity and quality to ensure sustainability in ecosystems, public health, food and energy security etc. (OECD, 2018). Consistency in good governance is necessary for decision-making towards agreed objectives (WHO, 2006).

2.5 Water Governance Configuration in Kenya

According to the (Constitution of Kenya, 2010), the state is the custodian of the entire water resources which is managed and coordinated through the Water and Sanitation ministry. There are several water policies governing water resources sector in Kenya (Figure 2.2 &Table 2.1) as well as their respective implementing institutions. Water governing institutions in Kenya are mainly categorized into three main compartments, namely, local, regional and national level.

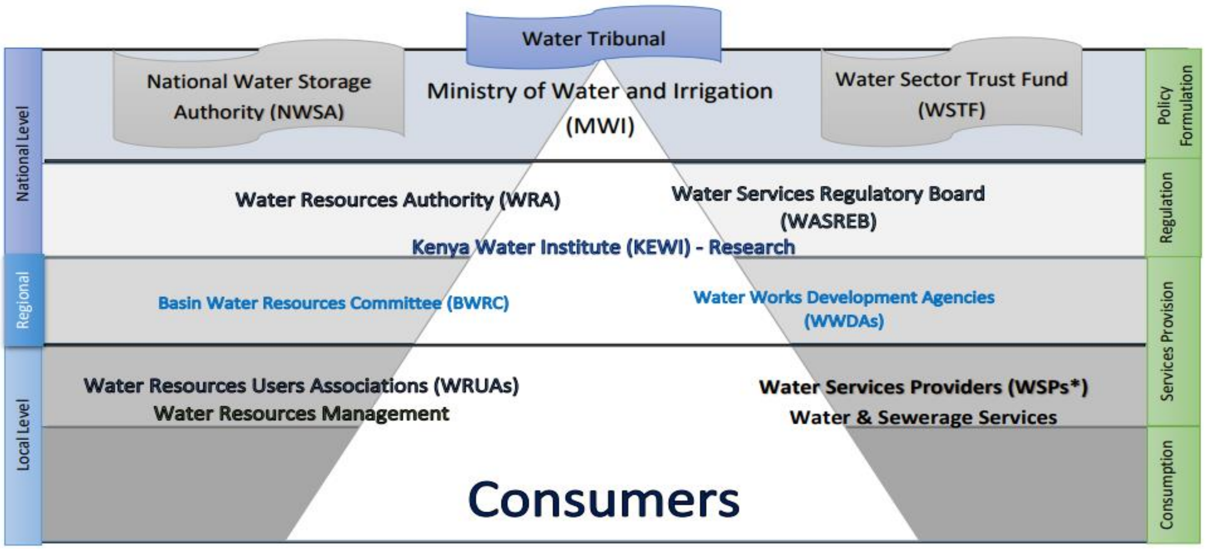

Figure 2.2: Kenya Water Sector Institutional Organogram - under the Water Act 2016

The national institutions are in-charge of policies and regulations formulation while regional and local institutions render services to the consumers. Water Service Providers (WSPs*) are also in-charge of wastewater ponds system etc. and are regulated by Water Works Development Agencies (WWDAs) as well the County governments (Water Act, 2016). There are quite often discord between these institutions characterized by poor communication and lack of proper platform through which data, opinions, and complaints could be relayed.

Table 2.1: Summary of major water policies in Kenya

Water Policies	**Main responsibilities**
Water Act 2002	Established the Water Resources Management Authority and defined its duties, regulated the ownership and control of water and made provision for the conservation of surface and groundwater and the supply of services in relation with water and sewerage.
Constitution of Kenya 2010	Devolved water and sanitation services to the county governments who are the owners of Water Service Providers (WSPs*).
Water Act 2016	Established the Water Resources Authority ("Authority"), the National Water Harvesting and Storage Authority, the Water Services Regulatory Board, the Water Sector Trust Fund and the Water Tribunal. This provides for the regulation, management and development of water resources, water and sewerage services; and for other connected purposes.
National Water Services Strategy	Meant to separate water resources management and development from water services delivery, while the Ministry in charge of water affairs deals with policy and strategy formulation, mobilization of funds, coordination and monitoring.
National Water Master Plan 2030	Aimed at assessing and evaluating the availability and vulnerability of country's water resources up to around the year 2050, taking climate change into consideration, as well as sustainable water resources development and management for the six catchment areas, namely, Athi, Ewaso Ng'iro, L. Victoria North and South, Rift valley & Tana.
Kenya Vision 2030	Aimed at accessing water and sanitation for all by 2030.

Improved sanitation in Kenya especially in the informal settlements e.g. slums, peri-urban areas etc. has been so slow with a record of just 7% increase in a span of almost 30 years from 25% in 1990 to 32% in 2019. This is despite the enactment of Environmental Management and Coordination Act (EMCA) 1999, Water Act 2002 and 2016, Vision 2030 promulgated in 2008, and Kenya new Constitution of 2010 etc. All these vital documents illustrate the roadmap to the improvement of sanitation and water services, penalties to polluters and illegal water abstractors, and infrastructural development among others. More action plans have been put in place as enumerated in this section.

Box 2.1 Increase in the access to improved sanitation in Kenya is about 7% in a span of almost 30 years from 1990 to 2019

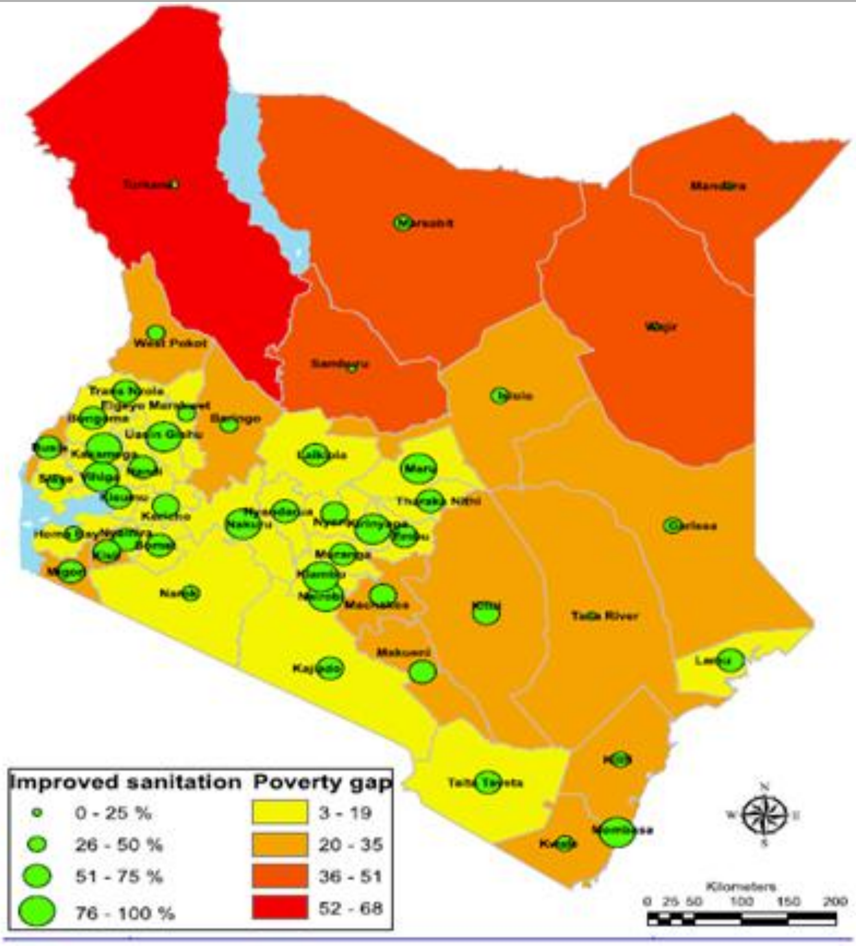

Figure 2.3: Kenya counties poverty gap and access to improved sanitation
Note: Kenya is subdivided into 47 counties according to the 2010 constitution.
Source: (Kenya Ministry of Health, 2016)

United Nations, 2011 reported that Kenya had by the year 2007 only 4.9% of its population connected to wastewater collecting system and the subsequent wastewater treatment system. This was very low compared to a country like Germany which by 2007 had 96% of its population connected to the wastewater collecting system and the wastewater treatment system (United Nations, 2011). Other countries like Singapore, Monaco, Spain, and Maldives had 100% population connection to the wastewater collecting system (United Nations, 2011). There were only 43 sewerage systems in Kenya and wastewater treatment plants in 15 towns with total population served: 900,000 inhabitants by the year 2009 (Kenya Ministry of Health, 2016). This is actually 2.4% of the Kenyan population served by 2009.

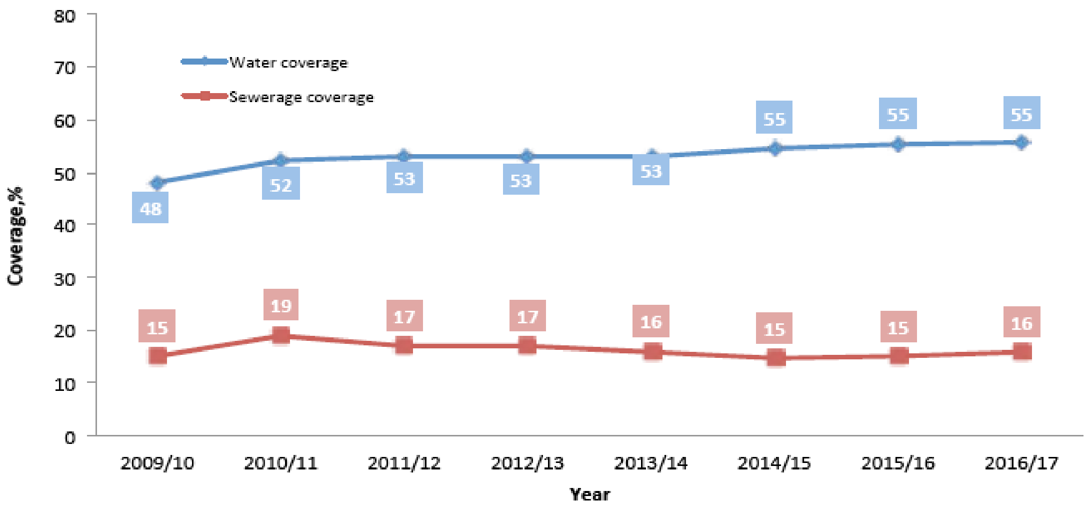

Figure 2.4: Water and sewerage coverage in Kenya
Source:(Kenya Ministry of Health, 2016) - (see details in Kenya Environmental Sanitation and Hygiene Policy – 2016 – 2030)
*The coverage could be calculated based on the number of people/households served by the system.
*Increased human population in most of the river basins in Kenya has largely affected the efforts and the subsequent progress on the water and sewerage coverage.

Very low number of wastewater and solid waste treatment systems in Kenya has left millions of inhabitants off-the-line of the sewage system. The current situation in Kenya has led to high disposal of both solid and liquid waste haphazardly in the public places, open fields, bushes, and in the water bodies etc.

Box 2.2 The major challenges facing improvement on the wastewater management in Kenya include, but not limited to;

i. Poor or lack of synchronized up-to-date wastewater reuse policies – treated water reuse is not fully recognized by the current in-country regulations
ii. Financial challenges, especially, in the implementation stage
iii. Inadequate operation and maintenance of the existing wastewater treatment systems
iv. Low connection rates to sewerage systems
v. Neglected or non-functional treatment sewerage systems
vi. Poor designs of the wastewater infrastructure leading to challenges e.g. overloaded pipes, blockages, sewer bursts etc.
vii. Discharge of the raw sewage into the watercourses etc.
viii. Increased human population in most of the river basins (e.g. 3.2% population growth rate per annum in Mara river basin) leading to increased wastewater generation.

2.5.1 The Kenya National Sustainable Waste Management Policy (KNSWMP)

KNSWMP is geared towards sustainability and circular economy. This policy is a roadmap towards realization of the Zero Waste principle, whereby waste generation is minimized or prevented. It will help ensure that waste is collected, separated at the source, reused and recycled, and that the remaining waste stream is destined to a secure, sanitary landfill. There is urgent need for synchronized and up-to-date regulatory frameworks and incentives. This will enable all stakeholders to work coherently, build long-term resilience, generate new business and economic opportunities and provide broad environmental and social benefits to all. There is need to apprehend those engaged in illegal dumping and uncontrolled dumpsites. This policy also supports the creation of the planning, finance, technical and governance capacities that county governments need to effectively deliver on their mandate under the Constitution of Kenya 2010, and to be the lead actors in delivering sustainable waste management services.

2.5.2 Constitution of Kenya (Chapter 4 - The Bill of Rights; part 2)

In the constitution of Kenya under rights and fundamental freedoms sub-section 42 – Every person has the right to a clean and healthy environment (Constitution of Kenya, 2010). This right as envisaged in the constitution has therefore been largely denied to the millions of Kenyans. The right to a clean and healthy environment should be achieved through regular revision and synchronization of relevant policies and active engagement and protection of the stakeholders for sustainability purposes. Of course, without taking this right to the implementation and enforcement arena, any other efforts would be futile.

2.5.3 Kenya National Solid Waste Management Strategy (NSWMS)

NSWMS seeks to establish a common platform for action between stakeholders to systematically improve waste management in Kenya (Water Act, 2002). The platform should be technologically oriented as well as integrated policy-based to allow more interactions between the relevant actors.

2.5.4 Environment Management and Co-ordination Act (EMCA) 1999 & 2015 (amendment)

EMCA encourages public participation in the development of policies, plans and processes for the management of the environment, intergenerational and intra-generational equity, the polluter-pays principle and the precautionary principle (Environmental Management and Coordination Act, 1999). The EMCA amendments of 2015 substitutes Environmental Impact Assessment with Integrated Environmental Impact Assessment. The proponent of any project shall undertake a full environmental impact assessment study and submit a report to the Authority prior to being issued with any license by the Authority (Environmental Management and Coordination Act, 2015). The Integrated aspect encourages active participation and consultation of all stakeholders.

2.5.5 National Water Policy (NWP) of 1999

NWP identifies that there are weak and unsustainable infrastructural or technological systems to enable water reuse and protection of the public health. This situation is characterized by non-operational or very low level operating water supply and reuse systems as well as inexperienced workforce (NWP, 1999).

2.5.6 National Environmental Action Plan (NEAP)

EMCA, 2015 sub-section 37. (1) proposes formulation of NEAP every six years and a revision after every 3 years. Devolution of the EMCA has been enacted through establishment of County Environment Committee (CEC) which shall formulate County Environment Action Plan (CEAP).

2.5.7 National Environment Policy (NEP), of 2013

Campaigns for prevention and minimization of health risks from untreated or unsafe drinking, wastewater and water reuse, and recreational water etc. The major issue is pegged on the sewerage systems and wastewater treatment plants whose operation and maintenance is inadequate while at the same time low connection rate to sewer lines (NEP, 2013).

2.5.8 National Environment and Management Authority (NEMA)

This is the main custodian or lead agency of EMCA 1999 and 2015 respectively. NEMA is mandated with supervision and coordination of all environmental based activities. Unfortunately, the amended act does not devolve the functions of NEMA but remains at the national level. This is a big challenge as the local stakeholders feel detached from the functions of NEMA. There are no clear lines between the environment conservation mandates vested on the NEMA and the County Government. This could be seen from the uncoordinated solid and liquid waste management as well as blame game between the two aforementioned stakeholders in Mara River basin.

Additionally, water reuse in Kenya is supported by National Food and Nutrition Security Policy (NFNSP) (2011), National Industrialization Policy Framework (NIPF) (2010), National Water Act (NWA) (2016), and the National Climate Change Action Plan (NCCAP) (2013–2020) etc. Kaluli et al., 2011 recommends formulation of a national wastewater reuse policy in order to allow for safe wastewater reuse in Kenya with clear guidelines as well as the requirements for water quality monitoring frequency on faecal indicators (*Escherichia coli*, faecal coliforms, *enterococci*), and maximum allowable concentration of nutrients (nitrogen and phosphorus) etc. Although wastewater reuse in Kenya has generally been considered illegal, the little efforts seen in various sectors on the wastewater reuse programs are positive and will in the end bear commendable outcomes.

Despite having a commendable policy framework – although there are still challenges in the synchronization and implementation – Kenya has no explicit, localized health guidelines for wastewater and excreta reuse. Instead, Kenya widely uses international health guidelines e.g. (WHO, 1989, 2001, 2006; FAO, 2010; US EPA, 1992, 2004, 2012) etc. While all these international guidelines are highly commendable, Kenya should customize and synchronize them with the local wastewater and excreta situation, socio-cultural patterns, economic activities, and climatic aspects etc. This will help the country to manage both solid and liquid waste based on the unique local situation.

2.6 Water Governance in South Africa

A South African institutional framework shows detailed and "attractive" water and sanitation management tools, (see Figure 2.5), but as is with the Kenyan case, implementation level is still very low. So, "attractive" as the water and sanitation management tools may look like, the situation will remain dire as long as the efforts towards realization are not actualized. A water stressed South Africa, has close to 5.7 million people that do not have access to basic water while 17–18 million lack access to adequate sanitary facilities while most effluent discharge and urban runoff are not reused (Swartz et al, 2016).

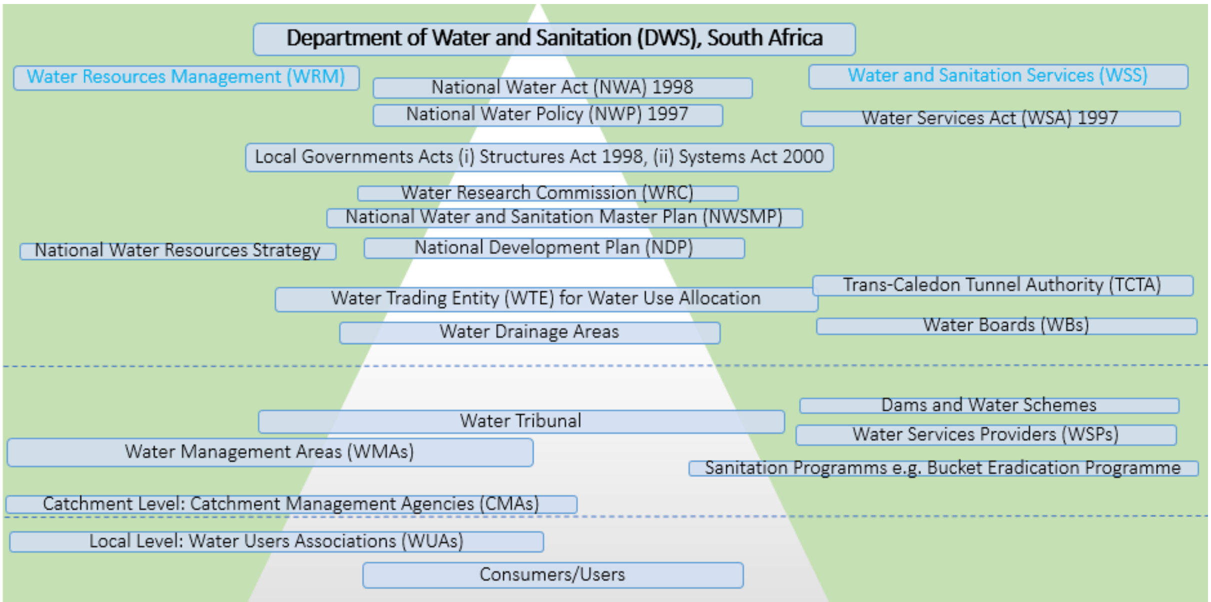

Figure 2.5: Water and Sanitation Institutional Framework, South Africa

2.7 Comparison between Current Water and Wastewater Mitigation Measures and Regulatory Framework in Kenya and South Africa

Several efforts have been put in place to try and address the challenges facing the water resources management in Kenya and South Africa. This analysis has identified some of the measures in place though not exhaustive (Table 2.2).

Table 2.2: Some of the current water and wastewater mitigation measures and regulatory framework in Kenya and South Africa

South Africa	Kenya
Enactment of new policies and regulations e.g. White paper on a National Water Policy 1997, Water Services Act (WSA) 1997, National Water Act 1998, Local Government Acts (Structures Act 1998, Municipal System Act 2000)	Enactment of new policies and regulations e.g. Water Acts 2002 Chapter 372; revised 2012; 2016,
Environmental legislations e.g. National Environment Management Act (NEMA) 1998	Environmental legislations e.g. Environmental Management and Coordination Act (EMCA) 1999; 2012; 2015, etc. EMCA 1999 led to establishment of National Environment Management Authority (NEMA) in 2002, National Environment Policy, 2013
Formulation of national, regional and sub-regional management plans e.g. National Water Resources Strategy (NWRS), Catchment Management Strategy (CMS) developed by Catchment Management Area (CMA)	Formulation of national, regional and sub-regional management plans e.g. National Water Services Strategy, National Water Master Plan 2030, Kenya Vision 2030, Catchment Management Strategy, Sub-Catchment Management Plans (SCMPs), WRUA Development Cycle (WDC) etc.
Commitment on the adherence with International visions, laws, standard and goals e.g. Sustainable Development Goals, IWRM paradigm	Commitment on the adherence with International visions, laws, standard and goals e.g. Sustainable Development Goals, IWRM paradigm
Conducting management projects and other initiatives in the basin e.g. iWaGSS (*http://www.iwagss.com/wordpress/*) in the lower Olifants basin etc.	Conducting management projects and other initiatives in the basin e.g. Mau Mara Serengeti (MaMaSe), and SafiSan (Safi Sanitation) etc.
Formation of regional authorities in charge of water management e.g. Water Management Areas (WMA)	Formation of regional authorities in charge of water management e.g. Water Resources Authority (WRA) formerly Water Resources Management Authority (WRMA)
Establishment of Water Services Providers (WSPs*) through Water Services Authorities (WSA)	Establishment of Water Services Providers through County Governments e.g. Bomet, Narok and Nakuru Counties in the region.
Formation of community based organizations to protect and conserve the	Formation of community based organizations to protect and conserve the respective sub-

respective sub-basin e.g. Water Users Associations (WUAs)	basin e.g. Water Resources Users Associations (WRUAs)
Formation of wildlife conservancies e.g. Kruger Park conservancies	Formation of wildlife conservancies e.g. Maasai Mara wildlife conservancies Association (MMWCA) since 2013
Establishment of catchment management initiatives	Establishment of Catchment Management Groups (CMGs) e.g. Greentown Initiative
Interventions from non-governmental organizations (NGOs)	Interventions from non-governmental organizations (NGOs) e.g. Worldwide Fund for Nature (WWF), USAID, Sustainable Water Partnership (SWP) etc.

*Regulatory framework for water management and services provision in both countries are shown.

Sources (South Africa): (Water Services Act, 1997; National Water Act, 1998; Municipal System Act, 2000; Municipal Structures Act, 1998)

Sources (Kenya): (EMCA, 1999; Water Act, 2016, 2002; NEMA, 2010)

The alarming water stress in Kenya and South Africa requires among other measures; harnessing of the nutrients rich wastewater that is hazardous to the public and the environment to a reusable approach in agriculture and aquaculture etc. There is therefore an urgent need to improve wastewater treatment systems in order to address the deteriorating water quality issues. An improvement on the water quality will be achieved through (i) active engagement of the stakeholders with a strict inclusion of the local and marginalized groups to the decision making platforms, (ii) formulation of local catchment management initiatives for the women, youth, and people living with disabilities who will be trained to observe the best practice of environmental conservation, (iii) financial support to various initiatives in the grassroots as well as livelihood enhancement, and (iv) up-to-date policies and designs that will alleviate the established hiccups during implementation of the previous action plans.

Water reuse will therefore boost the already existing initiatives to address water scarcity in the case study area(s). To protect health of the public, – by safeguarding the quality of the end products and the health of the subsequent consumers – a safe reuse of the treated wastewater e.g. in agriculture and aquaculture etc. should constantly be done through screening and scrutinizing using the certified procedures and the quality standards.

Chapter 3

Wastewater Treatment and Reuse

3.1 Chapter Overview

This chapter explores on wastewater treatment and reuse with a special focus on wastewater ponds system. On the wastewater treatment, a comparison between different technologies based on the reduction rates of pathogens and other indicator organisms is done. The use of treated effluent and excreta for agriculture with a strict consideration of the relevant health guidelines, assessment of health risks, and planning for the treated effluent and excreta reuse is presented. This is followed by demonstrating the fertilizer content in the wastewater and excreta, the general benefits of wastewater and excreta reuse, treated effluent and excreta recommended time of application, and proper infrastructural planning for the treated effluent and excreta reuse. This chapter also illustrates steps necessary towards monitoring the system performance. Finally, the chapter cites out some exemplary examples of water reuse in the world e.g. Namibia, Israel, South Africa, Singapore and Australia etc.

3.2 Wastewater Treatment

Wastewater includes both liquid and solid waste – which may harbor high concentrations of organic and inorganic pollutants, pathogenic microorganisms and toxic chemicals – transported in water from households, commercial establishments, industries, and stormwater and other surface runoff (Riffat, 2012).

There are various pollutants originating from domestic, and industrial wastewater among other sources of wastewater and excreta. Globally, these pollutants have been harnessed to some extent and the wastewater reclaimed for reuse in agricultural fields and aquaculture etc.

Figure 3.1: Main pollutants, their source and effects

Pollutant	Main representative parameters	Source				Possible effect of the pollutant
		Wastewater		Stormwater		
		Domestic	Industrial	Urban	Agricultural and pasture	
Suspended solids	Total suspended solids	XXX	←→	XX	X	-Aesthetic problems -Sludge deposits -Pollutants adsorption -Protection of pathogens
Biodegradable organic matter	Biochemical oxygen demand	XXX	←→	XX	X	-Oxygen consumption -Death of fish -Septic conditions
Nutrients	Nitrogen Phosphorus	XXX	←→	XX	X	-Excessive algae growth -Toxicity to fish (ammonia) -Illness in new-born infants (nitrate) -Pollution of groundwater
Pathogens	Coliforms	XXX	←→	XX	X	-Water-borne diseases
Non-biodegradable organic matter	Pesticides Some detergents Others	X	←→	X	XX	-Toxicity (various) -Foam (detergents) -Reduction of oxygen transfer (detergents) -Non-biodegradability -Bad odors (e.g. Phenols)
Metals	Specific elements (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, etc.)	X	←→	X		-Toxicity -Inhibition of biological sewage treatment -Problems in agriculture use of sludge -Contamination of groundwater
Inorganic dissolved solids	Total dissolved solids conductivity	XX	←→		X	-Excessive salinity – harm to plantations (irrigation) -Toxicity to plants (some ions) -Problems with soil permeability (sodium)

X: small *XX*: medium *XXX*: high ←→ : variable *empty*: usually not important

Source: (Von Sperling, 2007)

Sustainable wastewater engineering is therefore the application of the principles of science and engineering for the treatment of wastewater to remove or reduce pollutants to acceptable levels before discharging it to the receiving water bodies and other environments (Riffat, 2012) or to the reuse fields upon acquiring certain standards. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment (Pescod, 1992). Generally, wastewater contains about 99% water, and only 1% solid waste (Vigneswaran and Sundaravadivel, 2004); both domestic and municipal sewage contains approximately 99.9% water (Von Sperling, 2007; Pescod, 1992) together with relatively small concentrations of suspended and dissolved organic and inorganic solids (Pescod, 1992). There are also organic substances present in sewage, such as, carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries (Pescod, 1992).

Wastewater treatment is majorly categorized as (i) conventional wastewater treatment processes that include different stages such as preliminary treatment, primary treatment, secondary treatment, tertiary and/or advanced treatment, disinfection, and effluent storage etc. (Pescod, 1992). Effluent storage is optional depending on whether or not there are reuse plans, and (ii) natural biological treatment systems e.g. wastewater ponds system, overland treatment of wastewater, macrophyte treatment, and nutrient film technique etc. (Pescod, 1992). This work focuses specifically on the wastewater ponds system and the subsequent treated effluent for the reuse purposes especially in arid and semi-arid lands (ASALs).

3.2.1 Wastewater Ponds Systems (WPS)

WPS are impoundments where wastewater flows in and out after a defined retention period of time (Mara et al., 1992a) and they are nowadays a common method for treating municipal and industrial sewage (Rudolph et al, 2019). The treatment depends on the organic strength of the input waste and the effluent quality objectives (Pescod and Mara, 2013).

Table 3.1: Ponds primary cleaning objective

International common nomenclature	Primary cleaning objective
Anaerobic pond	Solids separation
Facultative pond	Carbon elimination
Aerated pond	Carbon elimination
Maturation pond	Disinfection

Source: (Rudolph et al, 2019)

Technology on wastewater ponds system has evolved over the years, but the main concept of biological based treatment and its underlying principles remains intact.

Table 3.2: Principles of Wastewater Ponds Systems (WPS) - Summary

Basic Principle	Wastewater flows In and Out after a defined Retention Period of time	
Treatment	Natural processes of biological purification	
Treatment optimization	Selecting appropriate organic loadings, retention periods and pond depths, to promote the maximum growth of organisms beneficial to the treatment process	
Energy source	Sunlight. NO external energy	
Types of Ponds	Anaerobic	Primarily designed to remove BOD; strong organic wastewaters devoid of oxygen
		Depth 3-4 m in order to accommodate sludge accumulation and maintain anaerobic conditions by reducing the surface area to volume ratio
		High organic loading – cold climate up to 100 g/m^3 d; warm climate – less days compared to cold climate
		Retention time – cold climate 2-4 days; warm climate – less days compared to cold climate
	Facultative	Designed to remove BOD; High removals of excreted pathogens seen. Dissolved oxygen persists in the water column
		Depth 1.5-2.0m relatively shallow to have sufficient surface area to volume ratio to enable good algal growth
		Surface organic loading – cold climate not exceed 100 kg/ha d; warm climate – less days compared to cold climate
		Retention time – cold climate 20-50 days
		Treatment relies on the mutualistic association between algae in the upper euphotic zone and

		bacteria in the lower layers. The algae supply photosynthetic oxygen is utilized by the bacteria, which in turn releases carbon dioxide, ammonia and phosphate that are utilized by the algae
	Maturation	Designed: To remove excreted pathogens e.g. faecal coliform (reduction achieved 4-6 log units), faecal viruses (reduction achieved 2-4 log units), and parasites (100% removal), etc. Pathogens are either eaten by bacteria or die-off. Pathogen die-off: Promoted by high levels of pH and dissolved oxygen generated in ponds due to algal photosynthetic activity.
		They are aerobic lagoons used as a polishing stage
		Depth – 1.5-2.0 m
		Retention time – cold climate (5-15 d)
Arrangement	Series typical arrangement	**A** ⟶ **F** ⟶ **M**

- **A** is Anaerobic, **F** is Facultative, and **M** is Maturation ponds respectively.
- Ponds designed on the basis of surface organic loading and the effluent quality objectives.
- For ease of maintenance and flexibility of operation, at least two trains of ponds in parallel are incorporated in any design.
- Anaerobic process often requires long retention time in cold climates e.g. below 15°C as anaerobic bacteria is inactive.

Source (compiled from): (Mara et al., 1992a; US EPA, 2011; Pescod and Mara, 2013)

Further WPS design information is found e.g. in (Oswald, 1968; Mara and Pearson, 1987; US EPA, 2011; Rudolph et al, 2019), etc.

Typically, there are various inputs and outputs from wastewater ponds system as demonstrated by (Verbyla et al., 2017) in (Figure 3.2).

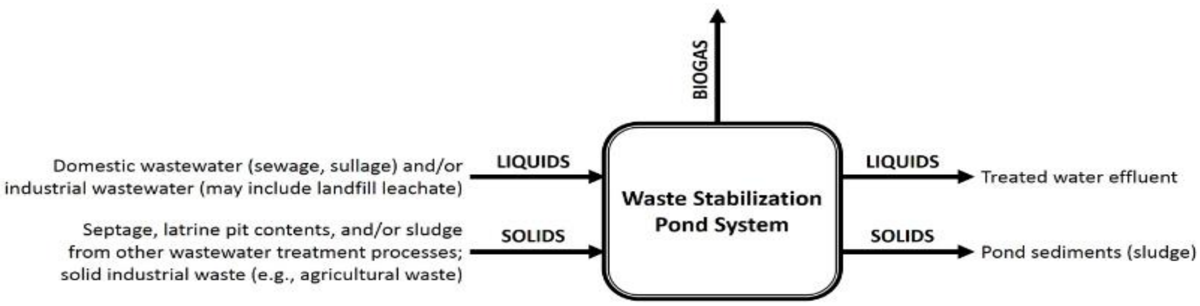

Figure 3.2: Typical inputs and outputs from wastewater pond system
Source: (Verbyla et al., 2017)

There are typical parameters that are measured in wastewater ponds system e.g. influent and effluent mainly biological, and chemical composition as well as physical and water percentage etc. (See more details by Rudolph et al, 2019) (Table 3.3).

Table 3.3: Typical measured parameters in wastewater ponds system

Parameter	Units
Daily load of COD at the influent of the pond, *Ld,COD,IP*	Kg/d
Concentration of COD at the effluent of the pond, *CCSB,EP*	mg/L
Concentration of COD at the influent of the pond, *CCSB,IP*	mg/L
Factor for consideration of solar radiation, *fSol*	-
Share of degraded COD load in the daily load of COD in the influent, *ηCSB*	%
Air temperature, *TA*	°C
Water Temperature, *TW*	°C
Areal COD loading rate, *LA,COD*	$g/(m^2 \cdot d)$*
Volumetric COD loading rate, *LV,COD*	$g/(m^3 \cdot d)$
Daily wastewater inflow into pond as annual mean, *QDW,d,aM,IP*	m3/d
(Global) solar radiation, *SR*	W/m^2

*kg/(ha·d) is widespread in international practice.
Source: (Rudolph et al, 2019)

3.2.1a Anaerobic Ponds

Anaerobic ponds are significantly deeper in comparison with the other ponds but their surface is relatively small in order to provide sufficient volume for the sediment substances and to limit the oxygen transfer through the water surface (Rudolph et al, 2019). Temperature plays a significant role in the determination of the permissible COD volume loading and the efficiency (Table 3.4).

Table 3.4: Guide values for the permissible COD volume loading and the percentage of COD removal

Water Temperature T_w (°C)	Permissible COD volume loading $L_{v,COD}$ ($kg/(m^3.d)$)	COD reduction η_{COD} (%)
< 15	0.24	30
15 to < 20	$0.24 + (T_W - 15) \cdot 0.0172$	$30 + (T_W - 15) \cdot 2$
20 to < 25	$0.326 + (T_W - 20) \cdot 0.0448$	$40 + (T_W - 20) \cdot 4$
≥ 25	0.55	60

Source: (Rudolph et al, 2019); (Equations 3.1 – 3.4)

The design stages of anaerobic ponds (see e.g. Table 3.5) must be adhered to in order to realize the optimum required levels of BOD removal and other solid substances.

Table 3.5: Anaerobic ponds design steps

Step	Parameter	Equations 3.5 and 3.6	Units
1	Effluent COD concentration	$C_{COD,EP} = \left(1 - \frac{\eta_{COD}}{100}\right) . C_{COD,IP}$	mg/l
2	Required pond volume	$V_{P,req.} = \left(\frac{L_{d,COD}}{L_{V,COD}}\right)$	m^3
			Recommendation
3	Geometric dimensions	Number of parallel-loaded ponds (n)	Depending on the overall size
		Depth (h)	typically 3 m
		Ratio of length to width (l:w)	typically 1.5:1 to 3:1
		Slope inclination	typically 1:1.5 to 1:3

Source: (Rudolph et al, 2019)

A typical cross-sectional representation of anaerobic pond has three main sections, namely, the intake, the pond and the outlet. The design of anaerobic ponds is primarily based on the definition of a permissible volumetric loading rate with an explicit difference between sedimentation effects (especially with impact on the particulate COD) and anaerobic degradation (particularly regarding the dissolved COD) (Rudolph et al, 2019). A single anaerobic pond in each treatment series is enough if the influent wastewater, L_i, is <1000 mg/l BOD_5 (McGarry and Pescod, 1970).

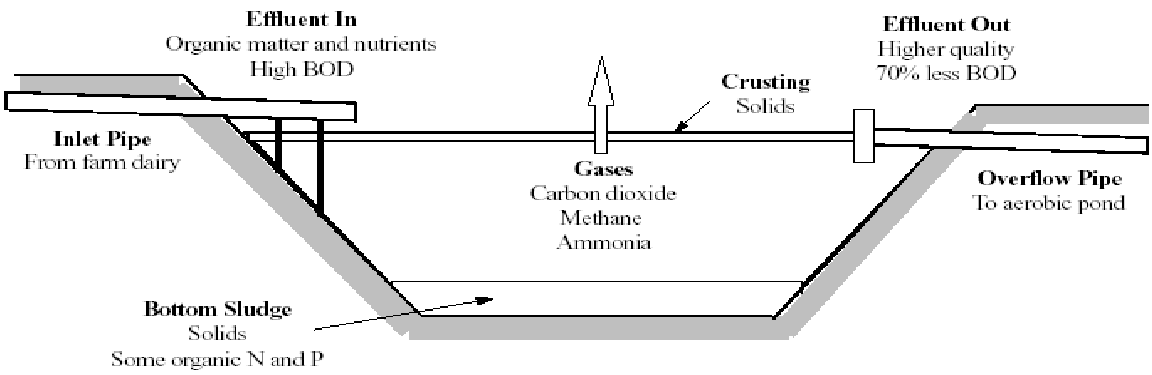

Figure 3.3: Anaerobic pond
Source: (Ramadan, 2020)

A maximum of three anaerobic ponds in series could be designed in the event of high-strength industrial wastes but the retention time, t_{an}, of each pond should be greater or equal to 1 day (McGarry and Pescod, 1970). High volumetric, λ_v organic loading, > 100g BOD_5/m^3 day is used to maintain anaerobic conditions in first-stage wastewater ponds system (Pescod and Mara, 2013).

$$\lambda_v = \frac{L_i Q}{V}$$ Equation 3.7

where
L_i =influent BOD_5, mg/l,
Q = influent flow rate, m^3/d,
V = pond volume, m^3

Since V/Q = t_{an}, the retention time is

$$\lambda_v = \frac{L_i}{t_{an}}$$ Equation 3.8

A maximum anaerobic pond loading of 400 g BOD_5/m^3d, in the case of typical municipal sewage, will prevent odor nuisance (Meiring et al., 1968) while very high loadings, up to 1000g BOD_5/m^3d, with wastewater containing sulphate concentrations in excess of 100 mg/l, may lead to the production of H_2S hence likelihood of causing odor problems (Pescod and Mara, 2013). Ambient temperatures in hot-climate developing countries are conductive to these anaerobic reactions and expected BOD_5 removals for different retention times in treating sewage (Mara, 1976).

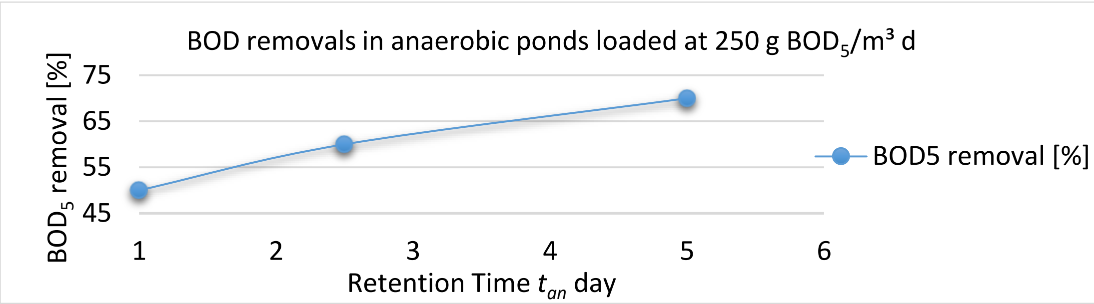

Figure 3.4: BOD removal in anaerobic ponds
Source: (Mara, 1976)

Anoxic conditions in anaerobic ponds must be maintained by a volumetric loading of at least 100g BOD_5/m^3d (Pescod and Mara, 2013). Under-loading in the anaerobic pond during operation is often shown by the appearance of an algal bloom and the aftermath of this condition is encouragement of inhibition of the methanogenic phase of digestion from the produced oxygen (Pescod and Mara, 2013). A very thin surface layer containing algae, usually the flagellate Chlamydomonas, is not generally harmful and no corrective action is required (Pescod and Mara, 2013).

Figure 3.5: Thin surface layer of algae at Bomet wastewater ponds system, Kenya

3.2.1b Facultative Ponds

Facultative wastewater ponds are large and shallow ponds with a water depth of up to 2.0m (Rudolph et al, 2019; Mara and Pearson, 1987; Mara et al., 1992a; Pescod and Mara, 2013). Organic matter dissolved or suspended in the water column will be metabolized by heterotrophic bacteria with the uptake of oxygen (Pescod and Mara, 2013). Oxygen is introduced via the surface and with the help of algal biocenosis (Rudolph et al, 2019). The dissolved oxygen utilized by the bacteria in facultative ponds is replaced through photosynthetic oxygen production by microalgae, rather than by aeration equipment (Pescod and Mara, 2013).

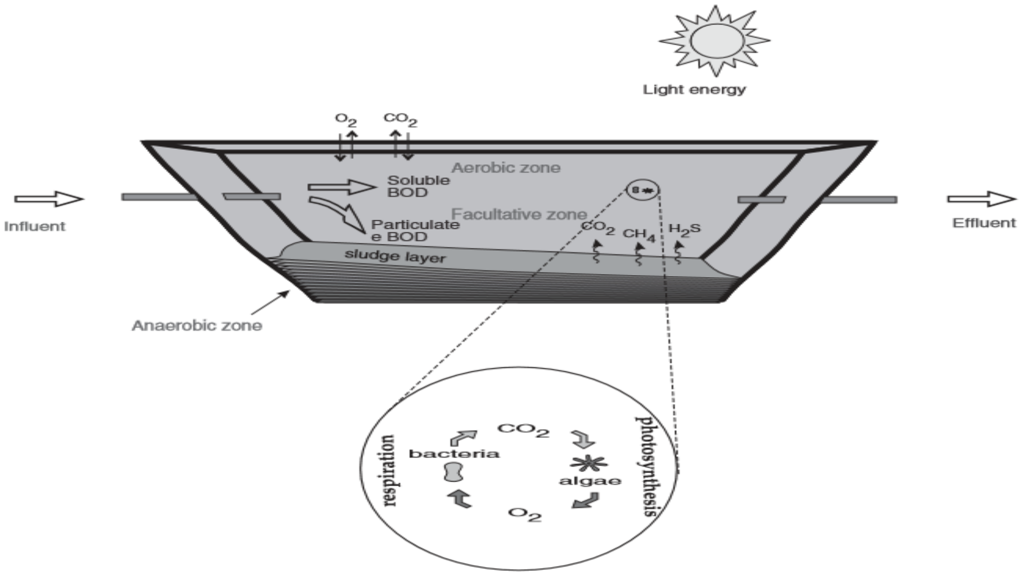

Figure 3.6: Simplified illustration of facultative pond
Source: (Von Sperling, 2007)

The environment in facultative ponds is ideal for the proliferation of microalgae e.g. in hot climates (Pescod and Mara, 2013). High temperature and ample sunlight create conditions which encourage algae to utilize the carbon dioxide (CO_2) released by bacteria in breaking down the organic components of the wastewater and take up nutrients (mainly nitrogen and phosphorus) contained in the wastewater (Pescod and Mara, 2013). Therefore, facultative ponds may also contribute significantly to nutrient removal under certain preconditions (i.e. water temperature T_w>15°C, sufficient retention time for carbon and nitrogen removal) (Rudolph et al, 2019).

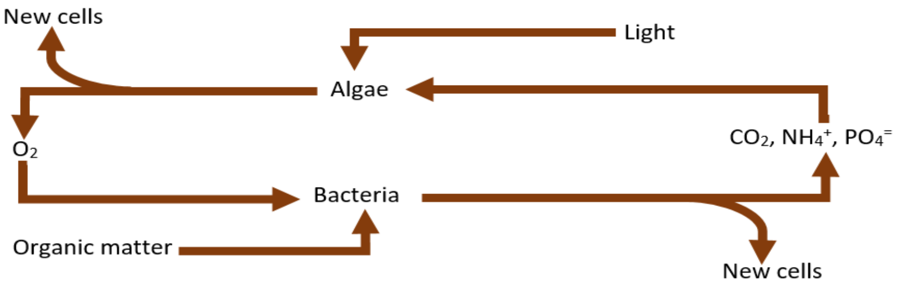

Figure 3.7: Algal-bacterial mutualism in facultative and maturation ponds
*The algae are oxygen generators for the pond bacteria, which in turn provide CO_2 for algal photosynthesis.
*This symbiotic relationship contributes to the overall removal of BOD in facultative ponds.
Source: (Mara et al., 1992a; Pescod and Mara, 2013)

Marais, 1970 illustrated the pathways of various processes during BOD removal in the primary facultative ponds (Figure 3.8).

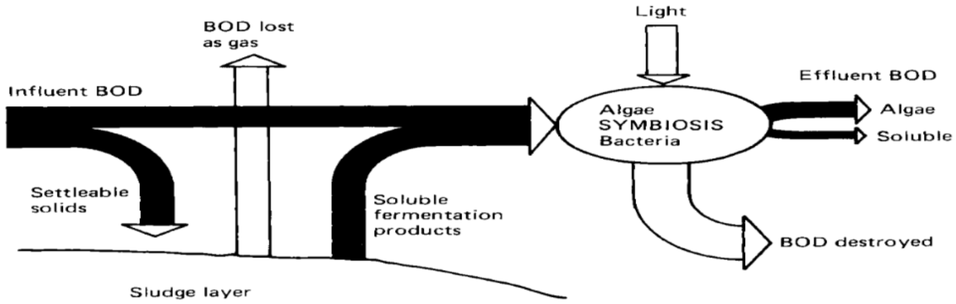

Figure 3.8: Pathways of BOD removal in primary facultative ponds
Source: (Marais, 1970)

A comparison between wastewater ponds and other treatment methods, shows that wastewater ponds without technical aeration are much more influenced by three main environmental impacts, namely, temperature, wind and sunlight (Rudolph et al, 2019). Temperature affects photosynthetic oxygen production and biological reactions in pond systems e.g. the optimum oxygen production is obtained at about 20°C with lower and upper values being approximately 4°C and 35°C respectively (Meiring et al., 1968).

Table 3.6: Facultative ponds design steps

Step	Parameter	Equations 3.9 – 3.14	Units
1	Maximum Permissible Surface Load	$L_{A,COD} = 61.5 \cdot (1.125 - 0.0023 \cdot T_W)^{(Tw-25)} . f_{Sol}$ 61.5 represents COD reference surface load kg/(m²·d) at a temperature of 25 °C.	$(\mathbf{g/(m^2 \cdot d)})$
	Solar Radiation Factor	$f_{Sol} = 1 + (0.0008 \cdot (SR - 150))$	(-)
2	Required area	$A_{P,req} = 1{,}000 \cdot \frac{L_{d,COD,IP}}{L_{A,COD}} - 1{,}000 \cdot C_{COD,IP} \cdot \frac{Q_{d,IP}}{L_{A,COD}}$	m²
		Recommendation	
	Depth (h)	typically 1.0 m to 2.0 m	
	Number of ponds in series (n)	Depending on overall size, two ponds at least	
	Freeboard	typically 0.5 m to 1.0 m	
	Ratio of length to width (l:b)	typically 2:1 to 3:1	
	Slope inclination (m)	typically 1:1 to 1:3 (depending on the soil conditions)	
	NOTE: Pond depths from 1.0 m to 1.5 m have become established in Europe, but greater depths are also used internationally.		
3	Consideration of the sedimentation and the sludge production	Create a depression (3 m deep from the pond surface) as a sedimentation zone (sludge pocket) at the inlet of the primary facultative pond to allow a hydraulic residence time of 1 additional day	
4	COD-effluent concentration	$C_{COD,EP} = C_{COD,IP} \cdot e^{-k1(Tw) \cdot HRT}$ where $k_{1(Tw)} = k_{1(20)} \cdot 1.05^{Tw-20}$ $k_{1(20)} = 0.15\ d^{-1}$	mg/l

- The maximum value for the solar factor is f_{sol} = 1.1 if there is no locally collected solar radiation data available.
- For waste water temperatures above 28 °C a further increase of the surface load based on the value of 28 °C should be avoided.
- On the basis of the selected pond geometry the pond volume V_T is determined.
- Reduction coefficient k_1 can vary due to pre-treatment (upstream anaerobic pond), the actual area load and other conditions (e.g. wastewater characteristics, very low temperatures).
- Note: coefficient of $k_{1\ (20)} = 0.15\ d^{-1}$ recommended if no own evaluations present.

Source: (Rudolph et al, 2019)

3.2.1c Maturation Ponds

The main objective of maturation ponds is the removal of excreted pathogenic organisms (Von Sperling, 2007; Pescod and Mara, 2013) or typically designed according to their disinfecting effect (see detailed design steps e.g. in Rudolph et al, 2019). Maturation ponds are therefore an economic alternative for the disinfection of the effluent, in comparison to more conventional methods, such as chlorination (Von Sperling, 2007). The environmental conditions maintained in these ponds are adverse to the pathogenic organisms, such as ultraviolet radiation, high pH, high DO, lower temperature (compared with the human intestinal tract), lack of nutrients and predation by other organisms (Von Sperling, 2007). Two maturation ponds in series, each with a retention time of 7 days, have been found necessary to produce a final effluent with BOD_5 <25 mg/l when the facultative pond effluent had a BOD5 < 75 mg/l (Pescod and Mara, 2013).

The effluent from a facultative pond treating sewage will generally require further treatment in maturation ponds to reach effluent standards imposed for reuse (Pescod and Mara, 2013). Maturation ponds should reach extremely high coliform removal efficiencies (E > 99.9 or 99.99%), so that the effluent can comply with usual standards or guidelines for direct use (e.g. for irrigation etc.) (Von Sperling, 2007). The design of the sludge treatment and final disposal stages is based on the sludge flow (volume per unit time) or in many cases, the dry solids load (mass per unit time) and the sludge flow is related to the SS load and concentration (Von Sperling, 2007);

$$\text{Flow} = \frac{\text{Load}}{\text{Concentration}} \qquad \text{Equation 3.15}$$

$$\text{Sludge flow}\left(\frac{\text{m}^3}{\text{d}}\right) = \frac{\text{SS load}\left(\frac{\text{kgSS}}{\text{d}}\right)}{\frac{\text{Dry solids (\%)}}{100}\ \text{X Sludge density}\left(\frac{\text{kg sludge}}{\text{m}^3\ \text{sludge}}\right)} \qquad \text{Equation 3.16}$$

3.2.1 d Multistage Pond Systems

Wastewater treatment plants are designed in multi-stage way although the calculation for each type of pond is carried out separately, in accordance with the course of procedure (Rudolph et al, 2019).

Table 3.7: Examples for multistage-designed wastewater plants

No.	Preliminary clarification	C-elimination	N-elimination	Disinfection	Scope, notes
1	-	Facultative Pond	Optional: additional biological treatment stage (e.g. trickling filter)	Maturation Pond	C-elimination, large area required
2	Anaerobic Pond	Facultative Pond		Maturation Pond	C-elimination, large area required
3	Anaerobic Pond	Aerated Pond		Maturation Pond	C-elimination, less area required than in examples no. 1 & no. 2

- Technological and structural demand increases from 1 to 3.
- Except for small sewage treatment plants, multiple treatment trains in parallel are recommended for minimizing operational disruptions at the desludging process and for creating redundancies.

Source: (Rudolph et al, 2019)

3.2.1 e Extension of Pond Systems

Pond systems could further be developed/upgraded stage-wise to address the overloading issues and enhance efficiency. This should also involve introducing and upgrading the pre-treatment mechanisms to relieve the load pressure at the ponds intake and in the ponds system. For example, (Rudolph, 2005) uses lamella clarifier (Figure 3.9) to achieve even higher levels of treatment efficiency e.g. for agricultural reuse etc. Additionally, the extension of wastewater ponds system involves integration of activated sludge system, and UV radiation component etc.

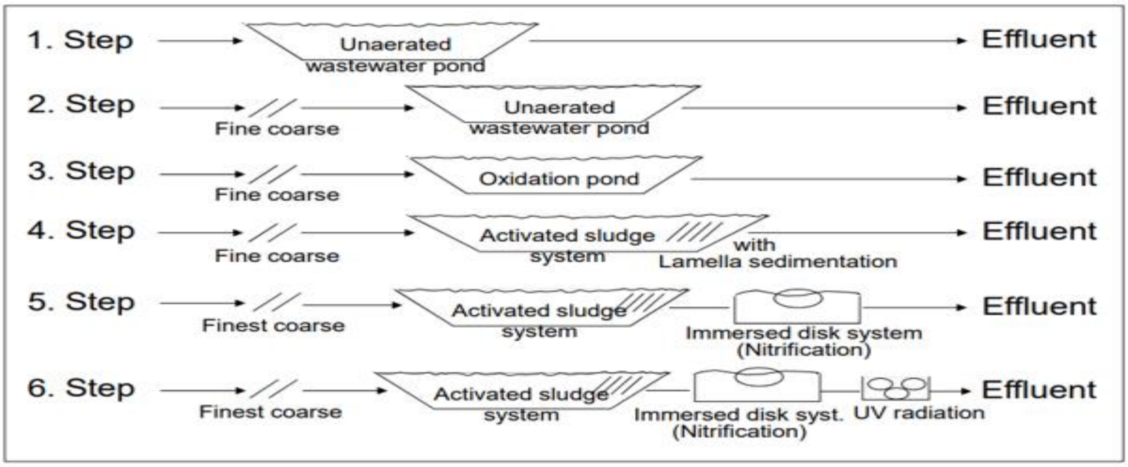

Figure 3.9: Step-wise extension of ponds system with lamella separators
Source: (Rudolph, 2005)

There are more ponds technologies, which are very important for the two case study areas (Olifants and Mara river basins), namely, the **P**ond **E**nhanced **TR**eatment and **O**peration (PETRO-System) (Shipin et al., 1997) (Figure 3.10) and the Bio-Percolation Filter (Figure 3.11) verified under the BMBF-Project EPoNa in Outapi, Namibia (Rudolph et al., 2020; Mohr et al., 2020). The PETRO concept constitutes an integrated pond system incorporating a facultative stabilization pond and oxidation ponds interlinked by high-rate interpond recirculation in a peculiar line-up (Shipin et al., 1997). The PETRO-System maximizes the use of anaerobic biodegradation followed by aerobic degradation in oxidation ponds prior to the polishing stage in a secondary unit and it uses low tech system with a high tech performance (Shipin et al., 1997). Therefore, a series of oxidation ponds using the PETRO-System treat up to 70% of the bulk of organic load, which substantially decreases the size of the relatively high tech secondary facility (Shipin et al., 1999).

