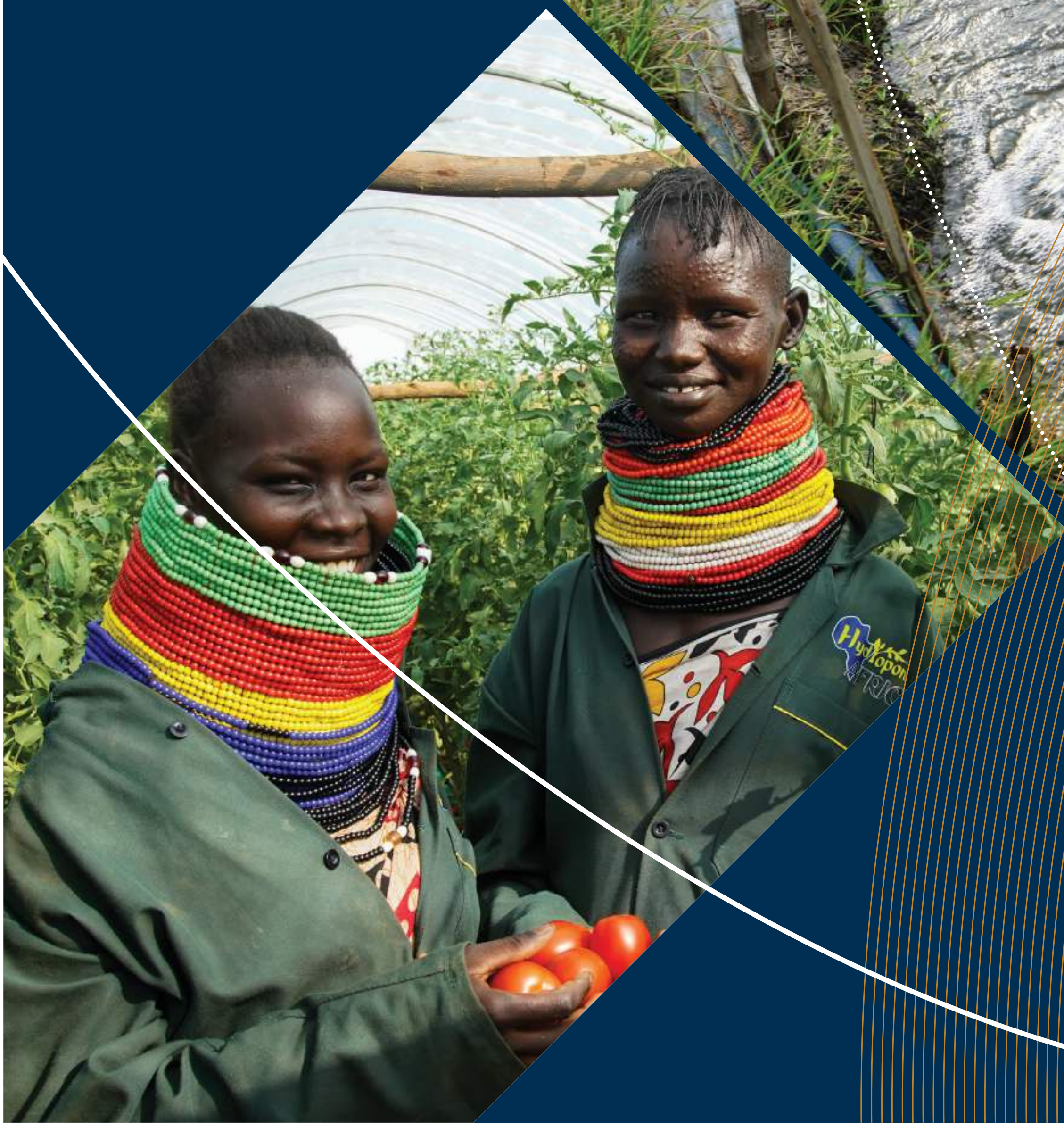
Feasibility Study
on Quality and Quantity of Water Available for Commercial Use
in Kakuma Refugee Hosting Area, North-western Kenya