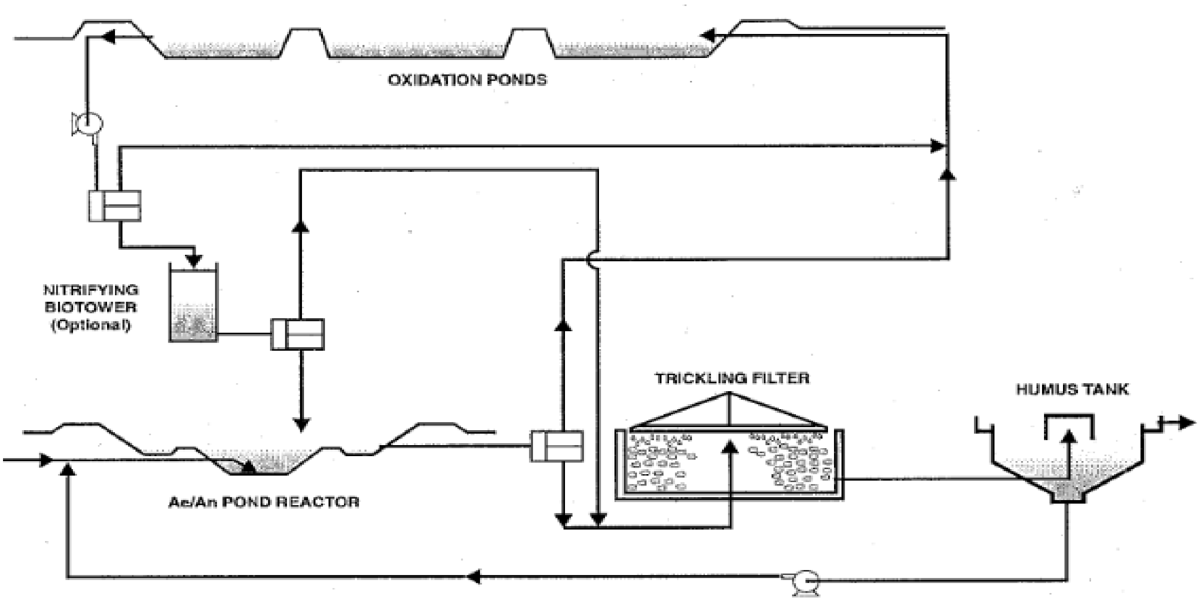

Figure 3.10: PETRO-System basic flow diagram (TF variant)
*Micro-algae produced in the stabilization ponds are removed in the TF.
*In a hybrid arrangement PETRO-System also involves a secondary facility such as a trickling filter (TF) or an activated sludge process (ASP).
Source: (Shipin et al., 1997)

Another remarkable technology is the Bio-Percolation Filter. It is part of the upgraded wastewater ponds system in Outapi, Namibia (see Pond 4 (A) in Figure 3.11) under the BMBF-Project EPoNa. The ponds system in Outapi is made up of two parallel treatment series, namely, A and B, consisting of four ponds each (one primary facultative pond and three maturation ponds). This Bio-Percolation Filter has been verified for the production of irrigation water agricultural from pond effluents and it provides a low-cost and lean-tech solution (Hilbig and Rudolph, 2019; Rudolph et al., 2020).

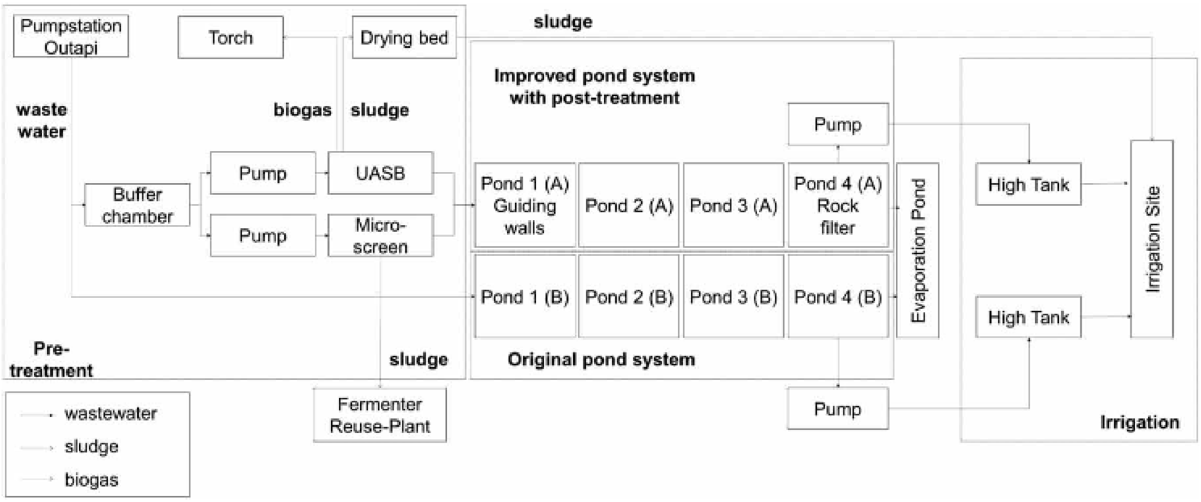

Figure 3.11: The structural outline of an upgraded wastewater ponds system in Outapi, Namibia
Source: (Mohr et al., 2020)

Apart from the post-treatment Bio-Percolation Filter in pond 4 (A) of the ponds system in Outapi, train (A) was equipped with a pre-treatment segment e.g. an up-flow anaerobic sludge blanket reactor (UASB) and a micro sieve to reduce the organic load (Sinn et al., 2019), and guiding walls to optimize the flow conditions in pond A1 (Mohr et al., 2020). All these efforts aimed at reaching an effluent water quality suitable for irrigation purposes to produce animal fodder (Lackner et al., 2017; Rudolph, et al., 2017).

More future potentials and options of wastewater pond systems include, evolution and diversification of pond systems and combinations with other treatment systems, wastewater reuse and wastewater disinfection options, decentralized wastewater treatment, and “high-brain - lean-tech” approaches (e.g. remote control, effluent disinfection by UV radiation), and economic aspects etc. (Fuhrmann and Rudolph, 2006).

On the population forecast, the design population is only a certain fraction of the total population (coverage index = population served/total population) served by the sewerage system (Von Sperling, 2007). The coverage index is a function of the following aspects: (i) physical, geographical or topographical conditions of the locality, (ii) adhesion index (ratio between the population actually connected to the system and the population potentially served by the sewerage system), and (iii) implementation stages of the sewerage system (Von Sperling, 2007). WPS should strictly be protected against wash-aways and the entry of natural run-off, and be properly fenced (Meiring et al., 1968).

3.2.2 Advantages and Disadvantages of Wastewater Ponds System

Over the years and based on tangible experience from various experts and application, wastewater ponds have emerged to have numerous advantages and therefore the best option in both cold and warm climates. They are at their best in warm climates only if they are properly designed and constructed, operated and maintained. Table 3.8 shows that the wastewater ponds offers simple construction and operation among other advantages. (WHO, 1989) recommends a series of wastewater ponds system in order to meet microbial water quality requirements. Qualified operators are essential to ensure that the reclaimed water produced will be acceptable for its intended use (US EPA, 2004).

Table 3.8: Advantages and disadvantages of various Wastewater Treatment Systems

Criterion	Treatment									
	Package plant	Activated sludge	Biological filter	Extended aeration	Oxidation ditch	Aeration lagoon	RBC	Reed bed	Wastewater Ponds System (inc. Anaerobic units)	Wastewater Ponds System (exc. Anaerobic units)
BOD removal	++	++	++	++	+++	+++	++	++	+++	+++
FC removal	+	+	+	++	++	+++	+	+	+++	+++
SS removal	++	+++	+++	+++	+++	++	+++	++	++	++
Helminth removal	+	++	+	+	++	++	+	+++	+++	+++
Virus removal	+	++	+	++	++	+++	+	++	+++	+++
Ancillary use possibilities	+	+	+	+	+	+++	+	+++	+++	+++
Effluent reuse possibilities	+	al+	al+	al++	++	+++	+	++	+++	+++
Simple construction	+	+	++	+	++	++	+	++	+++	+++
Simple operation	+	+	++	+	++	+	+	++	+++	+++
Land requirement	+++	+++	+++	+++	+++	++	+++	++	++	+
Maintenance costs	+	+	++	+	+	+	+	++	+++	+++
Energy demand	+	+	++	+	+	+	++	+++	+++	+++
Minimization of sludge for removal	+	++bl	++bl	++bl	+	++	+	++	+++	+++
Ability to accept shock loads	+	++	+	+	++	++	+	++	+++	+++

- Key: +++good; ++fair; +poor.
- *al* The effluents from activated sludge, biological filter and package plants have frequently high ammonia levels (>5 mg/l) and faecal bacterial concentrations (>10^6 per 100 ml), and are usually not suitable for irrigation or fish farming without tertiary treatment.
- *bl* Assumes provision of sludge digesters.

Source: (Mara et al., 1992a) – adapted from (Arthur, 1983); *see detailed explanation on the advantages of WPS in* (Mara, 2013)

One of the probably most important restriction and evaluation parameter regarding wastewater ponds system is the availability and value of land near the respective location. Land, respectively space is the very first restrictions to be assessed. In regions where sufficient area is available and the conditions for a demanding technical sewage plant operation are not met due to the infrastructure (e.g. power supply), wastewater ponds provide an affordable basic service for larger populations (Rudolph et al, 2019; Mara, 2009) as well as small communities (~500 population) and are widely acceptable as they are more *"natural"* with an extremely high-performance and not “*electromechanical*” as many other wastewater treatment systems (Mara, 2009). A key to promoting the implementation of water reuse is the continued development of cost-effective treatment systems (Asano and Levine, 1996), such as wastewater ponds system.

WPS are used primarily to reduce biochemical pollution and faecal bacteria contamination in wastewater before discharge to receiving water bodies (Mara and Pearson, 1987) and are effective in removing pathogens if properly designed (WHO, 1989), operated and maintained. A constant upgrade of the WPS should be taken seriously to ensure a high level of performance and protection of the health of the consumers of the end product(s). The treatment technology provided by WPS is cheap and simple and they are accepted as the most appropriate wastewater treatment method for the production of suitable effluent for reuse in agriculture and aquaculture. A series of ponds with a total retention time of 8-10 days can be designed to achieve adequate helminth removal, but at least twice that time in a hot climate to reduce bacterial numbers to the guideline level (WHO, 1987, 1989).

Table 3.9: Expected removal of excreted microorganisms in various wastewater systems[a]

Treatment process	**Removal (log_{10} units) of;**			
	Bacteria	**Helminths**	**Viruses**	**Cysts**
Primary sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemically assisted[b]	1-2	1-3[h]	0-1	0-1
Activated sludge[c]	0-2	0-2	0-1	0-1
Trickling filter/Biofiltration[d]	0-2	0-2	0-1	0-1
Aerated lagoon[d]	1-2	1-3[h]	1-2	0-1
Oxidation ditch[c]	1-2	0-2	1-2	0-1
Disinfection[e]	2-6[h]	0-1	0-4	0-3
Wastewater ponds system[f]	1-6[h]	1-3[h]	1-4	1-4
Effluent storage reservoirs[g]	1-6[h]	1-3[h]	1-4	1-4

[a]Source: reference 3. (WHO, 1989)
[b]Further research is needed to confirm performance.
[c]Including secondary sedimentation.
[d]Including settling pond.
[e]Chlorination or Ozonation.
[f]Performance depends on number of ponds in series and other environmental factors.
[g]Performance depends on retention time, which varies with demand.
[h]With good design and proper operation the recommended guidelines are achievable.

3.3 The Reduction Rates of Pathogens and other Indicator Organisms

Microbial pathogens have to be reduced to levels being suitable for irrigation applications, to protect workers conducting irrigation activities and population passing irrigated areas as well as protecting the environment from possible contamination (Rudolph et al., 2007, 2011). Therefore, the main goal of wastewater and excreta treatment is to reduce or remove certain pathogenic organisms and other indicator organisms to the levels that satisfy the intended effluent reuse or for discharging into the receiving water bodies. Table 3.10 (Von Sperling, 2007) shows some typical microorganisms that should be targeted for reduction in raw domestic sewage in developing countries – like the case study areas (Kenya and South Africa).

Table 3.10: Microorganisms present in raw domestic sewage in developing countries

Microorganisms	**Per capital load (org/inhab.d)**	**Concentration (org/100 ml)**
Total coliforms	$10^{10} – 10^{13}$	$10^{7} – 10^{10}$
Faecal (thermotolerant) coliforms	$10^{9} – 10^{12}$	$10^{6} – 10^{9}$
E. coli	$10^{9} – 10^{12}$	$10^{6} – 10^{9}$
Faecal streptococci	$10^{7} – 10^{10}$	$10^{4} – 10^{7}$
Protozoan cysts	$<10^{7}$	$<10^{4}$
Helminth eggs	$10^{3} – 10^{6}$	$10^{0} – 10^{3}$
Viruses	$10^{5} – 10^{7}$	$10^{2} – 10^{4}$

Source: (Von Sperling, 2007)

Various relevant set guidelines or benchmarks as discussed previously and hereafter in this study should be followed to the latter – of course together with local set guidelines – to safeguard the users and the environment. The reduction magnitude of aforementioned pathogenic organisms should be seen in the designed treatment system chambers progressively up to the last step. The rate of removal of pathogens, BOD, and COD etc. is a measure of the wastewater and excreta treatment success. (Metcalf et al., 2007) defines log reduction as reduction associated with wastewater treatment or water reclamation processes where levels of microorganisms are detectable. Log removal is defined as (Metcalf et al., 2007);

$$\text{Log removal} = -\log\left(\frac{\text{concout}}{\text{concin}}\right) \qquad \text{Equation 3.17}$$

Concentration in (concin) is taken as 100% of a given pathogen or microorganism per litre with a goal to reduce this concentration as much as possible to fit certain set standards or limits (concout) for water reuse, say in agriculture, land irrigation etc.

Reduction of faecal coliform bacteria in any lagoon (anaerobic, facultative and maturation) has been found to follow first-order kinetics (Pescod and Mara, 2013):

$$N_c = \frac{N_i}{1 + K_b t} \qquad \text{Equation 3.18}$$

Where N_c = Number of faecal coliforms/100 ml of effluent,
N_i = Number of faecal coliforms/100ml of influent,
K_b = First-order rate constant for faecal coliform removal, d^{-1}, and
t = Retention time in any pond, d.

when there are N ponds in series, Equation 3.18 becomes

$$N_e = \frac{N_i}{(1 + K_b t_{an})(1 + K_b t_{fa})(1 + K_b t_{m_1})(1 + K_b t_{m_n})} \qquad \text{Equation 3.19}$$

Where t_{m_n} = Retention time in the nth maturation pond.

The value of K_b is extremely sensitive to temperature (Marais, 1970)

$$K_{b(T)} = 2.6(1.9)^T - 20 \qquad \text{Equation 3.20}$$

where $K_{b(T)}$ = value of K_b at T°C
See Pescod and Mara, 2013 for detailed design, operation and maintenance of wastewater ponds system.

A performance target of 6 - 7 log units reduction is recommended based on the exposure of vegetables and on account of epidemiological evidence in order to achieve the tolerable additional disease burden from wastewater reuse of $\leq 10^{-6}$ DALY (**D**isability-**A**djusted **L**ife **Y**ears) per person per year (WHO, 2006). The DALYs is an attempt to measure the time lost through disability or death from a particular disease, by comparing it to a long life free of disability in the absence of the disease (Metcalf et al., 2007).

Hence DALY is calculated as follows;

$$\text{DALY} = \text{YLL} + \text{YLD} \qquad \text{Equation 3.21}$$

where
YLL = Years of life lost
YLD = Years lived with a disability or illness. In this context, disability refers to a condition that detracts from good health (WHO, 2006).

Log reduction using ponds system is further demonstrated by Oragui et al., 1987 (see Table 3.11) where the removal of excreted bacteria (faecal coliforms, faecal streptococci, Clostridium perfringens, total and sorbitol-fermenting bifidobacteria, salmonellae and thermophilic campylobacters) and viruses (enterovirus and rotavirus) was conducted in a series of deep anaerobic, facultative and maturation ponds (depth range: 2.8 - 3.4 m), with an overall retention time of 21 days and a mean mid-depth temperature of 27°C.

Table 3.11: Geometric mean bacterial and viral numbers* and BOD concentrations, and percentage removals, in raw wastewater (RW) and pond effluents (A6 – m6)

Organism	RW	A6	F8	M4	M5	M6	Percentage removal
Faecal coliforms	$2x10^7$	$4x10^6$	$8x10^5$	$2x10^5$	$3x10^4$	$7x10^3$	99.97
Faecal streptococci	$3x10^6$	$9x10^5$	$1x10^5$	$1x10^4$	$2x10^3$	300	99.99
Cl. Perfringens	$5x10^4$	$2x10^4$	$6x10^3$	$2x10^3$	$1x10^3$	300	99.4
Total bifidobacteria	$1x10^7$	$3x10^6$	$5x10^4$	100	0	0	100
Sorbitol +ve bifids	$2x10^6$	$5x10^5$	$2x10^3$	40	0	0	100
Campylobacters	70	20	0.2	0	0	0	100
Salmonellae	20	8	0.1	0.02	0.01	0	100
Enteroviruses	$1x10^4$	$6x10^3$	$1x10^3$	400	50	9	99.91
Rotaviruses	800	200	70	30	10	3	99.63
BOD (mg 1^{-1})	215	36	41	21	21	18	91.6

*Where A6 is anaerobic pond, F8 is facultative pond and M4, M5, M6 are maturation ponds.
*Bacterial numbers per 100 ml, viral numbers per 10 litres; mean based on 15 – 17 individual counts in triplicate.
Source: (Oragui et al., 1987); see also (Mara, 1996)

The pathogen reduction in pond systems is mainly caused by the combination of two key effects: (a) removal by sedimentation of particle-related pathogens as well as helminth eggs and (b) inactivation by insolation and biological processes (Fuhrmann and Rudolph, 2009). A further comparison of pathogen reduction between WPS and conventional treatment processes is shown by e.g. (Mara, 2013). The efficiency of WPS is very high (Table 3.12).

Table 3.12: Excreted Pathogen removals in WPS and conventional treatment processes

Excreted Pathogen	Removal in WPS	Removal in conventional treatment
Bacteria	Up to 6 log units	1 – 2 log units
Viruses	Up to 4 log units	1 – 2 log units
Protozoan cysts	99 – 100%	90 – 99%
Helminth eggs	100%	90 – 99%

Note: 1 log unit = 90 per cent removal; 2 = 99 per cent; 3 = 99.9 per cent, and so on.
Source: (Mara, 2013)

Effluent storage reservoirs (ESR) (*see detailed discussion in the subsequent section*) facilitates a further reduction of micro-organisms (WHO, 1989). The expected removal of excreted microorganisms in ESR reaches up to 1-6, 1-3, 1-4 and 1-4 (log_{10} units) for bacteria, helminths, viruses and cysts respectively (WHO, 1989).

Table 3.13: Reported effluent quality for several series of waste ponds system[a]

Location	No. of ponds in series	Retention time (days)	Effluent quality (No. of Faecal coliforms per 100ml)
Australia (Melbourne)	8-11	30-70	100
Brazil (Campina Grande)[b]	4	23	450
France (Cogolin)	3	30	100
Jordan (Amman)	10	42	30
Peru (Lima)	5	38	100

Source: [a]Obtained by (WHO, 1989) from Bartone, C.R. & ARLOSOROFF, S. Irrigation reuse of pond effluents in developing countries. Water science and technology, 19:289.297. Copyright 1987, Pergamon Press PLC.
[b]Experimental Centre for Biological Treatment of Wastewater (Extrabes).

Additionally, wastewater ponds system offer a wealth of more clearly additional utility functions (Table 3.14) in comparison with other wastewater treatment processes (Fuhrmann and Rudolph, 2009) as well as excellent (pre-)treatment features in terms of physical and biological reduction of pathogens in faecally-contaminated wastewater e.g. reduction rate of at least 3 log. units (= > 99.9 %), depending on depth, sedimentation, pH value, temperature, etc. (Rudolph et al., 2008).

To achieve quality treatment standards of wastewater, the wastewater should be collected and directed to the pre-treatment chambers before entering the wastewater ponds system. Pre-treatment is important in order to remove excessive wastewater elements that would interfere with normal functioning of the wastewater ponds system. This is because the wastewater ponds system relies entirely on biological treatment. There are a lot of wastewater ponds systems especially in Kenya that have lacked constant maintenance and are in dire need of rehabilitation and upgrading to enhance and optimize their functionality.

Table 3.14: Additional utility functions for wastewater ponds and the underlying pond properties (heavily supplemented on the basis of (Fuhrmann and Rudolph, 2009)

Useful functions	Relevant pond properties, other conditions	Drivers	Challenges
Retention and buffer function, especially for rainwater	Volume	Existing large volume	Design to avoid short circuits
Reservoir, storage function for the purpose of water reuse	Volume, depth	Existing large volume	Special geometry e.g. great depth to keep low evaporation
Biomass recovery e.g. for biofuel from algae	Algae mass and spp., solar radiation, temperature	Algae and plant material etc. could be used to generate energy; higher growth rates than land plants, especially in tropical climates	Algae separation and processing still in the development stage; it is only worthwhile in regions with many hours of sunshine
Hydrophyte production, utilization of aquatic plants	Water quality (nutrient content), temperature	In tropical climates, strong natural plant growth	If the harvest is irregular, heavy weeds and dying plants can lead to operational problems
Fish farming/ Aquaculture	Water quality	Natural nutrient supply through the wastewater	Problems with hygienic and pollutant parameters in wastewater
Biogas generation (Methane) for energy recovery	Anaerobic conditions, temperature, COD load, covering of pond surface with gas collection	Natural methane production in anaerobic ponds in warm climates	Difficult to use gas in small systems; Methane emissions into the atmosphere; especially relevant at higher temperatures
Wastewater disinfection e.g. for water reuse with low microbiological pollution	Hydraulic retention time, design, algae biocenosis, downstream disinfection in addition to natural germ reduction	High natural germs reduction rate in ponds	Additional post-treatment or further health protection measures are necessary, as natural fluctuations in the daily and seasonal course
Special cleaning services e.g. for industrial wastewater	Specific algae spp., volume	Easy to operate technology for remote locations; good buffering due to	Adapt the biocenosis to the given conditions; adapted hydraulic design for buffering shock loads

		the already existing large volume	
Hydro-energetic storage	Geodetic height difference	Search for suitable (decentralized) options for energy storage	Only works with the appropriate topography
"Blue Park" and "Green Park" for recreational purposes (water and green areas)	Environment, adequate landscaping	Better integration in natural surroundings or landscaped green spaces possible than with technical sewage treatment plants	High space requirement; near-natural design may collide with hydraulic-constructive requirements; additional maintenance costs
Keeping undeveloped land areas free/"land banking"	Environment, area/space	Existing open spaces; ponds as inexpensive interim solution	High space requirement in a developable location
CO_2 -Adsorption	Algae mass (as a renewable raw material)	Algal biomass already present; positive effect on algae growth and cleaning performance; increase in biomass production	Only relevant with the targeted cultivation of algae as an additional, renewable raw material, otherwise a "zero-sum game" in the CO_2 –balance; introduction of the gas

Source: (Fuhrmann and Rudolph, 2009); *see also in German* (Fuhrmann, 2014)

3.4 Wastewater Ponds System in Kenya

Kenya is celebrated as among the countries in Africa and the world at large which commissioned Dandora Wastewater Ponds System in Nairobi (Figure 3.12) as one of the largest of its kind in 1971. These ponds are located 30 km from the central business district (CBD) of the capital city Nairobi and treats a dry weather flow of about 80, 000 m^3 of industrial and domestic sewage per day (about 80% of Nairobi's wastewater). Since then the number of such ponds systems large and small serving hundreds to thousands of households have been established in various rural and urban areas in Kenya. The effluent, from Dandora ponds system, which does not meet the required standards due to overloading is discharged into the Nairobi river.

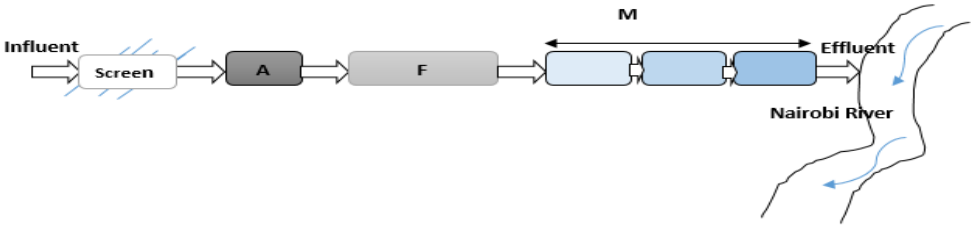

Figure 3.12: Schematic representation of Dandora WPS, Nairobi, Kenya
A-anaerobic pond, **F**-facultative pond, and **M**-Maturation ponds.

There are other towns in Kenya – apart from Nairobi – that have established wastewater ponds system (see for example Table 3.15) although some are either (i) old and defunct, (ii) under-designed (overloaded and sometimes operate beyond their original design capacity. This is mainly due to storm weather flow), (iii) over-designed (under loaded), (iv) stalled projects, (v) under construction, or (vi) in the planning or planned stages respectively, etc. Some of these projects have faced financial challenges, political interference, lack of community recognition and acceptance, and policies incoherence etc. Additionally, most of these wastewater treatment systems e.g. the pond systems are only connected to very few clients (such as households, and industries). Various County governments of Kenya – (Kenya has 47 county governments) – do not have wastewater strategic plans to enhance construction or rehabilitation of wastewater treatment systems. Some towns have adopted an integrated wastewater treatment system consisting of wastewater ponds system.

Table 3.15: Wastewater ponds system in some major towns in Kenya

Town/city	Pond description	Effluent disposal/reuse
Nairobi (Dandora)	Has three series of one anaerobic pond, one facultative, and three maturation ponds each; Dry weather flow of about 80, 000 m^3	Disposed into the Nairobi river
Nakuru (Kaloleni)	Has two anaerobic ponds, two facultative, six maturation ponds with rock and grass filters	Disposed into the lake Nakuru (which is also a National park)
Kisumu (Nyalenda)	Dry weather flow around 13,000m^3/d	Disposed into Winam Gulf, lake Victoria
Mombasa Island and North Mainland (planned)	Nguu Tatu and Shimo la Tewa have two anaerobic ponds, two primary and two secondary facultative ponds, and four maturation ponds each; Dry weather flow at Nguu Tatu 52,300m^3/d and Shimo la Tewa 9,900m^3/d respectively	To be disposed in the Indian Ocean, Sabaki river etc.
Eldoret	Dry weather flow around 4,900m^3/d	Disposed in the Sosiani river
Bomet	One train consisting of one anaerobic pond, one facultative, four maturation ponds; Dry weather flow around 786m^3/d	Disposed into the Nyangores/Chepkulo river

*Most of the towns in Kenya have at least one wastewater ponds system.

3.5 Water Reuse

Wastewater has been considered as a resource for many decades, especially if it does not contain substantial quantities of industrial effluent (Mara et al., 1989). Increased interest in wastewater reuse in many parts of the world is occurring in response to growing pressures for high quality, dependable water supplies by agriculture, industry and the public (Asano and Levine, 1996), due to increasing water scarcity affected by climatic changes as well as the overwhelming water consumption demand for human activities, wildlife and ecosystem at large. The common areas of application are identified by (Mara et al., 1989) as use of wastewater for crop irrigation, use of excreta for soil fertilization and soil structure improvement, and use of wastewater and excreta in aquaculture. A key to promoting the implementation of water reuse is the continued development of cost-effective treatment systems (Asano and Levine, 1996).

Wastewater reclamation has met a lot of challenges ranging from uncoordinated policy framework, poor design, construction and operation of the treatment systems leading to insufficient treatment hence risking the health of the public and the entire ecosystem (receiving water bodies, flora and fauna). Additionally, there is poor risk assessment wastewater reclamation and reuse, socio-cultural hindrances, and financial hiccups, etc. The source of wastewater and excreta should always be established and its physical, chemical and biological content evaluated to determine the treatment standards that should apply as well as establishing the types of re-usable nutrients that are embedded on the wastewater.

3.5.1 Use of Treated Effluent and Excreta for Agriculture

Globally, only a small proportion of treated wastewater is currently used for agriculture, but the practice is growing in many countries, and in some regions a high proportion of reclaimed water is used in irrigation (FAO, 2010). The growth in agricultural water reuse recorded 32% globally, followed by landscape irrigation with 20% and industrial uses at 19% while aquifer recharge as one of the least developed global uses recorded 2% of the reclaimed water (IEEP. et al., 2016). Irrigation farming using treated wastewater in arid and semi-arid areas is also becoming increasingly common (Ayres et al., 1996). Mara, 2009 predicts that wastewater reuse will become so important to feed the ~2.5 billion 'new' people arriving in the next 25–30 years that even conservative engineers will realize that 'wastewater is too valuable to waste' and that wastewater treatment in wastewater ponds system (WPS) and wastewater storage and treatment reservoirs, (WSTR) is an extremely reliable way to ensure the safety of the food so produced. Additionally, the upgraded ponds system enhances treatment process thereby producing an effluent with even higher quality standards suitable for reuse purposes. There are various technologies that have been employed towards extension or upgrading the ponds system (see e.g. section 3.2.1e) e.g. the Bio-Percolation Filter which has been verified especially for the production of irrigation (agricultural) water from pond effluents (Hilbig and Rudolph, 2019; Rudolph et al., 2020) etc.

3.5.2 Reclaimed Water Treatment Levels

Wastewater and excreta harbours enormous pathogenic microorganisms (e.g. bacteria, viruses, Helminth eggs, and Protozoan cysts) which are employed as indicators of the acquired and current water quality, subsequent quality requirements and the attainment of certain treatment levels. There are various factors that affect the quality of reclaimed water, namely, (i) source water quality, (ii) wastewater treatment processes and treatment effectiveness, (iii) treatment reliability, and (iv) distribution system design and operation (Grobicki and Cohen, 1999). Choosing the right level of treatment should be dictated by the end application of the reclaimed water for achieving economic efficiency and environmental sustainability (US EPA, 2012). Wastewater and excreta should primarily be subjected through various treatment stages e.g. pre-treatment, primary, secondary and advanced treatment etc. – as the case may be – in order to achieve the required set standards. Disinfection process is preceded by elimination of other suspended and dissolved oxygen depleting matters. There are typical wastewater and excreta disinfection procedure primarily depending on the required level of treatment and the availability of the desired technology (see for example Figure 3.13). Some of the nutrients (e.g. Nitrogen, and Phosphorus etc.) found in the wastewater and excreta may be preserved – during treatment process – if the reuse target of wastewater and excreta is agriculture or aquaculture etc. or otherwise eliminated before discharging the effluent to the receiving water bodies to avoid negative effects to the communities downstream, and the eutrophication of rivers, etc.

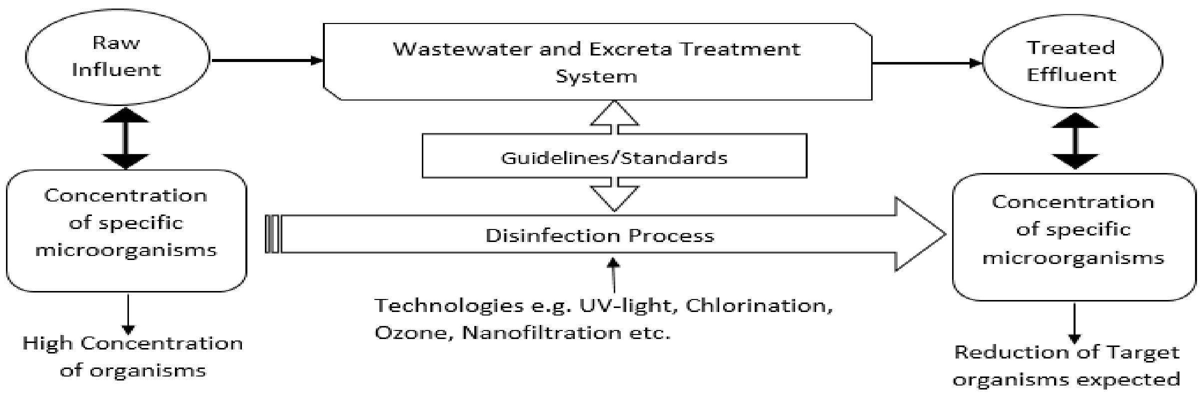

Figure 3.13: Typical wastewater and excreta disinfection procedure

Technically, disinfection of wastewater can be performed to nearly any wished level, up to the total sterilization of wastewater, although it should be limited to the concrete required levels due to the treatment costs and necessary competence of operational staff etc.(Fuhrmann and Rudolph, 2011). Extensive research on disinfection of wastewater – using UV-irradiation, membrane filtration, ozonation, chlorination, pasteurization, Ferrate etc. – for various reuse has been done by e.g. (Rudolph et al., 1992; Fuhrmann and Rudolph, 2007, 2011; US EPA, 2004, 2012) etc. As part of a multi-barrier concept to utilize wastewater from existing sewage systems, UV irradiation has been identified as most appropriate disinfection method within a compact and simplified treatment system (Rudolph et al., 2007).

3.5.3 The Health Guidelines for the Treated Effluent and Excreta Reuse

The driving forces behind the increased wastewater reuse in agriculture in the world is due to the (i) increasing water scarcity and stress, and degradation of freshwater resources resulting from improper disposal of excreta and greywater, (ii) population growth with subsequent increase in demand for food, (iii) a growing recognition of the wastewater value and the nutrients they contain, (iv) the goals of environmental sustainability and poverty and hunger elimination (WHO, 2006). The wastewater has been used by different countries for many decades in agricultural activities although with minimal treatment or even raw wastewater in some cases. As a result of this, a lot of water borne diseases and deaths have been reported in the history of wastewater reuse. The situation is still the same in some of the developing countries especially in sub-Saharan Africa and Asia. The growth of urban populations, especially in developing countries has led to generation of more wastes especially around the cities, difficulties on the on-site waste disposal in densely populated areas and increased urban agriculture in order to supply food to city dwellers (WHO, 2006). Cropland in peri-urban areas irrigated by mostly untreated urban wastewater is estimated to be approximately 36 million hectares (equivalent to the size of Germany)(WHO, 2019). This is true to various cities in Kenya especially the capital city Nairobi. Farmers in slums and peri-urban areas near central business district (CBD) of Nairobi (e.g. Dandora, Kibera etc.) have in the recent past doubled their efforts to grow vegetables like *sukuma wiki* (kales), spinach, onions and other crops like bananas, yams etc. using raw sewage diverted from mostly free flowing wastewater content through open channels to their farms (Figure 3.14). Farmers use untreated wastewater out of necessity and it is a reality that cannot be denied or effectively banned (Buechler et al., 2002; Metcalf et al., 2007). For developing countries, particularly in arid areas, wastewater is simply too valuable to waste (Metcalf et al., 2007). In South Africa (Grobicki and Cohen, 1998) reported that there were already a number of small urban wastewater reuse schemes in place for irrigation purpose.

Figure 3.14: Use of raw sewage to grow vegetables in Nairobi, Kenya
Source:(Shiundu, 2018)

Crops irrigation with untreated wastewater is more common than irrigation with treated wastewater as most wastewater in developing countries is not treated and many farmers only have untreated wastewater with which to irrigate their crops (Mara, 2013). More than 50% of the absolute poor live in urban areas and cannot afford imported food (WHO, 2006). The annual population growth rate of Nairobi is 4% recording almost 1 million increase in the last 4 years (Kenya National Bureau of Statistics, 2019a). The rural urban migration is so rampant as young people search for job opportunities leading to increased pressure on freshwater and food, compelling poor city dwellers to opt for the cheap vegetables grown using raw wastewater. A highly contaminated raw sewage food products poses a serious health risk to the consumers. Protection of the health of consumers of the end products of the treated wastewater fed crops is paramount.

3.5.4 Assessment of Health Risk

The risk that wastewater irrigation may facilitate the transmission of excreta-related disease (Ayres et al., 1996) has led to intensive research by (WHO, 2006), which evaluated health risks in terms of microbial analysis, epidemiological studies and quantitative microbial risk assessment (QMRA) and recommended health guidelines e.g. Disability Adjusted Life Years (tolerable burden of disease of $\leq 10^{-6}$ DALY per person per year). Several other organizations and researchers e.g. (US EPA, 1992, 2004; Metcalf et al., 2007; FAO, 2010) etc. have equally invested heavily on assessment of health risks.

Box 3.1: There are four groups of people identified by (WHO, 1989) as being at potential risk from the agricultural reuse of wastewater and excreta, namely,

(i) Agricultural field workers and their families,
(ii) Crop handlers,
(iii) Consumers of crops, meat and milk etc., and
(iv) Those living near the fields concerned.

Standards are often not enforced – as is demonstrated by the use of raw sewage to grow vegetables in some parts of Nairobi, Kenya – and therefore posing dire health problems emanating from unregulated, illegal irrigation of salad crops with raw wastewater (WHO, 1989). To forge ahead, realistic and very strict health guidelines must be established – not only internationally as is widely the case currently, but locally as well – and adhered to in order to safeguard consumers of products like vegetables etc. obtained using raw and partially treated wastewater. Reliable data from Kenya and other developing countries should strictly be considered in devising the current and future relevant guidelines. Most of the developed countries like Germany etc. have achieved a lot in terms of wastewater management and reuse and do not necessarily need so much attention as is the case with the developing countries whose wastewater management is still a nightmare. Various internationally recognized bodies have attempted to establish health guidelines for the reuse of the treated wastewater though faced with some realization challenges in some countries.

Box 3.2: Based on the available epidemiological evidence, it has been established that the major risks are:

- ❑ The transmission of intestinal nematode infections both to those working in the wastewater-irrigated fields and to those consuming vegetables grown in the fields; these infections are due to *Ascaris lumbricoides* (the human roundworm), *Trichuris trichiura* (the human whipworm), and *Ancylostoma duodenale* and *Necator americanus* (the human hookworms); and
- ❑ The transmission of faecal bacterial diseases – bacterial diarrhoea and dysentery, typhoid and cholera – to the crop consumers (Ayres et al, 1996)

Apart from the epidemiological evidence on the major health risks from intestinal nematode infections and faecal bacterial diseases (see Box 3.2) (Ayres et al., 1996), viruses pose relative health risks from use of untreated excreta and wastewater in agriculture and aquaculture (see Table 3.16) (WHO, 1989). The viruses present in raw domestic sewage per capita load (org/inhab.d) and concentration (org/100 ml) e.g. in developing countries are between 10^5 – 10^7 and 10^2 – 10^4 log units respectively (Von Sperling, 2007). The reduction of faecal viruses that can be achieved using wastewater ponds system is 2-4 log units (log_{10} units) (Mara et al., 1992a) and the percentage removal of the enteroviruses and rotaviruses using ponds system is 99.91 and 99.63 respectively (Oragui et al., 1987; Mara, 1996).

The research of viruses and wastewater pond's effluent is progressing but the level of monitoring and knowledge about virus control is far beyond that about bacteria. For example, the results of a survey of Australian Water Association on water reuse research priorities put viruses as "priority number 2" (see Table 8.2) (Dillon, 2000). Viruses (e.g. Severe Acute Respiratory Syndrome (SARS); SARS-CoV-1, SARS-CoV-2 etc.) can spread via wastewater systems (McKinney et al., 2006). These viruses – which can cause an epidemic or even pandemic problems – are said to die off during the wastewater purification process or afterwards (like the coronavirus). For example, the viral particles introduced in wastewater through shedding in faeces and urine may remain infectious for up to 2 days at 20°C (Amoah et al., 2020). According to (Gundy et al., 2008), there is a rapid coronaviruses die off in wastewater at 20°C for up to 99.9% in a period of 2–3 days. The evaluation of the survival of two surrogate coronaviruses, namely, transmissible gastroenteritis (TGEV) and mouse hepatitis (MHV) by (Casanova et al., 2009), found that the aforementioned viruses remained infectious in water and sewage for days to weeks before achieving a 99% reduction. Therefore, the survival period of coronaviruses in aqueous environments are firmly influenced by the temperature, property of water, concentration of suspended solids and organic matter, solution pH, and the dose of disinfectant used (Tran et al., 2021). The fact that coronaviruses are more rapidly inactivated in water and wastewater at ambient temperatures, makes the transmission of coronaviruses lesser than enteroviruses in the aqueous domain (Gundy et al., 2008). Additionally, the survival time of other excreted viruses e.g. enteroviruses including polio-, echo-, and coxsackieviruses in soil and on crop surfaces at 20-30°C is <70 but usually <20days and <60 but usually <15days respectively (see Table 3.20) (WHO, 1989).

The relative health risks from use of raw wastewater in agriculture and aquaculture ranges from "*nil*" to "*high.*" (see Table 3.16) (WHO, 1989).

Table 3.16: Relative health risks from use of untreated excreta and wastewater in agriculture and aquaculture

Type of pathogen/infection	**Excess frequency of infection or disease**
Intestinal nematodes *Ascaris* spp *Trichuris* spp Hookworms	High
Bacteria Bacterial diarrhoeas (e.g. cholera, typhoid)	Lower
Viruses Viral diarrhoeas Hepatitis A	Lowest
Trematodes and cestodes Schistosomiasis Clonorchiasis Taeniasis	From high to nil, depending upon the method of excreta use and local circumstances

Source: (WHO, 1989)

Due to the increasing importance of wastewater reuse in agriculture as well as the need for heath safety measures to protect the consumers of the end product, (WHO, 1989) has established wastewater reuse guidelines (Table 3.17) to spearhead the quest for enhanced food production through reclaiming the resources embedded on the wastewater.

Table 3.17: Recommended microbiological quality guidelines for wastewater use in agriculture[a]

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c]	Faecal coliforms (geometric mean no. per 100ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤1	≤1000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a]In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[b]*Ascaris* and *Trichuris* species and hookworms.
[c]During the irrigation period.
[d]A more stringent guideline (≤200 faecal coliforms per 100ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e]In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
Source: (WHO, 1989)

If necessary, modified microbiological quality guidelines for wastewater reuse in agriculture ought to be customized to reflect local epidemiological, socio-cultural, and environment factors (WHO, 1989) as well as being synchronized with relevant local and transboundary river basin policies. Kenya for example has adopted the (WHO, 1989, 2001, 2006) with some minor changes (Table 3.18) on the microbial quality guidelines for wastewater reuse as well as permissible levels for various parameters before subjecting water to the irrigation activities as retrieved from the eighth and ninth schedules of the Environmental Management and Coordination, (Water Quality) Regulations of 2006; (also revised in 2012) respectively. Adherence to these standards is monitored by the National Environment Management Authority (NEMA) through issuance of relevant licenses.

Table 3.18: Kenya microbial quality guidelines and standards for water and wastewater use in irrigation

Parameter	**Permissible levels**
pH	6.5-8.5
Aluminium	5 (mg/L)
Arsenic	0.1 (mg/L)
Boron	0.1 (mg/L)
Cadmium	0.5 (mg/L)
Chloride	0.01 (mg/L)
Chromium	1.5 (mg/L)
Cobalt	0.1 (mg/L)
Copper	0.05 (mg/L)
E.coli	Nil/100 ml
Intestinal nematodes (for both unrestricted and restricted irrigation)	<1(MPN/L)*
Coliforms (for unrestricted irrigation)	<1000(MPN/100 ml)**
Fluoride	1.0 (mg/L)
Iron	1 (mg/L)
Lead	5 (mg/L)
Selenium	0.19 (mg/L)
Sodium Absorption Ratio (SAR)	6 (mg/L)
Total Dissolved Solids	1200 (mg/L)
Zinc	2 (mg/L)

- And any other parameters as may be prescribed by the Authority from time to time.
- **Ascaris lumbricoides, Trichuris trichiura* and human hookworms.
- **A more stringent guideline (<200 coliform group of bacteria per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
- "No standard recommended" for restricted irrigation on Coliforms.
- For the definition of unrestricted and restricted irrigation, see (WHO, 1989, 2001, 2006).

Source: (Environmental Management and Coordination, Water Quality Regulations, 2006).

WHO, 2006 has further given guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture (Table 3.19) based mainly on Helminth eggs (number per gram total solids or per litre) and *E.coli* (number per 100 ml).

Table 3.19: Guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture

	Helminth eggs (number per gram total solids or per litre)	***E. coli* (number per 100 ml)**
Treated faecal and faecal sludge	<1/g total solids	<1000 g/total solids
Greywater for use in:		
Restricted irrigation	<1/litre	$<10^{5}$ [a] Relaxed to $<10^{6}$ when exposure is limited or regrowth is likely
Unrestricted irrigation of crops eaten raw	<1/litre	$<10^{3}$ Relaxed to $<10^{4}$ for high growing leaf crops or drip irrigation

[a]These values are acceptable due to the regrowth potential of E. *coli* and other faecal coliforms in greywater.
Source: (WHO, 2006).

WHO, 1989, 2006 gives two main conditions for the wastewater reuse, namely, (i) only treated wastewaters should be used for crop irrigation, and (ii) the treated wastewaters should comply with the microbiological quality guideline (Figure 3.15).

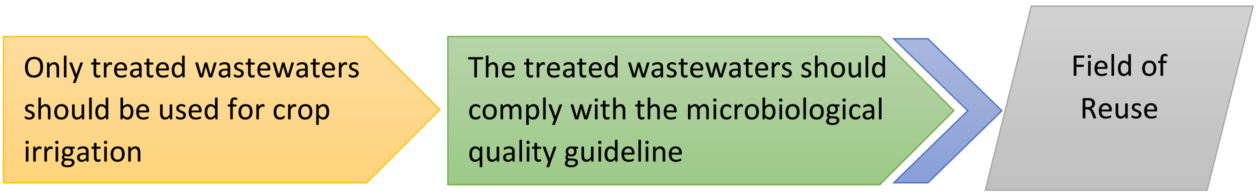

Figure 3.15: The two main conditions for the wastewater reuse
Source: Adapted from (WHO, 1989, 2006)

The reuse of treated wastewater for agriculture enables freshwater to be exchanged for more economically and socially valuable intentions, at the same time providing farmers with dependable and nutrient-rich water (FAO, 2010). This exchange also has prospective environmental benefits, minimizing the release of wastewater effluent downstream, and allowing the assimilation of its nutrients into the soil (FAO, 2010). Wastewater reuse projects can therefore offer a prospective double or even triple “dividend” to the urban users, farmers and the environment at large (FAO, 2010).

3.5.5 Planning for The Treated Effluent and Excreta Reuse

WHO, 1989; Mara et al., 1992a finds wastewater reuse as a feasible option which should primarily be geared towards removal of pathogens before re-using it in agriculture, and aquaculture etc. The lack of natural water resources from aquifers, rivers, and lakes has led to the growing recycling of domestic and municipal wastewater (both treated and untreated) for irrigation (FAO, 2010). United Nations, 2015 in sub-section 6.3 of its SDG 6 aims at, improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally by 2030. The wastewater reuse plan requires a comprehensive, progressive and incremental approach that responds to the greatest health priorities first (WHO, 2006). The excreted pathogens have a given period of survival time in soil and ponds at 20-30°C to pose health risks to farm and pond workers (Table 3.20) (WHO, 1989).

Table 3.20: Survival time of selected excreted pathogens in soil and on crop surfaces at 20-30°C

Pathogen	Survival Time	
	In soil	**On crops**
Viruses		
Enteroviruses[b]	<70 but usually <20days	<60 but usually <15days
Bacteria		
Faecal coliforms	<70 but usually <20days	<30 but usually <15days
Salmonella spp	<70 but usually <20days	<30 but usually <15days
Vibrio cholerae	<20 but usually <10days	<5 but usually <2days
Protozoa		
Entamoeba histolytica cysts	<20 but usually <10days	<10 but usually <2days
Helminths		
Ascaris lumbricoides eggs	Many months	<60 but usually <30days
Hookworm larvae	<90 but usually <30days	<30 but usually <10days
Taenia saginata eggs	Many months	<60 but usually <30days
Trichuris trichiura eggs	Many months	<60 but usually <30days

[b]Includes polio-, echo-, and coxsackieviruses
Source: (WHO, 1989)

Box 3.3: Epidemiological evidence shows that a bacterial guideline of a geometric mean of ≤1000 faecal/total coliforms per 100ml for unrestricted irrigation of all crops and the arithmetic mean number of eggs ≤1 human intestinal nematode eggs per litre for restricted irrigation (e.g. involving all crops with an exclusion of raw consumed salad crops and vegetables) is recommendable (WHO, 1989)

Ponds are useful for storing water for agricultural reuse (Bucksteeg, 1982, 1987). Mara et al., 1992b finds it worthy to consider the option of discharging wastewater ponds system (WPS) effluents to the land for irrigation and fertilization purposes. Algae rich effluent contains essential nutrients such as N, P, K and micro-nutrients such as Fe, Mg, S etc. for the growth and development of plants.

Newly designed and upcoming wastewater treatment systems such as wetlands and wastewater ponds system should incooperate the aspect of capturing the treated effluent for reuse. This could be achieved in the design stages or through modification, and renovation or upgrading the already existing systems. (Mara and Silva, 1986) states that faecal coliform bacteria are commonly used as indicators of excreted pathogens and maturation ponds can be designed to achieve a given reduction of faecal coliforms (FC). Protozoan cysts and helminth ova are removed by sedimentation in ponds system and a series of ponds with overall retention of 11 days or more will produce an effluent containing <:1 nematode egg/litre (Mara and Silva, 1986). There are a number of relevant quality parameters for water reuse according to (EPA, 2004) (see Table 3.21).

Table 3.21: Summary of the relevant quality parameters for water reuse

Parameter	Importance for reuse	Usual discharge values of biological wastewater treatment plants (without nutrient elimination)	Purification goal for water reuse
Filterable substances	Measure for particulate matter. May be related to microbial contamination. Can hinder disinfection. Danger of clogging of irrigation systems. Leads to deposits	5mg SS/l – 50mg SS/l	<5mg SS/l – 30 mg SS/l
Cloudiness		1NTU[5] – 30NTU	<0.1NTU–30NTU
BSB_5	Organic substrate for the growth of microorganisms. Can promote recontamination in pipeline and microbial fouling.	10mg/l – 30mg/l	<10mg/l–45mg/l
CSB		50mg/l – 150mg/l	<20mg/l–90mg/l
TOC		5mg/l – 20mg/l	<1mg/l – 10mg/l
Total coliforms Bacteria	Measure of the risk of infection due to the potential presence of pathogenic germs	<10 cfu/100ml – 10^7 cfu/100ml	<1 cfu/100ml – 200 cfu/100ml
Faecal coliforms Bacteria		1 cfu/100 ml – 10^6 cfu/100 ml	<1 cfu/100ml – 10^3 cfu/100ml
Helminths eggs		<1/l – 10/l	<0.1/l – 5/l
Virus		<1/l – 100/l	<1/50l
Heavy metals	Some elements (Cd, Ni, Hg, Zn, etc.) are poisonous to plants and there are limit values for irrigation	-	<0.001mg Hg/l <0.01mg Cd/l <0.1mgNi/l – 0.02mg Ni/l
Inorganic substances	High salt and Boron content (>1 mg/l) are disadvantageous for irrigation	-	<450 TDS/l
Residual Chlorine compounds	To prevent re-germination. Excessive free chlorine (>0.05) can be harmful for some crops.	-	
Nitrogen	Fertilizer for irrigation. Can contribute to algae growth, corrosion ($N-NH_4$) and clogging (P)	10mg N/l – 30mg N/l	<1mg N/l – 30mg N/l
Phosphorus		0.1mg P/l – 30mg P/l	<1mg P/l – 20mg P/l

Source: (EPA, 2004) adapted from (Lazarova et al., 2001; Metcalf and Eddy, 1991; Pettygrove and Asano, 1985).

There are various crop restrictions and measures (see Figure 3.16) to those planning to apply treated effluent to category B (Table 3.17) in order to protect the consumers (WHO, 1989).

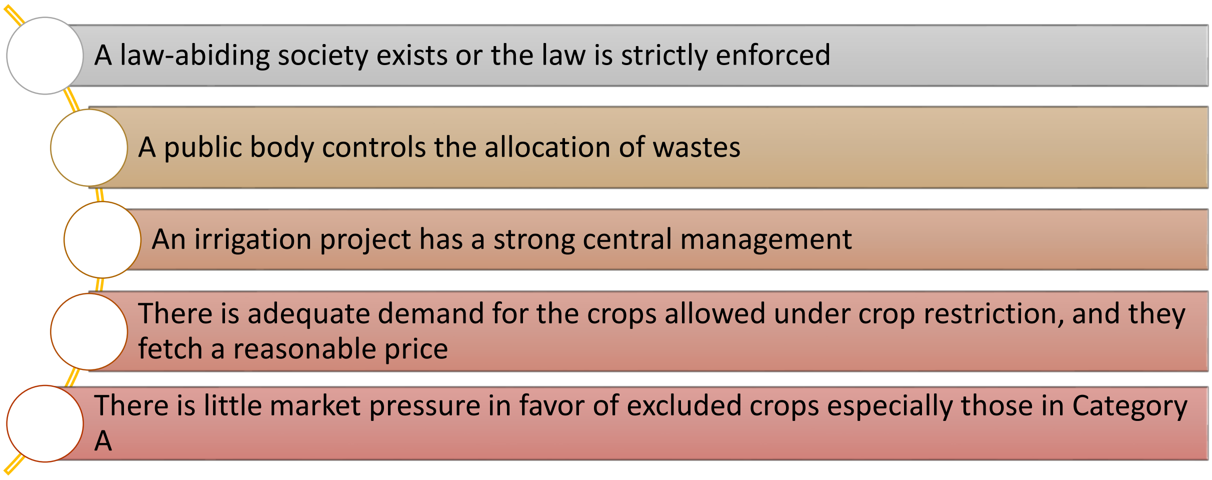

Figure 3.16: Crop restrictions and measures for treated effluent and excreta reuse
Source: Adapted from (WHO, 1989)

It should be noted that adopting crop restrictions as a means of health protection in reuse schemes will require a strong institutional framework and the capacity to monitor and control compliance with regulations and to enforce them (WHO, 1989). Some earlier cultural objections on the reuse of wastewater have now – to a commendable milestone – seen the importance of applying the treated effluent not only for the fodder crops and flower gardens but also food crops especially in water scarce areas.

An example of quality requirements for water reuse in the USA and other countries as compiled by US EPA, 2004 focused on fecal and total coliforms, Helminth eggs, BOD_5, turbidity, total suspended solids (TSS), dissolved oxygen (DO), pH, and Chlorine residual (Table 3.22).

Table 3.22: Compilation of quality requirements for water reuse in the USA and other countries

Country/ Region	Faecal Coliforms (CFU/100ml)	Total Coliforms (CFU/100ml)	Helminth Eggs (#/L)	BOD_5 (ppm)	Turbidity (NTU)	TSS (ppm)	DO (% OF Sat)	pH	Chlorine Residual (ppm)
Australia (New South Wales)	<1	<2/50	--	<20	<2	--	--	--	--
Arizona	<1	--	--	--	1	--	--	4.5-9	--
California	--	2.2	--	--	2	--	--	--	--
Cyprus	50	--	--	10	--	10	--	--	--
EO Bathing water	100 (g) 2000 (m)	500 (g) 10000 (m)	--	--	2 (g) 1 (m)	--	80-120	6-9	--
France	<1000	--	<1	--	--	--	--	--	--
Florida (M)	25 for any sample for 75%	--	--	20	--	5	--	--	1
Germany (G)	100 (g)	500 (g)	--	20 (g)	1-2 (m)	30	80-120	6-9	--
Japan (M)	10	10	--	10	5	--		6-9	--
Israel	--	2.2 (50%) 12 (80%)	--	15	--	15		--	0.5
Italy	--	--	--	--	--	--		--	--
Kuwait Crops not eaten raw	--	10000	--	10	--	10	--	--	1
Kuwait Crops eaten raw		100		10		10			1
Oman 11a	<200	--	--	15	--	15	--	6-9	--
Oman 11b	<1000			20		30		6-9	
South Africa	0 (g)	--	--	--	--	--	--	--	--
Spain (Canary Islands)	--	2.2	--	10	2	3	--	6.5-8.4	1
Texas (M)	75 (m)	--	--	5	3	--	--	--	--
Tunisia	--	--	<1	30		30	7	6.5-8.5	--
UAE	--	<100	--	<10	--	<10	--	--	--
UK Bathing water criteria	100 (g) 2000 (m)	500 (g) 10000 (m)	--	--	2 (g) 1 (m)	--	80-120	6-9	--

USA EPA (G)	14 for any sample, o for 90%	--	--	10	2	--	--	6-9	1
WHO (Lawn irrigation)	200 (g) 1000 (m)	--	--	--	--	--	--	--	--

(g) signifies that the standard is a guideline and (m) signifies that the standard is a mandatory regulation.
Source:(US EPA, 2004) adapted from Cranfield University, 2001. Urban Water Recycling Information Pack, UK

3.5.6 Fertilizer Content in The Wastewater and Excreta

Wastewater is not wasted water but resourceful water. This is because, reclaimed water usually contains enough of the most vital crop nutrients e.g. nitrogen, phosphorus, potassium, zinc, boron, and sulfur (US EPA, 2004). The regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 (European Union, 2020) on minimum requirements for water reuse states that *"…water reuse for agricultural irrigation can also contribute to the promotion of the circular economy by recovering nutrients (such as nitrogen, phosphorus and potassium) from the reclaimed water and applying them to crops, by means of fertigation techniques."* The positive value of agricultural nutrients (N, P, K) present in reused wastewater should be considered as an "extra bonus" (Shelef, 1991). Nitrogen and phosphorus levels in sewage can range from 20 to more than 100 mg/l and 5 to 50 mg/l respectively, depending on in-house water use and diet of the local population and on the treatment of the sewage effluent (Pescod, 1992). Therefore, complete reduction of organics and nutrients in wastewater is usually not required, if the treated water is used for irrigation purposes, as the contained nutrients can partly be used as valuable fertilizer (Rudolph et al., 2007, 2011). US EPA, 2004 provides recommendations on the limits for constituents in reclaimed water for irrigation.

3.5.6a Urine and Faecal Matter Nutritional Value in Crops

Urine and faecal matter are rich in various valuable nutrients that can fertilize crops, flowers in the garden, grass etc. Urine is rich in nitrogen (N) and can be used for fertilizing most non-nitrogen-fixing crops after proper treatment to reduce potential microbial contamination (WHO, 2006). The amount of nitrogen produced is 30 – 70 kg/capita/year supporting one crop on 300 – 400 m^2 while faecal matter from one person is enough to fertilize 200 – 300 m^2 of wheat at a yield of 300 kg/ha based on the P content (WHO, 2006). Therefore, crop yields are higher as the wastewater contains not only water for crop growth, but also plant nutrients (mainly nitrogen and phosphorus) (Ayres et al., 1996). P is particularly valuable for the plant in its early development and important for good root development (Jönsson et al., 2004). The nutrients in urine are in ionic form and their plant-availability compares well with chemical/inorganic fertilizer (Johansson et al., 2001; Kirchmann and Pettersson, 1995; Kvarmo, 1998; Richert Stintzing et al., 2001). Urine is rich in ammonium and urea (Equation 3.24) which are the mainly used N fertilizer in the agricultural world (Jönsson et al., 2004).
The total amount of nutrients excreted is lower in faeces than in urine, but the concentrations of phosphorus and potassium are higher in faeces than in urine, making it useful to the crop yield as it is a complete phosphorus-potassium fertilizer e.g. (Jönsson et al., 2004; WHO, 2006). Additionally, urine and faecal matter regulates pH (Mara and Pearson, 1987), conditions the

soil, content of organic matter in faeces increases the water holding and ion-buffering capacities of soil, hence improving soil structure and stimulates the microbial activity (Jönsson et al., 2004; WHO, 2006).

3.5.6b Algae Nutritional Value in Crops

According to (Mara et al., 1992a), algae act as a slow-release fertilizer in the soil, supplying just the right proportions of nutrients (N, P, K) and micro-nutrients (e.g. Fe, Mg, S) for plant growth. Wastewater ponds system effluents would provide a continuous supply of fertilizer, thereby reducing chemical/inorganic fertilizer requirements and groundwater contamination. Chemical/inorganic fertilizers are generally applied to land in large slug doses which are then gradually leached from the soil (Mara et al., 1992a). Algae is easily recognized in ponds system due to its green color pigmentation; see for example green effluent due to high amount of algae in Ruai ponds system in Nairobi, Kenya (Figure 3.17)

Figure 3.17: Green effluent due to high amount of algae in Ruai treatment ponds, Nairobi, Kenya
Source: (SuSanA, 2011) - Sustainable Sanitation Alliance

The nutrients and other suspended or dissolved matter in the wastewater and excreta have been established by various researchers. (Jönsson et al., 2004) used FAO statistics (*www.fao.org*) and an estimation of the average excretion by the Swedish population to develop Equations for estimation of Nitrogen and Phosphorus in different countries.

N= 0.13* Total food protein   Equation 3.22

P= 0.011* (Total food protein + vegetal food protein)   Equation 3.23

Where N is nitrogen and P is phosphorus; the units of N and P are the same as those of the food protein. Equation 3.23 shows a strong positive correlation between the contents of protein and phosphorous in the food stuff. Phosphorus per gram of protein is double on average in vegetable food stuff in comparison with the animal protein. This explains why the vegetable protein is counted twice in Equation 3.23.

Estimation of excretion of fertilizer nutrients (e.g. N,P,K) per capita in different countries has been done by various studies, see e.g. (Jönsson et al., 2004) (Table 3.23).

Table 3.23: Estimated excretion of nutrients per capita in different countries

Country		Excreted fertilizer nutrients (kg/capita/year)		
		Nitrogen (N)	Phosphorus (P)	Potassium (K)
China, total		4.0	0.6	1.8
	Urine	3.5	0.4	1.3
	Faeces	0.5	0.2	0.5
Haiti, total		2.1	0.3	1.2
	Urine	1.9	0.2	0.9
	Faeces	0.3	0.1	0.3
India, total		2.7	0.4	1.5
	Urine	2.3	0.3	1.1
	Faeces	0.3	0.1	0.4
South Africa, total		3.4	0.5	1.6
	Urine	3.0	0.3	1.2
	Faeces	0.4	0.2	0.4
Uganda, total		2.5	0.4	1.4
	Urine	2.2	0.3	1.0
	Faeces	0.3	0.1	0.4

Source: (Jönsson et al., 2004)

Urine is rich in ammonium and urea (Equation 3.24) which are the mainly used N fertilizer in the agricultural world (Jönsson et al., 2004).

$$\underset{\text{urea}}{CO(NH_2)_2} + \underset{\text{water}}{3H_2O} \xrightarrow{\text{urease}} \underset{\text{ammonium}}{2NH_4^+} + \underset{\text{hydroxide}}{OH^-} + \underset{\text{carbonate}}{HCO_3^-} \qquad \text{Equation 3.24}$$

Ammonium applied to arable soil is transformed within a few days to nitrate (Equations 3.25-3.27) (Jönsson et al., 2004).

$$NH_4^+ + 1.5\,O_2 \Rightarrow NO_2^- + 2H^+ + H_2O \quad \text{Nitrosomonas} \qquad \text{Equation 3.25}$$

$$NO_2^- + 0.5\,O_2 \Rightarrow NO_3^- \quad \text{Nitrobacts} \qquad \text{Equation 3.26}$$

$$NH_4^+ + 2\,O_2 \Rightarrow NO_3^- + 2H^+ + H_2O \quad \text{Cumulative transformation} \qquad \text{Equation 3.27}$$

Comparison between organic and chemical/inorganic fertilizers has been widely researched, with the former having received more applause from most of the experts and farmers especially based on environmental conservation. Organic fertilizer – which can be harnessed from wastewater and excreta – improves the structure of the soil hence facilitating more aeration as well as water holding capacity among several other benefits.

3.5.7 The general benefits of wastewater and excreta reuse

With many communities approaching the limits of their available water supplies, water reclamation and reuse have become an attractive option for conserving and extending available water supply (Metcalf et al., 2007). Benefits in this case could be defined as the specific things/elements that the users of the treated effluent including the solid aspect (e.g. faeces) find helpful or meet their tastes and preferences. There are various benefits of wastewater (see e.g. Dimitriadis, 2005; IEEP. et al., 2016; European Commission, 2020) and excreta reuse (FAO, 2010) (Figure 3.18).

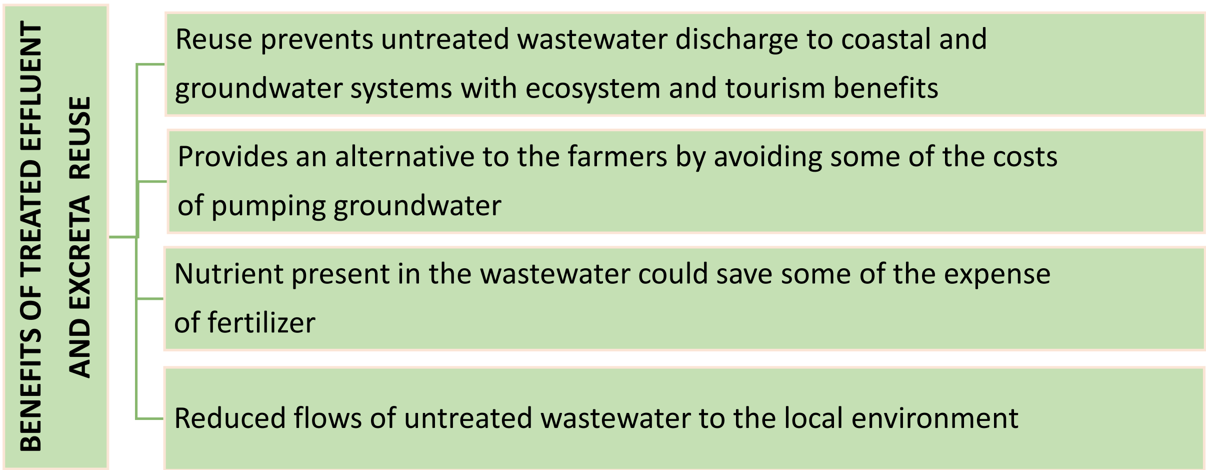

Figure 3.18: Benefits of treated effluent and excreta reuse
Source: Adapted from (FAO, 2010)

Most importantly the wastewater and excreta reuse can prevent surface water pollution, as well as agronomic advantages such as increased crop yields due to the nutrient content of the wastewater (Mara and Pearson, 1992) and increased protection against frost damage (Asano and Levine, 1996). Reclaimed wastewater helps to close a negative water balance in a country where all the conventional water resources are exploited to their maximum capacity and may improve public health (directly or indirectly) instead of endangering it (Friedler, 1999). Reuse of water can be the source of win-win outcomes, in which several different aims can be achieved, and several stakeholders can benefit simultaneously (FAO, 2010). For more details on the water reclamation and reuse: rationale, potential benefits, and factors driving its further use, see (Metcalf et al., 2007).

The fertilizer rich effluent would provide a worthy alternative for the commonly used chemical/inorganic fertilizer that mostly through leaching and surface runoff contaminate both surface and groundwater. The economic value of the treated effluent is therefore without a doubt tremendous. Unfortunately, most countries especially developing ones are yet to devise proper wastewater and excreta reuse strategies.

Box 3.4: Some reasons for poor wastewater and excreta reuse strategies in the developing countries include:

a. Sub-standard attainment of the required wastewater treatment,
b. Low-level of awareness and therefore lack of appreciation of the economic value of the properly treated wastewater by the stakeholders,
c. Interferences from the “influential” and “political” stakeholders, and
d. Discordance in the relevant wastewater policies etc.

3.5.8 The Recommended Time of Application for the Treated Effluent and Excreta

Although the urine and faeces have different uses to the soil and the growing crop, the recommended time of application is during sowing/planting in order to prepare the soil in advance and to minimize the disturbance to the delicate growing crops (Jönsson et al., 2004). This does not exclude administering the excreta at any other time of the crops growing season as long as strict measures and guidelines are observed.

3.5.9 Infrastructural Planning for the Treated Effluent and Excreta Reuse

There are various special infrastructure and planning (engineering) issues involved in the reclaimed water system design, namely, (1) water quality, (2) public health protection, (3) wastewater treatment alternatives, (4) pumping, storage, and distribution system siting and design, (5) on-site conversions at water reuse sites, such as potable and reclaimed water plumbing separation, (6) matching of supply and demand for reclaimed water, and (7) supplemental and backup water supplies (Metcalf et al., 2007).

Generated wastewater could be treated and used close to their origin, either on-site or in decentralized treatment systems in order to (i) prevent their discharge into surface waters, (ii) to reduce downstream microbial and chemical contamination, and (iii) to reduce costs of developing infrastructure for elaborate conveyance systems such as sewer networks (WHO, 2006). Additional benefits of infrastructural planning for wastewater reuse are summarized in Figure 3.19.

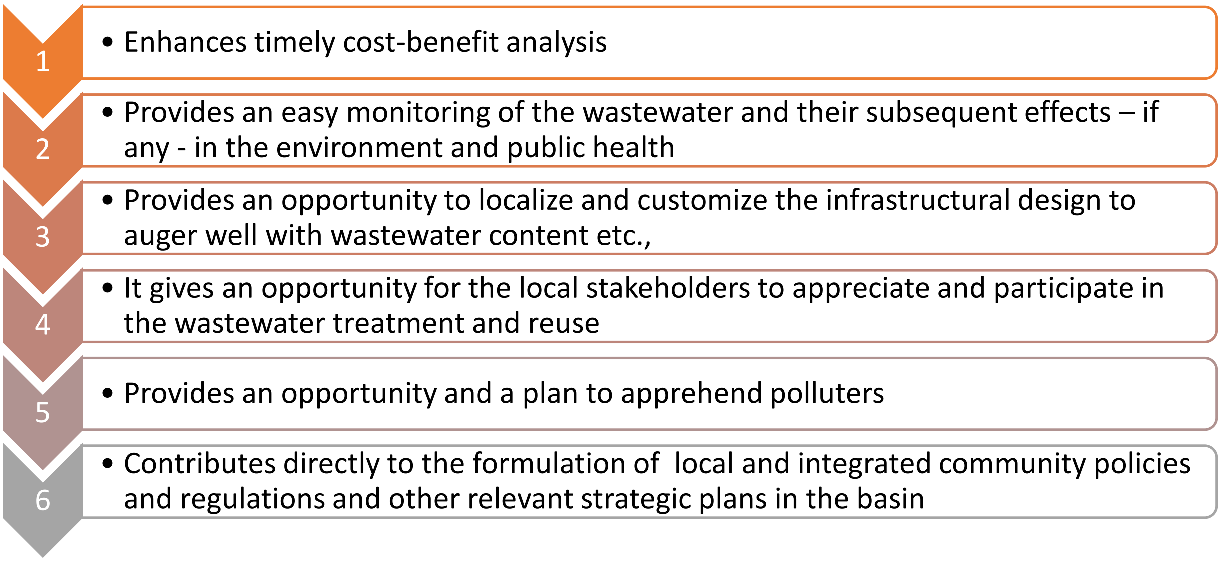

Figure 3.19: Benefits of infrastructural planning for wastewater reuse

3.6 Monitoring the System Performance

To ensure that treatment schemes (individually or centrally-operated) continue to meet required standards and guidelines, monitoring programs (e.g. real-time remote monitoring systems, and multi-layered alarm response protocols coupled with early warning devices etc.) are essential (Dimitriadis, 2005). WHO, 2006 provides three types of monitoring criteria to ensure system performance on the health-based targets (Figure 3.20).

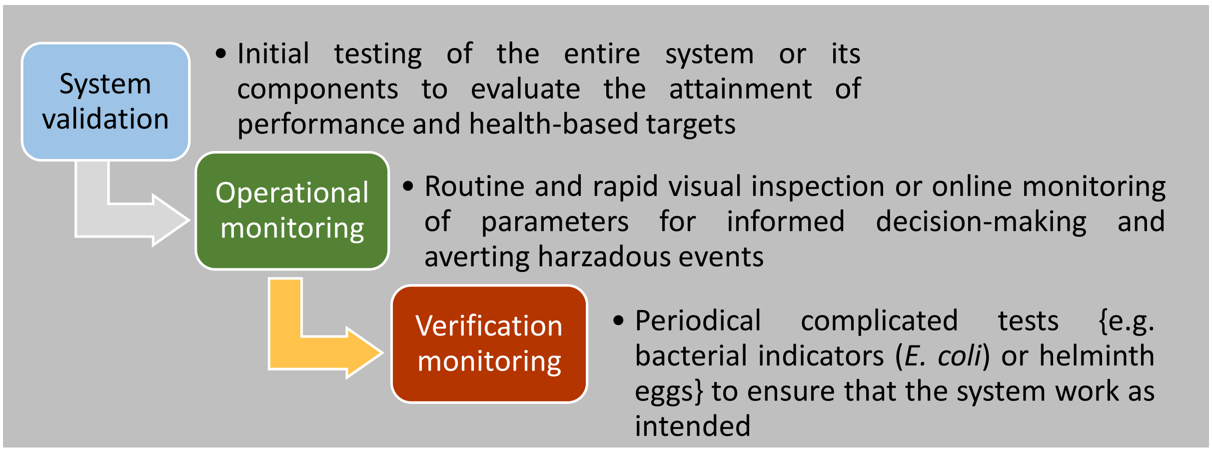

Figure 3.20: System Performance Monitoring Criteria
Source: Adapted from (WHO, 2006)

The three system performance criteria can be evaluated through a comprehensive risk assessment and risk management approach and all the stages involved – e.g. from wastewater and excreta generation to the reuse and consumption of agricultural products – are contained in the comprehensive risk assessment and management (WHO, 2006). Two major hazards, namely, chemical and microbiological are monitored in order to protect the health of the public while chemical hazards are expressed in terms of concentration of the substance of concern while microbiological hazards are expressed through indicators that are expected to operate within certain limits (WHO, 2001a) (see Table 3.24). Both hazards are characterized by rapid and wide spreading in time and space within a short exposure (WHO, 2001a).

Table 3.24: Indicators and good practice requirements by guideline area

Guideline area	Indicators	Good practice requirements
Drinking-water Quality	Value stipulated for faecal coliforms, with recommendations on turbidity, pH and disinfection (chlorination)	Groundwater source protection Treatment proportional to (surface) water quality Sanitary inspection as part of surveillance and control
Safe use of wastewater and excreta in agriculture and aquaculture	Faecal coliforms (unrestricted irrigation) Intestinal helminth counts (restricted and unrestricted irrigation) Trematode egg counts (aquaculture)	Involvement of adequate treatment chains
Safe recreational water environments	Numerical values for indicators (faecal streptococci/enterococci) related to defined levels of risk	'Annapolis Protocol' proposes a series of interventions

*Annapolis Protocol is an outcome of an expert consultation on health based monitoring of recreational waters that occurred in Annapolis, USA. (see details in WHO, 1999, 2001).
Source: (WHO, 2001a)

The Stockholm harmonized framework of microbiological hazards (Figure 3.21) integrates comprehensive risk assessment, risk management options and exposure control elements with specific public health quality targets in three areas, namely, drinking water, wastewater and recreational water and whose detailed explanation on the elements is captured in (WHO, 2006 section 2.2)

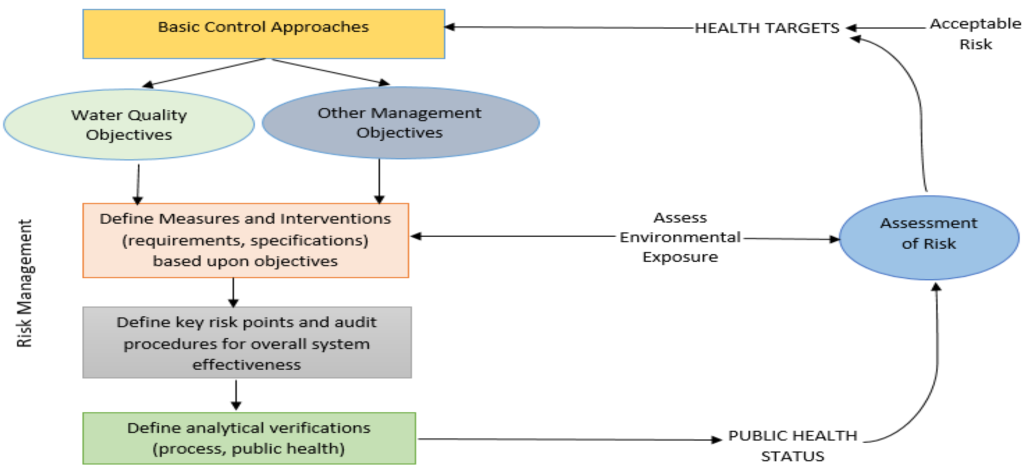

Figure 3.21: Stockholm Framework - for the risk assessment of water related microbiological hazards
Source: (WHO, 2001a) - adapted from (Bartram et al., 2001)

The application of the Stockholm framework in this study is specifically on wastewater to facilitate planning for reuse and nutrients reclamation for agriculture and aquaculture. This study therefore zeros in on the wastewater ponds system technology. The wastewater and excreta reuse plan should be incorporated in the localization of the Stockholm framework. The European Commission through (IEEP. et al., 2016) on addressing the issue of water reuse economic risks, states that, "*The infrastructure costs for a reuse scheme, including treatment works, water distribution systems and irrigation systems may need financing and the economic viability of such projects will depend on the specific situation*." Further discussion on the risks and the safety of wastewater reclamation and reuse could be found in e.g. (WHO, 1989, 2006; Asano and Levine, 1996; US EPA, 2004, 2012) etc. There are better ways of comprehending and therefore reducing various risks involved in water reuse (Dillon, 2000) (Figure 3.22).

1. Greater public confidence
2. Enhanced and better focused investment and development
3. Preservation of natural resources
4. Adoption of appropriate and more economic technologies
5. Detailed research for greater knowledge e.g. on the guidelines etc.

Figure 3.22: Better ways of comprehending and reducing risks involved in water reuse
Source: Adapted from (Dillon, 2000)

Whether water reuse will be appropriate depends upon careful economic considerations, potential uses for the reclaimed water, public health protection, stringency of waste discharge requirements, and public policy where the desire to conserve rather than develop available water resources may override other obstacles (Metcalf et al., 2007).

3.7 Examples of Water Reuse in Different Parts of the World

In 2011, 7km^3 per year of municipal treated wastewater was reused throughout the world and this represented 0.59% of the total water use (IEEP. et al., 2016). It is foreseen that, by 2030, water reuse will represent 1.66% (26 km^3 per year) of the total water use (Global Water Intelligence, 2015; European Commission, 2020). Various countries in the world have enacted guidelines and risk management plans that have been used locally to implement water reuse projects. This research has highlighted just a few of the many countries in the world that are currently implementing water reuse projects.

3.7.1 Water Reuse in South Africa

Although in 1996 had South Africa an estimated less than 3% reuse of its total treated sewage effluent (TSE) – (estimated to be 1 086 x 10^6 m^3/a from urban and domestic using 0.5 as ratio of return of TSE to water demand (TSE ratio is the average of the typical return ratios from a large city (0.65) and a small town (0.35)) – and that the majority of treated sewage effluent was discharged either into inland water bodies (rivers, lakes, dams) or into the sea (Grobicki and Cohen, 1998), commendable water reuse programs have been implemented in the Durban (eThekwini Municipality, 2011). Durban is the third biggest city in South Africa and one of the main commercial centers. A notable water reuse initiative include Durban Water Recycling Project (DWRP) within the jurisdiction of eThekwini Water Services (EWS) in KwaZulu-Natal province (eThekwini Municipality, 2011). The technology used by DWRP include secondary treatment (conventional activated sludge and secondary sedimentation tanks), and tertiary treatment (lamella settlers, addition of polialuminium chloride (PAC), dual media filtration ozonization, Granular Activated Carbon (GAC) Adsorption, and chlorine disinfection) (World Bank, 2018). See also, "*Guidelines for Water Reuse: Durban Water Recycling Project.*"(Bhagwan, 2012).

DWRP has been treating 47.5 million litres/day for nearly two decades since 2001 to provide high quality treated domestic and industrial wastewater for reuse in the industries at a lower tariff compared to high tariff incurred to obtain potable water (eThekwini Municipality, 2011). Example of the industries that obtain treated effluent from DWRP for the processing purposes include Mondi Durban Paper Mill and SAPREF oil refinery. In collaboration with the other three independent organizations, namely, EWS, Mondi Paper, and SAPREF, the main innovations employed by DWRP are integrated wastewater management plan, multi-quality recycled water and innovative contract agreement and finance that resulted into a win-win solution for all stakeholders (World Bank, 2018). This is an outstanding example of a successful and innovative Public Private Partnership that harnesses the synergies of the partners to improve the sustainability of wastewater management, minimizing environmental impact and having multiple benefits for the community and to achieve an outcome that is unprecedented in the water industry in South Africa (Gisclon et al., 2002; World Bank, 2018).

In close collaboration amongst the mines in the Olifants river basin, a 25 ML/d (9.1 million m^3/a) Emalahleni Mine Water Reclamation Plant has been constructed due to the excess water (groundwater ingress), the poor quality of the water, and the lack of assimilative capacity in the Olifants River to accept discharges of mine water. The mine water is treated to potable standard and supplied to Emalahleni Municipality under contract (DWA, 2010).

Additionally, dire water scarcity problems in South Africa have compelled some communities to employ small scale non-potable water use/reuse (e.g. rain water and grey water) (Salukazana et al., 200; Water and Sanitation Effluent Africa, 2006; Ilemobade et al., 2009) that include, (i) individual non-potable water use/reuse on-site which is treated and used on-site by single or multiple dwellings e.g. greywater scheme at Carnarvon, the Northern Cape Province etc., and (ii) district non-potable water use/reuse which involves central collection within a community and used by several dwellings/buildings within the community e.g. the treated effluent reuse scheme at the Lynedoch Eco-Village at Stellenbosch, Western Cape Province etc. (Ilemobade et al., 2009).

Some of the regulations that govern water reuse in South Africa include; Government Gazette No. 9225, Regulation 991, Water Services Act of 1997, National Water Act of 1998 among other water quality guidelines. More on the guidelines to the wastewater treatment using e.g. pond systems in South Africa, (see e.g. Meiring et al., 1968).

3.7.2 Water Reuse in Namibia

Even among water experts, most people are unaware that Windhoek, Namibia is the "cradle of potable water reuse", being the very first city in the world to process drinking water from wastewater already in 1968 (Veolia, 2018; Rudolph et al., 2019) (long before Singapore, Australia, California, South Africa et al.) (Rudolph et al., 2019). This followed an extensive research conducted in Windhoek on direct potable reuse the same year (Asano and Levine, 1996). Until 2004, Windhoek was the only city in the world that practiced a direct potable water reuse on an intermittent basis (US EPA, 2004). This achievement was as a result of pressure exerted by various drivers in Windhoek, namely, (i) low rainfall, (ii) high evaporation, and (iii) low runoff (Law, 2003; Lahnsteiner et al., 2013). Additionally, all surface water sources within 500 km of the city had been exploited, water sources were expensive and obtaining them was controversial, maximum groundwater utilization was already occurring, demand management had already been implemented, and no other option was at hand except wastewater reclamation (Law, 2003). The direct potable water reuse has been realized through e.g. the New Goreangab Water Reclamation Plant (NGWRP) which is a treatment train for water recycling (with a capacity of 21,000 m^3/d) that transforms secondary domestic effluent into high quality drinking water by means of an advanced multi-barrier system (Lahnsteiner et al., 2013). The DPR (direct potable water reuse) breakthrough in Windhoek is an encouraging case, especially how it was done within reasonable budget under a pragmatic approach in Africa (Rudolph et al., 2019).

A schematic representation of the urban water cycle in Windhoek by (Lafforgue and Lenouvel, 2015) (Figure 3.23) shows an improvement in the city's water supply, not only on the water reuse, but also the surface and groundwater resources too.

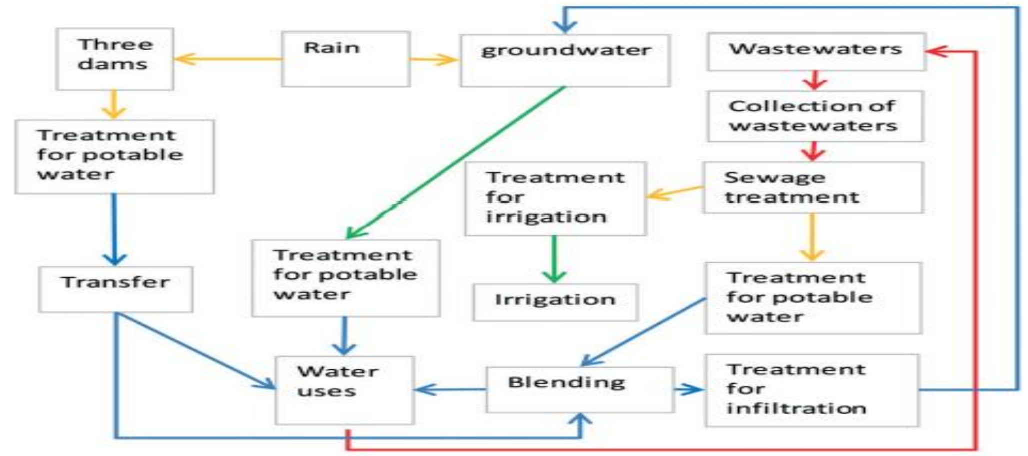

Figure 3.23: The urban water cycle in Windhoek (red: wastewater, yellow: raw water, green: treated water for non-potable uses, blue: drinking water)
Source: (Lafforgue and Lenouvel, 2015)

3.7.3 Water Reuse in Singapore

Although Singapore is a water scarce Island that lacks natural aquifers and lakes as well as limited amount of land area where rainfall can be stored (Tortajada, 2006), it is globally known for its achievement in the water reuse technologies. Singapore has a commendable historical struggle on water challenges geared towards improving its various demand and reduce over-dependence on the water supply from Johor, Malaysia.

A notable example of a technological breakthrough in Singapore is NEWater reuse project (*https://www.pub.gov.sg/watersupply/fournationaltaps/newater*) commissioned in 2000 and managed by Singapore's Public Utilities Board (PUB) with a total capacity of 76,000m^3/d (PUB, 2020). It is largely used for non-potable applications which include industrial, and commercial buildings etc. while indirect potable water use is achieved by blending treated water with raw water before subjecting it to a further treatment to achieve tap water standards (PUB, 2020). NEWater is an example of a high-grade, reclaimed wastewater project built to address the country's critical water demand and the innovative technology employed by the NEWater include, microfiltration/Ultrafiltration; Reverse osmosis; Ultraviolet disinfection in stages 1, 2 and 3 respectively (PUB, 2020). Today, there are five NEWater plants supplying up to 40% of Singapore's current water needs with a projection of up to 55% by 2060 and this will significantly reduce the amount of water imported from Johor state in Malaysia (PUB, 2020). The new plans for increasing of water security and self-sufficiency as well as more efficient water management in Singapore – apart from extensive reuse of wastewater – which include formulation and implementation of new water-related policies, heavy investments in desalination and catchment management and other similar actions (Tortajada, 2006), have been achieved and are categorized into four main supply sources of water, known as the Four National Taps (Figure 3.24) (Lafforgue and Lenouvel, 2015).

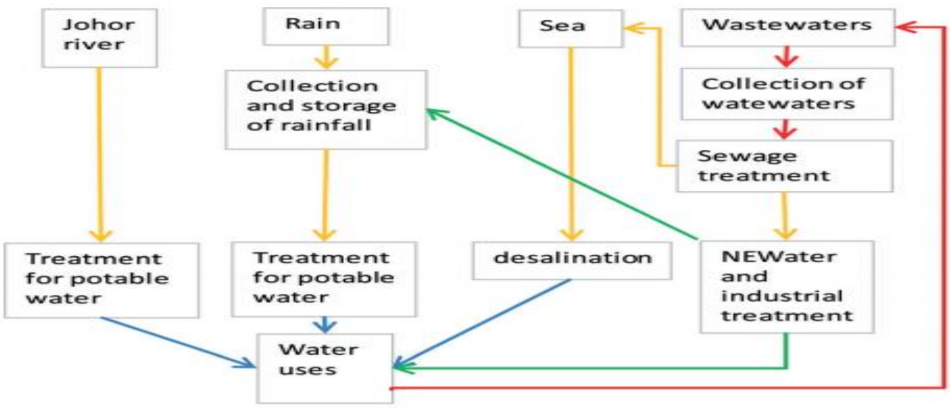

Figure 3.24: The urban water cycle in Singapore (red: wastewater, yellow: raw water, green: treated water for non-potable uses, blue: drinking water)
Source: (Lafforgue and Lenouvel, 2015)

Singapore has been successful due to concurrent emphasis on supply and demand management, wastewater and stormwater management, institutional effectiveness and creating an enabling environment, which includes a strong political will, effective legal and regulatory frameworks and an experienced and motivated workforce (Tortajada, 2006). Singapore has implemented all new technologies and the challenging O&M schemes under services contracting or PPP-Models. Without rapid access to the latest technologies, through PPP, Singapore wouldn't have been able to realize the progress it has realized.

3.7.4 Water Reuse in Australia

Water scarcity and a series of droughts in Australia have resulted to heavy demands on their water utilities and are set to intensify (Dimitriadis, 2005). There are numerous water reuse projects in Australia that are often carried out on a small scale basis and are generally designed for non-potable purposes, such as landscape irrigation, agricultural or horticultural irrigation, industrial water recycling, residential garden irrigation and toilet flushing (Po et al., 2003). Virginia Pipeline Scheme at Bolivar, Southern Australia is the largest horticultural reuse project in Australia and it supplies over 20 billion litres of irrigation water a year for at least 120 market gardens by the year 2002 (Po et al., 2003) and the production was the same by the year 2020 (SA Water, 2020). Another water reuse scheme is the Northern Adelaide Irrigation Scheme (NAIS), in north of Adelaide that has unlocked 12 gigalitres (12 billion litres) of quality water to be used in agricultural food production, supporting more than 300 hectares of high-technology horticulture, and a further 2,700 hectares of advanced agri-food production (SA Water, 2020). These commendable water reuse efforts to address water shortage have reduced residential water consumption in Australia by 40%-50% (Vigneswaran and Sundaravadivel, 2004). Successful Australian water recycling ventures invariably demonstrate the need for appropriate and adequate stakeholder engagement and public consultation, adequate infrastructure, research and development, as well as fair water price setting and incentives for the development of markets for water recycling services and technology (Dimitriadis, 2005).

3.7.5 Water Reuse in the United States

The development of programs for planned reuse of wastewater within the U.S. began in the early part of the 20th century followed by the passage of the Federal Water Pollution Control Act in 1972 (PL 92-500) (Asano and Levine, 1996). The State of California pioneered efforts to promote water reclamation and reuse and the first reuse regulations were promulgated in 1918 (Asano and Levine, 1996). Water reuse has been widely used in the United States e.g. at the Fred Harvey Water Reclamation Facility in the state of Texas, Water Factory 21 in California, and the northern Virginia Upper Occoquan Sewerage Authority Water Recycling Project (Po et al., 2003). The most extensive research focusing on direct potable reuse in the US has been conducted in Denver, Colorado; Tampa, Florida; and San Diego, California (US EPA, 2004). A case in point is the Irvine Ranch Water District (IRWD) in California which has been operational for more than 50 years. Information obtained from IRWD website (*https://www.irwd.com/services/recycled-water*) shows that it recycles wastewater to achieve the so called "*Title 22 water*" for public and commercial irrigated landscape in its service area including parks, medians, golf courses, community association property, toilet-flushing, cooling towers in commercial buildings, dust control on construction sites and industrial processes etc. The treated water from IRWD meets about 25% of its service area's water demands and about 80% of the public and commercial irrigated landscape in its service area (Irvine Ranch Water District, 2020). An estimated 25 million gallons per day of recycled water is delivered to more than 5,500 metered customer connections. Some of the regulations that spearhead the operations of IRWD include Title 22 and Title 17 of the California Code of Regulations respectively (*https://www.irwd.com/services/recycled-water*). These regulations describe the treatment requirements for recycled water as well as the approved uses based on the level of treatment, the use area requirements, and the backflow devices required at a site when recycled water is being used, to maintain a clear separation between recycled water and drinking water etc. (Irvine Ranch Water District, 2020). Initiatives geared towards reduction of wastewater generation and water reuse in domestic, industrial and agricultural sectors have been instrumental in the wastewater management in European Union and North America (Seadon, 2010). By 2003, there was 48% and 19% agricultural water reuse as well as 20% and 44% in landscape irrigation in California and Florida respectively (Figure 3.25).

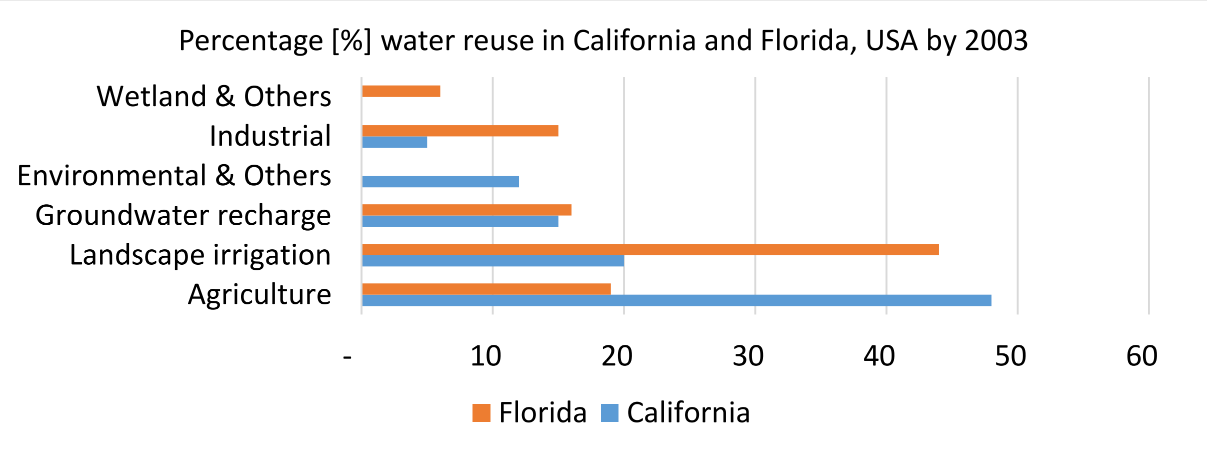

Figure 3.25: Percentage water reuse in California and Florida by 2003
Source: (Florida Reuse Coordinating Committee, 2003)

3.7.6 Water Reuse in the European Union

Although water reuse has been successfully practiced in several European Union (EU) member states – mostly Southern Europe or Mediterranean region (e.g. France, Spain, Greece, and Italy, etc.), – it is so far deployed below its potential (European Commission, 2020). An example of a directive on the water reuse include the European Communities Commission Directive (91/271/EEC) of 1991 that declared that "*treated wastewater and sludge arising from waste water treatment shall be reused whenever appropriate. Disposal routes shall minimize the adverse effects on the environment*" (European Commission, 1991). Another key water and wastewater guideline in Europe include the European Union Water Framework Directives of 2000 (European Commission, 2020). The (European Union, 2020) has in 2020 enacted a new regulation (EU) 2020/741 on minimum requirements for water reuse. The new EU water framework directive mainly provides recommendations for the agricultural irrigation. The driver(s) behind the new regulation (EU) 2020/741 is that *"..the water resources of the Union are increasingly coming under pressure (e.g. from climate change, unpredictable weather patterns and drought), leading to water scarcity and a deterioration in water quality..."* (European Union, 2020).

The two major barriers preventing a wider spreading of this practice in the EU include, limited awareness of potential benefits among stakeholders and the general public, and lack of a supportive and coherent framework for water reuse (European Commission, 2020). Although 964 million m^3/year of treated wastewater reuse in EU was achieved in 2006, it only accounted for 2.4% of the treated urban wastewater which is approximately 1 billion cubic metres or less than 0.5% of annual EU freshwater abstraction. Germany reused 42 million cubic metres of treated effluent in 2006 (Raso, 2013; Kirhensteine et al., 2016).

3.7.7 Water Reuse in Israel

Wastewater reuse is considered as a major and vital water resource in Israel due to; severe water shortage, severe pollution threat to the diminishing water resources, highly concentrated urban population, highly intensive agricultural irrigation and high environmental awareness of the public and general acceptance by the public for the need of recycling and reuse (Shelef, 1991). The Israel government issued regulations to allow the reuse of secondary effluents for crop irrigation with the exclusion of vegetable crops that are eaten uncooked in 1965 (Asano and Levine, 1996) and by 1994, Israel was already reusing 194 $x10^6$ m^3/a or 84% of the total treated sewage effluent (TSE) (232 $x10^6$ m^3/a) produced in the country (Shelef and Azov, 1996; Grobicki and Cohen, 1998). Israel was the first country to develop and use the effluent storage reservoirs (ESR) (Juanico and Shelef, 1991) to enable storage of the treated effluent before being reused in irrigation schemes. Therefore, Israel is an example of a successful intensive reuse in agricultural irrigation with a lot of experience in treatment technology, seasonal storage reservoirs and the research towards establishing the quality requirements (Shelef, 1991) to protect human health and environment.

Finally, a 2009-2016 projection done by (Global Water Intelligence, 2009) on water reuse capacity put some countries such as USA, Australia, China and Spain at 10.7, 2.5, 5.9 and 2.1 million m^3/d respectively (Global Water Intelligence, 2012). Water quality monitoring systems have been one of the major factors behind the successful water reuse examples drawn from Singapore, Namibia, Israel, US, Australia, Germany, South Africa, Tunisia etc.

Chapter 4

Materials and Methods

4.1 Chapter Overview

This chapter deals with materials and methods, and the description of the study areas e.g. Case Study 1: The transboundary Mara river basin, Kenya and Case Study 2: The transboundary Olifants River Basin, South Africa. This is followed by the problem statement of both case studies, the vulnerability levels, and protected areas (e.g. the wildlife reserves/parks and their level of deterioration) in both cases. This chapter also explains the focus of the study, namely, (i) enhancing local level performance using micro-water-governance, and (ii) evaluation of the water reuse value as a driver towards IWRM implementation. This is achieved through performing an analysis of different cases within the river basins e.g. the water resources users associations (WRUAs), the Maasai Mara wildlife conservancies association (MMWCA) and other water management activities. Data analysis methods have been explained e.g. using quantum geographic information system (QGIS), and statistical package for the social sciences (SPSS) etc. Finally, a closer look at water demand (e.g. domestic, agricultural, industrial, environmental etc.) in Mara River Basin has been done.

4.2 Description of the Study Areas

Two case study areas presented in this research include, the transboundary Mara river basin, Kenya and the Olifants river basin, South Africa hereafter abbreviated as MRB and ORB respectively. In the spirit of inter and intra-basin transfer of technology and concepts, ORB has been used due to high replication level it has with MRB. A comparison between case study 1 (MRB) and case study 2 (ORB) – (see details in the subsequent sections of this study) – shows a strong replication of characteristics in terms of land use/economic activities as well as the challenges emanating mainly from anthropogenic activities and most specifically the pressure coming from the increasing volume of wastewater and the subsequent need for water reuse. The two basins almost mirror one another.

4.2.1 Case Study 1: The Transboundary Mara River Basin, Kenya

This basin is one of the six main river basins in Kenya originating from Mau forest complex, the East Africa's largest closed canopy forest (Omondi and Musula, 2011) and home to around 1.7 million inhabitants. MRB is one of the ten drainage basins that feed into Lake Victoria, and is therefore functionally and ecologically related to the socio-economic activities in the Lake

Victoria and along the River Nile (Melesse et al., 2008; SCMP-Amala, 2011). The main Mara river flows South West towards the border between Kenya and Tanzania meandering through upper Mau forest complex, Loita hills, trans-boundary region and finally at its mouth at L. Victoria covering a distance of 395km and an area of around 13,750km² (Gereta and Wolanski, 1998; Mati et al., 2005; Dessu and Melesse, 2013). The Basin is located roughly between longitudes 33°47'E and 35°47'E and latitudes 0°38'S and 1°52'S, with the upper 65% area (8,941km²) in Kenya, while the remaining lower portion (35%) is in Tanzania (Figure 4.1) (Gereta and Wolanski, 1998; Mati et al., 2005; Dessu and Melesse, 2013) making it a transboundary basin and a basin of international importance.

Figure 4.1: A map of Mara River Basin
Source: (Hoffman et al., 2015)

4.2.1a Tributaries of the Transboundary MRB

There are six major tributaries within the basin that feed into the main Mara river, namely the perennial Nyangores and Amala tributaries on the upper region and seasonal tributaries such as Engare Ngobit and Talek in the middle region, and Sand and Bologonja in the lower region (Williams, 1961; Mati et al., 2005, 2008; McClain et al., 2014).

4.2.1b Transboundary MRB Altitude

This basin ranges from an altitude of around 3000m at Mau Forest to 1134m above sea level at Lake Victoria (Mati et al., 2005; Mutie et al., 2006) (Figure 4.2). The transboundary middle savannah grassland region ranges at 1500 – 2000 m above sea level, lower Loita hills at 2000 – 2500 m above sea level and the region around Lake Victoria at 1100 – 1500 m above sea level (Mati et al., 2005).

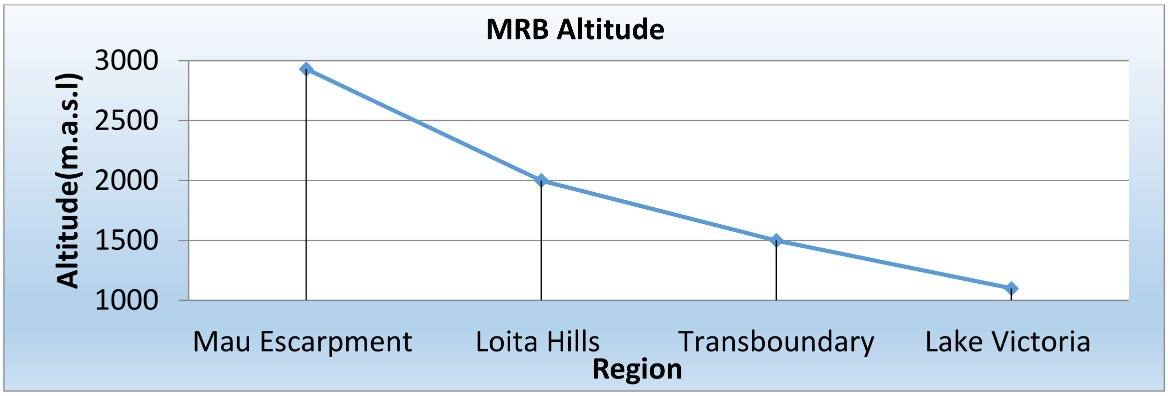

Figure 4.2: Mara river basin altitude

4.2.1c Rainfall Patterns in the Transboundary MRB

The basin has a bimodal type of rainfall seasons with long rains from mid-March to June and short rains in September and November (Mutie et al., 2006; Melesse et al., 2008). The Mara river basin is known for its rainfall variability in time, where different regions receive variable amounts of rainfall over the year. The mean annual rainfall ranges from 1400mm/year around Mau forest region to 600mm/year in the lower (Loita) region with the Mau Escarpment region receiving the highest amount of rainfall with a mean annual rainfall between 1,000 mm and 1,750 mm (Mango et al., 2011; Defersha et al., 2012) (Figure 4.3). The transboundary middle savannah grasslands obtains an average between 900 and 1,000 mm, and the Kenyan lower Loita hills and the region around Lake Victoria receives about 700 and 850 mm rain annually (Mango et al., 2011; Defersha et al., 2012).

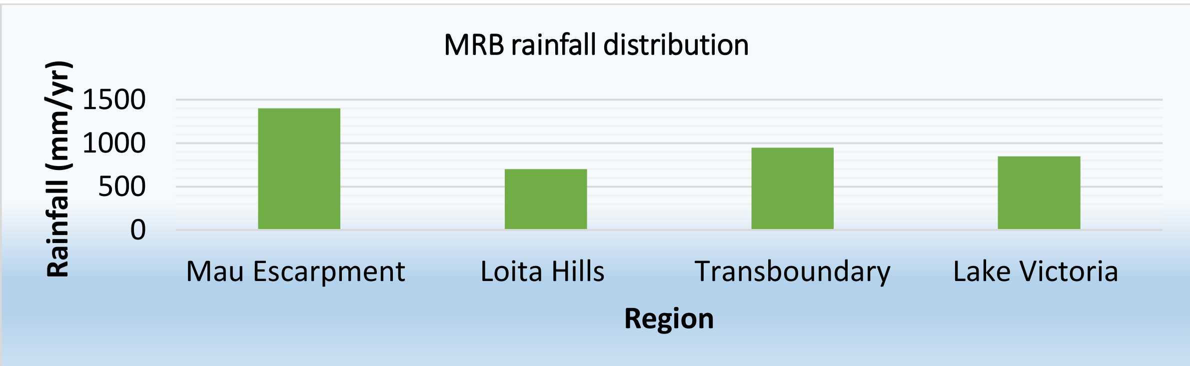

Figure 4.3: Mara river basin mean annual rainfall distribution

4.2.1d Transboundary MRB Temperatures and Aridity

Most part of the basin lies in the semi-arid region (Mati et al., 2005; Mutie et al., 2006). The mean annual temperature is approximately 25.5°C and in general, temperatures and aridity in the basin increase southwards (WREM, 2008).

The seasonal variation as evidenced in the Mara basin plays an important role in water management. (US EPA, 2004) defines seasonal variation as a function of rainfall, temperature, crop type, stage of plant growth, and other factors, depending on the method of irrigation being used.

4.2.1e Hydrogeological and hydrological characteristics of MRB

Geology and groundwater potential: MRB is mainly composed of volcanic rocks (that cover ~26% of Kenya) of the tertiary and Nyanzian age, rocks of the Nyanzian system consisting of volcanic rocks and granites of Archean age in Tarime district, and massive outcrops of granites in areas of the Serengeti and Musoma districts (WREM, 2008). The region has grey sandy soils that dry up quickly during the dry season. Basically, the geology of MRB ranges from Nyanzian granite gneiss to Kavirondian conglomerates, coarse arkosic, and feldpathic grits and quartzites. According to (Williams, 1961), the rocks of the Mara River-Sianna area fall into four groups, namely, metamorphic rocks of the basement system (Archaean), Kilgoris granite (Precambrian), tertiary volcanic rocks, and superficial deposits of Pleistocene to recent age. There are two types of aquifers in the MRB, namely, stratum and fissure that combined with rainfall regimes defines the MRB groundwater potential (WREM, 2008).

Hydrological measurements: The river stage and discharge in the basin is mainly measured at the river gauging stations (RGS) (see Figure 4.17) automatically and electronically by the data loggers, use of the Acoustic Doppler Current Profiler (ADCP) or conventional current meters by a monitoring group of experts or trained locals. The design of the hydro-meteorological network for the MRB was commenced by the Nile Basin Initiative and a total of 5 RGS recommended to be established in the basin (WREM, 2008). The data loggers in the basin were installed in 2014 under MaMaSe project (*https://mamase.delft-hydrological.com/WRA/wrma.html*, MaMaSe, 2020) and they measure rainfall, pan evaporation and hydrometric station (e.g. stage observation). Figure 4.4 shows stage observation (in metres) for the RGS 1LA03 at Bomet Bridge from January 2015 to around January 2020 and RGS 1LB02 at Kapkimolwa from around June 2016 to March 2019. There have been challenges emanating from theft and/or vandalism of some RGS (e.g. 1LA04 at Mara bridge was removed due to vandalism and theft) hence poor or lack of data collection.

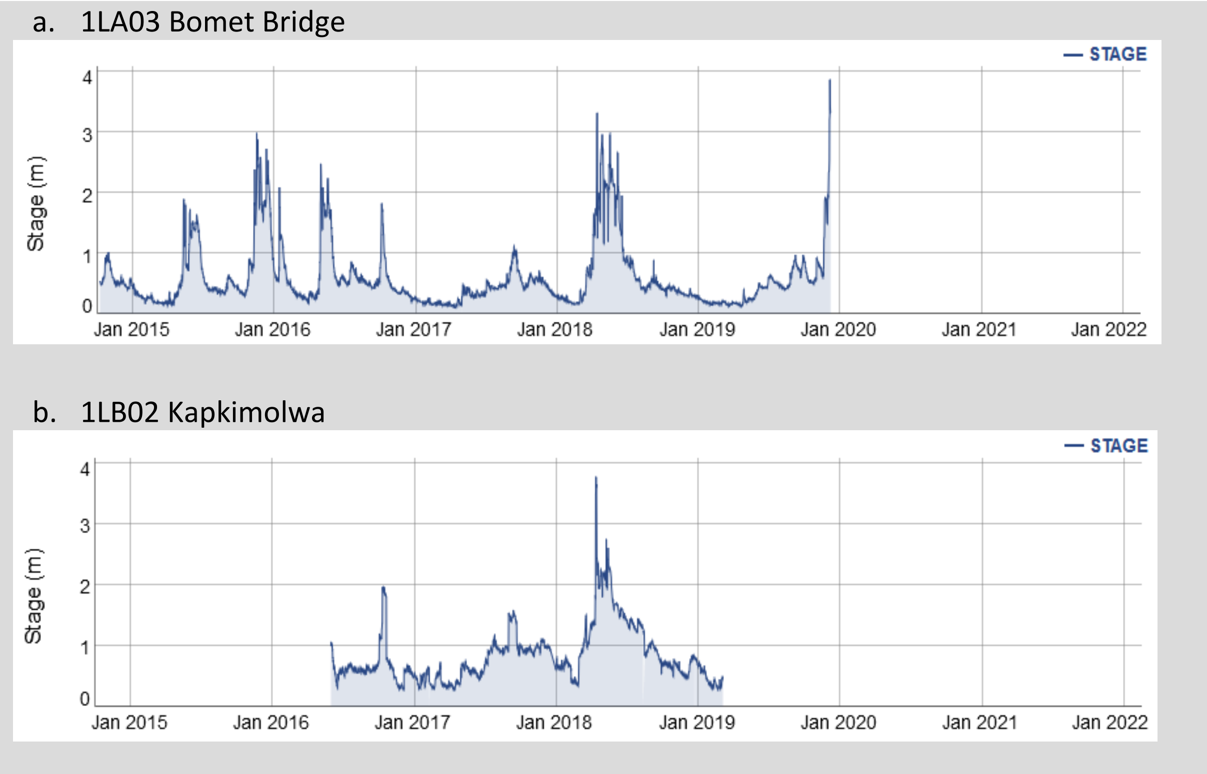

Figure 4.4: Stage observations for RGS at (a) 1LA03 Bomet Bridge and (b) 1LB02 Kapkimolwa in MRB
Source:(MaMaSe, 2020); see also detailed information on rating curves and stream flow data etc. in MRB Monograph (WREM, 2008)

Two hydro-meteorological data stations 1LB02 at Kapkimolwa (along Bomet/Narok border) and 1LB03 at Matecha (currently abandoned) have been used to monitor Amala river which has an average flow of 8.68m³/s (see Figure 4.16) (Amala SCMP, 2011). The peak flows in the upper reaches of the MRB on the Amala tributary (1LB02 at Mulot-Narok bridge), is approximately 30m³/s in an average year with about 8m³/s during the dry year and may extend over 150m³/s during a wet year (LVBC and WWF-ESARPO, 2010). At Mara mines (1LA04 at Mara bridge) in the lower MRB along the Kenya-Tanzania border, peak flows can reach up to 300m³/s in an average year, varying from 90 to over 400m³/s, depending on whether it is a dry or wet year (LVBC and WWF-ESARPO, 2010).

The MRB flow hydrographs and rating curves generated by e.g. (WREM, 2008) shows various inconsistencies e.g. in the rating curves among other issues that affect the reliability of the data obtained from the RGS. The challenges are drawn from the operation of the hydrological network in the basin, such as, lack of sufficient current meter gauging leading to very few measurements, lack of specialized monitoring equipment to record flood events, and lack of funds etc. (WREM, 2008). A flow duration curve (FDC) for monthly mean flows at the Mara mines (1LA04 at Mara bridge) from 1970-1990 shows that the flow exceeds 11m³/s 50% of the time (Q50) and exceeds 0.9m³/s 95% of the time (Q95) (Figure 4.5) (LVBC and WWF-ESARPO, 2010).

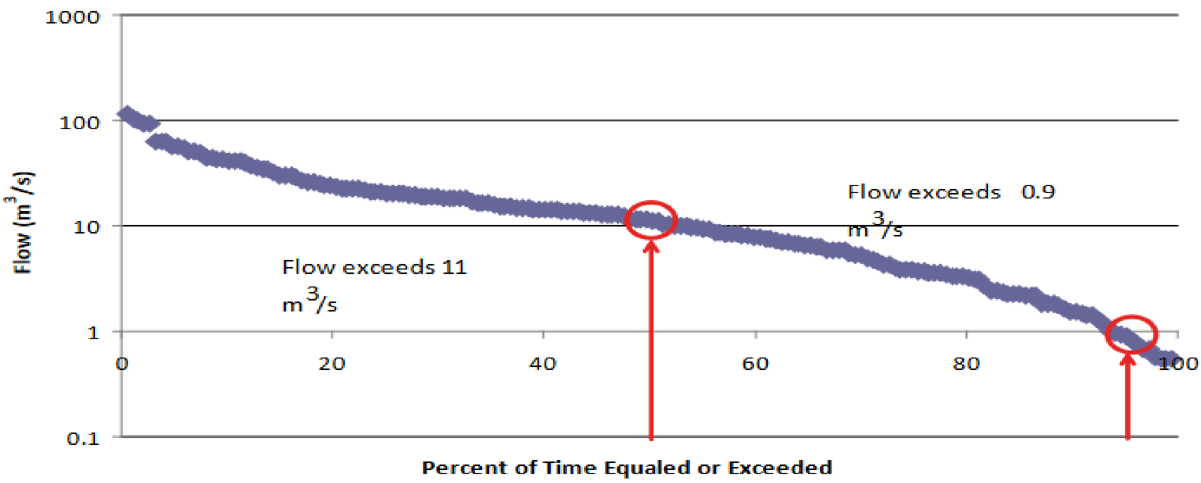

Figure 4.5: Monthly FDC calculated for mean flow levels for the period 1970-1990) at 1LA04 at Mara bridge along the Kenya-Tanzania border
Source: (LVBC and WWF-ESARPO, 2010)

4.2.1f Economic and Land-Use Activities in the Transboundary MRB

The Arid and Semi-Arid Lands (ASALs) of this basin are used by ranches, semi-pastoralists and pastoralists as rangelands. Mara river flows through the Mau forest, tea plantations and industries, settlements, and small-scale agricultural lands, Maasai ranches, protected areas such as Maasai Mara National reserve and Serengeti national park which is a large biodiversity of more than 2 million wild animals and estimated 500 species of birds that need to be sustained (UNESCO World Heritage, 2010). Thousands of tourists come to see the great wildebeests migration which is categorized as one of the seven natural wonders of the world (UNESCO World Heritage, 2010). There is also rampant growth of urban centers and commercial activities as well as fishing and small scale gold mining in the Tarime district on the Tanzanian side, that uses river water for gold extraction. This basin therefore supports a wide spectrum of consumers with various services such as drinking and irrigation water and water for sustenance of the entire biodiversity of Mara and Serengeti, etc.

There are various irrigation farms in MRB ranging from large to micro irrigation schemes, namely, (i) large scale of approximately 1,000 Ha (e.g. Nogirwet (81 Ha) and Chebara (73 Ha) in Bomet) and >5000Ha at planning stage e.g. Kaboson irrigation scheme (250 Ha), and (ii) micro irrigations – up to 6 Ha etc. (Table 4.9) (Bomet CIDP, 2018). The source of water for all the irrigation schemes is Mara river and its tributaries. Irrigation accounts for roughly half of the water demand in the basin (Bomet CIDP, 2018; Zermoglio et al., 2019).

The implementation and the success of irrigation schemes e.g. in Mara and Olifants river basins, should be pegged on – among others considerations – the establishment of the water requirements for the crop(s) (see e.g. Table 8.6), efficiencies of the selected irrigation system (see Table 8.10) and adherence to the laid out regulations and guidelines (see for example WHO, 1989, 2006; FAO, 2010, 2016; US EPA, 1992, 2004, 2012 etc.).

4.2.2 Case Study 2: The Transboundary Olifants River Basin, South Africa

The ORB is one of the major tributaries of the Limpopo River (McCartney et al., 2004) and one of South Africa's most stressed basins as far as water quantity and water quality is concerned (Hilbig et al., 2016b). The ORB is one of the 22 primary drainage regions in South Africa and it lies within the northern region strategic planning area (McCartney et al., 2004). There are five regions in the Olifants river basin with quaternary catchments to facilitate water management (McCartney et al., 2004).

4.2.2a Tributaries of the Transboundary ORB

There are at least 10 tributaries within the basin that feed into the main Olifants river, namely Letaba, Wilge, Steelpoort, Blyde, Tongwane, Elands, Klein Olifants, Nkumpi, Ga-Selati, Lepellane, Klaserie, Makhutswi, Spekboom, Mohlapitse, Ngwaritsi, and Moses etc. (FAO, 2004; McCartney et al., 2004). Letaba river is one of the major tributaries with a catchment area of about 3,264km^2 that joins ORB in the Kruger National Park (McCartney et al., 2004).

4.2.2b Rainfall Patterns and Evaporation in the Transboundary ORB

The mean annual rainfall of the basin varies considerably (200-1 500 mm) and the bulk of the basin receives less than 500 mm/year (FAO, 2004). Rainfall is highly seasonal with 95% occurring between October and April and the rainy season is short with the annual number of rain days seldom exceeding 50 (FAO, 2004). Evaporation ranges from 1800 mm to 2200 mm/ year and has been identified as one of South Africa's most stressed basins for both water quantity and quality (DWA, 2011; Hilbig et al., 2016b).

4.2.2c Transboundary ORB Temperatures, Altitude and Aridity

Most of the ORB lies in the semi-arid region with annual temperatures varying between -4°C and 45°C while elevations range from 300m to over 2300m (DWA, 2011).

4.2.2d Economic and Land-Use Activities in the Transboundary ORB

The basin has a considerable proportion of South Africa's mining activities, (that include, coal, copper, chrome, iron, vanadium and platinum), power production, forestry, industries, improved and unimproved grazing, agricultural activities e.g. intensive irrigation schemes and dry land cultivation as well urban and rural settlements (McCartney et al., 2004).

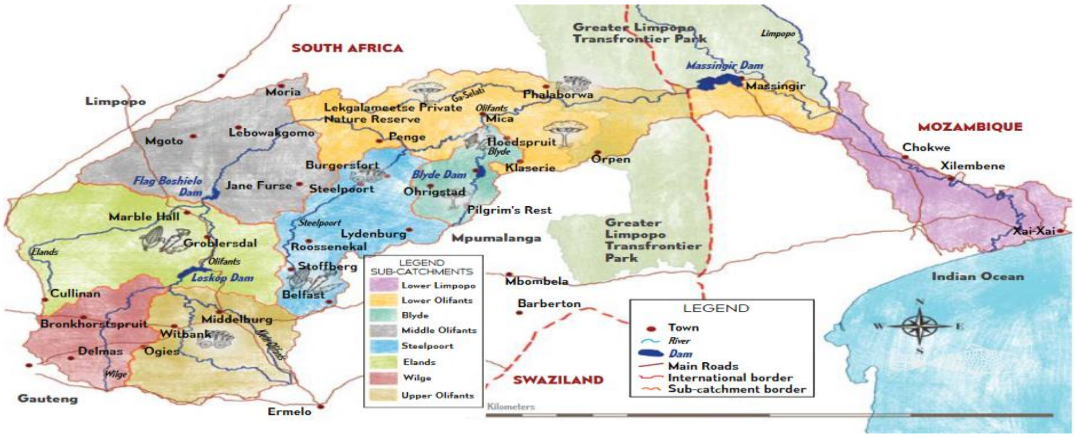

Figure 4.6: Map of the Transboundary Olifants River Basin, South Africa/Mozambique
*Different sub-catchments in this basin are clearly shown.
Source: (AWARD, 2016)

4.2.2e Main hydrological regions in the Olifants river basin

There are five main hydrological areas in the Olifants basin that are regrouped into four ecological regions (Figure 4.7), namely, (i) the upper Olifants in the Highveld region, (ii) the Upper Middle and Lower Middle Olifants in the Middleveld region, (iii) the Steelpoort basin in the mountain area, and (iv) the Lower Olifants in the Lowveld region (de Lange et al., 2003).

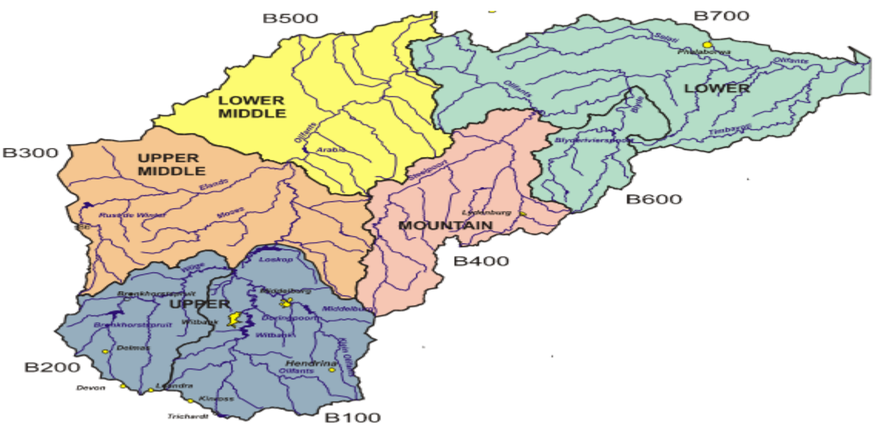

Figure 4.7: Main hydrological regions in the Olifants River Basin
Source: (de Lange et al., 2003)

4.2.2f Terrestrial biomes of both Olifants and Mara river basins

The transboundary ORB is a home to three terrestrial biomes, namely, (i) Savanna, (ii) Forest and (iii) Grassland (AWARD, 2018) while Mara River Basin consists of (i) Forest, (ii) Savanna, (iii) Grassland, (iv) Shrubland, and (v) Wetland (Mati et al., 2008).

4.3 Problem Statement of Both Case Studies: The Transboundary Mara and Olifants River Basins

There is currently a litany of challenges in the transboundary Mara and Olifants river basins mainly due to poor transboundary water governance. Olifants river basin is located in a country characterized by semi-aridity, limited water resources and a rapidly growing population as well as increasing industrial and urban development; - as a result the demand on the South Africa's water resources is likely to exceed conventional supplies (Grobicki and Cohen, 1999). The ORB especially Middle Olifants, faces inefficient water use (water losses and run-off), over-exploitation due to a lack of demand management and insufficient sewerage disposal and wastewater treatment (Kalinowski-Gausepohl et al., n.d.).

Poor management of the ever growing volumes of both solid and liquid waste in the Mara and Olifants river basins is chronic and must be addressed as a matter of urgency. The waste in this regions is largely not separated making the treatment efforts to be so difficult. This is evident also in the wastewater received at the treatment systems that quite often harbours pieces of clothes, plastic bottles and bags, and other debris (Figure 4.8).

Figure 4.8: Building up of non-biodegradable (solid) waste at Bomet WPS (left) and Nyangores river (right)

The deteriorating water quality due to increased pollution has led to constant outbreak of waterborne diseases to the extreme cases of deaths of human beings and both domestic and wild animals. This has also been largely as a result of poor transboundary water governance since the two case study basins flows between Kenya and Tanzania and South Africa and Mozambique respectively. As a result of continuous human and animal population growth, the basins have experienced a lot of human encroachment into the forest and riparian land through deforestation in the headwaters, mainly for timber, charcoal, settlements, farming etc. Forest cover decreased by about 30% in Kenya between 1990 and 2010 and a Mara wetland expansion by a factor of 4 (Mati et al., 2005). There has been massive expansion of poor agricultural activities, as well as over-abstraction of water due to the increasing water demand. This has largely led to reductions in river flows hence affecting the habitation and migration cycle of wildebeest in the Maasai Mara-Serengeti ecosystem (Homewood et al., 2001) as well as the rich Kruger Park wildlife ecosystem. Highly polluted sediment loads and wastewater emission into the MRB has adversely affected the quality of water. Water resources in Mara are highly exploited for large scale irrigation, domestic water supplies, livestock, and wildlife watering (WREM, 2008; Bregoli et al., 2019). The water services delivery in ORB is directly affected by the national challenges such as poor water services and planning, increased investment needs due to the ageing water infrastructure, climate change, shifting patterns in water demand, competing political priorities, and poor economic conditions etc. (DWS, 2015b).

4.3.1 Vulnerability Levels of the Olifants and Mara River Basins

The percentage of the endangered land, plants and animal species of the two basins have constantly increased. The endangered land is as a result of excessive encroachment of the riparian land, mining, agricultural activities as well as urbanization. Vulnerability profile of Mara wetland – located near Lake Victoria at the lower side of the MRB on the Tanzanian side – is a riverine swampland dominated by papyrus and it covers a total area of more than 500km² (Zermoglio et al., 2019). This wetland experiences excessive anthropogenic activities directed towards the swamp. It is a home to a wide spectrum of bird species, terrestrial and semi-aquatic mammals as well as fish (Zermoglio et al., 2019).

Water quality in the Olifants River is affected by coal mining in the area, and in particular acid water decanting from existing and defunct mines (DWA, 2010). Some wild animals and birds as well as fishes and other aquatic animals (e.g. crocodiles and hippos in MRB) faces threat of death or extinction. The building up sediments in the beds of the Mara and Olifants rivers affects the carrying capacity, navigation and the hydraulic structures within these channels. There have been reported cases of frequent floods in MRB in the recent past affecting the riparian communities. Settlements and/or cultivation on the riparian land has led to excessive erosion on the river banks, displacement of important aquatic vegetation and shrinking of the river channels.

The general Olifants River Basin continues to be threatened by various anthropogenic activities leading to increased industrial return flows, water shortages and poor water quality, environmental degradation e.g. soil erosion, high sediment loads, overgrazing etc., unsustainable agriculture, uncoordinated water resources planning and management processes, endangered tourism, and vulnerability to climate change etc. (AWARD, 2018). The threat status is categorized into four (AWARD, 2018), namely (i) critically endangered, (ii) endangered, (iii) vulnerable, and (iv) least threatened (Figure 4.9).

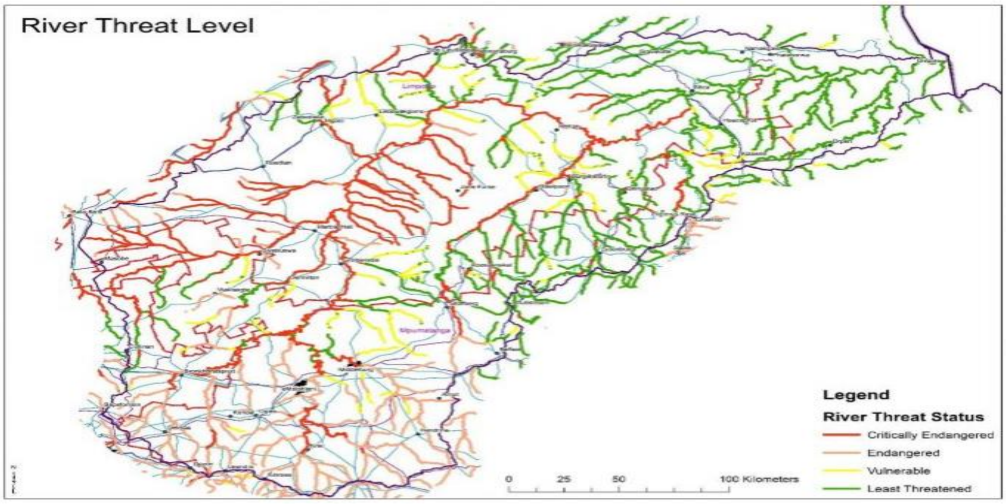

Figure 4.9: Threat level facing Olifants River Basin within South Africa
Source: (AWARD, 2018)

4.3.2 Protected Areas in Olifants and Mara River Basins

There exists a serious threat on the major protected areas in both basins, namely, poaching, human population pressure, encroachment for agriculture, mining, commercial purposes and settlement etc. According to the International Union for Conservation of Nature (IUCN, 2008), a protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values. (Table 4.1) shows the major natural protected areas in the two case study areas (ORB and MRB).

Table 4.1: Major Natural Protected Areas in ORB and MRB

Olifants River Basin (ORB)	Mara River Basin (MRB)
i. Kruger National Park	i. Maasai Mara National Park – whose annual wildebeest migration is regarded as one of the seven natural wonders of the world
ii. The Great Limpopo Transfrontier Park	ii. Serengeti Wildlife reserve – World Heritage Site 1981
iii. Makuleke Wetlands (Ramsar site No. 1687) within Kruger National Park	iii. Mau forest complex (273,300 Ha) - largest indigenous montane forest in East Africa. Source to 12 major rivers
iv. Verloren Valei Nature Reserve (Ramsar site No.1110) – Upstream (Mpumalanga Province)	

Sources: (Ramsar, 2001, 2007; UNESCO World Heritage, 1981, 2010)

There are other areas that should be protected according to their ecological benefits to a large biodiversity but are unfortunately not protected e.g. Enapuyapui swamp the source of Mara River Basin, and Mara (also known as Masurua) swamp near the mouth of Mara river at Lake Victoria, Tanzania etc.

4.3.3 Deterioration of Wildlife Reserves/Parks

The wild animals, bird species, different vegetation types and human community within and around Kruger Park in the transboundary Olifants River Basin are struggling with decreased water resources as well as deteriorating water quality due to a wide scale threats to the rich biodiversity and the ecosystem services that supports the livelihood of the people (AWARD, 2018). Kruger National Park covers an area of about 2 million hectares and is a home to almost 150 mammals and over 500 species of birds (AWARD, 2018).

The intertwined Maasai Mara National park on the Kenyan side and Serengeti wildlife reserve on the Tanzanian side – which are popularly known for their extraordinary annual migration of some 2.3 million wildebeests *(Connochaetes taurinus)* and over 200,000 common Zebra (*Equus burchelli)* (UNESCO World Heritage, 2010) – are facing severe declined water quantity, excessive siltation, and water pollution etc. emanating from uncontrolled anthropogenic activities. The annual wildebeests and common zebra migration from the Serengeti wildlife reserve in Tanzania to the Maasai Mara National Park in Kenya earned the park the status of one of the seven natural wonders of the world as its' the only migration of its kind in the world (UNESCO World Heritage, 2010). The riparian community in all stages of the river basins – upstream to the downstream – have contributed negatively through their unplanned and excessive activities to the direct deterioration of the Kruger National Park as well as Maasai Mara and Serengeti wildlife reserves. Encroachment and land grabbing, deforestation, overstocking, poaching and vandalism/stealing of the key river monitoring equipment, etc. are still challenges in the two national parks as the poverty and the effects of COVID 19 pandemic increases in the regions.

Additionally, there are cases of drinking water mains being laid down in the open sewer lines in the MRB as well as other cases of cross-connections (see for example Figure 4.10). Sewage intrusion in drinking water distribution system is rampant in the region. US EPA, 2004 defines cross-connection as a physical connection between a potable water system used to supply water for drinking purposes, and any source containing nonpotable water through which potable water could be contaminated. Addressing cross-connections involves identification of transmission and distribution lines and appurtenances via color-coding, taping, or other means; separation of reclaimed water and potable water lines; allowable pressures; surveillance; and backflow prevention devices (US EPA, 2003; Metcalf et al., 2007).

Figure 4.10: Drinking water main in the open sewer line, and visible solid waste and excessive siltation in Mara river, Bomet town, Kenya

The major challenges in the region is the extraction of nutrients and micro-pollutants emanating from agrochemicals, detergents, fuels (due to excessive car wash activities in/by the rivers) as well as storm water intrusion in the water and wastewater treatment structures. Most of these pollutants are not captured *off-site* by the wastewater treatment systems nor are they treated *on-site* but rather find their way to the water bodies.

4.4 Focus of the Study

This study zeroes in on two drivers of integrated water resources management, namely, the (i) micro-water-governance and the (ii) water reuse. These drivers are explored as a contribution towards unlocking the current stalemate emanating from uncertainty and slow implementation of IWRM, which has led to continued poor performance on the water governance, and increased unregulated wastewater and poor management in the receiving water bodies, etc. (Global Water Partnership, 2000) recommended that, "*Regional and national institutions must develop their own IWRM practices with regard to the relevant context.*" It is evident that the uncertainty and slow implementation of the IWRM is as a result of neglecting the micro-governance water aspect and focusing too much on the macro-governance and theory. Therefore, this research embarked on the development of a water reuse plan and an interactive water governance scheme to enhance local level performance on both water resources management and development. Additionally, a comparative analysis on the water reuse is done between case study 1 (Mara) and the case study 2 (Olifants) river basins from Kenya and South Africa respectively (*see description of both basins in the beginning of this chapter*).

Water reuse in the basin is an inevitable investment, necessary to avert the growing pressure originating from the increased volume of wastewater and other chemical pollutants disposed of haphazardly into the river basin. Extracting the economic value(s) embedded on the water reuse will augment freshwater demand in the specific region of interest.

4.4.1 Enhancing the Local Level Performance using Micro-Water-Governance

The grassroots operations on water resources protection, management and development have been neglected by the national and some regional stakeholders in the case study areas. Local stakeholders feel detached from key decision making platforms towards the implementation of various water related programs in the region. Quite often, "strangers" are brought to implement such programs leaving out the locals especially people living with disabilities, women and youth who are largely jobless. Therefore, this part of the study focuses majorly on some of the water governance models/concepts that fosters local level water resources management and development, namely, (i) the second OECD water governance principle (**P2**) on the management of water at the appropriate scale(s) within integrated basin governance systems that reflects on the local conditions, and foster co-ordination between the different scales (OECD, 2015), (ii) the innovative water governance concept – specifically, the real-time online water management system employed by iWaGSS project (Rudolph et al., 2020; *http://www.iwagss.com/wordpress/en/*) in the lower Olifants river basin in South Africa (iWaGSS, 2021), and (iii) the first (**S1**) and fifth (**S5**) local water management success factors according to (Rudolph et al., 2020) (Figure 4.11). S1 encourages incentive-driven water service performance since the current approach on water service performance is poorly executed, while S5 campaigns for the strengthening of the local water business development from the current weak status. Incentives should be granted to local, technical and operational water management levels to stimulate their performance. S5 is aimed at empowering the local actors by engaging them actively in the entire process of giving water and sanitation services. This forms an important approach to address major threat to the provision of water services that are fueled by the "*Seven Sins in Local Water Management*" and will ultimately support part of the SDGs objectives (Rudolph et al., 2020). Addressing the "*Seven Sins in Local Water Management*" should start from the bedrock of the water governance, which is the local level. The bedrock of the water governance could further explicitly be reinforced through resolving management issues within the households and at individual level. Therefore, the bedrock of a good water governance involves creating an interactive platform for the entire spectrum of the stakeholders with a key emphasis on the local actors.

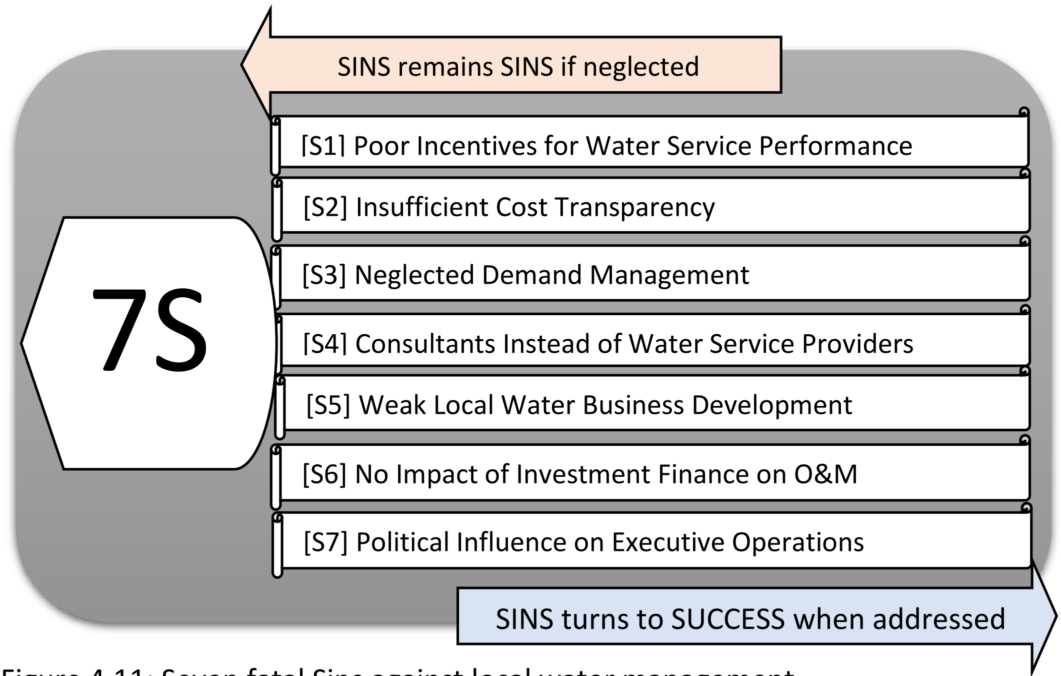

Figure 4.11: Seven fatal Sins against local water management
Note: **S** could be **S**in or **S**uccess depending on whether the topic is addressed (Success) or neglected (Sin).
Source: (Rudolph et al., 2020)

The seven fatal sins against local water management – that are key threat to the sustainability in the operation of the water infrastructure and the allocation of the corresponding water services – could actually be considered as success factors if addressed and implemented appropriately (Rudolph et al., 2020) or otherwise remain sins if they continue being neglected. (Rudolph et al., 2020) provides comments on *Why* these topics – the seven fatal sins against local water management – urgently need to be addressed and *How* to go about finding the lasting solutions.

One of the essential component of a successful local water management is the installation of real-time monitoring systems. The real-time water management system by iWaGSS (Figure 4.12) provides an application-oriented data and information in order to boost water governance and facilitate efficiency in the growth of the resource management (Rudolph et al., 2020). It lays a strong background for an informed and sustainable water resources development by the relevant developers and water utilities such as water service providers.

Figure 4.12: Components of the iWaGSS real-time water management system
Source: (Rudolph et al., 2020)

Several questions towards good water governance concerning the target regions and with regards to the target regions – though not exhaustive – may be posed as follows; (i) how much "water resources" are within the basin?, (ii) who consumes or depends on the available water resources?, (iii) how much does each consumer use per day (per capita per day)?, (iv) how much water is lost, say, through evapotranspiration etc.?, (v) who should be given water priority with all fairness and keen consideration(s)?, (vi) are there any consumers who may use other means of quenching their thirst for water, say, treated wastewater reuse for irrigation farms, fish ponds etc.?, (vii) are there working systems to ensure that acceptable quality standards for the consumers of both freshwater and treated wastewater is achieved?, and (viii) is there regular monitoring and evaluation of the performance of the established approaches on the water resources management and development within the basin to maximize consumer (both inland and at the transboundary scale) satisfaction?

4.4.2 Evaluation of the Water Reuse Value as a Driver Towards IWRM Implementation

This section focusses on wastewater ponds system (WPS) and the subsequent effluent allocation plan for the communities especially in the arid and semi-arid lands (ASALs) of the transboundary Mara and the Olifants River basins. There is need for a reliable low cost and technology method needed for acquiring new water supplies and protecting the existing water sources from pollution in developing countries, particularly those in arid parts of the world (Asano and Levine, 1996) e.g. WPS. Wastewater ponds system is a wastewater treatment technology suitable for regions with less financial stability as well as due to its low technical as well as low operation and maintenance requirements (detailed analysis of the design, operations, advantages and disadvantages of wastewater ponds system has been dealt with previously in this study. (See also WHO, 1989, 2001, 2006; Mara et al., 1992, 1996; Mara and Pearson 2013 etc.). Treatment in the ponds system relies solely on the natural processes of biological purification that would occur in any natural water body as no external energy, other than that derived from sunlight, is required for their operation (Mara et al., 1992b) and are very much influenced by climatic conditions. Temperature plays a decisive role in the natural-based and non-mechanized wastewater treatment processes (Von Sperling, 2007). The mean annual temperature in the Mara river basin is approximately 25.5˚C (Mati et al., 2005; Melesse et al., 2008) making ponds system technologies best fit. One of the probably most important restriction and evaluation parameter regarding wastewater ponds system is the availability and value of land near the respective location. Land, respectively space is the very first restrictions to be assessed. WPS are – according to (Von Sperling, 2007) – simple, economical and sustainable solutions.

4.5 Analysis of Different Cases within Mara River Basin

The cases that have been analyzed on water reuse objective include wastewater management initiatives – with a special focus on WPS – in the agricultural lands, urban centers, learning institutions, medical facilities, and Maasai Mara wildlife reserve. The formal and informal initiatives (e.g. catchment management groups (CMGs), CBOs, tree planting, apiculture (bee keeping in Talek), floriculture (fruits e.g. avocados and vegetables), farmers' associations and savings and credit co-operative (SACCO) such as STEGRO (Sotik TEa GROwers) have been evaluated. The sample size of 330 questionnaires was administered in various strategic points within the case study area as well as the use of Focus Group Discussions (FGDs). The developments of this work has been inspired by the quantitative (statistical) and qualitative outcomes of the aforementioned questionnaires, interviews and other methods of data collection.

Secondly, various cases on the micro-water governance have been analyzed, namely, Water Resources Users Associations, water supply schemes, wildlife conservancies within Maasai Mara wildlife reserve as well as the community (including minority and indigenous communities such as *Ogiek*). These cases combined with a case of water governance employed by the Integrated Water Governance Support System (iWaGSS) project in the lower Olifants basin in South Africa have been used in this study to develop an interactive umbrella scheme of water governance (iUWG) and integrated treated effluent and excreta allocation plan (TEA-Plan) as will be explained in the subsequent sections of this work.

4.5.1 Water Resources Users Associations (WRUAs)

These are community based associations established at the sub-basin level for collaborative management of water resources and resolution of conflicts concerning the use of water resources under Section 29 part 2 of the Water Act, 2016. The establishment and operations of WRUAs are facilitated by basin water resources committee (Section 27g of the Water Act, 2016). The operations on water resources management and development should be done in collaboration with the water resources authority and county governments, at the respective regional offices. A total of 25 WRUAs have been established so far on the Kenyan side of the MRB. Nineteen (19) WRUAs are active though at different growth stages and have received empowerment on the sub-catchment management plan (SCMP) through the water resources authority (WRA) in charge of the basin. The most active WRUAs include the Mara (or the umbrella WRUA), Nyangores, Amala and Talek. All these WRUAs are in the jurisdiction of Lake Victoria South Catchment Area (LVSCA) whose headquarters are in Kisumu, Kenya.

4.5.1.1 Mara WRUA

This is the umbrella WRUA based in Mulot town and brings all WRUAs onboard. Amala tributary runs through Mulot town and the town is located on the border between Narok and Bomet counties. Representatives drawn from all the 25 WRUAs performs regular meetings to deliberate on the issues affecting all the WRUAs (Table 4.2) & (Figure 4.13).

Table 4.2: Water Resources Users Associations (WRUAs) on the Kenyan side of MRB

WRUAs	**Area [km²]**
Ol Chorro Lemek	902
Ol Ongaianiet	734
Mara	664
Upper Nyangores	654
Mara Emarti	484
Olare Lamuny	439
Upper Amala	365
Lairiak	349
Isupukiai	311
Parketapu	309
Lower Nyangores	275
Sigirar	269
Esitoti	247
Talek	237
Upper Migori	225
Olado Lemisigio	220
Sisei	219
Okeju Gem	213
Engare Engito	207
Lower Sand River	201
Engare Gituak	194
Moghor	191
Amala Mulot	190
Middle Kipsonoi	188
Ol Olaimitiek	183
Cheptarei	181
Maragamere	175
Upper Kipsonoi	173
Upper Sand River	169
Isei	147
Laigilai	145
Seganani	142
Ol Merrol	120
Nairotia	115
Nyamora	112
Ongonyeti	112

~Some WRUAs are sub-divided into different zones. (*Data obtained from BOMWASCO*)

4.5.1.2 Nyangores WRUA

This WRUA is located on the Nyangores tributary which is one of the only two perennial tributaries (Williams, 1961) that feed the main Mara river from the headwaters. It is the most active of the 25 WRUAs and is divided into three zones, namely, upper Nyangores, mid-Nyangores and lower Nyangores. Each zone has its catchment management groups (CMGs) drawing representatives from various initiatives such as community based organizations (CBOs), farmers' associations and savings and credit co-operatives (SACCOs) such as STEGRO (Sotik TEa GROwers) SACCO, business communities, and self-help initiatives etc. Nyangores WRUA is characterized by a mixture of small and large scale farming, industries such as tea processing factories, commercial activities etc.

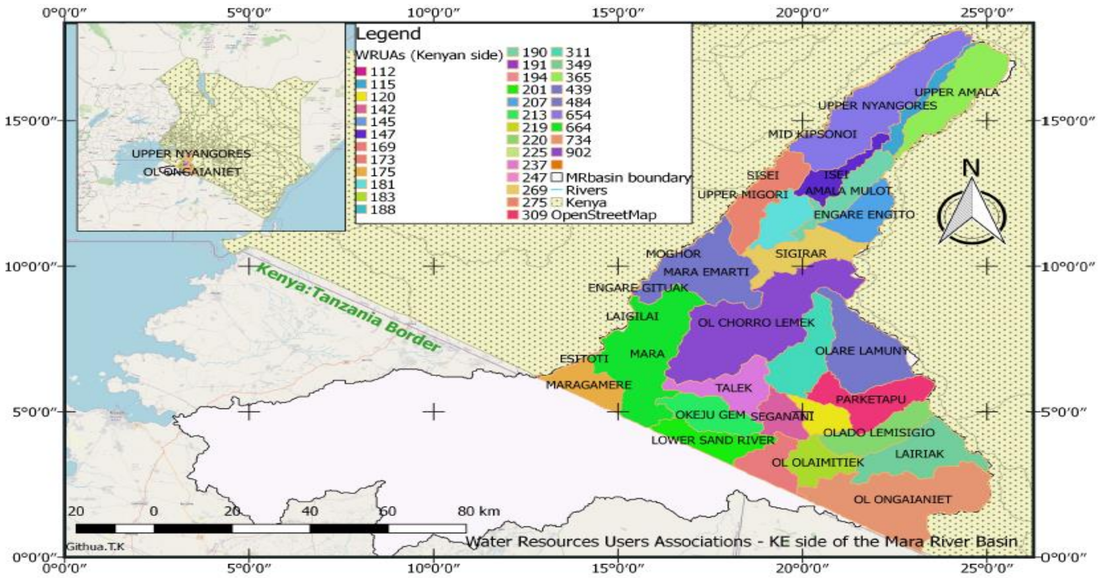

Figure 4.13: A map of Water Resources Users Associations on the Kenyan side of MRB
-Most of these WRUAs are at infant stage although 19 of them have received capacity building and empowerment and have been trained on preparation of sub-catchment management plan.
-WRUA areas [km²] are displayed on the legend. Data (e.g. shapefiles etc.) to generate this map was obtained from MaMaSe website, BOMWASCO and Open Street Map. The map was generated using QGIS.

At the helm of the WRUAs are majorly three wings, namely, management, finance, and procurement (see Figure 4.14). However, Nyangores WRUA has added more wings such as monitoring, livelihood and disaster management (in case of floods, and landslides etc.)

Figure 4.14: A Schematic structure of Nyangores WRUA

The progress seen in Nyangores WRUA – structurally and in execution – is an example of possibilities of a working micro-governance system if conscientiously customized, localized and monitored. Expansion of operational systems and inclusion of all stakeholders presents an advanced approach, widens the opinion and technical-based spectrum and even increases probabilities of having a successful implementation of an integrated water resources management.

4.5.1.3 Talek WRUA

Talek WRUA is located on the Talek tributary flowing from Loita hills through Maasai Mara National Park. The WRUA is therefore situated at the central of MRB as well as the heart of Maasai Mara National Park. Maasai Mara is remarkable for its extraordinary annual migration of some 2.3 million wildebeests *(Connochaetes taurinus)* and over 200,000 common Zebra (*Equus burchelli)* (UNESCO World Heritage, 2010). The annual wildebeests and common zebra migration from the Serengeti wildlife reserve in Tanzania to the Maasai Mara National Park in Kenya earned the park the status of one of the seven natural wonders of the world as its' the only migration of its kind in the world (UNESCO World Heritage, 2010). Talek WRUA is divided into three zones, namely, Upper Talek, Middle Talek and Lower Talek. The following tributaries feed in to the Talek river, namely, Molimbany, Olari Orok, Ntiakitiak, and Olosokon. The main water consumers include hoteliers, camps, community largely Maasai, and livestock. The Maasai community is an indigenous ethnic group who are mostly pastoralists and live near wildlife reserves and/or expansive arid and semi-arid lands. The economic activities in this WRUA include hotels, camps and lodges for tourists, pastoralism, subsistence farming, skin and hide industries etc. This WRUA has in the recent past been affected by flash floods (see Figure 4.15) affecting Maasai Mara National Park, some parts of Talek center, hotels, camps and lodges.

Figure 4.15: Heavy erosion due to flash floods in Talek, Maasai Mara National Park
*From left: pictures 1 and 2 were taken at the exit gate of the Maasai Mara National Park near Talek trading center, and 3 shows an Eland antelope (*Taurotragus oryx*) loitering in the Talek center.

The river banks and the riparian land protection against excessive effects of floods is recommended in Talek region. Additionally, there is high potential of harvesting rainwater due to increased frequencies of flash floods in the region. It should be noted that Talek lies in an ASAL region.

4.5.1.4 Amala WRUA

The WRUA – established in 2009 – is located on the Amala river which is one of the only two perennial tributaries (Williams, 1961) that feed the main Mara river from the headwaters. Amala river originates from the Nairotia forest and runs south east for approximately 95km before joining Nyangores river. Therefore, the confluence between the two perennial tributaries Nyangores and Amala is at Kaboson where they form the main Mara river. Amala WRUA is also divided into three zones, namely, Segamian (Kimuchul), Ilmotiok, and Mulot/Kiplabotwa. Amala river has its own tributaries, namely, Isei, Simwaga, Kagawet, Lelaitich, Kiplesan and Ngito. Isei – which is the major stream feeding into Amala river – has five tributaries namely Njerian, ilagan, Cheien and Bugunye. Two hydro-meteorological data stations 1LB02 at Kapkimolwa at the Bomet/Narok border and 1LB03 at Matecha (currently abandoned) have been used to monitor Amala river which has an average flow of 8.68m^3/s (Figure 4.16) (Amala SCMP, 2011).

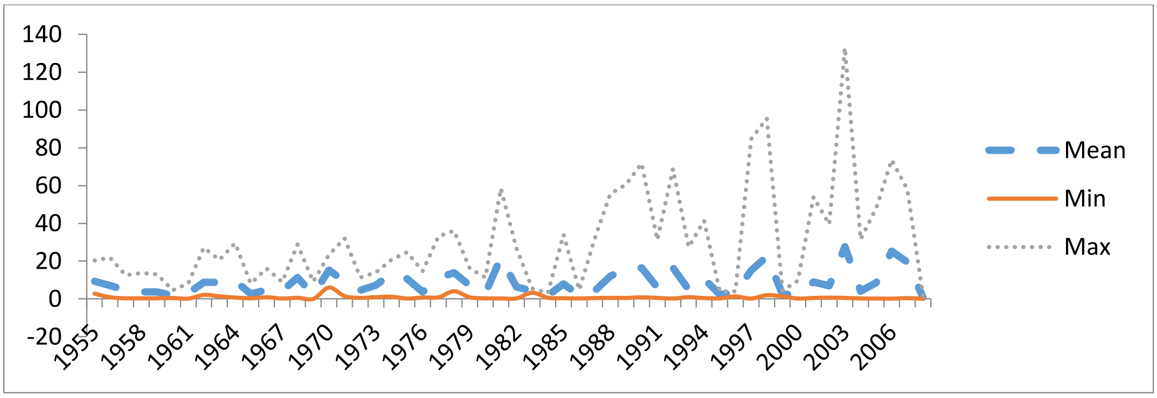

Figure 4.16: Long term annual flows at Amala River RGS 1LB02 in m^3/s
Source: (Amala SCMP, 2011)

According to Amala SCMP, 2011, the average demand estimated from domestic use, learning institutions, local health facilities, livestock, industries, commercial and irrigation uses etc. is about 30,000m^3/day which is available in the Amala River for about 3 months in the year. There are around 100ha of land under irrigation activities in this sub-basin (Amala SCMP, 2011).

All the WRUAs faces a lot of challenges as enumerated under problem statement. There is very minimal support on the WRUAs from other stakeholders both locally and nationally. WRUAs largely depend on well-wishers as well as voluntary workmanship which eventually demoralizes the community – (given that most of the youth and women are jobless and are in dire need to earn a living) – from rendering their support to various sub-catchment protection and rehabilitation mechanisms. Most of WRUA leaders lamented lack of finances e.g. to fuel their motorbikes to attend to various duties etc.

4.5.2 The Maasai Mara Wildlife Conservancies Association (MMWCA)

These are community based organizations within the Maasai Mara wildlife ecosystem in Kenya. They were established in 2013 to conserve the rivers, riparian land and protected areas for the wildlife, the community around and tourism activities. There are at least 15 conservancies in Maasai Mara national reserve (MMWCA, 2019). These conservancies are also engaged in community sustainable livelihood to enhance the living standards of the poor community. MMWCA are members of the Kenya Wildlife Conservancies Association (KWCA) and they include Enonkishu, Olare Orok, Naboisho, Olerai, Ol Kinyei, and Nashulai etc. Most of the conservancies are still at infant stage of development and have not yet spread to the entire Mara-Serengeti community. The conservancies are largely based on the Maasai community and tourism organizations on the Kenyan side despite the fact that there are other tribes within the region. Conservancies should establish a more working relationship with local stakeholders such as wardens and game rangers, Mara-Serengeti Hoteliers Forum, Maa Trust, Base Camp Foundations, and Maasai Cultural villages etc. An all-inclusive community engagement is therefore recommended. The wildlife conservancies are a commendable initiative that should be empowered to authoritatively collaborate with other stakeholders within the basin in order to achieve sustainability in the creation and development of the conservation areas.

4.6 Water Management in MRB

4.6.1 Technological-based Water Management

There are various modern water management techniques employed in the MRB, namely, use of monitoring and river gauging stations equipped with data loggers since October 2014 (see Figure 4.17), water quality laboratories (e.g. the one located at Bomet next to Nyangores river), and online database (e.g. the MaMaSe website) etc. The river gauging stations in Mara basin have poor data record on important parameters such as Total Phosphorous, and Nitrite etc. and they typically measure pH, temperature and conductivity only.

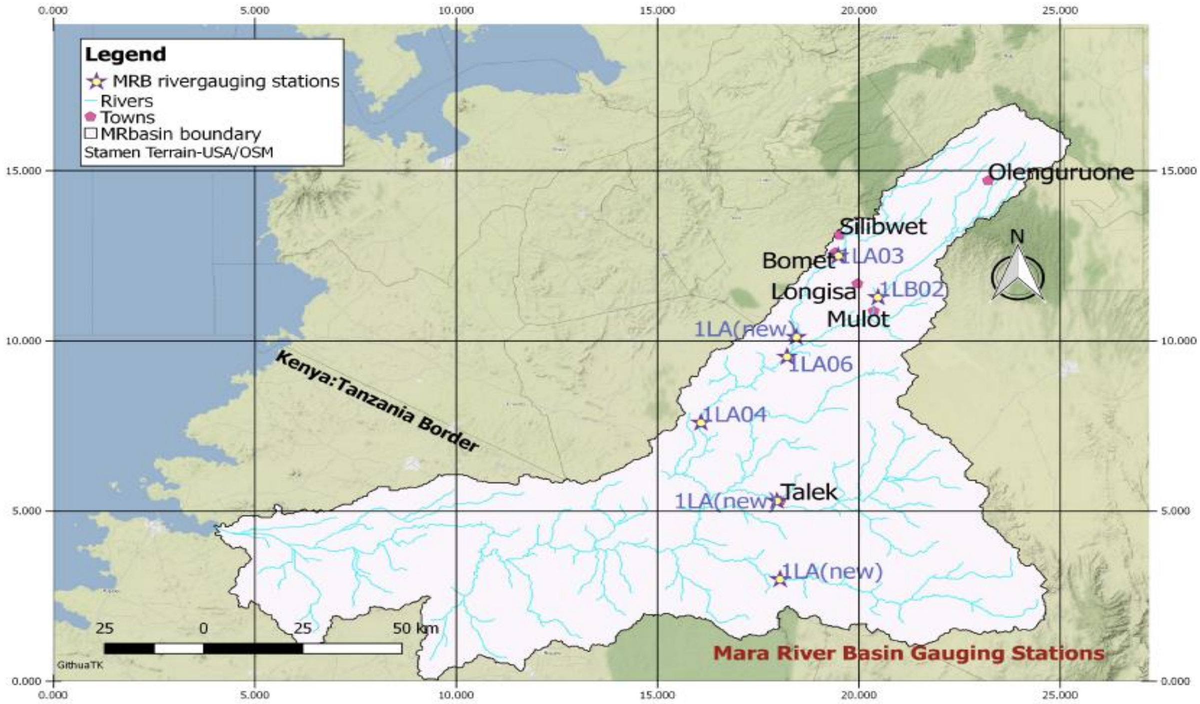

Figure 4.17: A map of River Gauging Stations in Mara region

*The main RGS include (i) 1LA03 at Bomet bridge in Nyangores river, (ii) 1LB02 at Mulot-Narok bridge in Amala river, (iii) 1LA06 at Emarti, and (iv) 1LA04 at Mara bridge (removed due to vandalism and theft) etc.

*The map was generated using QGIS. Data obtained from MaMaSe.

The data loggers – also established under MaMaSe project by Delft University – in the MRB (*https://mamase.delft-hydrological.com/WRA/wrma.html*) observe mainly rainfall, pan evaporation and hydrometric station (e.g. stage observation).

4.6.2 Community Water Supply Schemes (CWSS)

Water supply is vested on the County governments (Water Act, 2016); Section 72) through county or cross-county water services providers (CWSPs) and other companies licensed by the regulatory board to operate as water services providers. CWSPs receive financial support from the water sector trust fund (WSTF) to enable their smooth operations in water services and asset development. CWSPs work directly with the community to establish schemes that are proximal to the water consumers (Water Act, 2016). An example of such CWSP is Bomet Water and Sewerage Company (BOMWASCO) which has 9 CWSS, 5 of which – namely, Olbutyo/Chebalungu, Sigor, Longisa, Bomet and Sergutiet – are within the Mara basin while the 4 others, namely, Konoin/Itare, Sotik, Ndanai and Kamureito are outside the basin. These schemes are further subdivided into smaller operational zones – District Meter Areas (DMAs) – which are monitored by a flowmeter to enhance water services and rationing to the consumers as well as leakage detection and calculation in the distribution system (Farley, 2001). DMAs are expected to address the growing problem of non-revenue water (NRW) in the region which is estimated to be 42% in the basin.

4.6.3 Catchment Protection Mechanisms in MRB

There are various catchment protection mechanisms that are currently in place in the basin. These mechanisms include, avocado and indigenous tree planting (as a win-win approach where farmers harvest fruits while the presence of trees help reduce surface runoff etc.), and napier grass along the riparian land. There are also campaigns to eliminate exotic trees e.g. *Eucalyptus spp* (such as *grandis, saligna, regnans, globulus etc.)* – (known to be "water-hungry" trees) – that are within 30 metres from the water bodies, and encourage people to reduce livestock and keep rather dairy cattle, and goats etc. Local community is also sensitized on the need to stop pollution activities along the water bodies e.g. bathing, washing clothes and car washing and other activities that lead to spilling of both liquid and solid waste into the water bodies. There are also efforts to encourage proper cropping system since close to 75% of the inhabitants practice agricultural related activities, and enhance water springs protection and rehabilitation. Scores of small springs in this region are to be found around the quartzite hills (Williams, 1961). The status of a number of springs has been improved, especially, in Nyangores WRUA (Figure 4.18).

Figure 4.18: Lelechonik (left) and Ngomwet (right) Community Water Springs Rehabilitation and Protection in Nyangores WRUA, in MRB

The major challenges facing water springs rehabilitation and protection exercise in this region include (I) conflicting policy framework where some springs e.g. Lelechonik is privately owned contradicting the Kenyan law, Chapter 5 on land and environment, section 62:clause 1(g) on water catchment areas and clause 1(i) which states that all rivers, lakes and other water bodies are categorized as public land; springs and wetlands as well as other water bodies are under the custodian of the state, (II) financial challenges to improve the springs, (III) community is reluctant to participate in the rehabilitation and protection exercise. There are efforts to conduct capacity building and engage catchment management groups, and (IV) lack of political will.

4.7 Statistical Analysis

Data manipulation, processing and analysis in this study employed statistical tools such as Quantum GIS and Statistical Package for Social Sciences (SPSS) and later displayed on the same platforms as graphs, charts, and maps etc.

4.7.1 Quantum GIS

Raw and processed data inform of either raster (data displayed as cell, pixels, or elements) or vector (data associated with points located using coordinates (x, y), lines, or boundaries enclosing areas) (QGIS, 2021) was obtained from different sources. These data sources include, earth observation (EO) satellites e.g. satellite imageries etc., online databases (e.g. Mau-Mara Serengeti project etc.), and Regional Center for Mapping of Resources for Development (RCMRD) headquarters in Kasarani, Nairobi, etc. All these sources of data formed a wide and rich background to the production of information necessary to arrive at various points of decision making. Land use images with clear land use changes that have occurred over time due to anthropogenic and climatic changes were obtained from e.g. Landsat satellite in Copernicus before undergoing both visual and computer aided interpretation (see e.g. Figure 4.19).

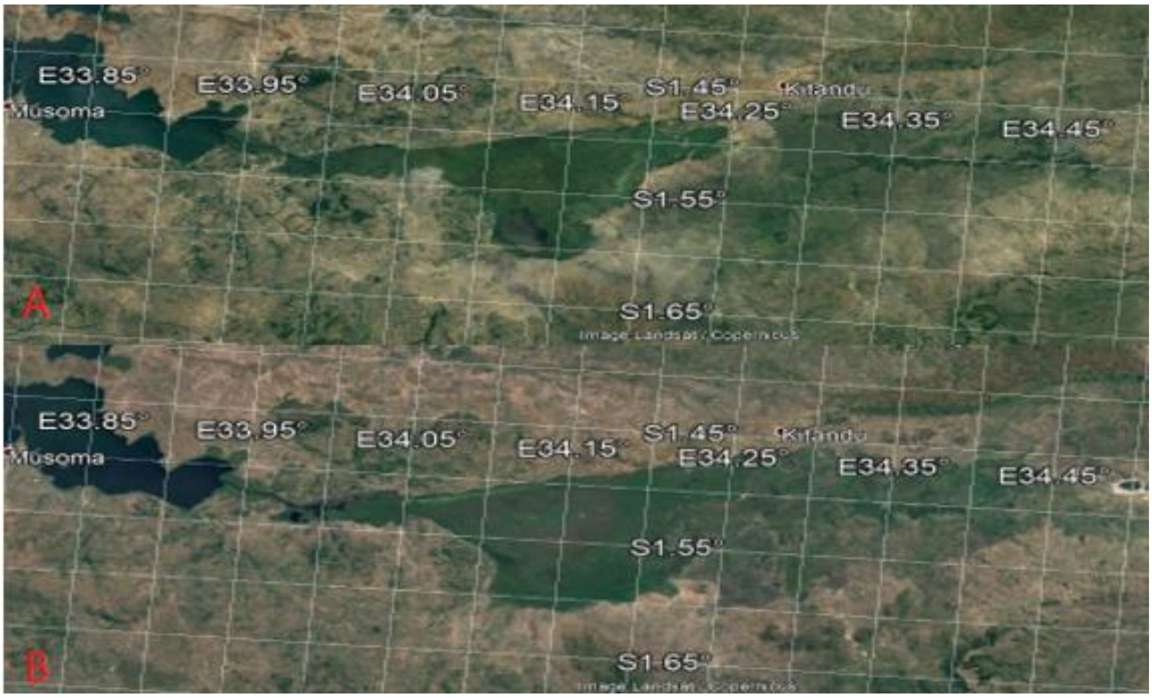

Figure 4.19: Copernicus Landsat images for (A) Mara wetland in 1984 and (B) 2016
*Mara wetland/Masurua swamp is located in the downstream of MRB, near the mouth at Musoma area.
*Mara wetland has increased in size over the decades due to increased sedimentation and excessive growth of aquatic plants.
*Sediment deposition have increased due to the upstream deforestation, encroachment on the riparian land, and expansion of more often poor agricultural methods etc.
*Floodplains have increased displacing the riparian community e.g. in Kitandu, Tanzania.

Apart from land use and land cover change of the case study areas, more data such as river discharge, rainfall and temperature, basin topography, soil data, human population/rate of water consumption, hydro-meteorological data, river morphodynamics (e.g. encroachment, erosion and siltation), and water quality was explored. Apart from satellite images, most of the data obtained was already digitized from analog maps and geo-referenced and there was no need to subject it to the digitizing or geo-referencing process. The commonly used coordinate reference system was WGS84. Through QGIS platform (QGIS, 2021), various observations and measurements were made, followed by spatial (geographic) data descriptions, and forecasting before arriving at various key decisions. QGIS is equipped with GDAL (Geospatial Data Abstraction Library) – with two sections e.g. OGR for vectors and GDAL for rasters – that enables reading and writing various GIS data formats. Data manipulation (e.g. addition and organization of layers in the QGIS Map Canvas), analytical processing, and analysis as well as visualization culminated to various outputs such as maps, graphs, and tables etc.

4.8 Wastewater Treatment Strategies in Mara River Basin

The effluent control strategies are poor in most cases in MRB. This has led to constant building up of wastewater and excreta pools and subsequent hazardous and free flow in open channels. The raw wastewater finds itself often in public places and eventually into the rivers such as Nyangores, Amala, and Talek etc. Although some institutions such as Tenwek hospital have attempted to establish effluent discharge control plan (EDCP) based on wetland technology (Figure 4.20), WPS remain common within the basin. Protection of water resources is paramount though it has failed in some river basins or is moving slowly in many countries. Kenya faces a high deterioration of the water quality due to the growing poor solid and liquid waste disposal, lack of recycling or reuse programs etc.

In the EDCP at Tenwek hospital, wastewater is collected directly from the hospital in a large rectangular septic tank (dimensions: length 50ft x width 15ft x height 30ft) as well as several other minor septic tanks meant for the hospital staff. Effluent intake at the EDCP from septic tanks is estimated to be 17 litres in every 10 seconds. The intake section is divided into 4 chambers, namely, the receiving chamber where suspended solid waste is broken down by the circular rotating disc followed by settling and screening of the solid waste. The second chamber continues with the circular motion based technology and the remaining solid waste is further screened. Sedimentation is then done in the third chamber while the sludge is pumped back to the first chamber to begin the cycle. The fourth chamber holds wastewater without solids before releasing it to the wetland channels. The wastewater flows slowly through the wetland (mostly dominated by papyrus reeds) in a circular motion to increase the path and the time taken for better purification. There are four meandering channels connected before getting to the rock filter. The rock filter situated towards the end of the fourth channel enhances extraction of the sludge. The rock filter is further expected to enhance biological decomposition of the remaining pollutants in the effluent (Mara and Johnson, 2007). The next stage involves chlorination which follows the rock filter before the water gets to the last tank. The last stage involves the trace sludge settling tank which allows any remaining sludge to be eliminated before releasing the treated wastewater to the

Nyangores river. There was no clear monitoring of the water quality achieved before discharging the effluent to the Nyangores river.

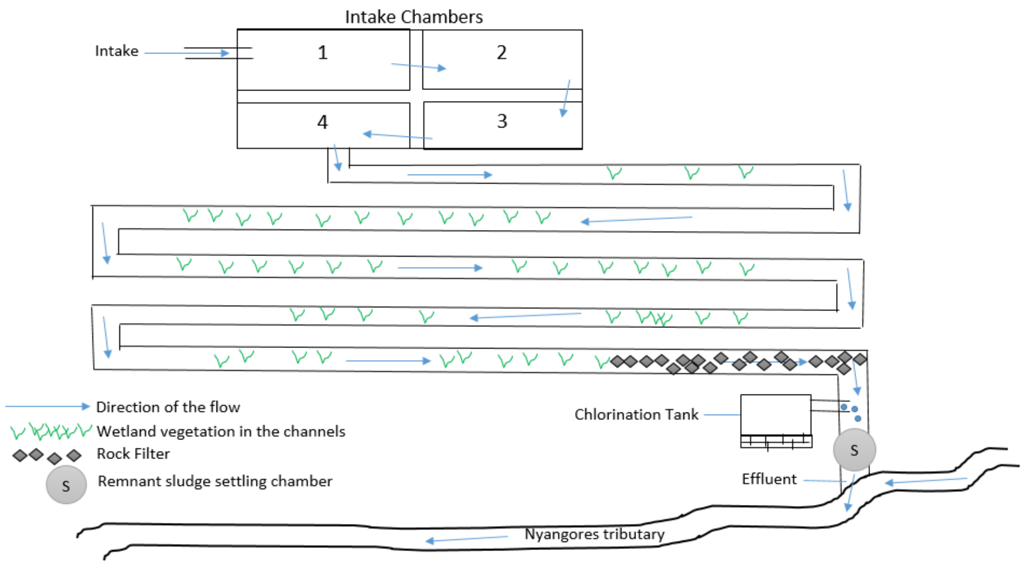

Figure 4.20: Effluent Discharge Control Plan (EDCP) at Tenwek Mission Hospital
*Nevertheless, there is poor database and very few population is connected.

4.8.1 Bomet Wastewater Ponds System

The design capacity of the planned wastewater ponds in Bomet region – upstream of the Mara river basin – was supposed to be 1,469m^3/day. However, the initial two series design (each with six ponds e.g. A1, F1, M1, M2, M3 and M4) with each train capable of treating 734.5m^3/day) (Figure 4.21) (Table 4.3) has not been realized. This has been attributed to the difficulties in acquisition of extra land for the ponds. Nevertheless, there is a one train wastewater ponds system that was established in 2015 (Figure 4.22).

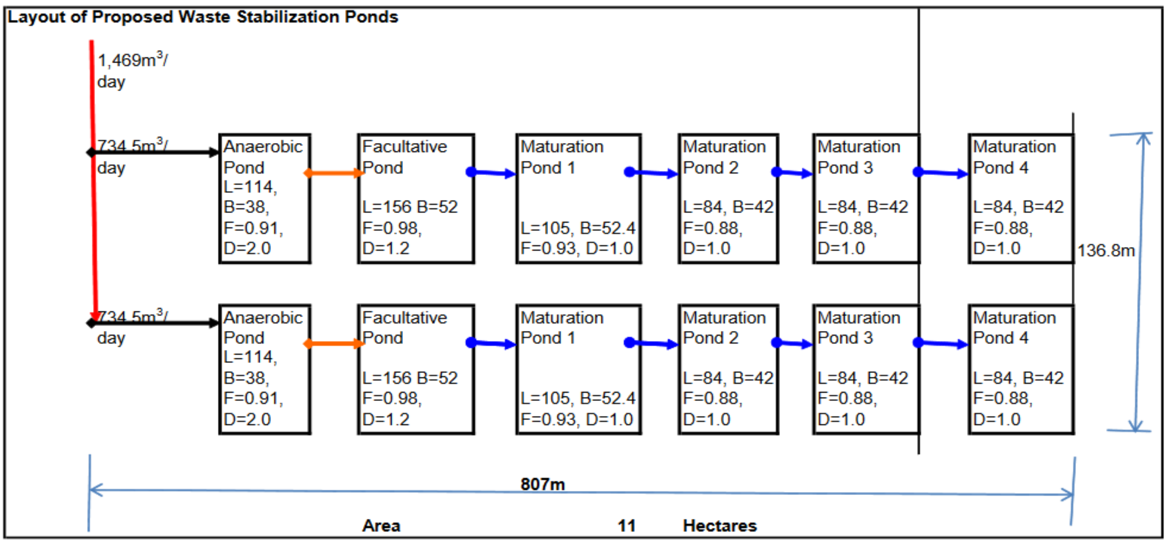

Figure 4.21: Proposed Rehabilitation of Bomet Sewerage System
Source: (Lake Victoria South Water Services Board, 2013)

Table 4.3: The proposed Bomet two series wastewater ponds overall retention time model

Pond	Number of ponds	Volume, m^3	Mid depth Area, m^2	Retention Time, days
AP	2	1,487	743.5	2.0
FP	2	9,729.6	8,108	13.4
MP			8	
MP1		5,478	5,478	7.5
MP2		3,558	3,558	5
MP3		3,558	3,558	5
MP4		3,558	3,558	5
Total		**27,368.6**		**37.9**
Effluent Analysis				
Description		**Influent**	**Effluent**	**% Reduction**
Faecal Coliforms		10^8	10^3	99.99

AP – Maturation pond, FP – Facultative Pond, MP – Maturation Pond
Source: (Lake Victoria South Water Services Board, 2013)

Wastewater ponds system in Bomet obtains raw sewage from domestic wastewater (households and toilets) which constitutes mainly, non-biodegradable and biodegradable organic matter, nutrients, suspended solids and pathogenic organisms such as *Escherichia coli* among other faecal coliform bacteria. According to (Von Sperling, 2007), domestic sewage contains approximately 99.9% water while the remaining part includes organic and inorganic, suspended and dissolved solids, together with microorganisms; and it is because of this 0.1% that water pollution takes place and the wastewater needs to be treated.

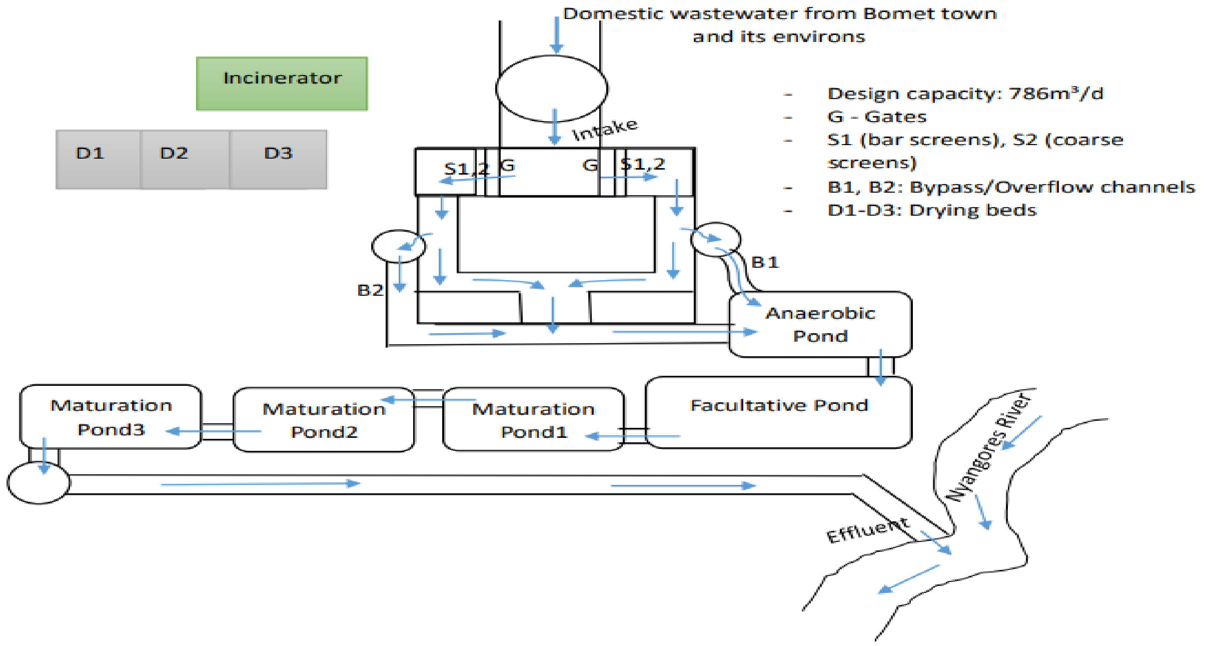

Figure 4.22: One series wastewater ponds system serving Bomet town (Kenya) and its environs.
*1 Anaerobic (depth 2.5m), 1 Facultative (depth 1.5m) and 3 maturations ponds (1.5m each).

Very few households were by the year 2020 connected to the Bomet wastewater ponds system; statistics shows that only 150 households are connected although there are plans – according to the Bomet water and sewerage company (BOMWASCO) – of expanding the sewer line to reach more households. The design capacity is 786 m^3/day although the system currently receives a quarter of the aforementioned value. There is no analysis of the influent (Figure 4.23) and a poor analysis of the effluent before discharging it to the Chepkulo (Nyangores) tributary could be observed; (see in the appendix B an excerpt of the effluent data obtained from BOMWASCO).

Figure 4.23: Intake point at Bomet wastewater ponds system

The concentration of the incoming wastewater fluctuates with seasons, mainly due to the dilution from storm water intrusion. Therefore, stormwater intrusion has occasionally led to overflowing of the ponds and high cost of treatment. The general solid and treated effluent disposal methods in Bomet ponds include; (i) discharge of the treated effluent into the river, (ii) incineration of the non-biodegradable waste, and (iii) *onsite* drying of the organic matter by use of the drying beds before selling it to the farmers as manure. Some of the manure is used *onsite* to fertilize the growing vegetables and trees.

4.8.2 Management of Sludge

Sludge production in the wastewater treatment systems requires further treatment where necessary e.g. in the drying beds, or with some additives before it is disposed or reused as manure for farming activities. There are three drying beds in Bomet wastewater ponds system (Figure 4.24), although only two appeared to be actively used. It should be noted that there is no clear treatment of sludge – apart from drying it up in beds – in Bomet pond system before application as manure. Handling of sludge should strictly adhere to the treatment and reuse guidelines e.g. WHO, 2006 etc.

Figure 4.24: Screened non-biodegradable and biodegradable organic matter (left) and the drying beds (right) at the Bomet wastewater ponds system, Kenya

4.8.3 Energy Supply and Demand in Water and Wastewater Sector

Water and wastewater systems consumes massive energy in order to operate as expected. These systems can also produce energy in a "self-sustenance" or "giving back" kind of approach e.g. hydropower whose energy can be used within the system of production or put into the grid system when in surplus to be used elsewhere. Therefore, it is important to understand the nexus between energy and water, that is, water used for energy and energy used for water, an indication that energy and water are intimately interrelated; energy is used for water and water for energy (Stillwell et al., 2011). Energy is required for lifting, moving, distributing, and treating water with non-conventional water sources, (such as reclaimed wastewater or desalinated sea-water), being often highly energy intensive (Hoff, 2011). Water for energy currently amounts to about 8% of global water withdrawals and it is required for the extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing biofuels and for generating electricity (Hoff, 2011).

According to (Kenya National Bureau of Statistics, 2021), geo-thermal is the main source of electricity in Kenya producing averagely 400KWh Million per month, followed by hydropower whose production has seen a positive trend moving from 200KWh Million in April 2019 to 400KWh Million in December 2020. Although there are some positive trends in the energy generation in Kenya especially the hydro-energy, the total local electricity generation decreased from 1,022.74 million KWh in October 2020 to 997.65 million KWh in November 2020 (see Figure 4.25).

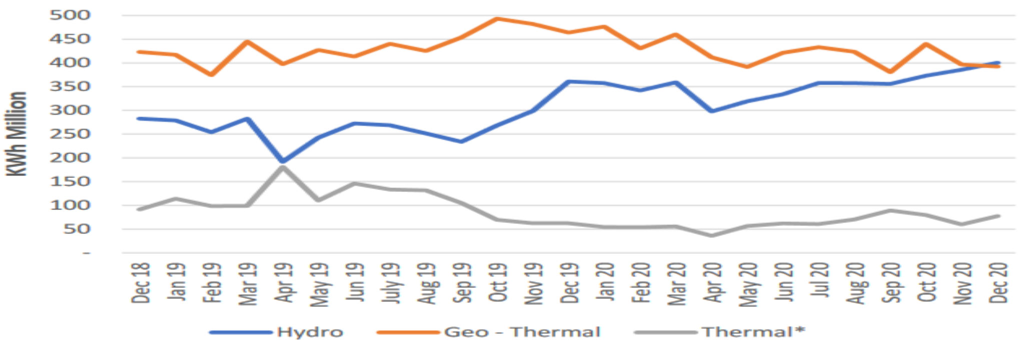

Figure 4.25: Kenyan Electricity Generation by Source
Source: (Kenya National Bureau of Statistics, 2021)

Additionally, Kenya receives an average daily insolation of 4-6KWh/m² of solar energy (Energy & Petroleum Regulatory Authority, 2021) and the conversion rates into electricity is still very low (Kenya National Bureau of Statistics, 2021). Kenya generated 43.79% geothermal, 32.55% hydro, 11.29% thermal, 1.48% imported energy and 0.52% solar energy in 2019 (Kenya Power and Lighting Company, 2019). Examples of energy policy framework in Kenya include the Energy Act, 2006 and 2019 and the Energy Regulations, 2012. The policy framework provides a roadmap for the energy generation and supply as well as the current rural electrification exercise. Apart from the use of the national electricity distribution network (the Kenya Power and Lighting Company), there are some cases of mini-grids electrification in Mara river basin (e.g. Talek area) – courtesy of GIZ ProSolar initiative on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) as part of the German Climate Technology

Initiative (DKTI). Mini-grids are meant to increase levels of cost-effective, affordable and sustainable rural electrification through private sector leadership (*http://www.minigridbuilder.com*). A mini-grid is an integrated local electricity generation, transmission and distribution system that typically utilize renewable energy (solar, wind, and biomass) as well as battery, diesel or hybrid fuel to produce power (*www.giz.de*). The price of electricity – energy consumption charges, distribution as well as tax – in Kenya is around 0.17 and 0.12 Euro per kWh for domestic and commercial consumption respectively. These charges are also affected by the consumption band (e.g. 0 -10, 0 -100) in terms of units consumed per month. Kenya power consumption in kWh/person increased by 2% between 1995 and 2014 (World Bank, 2017).

4.8.4 Energy Supply and Demand for Water and Wastewater in Some Selected Cases in MRB

Water and wastewater abstraction/lifting and treatment, and supply/distribution systems requires a given amount of energy for the efficient operation and the ultimate attainment of the set objective(s). MRB especially in the rural areas has experienced poor or intermittent water services due to energy shortage – especially in areas where gravity flow is infeasible – necessary to distribute water to the consumers and to the treatment works, etc. Water in this region is mainly abstracted from rivers (e.g. Mara river and its tributaries), dams, pans, boreholes, wells, springs, and rainwater. Apart from energy shortage, there are other challenges that affect water and wastewater transportation in Mara basin, namely, topography, distance to the water points and scattered households, and poor infrastructure and equipment (e.g. pumps failure, poorly designed, constructed and/or maintained storage tanks and pipeline etc.). Table 4.4 shows energy source and area of service for some water supply schemes under Bomet water and sewerage company (BOMWASCO).

Table 4.4: Energy source and area of service for some water supply schemes under Bomet water and sewerage company

Water supply scheme	Source of Power	Served Area [km²]
Bomet	E	3.28
Itare/Konoin~	E	156.93
Olbutyo/Chebalungu	E	40.52
Sigor	S	40.68
Sergutiet	E	1.15
Kamureito~	E	17.29
Ndanai~	E	1.60
Sotik~	E	10.27
Longisa	E	6.88
Total Served Area		**278.6**

- E=Electric power, S=Solar energy
- The schemes combine low and high lift energy consumption
- Pumping done using mostly centrifugal pumps
- Some regions use gravity flow in some sections of the system
- ~Indicates regions that are outside MRB but under BOMWASCO

There are plans to implement Bomet-Longisa-Mulot water supply and sanitation project expected to benefit more than 200,000 inhabitants with clean water (Bomet County, 2020). This is expected to consume more energy ranging from water withdrawal from the source and lifting to the treatment works, flow within the treatment chambers, and to the distribution network(s) etc. There are various benefits of energy optimization in water and wastewater systems, namely, (i) reduction of operating costs, (ii) enhance long-term sustainability of energy resources, (iii) support sustainable decisions in facility expansion, upgrades, and retrofits, and (iv) facilitate efforts geared towards easing greenhouse gas (GHG) emissions such as CO_2, CH_4, and N_2O (Biehl and Inman, 2010).

4.8.5 Biogas Energy as a source of Income for the WPS Operation and Maintenance

Biogas could be harnessed from wastewater ponds system (WPS) for energy purposes. This could best be tapped from anaerobic digestion of accumulated sludge in the ponds. The revenue collected from biogas energy could then be used for O&M of the WPS hence making it a win-win situation. Recycling biogas may facilitate some reduction of energy required by the system (Tsagarakis et al., 2003). Energy costs account for most of the cost of operation and maintenance of wastewater treatment works where medium sized systems operating conventionally consumes higher amount of energy than extended aeration systems (Tsagarakis et al., 2003). However, it must be understood, that the energy cost issue is a fact because (a) O&M expenses are often ignored or neglected, and (b) the tariffs for electric power are near to real cost in the sub-Saharan Africa, unlike the subsidized wastewater tariffs fees respectively.

4.8.6 Stakeholders Active Consultation

All stakeholders should be engaged in the process of waste management including waste treatment and reuse and dumpsites/landfills selection, etc. This is inevitable as such consultations and decisions arrived at affect them directly, e.g. in terms of their health, and other welfare. Collaboration of all stakeholders will facilitate establishment of the sources of wastewater (especially from ghost polluters) and the propagation paths as well as the possible and widely acceptable and practical control measures. This will clear the way for the customized planning of wastewater treatment and discharge mechanisms.

4.9 Water Demand in Mara River Basin

As expected, there has been growth in the water demand in the basin due to the population increases (see Table 4.5), and changing lifestyle, etc. Water scarcity and stress has affected negatively the food production in the region, owing to the fact that the basin is largely arid in nature. Additionally, the demand growth is due to the two world prominent wildlife reserves (Maasai Mara on the Kenyan side and Serengeti on the Tanzanian side) which is home for the millions of animals, birds and plant species.

Table 4.5: Human population growth and water demand in the two major counties in MRB

Counties	2009		2019	
	Population	Water demand [m^3/day]	Population	Water demand [m^3/day]
Bomet	723,813	100,234.52	875,689	152,414.94
Narok	850,920	142,796.89	1,157,873	181,780.63
Total	**1,574,733**	**243,031.41**	**2,033,562**	**334,195.57**

4.9.1 Domestic Water Use

Between 2002-2007, more than 50% of households within the MRB relied on Mara river for domestic and livestock needs (Aboud et al., 2002; Hoffman, 2007). Currently the population that obtains water and related resources directly from Mara river and its tributaries has increased to 62.3%. Other sources of water for various uses include, springs, water pans, dams, and rain water harvesting. There are community water supply schemes such as the 9 schemes managed by Bomet Water and Sewerage Company (BOMWASCO), 5 of which – namely, Olbutyo/Chebalungu, Sigor, Longisa, Bomet and Sergutiet – are within the Mara basin while the 4 others, namely, Konoin/Itare, Sotik, Ndanai and Kamureito are outside the basin (Table 4.4). It should be noted that it is typical for the county government demarcations in Kenya to not necessarily follow the river basins boundaries. The water schemes are further subdivided into smaller zones – District Meter Areas (DMAs) – which are monitored by a flowmeter to enhance water services and rationing to the consumers as well as leakage detection and calculation in the distribution system (Farley, 2001). Community water projects in the basin are also supported by the county government, national institutions such as water service trust fund (WSTF) and State Department of Water, and other development partners e.g. African Development Bank (AfDB), World vision, USAID etc. (Bomet CIDP, 2018; Narok CIDP, 2018).

Table 4.6. Average distance to the water point

Region	Average distance (km) to the water point	
	Wet season	Dry season
Narok	4	12
Bomet	1.5	7

The distance to the water point is a big challenge (Table 4.6) especially to the women, girls and children who bear full responsibility of fetching water for their families. The common method of carrying water from the river include, donkeys, on the women's and children's back or head, (see Figure 4.26) and sometimes motorbikes etc. Therefore, a lot of time is wasted by women, girls and children fetching water leading to increased school dropout and lack of career growth.

Figure 4.26: Women fetching highly turbid water for domestic use in Amala river

Women washing clothes and men bathing along the banks of rivers Nyangores, Amala, and Talek is a common practice. Domestic animals like cattle, sheep, and goats are commonly watered directly from the rivers. Additionally, river banks are not protected (see for example Figure 4.26) and the floodplains keeps on expanding, often times leading to human displacement, destruction of crops and property during floods.

4.9.2 Agricultural Water Use

Crop farming and livestock rearing are the main economic activities in Bomet and Narok regions of the basin (Table 4.7) (Table 4.8). The area under agriculture is approximately 6,021Km^2 in Narok alone while Bomet counties and other regions in the basin have more agricultural activities. Generally, agricultural activities have increased in the Mara river basin especially in the Mau forest complex, along Nyangores, Amala tributaries and the main Mara river. There is also increased encroachment in the Maasai Mara wildlife reserve.

Livestock breeds in Bomet region include, dairy breeds (Friesians, Ayrshire, Jersey and crosses), beef breeds crosses, dairy goats (e.g. Toggenburg, Germany Alpine, Kenyan Alpine, Saanen and Crosses), and chicken etc. (Bomet CIDP, 2018). The major part of Narok is dominated by pastoralism, ranches and wildlife conservancies. This is a clear indication of more water demand for the millions of wild and domestic animals and birds.

Table 4.7: Livestock population and crops in Narok region

Type	Livestock Population (2012)
Cattle	1,227,879
Sheep	1,134,049
Goats	752,477
Donkeys	68,789
Poultry	670,898
Pigs	299
Rabbits	5,643
Camels	8
Beehives	54,823
	Crop farming
Wheat	main
Barley	
Maize	main
Beans	
Irish potatoes	
Sugarcane	

*Average wheat and maize produced annually in Narok 3.5 – 4 million 90kg bags
*Most of the crops in Narok are grown as cash crops
Source: (Narok CIDP, 2018)

Table 4.8: Crops produced in Bomet county

Crop	Area in Ha	Production
Maize	30, 940	590,672 bags
Beans	31,857	238,668 bags
Sorghum	442	5,432 bags
Finger millets	992	13,096 bags
Irish potatoes	2,899	64,420 mt
Sweet Potatoes	2,300	2,300 mt
Tea	13,562	135,620,000 kgs
Tomatoes	650	10,750 mt
Cabbages	804	23,865 mt
Bananas	432	10,238 mt
Kales	824	12,171 mt
Carrots	52	360 mt
Coffee	120	600 mt
Avocados	220	2,200 mt
Pumpkin	70	1,400mt
Spring onions	45	1,350 mt
Melons	16	640 mt
Mangoes	20	300 mt
Passion fruits	40	600 mt
Bulb onions	25	250 mt

*mt – metric tons, and bags are in 90kgs each.
Source: (Bomet CIDP, 2018) - Department of Agriculture Livestock and Cooperatives, Bomet County.

4.9.3 Industrial Water Use

There are various industries in the basin, namely, agricultural processing industries (e.g. the seven tea processing industries in Bomet county, sugar processing industry in Trans-Mara West, Narok, milk processing plant in Sotik, and Narok, wheat and maize milling plants, tanneries, water bottling plants in Sotik, Bomet East and Konoin Sub-counties, leather (hides and skins), handicraft, carpentry, gold mining etc. (Bomet CIDP, 2018). These industries consume large amounts of water directly from the rivers. Unfortunately, water recycling in these industries is yet to be realized and instead, most of them dispose wastewater – sometimes untreated or partially treated – into the receiving water bodies. The effects of the disposed effluent in the basin is largely undocumented.

4.9.4 Commercial Water Use

Commercial activities in the case study area ranges from Micro, Small to Medium Enterprises (MSMEs). Hotels and lodges consume a lot of water for food, drinking water and sanitation purposes. The number of hotels and guest houses, car washing activities, open-air-markets, retail shops and supermarkets have increased in the mushrooming urban centers like Bomet, Mulot, Longisa, Silibwet, Talek, Narok and within and in the outskirts of Maasai Mara national park. These commercial activities are contributing directly to the increased water demand and the subsequent wastewater disposal.

4.9.5 Tourism Water Use

MRB is home to two globally renown Maasai Mara national park and Serengeti wildlife reserve in Kenyan and Tanzanian side respectively. Millions and diverse wild animals, birds and plant species are found in these ecosystem. Maasai Mara national park accounts for close to 50% of Kenya's wildlife based income emanating mainly from tourism activities including hotels and lodges such as Mara Serena, Keekorok, Kichwa Tembo, and Mara Timbo, etc. As such, the demand for water in these ecosystem is high and the subsequent wastewater disposal. Although not yet fully established, some tourism hotels in this region have started treating their waste through wetland system. Additionally, there are some eco-rated tourism facilities in the Maasai Mara by the eco-tourism Kenya (*https://ecotourismkenya.org/eco-rated-facilities/*). The identified tourism facilities are awarded either gold, silver or bronze medal according to their performance. This is a commendable initiative that will encourage water and wastewater management and conservation, and environmental sustainability at large.

4.9.6 Environmental Water Use

Generally, the ecological flow in Kenya is Q95 (flow rate (Q) equalled or exceeded for 95% of the time) but many are the times when this flow is exceeded, especially in the MRB, hence endangering the ecosystem. There has been a major challenge in allocating the required amount of ecological flow for the flora and fauna in the Mara basin. The dwindling water quality and quantity required to sustain the ecosystem has led to dying and/or migration of mainly fish as well as birds and animals like crocodiles, and hippopotamus etc. A number of birds and animals have migrated to other places or migrate annually e.g. wildebeests, zebras, and antelopes to look for water and pasture. Cases of human-wildlife conflict has been experienced as wild animals move out of their reserves to look for pasture and water in the community's crop fields and water points (e.g. water pans etc.)

4.9.7 Aquaculture in the Mara River Basin

Fishing is mainly done directly from the rivers e.g. Nyangores, Amala, Kipsonoi, Mara, Itare, and Kiptiget. There are several fish farming activities in the basin e.g. up to 100 fish ponds by 2018 were constructed in Bomet county, about 100,000 fingerlings reared in 10 dams, and 10, 000 trout fingerlings in Kipsonoi river etc. There is also a fish feed mill in Sisich farm cooperative society (SFCS) located in Chesoen in Bomet. Fish Farming Enterprise and Productivity Programme (FFE&PP) started in 2009 in the basin through the support of the national and county government (Bomet CIDP, 2018).

4.9.8 Irrigation Potential

Despite the declining renewable water resources in Kenya, the need for irrigation (due to climate change, demand for food and population growth) has kept on growing from 14 thousand hectares in 1961 to 150.6 thousand hectares in 2016 at an average annual growth rate of 4.3% – Only 12.5 thousand hectares of croplands are currently irrigated in Kenya (FAO, 2019). There is high irrigation potential in the MRB yet the demand has not yet been met and therefore a need to increase access to water for irrigation in the entire transboundary region especially the ASAL region. County governments in the basin (see e.g. major Bomet irrigation schemes, Table 4.9) have in their strategic plans earmarked various irrigation lands though most of them are not yet developed due to low access to water for irrigation, lack of required irrigation skills, poor drainage systems, and financial challenges etc.

Table 4.9: Major irrigation schemes in Bomet County, MRB

Irrigation scheme	land size (Ha)	Comment
Kaboson	250	Planning stage
Nogirwet	81	Under irrigation
Chebara	73	Under irrigation

Source: Adapted from (Bomet CIDP, 2018)
*There are other undocumented micro irrigation activities in the basin.
*There is a target increasing the irrigation acreage to 1200 Ha by the year 2022.
*Irrigation infrastructure is still a challenge e.g. drip kits, pipes and fittings etc.

Narok region has eight irrigation schemes for wheat, barley, maize, beans, Irish potatoes and horticultural crops (Narok CIDP, 2013).

4.10 Findings and Impact on the Materials and Methods

The models employed by this study, namely, the second OECD water governance principle (P2) (OECD, 2015), the innovative water governance and the "*Seven Sins in Local Water Management*" (Figure 4.11).(Rudolph et al., 2020) have been instrumental in the realization of the set objectives. The two drivers of IWRM e.g. the (i) micro-water-governance and (ii) water reuse – as investigated by this work –, have been researched on and resulted to some important developments as explained in the subsequent chapters. The route to the realization of the objectives has been both quantitative (statistical e.g. QGIS, and SPSS etc.) and qualitative (e.g. interviews, observations, focus groups discussions etc.) analyses of different cases and subjects within the study areas. The different cases and subjects included, the water resources users associations (WRUAs), the Maasai Mara wildlife conservancies association (MMWCA), the local community and other water management activities within the river basins.

Therefore, the findings of this work – based on the aforementioned objectives – are distributed in different chapters for a better understanding. For example, chapter 5 illustrates the roadmap towards the development of an interactive umbrella scheme of water governance and its performance monitoring criterion coined as the 5-stars of a good water governance, and chapter 8 demonstrates the procedures followed to develop a water reuse plan, hereby referred to as the integrated treated effluent allocation plan (TEA-Plan) and its related components, etc.

Chapter 5

The Micro-Water-Governance

5.1 Chapter Overview

This chapter expounds on the micro-water-governance especially the micro-based strategies (e.g. WRUA Development Cycle and Sub-Catchment Management Plan) and the crucial and indivisible role played by the youth and women in the water governance. The chapter further recommends a comprehensive sub-catchment sustainable management and development, incentive-driven water service performance, and the enhancement of the communication channels. Finally, an interactive umbrella scheme of water governance (iUWG) and a water governance evaluation criterion coined as the 5-Stars of a good water governance are developed and explained.

5.2 Introduction to the Micro-Water-Governance

The micro-water-governance entails small-scale interventions in a given sub-basin or zones through putting the local stakeholders at the center-stage of all the operations related to water resources management and development. This should be done through customization of all relevant policies and regulation framework to reflect the actual scenario(s) in the grassroots as well as actively engaging all micro-water governance units such as, water resources users' associations, wildlife conservancies, farmers, pastoralists, business community, women and youth initiatives, learning institutions, minorities and the general indigenous communities, etc. The micro-water-governance is a manageable chunk that should first be verified and exploited on the local level development before getting to macro-water-governance in the regional, national and international levels. Engaging the actors at the micro-units guarantees high level – if not full ownership and appreciation – of the available water resources and eco-services as well as "jealously" guarding aforementioned services from any source of degradation.

Unfortunately, this study established that the interaction between water services providers and water consumers in Mara basin is 56% poor (Figure 5.1).

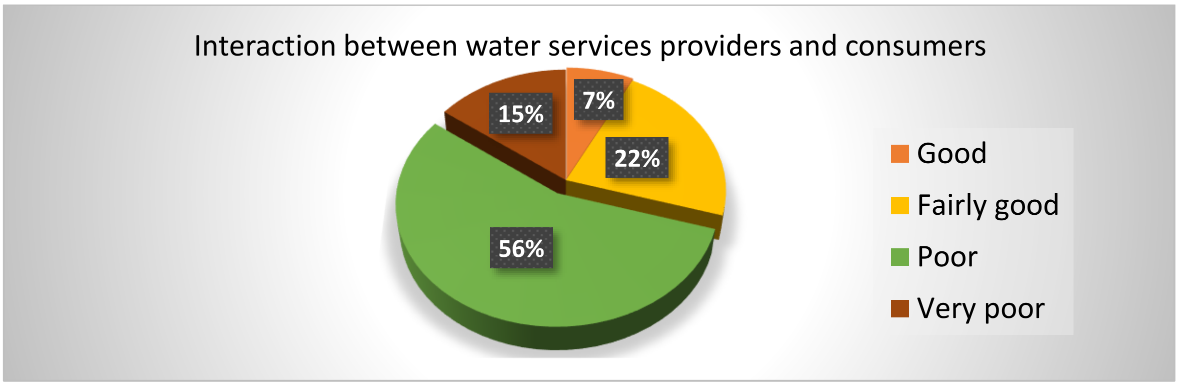

Figure 5.1: Interaction between water services providers and water consumers in MRB

A poor interaction between county water services providers (CWSP) and the water users is fueled by lack of complaints implementation by the former among other relevant authorities (Figure 8.16). The general basic human water rights in the basin, namely, availability, accessibility, adequacy, safety, and affordability are for example "*partially observed*" (48%) and "*lowly achieved*" (41%) respectively (Figure 5.2). Around 3% of the stakeholders do not see any achievement in the fulfillment of the general basic human water rights.

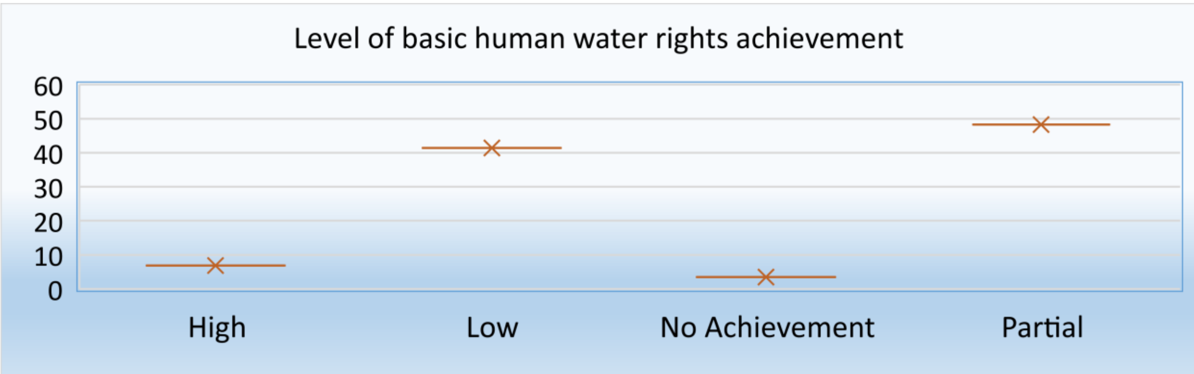

Figure 5.2: Fulfillment of the general basic human water rights

Some WRUAs such as Nyangores in collaboration with Water Resources Authority and other well-wishers are currently trying to engage the community through livelihood enhancement and water points (e.g. springs, water pans etc.) rehabilitation and protection exercises. The response from the community and other stakeholders is low due to minimal community sensitization. Additionally, a section of the community wants quick livelihood booster but most of the concrete benefits especially in matters economic activities can only be realized in mid-term or long-term basis. Generally, capacity building and community sensitization has poorly been done in the basin (Figure 5.3). On the other hand, there is at least 32% of the local stakeholders that have participated in the capacity building exercise. The community participation shows a positive trend although faced with a lot of delays, political and corruption issues.

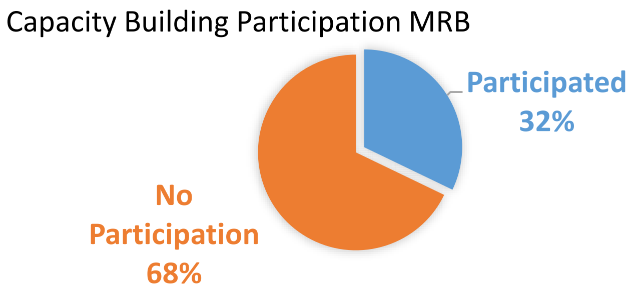

Figure 5.3: Capacity building on water governance

Active participation of all actors in the entire exercise of water governance is a prerequisite for the enhancement of the level of satisfaction. Both participation and satisfaction levels of the services rendered to the local stakeholders in the basin is low (Figure 5.4).

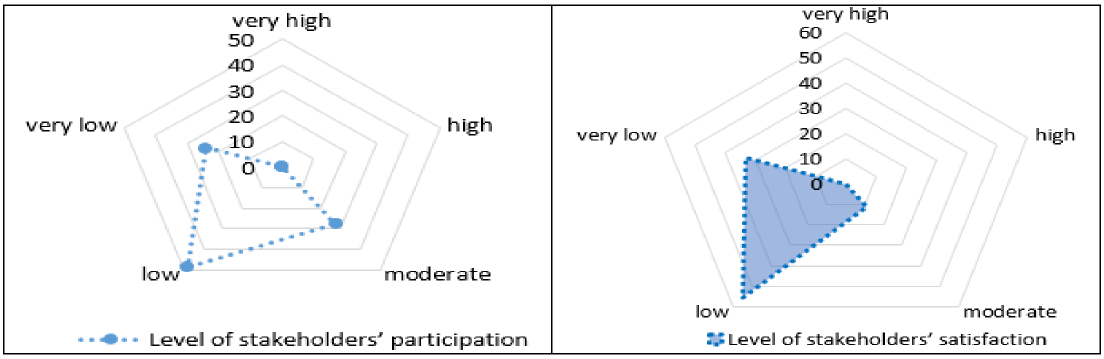

Figure 5.4: The level of stakeholders' participation and satisfaction

A direct proportionality between the stakeholders' participation and satisfaction has been clearly demonstrated by the response obtained from the case study areas. The participation in various activities, initiatives or even in the decision making platforms motivates the local community and other stakeholders to continue cooperating in the water and wastewater management and development as well as the water governance in general.

5.3 Micro-Based Strategic Plans

There are several micro based strategic plans that are in place to spearhead Mara River Basin management, development of resources and protection at large. This study explored, WRUA - Development Cycle (WDC) and Sub-Catchment Management Plan (SCMP).

5.3.1 WRUA Development Cycle (WDC)

This is a catchment based plan meant to improve stakeholders' participation and investment in the management of the water resources, as well as provision of technical and financial support. Therefore, WDC compliments other sources of funding for community based activities in water resource management (Water Sector Trust Fund, 2009). Attempts to implement WDC through WRUAs formulation and empowerment has faced a lot of challenges, mainly due to lack of realization of the promised funding to the WRUAs as well as complex bureaucratic process in the acquisition of the aforementioned financial support. As such, many local stakeholders have since withdrawn their active participation from WRUAs. This withdrawal of the community participation has led to a transfer of the same negative propensity in the subsequent water governance initiatives. The original or previous "sin(s)" committed by the stakeholders in the upper segments of the water governance spectrum (*see* Figure 5.6) have continuously made the community to find it difficult to trust any water governance ideas or initiatives brought to them by the same authorities.

Finally, WDC contains the technical arrangement for the development and operationalization of the Sub-Catchment Management Plan (SCMP).

5.3.2 Sub-Catchment Management Plan (SCMP)

The SCMP involves description of the water resource management challenges within a sub-basin and a set of prioritized activities aimed at finding the solutions to the challenges (Water Sector Trust Fund, 2009). SCMP is an ongoing action plan that is specific to the WRUA that developed it and encourages WRUAs coverage area of between 100-250km². The reduction of the coverage area is meant to facilitate good services to the people in the grassroots through thorough identification of challenges, mapping of water resources and establishing sustainable course of action.

The policy direction for the development of SCMP is given by the Water Policy of 1999 and the Water Act 2002. Both have been reviewed as contained in Water Policy and Water Bill of 2012 and 2014 respectively (Nyangores SCMP, 2019). There are continuous efforts by water resources authority (WRA) as well as all Mara WRUAs management team (whose main office is in Mulot town) to sensitize the community on the active engagement on the basin's water resources protection. All residents of the basin are by default members of these WRUAs due to the fact that they use water resources within the basin. Despite this, very few residents are active or even know that WRUAs exist. Many WRUAs are at infant stage of their formation and have not developed their SCMPs. This study received and analyzed three SCMPs from Nyangores, Amala and Talek WRUAs for the period between 2019-2023, 2011-2016 and 2019-2023 respectively. It should be noted that while the SCMPs for Nyangores and Talek are up-to-date, the Amala SCMP is long overdue. Sub-catchment Management Plans are undoubtedly strong action plans but the rate of their implementation and revision are hampered by the poor community sensitization, lack of financial support, policy incoherence, political interference and corruption among other issues.

Other strategic plans in place include; the Kenya National Water Resources Management Strategy (NWRMS) and Catchment Management Strategy (CMS) which covers the national and regional levels respectively.

5.4 The Indivisible Role of Youth in the Good Water Governance

The youth is a very crucial segment of the stakeholders. They perform an undisputable role especially towards realizing good water governance as they are a symbol or an avenue to the future generations. This important role stamps the need for sustainable development. Engaging the youth actively is a score towards realizing not only the sustainable development goals (SDGs) but also other local and international water resources management and development visions. Many countries especially in sub-Saharan region are dominated by the youth population. A youth is a person between the age of 15 to 24 (United Nations, 1981) and up to the age of 35 (Constitution of Kenya, 2010). Kenya is composed of more than 75% of individuals below the age of 35 (Kenya National Bureau of Statistics, 2019b). This translates to slightly above 35 million youth in a country of 47 million people by the year 2019.

The Mara basin has hundreds of learning institutions (from primary schools to colleges) where relevant youth and children sensitization programs could be established. Unfortunately, this study established that many young people are not aware of any water governance activities going on around them. This means that they do not belong to the existing good water governance interventions in their region either by choice or being neglected or seen as less important. Most of them showed interest of joining water governance initiatives but lamented of their joblessness situation. This therefore calls for livelihood enhancement programs to motivate more youth to join the water governance initiatives.

5.5 The Women and the Good Water Governance

The role played by women is very important as they are central according to the Dublin Principle 3 (Water and Environment, 1992). This principle further demonstrates that women play the role of provision and management of water to their families. On the focus on women, (Global Water Partnership, 2003) observed that when women participate in water management, the projects often performs better, there is less wastage of water, the environment stays cleaner and there is a positive impact on women and children and yet in many societies women seldom play an active role in the processes of planning, developing and managing water resources.

Traditionally, many men in Mara basin still believe that provision and management of water is the work of women. Women being core in the provision and management exercise, doesn't exclude men from actively supporting their women; the Dublin Principle 3 did not whatsoever exclude men or downplayed their expected participation in the water resources management. Men especially those with women around appeared to have less information about water issues (e.g. the source, amount consumed, quality of water etc.). Additionally, women are culturally widely denied chances to attend public meetings and consultations. This study confirms that women in this region still fear talking in front of men in gatherings as it is largely seen as disrespecting their men. In order to address these challenges, WRUAs in the basin have attempted to elect women representatives in the leadership, although their scarcity in the active management level was noted.

Women and youth should therefore be (i) consulted during water policy formulation, implementation and operation and maintenance stages. Men should be encouraged to actively support women in the water resources management and development, (ii) empowered through relevant education and/or trainings, (iii) elected as community representatives in various key decision making platforms, and (iv) cushioned from negative cultural beliefs that intimidates or violates their basic human rights.

There is a divided opinion on who is in charge of water governance (Figure 5.5). Most of the respondents believe that water governance is the responsibility of either national (28%) or county governments (23%) respectively. Unfortunately, 17% of the local stakeholders have no idea as to who is in charge of water governance.

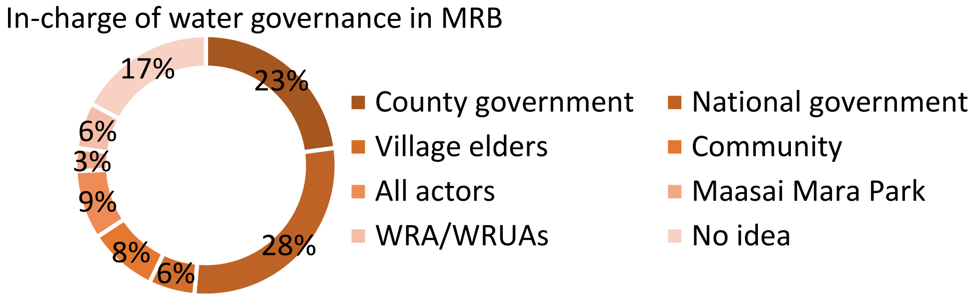

Figure 5.5: In-charge of water governance

Water governance should be a collective responsibility. However, this is currently not the case. A large number of stakeholders do not know that they are part and parcel of this noble task. Only 9% of the respondents recognizes that water governance is an “all actors” mission. Water governance in Kenya has for so long been almost a “one-man show” operation. Worse enough is the fact that those who seem to be concerned do not have proper information on how to enhance a good water governance especially at the micro-governance level. Water governance is not a “burden” of the few stakeholders but the entire spectrum of stakeholders, namely, those who are connected to the water and wastewater management directly or indirectly, vertical and horizontal actors, “major” and “minor”, in- and trans basin as well as local, regional, national and international stakeholders. A multisectoral approach is paramount towards a working water governance.

A good water governance is a super dynamic system that is bound to fail or stall if real-time monitoring and actual synchronization of its dynamism is not observed. Lack of policy-synergies among relevant stakeholders has resulted to a chaotic or disorderly implementation of water governance. A case in point is the poor management of solid and liquid waste disposed-off haphazardly and the subsequent piling up in the major towns of Mara river basin. Various enforcers of the established laws and regulations such as National Environment and Management Authority (NEMA), and Policing Unit appear to be reading from different scripts. This has led to a blame game towards apprehending the polluters. Additionally, cases of bribery have been reported by various respondents in this study.

5.6 Comprehensive Sub-Catchment Sustainable Management and Development

Development of natural resources is inseparable from the resources management. A good water governance will be realized by synchronizing the development and management policies. This could be achieved through, (i) mapping of all natural resources and model or establish their finite probability. All natural resources are intertwined and management of water resources without managing the other resources such as vegetation cover, land, minerals, natural gas etc. is a futile exercise, (ii) establishing the water and related natural resources demand dynamics, (iii) capacity building to all stakeholders including the local and vulnerable actors, (iv) developing a real-time database that is interactive and accessible to all actors, (v) real-time monitoring systems of the natural resources, (vi) actualized environmental and social impact assessment (ESIA), (vii) modern and eco-friendly water infrastructural designs and constructions, and (viii) synchronized operation and maintenance (O&M) measures. A comprehensive sub-catchment sustainable management and development will directly enhance smooth operations in water services and asset development.

Politics as in many other regions in the world dominate in the governance decision making process. A stakeholders' analysis in Nyangores WRUA shows that water services providers and county government have shown little or no efforts towards water resources management (Nyangores SCMP, 2019). This is a big hindrance in the efforts of realizing an integrated water resources management. A working water governance and a good relationship between water resources management and services providers are inseparable and must work in harmony. The linkages between various stakeholders is feeble and they have more often than not conflicting interests. A working collaboration between water resources managers and water services providers as well as all the other relevant stakeholders is therefore inevitable. This is in line with Dublin principle 2 which states that water development and management be based on a participatory approach, involving users, planners and policy makers at all levels (Solanes and Gonzalez-Villarreal, 1999). The local stakeholders largely feel detached from water development and management programs within the region.

5.7 Incentive-Driven Water Service Performance

Incentives should be granted to local, technical and operational water management stakeholders. This is a drive towards performance stimulation and enhancement of satisfaction. This can be achieved through a positive livelihood sustainability (income generating initiatives) of the local stakeholders not only in terms of water demand but other economic aspects as well. This is pivotal in curbing cases of negative livelihood activities such as deforestation, and encroachment on the riparian land as witnessed in the Mara river basin from farmers, sand harvesters and other investors trying to augment their production. Securing funds and other support is delayed in this region because of the long bureaucratic process that wastes a lot of time and thereby enhancing corruption. This has delayed development and denied the local stakeholders the support and services they need for their livelihood. Resource mobilization exercise should not entirely be left to the WRUAs as this weakens the stimulus towards a good water governance. Abject poverty (currently around 80% in the Mara basin) among local stakeholders hinders them from participating actively on the water governance efforts.

5.8 Communication Channels and the Good Water Governance

Lack of proper communication and complaints implementation channels is still a challenge to the design and implementation of a working water governance (see Figure 8.16). There is no water governance without proper communication of relevant stakeholders and constant deliberation of the issues affecting the local actors. This can be achieved through establishing digital platforms where real time information could be relayed to all stakeholders for immediate action or response. An attempt by the national and international stakeholders to formulate and implement water governance policies without consulting local stakeholder is like a government without a watchdog. Local stakeholders are watchdogs for the success of water governance and other related initiatives in the grassroots. An active collaboration between local, regional, national and international stakeholders has performed so poorly in the region.

The analysis of the case study has been the cornerstone in the development of the iUWG and the 5-Stars of a good water governance. It should be noted that the concept of water governance, as is the case for governance in general, is still evolving (Tortajada, 2010).

5.9 The Interactive Umbrella Scheme of Water Governance

The development of the interactive umbrella scheme of water governance (iUWG) has gone through four main stages, namely, (i) hypothetical stage, (ii) facts-finding stage, (iii) processing and analysis stage, and (iv) display or presentation stage. Hypothetical stage involved the supposition that water governance can work as currently constituted in the two case study areas but the facts-finding stage overturned this assumption. Therefore, some facts that have necessitated a need to develop the interactive model include the visible lapses and gaps in the manner in which policy framework is structured, the subsequent implementation and evaluation measures in place, as well as stakeholders' participation and the ultimate satisfaction. The augmentation of the policies and collaboration among players is an outright booster on the synergism in the water governance. The processing and analysis of the data has been done mainly using SPSS and the spreadsheets.

Therefore, a water governance model based on the open umbrella scheme has been developed (Figure 5.6). The model mimics snowball that develops from small to a big structural and complex network. Just like the umbrella is operated from the bottom – through the opening and closing the button (spring) as well as holding firm the handle for the stability, - so should the good water governance. This model is a simple, yet an all-inclusive demonstration of a bottom-up and inside-out approach.

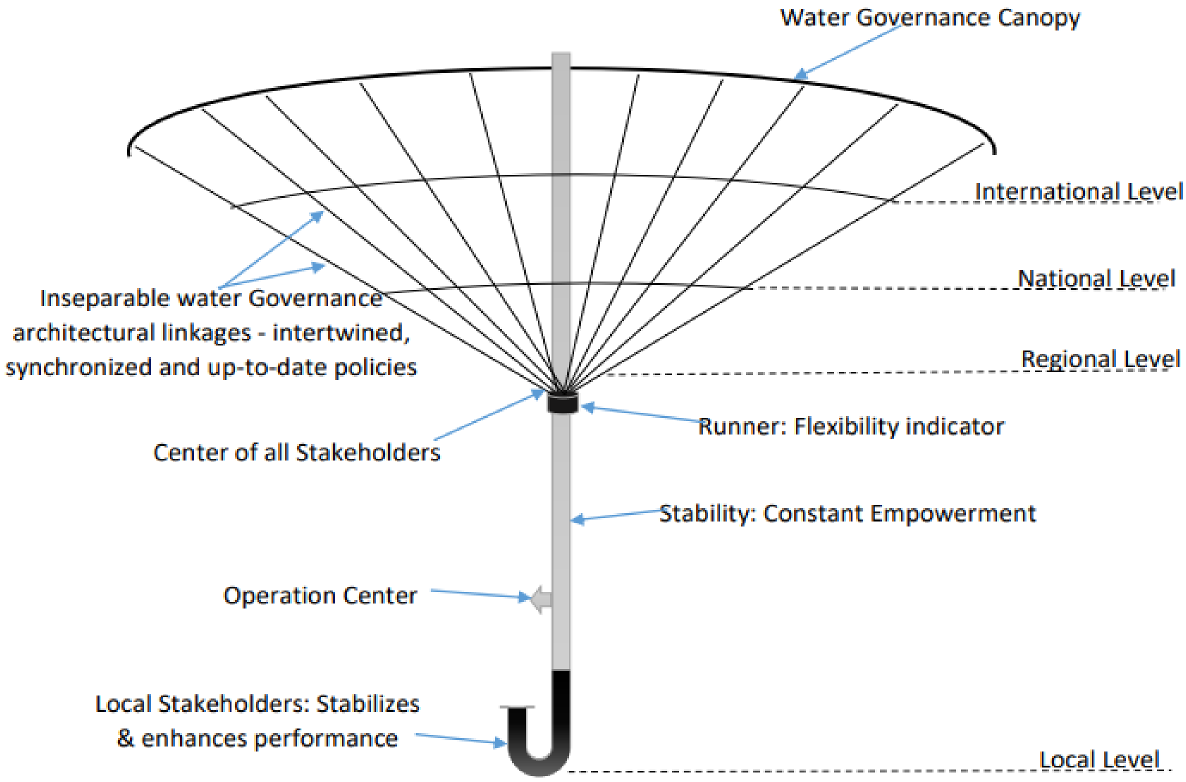

Figure 5.6: The interactive umbrella scheme of water governance

The stakeholders at the local level holds firm the umbrella handle (or at least are expected to do so) hence stabilizing and enhancing its performance. As the functioning of the runner of the umbrella is at the control level, so is the water governance whose stability or collapsing would be determined largely by the local stakeholders. The largest and the most important segment of the water governance lies squarely at the local level. The local segment of this scheme forms the central position where all stakeholders should constantly operate from, represented in this case by the merging of all the stretchers of the umbrella. Linking all the regulations and operations of the water governance to the operation center (which is in the local level), boosts the stability of the canopy through the stretchers (the inseparable water governance linkages among the stakeholders). If the national and regional segments of the water governance exclude the local stakeholders from active participation, a disconnect will be inevitable. The emerged disconnect among actors will lead to the collapsing of the canopy (the water governance shield) and its functionality. Therefore, the role played by the canopy in this case will be compromised.

Having the operation center in the grassroots (i) enhances proximity to the water and other natural resources, (ii) ensures that actors are close to or interact with the real issues affecting the success of the water governance, (iii) provides an opportunity of interaction between regulators and operators as well as strengthening their working relationship, (iv) increases the possibilities of identification and appreciation of talents, tastes and preferences, (v) facilitates timely and constant youth and women empowerment (e.g. through trainings, capacity building etc.) in the region of interest, and (vi) it maximizes conflict resolution mechanism through a well-informed-based approach.

The operations of the grassroots actors therefore should be shielded from above using the umbrella's canopy by the regional, national and international stakeholders. This can be achieved through actively engaging the local level stakeholders including minority and vulnerable groups in the decision making process as well as implementation. The opinion of the minority and vulnerable stakeholders in the water governance implementation can never be wished away. The relationship between the entire spectrum of stakeholders is therefore symbiotic in the proposed model of water governance. The practical functioning of the water governance should strongly grow from micro-governance realms to the higher levels. The strings or umbrella stretchers would then represent the inseparable architectural linkage that exists or should exist between all stakeholders. As such, the water governing policies and regulations as well as information flow should be intertwined, synchronized and up-to-date to minimize discordance and enhance proper functionality. This calls for the formulation of a critical and balanced analysis of legislation, regulatory frameworks and public policies for water resources management and provision for the related public services. The shaft of the umbrella model should provide the needed stability of the good water governance. The regulators should constantly empower the operators who directly experiences the actual challenges of water and environmental services at the micro level. The collapsible umbrella shaft which has two telescopic pieces would even demonstrate better the flexible link between the highest and local stakeholders.

An all-inclusive opinion and technological based water governance system should be devised and constantly be up-graded going forward. The regulation responsibilities should also be devolved such that the so called operators have a stake too. This model recognizes that, there are various aspects of regulations that can well be addressed when the operators and other grassroots stakeholders are actively engaged in a cyclopedic modus operandi. These aspects include, but not limited to, (i) identification of the water resources that may have not been mapped or accounted for through the water balance exercise, (ii) identification of the "ghost" water polluters and abstractors, (iii) enforcement of the current and up-coming water governance rules and regulations, (iv) addressing specific ethnic-cultural issues attached to the water resources and environment, and (v) riparian land ownership conflicts etc.

The model encourages both vertical and horizontal coordination and development. The links can spread as far as possible as long as their roots are strictly engraved on the local level. There should not be a rift or large gaps between the stakeholders; be it vertically or horizontally. The model shows that water governance could be realized when the perceived lowest actors such as farmers, pastoralists, fishermen, business communities among other water users are given priority in the management and development of not only water but other natural resources too. It enables a clear focus on the pitfalls of the *status quo* course of action by making the new approach to remain synergetic and coherent. This is a roadmap to winning back the lost trust from local stakeholders as well as cultivating transparency, reliability and timely flow of crucial information that is affecting the water and other natural resources in the grassroots.

5.9.1 The 5-Stars of a Good Water Governance

There is need to have a performance evaluation criterion for the success of the water governance; both macro and micro-water governance. This research has coined a performance evaluation criterion named as the 5-stars of a good water governance (Figure 5.7). The 5-stars of a good water governance is geared towards interacting with the umbrella scheme of a good water governance to provide the needed evaluation formula. A 5-star water governance requires (1) an enormous inclusivity (integration) of the stakeholders vertically and horizontally with their tastes and preferences onboard. Community empowerment and sensitization through livelihood enhancement and capacity building are some of the prerequisites for the stakeholders' inclusivity, (2) practical and synchronized policies to curb incoherence, conflicts and delays on the water governance implementation. Synchronization is vital as tastes and preferences from the wide spectrum of stakeholders are without a doubt highly complex and diverse. Pahl-Wostl, 2015 builds on this by stating that goals for water policies should be distinct.

Synergism can be achieved when policies are crystal clear. This is a two-way traffic operation between stakeholders within a framework of strict consideration of the water and environmental services. This study encourages regular evaluation of the policies achievements and possible areas of improvement by involving all players, independent institutions and consultancy firms that will paint the real picture on the ground. This will enable preparedness and addressing the unforeseeable unique cases in the dynamic water governance structure. The 5-stars of water governance involves also (3) the localization and customization of strategic plans to enable detailed and all-encompassing action plans that focuses largely on the micro-governance domain, (4) constant systemic monitoring for early and timely detection and rectification of the emerging issues as well as the challenges. This will enable up-to-date innovative water resources information system for the basin with an actual information on water balance and quality issues etc. Real-time monitoring of the potential threats and methods of thwarting them must also include penalties to the polluters as well as improving or replacing systems that pose threat to the water resources and (5) innovative and technological investment should be enhanced in the micro-governance systems.

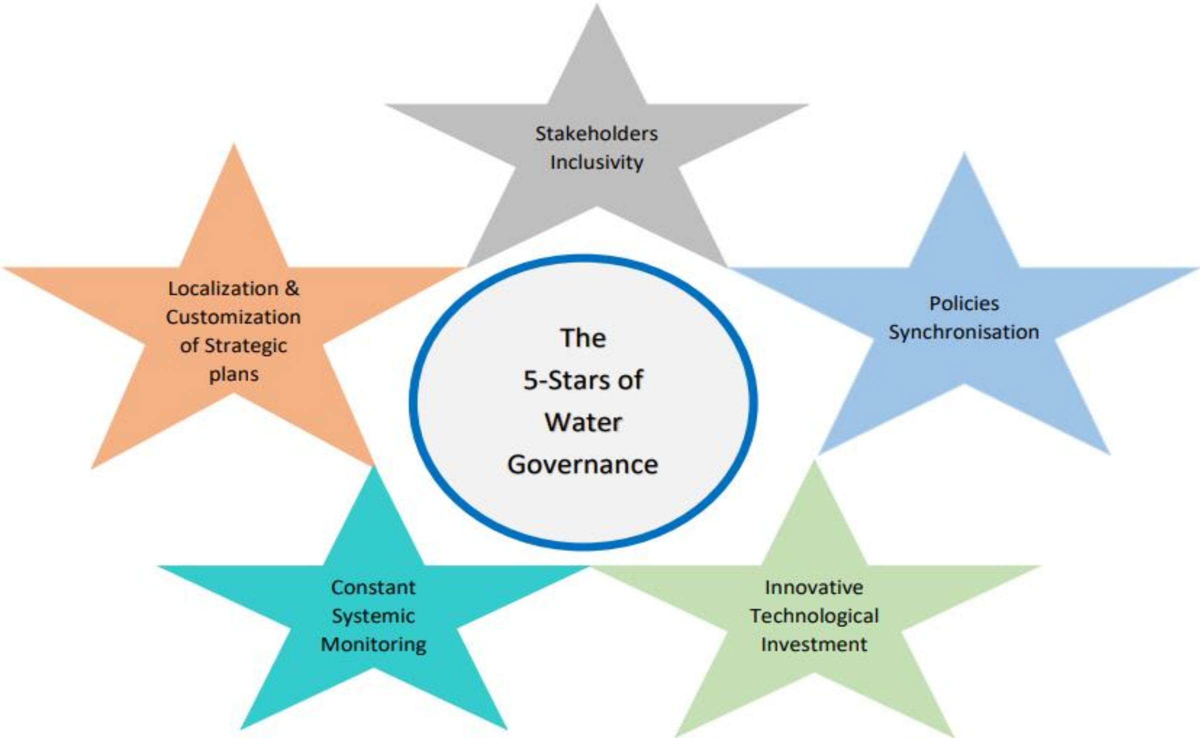

Figure 5.7: The 5-Stars of a good water governance - a performance evaluation criterion for the success of water governance

A good water governance system – that is functional – should be able to manage water quantity and quality to ensure sustainability in ecosystems, public health, food and energy security etc. – this should, additionally, provide rationales on whom and what purposes should there be water provision (OECD, 2018). Water governance is a management prototype of the entire spectrum of stakeholders' political, social and economic influence in their respective water basin and most importantly the sub-basin. Finally, the realization of a good water governance is pegged on a continuous synchronization of its building blocks, owing to its ability to mutate with time and space. However, the synchronization of strategic planning must not be mixed up with technological and financial facts and findings; the latter is not a matter of reconciliation or synchronization.

Chapter 6

The Role of the Local Stakeholders in the Water Reuse

6.1 Chapter Overview

This chapter demonstrates the role of local stakeholders in the water reuse and the necessity for public consultation and active engagement in the water management and related assets development initiatives; including formulation of the necessary policies.

6.2 The Vital Segment of the Local Actors in the Water Reuse

Local stakeholders hold a vital segment of the water governance especially at the micro-governance realm. The local level is the best-fit sphere of influence for the local stakeholders in the water governance. These grassroots stakeholders are the stronghold and custodians of the water resources and their grievances should be addressed or incorporated in any action plans locally, regionally and beyond.

Wastewater and excreta reuse is not an exception in the efforts of engaging the local actors. In fact, more engagement – through community sensitization etc. – is inevitable as significant number of local stakeholders (especially illiterate and semi-illiterate) are hesitant to appreciate the diverse values that could be extracted from wastewater and excreta.

The successful implementation of any reuse projects are anchored on public acceptance (Po et al., 2003). While we have the technology to produce whatever quality is required or for every consumptive use (Shelef, 1991; Law, 2003), we do have to ensure that all regulators, water professionals and the community at large accept planned water reuse as a viable way of augmenting our dwindling fresh water supplies - this is the ultimate challenge (Law, 2003). The value of water reuse is weighed within a context of larger public issues as water reuse implementation continues to be influenced by diverse factors such as opportunity and necessity (Metcalf et al., 2007). The negative public view of the treated wastewater is the major stumbling block in the water reuse initiatives (Po et al., 2003; Marks, 2006; Friedler et al., 2006) and is a social risk that may lead to a distrust of water reuse practices in some countries (IEEP. et al., 2016).

There are several issues that delays the community acceptance of wastewater and excreta reuse, namely, (i) socio-cultural stumbling blocks (e.g. traditionally, wastewater and excreta handling and reuse is seen by a section of the community as taboo and filthy exercise). Some communities view it as an embarrassing topic of discussion that wastewater and excreta could be reused and there are difficulties therefore finding volunteers who could create relevant awareness., (ii) Lack of capacity building (this would be the best opportunity to create awareness on the importance of wastewater and excreta reuse etc.), (iii) Poor public consultation and participation. This challenge could be addressed by engaging the community and the other local stakeholders in decision making platforms. The local stakeholders could further be engaged through offering them some relevant key leadership positions, and employing the jobless youth and women in various initiatives., (iv) there are those who view water reuse as a sign of poverty and only meant for the poor people who cannot afford constant freshwater for all their needs. Efforts must be made to educate the people with such school of thought that water reuse is not a sign of poverty but a show of wealth in terms of resources that could be extracted from wastewater and excreta. Additionally, (Po et al., 2003) summarized different factors in literature that may influence the behavioral acceptability of a reuse scheme to the general community (Figure 6.1). An investment in greater community awareness will encourage them to judge water by its quality and not by its history (Vigneswaran and Sundaravadivel, 2004).

i. Disgust or “Yuck” factor
ii. Perceptions of risk associated with using recycled water
iii. The specific uses of recycled water
iv. The sources of water to be recycled
v. The issue of choice
vi. Trust and knowledge
vii. Attitudes toward the environment
viii. Environmental justice issues
ix. The cost of recycled water
x. Socio-demographic factors

Figure 6.1: Factors that may influence the general community behavioral acceptability of a reuse scheme
Source: Adapted from (Po et al., 2003) – supported by CSIRO Land and Water

It must not be forgotten that people change their opinions and accept reuse water as soon as they have no choice or no affordable alternative(s).

6.2.1 Public Consultation

Public inclusion or participation initiatives work to identify key audiences and distinct community issues at a very early stage, offering information and opportunities for input in a clear, comprehensible way (US EPA, 2004). Effective public engagement begins at the earliest planning stage and lasts through implementation and beyond (US EPA, 2004). The public bears part or whole of the financial burden, experiences possible exposure to recycled water, and may experience aesthetic or other impacts from water recycling projects (Dimitriadis, 2005). Dimitriadis, 2005 (Figure 6.2) recommends some general principles for ensuring adequate public participation.

1. Transparency of decision making processes
2. Opportunities for involvement in all phases of project planning and development
3. Problems clearly defined—i.e. goals for improvement stated
4. Concerns and fears considered real and valid, noted and responded to appropriately (embracing potential conflict and opposition to schemes)
5. Social values and needs are incorporated into decision criteria
6. Alternatives are openly stated for comparison—choices are open
7. Accurate information and adequate research is made available
8. Projects justified by real needs
9. Environmental principles applied e.g. prevention of water pollution
10. Costs and benefits of projects are equitably shared

Figure 6.2: The general principles for ensuring adequate public participation
Source: Adapted from (Dimitriadis, 2005)

It is important to recognize that public acceptance of reuse projects is vital to the future of wastewater reclamation, recycling, and reuse; the consequences of poor public perception could jeopardize future projects involving the use of reclaimed wastewater (Asano and Levine, 1996). Active stakeholders' participation from planning level to the operation and maintenance (O&M) of the water reuse projects affects directly their level of satisfaction and therefore enhanced level of acceptance of such initiatives. However, it should be noted and emphasized that technological expertise cannot be substituted by the engagement of stakeholders, water users, NGOs etc., unless the needed technological expertise is drawn from the stakeholders themselves, which is possible. Engaging unskilled or non-professional stakeholders can even lead to a chaotic implementation or even failure of projects; This is one of the reasons for failure of some projects in regions like Africa, India and many other countries in the worldwide. Therefore, it would be noble to source the technological expertise locally if it is available but must strictly meet the required standards. Mara River Basin has achieved between very low to low levels of such kind of participation (see Figure 6.3). Active participation of all actors in the entire exercise of water governance is a prerequisite for the enhancement of the level of satisfaction and are inseparable, lest the decline in the latter will be imminent. Stakeholders participation is directly proportional to the satisfaction.

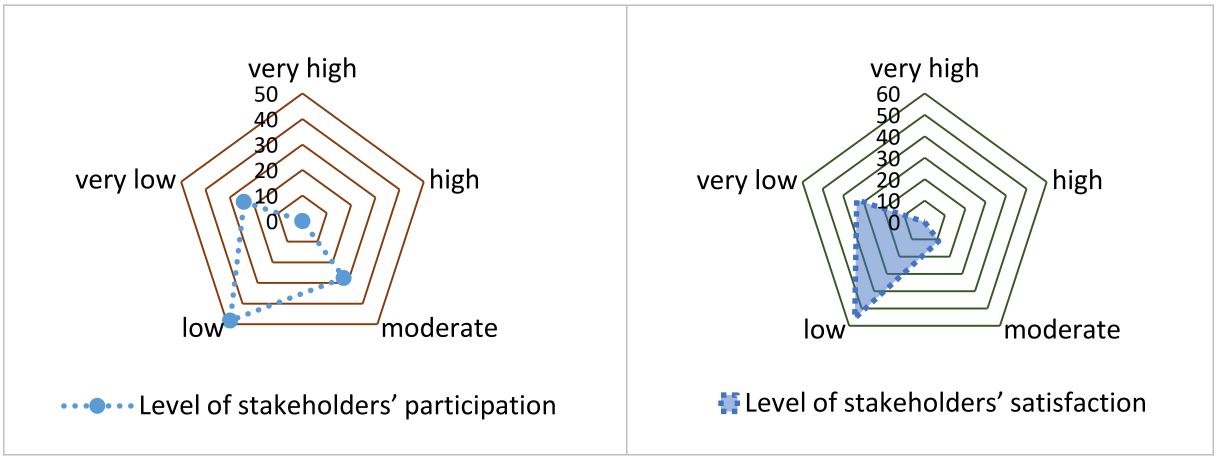

Figure 6.3: Direct proportionality of the stakeholders' participation and satisfaction in water resource management and development

As such, several conditions for a good water governance in Mara and Olifants basin have failed or are performing poorly. The conditions for good water governance identified by (Global Water Partnership, 2003) include inclusiveness, accountability, participation, transparency, predictability and responsiveness.

Chapter 7

Effects of Wastewater and Excreta to the Environment

7.1 Chapter Overview

This chapter takes a look at the effects of wastewater and excreta to the receiving water bodies and the environment at large. There are various destinations where disposed wastewater and excreta find its way to after a long or short propagation journey in a given river basin. The propagation journey advances through various sections e.g. point of generation, disposal point(s), and transit stage(s) etc. Disposal point(s) may be in the upstream, mid-stream and downstream etc. The disposal point(s) are sometimes different from the generation point; where fluid and/or solid waste is transported before disposal. During transit stage, raw or poorly treated wastewater carries with it pollutants and other contaminants that leave behind a trail of effects ranging from mild to deadly ones on the human beings, flora and fauna. These effects are often times felt in the different chambers of hydrogeological cycle or the water bodies (e.g. aquifers, rivers, boreholes/wells, water pans, dams, springs, and lakes etc.). Finally, the chapter explores on the aforementioned effects of wastewater and excreta mainly to the receiving water bodies and the aquatic life, and to the wildlife and the tourism sector in the main case study area.

7.2 Effects of Wastewater and Excreta to the Receiving Water Bodies

Raw, partially, and fully treated wastewater and excreta have different effects to the receiving water bodies ranging from detrimental to reasonably good depending on the treatment level. Most of the river basins in the world and especially in the developing countries have faced stress for many decades emanating from wastewater and excreta contamination.

Discharge of the sewage in the receiving water bodies mainly rivers, lakes, and reservoirs can lead to pollution by organic matter (dissolved oxygen consumption), contamination by pathogenic microorganisms (bacterial die-off), pollution of lakes and reservoirs (eutrophication, caused by nitrogen and phosphorus) etc. (Von Sperling, 2007). This study established that raw sewage from various sources in the basin have become menace to the health of the public and the environment (see for example Figure 7.1). Additionally, Mara basin experiences increased algal bloom and excessive vegetation (due to eutrophication) in the ever increasing stagnant water pools. Such water pools are seen in urban and peri-urban areas as well as areas with reduced flow velocities in the water channels.

Figure 7.1: Open raw sewage pool (top left), solid waste disposal and burning in the middle of Bomet town (top right), and open disposal site next to Nyangores river (bottom)

There are increasing volumes of solid and liquid waste in most of the open places and the rivers in this region. This is an indication of a failed solid and liquid waste management system. This has led to decline of fish and other freshwater aquatic indicators in Mara river and some of its tributaries. As contamination of the freshwater in this basin increases, more oxygen depletion is expected. Dissolved oxygen consumption occurs as a result of the processes of the stabilization of the organic matter undertaken by bacteria, which use the oxygen available in the liquid medium for their respiration (Von Sperling, 2007). Some of the sections of the tributaries and the main Mara river have reached the so called – according to (Von Sperling, 2007) – assimilative capacity and as such finds it difficult to undergo a complete self-purification process (Figure 7.2).

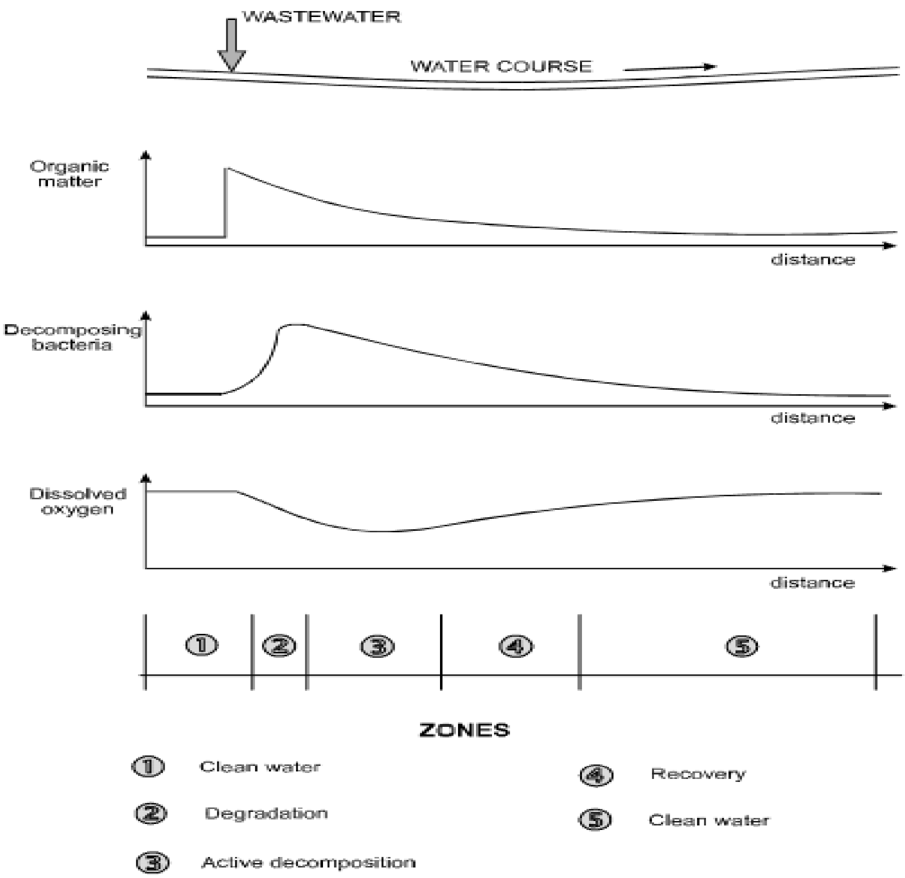

Figure 7.2: Self-Purification Zones
Source: (Von Sperling, 2007)

The assimilative capacity can be confirmed from the outbreak of waterborne diseases from direct consumption of the water obtained from some rivers in Mara basin, high levels of turbidity, suspended materials, extinction and introduction of new species of aquatic plants and animals etc. Eutrophication in this river basin is characterized by increased Nitrogen and Phosphorus, excessive and overgrown vegetation that keeps on encroaching the river banks, beds and the surface of the rivers. As a result, the excessive sediments generated from various anthropogenic activities (e.g. agriculture and overstocking etc.), finds it difficult to dissipate hence building up in areas with low flow velocities (e.g. river banks etc.), hydraulic structures (e.g. Bomet and Mara bridges, weirs, and reservoirs etc.), and swampy areas (e.g. Mara/Masurua Swamp in the downstream etc.) (see Figure 7.3).

Figure 7.3: Quarrying in the riparian land (left) and subsequent high sedimentation in the Nyangores river (next to the Bomet bridge) (right)
*Excessive sedimentation has led to reduced carrying capacity of the rivers, reduced flow, increased flooding, and displacement of the riparian communities etc.

Illegal water reuse – mostly untreated or partially treated – is spreading in urban and peri-urban areas of the transboundary Mara river basin mainly due to water shortage and droughts especially in arid and semi-arid regions e.g. Narok, Talek and some parts of Bomet. The dominant agricultural activity e.g. food crops as well as cash crops in some regions compels the local communities to illegally tap untreated or partially treated wastewater in order to irrigate their vegetables, and fruits etc. This is an indication that acceptance of the value embedded on the wastewater and excreta is growing among the public. There is urgent need to enlighten the public on the need to ensure that there is proper treatment before water reuse. As discussed earlier, pathogens from wastewater and excreta are the main threat to the health of the public in the world today. This is evident in the constant outbreak of various waterborne diseases in the MRB, namely, typhoid, cholera, and other diarrheal diseases. The escalating pollution has also been attributed mainly to the discharge of raw or partially treated wastewater into the rivers, groundwater and other receiving water bodies in the region.

7.3 Effects of Wastewater and Excreta to the Aquatic Life in MRB

Aquatic life in main tributaries of Mara basin have not been spared by the current wave of increased reckless solid and liquid waste disposal. It should be remembered that Mara is a world renown basin that harbours a number of aquatic large and small animals, fishes, insects and plants. (Pringle et al., 2020) (Table 7.1) found at least 473 native freshwater species and 10 threatened freshwater species in the Mara basin.

Table 7.1: Status of threatened freshwater biodiversity in Mara river basin

IUCN threatened category	Taxa	Species
Critically Endangered	Fishes	Ningu (*Labeo victorianus*) Singidia tilapia/ngege (*Oreochromis esculentus*) Victoria tilapia/mbiru (*Oreochromis variabilis*)
Endangered	Water birds	Grey-crowned crane (*Balearica regulorum*) Madagascar pond-heron (*Ardeola idae*)
	Fishes	Killifish species (*Nothobranchius sagittae*)
Vulnerable	Mammals	Hippopotamus (*Hippopotamus amphibus*)
	Water birds	Shoebill (*Balaeniceps rex*)
	Invertebrates	Crab species (*Potamanautes gerdalensis*) Freshwater mussel species (*Coelatura alluaudi*)
Total number of species assessed		370
Total number of threatened species		10
Percentage of species threatened		3%

Source: (Pringle et al., 2020)

7.4 Effects of Wastewater and Excreta to the wildlife and their habitation in Mara River Basin

There are millions of wild animals and birds in the two main wildlife reserves in the MRB, namely, Maasai Mara in Kenya and Serengeti in Tanzania. These two wildlife reserves are interconnected. Therefore, there is free migration of wild animals in these reserves e.g. wildebeests, zebras and antelopes etc. The disposal of solid and liquid waste without proper treatment threatens the rich worldly renown wildlife network and the entire ecosystem. Apart from contaminated water and environment, some wild animals and birds faces threat of death or extinction due to drying rivers and other water points as well as diminishing pastures, and widespread poaching etc. (Ogutu et al., 2016) reported extreme wildlife population declines in the Maasai Mara ecosystem and other wildlife systems in Kenya between (72–88%) for warthog (*Pharcoerus africanus*), lesser kudu (*Tragelaphus imbermbis*), Thomson's gazelle, eland (*Taurotragus oryx*), oryx (*Oryx gazelle beisa*), topi (*Damaliscus lunatus korrigum*), hartebeest (*Alcelaphus buselaphus*), impala (*Aepyceros melampus*), Grevy's zebra (*Equus grevyi*) and waterbuck (*Kobus ellipsiprymnus*); severe (60–70%) for wildebeest, giraffe (*Giraffa cemelopardalis*), gerenuk (*Litocranius walleri*) and Grant's gazelle (*Gazella granti*); and moderate (30–50%) for Burchell's zebra, buffalo (*Syncerus caffer*), elephant (*Loxodonta africana*) and ostrich (*Struthio camelus*). (Ottichilo et al., 2000, 2001) also observed the declining trend of more than 50% for the non-migratory wildlife herbivores in the Maasai Mara ecosystem and 81% decline of the resident wildebeest between 1977 and 1997, attributed to the rainfall fluctuations and possible competition between wildebeest and cattle.

7.5 Effects of Tourism activities to the Water Resources in Mara River Basin

Kenya experienced 3.7% growth in the number of tourists that visited its national parks and wildlife reserves and subsequent 3.9% growth in tourism earnings in 2019 (Kenya National Bureau of Statistics, 2020). While growing of the local tourism sector is a pride of every nation in the world, tourism activities may be having some negative effects to the water resources and the environment at large if not well regulated. This is true to the MRB especially Maasai Mara wildlife reserve due to the generation of both solid and liquid waste. These waste originate largely from hotels, camping centers and lodges that hosts hundreds of tourists every year especially during annual wildebeests' migration. This has negatively affected the water bodies through haphazard disposal of mostly raw or poorly treated wastewater and excreta. As a result, some regions have become less attractive to the tourists due to the building up of waste and of course a threat to the local community, wildlife, flora and fauna.

Various initiatives from the government and non-governmental organizations have attempted to address some of the challenges highlighted here. They include business community, farmers' associations, community based wildlife conservancies (*see details in Chapter 4*) under the auspices of Kenya Wildlife Conservancies Association, and other CBOs.

Chapter 8

Water Reuse Plan

8.1 Chapter Overview

This chapter explores widely on the water reuse plan, the principles and criteria for sharing water, and typical generation and propagation routes for wastewater and excreta. These forms the foundation of the integrated treated effluent allocation plan (TEA-Plan) with an inclusion of the analysis and the establishment of the TEA-Plan objectives. The Integrated TEA-Plan modelling framework further navigates through various essential and inescapable water reuse stages required to maximize the output and protect the health of the public and the environment. There are various key requirements of the TEA-Plan categorized into three main segments. These key requirements include, (i) the design stage (which involves measures to be taken before the commencement of wastewater allocation plan), (ii) the implementation stage (entails measures to be taken during the actual execution of the wastewater and excreta allocation plan), and (iii) the post allocation stage (that appertain to measures to be taken after the actual execution of the wastewater and excreta allocation plan). The final issue handles water reuse quality assurance, the costs and benefits of the water reuse, the possible TEA-Plan customization strategy in the micro-governance water level, as well as the contemporary and probable future challenges of Integrated TEA-Plan.

8.2 Principles and Criteria for Sharing Water

While acknowledging that there is no standard formula for the allocation of water amongst users, (Speed et al., 2013) divides considerations in sharing water into three main categories, namely, (i) proportionate division, (ii) existing use, and (iii) future use (Table 8.1).

To achieve equitable fresh water use and wastewater reuse allocation in the river basin or sub-basin, all stakeholders must be consulted and actively involved in the entire allocation process. This has not been the case in most regions in Kenya and most specifically the transboundary Mara river basin as well as its replica the Olifants river basin in South Africa. The aftermath of the community exclusion or partial engagement (e.g. due to nepotism, based on gender, tribe, and political affiliation etc.) has culminated to unpopular water allocation plans, divisive and in some cases have resulted to serious conflicts e.g. fights between Maasai and Kipsigis communities along Narok-Bomet border (cross border conflict) in Kenya over water resources. It is therefore difficult to address future water uses without meeting the current demand; the future is without a doubt compromised if the current water resources management and governance is weak or compromised.

Table 8.1: Principles and criteria for sharing water

	Consideration	Measure
	Proportionate division	
1	Equal division	Equal shares for each riparian state/province
2	Physical characteristics of the basin	Area, rainfall, length of river
3	Population	Population numbers in, or dependent on, the basin
	Existing use	
4	Historical or current use	Existing diversions or shares
5	Estimated demand	Water demand assessment, e.g. crop water needs
6	Efficiency of water use	Output per unit of water (physical or economic)
7	Social and economic dependency	Socio-economic reliance of the population on the waters of the basin
	Future use	
8	Growth projections	Regional and sectoral gross domestic product (GDP) growth estimates
9	Alignment with development planning	Development space, future development priorities, value added per unit of water

Source: (Speed et al., 2013)
*Political-will is key to a successful allocation plan.

A situation where some influential users "take-it-all" as far as water resources is concerned is rampant in the region. According to (Castro, 2007), the major drivers of water conflict are insecurity, injustice, and inequality. These three drivers of water conflict are evident in many regions especially Mara basin e.g. land issues in the Mau forest, conflict over pasture and water for thousands of livestock owned by Maasai and Kipsigis communities etc. Therefore, an elaborate roadmap should be put in place to resolve these challenges that are derailing the implementation of a good water governance.

There are various water allocation plans in Kenya prepared by various river basin commissions e.g. a Mara river basin-wide water allocation plan which was prepared by Lake Victoria Basin Commission, (LVBC) (Lake Victoria Basin Commission, 2013) and later improved in conjunction with Mau-Mara Serengeti (MaMaSe) sustainable water initiative (*http://www.mamase.org/*) and Water Resources Authority (WRA) in-charge of the region, *see details in* (Talek SCMP of 2019-2023). Most of these plans do not recognize wastewater as a valuable reusable resource and therefore fail to specifically define the allocation of the treated effluent. Various plans within the basin and sub-basins (e.g. strategic plans, action plans, and visions etc.) as well as policies and legislative framework (e.g. water acts, environmental management acts, etc.) should be integrated with the water reuse plans at river basins and sub-basin levels. The integration of policy framework, relevant acts of the parliament, strategic plans and water allocation plans will enhance efficiency, effectiveness, acceptance, harmony, and accountability. Currently, MRB and ORB have not clearly demonstrated coherent, coordinated, clear and up-to-date policies and legislations that govern water resources management and relevant asset development. Additionally, water governance strategic plans are not properly synchronized and not up-to-date (Figure 8.1). More than 55% of the respondents in the Mara basin agrees that water governance strategic plans are not working and are segregated. However, the synchronization of strategic planning must not be mixed up with technological and financial facts and findings; the latter is not a matter of reconciliation or synchronization.

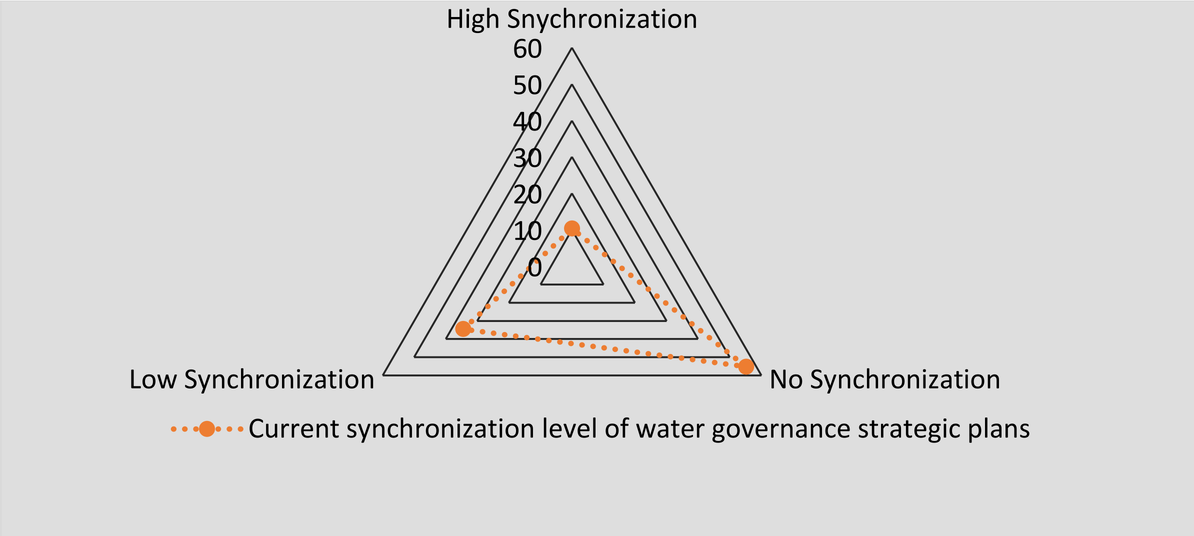

Figure 8.1: Current status of water governance strategic plans in the Mara river basin, Kenya

Integration further creates a platform where all stakeholders deliberate on the areas of improvement, projects funding, positive livelihood, solutions to existing conflicts, capacity building and empowerment of vulnerable and marginalized communities. It is through such collaborations that timely revision and establishment of synergies in various strategic plans (e.g. water governance and its respective constituents and building blocks) will be facilitated. Inter and intra-sectoral collaborations are fostered through integration of wastewater and excreta allocation plans with other relevant existing plans in the river basin. (Metcalf et al., 2007) emphasizes on the importance of placing water reuse within the broader context of water resources management.

8.3 Typical Generation and Propagation Wastewater and Excreta Routes

Both raw and treated wastewater and excreta – point and non-point sources – have typical propagation routes in the basin. The propagation routes are in most cases highly complex and sometimes undocumented. The wastewater pathways can be guided (e.g. using established open or closed conveyance systems) or unrestrained (e.g. haphazard free flow). The unrestrained flow of wastewater has increasingly become disastrous to the health of the public, and the environment. In Mara river basin, about 12% of the generated wastewater is captured by the sewerage systems but due to high cases of sewer bursts, only 10% of the wastewater finds its way into the wastewater treatment systems before disposal. Another 1.5% is reused onsite by farmers either as raw or partially treated. This means that more than 85% of the generated wastewater flows haphazardly in the basin. Therefore, the raw wastewater, partially treated and/or fully treated effluent is mostly discharged into the receiving water bodies in this basin without a follow up of its performance in the environment and to the riparian communities. Due to the water scarcity in the basin, various agricultural fields are in dire need of water for irrigation.

This study has attempted to simplify the complex wastewater and excreta propagation routes (Figure 8.2) from the source. The possible points of effluent reuse have been illustrated – though not necessarily the actual point of reuse in the basin. The model illustrates that wastewater and excreta is typically disposed-off into the receiving water bodies. The disposal leads to an escalation of the rate of contamination of water and a threat to the riparian community at the point of disposal and in the downstream. The wastewater propagation routes are normally linked in a cascading effect mode. The cascading effect of wastewater from the source to the disposal or reuse point could be positive or negative. This depends on the treatment measures and the establishment of water-tight conveyance and storage systems. In the absence of properly designed and operated conveyance and treatment systems, a negative trail of effects will be experienced along the entire propagation routes.

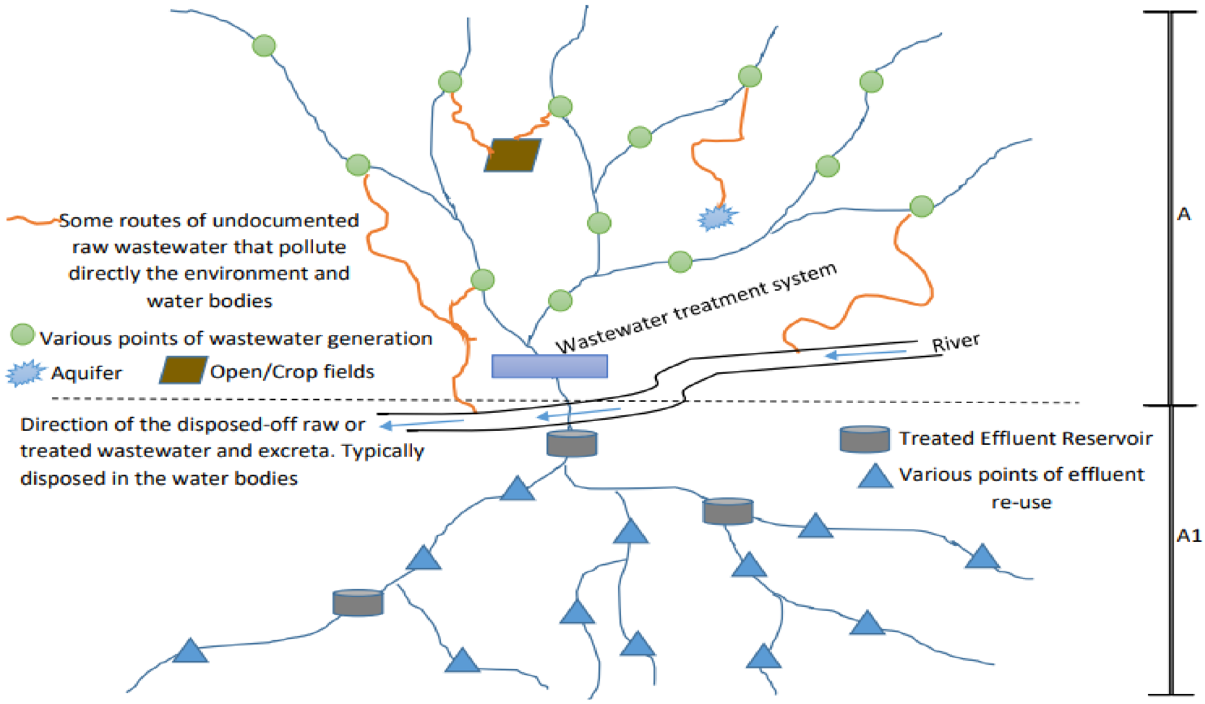

Figure 8.2: The typical generation and propagation wastewater and excreta routes

A1 in Figure 8.2 illustrates an inverted or reverse flow of the treated effluent to various reuse points within the basin from which the wastewater and excreta was generated – in a "giving back approach". Therefore, **A1** mirrors **A** as an indication that the treated effluent – according to various international and local quality guidelines – could be harnessed, reclaimed and reused in different fields, namely, irrigation, and aquaculture etc. within the basin of origin or in the neighboring river basins in surplus cases.

The negative cascading wastewater and excreta effect(s) could be cut or curbed through principally (i) comprehending the dynamics in the wastewater flow, (ii) understanding the pollutants embedded on the wastewater, (iii) employing the pre-treatment techniques, (iv) maximizing on the onsite reuse e.g. industrial reuse, and (v) enhancing the connectivity to the sewer network. In the absence of a well-established wastewater propagation pathways, it will be highly complex, expensive and time consuming to re-establish the lost track of the flow of the pollutants; especially when the pollutants get into the soil and in the ground water.

The cascading model on the wastewater and excreta propagation routes forms a backdrop in the development of an integrated treated effluent and excreta allocation plan. There is no an all-inclusive and a successful reuse plan in the absence of detailed information on the sources (point of generation) and propagation routes of wastewater and excreta as well as the final destination (disposal point or reuse). Understanding the wastewater and excreta propagation routes could be beneficial to other research activities, such as, surface water quality modelling, groundwater remediation plans, effects of the unregulated wastewater and excreta to the soil, crops, human beings, wildlife, aquatic plants and animals etc.

The IWRM approach in developing countries must be handled very differently from industrialized countries, where the design of wastewater plans is directly depending on the existing or planned sewerage system; The IWRM approach should be on a case by case basis, mainly due to the uniqueness of various regions.

8.4 Integrated Treated Effluent Allocation Plan (TEA-Plan)

Whilst commendable research has been done on the fresh water allocation plan, there is still a lot to be done on the water reuse plans. The effluent in the case study area is largely discharged-off into the receiving water bodies or reused without a clear plan. Lack of proper allocation of the reclaimed wastewater has led to the poor monitoring of its performance in the places of reuse (e.g. in the agricultural activities, etc.) or to the receiving water bodies and environment at large. The immense wealth embedded on the wastewater and excreta has been demonstrated by various researchers as well as this study. The effluent obtained from the upgraded wastewater ponds system (WPS) and other treatment works could be allocated to different irrigation schemes and fish farming within the region of interest. There should be an integrated treated effluent allocation plan (TEA-Plan) to achieve a water reuse plan.

TEA-Plan is a tool that has been developed in this study to augment and integrate with the existing water allocation plans to address the water stress and scarcity issue especially at sub-basin level. A well-established TEA-plan will contribute towards the reduction of fresh water abstractions for purposes that can otherwise be achieved using treated wastewater and excreta. TEA-Plan should also be incorporated into the catchment level water resources strategic plans. This should be followed by rolling out the TEA-Plan to several other regions. There should be strict protection measures to the vulnerable groups of people identified by (WHO, 1989) namely, (i) agricultural field workers and their families, (ii) crop handlers, (iii) consumers of crops, meat and milk etc., and (iv) those living near the fields concerned. Various public health guidelines established by various organizations e.g. (WHO, 2006; FAO, 2010; EPA, 2012 etc.) should be adopted with a clear emphasis on the local epidemiological and microbiological characteristics. Every wastewater treatment system should in its design include a TEA-Plan as well as a health performance follow-up to the receiving point(s) of reuse or the water bodies. This could be the roadmap to maximizing the extractable wealth from the wastewater as well as protecting the health of the public and the environment.

Stakeholders should be encouraged to reuse wastewater that do not necessarily require to undergo any treatment procedure to water flower gardens etc. Offsite wastewater treatment requires a well-established, water-tight network of sewer line to minimize unauthorized and uncontrolled discharge of wastewater to the environment. Inter-basin sharing of the reuse effluent should be encouraged in the event of excess supply in comparison to the demand within the catchment of effluent production.

8.4.1 Integrated TEA-Plan Modelling Framework

Practical implementation of an integrated TEA-Plan has a number of requirements which are categorized in three main sections, namely, technical framework, water treatment and reuse systems, and policy framework (Figure 8.3). Therefore, based on the three sections of the TEA-Plan modelling framework, the explicit components are the, (i) relevant infrastructure (e.g. conveyance network – could be closed or open channels, treatment works, effluent storage tanks, and irrigation systems etc.), (ii) treated effluent availability and reliability to augment the water demand, (iii) identification of the target group/reuse areas, (iv) capacity building to the handlers of the treated effluent and excreta and the subsequent end products (e.g. crops, fish etc.) in every stage, (v) adherence to the laid out public health guidelines, (vi) localization of relevant policies, and (vii) economic (Cost-Benefit) analysis. The three sections of the TEA-Plan modelling framework are synchronized through an intersectoral coordination. Therefore, an intersectoral approach that brings on board all vertical and horizontal stakeholders will facilitate timely formulation, actualization and implementation of the relevant policies and guidelines. However, the synchronization of strategic planning must not be mixed up with technological and financial facts and findings; the latter is not a matter of reconciliation or synchronization.

The availability of wastewater is with no doubt not a major problem – in fact it is becoming a menace with time – but how the wastewater is harnessed, reclaimed and reused. As long as water is consumed (especially for domestic purposes etc.), wastewater will be generated. Capacity building and community training should be encouraged in order to empower and create awareness on the ways of handling waste, right from the point of its generation including pre-treatment measures before releasing it to the sewer network. The stakeholders should also understand or at least be informed of the need for the operational treatment systems before channeling the treated effluent to the point of reuse or receiving water bodies. Most of the wastewater conveyance and treatment infrastructure especially in the case study area can be categorized as either under-designed, old (technologically, infrastructural), worn out, stalled projects and some are generally defunct. An investment in the infrastructure through upgrading the existing ones, integrating different treatment works with other systems, and incorporating a modern real-time monitoring system is recommended. Adherence to the relevant public health guidelines and policies is mandatory in order to enhance systems efficiency, reliability, accountability and safeguarding the health of the public and other consumers. The widely known international guidelines should be localized and synchronized as situations at micro-scales are so unique and mutate with time.

Integrated water resources management (IWRM) paradigm and the sustainable development goals (SDGs) forms the back-drop in the development of a successful integrated treated effluent allocation plan (TEA-Plan) and its modelling framework.

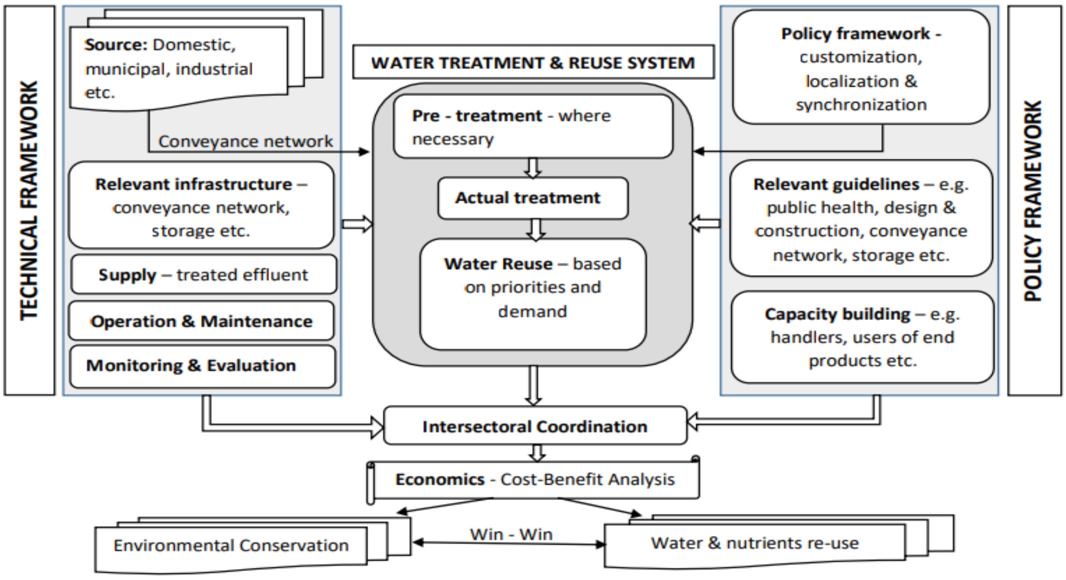

Figure 8.3: Integrated TEA-Plan modelling framework

Allocation of the reclaimed wastewater and excreta entails equitable apportionment to the demand areas such as agriculture and aquaculture etc. The equitable apportionment will foster the quest for food production among other relevant objectives, namely, environmental conservation and safeguarding the health of the public. It should be noted that this model is not limited to agricultural water reuse but could be applicable and be customized to other water reuse areas, such as, land irrigation, and industrial areas etc.

8.4.2 Objectives of the TEA-Plan

Water reuse has more or less the same objectives in various river basins. Nevertheless, there are some specific reuse aims that are only unique to a certain river basin or sub-basin. These objectives may further mutate with time due to various reasons, namely, water demand or the economic activities, fluctuations in the wastewater generation, food security, political will, etc. Clear objective(s) of the water reuse can best be established by the stakeholders in the specific region of interest through in-depth deliberations. Some of the objectives of water reuse are shown in Figure 8.4.

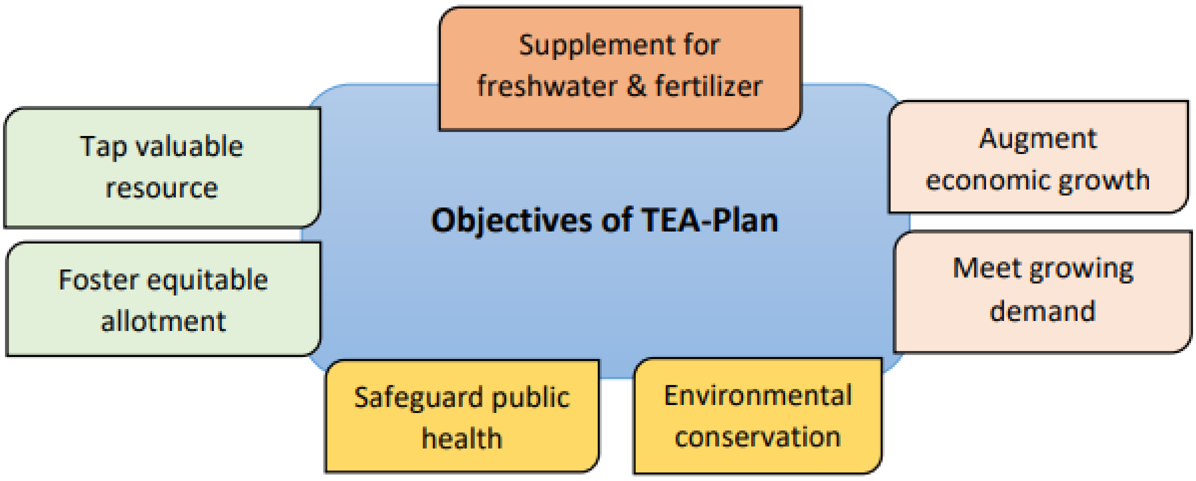

Figure 8.4: Objectives of the TEA-Plan

Capitalizing on the TEA-Plan – and ensuring that it remains strongly anchored to the other strategic plans in the river basin, but equally important – will enable public recognition of the diverse values linked to the wastewater and excreta, namely, (Figure 8.5) (i) physical aspect e.g. sludge, (ii) chemical aspect e.g. nutrients, (iii) biological aspect e.g. the useful microorganisms, and (iv) wet-value e.g. the reclaimed water. There are various microorganisms that thrive in this environment and they play important role in the soil structure. The enhancement of the soil structure also improves the soil water holding capacity, soil aeration and other relevant enrichments.

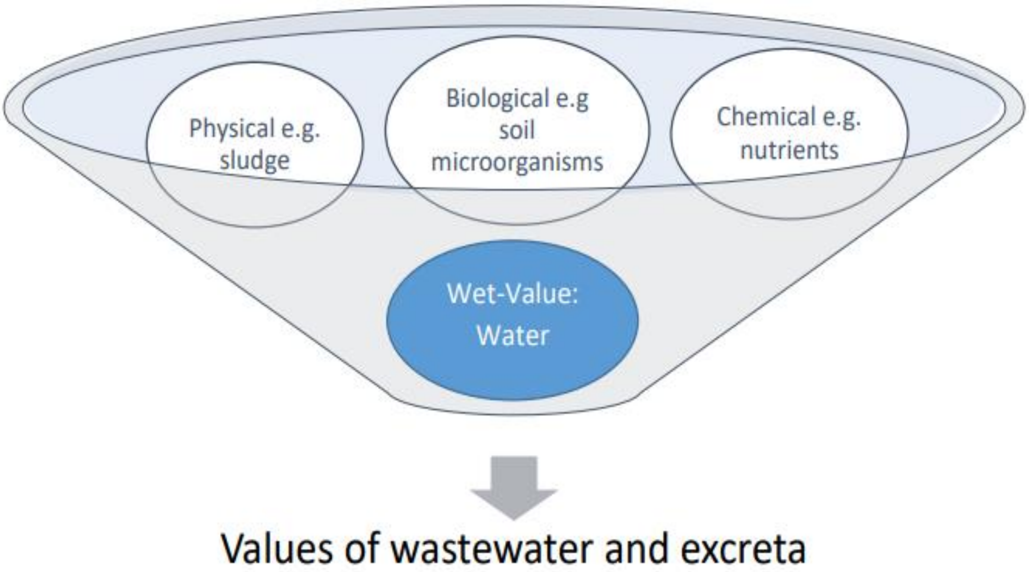

Figure 8.5: Major values of wastewater and excreta for the reuse purposes

The wet-value is the most important and targeted component of wastewater harnessing, treatment and reuse. The water (wet-value) is generally the most abundant value. The percentage of the other wastewater and excreta components (physical, biological and chemical values) varies greatly depending on the source. Additionally, the TEA-Plan emphasizes on wastewater and excreta reliability, and a commendable solution it provides so as to avert the haphazard disposal and flow of wastewater including in the two case study areas (Mara and Olifants). Therefore, getting the best out of the 4 aforementioned main values embedded on the wastewater and excreta is paramount. Recognition of diverse values from wastewater – specifically the augmentation offered on water for irrigation and crop enriching nutrients – will stimulate acceptance of water reuse programs by the local stakeholders. The stakeholders' motivation to support and participate in water reuse initiatives will be achieved through constant capacity building and community sensitization.

8.4.2a. Tapping the Re-Usable Elements of Wastewater and Excreta

A narrowed and special focus on a plan to extract and reuse the useful elements of wastewater and excreta will help popularize the TEA-Plan to the general public for acceptance. Several useful components of the wastewater and excreta that are necessary for irrigation, and crop nutrients have been established by various researchers (*see details in section 3.5.6 and 3.5.7 respectively*). Additionally, biogas as a source of renewable energy has also for many decades been obtained from wastewater and excreta.

8.4.2b. Water and Excreta Reuse as Supplement for Freshwater and Inorganic Fertilizer

Some researchers (e.g. Von Sperling, 2007 etc.) have reported that the largest volume of wastewater is dominated by water e.g. up to 99.9% in the domestic wastewater. Reclaimed and treated organic manure from the sludge obtained from wastewater and excreta provides not only crop nutrients but also a good environment for the growth of some useful soil micro-organisms that improves the soil structure.

8.4.2c. Enhancement of the Equitable Allotment of the Water Resources

Water allocation plans have experienced challenges of meeting the ever growing water demand as well as a myriad of other related uncertainties. In most cases, the water demand surges with the increasing water scarcity. This trend can significantly be regulated by the introduction of an integrated treated effluent reuse and equitable water allocation plan (TEA-Plan), linked to other initiatives that are there in the river basin. TEA-Plan will without a doubt help strike a balance between supply and demand of the water resources through enhancing the allotment plans in the river basin.

8.4.2d. Water and Excreta Reuse to Safeguard Health of the Public

The main focus of the wastewater and excreta reuse should be protection of the public health. Various respondents have experienced, directly or indirectly, a case of waterborne disease in their families and even deaths of especially children due to outbreak of Cholera, Typhoid, and Malaria etc. The often open free flow of raw sewage and disposal is so devastating in some sections – especially urban and peri-urban areas – in the case study areas. The menace of the haphazard flow of wastewater escalates during rainy season. This dire situation renders some places especially in the case study area impassable. The international and national set health guidelines e.g. epidemiological, and microbiological etc. must be fulfilled before subjecting treated effluent and excreta to any use; This is not negotiable.

8.4.2e. Water and Excreta Reuse to as an Augmentation of Economic Growth

Treated effluent and excreta reuse should be seen as a driver towards a positive livelihood economic growth by all stakeholders; including the local, marginalized and vulnerable groups. Constant campaigns on the wealth contained in the wastewater and excreta should be established starting from the grassroots in the river basin. An open and all-inclusive stakeholders' forum should be the source of decision making on the best use of the treated effluent and excreta. The interactive umbrella scheme of water governance (Figure 5.6) that fosters a bottom-up and inside-out approach demonstrates a formula to engage stakeholders during deliberations on the establishment of water reuse objective(s). This could be a certain crop that the community finds economically viable for their food production, or even cash crop. Mara river basin is characterized by both food and cash crops, namely, maize, wheat, vegetables, sweet and Irish potatoes, millet and sorghum, tea, and coffee.

8.4.2f. Water and Excreta Reuse as a Boost Towards Environmental Conservation

Most of the river basins in the world are under stress emanating from excessive flow of raw wastewater and excreta into the surface water, groundwater, and soil etc. The wastewater originates mostly from households, industries, and municipalities among other sources. An illustration on the wastewater propagation routes (Figure 8.2) clearly shows some destinations of the disposed of pollutants. An investment in the water reuse is a score towards safeguarding the integrity of the riparian community, wild animals (e.g. in Maasai Mara and Serengeti wildlife reserves in Mara basin), birds, plant species, agricultural soil, fresh air circulation, and freshwater resources etc.

8.4.2g. Water and Excreta Reuse to Meet the Growing Demand

Population growth, the changing lifestyle and climate change are some of the factors that leads to the increased demand for water, food, and energy. Therefore, the reuse of the treated effluent and excreta will come in handy to enhance the aforementioned demand. Constant monitoring and trend analysis as well as future projections will help in the planning and preparedness of the highly dynamic water demand in the river basin.

8.5 Requirements of the TEA-Plan

There are a couple of factors to consider before, during, and after the allocation of the treated effluent (Figure 8.7). It should be noted that wastewater and excreta reuse may not entirely solve the water scarcity issue but can at least improve the situation significantly especially on presenting to the respective stakeholders and planners a "worthy supplement" instead of discharging treated effluent directly to the receiving water bodies. The available reclaimed wastewater and its respective nutrients should be directed mainly to the major economic activities that fall within the guidelines of wastewater and excreta reuse. The major economic activities especially in the case study areas include agriculture (both crop farming and livestock rearing) and aquaculture especially in the two major regions (Narok and Bomet Counties). The local community should be involved actively in the identification exercise of the most critical crop for instance, that will play a significant role towards improving their source of food and livelihood. Water scarcity especially in arid and semi-arid regions of Talek, Narok, and Bomet has contributed towards the decline in the harvests of subsistence crops (e.g. vegetables, maize, wheat, potatoes, and beans). Millions of wild animals, birds and plant species in Maasai-Mara and Serengeti wildlife reserves and Kruger Park in the heart of Mara and Olifants river basins respectively have been affected by the water scarcity (see for example Figure 8.6).

Figure 8.6: Crocodiles at the drying Mara River, Kenya
Source: (Daily Nation Kenya, 2018)

It is therefore vital to emphasize on having a well-established treated effluent and excreta allocation plan (TEA-Plan) that augments the existing fresh water allocation plans (WAPs) in the region of interest. Strategic plans that are not annexed with other existing plans in a river basin or sub-basin faces some design and implementation challenges including possible rejection by the local community. Intertwining such plans opens a wide deliberation spectrum for the best-fit approach to the unique problems facing the river basin in a bottom-up model e.g. from the sub-basin (micro-governance water) to the basin and transboundary (macro-governance water) levels. It also lays a platform to exercise an inside-out model that incorporates actors from diverse sectors, namely, health care, forestry, business, industrial, education and research etc. There are several activities that form the backbone of the TEA-Plan e.g. activities before the commencement of the allocation plan (the design stage), during the allocation (execution stage) and after the allocation (post-allocation stage) (Figure 8.7).

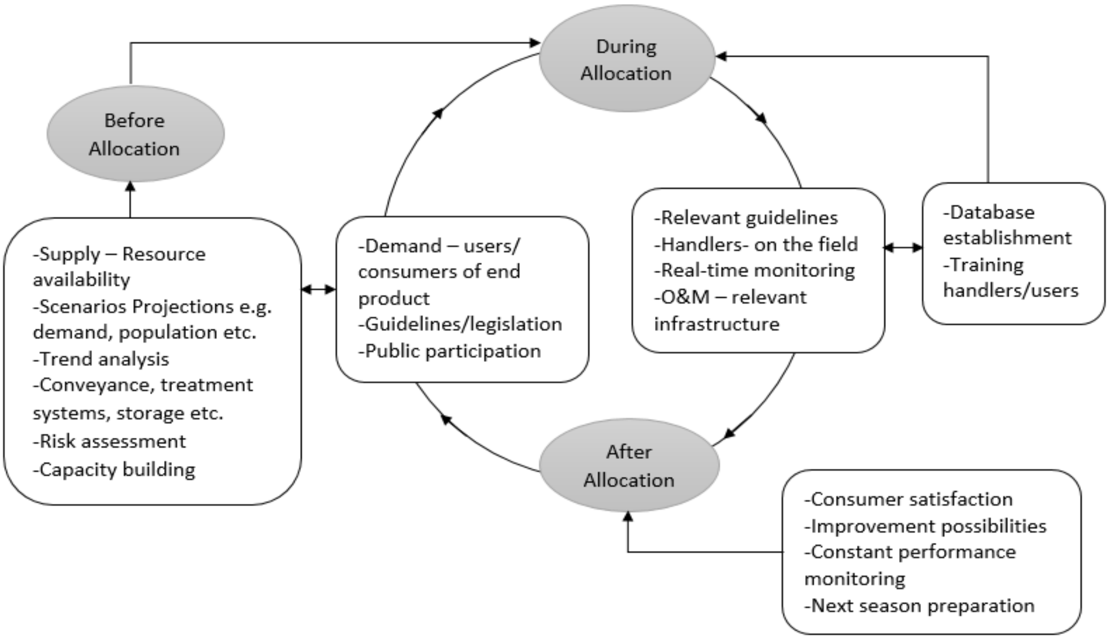

Figure 8.7: The building blocks of the TEA-Plan
*More measures should be put in place before the commencement (the design stage) of any TEA-Plan to minimize activities/planning in the subsequent stages and optimize the general performance.

Asano and Levine, 1996 clearly stated that; "*water reuse has evolved to become an integral factor in fostering the optimal planning and efficient use of water resources*" and "*In the planning and implementation of water reclamation and reuse the intended water reuse applications dictate the extent of wastewater treatment required, the quality of the finished water, and the method of distribution and application*." US EPA, 2004 identified the following technical issues (Figure 8.8) associated with planning the beneficial reuse of reclaimed water derived from domestic wastewater facilities.

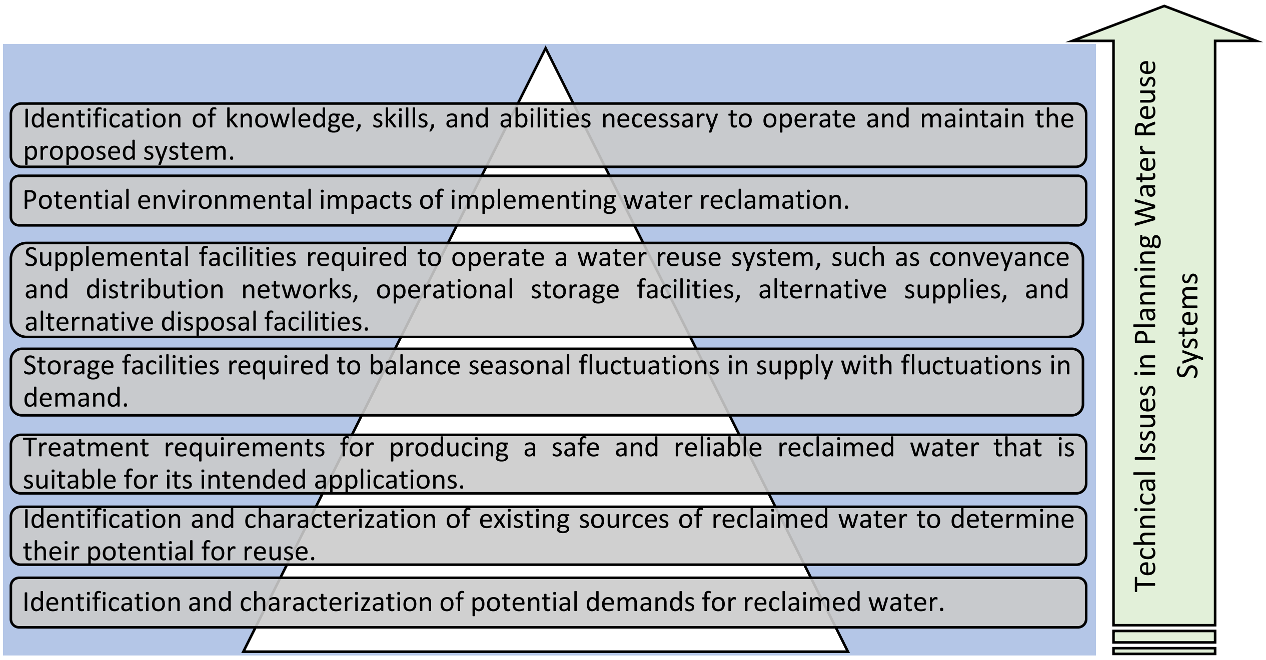

Figure 8.8: Technical Issues in Planning Water Reuse Systems
Source: Adapted from (US EPA, 2004) – detailed information is contained in chapter 3 of the (US EPA, 2004) titled "*Guidelines for Water Reuse*."

8.5a The Design Stage: Measures to be Taken Before the Commencement of the TEA-Plan

8.5a.1 Water Reuse Priorities

An establishment on the priorities of the water reuse is a stage that should never be ignored in the TEA-Plan. Dillon,2000 conducted a pilot survey on water reuse research priorities in Australia using the water aspects such as water quality, health and environment, and social/legal/economic, (see Table 8.2).

A significant percentage of the stakeholders in the transboundary Mara River basin have not fully accepted that treated wastewater and excreta could be reused; not even after treatment. Therefore, challenges emanating from socio-cultural background, illiteracy, and the trust given to the treatment systems should be addressed. Some stakeholders find it too risky to trust a water and wastewater treatment system that has failed them in the past. The lost trust is mainly due to poorly treated effluent leading to the outbreak of waterborne diseases and deaths, poorly maintained sewer line hence leading to unattended bursts, blockages, and odors in the environment and unpleasant smell in the water fetched from the rivers e.g. some sections of Nyangores and Amala tributaries especially next to mushrooming urban centers, hospitals, learning institutions, and industries. Nevertheless, a positive mindset can be cultivated through community sensitization and capacity building initiatives. Though the damage is huge, it is possible to step-wise "win back the trust" of the community and other stakeholders.

Table 8.2: Results of a survey of Australian water reuse research priorities

Rank	Field of Research	Theme
1	Factors affecting public acceptance of reuse	H,E,S
2	Viruses	H
3	Public health impacts of reuse	H
	Impacts on food quality of reuse on crops	H,E
4	Publishing a summary of existing research	All
	Economic of reuse	Ec
5	Disinfection effectiveness	H
	Environmental impacts of reuse	E
	Salinity	E
	Pathogenic bacteria	H
	Legislation and regulations	H,E
6	Algae prevention/removal	E
	Impacts on soils	E
	Impacts on groundwater	E
	Impacts on fresh surface water	H,E
	Sodicity	E
7	Suspended solids removal	H,E
8	Algal toxin removal	H
	Packaging existing information for regulators	H,E
	Cryptosporidium	H
	Insurance for reuse schemes	All
9	Endocrine disruptors	H,E
	Impacts on estuarine and marine waters	H,E
	Nitrogen	E

Themes: E = environment, Ec = economics, H = public health, S = sociological

Source:(Dillon, 2000) – supported by Australian Water Association (*https://www.awa.asn.au/*)

8.5a.2 The Supply (Resource Availability)

Establishing the availability of the wastewater and excreta is key to enabling an informed planning and execution of water reuse projects. Examples of sources include, domestic, municipal, and industrial wastewater. Some of the possible locations of the resource (wastewater and excreta) for the reclamation purposes in MRB include, households, old and upcoming urban centers in the MRB such as Narok, Mulot, Bomet, Silibwet, Talek, and Longisa etc. Additionally availability of the wastewater and excreta could be drawn from processing industries such as tea, leather, and milling etc.

Box 8.1: Factors that contribute to the wastewater and excreta availability for reuse include, but not limited to;

I. Per capita water consumption and the availability of water for consumption,
II. Percentage of the captured wastewater and excreta by the sewerage network,
III. The volume that find its way into the treatment plant – efficiency and coverage of the conveyance system. It should be noted that there are cases of losses as a result of leaks and bursts, and evaporation, or the on-site treatment, reuse or disposal, and diversion of raw sewage e.g. from manholes, open distribution channels, and/or open pools to agricultural lands beforehand, and
IV. The efficiency of the treatment system e.g. rate of pathogens reduction according to the recommended guidelines etc.

Box 8.2: Factors considered during the evaluation of wastewater resources availability,

(i) Current human population and the growth rate (%),
(ii) The general rate of raw wastewater production (m^3/d)
(iii) Quantity (m^3/d) and Quality (log units) of the treated effluent and excreta (sludge),
(iv) Availability of the relevant effluent nutrients (e.g. N, P, K etc.) for agriculture etc.,
(v) The target crop's rate of water consumption (based on evapotranspiration, ET_c),
(vi) Effluent storage capacity awaiting the irrigation period,
(vii) General conveyance network (pipeline) e.g. to the point of reuse,
(viii) Irrigation method (e.g. drip, furrow, sprinkler etc.) and its efficiency (%),
(ix) Uncertainties (probabilities), and
(x) Alternative resource – e.g. freshwater (m^3/d), inorganic fertilizer (bag(s) or kg/ha).

8.5a.2i Factors that Affect Per Capita Water Consumption in Mara River basin

The amount of water consumed by one person in one day is referred to as per capita water consumption per day. The water consumption is usually calculated as a function of the design population and of a value attributed for the average daily per capita water consumption (Von Sperling, 2007). Per capita water consumption in MRB is largely affected by high rates of non-revenue water (NRW). It is estimated that 42% of the fresh water in the water supply network is lost before reaching the water meters in Mara basin. Most of the water for consumption is obtained directly from the water points such as rivers, water pans, wells, boreholes, springs, and rainwater. Most of the households especially in the vast rural areas are not connected to the water supply systems. Typical ranges of per capita water consumption are shown by e.g. (Von Sperling, 2007) (see Table 8.3).

Table 8.3: Typical ranges of per capita water consumption

Community size	Population range (inhabitants)	Per capita water consumption (L/inhab.d)
Rural settlement	<5,000	90 - 140
Village	5,000 – 10,000	100 - 160
Small town	10,000 – 50,000	110 - 180
Average town	50,000 – 250,000	120 - 220
Large city	>250,000	150 - 300

Note: In places with severe water shortages, these values may be smaller.
Source: (Von Sperling, 2007) adapted from (CETESB, 1977, 1978; Barnes et al., 1981; Damrath, 1992; Bischof and Hosang, 1984).

The long distances to the water points – up to 12 km in the ASALs e.g. Narok, and Talek – coupled by the water scarcity reduces per capita water consumption in the Mara river basin. Additionally, water consumption has been affected by (i) perennial conflicts in the basin between Maasai and Kipsigis communities as well as wildlife-human conflict, (ii) absence of some (or all in some cases) of the general basic human water rights namely, availability, accessibility, adequacy, safety, and affordability. This has directly affected per capita water consumption, and (iii) inequality or poor water allotment as the poor water users go for weeks without water in their communal taps. According to (Castro, 2007), the major drivers of water conflict are insecurity, injustice, and inequality. There are more factors that influence water consumption, (see Table 8.4).

Table 8.4: Factors that influence water consumption

Influencing factor	Comment
Water availability	In locations of water shortage consumption tends to be less
Climate	Warmer climates induce a greater water consumption
Community size	Larger cities generally present a larger per capita water consumption (to account for strong commercial and institutional activities)
Economic level of the community	A higher economic level is associated with a higher water consumption
Level of industrialization	Industrialized locations present a higher consumption
Metering of household consumption	Metering inhibits greater consumption
Water cost	A higher cost reduces consumption
Water pressure	High pressure in the distribution system induces greater use and wastage
System losses	Losses in the water distribution network imply the necessity of a greater water production

Source: (Von Sperling, 2007)

8.5a.2ii Factors Influencing Residential Sewage Flow

There are normally high variabilities in the residential sewage flow due to; (i) the size of the family, (ii) socio-economic status, (iii) source of water supply, (iv) type of residential unit, (v) geographic location, and (vi) wastewater disposal methods (Siegrist et al., 1978; Washington State Department of Health, 2002) etc. While these factors are mainly the influential components, TEA-Plan should establish the actual characteristics of the sewage flow in the region of interest since cases are often unique and dynamic.

The average domestic sewage flow calculation is given by (Von Sperling, 2007) as;

$$Q_{d_{av}} = \frac{\mathrm{Pop.\,L_{pcd}.\,R}}{1000} \qquad (\mathrm{m^3/d}) \qquad \text{Equation 8.1}$$

$$Q_{d_{av}} = \frac{\mathrm{Pop.\,L_{pcd}.\,R}}{86400} \qquad (\mathrm{L/s}) \qquad \text{Equation 8.2}$$

where: $Q_{d_{av}}$ = average domestic sewage flow (m^3/d or L/s).
L_{pcd} = per capita water consumption (L/inhabitant/day).
R = Return Coefficient is the fraction of the supplied water that enters the sewerage system in the form of sewage; (R = sewage flow/water flow). Typical values of R vary between 60% and 100%, and a value of 80% (R = 0.8) is usually adopted.
Note: The water flow to be considered is the flow actually consumed, and not the flow produced by the water treatment works.

The driving force behind the quality requirements of the treated effluent is the type of crop (if the application is in agriculture) or aquaculture etc. (see relevant guidelines e.g. (WHO, 2006) etc. There are right proportions of nutrients (e.g. N, P, K,) and micro-nutrients (e.g. Fe, Mg, S) for plant growth (Mara et al., 1992a) that can be preserved during wastewater and excreta treatment. The irrigation is then categorized into restricted or unrestricted (WHO, 1989 , 2001, 2006).

8.5a.3 Scenario Projection and Trend Analysis

Scenario analysis offers structured descriptions of possible long-range futures (Raskin et al., 1998). Additionally, scenarios project short and unforeseeable future and lays a foundation for an informed planning or preparedness. Raskin et al., 1998 states that the value of scenarios lies not in their capacity to predict the future, but in their ability to provide insight into the present. Scenarios enlarge the canvass for reflection to include a holistic perspective over space, issues and time (Raskin et al., 1998). Various dynamic components of planning are considered in estimating future changes such as population (see e.g. Table 8.7), lifestyle (behavior change), tastes and preferences, economic growth, social-cultural issues among others. All these factors will directly affect the demand on food and water for the population and therefore more urgent need for acquiring treated effluent to irrigate the preferred crop(s).

Trend analysis is in this stage vital for the estimation of nutrients and micro-nutrients availability in the future etc. Trend detection in hydrologic and water quality time series has received considerable attention in the recent past (Hamed and Rao, 1998). There are various tools for performing trend analysis (see e.g. the commonly applied Mann Kendall test (Mann, 1945; Kendall, 1975) which statistically assesses if there is a monotonic upward or downward trend of the variable of interest over time. The test statistic *S* (Hirsch et al., 1982) is defined as;

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(x_j - x_k\right) \qquad \text{Equation 8.3}$$

where

$$sgn\,(\Theta) = \begin{cases} 1 & if \quad \Theta > 0 \\ 0 & if \quad \Theta = 0 \\ -1 & if \quad \Theta < 0 \end{cases} \qquad \text{Equation 8.4}$$

n is the number of data points,
x_j and x_k are the data values in time series *j* and *k*, respectively; (*k*>*j*)

Under null hypothesis, H_o, the limit distribution of statistic *T* is normal (Mann, 1945) and symmetrical; and so is *S* (Kendall, 1975), (where *T* is a linear function of the statistic *S*) in the limit as $(n \to \infty)$. There is normality tendency of *S* in cases of large n (Hamed and Rao, 1998), with mean and variance of *S* under H_o given the possibility of existence of x values ties (Hirsch et al., 1982).

$$E[S] = 0 \qquad \text{Equation 8.5}$$

$$Var[S] = n(n-1)(2n+5) - \textstyle\sum_t t(t-1)(2t+5)/18 \qquad \text{Equation 8.6}$$

where *t* is the extent of any given tie (number of *x*'s involved in a given tie) and $\sum_t$ denotes the summation over all ties. Hirsch et al., 1982 further demonstrates that both Mann and Kendall derive the exact distribution of *S* for $(n \leq 10)$ and shows that even for $(n = 10)$, the normal approximation is excellent, with a condition that a one-unit continuity correlation is employed. It follows that, the standard normal variate Z is computed by;

$$Z = \begin{cases} \dfrac{S-1}{(\mathrm{Var}\,(S))^{1/2}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{(\mathrm{Var}\,(S))^{1/2}} & if \quad S < 0 \end{cases} \qquad \text{Equation 8.7}$$

The null hypothesis, H_o is accepted if $|Z| \leq Z_{\propto/2}$, where $F_N(Z_{\propto/2}) = \propto/2)$, F_N being the standard normal cumulative distribution function and ∝ being the size of the significance level for the test. A positive value of *S* indicates an upward trend (increase on values with increasing time) while a negative value indicates a downward trend.

8.5a.4 The Demand Projection (e.g. on the crop type and consumers)

Sustainability is paramount in the process of planning for the current consumers in order to ensure that there is guaranteed continuity for the future demand. The projection of demand attempts to foretell some of the uncertainties in a specified time or a period of time in future. It should be noted that the demand projection and design population are inseparable. The demand of a treated effluent and excreta should then be identified and quantified based mainly on the design population and the type of reuse objective(s). This will involve calculation of the actual amount of water that is expected to irrigate a certain type and amount of crops or for the fish ponds. There should be an establishment of the need for extracted nutrients (organic fertilizer) from the wastewater and excreta for the reuse purposes.

The need for supplemental irrigation will vary from month to month throughout the year since the variations of crop water requirements is driven mainly by the climatic conditions (US EPA, 2004). The seasonal variation is a function of rainfall, temperature, crop type, stage of plant growth, and other factors, depending on the method of irrigation being used (US EPA, 2004). Predictive equations – in the absence of actual water use data – must be used to estimate evapotranspiration, percolation and runoff losses, and net irrigation in order to estimate irrigation demands and reclaimed water supplies in the assessment of the water reuse feasibility (US EPA, 2004). Estimation of crop water consumption involves the actual crop evapotranspiration (ETa, mm/day) which depends on climate parameters that determine potential evapotranspiration, crop characteristics and soil water availability (Allen et al., 1998):

$$ET_a[t] = K_c[t] \times K_s[t] \times ET_o[t] \qquad \text{Equation 8.8}$$

where
K_c is the crop coefficient (dimensionless),
K_s [t] a dimensionless transpiration reduction factor dependent on available soil water
$ET_o[t]$ the reference evapotranspiration (mm d^{-1}). *See detailed information in* (Allen et al., 1998).

Various crop coefficient values are given in details see e.g. "*Crop evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56*" (Allen et al., 1998) e.g. the initial crop coefficient ($K_{C\ ini}$) for cereals like maize is 0.3 while its mid-crop coefficient ($K_{C\ mid}$) is 1.20 and end crop coefficient ($K_{C\ end}$) is 0.60-0.35 etc.

Table 8.5: Water requirements, sensitivity to water supply and water utilization efficiency of some selected crops

Crop	Water requirements (mm/growing period)	Sensitivity to water supply (ky)	Water utilization efficiency for harvested yield, Ey, kg/m³ (% moisture)
Alfalfa	800-1600	low to medium-high (0.7-1.1)	1.5-2.0 hay (10-15%)
Banana	1200-2200	high (1.2-1.35)	plant crop: 2.5-4 ratoon: 3.5-6 fruit (70%)
Bean	300-500	medium-high (1.15)	lush: 1.5-2.0 (80-90%) dry: 0.3-0.6 (10%)
Cabbage	380-500	medium-low (0.95)	12-20 head (90-95%)
Citrus	900-1200	low to medium-high (0.8-1.1)	2-5 fruit (85%, lime: 70%)
Cotton	700-1300	medium-low (0.85)	0.4-0.6 seed cotton (10%)
Groundnut	500-700	low (0.7)	0.6-0.8 unshelled dry nut (15%)
Maize	500-800	high (1.25)	0.8-1.6 grain (10-13%)
Potato	500-700	medium-high (1.1)	4-7 fresh tuber (70-75%)
Rice	350-700	high	0.7-1.1 paddy (15-20%)
Safflower	600-1200	low (0.8)	0.2-0.5 seed (8-10%)
Sorghum	450-650	medium-low (0.9)	0.6-1.0 grain (12-15%)
Wheat	450-650	medium high (spring: 1.15; winter: 1.0)	0.8-1.0 grain (12-15%)

Source: (Doorenbos and Kassam, 1979; Pescod, 1992)

Water requirements for biofuel crops such as maize which is common in the case study area have been researched on widely by e.g. (FAO, 2008) (Table 8.6) etc. Doorenbos and Kassam, 1979; Pescod, 1992 shows that the water requirements (mm/growing period) for maize, beans and wheat (see Table 8.5) is 500-800, 300-500, and 450-650 respectively. Therefore, it is evident that crop water consumption varies greatly.

Table 8.6: Water requirements for biofuel crops

Crop	**Annual obtainable fuel yield**	**Energy yield**	**Evapotranspiration equivalent**	**Potential crop evapotranspiration**	**Rainfed crop evapotranspiration**	**Irrigated crop water requirement**	
	(Litres/ha)	(GJ/ha)	(Litres/ litre fuel)	(mm/ha)	(mm/ha)	(mm/ha)[1]	Litres/litre fuel
Sugarcane	6000	120	2000	1400	1000	800	1333
Maize	3500	70	1357	550	400	300	857
Oil palm	5500	193	2364	1500	1300	0	0
Rapeseed	1200	42	3333	500	400	0	0

[1]On the assumption of 50 percent irrigation efficiency.
Source: (FAO, 2008)

Although the dominant crops are maize and wheat, Mara river basin presents a diverse irrigation potentials ranging from vegetables, cereal and cash crops. The vegetables (e.g. kales, cabbages, spinach, onions etc.) fall in class A of the recommended microbiological quality guidelines for treated wastewater reuse in agricultural irrigation while cereal crops (e.g. sorghum, millet, etc.) and cash crops such as tea fall in class B. (see e.g. WHO, 2006). Additionally, the irrigation would extend to animal feed grown in the region e.g. grass and other fodder crop for thousands of livestock reared by the pastoralist in the region e.g. the Maasai community. Dillon, 2000 identifies various water reuse issues in Australia that affect significantly continued demand for reuse (Figure 8.9).

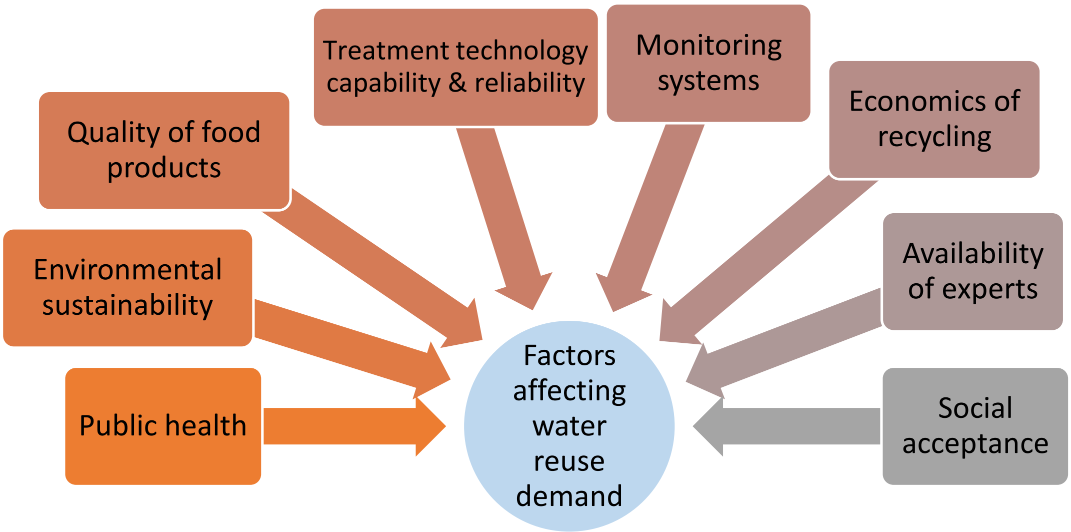

Figure 8.9: The main factors that affect continued water reuse demand
Source: Adapted from (Dillon, 2000).

8.5a.5 Design Population

On the population forecast, the design population is only a certain fraction of the total population (coverage index = population served/total population) served by the sewerage system (Von Sperling, 2007).

$$\text{Coverage Index} = \frac{\text{Population served}}{\text{Total population}} \qquad \text{Equation 8.9}$$

The coverage index is a function of the following aspects: (i) physical, geographical or topographical conditions of the locality, (ii) adhesion index (ratio between the population actually connected to the system and the population potentially served by the sewerage system), and (iii) implementation stages of the sewerage system (Von Sperling, 2007).

Table 8.7: Population forecast. Methods based on mathematical formulas

Method	Description	Growth rate	Forecast formula	Coefficients (if regression analysis is not used)
Linear growth	Population growth follows a constant rate. Method used for short-term forecasts. Curve fitting can also be done through regression analysis.	$\frac{dP}{dt} = K_a$	$P_t = P_0 + K_a.(t - t_0)$	$K_a = \frac{P_2 - P_0}{t_2 - t_0}$
Geometric growth	Population growth is a function of the existing population at every instant. Used for short-term forecasts. Curve fitting can also be done through regression analysis	$\frac{dP}{dt} = K_g.P$	$P_t = P_0.\ e^{K_g.(t-t_0)}$ or $P_t = P_0.(1+i)^{(t-t_0)}$	$K_g = \frac{\text{In}P_2 - \text{In}P_0}{t_2 - t_0}$ or $i = e^{K_g} - 1$
Multiplicative regression	Fitting of population growth by linear regression (logarithmic transformation of the equation) or non-linear regression.	-	$P_t = P_0 + r.(t - t_0)^s$	r, s – regression analysis
Decreasing growth rate	Assumption that, as the town grows, the growth rate becomes lower. The population tends asymptotically to the saturation value. The coefficients can be also estimated by non-linear regression	$\frac{dP}{dt} = K_d.(P_s - P)$	$P_t = P_0 + (P_s - P_0)\ X\ [1 - e^{-K_d.(t-t_0)}]$	$P_s = \frac{2.P_0.P_1.P_2 - P_1^2.(P_0 + P_2)}{P_0.P_2 - P_1^2}$ $K_d = \frac{-\text{In}[(P_s - P_2)/(P_s - P_0)]}{t_2 - t_0}$

Logistic growth	The population growth follows an S-shaped curve. The population tends asymptotically to a saturation value. The coefficients can also be estimated by non-linear regression. Required conditions: $P_o < P_1 < P_2$ and $P_0 . P_2 < P_1{}^2$. The point of inflexion in the curve occurs at time $t = [t_o - \ln(c)/K_1]$ and with $P_t = P_s/2$.	$\frac{dP}{dt} = K_1.P.\left(\frac{(P_s - P)}{P_s}\right)$	$P_t = \frac{P_s}{1 + c.e^{K_1.(t-t_0)}}$	$P_s = \frac{2.P_0.P_1.P_2 - P_1^2.(P_0 + P_2)}{P_0.P_2 - P_1^2}$ $C = (P_s - P_0)/P_0$ $K_1 = \frac{1}{t_2 - t_1}.\ln\left[\frac{P_0.(P_s - P_1)}{P_1.(P_s - P_0)}\right]$

Source: (Von Sperling, 2007) partly adapted from (Qasim, 1985)

- dP/dt = population growth rate as a function of time.
- P_o, P_1, P_2 = population in the years t_o, t_1, t_2. The formulas for the decreasing and logistic growth rates require equally-spaced values in time if regression analysis is not employed (inhabitants).
- P_t = population estimated for year t (inhabitants); P_s = saturation population (inhabitants).
- K_a, K_g, K_d, K_l, i, c, r, s = coefficients (obtaining coefficients by regression analysis is preferable as all of the existing data series can be used, and not only P_o, P_1 e P_2).
- Equations 8.10 – 8.27.

The estimated MRB population in the year 2019 was 1.7 million with an annual growth rate of 3.2 % as opposed to 2.2% nationwide. The nationwide growth rate has declined to 2.2% in 2019, from 2.9% in 2009 (Kenya National Bureau of Statistics, 2019c). The annual growth rate in the basin was 3% by the year 2007 (Hoffman, 2007) and therefore, 0.2% increase has occurred. The families are bigger in the Mara basin; a region that is dominated by two ethnic groups, namely, the Maasai community - in the arid and semi-arid lands (ASALs) of the basin and the Kipsigis. The Maasai community is popularly known for pastoralism (they rear hundreds of cattle and sheep) and Kipsigis are largely subsistence farmers. The Kipsigis community largely occupy the highlands, upstream and partly mid-stream of the basin e.g. the Mau forest and Bomet regions. Table 8.8 shows population in the two main counties of the Mara river basin. There are also animal ranches and conservancies in the ASALs as well as millions of wild animals in the world famous Maasai Mara wildlife reserve that is connected directly to Serengeti wildlife reserve on the Tanzanian side of the basin.

Table 8.8: Population in the two main counties of MRB – Kenyan side

County	Male	Female	Total
Bomet	434,287	441,379	875,689
Narok	579,042	578,805	1,157,873
Total	**1,013,329**	**1,020,184**	**2,033,562**

Source: (Kenya National Bureau of Statistics, 2019a)

Note: The entire administrative boundaries of these counties are not necessarily within the river basin.

Based on the mathematical formulas (see for example Von Sperling, 2007; Qasim, 1985 etc.), the population forecast in the case study area is determined. According to (Zermoglio et al., 2019), the population of MRB is projected to increase up to approximately 2.1 million by the year 2030 (see Figure 8.10).

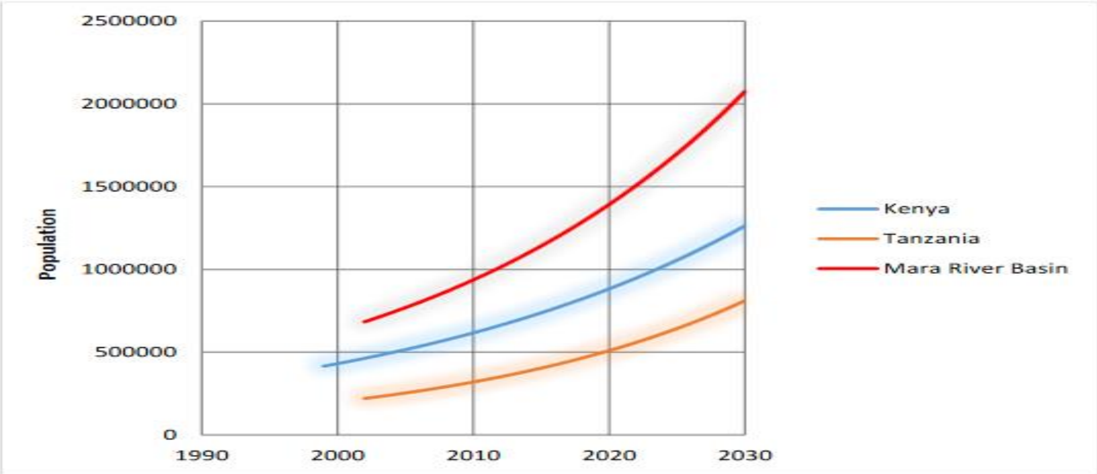

Figure 8.10: Population projections for the MRB
Source: (Zermoglio et al., 2019) – for USAID

8.5a.6 Conveyance Network, Treatment System, and Storage

Water reclamation facilities, and distribution system, including storage and pumping facilities must provide the required treatment to meet appropriate water quality standards for the intended use (US EPA, 2004). To achieve a high-performance TEA-Plan, a modernized or an upgraded network of both raw and treated wastewater should strongly be considered during the planning stage. This will enable protection of the health of the public and environment through curbing the current haphazard disposal and flow of wastewater and excreta as witnessed mainly in the urban and peri-urban areas of the case study areas. The decentralized or centralized *on-site* or *off-site* treatment systems are supposed to be evaluated. In the same breath, there should be an identification of the system that is best fit for the treatment of the wastewater and excreta to achieve the required standards for reuse in agriculture, and aquaculture etc. In this study, a special focus is made on the wastewater ponds system (WPS) systems and the subsequent treated effluent for reuse purposes. A special focus is made on water reuse in ASALs of MRB and a possibility to transfer the findings to the second case study (the Olifants river basin) and beyond.

A lot of the problems many water utilities are faced with could be solved by improved operation and maintenance, because it reduces water losses, which results in better plant performance, and leads to improved water service quality (Rudolph and Harbach, 2006). Design, operation and maintenance of treatment systems e.g. wastewater ponds system can be seen in *e.g.* (McGarry and Pescod, 1970; Mara and Pearson, 1987; Mara and Marecos do Monte, 1990; Pescod and Mara, 2013; Rudolph et al, 2019 etc.). The design requirements of reclaimed water conveyance systems vary according to the needs of the users and water quality etc. (US EPA, 2004).

Although conventional WPS do not provide for effluent storage (Mara and Pearson, 1992), the storage of the treated effluent is important before it is released for irrigation and other uses during dry seasons. According to (US EPA, 2004), storage of effluent is inevitable or else disposed-off in some manner due to its continuous generation. Storage is needed in order to regulate between sewage 'production' which occurs throughout the year and effluent demand for irrigation which occurs only during the dry summer months (Juanico and Friedler, 1999). Effluent storage is therefore a critical link between the wastewater treatment plant and the irrigation system (Pescod, 1992). Pescod, 1992 further gives three main reasons for the effluent storage, namely, (i) equalization of daily variations in flow from the treatment plant and to store excess when average wastewater flow exceeds irrigation demands; includes winter storage, (ii) to meet peak irrigation demands in excess of the average wastewater flow, and to (iii) to minimize the effects of disruptions in the operations of the treatment plant and irrigation system. Storage is used to provide insurance against the possibility of unsuitable reclaimed wastewater entering the irrigation system and to provide additional time to resolve temporary water quality problems (Pescod, 1992). Sufficient storage to accommodate diurnal flow variation is essential to the operation of a reclaimed water system (US EPA, 2004). Effluent storage reservoirs (ESR) first developed and used in Israel (Juanico and Shelef, 1991) - also called wastewater storage and treatment reservoirs (WSTR) facilitates the storage of effluent awaiting the irrigation season (Juanico and Friedler, 1999; Mara, 2013). Therefore, WPS and WSTRs are two possible treatment options prior to water reuse in agriculture (WHO, 1989; Metcalf et al., 2007). Reclaimed water has the advantage of flowing uniformly throughout the year and being relatively consistent in quality, having been through a treatment chain with some quality assurance (unlike inflows from some catchments to reservoirs for urban water supplies) (Dillon, 2000). The storage of the treated effluent in ESRs allows a much greater area of land to be irrigated during the irrigation season (Mara, 1996) and maximizes the potential of wastewater reuse for crop production in water-short areas in many parts of the developing world (Mara, 2013). The length of the irrigation season affects the number of storage reservoirs and the timing of the fill/rest/use cycle (Mara and Pearson, 1992). ESR is necessary to cater for months in which the WPS effluent is not required for irrigation and avoid or minimize wastage or discharging of the effluent to a surface watercourse or for groundwater recharge (Mara and Pearson, 1992). The volume of storage required can be determined from the daily reclaimed water demand and supply curves (US EPA, 2004). Generally, the goal of storage of wastewater is twofold, namely, (i) to match supply and demand, and (ii) to perform additional treatment and to equalize wastewater quality (Juanico and Friedler, 1999). The expected removal of excreted microorganisms in ESR reaches up to 1-6, 1-3, 1-4 and 1-4 ($\log_{10}$ units) for bacteria, helminths, viruses and cysts respectively (WHO, 1989). An example of ESR is presented in Figure 8.11 as obtained from the Irvine ranch water district in California, USA.

Figure 8.11: The Sand Canyon effluent storage reservoir at the Irvine Ranch Water District in California, USA

*Irvine Ranch Water District has 16 recycled water reservoirs which include four open-air seasonal-storage reservoirs (Rattlesnake, San Joaquin, Syphon and Sand Canyon) with combined storage capacity of 1.6 billion gallons.

Source: (Irvine Ranch Water District, 2020)

Mara and Pearson, 1992 proposed to use three or four ESRs in parallel - instead of a single ESR as originally used in Israel (see e.g. Juanico and Shelef, 1991) – in order to allow sequential batch feeding (Figure 8.12) to provide a sufficient period between filling a reservoir and using its contents. This insulates the ESR's effluent from being contaminated by a lower quality influent and therefore will contain fewer than 1, 000 faecal coliforms per 100ml (Mara and Pearson, 1992).

Box 8.3: The system of ESRs in parallel receiving anaerobic pond effluent has the potential of permitting a much more efficient use of wastewater, and hence of available water resources in arid or semi-arid areas, than the single ESR system, as it allows unrestricted irrigation to be undertake so as to produce greater quantities of higher value crops (Mara and Pearson, 1992).

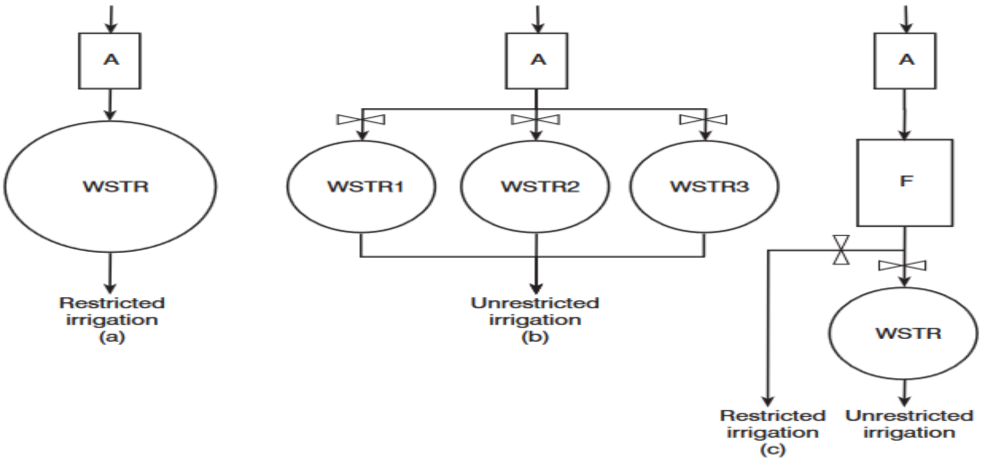

Figure 8.12: Wastewater Storage and Treatment Reservoir Systems

Note: (a) single WSTR for restricted irrigation; (b) sequential batch-fed WSTR for unrestricted irrigation; and (c) hybrid WPS–WSTR system for both restricted and unrestricted irrigation. A, anaerobic pond; F, facultative pond.

Source: (Mara, 2013)

The performance of ESR/WSTR depends on good design and proper operation as well as retention time, which varies with demand (WHO, 1989). Owing to the quality of the effluent stored in the ESR, strict protective measures should be taken to safeguard the public from mistaking the effluent for domestic uses. The ESRs should be constructed, demarcated and clearly labelled to ensure that the effluent is correctly used. Labelling should use a popularized and a simple-to-understand coding system either by use of colors, figures or alphabets or a mixture of figures and alphabets to eliminate risks of e.g. consumption of effluent by human beings. There should be a real-time monitoring system attached to the treatment and conveyance systems, ESRs, and irrigation systems that sends relevant signals to the control center for the timely and informed response.

Additionally, to protect public health from the outset, a reclaimed water distribution system should be accompanied by health codes, procedures for approval (and disconnection) of service, regulations governing design and construction specifications (e.g. to prevent cross-connection etc.), inspections, and operation and maintenance staffing (US EPA, 2004). Cross-connections should be addressed through identification of transmission and distribution lines and appurtenances via color-coding, taping, or other means; separation of reclaimed water and potable water lines; allowable pressures; surveillance; and backflow prevention devices (Metcalf et al., 2007).

Box 8.4: The design of ESR should focus primarily on the;

(i) Length of the irrigation season per annum,

(ii) Rate of treated effluent flow into the reservoir (i.e. effluent production rate at the wastewater treatment system),

(iii) Rate of crop water consumption or size of field to be irrigated or the demand,

(iv) Need for extra pathogen reduction ($\log_{10}$ units) requirements (e.g. for restricted or unrestricted irrigation etc.)

There are two irrigation seasons in the ASALs of the transboundary Mara River Basin. Long rains are experienced between mid-March and June and short rains from September to November. The dry seasons in Narok, Loita and Talek regions are intense than the upper catchment region. Generally, the temperature and aridity in the basin increases downstream (WREM, 2008). ESR in ASALs of Mara basin could be designed for around 5 months, namely, December to mid-March and July to August. The safest design period would be 6-7 months since the availability of irrigation water in the arid areas in the basin is highly unpredictable. Sequential batch-fed ESRs as proposed by (Mara and Pearson, 1992) are recommended in the case study area for the storage of treated effluent and a possible further pathogens reduction prior to unrestricted crop irrigation. The filling, use and resting of three ESRs in parallel for six months' irrigation period are demonstrated (Table 8.9).

Table 8.9: Possible management strategies for three ESRs in parallel

Month	R1	R2	R3
January	Rest	Fill (1/2)	Fill (1/2)
February	Rest	Fill (1/2)	Fill (1/2)
March	Rest	Rest	Fill (1)
April	Rest	Rest	Fill (1)
May	Use	Rest	Fill (1)
June	Use	Rest	Fill (1)
July	Fill (1)**	Use	Rest
August	Fill (1)	Use	Rest
September	Fill (1/2)	Fill (1/2)	Use
October	Fill (1/2)	Fill (1/2)	Use
November	Fill (1/3)	Fill (1/3)	Fill (1/3)
December	Fill (1/3)	Fill (1/3)	Fill (1/3)
Volume***	$3\,^{2}/_{3}$	$2\,^{2}/_{3}$	$5\,^{2}/_{3}$

R1-R3 are the Effluent Storage Reservoirs.
Note: The irrigation season is six months and the interval between filling and using the contents of any one reservoir varies between two and four months.
*The hot season is assumed to be in July and August, so ESR no. 3 has the minimum rest period of two months in these months. The other ESRs have rest period of four moths.
**Proportion of monthly flow diverted to each ESR.
***Volume expressed as multiple of monthly wastewater flow.
Source: (Mara and Pearson, 1992); (see also Mara, 2013)

Similar approach as in (Mara and Pearson, 1992; Mara, 2013) should be followed in establishing treated effluent management strategy (TEMS) in ASALs and any other region whose aim is to protect the receiving water bodies from increased stress of wastewater disposal and the ultimate protection of the public health.

8.5a.7 Guidelines and Legislative Measures

The international and national guidelines and standards on the design, construction and operation and maintenance of the relevant structures as well as safeguarding public health should be employed in every stage of water reuse. Policy update and synchronization is fundamental towards bringing all stakeholders onboard to enhance performance in the basin.

8.5a.8 Risk Assessment

Handling wastewater and excreta contains various risks and should follow laid out guidelines and meet specific standards. These risks should be observed as explained in the Stockholm harmonized framework (e.g. on microbiological hazards which integrates comprehensive risk assessment, risk management options and exposure control elements with specific public health quality targets in wastewater) (WHO, 2001a). US EPA, 2004 on the public health safeguards states that planners of water reuse must establish that public health is the overriding concern. Use of a well popularized and easy-to-understand coding system in the infrastructure used for wastewater and excreta collection, transportation/distribution, storage and effluent irrigation etc. is inevitable in order to protect all handlers of the treated effluent and excreta as well as the livestock (as in the case with pastoralism in Mara basin).

8.5a.9 Capacity Building and Public Participation

All stakeholders within the basin starting most specifically at the sub-basin levels are supposed to be enlightened on the importance of proper disposal of wastewater and excreta, and enroll in various environmental conservation and wastewater and excreta reuse initiatives. This involves constant training and workshops that bring relevant stakeholders including youth and women in the active public consultation platforms. Capacity building and community sensitization is a roadmap to acceptance of this noble exercise and addressing various socio-cultural stumbling blocks towards wastewater and excreta reuse.

8.5b Implementation Stage: Measures to be Taken During the Actual Execution of the TEA-Plan

8.5b.1 Registration of the Target Fields of Reuse

Databases and other online platforms are necessary for the registration of the users and the water reuse based agricultural fields to enhance accountability and efficiency of the plan. This should be followed by the issuance of relevant permits that stipulates various conditions that should be met before, during and after application of the treated wastewater and excreta. Registration should be done through water services providers and water resources authorities in-charge of the basin.

8.5b.2 Training Workers and Handlers of Treated Effluent and Users of the End Products

To protect workers conducting irrigation activities and population passing through or near irrigated areas as well as protecting the environment from possible contamination (Rudolph et al., 2007) and consumers of the harvested crops, a training exercise before the onset of the water reuse exercise is inevitable. Training the registered workers, handlers and users is vital and should be constant to ensure that they all strictly adhere to the stipulated guidelines. The crop yields and quality will without a doubt directly be affected by the professionalism observed by the crop workers, handlers and operators in the irrigation scheme. Competence should be adhered to from receiving the treated effluent directly from the wastewater treatment system or from a storage reservoir, in the reuse field to the harvesting of the crops.

A possibility to train some local people to help in physical monitoring and adherence to the guidelines is hereby recommended in order to boost efforts to safeguard the health of the public and create more sense of ownership by the community in the specific region of interest. Therefore, existing guidelines on the soil/field preparation, recommended type of irrigation, time of irrigation, harvesting and cleaning of the products before consumption among other measures should strictly be observed. US EPA, 2004 recommends "*code of Good Practices for Water Reuse*" designed to aid reuse utilities as they implement quality water reuse programs developed by Florida Department of Environmental Protection (FDEP) and the Florida Water Environment Association's (FWEA) Water Reuse committee (FDEP, 2000).

8.5b.3 Irrigation System

Although other methods of irrigation are used globally, drip irrigation is the most recommended method of microirrigation (see e.g. WHO, 2006) because of its high efficiency levels of up to 95% (Table 8.10) (Vickers, 2001; US EPA, 2004). Nevertheless, the actual efficiency of a given system will be site specific and vary widely depending on management practices followed (US EPA, 2004). Basically, irrigation systems are selected based on the crop types, water quality and quantity requirements, site characteristics, and management costs and skilled labor requirements (Metcalf et al., 2007). To check the details on restricted and/or unrestricted irrigation (see e.g. WHO, 1989). In order to maximize farm produce, the most appropriate irrigation method should be selected and installed/constructed within the stipulated design parameters, operation and maintenance as well as monitoring and evaluation. Real-time monitoring system should be set in place to enhance the management of the irrigation system. Pescod, 1992 recommended some technical factors that should be considered while choosing irrigation method based on wastewater, namely, (i) the choice of crops, (ii) the wetting of foliage, fruits and aerial parts, (iii) the distribution of water, salts and contaminants in the soil, (iv) the ease with which high soil water potential could be maintained, (v) the efficiency of application, and (vi) the potential to contaminate farm workers and the environment. Find more details on "*Wastewater treatment and use in agriculture - FAO irrigation and drainage paper 47*" by (Pescod, 1992).

Table 8.10: Efficiencies for Different Irrigation Systems

Irrigation System	**Potential on-Farm Efficiency (Percent)[1]**
Gravity (Surface)	
Improved gravity[2]	75-80
Furrow	55-70
Flood	40-50
Sprinklers	
Low energy precision application (LEPA)	80-90
Center pivot[3]	75-85
Sideroll	60-80
Solid set	65-80
Hand-move	60-65
Big gun	60-65
Microirrigation	
Drip	80-95

[1]Efficiencies shown assume appropriate irrigation system selection, correct irrigation design, and proper management.
[2]Includes tailwater recovery, precision land leveling, and surge flow systems.
[3]Includes high- and low-pressure center pivot.
Source: (Vickers, 2001), *see also* (US EPA, 2004)

There are various basic conditions that should be met at farm level according to (Pescod, 1992) in order to make irrigated farming a success: (i) the required amount of water should be applied; (ii) the water should be of acceptable quality; (iii) water application should be properly scheduled; (iv) appropriate irrigation methods should be used; (v) salt accumulation in the root zone should be prevented by means of leaching; (vi) the rise of water table should be controlled by means of appropriate drainage; and (vii) plant nutrients should be managed in an optimal way. Additionally, there should be agricultural and public health officers in such areas to provide with relevant quality directions in order to ensure that the health of the public is safeguarded and farm produce is optimized.

There are several exposure control measures related to various exposure points such as agricultural sites and use of products (WHO, 2006) (see Box 8.5 and Table 8.11).

Box 8.5: Exposure control measures at agricultural sites and use of products relates to:

- Crop restriction
- Application techniques
- Fieldworkers
- The withholding period (from fertilization to harvesting time), and
- Die-off of organisms before consumption (WHO, 2006)

The exposure control measures should be applied when implementing the integrated TEA-Plan in any river basin. Of great importance is also the unique characteristics of different crops which affect choice of e.g. (i) irrigation category (restricted or unrestricted), (ii) method (e.g. drip etc.), (iii) duration and therefore water demand, and (iv) harvesting time, etc.; This require special analysis before the commencement of any water reuse operations to maximize the output and minimize the unforeseeable shortcomings.

Table 8.11: Major exposure points for the reuse of excreta and greywater

Risk activity[a]	Major exposure route	Group at risk	Risk management considerations
Emptying the collection chamber/vessel (1-4)	Contact	Entrepreneurs Residents Local communities	Provision of protective clothing and suitable equipment for persons involved Training Facility should optimize on-site treatment
Transportation (1-5)	Contact Secondary spread through equipment	Entrepreneurs Local communities	Avoid spillage Equipment not used for other purposes without proper disinfection/cleaning
Off-site secondary treatment facility (1-3) Ponds (5)	Contact (all) Vectors	Workers Nearby communities	Ensure treatment efficiency Protective clothing Facility should be fenced off Ensure no access for children Consider and minimize vector propagation Exclude recreational activity and consider vector (5)
Application (1-3.5)	Contact Inhalation	Entrepreneurs Farmers Local communities	Use "close to the ground application" Work the material into the soil directly and cover Reduced access should be ensured if quality is not guaranteed; in such cases, applications to parks, football fields or where the public have access should be avoided Protective clothing for workers Minimum one month between application and harvest
Crops Harvesting Processing Sale (1-5)	Consumption Handling	Consumers Workers Vendors	Crops eaten raw pose the most risk; Industrial crops, biofuels or crops eaten only after cooking pose less risk Adequate protective clothing (gloves, shoes) Provide safe water in markets for washing and refreshing vegetables
Consumption (1-5)	Consumption	Consumers	Practising good personal, domestic and food hygiene Cooking food thoroughly

(1) Dry collection; (2) Faecal sludges; (3) Wet systems; (4) Urine; (5) Greywater.
Source: (WHO, 2006)

1-2 weeks cessation of irrigation with wastewater is effective in the reduction of crop contamination as this time allows pathogen die-off (da Costa Vargas et al., 1996). This is necessary in order to safeguard the health of the handlers/workers, vendors, consumers, and the entire local community at large. Generally, the main reasons for managing treated wastewater on the farm include to overcome salinity hazards, to overcome toxicity hazards and to prevent health hazards (Pescod, 1992).

8.5b.4 Operation and Maintenance of the Conveyance Network and the Treatment System

Infrastructure and the affiliated fundamental systems are bound to wear and tear, aging, erosion, corrosion, bursts, and leaks etc. All these aspects should be inspected invariably and repaired or replaced accordingly. There should be well trained operators and/or workers to conduct the required operation and maintenance and monitoring and evaluation. Clogging is a typical challenge that faces any irrigation scheme. To prevent complete or partial clogging of emitters and to enhance a good filtration system, (US EPA, 2004) recommended the use of in-line filters of an 80 to 200 mesh when reclaimed water is used in a micro-irrigation system. The bottleneck of sufficient water services to the people is sustainable operations and maintenance to reduce water losses, boost plant performance, and collection rates etc. If such problems are timely and constantly addressed, water service quality would improve, revenues from water customers would be easier to collect, and – as result of this – financing and investment of new facilities would become more feasible (Rudolph and Harbach, 2006). A routine monitoring system enables timely detection of the problem as well as fixing it to avoid irreversible damage and reduce the cost of repair and maintenance.

8.5b.5 Establishing Real-Time Monitoring System

Modern technology provides for the opportunities to monitor systems on-site or remotely. This aspect should be considered to ensure that all uncertainties and looming crises are promptly addressed. Any risk assessment plan cannot be efficient devoid of an all-round monitoring system (see e.g. Box 8.6).

Box 8.6: Monitoring is an all-the-time exercise, mainly during;

- The treatment process,
- Final effluent quality analysis and distribution,
- Effluent storage,
- Effluent application (e.g. through irrigation etc.),
- Evaluation of crops response to the effluent and its constituents e.g. micro and macro-nutrients (e.g. N, P, K, S, Mg etc.),
- The operation of the irrigation drainage systems to regulate the water table, control waterlogging and salts accumulation in the soil,
- The assessment of the response of the field workers, crop handlers (e.g. health status, adherence to the guidelines etc.), and
- The analysis of the response of the consumers of the end product(s) etc. – examine the consumer satisfaction

Presence of a real-time monitoring system enhances operation and maintenance of various infrastructure within the entire treatment and effluent allocation plan. According to (Pescod and Mara, 2013) routine monitoring permits a regular assessment to be made of whether or not the effluent is complying with the local discharge or reuse standards. Lack of a real-time database diminishes possibilities to plan for the water resources and reduces chances to improve the existing plans. Data and the relevant information on water resources as well as wastewater management in MRB is still scanty. 39% of the respondents in the Mara basin confirms that real-time databases are either not available or not accessible to some experts, researchers and the general public (see Figure 8.13). Additionally, 46% of the respondents do not have any idea whether there is real-time database(s) or not. It is therefore important to invest in stakeholders' capacity building and other relevant trainings in line with modern technology such as application of online platforms etc.

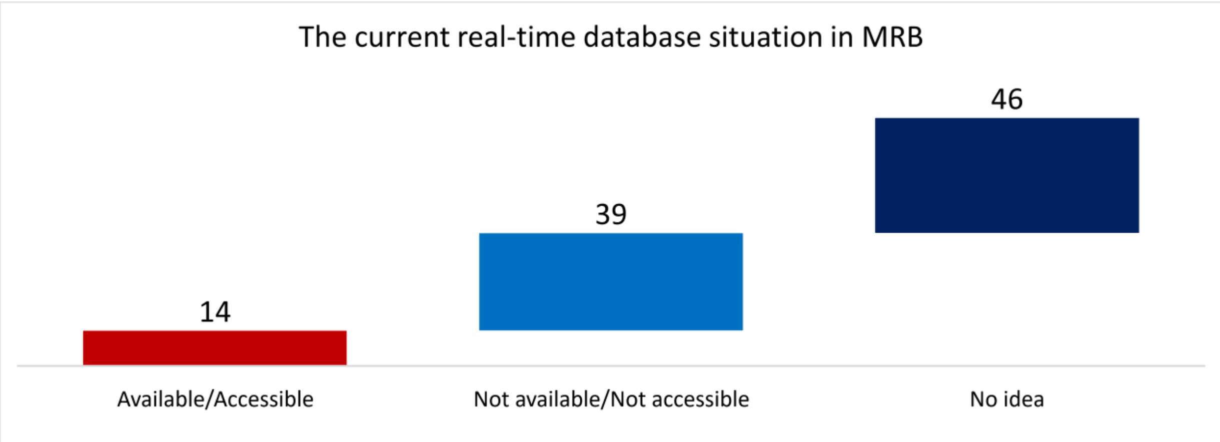

Figure 8.13: The current real-time database situation in Mara River basin

A notable real-time monitoring system that could be employed in the water reuse schemes e.g. by the farmers in the case study areas include "smart farming." Smart farming involves new technologies such as the Internet of Things (IoT) and Cloud Computing thereby drawing attention on the use of information and communication technology (ICT) in the cyber-physical farm management cycle (Wolfert et al., 2017). The IoT devices (such as wireless sensor networks, network-connected weather stations, cameras, and smart phones) can be used to collate vast amount of environmental and crop performance data, ranging from time series data from sensors, to spatial data from cameras, to human observations collected and recorded via mobile smart phone applications (Jayaraman et al., 2016). Therefore, the success of smart farming is strongly pegged on four main aspects, namely, (i) technology, (ii) diversity of crop and livestock systems, (iii) networking and (iv) institutions (e.g. markets and policies) (Walter et al., 2017). Smart farming could become practical especially in developing countries if the information and communication technology is first managed locally at the farmers' associations level and other relevant group of stakeholders to widen the expertise spectrum and share the cost that come with the procurement, installation and O&M of the systems related to smart farming. However, it should be noted and emphasized that technological expertise (e.g. Internet of Things (IoT) and Cloud Computing in smart farming etc.) cannot be substituted by the engagement of farmers' associations and other stakeholders, unless the needed technological expertise is drawn from the farmers' associations and/or the stakeholders themselves, which is possible. Engaging unskilled or non-professional stakeholders can even lead to a chaotic implementation or even failure of smart farming and other related projects. Therefore, as much as it is noble to source the technological expertise locally if it is available – so as to promote local experts – there must be strict adherence of the required standards.

In Kenya for example, the Kenya National Farmers' Federation (KENAFF) and the Women Farmers Association of Kenya (WoFaAK) as well as other farmers' cooperatives and unions could collaborate with the county governments, NGOs and local farmers to uplift the smart farming at the local levels through (i) the establishment of an all-inclusive digital platform that has relevant data for the farmers and other stakeholders, (ii) educate/train local farmers on the hands-on ICT issues, and benefits of smart farming etc., (iii) provide financial support for the procurement of the relevant digital equipment, (iv) facilitate the installation and protection of the digital equipment as well integration of the installed digital system with locally available information and communication networks, (v) connect farmers digitally e.g. using their mobile phones etc. to the local and global market, and (vi) provide constant O&M to the digital systems. Various ICT policy documents in Kenya (see e.g. Ministry of ICT Strategic Plan 2013 – 2017; Kenya National ICT Master Plan 2013/14 – 2017/18; Kenya Digital Economy Blueprint 2019) aims at digitization of the agricultural sector through development of a digital land management system, Geographic Information System, mapping of farm productivity, forecasting, digital meteorological systems, and market information systems, e-farming, farm produce management systems, agricultural information systems, remote sensing, population management systems and health and nutrition information systems. The digitization process is meant to collect data of all farmers on all commodities and connect farmers and other stakeholders via mobile phones and other end-user devices. The ultimate goal(s) of the ICT policy documents is to offer new opportunities through innovations that upscale the agricultural value chain, bring farmers closer to the traders through electronic trade platforms – where there is access to timely and accurate marketing and price information –, and connect government, farmers and agro-business to improve food security. In addition, an electronic animal monitoring system that is able to track livestock ownership for security reasons and feeding practices is to be implemented in order to provide end to end data of farm animal produce and finally open up the global market for Kenyan meat and increased trade opportunities. Unfortunately, there has been minimal progress and actualization of the Kenya ICT policy documents within agricultural sector. It should be noted that, the success of smart farming will contribute to sustainable consumption of water (and possibly treated wastewater) in farms, thereby impacting positively on the IWRM realization.

There are major considerations in developing an instrumentation/control system for a reclamation facility according to (US EPA, 2004), namely, (i) ability to analyze appropriate parameters, (ii) ability to maintain, calibrate, and verify accuracy of on-line instruments, (iii) monitoring and control of treatment process performance, (iv) monitoring and control of reclaimed water distribution, (v) methods of providing reliability, and (vi) operator interface and system maintenance.

A monitoring and evaluation (M&E) plan for the reuse of treated effluent and excreta has been proposed by this study (Figure 8.14). According to (Pahl-Wostl, 2015) "*Monitoring and evaluation are essential prerequisites for learning for any adaptive governance and management approach. This implies setting tangible short-term targets for assessing success or failure and implementing transparent processes with respect to who decides on which kind of evidence is required for the adjustment of policies and/or measures.*" Therefore, the management of the TEA-Plan is highly pegged on the practical monitoring and evaluation program.

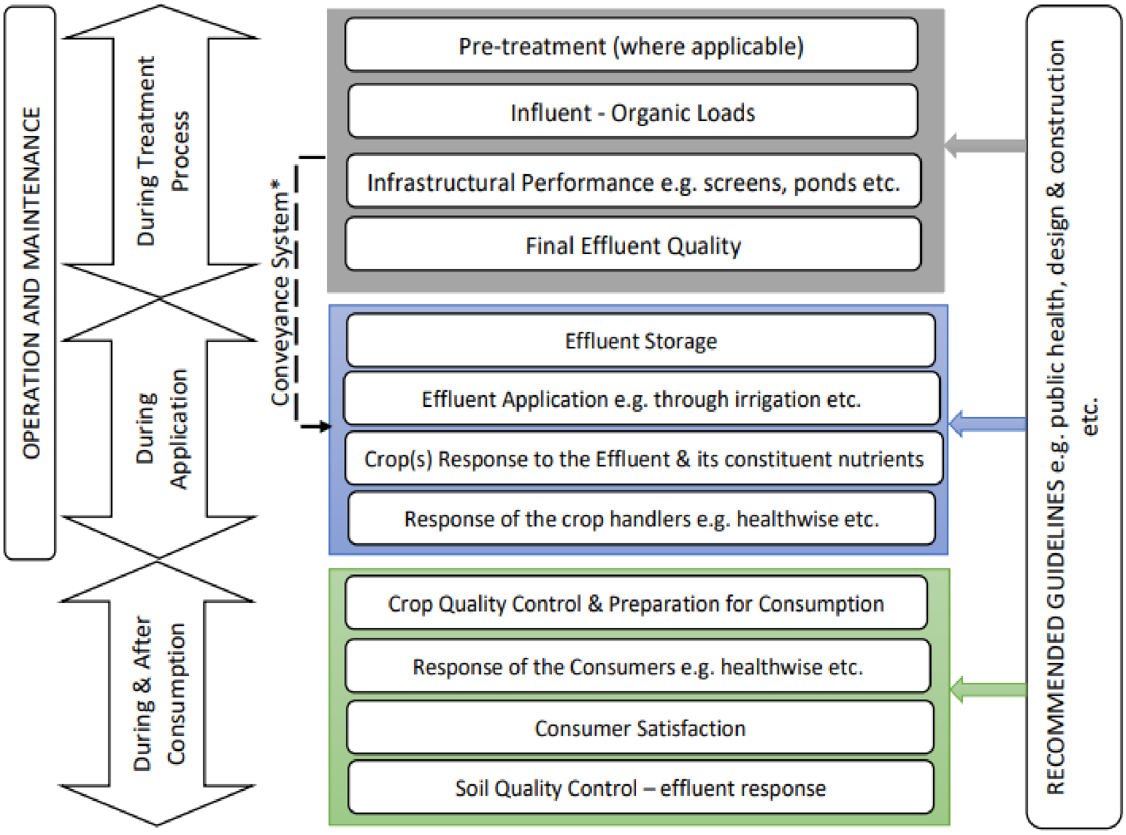

Figure 8.14: Monitoring and Evaluation (M&E) plan for the water reuse
*Encompasses all distribution network involved in the entire M&E Plan; especially in the first and second compartment (grey and blue areas) respectively.

8.5c Post Allocation Stage: Measures to be Taken After the Actual Execution of the TEA-Plan

8.5c.1 Crop Preparation for Consumption

There are clear guidelines (e.g. WHO, 2006) on major exposure points for the reuse of excreta and greywater and on the preparation of crops after harvesting for consumption. This includes care taken during transportation, as well as handling crops in the market places. In this case, vendors and consumers are encouraged to thoroughly wash the crops with clean water before consumption. Water used to clean crops should have attained certain level of treatment for it to be categorized as clean. There are tendencies of labelling water as clean in some cases even without having achieved the expected level of treatment e.g. water from some polluted water bodies. The crop markets should have water points where all vendors and consumers can easily wash the crops before consumption (see for example Figure 8.15). Additional notice boards visible and understandable – (preferably written in the local language) – to all should be erected in market places. Local press and print media should also be used to educate the people on the best ways of handling such products. Relevant experts are expected to collaborate with vendors in the market places to create more awareness on the importance of cleaning the crops before consumption.

Figure 8.15: Water kiosks at Bomet and Mulot markets respectively in MRB, Kenya

Although the water kiosks at Bomet and Mulot market are mainly meant to offer drinking water for the vendors and the community, the capacity should be increased to cater for the washing of crops and other water reuse based products to safeguard the health of the public, in the event such water reuse schemes are implemented.

8.5c.2 Assessment of Consumers Satisfaction

It is always noble to establish whether the consumers are satisfied with the supplied products or are complaining and if their complaints are being addressed. This will enable the planners and suppliers of the resource(s) to look for means of improving the future services as well as safeguarding the consumers from unforeseeable risks. Consumer satisfaction is directly influenced - or affected positively or negatively - by the ability to meet (or supply) their specific taste(s) and preferences. Narrowing down to the specific water reuse priorities is a prerequisite for the fulfillment of the community's primary demand e.g. food crop(s). Owing to the fact that majority of local stakeholders in Mara River basin are agriculturalists, crops like maize, wheat and other cereal products as well as vegetables have been established as the core water reuse priorities. Effluent supply to the irrigation farms (or fish ponds) should contribute positively to the efforts of addressing water insecurity issues in any region of its reuse. Majority of the respondents in the case study area feels that their complaints concerning water and wastewater related services have not been implemented (Figure 8.16). This is an indication that a lot has to be done towards the implementation of the lodged complaints as well as encouraging more ideas in the stakeholders' forums. Accessible and simple complaints lodging platforms and timely response is always the best approach to achieve consumer contentment. A case of instilling fear to the complainants so as to stop them from lodging further complaints in the future should never arise.

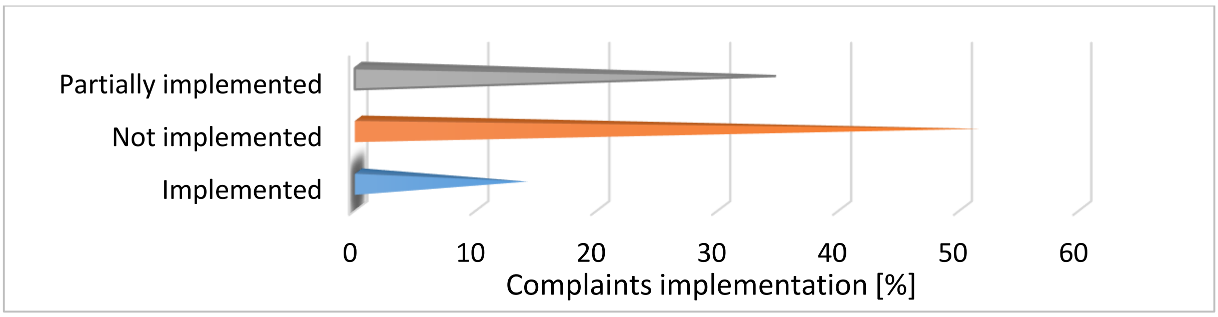

Figure 8.16: Rate of complaints implementation on water and wastewater services

8.5c.3 Establish Areas of Improvement

The entire plan, policies and legislative framework need a constant review to meet the growing demand and changes in the guidelines and standards. The force behind the aforementioned appraisal include but not limited to the new scientific revelations, technological changes, consumer tastes and preferences, and possible dynamic constituents of the generated wastewater. The enhancement of such plans is not independent from other existing strategic plans within the basin. Integration as envisaged in the IWRM paradigm is inexorable towards addressing various challenges in the basin and transboundary realms. Additionally, the entire spectrum of stakeholders should actively be consulted and motivated – starting from the local stakeholders – through incentives and other means of inculcating positive mindsets.

8.5c.4 Land Preparation for the Next Season

There are various existing land preparation guidelines (e.g. WHO, 2001, 2006; FAO, 2010; EPA, 2012 etc.) that should be employed by farmers through the guidance of agricultural and public health officers among other relevant experts. Land preparation for irrigation may involve more site control measures such as restrictions on the times that irrigation can take place, restrictions on the access to the irrigated site and creation of buffer zone around areas irrigated with reclaimed water etc. (US EPA, 2004). The size of the buffer zone is often associated with the level of treatment the reclaimed water has received and the means of application (US EPA, 2004). The reason for buffer zone is due to possible drifting of water droplets or aerosols by wind from sprinkler systems and this may be solved by dropping nozzles closer to the ground to reduce aerosol drift and thus minimize the buffer requirements (US EPA, 2004). More trainings to the handlers may be necessary in case the numbers of workers in the field are to be increased, and when new skills and/or technology is to be passed on to the handlers, and other stakeholders.

8.5c.5 Quality Assurance

A three-tier analysis on quality assurance, based mainly on the effluent, soil, and crop, forms the cornerstone of a successful water reuse scheme (Figure 8.17). The three-tier does not by no means exclude any other parameters of the quality assurance. Addressing the quality of these three components will by far guarantee safety and health of the handlers, and consumers of the end products.

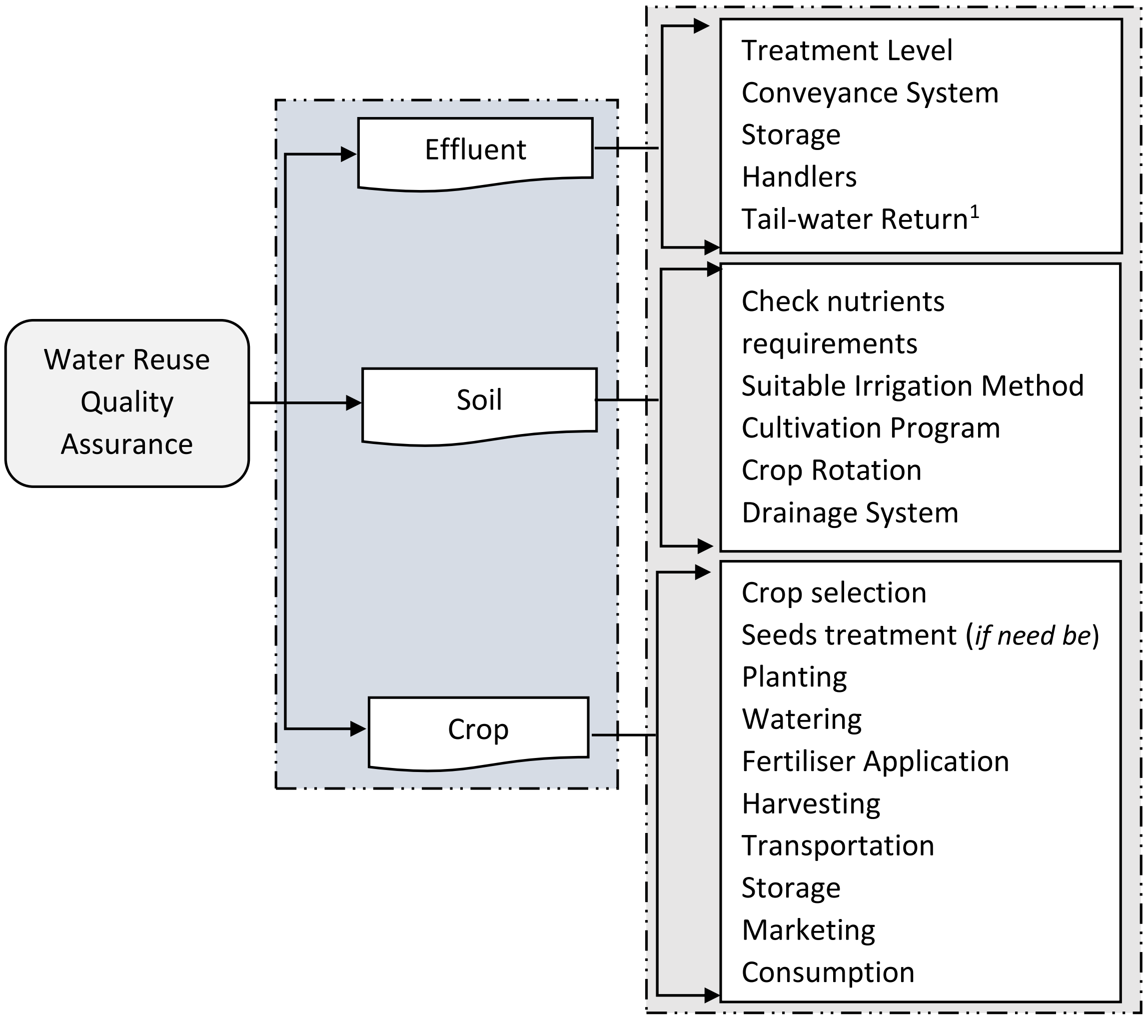

Figure 8.17: Three-tier analysis of water reuse quality assurance
Note: The three-tier analysis is proposed by this study.
[1]Details on tail-water return or pump-back is found in *e.g.* (US EPA, 2004)

8.5c.5i Effluent

A foreshadow of the possible success of the effluent at point of reuse is embedded its constant analysis and monitoring for the quality standards e.g. log unit reduction etc. The professionalism observed in the design, construction, operation and maintenance of the conveyance network, treatment works, storage facilities and application/irrigation infrastructure contributes directly to the performance of the effluent. The workforce (e.g. operators or field workers), vendors and the consumers forms a vital component of the water reuse that contributes highly to the accomplishment of the effluent based schemes. Additionally, (US EPA, 2004) recommended some method of tail water return or pump-back where reclaimed water discharge is not permitted. This step ensures that the expected treatment level is achieved in the environment of an upgraded or an integrated treatment system as well as handling of the effluent during and after irrigation exercise. It should be noted that an effluent that meets given reuse standards must be preceded by optimized and properly working treatment systems. This calls for a quality assurance (QA) in monitoring of a reclamation program. (see details in section 3.4.3.4 as published by US EPA, 2004).

8.5c.5ii Soil

The type and integrity of the soil is crucial for the growing crop. The expected water holding capacity and the soil aeration are some of the crucial elements of a soil with a good structure. The fertility of the soil dictates that the soil must meet the minimum nutrients value required for a successful germination, growth and development of the selected crop. The soil should be free from harmful crop insects and devoid of underlying disease carrying vectors. There should be a mechanism to control or get rid of any crop pests (e.g. insects, rodents, nematodes etc.) and infectious pathogens (e.g. virus, fungi, bacteria etc.) that thrive mostly in the soil, in the seeds and field crop(s). The soil preparation as well as design and construction of suitable irrigation infrastructure will provide an assurance for a successful crop growth and achievement of high yields. This entails proper drainage systems to control the water table and prevent waterlogging.

8.5c.5iii Crop

The third tier should focus on the methods of handling the selected crop e.g. from the seed selection and treatment, planting, watering and fertilizing, harvesting, transportation to the market, possible storage of the produce before selling to the consumers, and washing before consumption etc. Crop selection should be based on the rate of water consumption, tastes and preferences/market/demand, crops categorized under unrestricted or restricted irrigation, climatic conditions, crop versatility, resistance to pests and diseases, required workforce, expertise and technological system etc. Salt accumulation in the root zone of the growing crop should be avoided through a properly designed and operated drainage system. Constant capacity building and community sensitization as well improvement on the relevant micro-governance policy framework is without a doubt part and parcel of a successful water reuse quality assurance programs.

There are other elements of TEA-Plan whose control is also important before, during and after the reuse exercise in order to maintain the set quality standards, (*see e.g.* monitoring and evaluation plan section). Although samples (e.g. soil, effluent, manure etc.) are likely to be analyzed in a certain laboratory far from the site – as is the case mostly due to lack of relevant and well equipped facilities in the case study areas –, *on-site* sample analysis would be recommended to offer likelihood of less costly and timely services. *On-site* analysis enables close-range monitoring of the system performance and would encourage the local community and other stakeholders to acquire necessary analytical skills and participate in the exercise where possible. This is an opportunity to employ real-time online analysis of various quality parameters. Quality assurance officers should be deployed *on-site* to facilitate implementation of the aforementioned international and national applicable standards as well as other localized guidelines. US EPA, 2004 recommends sampling of the effluent by supplier at specific intervals for specific constituents at the water reclamation plant and, in some cases, in the distribution system. Improvements in treatment process reliability, risk assessment, and public confidence in reuse systems in conjunction with increasing water demands and pollution control requirements have promoted the integration of water reuse into water resources management strategies throughout the world (Asano and Levine, 1996) which is a prerequisite for quality assurance in any integrated TEA-Plan.

8.6 The Costs and Benefits of the Water Reuse

The costs of the reuse option could include the installation or upgrade of wastewater treatment systems to produce effluent of the desired standard, any addition or modification to the infrastructure for water and reclaimed water distribution, the extra recurrent costs of treatment, and the cost of any produce restrictions imposed by the use of reclaimed water in irrigation (FAO, 2010). Where climatic and geographical features are suitable, low-cost treatment of wastewater may be an option through the use of ponds system, constructed wetlands, etc. (FAO, 2010). For further economic justification and financial feasibility of wastewater and excreta reuse (see e.g. FAO, 2010; WHO, 2006).

8.7 Possible TEA-Plan Customization Strategy in the Micro-Governance Water Level

Owing to the unique characteristics of the micro-governance water units (e.g. local water utilities, community initiatives, water resources users associations, sub-basins and zones water management organizations, etc.), TEA-Plan should explicitly – in the region of interest – focus on the specific (i) population behavior (e.g. in terms of water consumption, socio-cultural alignment, economic activities, tastes and preferences, etc.), (ii) existing regulations (with a possibility of formulation and enactment of new and updating regulations and policies), (iii) resource availability and variability, (iv) current demand and its dynamic behavior, and (v) climatic conditions among other considerations. Wastewater and excreta generation, propagation, treatment and disposal or reuse patterns should equally be considered. The TEA-Plan should basically be an all-inclusive (e.g. foster integration and collaboration among actors in all directions), social-culturally and economically viable, politically acceptable, and efficient etc. Water regulators and operators should understand these facts on the ground and employ them before (design stage), during (execution stage) and after the effluent allocation plan. As previously discussed, Figure 8.7 shows the possible order of events or the so called the building blocks of treated effluent and excreta allocation plan. Customization of the TEA-Plan is a prerequisite for the stakeholders' acceptance of the water reuse project and the end products, motivation to participate, and the ultimate consumer satisfaction. The customization process may be somehow complex and time consuming but eventually simple to; implement, monitor, revise or improve where necessary, and detect and rectify possible hazardous events (uncertainties) etc. Investing in the customization process boosts integration, enhances sustainability, as well as the medium and long-term benefits.

The complex nature of the water reuse could be simplified through (I) constantly studying the supply and demand patterns which may fluctuate with time, (II) following all the set guidelines and standards (e.g. on the protection of the public health, selection of tools and equipment, design, and construction of the relevant infrastructure), (III) constant and updated operation and maintenance of the water reuse system, (IV) capacity development and engaging the local stakeholders to increase project's acceptability. This should also address the socio-cultural stumbling blocks, (V) updating, customizing and synchronizing the relevant regulation framework, policies, and strategic plans, (VI) timely funding of the reuse project(s), (VII) establishing a good working relationship between public and private partners in the region of interest, (VIII) engaging lawmakers/legislatures and the local/national government in order to obtain the relevant political will, and (IX) employing innovative and real-time monitoring system(s).

8.8 Possible Challenges of the Integrated TEA-Plan

Implementation of Integrated TEA-Plan, like any other plan, is bound to a couple of pitfalls (see Box 8.7).

Box 8.7: Possible challenges of the integrated TEA-Plan;

- Lack of political will – from local, county and the national level,
- Variability of the resource – sometimes unpredictable fluctuations,
- The demand – highly dynamic,
- Climate change – high uncertainty levels,
- Lack of consumer satisfaction – changes in tastes and preferences, poor quality products etc.
- Lack of or poor adherence to the relevant guidelines/standards e.g. public health etc.,
- Poor infrastructural design, construction, operation and maintenance,
- Absence of or poor monitoring and not up-to-date database especially on wastewater, pollution sources, water demand, etc.
- Scanty information on wastewater propagation routes e.g. point and non-point,
- Ghost polluters i.e. unmonitored and unlicensed wastewater disposers, and,
- Delayed review and synchronization of the relevant policies, and strategic plans etc.

Though difficult to quantify, especially in cases where source(s) of wastewater is unknown, it is unfortunate that some experts such as environmental protection authorities, technical water managers and water services providers in the case study area have no relevant data on the quantity of wastewater generated (including the known sources) and do not have a clear wastewater management plan. Wastewater emanating from car washing lots, learning institutions, hospitals, commercial activities, and agricultural fields are rampant and not properly quantified or regulated. A survey on who to blame for the increased river basin degradation (Figure 8.18) shows that some leaders, poor politics and law enforcing agencies and to some extent polluters such as hospitals, agricultural activities, and learning institutions etc. are largely blamed for the current “shaky trust” that the stakeholders in case study areas have towards the water reuse plans.

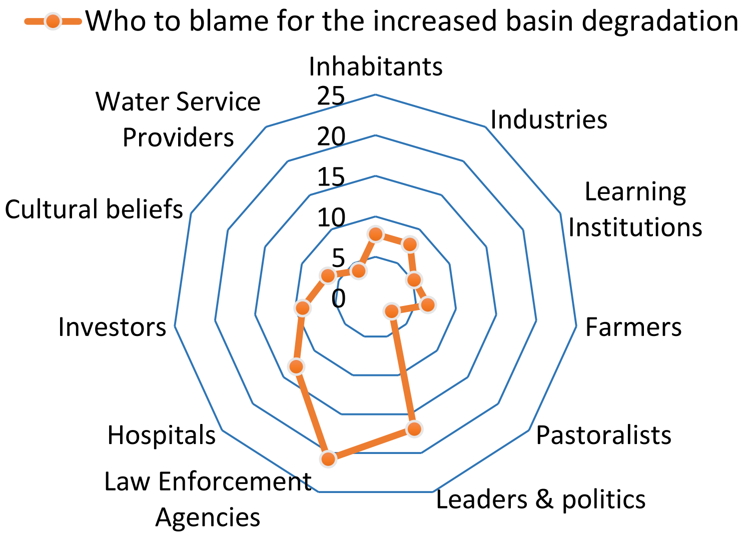

Figure 8.18: A survey on who to blame for the increased basin degradation in MRB

Institutional barriers – the human side of politics, public policy, and decision-making associated with technological advances – as well as varying agency priorities can make it difficult to implement water reuse projects in some cases (Metcalf et al., 2007).

One particular area that requires urgent efforts towards enhancing inter-disciplinary coordination between the technological and the social sciences concerns the study of the uncertainties and conflicts emerging around the management of water and water services (Castro, 2007). There are several uncertainties that lay ahead of any water reuse plan. According to (Sayers et al., 2013), the levels of uncertainty increases with time and are driven by factors such as climate change, socio-economic change and management responses (Figure 8.19). The large uncertainties usually connected to water management with respect to the physical settings, climate, socio-economic and political environment make it difficult to develop a consistent water management strategy (Van der Keur et al., 2008).

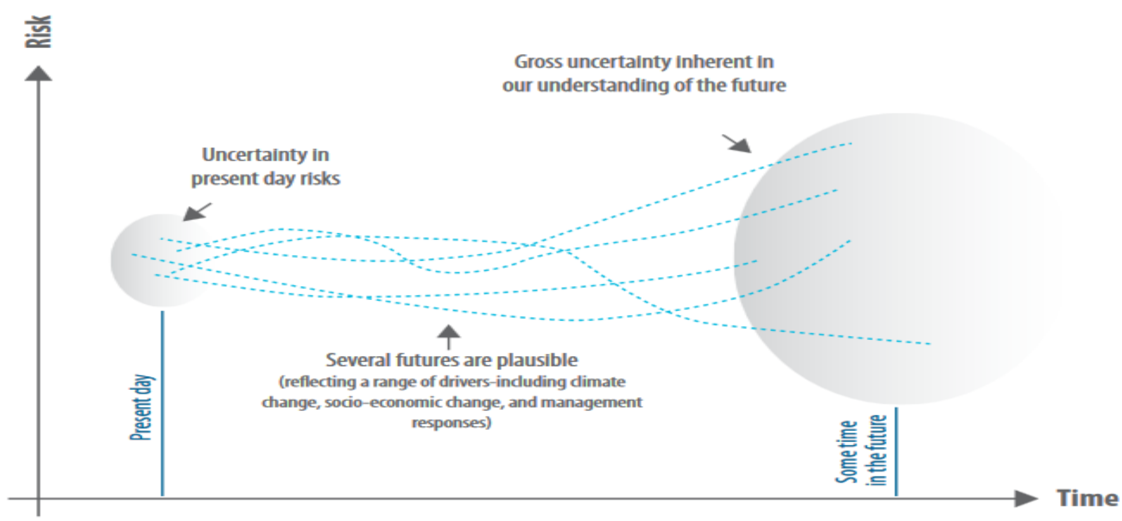

Figure 8.19: Increasing levels of uncertainty with time
Source: (Sayers et al., 2013)

There is hope that depoliticizing water management activities and instead presenting them as mainly (or even merely) "technical" in nature would provide opportunities for abating or at least controlling water uncertainty and conflict (Castro, 2007). In a country like Kenya where political alignment shifts so often, more uncertainties driven by political interference on the existing allocation plans are experienced. Additionally, poor representation of some stakeholders in the future – if not addressed – may result to a decline in the popularity of the plan as well as challenges in its implementation, and lack of timely and constant evaluation or monitoring of its performance. The implementation of any long-term vision on water governance will require the understanding of the immense changes and challenges that are likely to be faced in the coming years, and on defining the ways in which these can be best understood and addressed for the overall socio-economic benefits of the countries and their citizens (Tortajada, 2010). Social participation in relation to problems of water uncertainty and risk is a central component of the process of democratic governance (Castro, 2007). The regulators and operators as well as all users or consumers have a great role to play in order to ensure that a well-informed uncertainty preparedness is established (see for example Figure 8.20). This could be achieved by (i) installing real-time monitoring systems that will facilitate prediction of the future scenarios, (ii) use of modelling tools, (iii) employ the modern weather forecasting technology, (iv) establish groups of experts drawn from intra and inter-sectors, vulnerable and marginalized actors, as well as the overall horizontal and vertical representatives, (v) conducting environmental and social-cultural impact assessments of all projects, and (vi) political considerations.

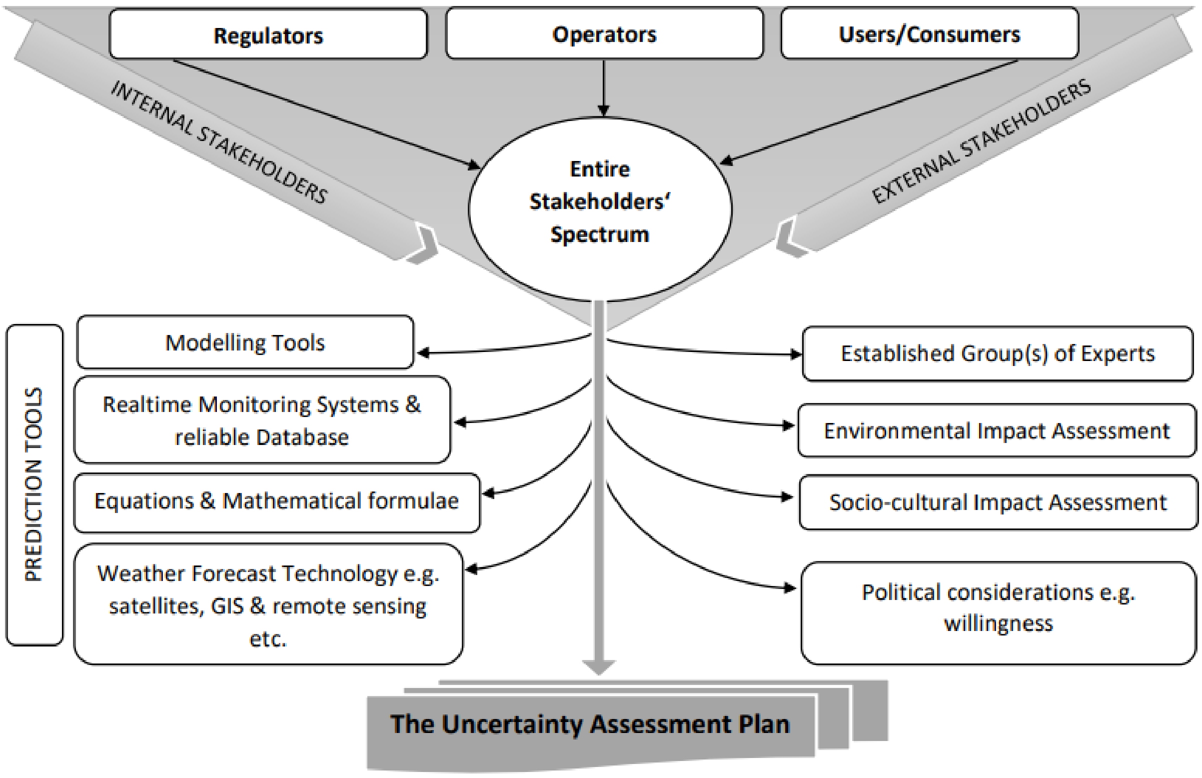

Figure 8.20: The Uncertainty Assessment Plan

Additionally, integrated TEA-Plan cannot excel independently but rather requires intertwining with other existing strategic and water allocation plans in the region.

Basically, there have to be radical changes in the governance processes and the institutions responsible for water to cope with the immediate challenges, potential future changes and uncertainties both from within the sector and around the sector (Biswas and Tortajada, 2010).

While acknowledging that incorporating wastewater reuse programs within the overall water resources management of a country, state, and region etc. is not a simple task, (Shelef, 1991) outlines some general considerations for a successful water reuse, namely, (I) the consumptive uses of the reclaimed waters, (II) the water quality required for each consumptive use, (III) the degree of treatment required to attain the assigned water quality, (IV) monitoring and surveillance, (V) the overall economy and division of the treatment cost between 'environmental' and 'consumptive' purpose, (VI) agricultural irrigation techniques or methodology of urban reuse, such as establishing a dual distribution system, (VII) pricing of water to consumers according to their consumptive use and the quality of water, (VIII) risk assessment and public health considerations, (IX) public acceptance, education and endorsement respectively, (X) legal aspects e.g. on responsibilities, ownerships, 'water rights', risks and possible indemnities, and (XI) political aspects.

In a research on the drivers, challenges and solutions for water reuse, (Rudolph et al., 2020) provides seven fatal sins against local water management and the comments on *Why* these topics (see Figure 4.11) urgently need to be addressed and *How* to go about finding the lasting solutions in order to have a successful local water management e.g. on the water reuse etc.

Therefore, the implementation of the integrated TEA-Plan involves a procedural realization of its essential components (Figure 8.21) for a successful water reuse program.

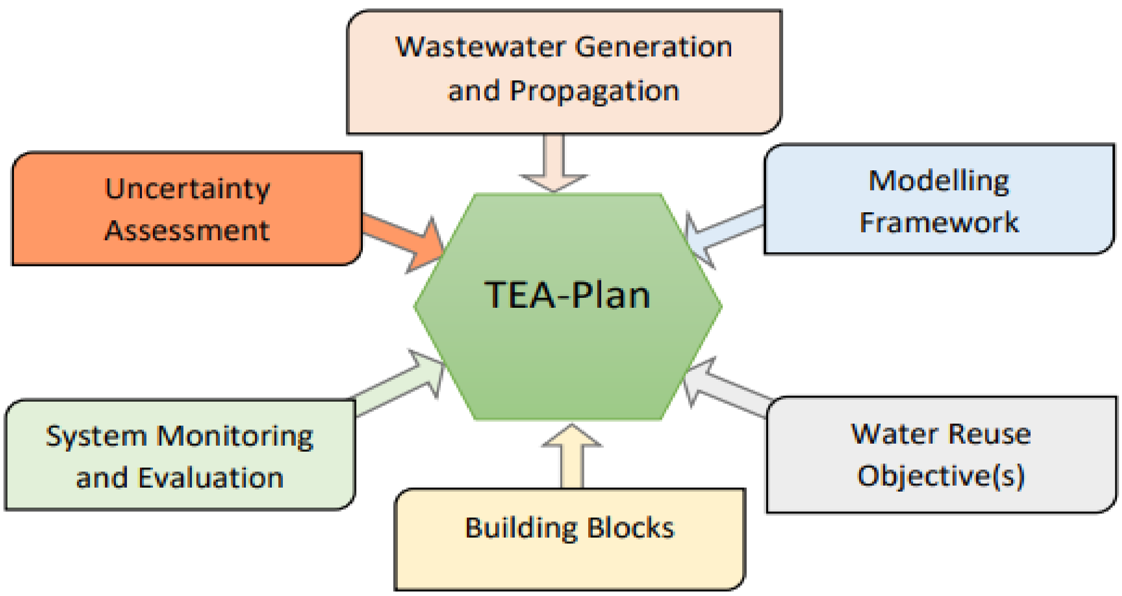

Figure 8.21: The fundamental components of the TEA-Plan
*See detailed discussion of these components previously in this chapter.

8.9 The Power of Public-Private Partnership (PPPP)

Partnerships between public and private stakeholders should form the core of the TEA-Plan as one of the key drivers to achieving IWRM. This will create a platform for diversification of ideas and innovations, increase chances of project acceptance by all actors, enhance efficiency, sustainability, and provide ready market for the end products etc. Various water reuse success examples from different cities in the world e.g. Irvine, Windhoek, Durban, and Singapore etc. have illustrated the power and driving force behind creating strong and working links between public and private sectors. Singapore has implemented all new technologies and the challenging O&M schemes under services contracting or PPP-Models. Without rapid access to the latest technologies, through PPP, Singapore wouldn't have been able to realize the progress it has realized.

Therefore, the sub-Saharan Africa and other developing countries should strongly invest in the new technologies and upgrading of the current water treatment and reuse systems to resolve the huge problems as explained under the problem statement. The local companies should work closely with the external investors, technology providers, and management service providers in order to achieve locally acceptable and sustainable wastewater treatment and reuse solutions.

The success of public private partnership in Kenya and most of the African countries has been hampered mainly by the political interferences and lack of public control and sense of ownership of the projects. Lack of engagement of the local community (especially the jobless youth and women) in the projects implementation brings about attacks on social networks and sometimes total rejection (e.g. through protests, and vandalism). A case in point is that some international construction companies have been accused of racial discrimination against their workers in Kenya and sometimes unreasonable lay off of workers. Additionally, there has been cases of adverse effects to the surrounding community due to poor assessment of the project's environmental and social impacts, hence affecting negatively the expected success of the public private partnership. Therefore, improvement on approaches or communication concepts is inevitable in order to have a successful PPP.

According to (Metcalf et al., 2007), planning of water reuse should evolve through a community value-based decision-making model so as to identify community values and priorities to guide planning from the beginning in the formulation and selection of alternative solutions. This is an essential component in the efforts towards activating the potentials hinged on the local and regional governmental and non-governmental initiatives such as catchment management groups (CMGs), community based organizations (CBOs), farmers associations, business community etc.

Chapter 9

Conclusions and Recommendations

9.1 Chapter Overview

The chapter finalizes this work by drawing all the necessary conclusions and recommendations in terms of the two major drivers of IWRM researched on in this study, namely, micro-water-governance and the water reuse.

9.2 Micro-Water-Governance

Proper water management at the appropriate scale(s) within the integrated basin governance systems can be achieved through coupling the water management and the local or micro scale(s) issues. It is evident that the slow implementation of the IWRM is as a result of neglecting the micro-governance water aspect and focusing too much on the macro-governance. The macro-governance approach has for so long denied the local stakeholders opportunity to showcase their role and ability in the safeguarding of the water resources. The developed interactive umbrella scheme of water governance and its performance evaluation criterion “the 5-Stars of a good water governance”, should be implemented in collaboration with the localized approaches taking into account the dynamism and uniqueness of every case study. This should be done through dissecting and addressing the very unique local level water governance challenges and opportunities before rolling the efforts out to the regional, national and the international domains. The transfer of models and findings to other research areas (e.g. river basins) should be preceded by a comparative analysis. All micro-water governance units such as, water resources users’ associations, wildlife conservancies, farmers, pastoralists, business community, women and youth initiatives, learning institutions, minorities and the general indigenous communities among other initiatives are some of the areas that should be emphasized through formulation and/or empowerment drive. The role played by such micro-units are immense only if they are given an opportunity to unlock their potential(s). Therefore, all stakeholders including the so labelled or thought as “insignificant” must be brought on board for an immediate action plan as they equally matter a lot in the entire water governance activities. Presence of water and other natural resources consumers in the entire exercise of water governance is a prerequisite for the enhancement of the level of satisfaction. Active participation contributes greatly to the satisfaction.

9.3 Water Reuse

Wastewater and excreta is “wealth” yet to be fully tapped by many river basins in the world. The problem of water scarcity could be solved significantly by the augmentation provided by the treated wastewater and excreta in various fields of application, namely, agriculture, aquaculture, land irrigation, industrial use etc. Additionally, the valuable nutrients mined from wastewater and excreta are highly beneficial to the growing crops, flowers in the gardens, grasses, fishponds etc. Water reuse offers a win-win situation economically and on environmental conservation at large.

An integrated treated effluent and excreta allocation plan (TEA-Plan) has been recommended by this study to spearhead further planning and implementation of the reuse of the reclaimed wastewater and excreta. This is a roadmap to capitalize the importance of investing in the values (see Figure 8.5) embedded on the wastewater and excreta. The following are the key considerations in the process of customization of the TEA-Plan in the river basin; (i) the typical generation and propagation routes of wastewater and excreta, (ii) integrated TEA-Plan modelling framework, (iii) specific objective(s), (iv) the building blocks, and (v) monitoring and evaluation (M&E) plan of the TEA-Plan among other considerations.

The laid out guidelines with the help of various experts such as agricultural extension officers, public health officials, quality assurance officers, managers, planners, and engineers etc. must be adhered to as the health of the public cannot be compromised. The two main conditions for the wastewater reuse as recommended by the World Health Organization – (namely, (i) only treated wastewaters should be used for crop irrigation, and (ii) the treated wastewaters should comply with the microbiological quality guideline) – and crop restrictions and measures for treated effluent and excreta reuse are crucial.

The developed TEA-Plan and the interactive umbrella scheme of water governance offers solutions to some of the challenges described in the sub-catchment management plan (SCMP) e.g. water shortage, wastewater disposal and pollution, deteriorating water quality, waterborne diseases, and human-wildlife conflict, etc.

APPENDIX A: Sample Questionnaires

§1: Water Governance

Water Governance Questionnaire

This research is funded by German Catholic Academic Exchange Service (KAAD) under Karlsruhe Institute of Technology (KIT) & Institute of Environmental Engineering and Management (IEEM), at University of Witten/Herdecke, Germany

Name:…………………………………………………………………………………… Date:……………

What section do you work in?...

(*Kindly provide data for the period 1990 – to-date in form of excel sheets, Tables etc. where possible. Thank you*)

1 a. What are your mandate(s) in terms of water services in the region? …………………..

b.Who are the other water service providers/actors in the region?...........................

c. How do you work or **coordinate with the other** water services providers? Any links?..

d. Describe **cases of overlap or incoherence of responsibilities** among the water service providers…………………………………………………………………………………………………

2 a.What are the **major challenges** related to the management of water resources in the basin?

Please, describe each challenge………………………………………………………………………….

b.To what extent has the following affected water related services in the basin?

[I] Modification of flow regime…………………………………………………………………………

[II] Physical water scarcity due to over abstraction, demand increase etc.

………

[III] High hydrologic variability e.g. precipitation, aridity, among other climatic issues…….

3 a.Who is in charge of water governance/management in the region?..

b.Are there micro-water governance (small-scale interventions) e.g. associations etc.?

[Yes] [No]

If Yes, (i) How do they operate/coordinate with the relevant actors both vertically and horizontally? Vertical coordination refers to coordination among actors from different governance levels (e.g. local, regional, national, international, sub-basin, basin, supra-basin). Horizontal coordination refers to coordination among actors from different sectors (e.g. water supply, agriculture). ………

4 Given that Mara River is a transboundary basin, how are consultations done among stakeholders, locally, regionally, nationally and internationally?................................

5 Are there coherent, coordinated, clear and up-to-date policies and legislations that govern water resources management? Say, water governance strategic plans locally?

[Yes] [No]

If Yes,

i. Give examples……

ii. How have they been implemented? ………………………………………………………………….

iii. What are their achievements? Please categorize them in the following order;

*The last 10 years……………………………………………………………………………………………….

*The last 15 years……………………………………………………………………………………………….

*The last 20 years……………………………………………………………………………………………….

If No, (iii) What should be done? Any efforts towards having some strategic plans?...

6 i. What are the existing water resources management conflicts in the basin?

………

ii.How has the conflict(s) in terms of stakeholders' coordination, water policy making, implementation, operational management and regulations been solved? Please, describe……………………………………………………………………………………………….

7 a. What's the level of stakeholders' participation and satisfaction?

[Very high] [High] [Moderate] [Low] [Very low]

b. What are the channels of communication or complains in case of poor service delivery or reporting an issue? ……………………………………………………………………………..

c. How have the complains been implemented?...

d.How could the level of satisfaction be enhanced?...

e.How is capacity building done among stakeholders?...

8 How have the local water utilities been promoted or empowered? To what extent do laws and regulations devolve decision-making power and financial resources to public actors at the lowest appropriate level of government?

……

9 What is the actual role given to the following in relation to water resources management?

(i)Water Resources Users Associations (WRUAs)…………………………………………………..

(ii)Wildlife conservancies in Maasai Mara-Serengeti……………………………………………

(iii) Minority/vulnerable groups such as Ogiek community etc………………………………

(iv)Informal groups, if any…………………………………………………………………………………..

10 Are the general basic human water rights namely, availability, accessibility, adequacy, safety, and affordability observed?

[Yes] [No]

If Yes, (i) How………………………………………………………………………………………………………

If No, (ii) What should be done?...

11 How are services delivered to the water consumers? …………………………………………..

12 How much water resources are within the basin?..

13 Who consumes or depends on the available water resources?.................................

14 How much does each consumer use (per capita per day)?...

15 a. What is the cost of water per litre? ………………………………………………………………

b.How much water is lost through evaporation etc.?...

16 How has household water security (Quantity & Quality) changed over the years? e.g. 10, 15, 20 years ago etc. Please describe further (kindly avail Tables, excel sheets etc.)

[Clearly improved/declined] [Slightly improved/declined] [hardly changed]

*The last 10 years…………………………………………………………………………………………………

*The last 15 years…………………………………………………………………………………………………

*The last 20 years…………………………………………………………………………………………………

17 Who should be given priority in the water apportionment with all fairness and keen consideration(s)……………………………………………………………………………………………………

18 Who are the other consumers who may use other means of quenching their thirst for water in the basin, say, treated wastewater reuse for irrigation farms, fish ponds etc.?..

19 a.How much is the designed environmental flow?..

b. What are the reasons for the failed implementation of the designed environmental flow?..

c.How has the state of environmental flow in 20, 15, 10 years etc. changed?

[Clearly improved/declined] [Slightly improved/declined] [hardly changed]

*The last 10 years……

*The last 15 years……

*The last 20 years……

Please describe further (with Tables, excel sheets etc. where possible)

………

20 Are the water resources distributed to all equitably and round-the-clock?

[Yes] [No]

If Yes, (i) How………

If Not, (ii) How should this challenge be solved?..

21 How have the main ecosystem services (water Quality & Quantity) changed in the last 10,15,20 years? Please describe further (with Tables, excel sheets etc.)

[Clearly improved/declined] [Slightly improved/declined] [hardly changed]

*The last 10 years……

*The last 15 years……

*The last 20 years……….

22 What are the water and wastewater infrastructural achievement?...

23 Are there real-time databases in place?

[Yes] [No]

If Yes, (i) How do they work……..

If No, (ii) What should be done to produce, update, and share timely, consistent, comparable and relevant water related data?...

24 Which water resources monitoring techniques are in place?...

25 What are the catchment protection mechanisms in place against degradation?..

26 Which innovative water governance practices are in place?...

27 a. Do you think there are any benefits of implementing IWRM in the Mara basin?

[Yes] [No]

If Yes, (i) who will benefit from such implementations?...

b.Who do you think will suffer if IWRM fails in the basin?

………

c.Who is to blame for the current increase of poor waste disposal, over abstraction of water, drying of Mara river, etc.?

………

§2: Water Quality

Water Quality Questionnaire

This research is funded by German Catholic Academic Exchange Service (KAAD) under Karlsruhe Institute of Technology (KIT) & Institute of Environmental Engineering and Management (IEEM), at University of Witten/Herdecke, Germany

Name:…………………………………………………………………………………………… Date:……………………

What section do you work in?..

(*Kindly provide data for the period 1990 – to-date in form of excel sheets, Tables, images etc. where possible. Thank you*)

1 a. What are the major sources of solid and liquid waste contamination in the region?
……

b. Select and describe in details at least two most dominating source of water contamination

……

c.How much (in volume) wastewater and sediment is generated in the basin?...

2 a.How is waste disposed in the region?..

b.What are the treatment measures taken before disposing both solid and liquid waste?

……

c.Is there any modern and effective wastewater treatment method(s) in place?

[Yes] [No]

If Yes, (i) Give examples………………………………………………………………………………………………………

ii. What are their achievements in terms of water quality improvement?
……

If No, (iii) What do you think is the best technology for the wastewater treatment?...

3 Which types of wastewater recycling/reuse measures are in place?...

4 How much wastewater (in volume) is captured by sewer lines?..

5 a.Which are the techniques applied to monitor the leaks and bursts to reduce unaccounted for wastewater from the source?...

b.Are there cases of illegal diversion(s) of raw sewage from manholes to private farms?

[Yes] [No]

If Yes, how are they dealt with?...

6 What are the effects of unregulated wastewater and excessive sediments to the <u>water consumers</u> and <u>water supply systems</u>?...

7 What are the types of pollutants embedded on the sediments? (*Kindly share the available monthly data*)……

8 Which types of water quality parameters have been **monitored** and **analyzed** so far? *(Kindly share the available monthly data*)……

9 a.What is the **technology** used to enable **real-time monitoring** of the water quality?

....

b.Which **technology** or approaches do you **suggest** towards finding a lasting solution on water quality problem?...

10 a How many <u>**Wastewater Ponds System**</u> are there in the basin?...

b How do they operate (specific techniques)? (*Kindly outline the procedure(s) used from the influent to the effluent; images requested*)……

c Is there any pre-treatment to the wastewater before getting into the Wastewater Ponds System?

[Yes] [No]

If Yes, which one(s)?...

If No, which pre-treatment methods do you suggest?...

d Is there a bypass channel at the entrance to transfer extra volume of sewage during floods?

[Yes] [No]

If Yes, (i) where to?

……..

If No, (ii) how do you deal with excessive sewage situation?

……..

e How many people are connected to the ponds system?...
.

f How many are not connected neither to the ponds system nor to the other means of wastewater treatment systems?...

g How much in volume (design treatment capacity) does the pond receive or meant to receive per day (m^3/day)?……………………………………………………………………………………………………

h What is the typical content/composition of the incoming wastewater?..

i Do the concentrations of the incoming wastewater/influent change over time?

[Yes] [No]

If Yes, What leads to this change(s)?..

j Which are the challenges faced as a result of changing concentrations of the wastewater?

……….

k What are typical parameters measured during the treatment process?

……….

l Which Water Quality standards are used to determine the suitability of the treated wastewater?..

m What is the effluent quality achieved in relation to the existing guidelines? (*Kindly provide detailed data. Extra Tables or excel sheets will be so helpful*)……

n Is there any monitoring of Wastewater Ponds System performance ?

[Yes] [No]

If Yes, which methods are used?..

If No, which method(s) do you suggest?..

o What is the efficiency (%) of wastewater ponds system treatment technique in the region?..

p How is the treated effluent from the wastewater ponds used?..

q Is there any tracking of the performance of the effluent to the environment, receiving bodies, irrigation farms, fish farms etc.?

[Yes] [No]

If Yes, how is it done?..

If No, which method(s) do you suggest for monitoring the effects of treated wastewater to the environment?..

11 a.Who do you think will suffer if Water Quality and the Environment is not protected from contaminations?

………

b.Who is to blame for the current situation in the Mara river basin?

………

c. Do you think there are any benefits of improving the situation in the basin?

[Yes] [No]

If Yes, who will benefit from such improvement(s)?..

APPENDIX B: An excerpt of the measurements of Dissolved Oxygen [DO] [mg/L] and Temperature [°C] at Bomet Wastewater Ponds System

	Dissolved Oxygen [DO] [mg/L]		Temperature [°C]	
DATE	**Maturation Pond 3**	**Maturation Pond 2**	**Temp. Pond 3**	**Temp. Pond 2**
15.10.2019	3,41	1.49	21.3	21.3
16.10.2019	5,8	4.38	21.1	21.8
17.10.2019	4,1	3.1	21.4	21.9
18.10.2019	3.81	2.1	21.1	21.4
19.10.2019	4,1	2.3	21.9	21.9
20.10.2019	4,0	2.4	22.3	22.9
21.10.2019	3.49	1.31	21.2	21.3
22.10.2019	11.9	3.66	22.2	22.6
23.10.2019	6.1	2.9	22.4	22.4
24.10.2019	5.3	3.1	21.1	21.3
25.10.2019	4.3	3.3	21.9	21.8
26.10.2019	6.1	3.9	22.3	22.1
27.10.2019	5.3	2.3	21.2	21.3
28.10.2019	4.34	3.75	21.4	21.6
29.10.2019	3.23	1.43	21.1	21.0
30.10.2019	10.36	3.5	19.4	19.7
31.10.2019	1.91	7.37	20.1	19.8
01.11.2019	4.39	3.45	21.2	21.3
02.11.2019	6.40	4.3	21.3	21.5
03.11.2019	4.3	3.1	22.0	22.3
04.11.2019	8.34	0.87	21.5	21.5
05.11.2019	6.79	1.86	20.4	20.6
06.11.2019	3.67	1.19	21.0	21.1
07.11.2019	4.26	3.74	21.4	21.3
08.11.2019	4.98	2.14	21.3	21.5
09.11.2019	4.9	2.40	22.1	22.2
10.11.2019	3.67	2.58	21.7	21.9
11.11.2019	5.95	3.14	21.9	22.0
12.11.2019	9.6	2.25	21.4	21.3
13.11.2019	4.61	1.07	21.6	21.3
14.11.2019	3.8	2.01	22.3	21.4
15.11.2019	2.1	1.41	22.6	22.9
16.11.2019	3.41	2.1	21.9	22.0

17.11.2019	4.38	3.9	21.3	22.2
18.11.2019	5.52	2.05	22.2	21.1
19.11.2019	8.20	5.27	22.5	23.0
20.11.2019	4.03	14.11	22.8	23.0
21.11.2019	13.91	8.91	22.0	22.1
22.11.2019	7.1	6.31	22.6	23.1
23.11.2019	4.9	5.8	22.0	22.4
24.11.2019	6.3	4.1	21.9	22.3
25.11.2019	3.8	2.2	21.0	21.9
26.11.2019	2.13	1.97	22.0	21.9
27.11.2019	2.81	1.81	21.8	23.2
28.11.2019	3.91	2.30	20.8	21.0
29.11.2019	4.3	3.8	21.0	22.0
30.11.2019	3.9	2.99	20.5	20.6
01.12.2019	3.51	2.46	21.8	21.8
02.12.2019	3.94	1.48	21.3	21.4
03.12.2019	3.88	2.1	21.0	21.6
04.12.2019	4.99	4.31	22.0	22.3
05.12.2019	5.14	3.1	22.1	22.4
06.12.2019	3.15	8.4	20	21.0
07.12.2019	4.1	3.8	20.1	20.9
08.12.2019	6.3	4.9	20.5	21.4
09.12.2019	3.3	2.1	20	20.5
10.12.2019	3.9	1.96	21.0	21.3
11.12.2019	1.98	12.11	21.2	20.4
12.12.2019	5.3	3.1	20.3	21.0
13.12.2019	3.45	2.0	20.9	21.3
14.12.2019	5.31	3.0	20.6	20.9
15.12.2019	4.3	2.31	20.3	21.4
16.12.2019	4.8	3.3	20.2	21.0
17.12.2019	1.55	1.5	20.9	21.0
18.12.2019	3.78	1.16	21.2	21.3
19.12.2019	2.18	1.39	21.7	21.6
20.12.2019	2.58	2.11	21.3	21.4
21.12.2019	3.8	4.1	20.3	21.0
22.12.2019	3.1	1.39	21.1	21.5
23.12.2019	4.1	3.1	20.8	20.6

24.12.2019	3.1	2.8	21.7	21.9
01.01.2020	13.34	6.5	22.2	22.5
02.01.2020	11.29	7.1	21.9	22.0
03.01.2020	13.65	6.8	22.1	22.4
04.01.2020	6.31	5.1	21.3	21.4
05.01.2020	8.1	6.3	21.4	21.6
06.01.2020	3.43	6.86	22.2	22.3
07.01.2020	2.15	2.37	22.1	22.3
08.01.2020	12.16	11.33	21.4	21.3
09.01.2020	6.3	5.3	21.3	21.8
10.01.2020	5.8	4.9	20.3	20.9

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