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Contents

List of Abbreviations

AAH-I	Action Africa Help International
ADF	Agricultural Development Fund
AET	Actual Evapotranspiration
AFDM	Africa Flood and Drought Monitor
AI	Aridity Index
AIC	Africa Inland Church
ALOS	Advanced Land Observation Satellite
AMREF	African Medical & Research Foundation
AMSL	Above Mean Sea Level
AMT	Audio-Magneto Tellurics
ASAL	Arid and Semi-Arid Land
BCM	Billion Cubic Meter (10^9 m^3)
BCR	Borehole Completion Record
BGL	Below Ground Level
BH	Borehole
CA	Conservation Agriculture
CBO	Community Based Organization
CHC	Climate Hazards Center
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CIDP	County Integrated Development Plan
CLTS	Community Led Total Sanitation
CRT	Constant-Rate Test
CWR	Crop Water Requirement
DCA	Danish Church Aid
DEM	Digital Elevation Model
DfiD	Department for International Development
DRC	Danish Refugee Council
EC	Electric conductivity
EIA	Environmental Impact Assessment
EMCA	Environmental Management and Co-ordination Act
ERT	Electrical resistivity tomography
ET	Evapotranspiration
EWL	Earth Water Ltd
FAO	Food and Agricultural Organization
FFA	Food for Asset
GHG	Green House Gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
GRP	Gross Regional Product
GW	Groundwater
IFC	International Finance Corporation
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISUDP	Integrated Spatial Urban Development Plan
IWR	Irrigation Water Requirement
JICA	Japan International Cooperation Agency
JMP	Joint Monitoring Program
KATOWASE	Kakuma Town Water Services
KDRDIP	Kenya Development Response to Displacement Impacts Project
KEBS	Kenya Bureau of Standards
KISEDP	Kalobeyei Integrated Socio-Economic Development Plan
KKCF	Kakuma Kalobeyei Challenge Fund
KPHC	Kenya Population and Housing Census

KRC	Kakuma Refugee Camp
KRCS	Kenya Red Cross Society
Ksh(s)	Kenya Shilling(s)
KVDA	Kenya Voluntary Development Association
LOKADO	Lotus Kenya Action for Development Organization
LWF	Lutheran World Federation
m	Meter
MAI	Moisture Availability Index
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCM	Million Cubic Meters (10^6 m^3)
MoWSI	Ministry of Water & Irrigation and Sanitation
NARIG	National Agriculture and Rural Inclusive Growth
NDMA	National Disaster Management Authority
NEMA	National Environment Management Authority
NGO	Non-Governmental Organization
NMR	Nuclear Magnetic Resonance
NRC	Norwegian Refugee Council
NWMP	National Water Master Plan
NWHSA	National Water Harvesting and Storage Authority
O & M	Operation & Maintenance
PAYG	Pay-As-You-Go
PET	Potential Evapotranspiration
PPP	People Planet Profit
PWJ	Peace Winds Japan
RBA	Rights-Based Approach
RF	Rural Focus
RUSLE	Revised Universal Soil Loss Equation
RVBP	Rift Valley Basin Plan
RVWSB	Rift Valley Water Service Board
RVWWDA	Rift Valley Water Works Development Agency
RTI	Radar Technologies International
SW	Surface water
SWL	Static Water Level
TCADP	Turkana County Annual Development Plan
TCG	Turkana County Government
TDEM	Time Domain Electromagnetic
TRMC	Time Resolved Microwave Conductivity
TRP	Turkana Rehabilitation Program
UDDT	Urine Diversion Dry Toilet
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNHCR	United Nations High Commissioner for Refugees
USAID	United States Agency for International Development
USGS	United States Geological Society
VIP	Ventilated Improved Pit
VES	Vertical Electrical Sounding
WASH	Water, Sanitation and Hygiene
WASREB	Water Services Regulatory Board
WFP	World Food Programme
WQ	Water Quality
WRA	Water Resources Authority
WRUA	Water Resource User Association
WSL	Water Strike Level
WSP	Water Service Provider
WSTF	Water Sector Trust Fund
WWDA	Water Works Development Agency

Executive Summary

In March 2020, a study was started for IFC under the title "*Feasibility Study on Quality and Quantity of Water for Commercial Use in Kakuma Refugee Hosting Area, North-western Kenya*". During the Inception Phase, three project goals were formulated in order to define the project activities. These project goals are:

Goal 1 – Context analysis (present situation)

Determine the overall circumstances for agribusiness development in the Kakuma / Kalobeyei region in terms of water availability and social/legal situation.

Goal 2 – Room for development

Determine the room for development for agribusiness in the region, with emphasis on groundnuts.

Goal 3 – Assessment of possible measures

Determine which measures might be taken to mitigate observed limitations in terms of water resources and social/legal situation.

As a result of the study, the following conclusions can be drawn:

- There is potential for the implementation of irrigated agriculture in general in the region of study. However, given the present stress on the water resources, particularly evident from the water supply to the refugee settlements and host community, such a development requires investment in infrastructure. Both surface water and groundwater sources can be made available, but they need special attention in terms of more detailed assessments;
- Rain-fed farming in this part of Turkana is almost infeasible, but it can serve as subsistence to any other form of irrigation farming. Utilizing groundwater for large-scale irrigation is challenging as irrigation from borehole water competes with other water needs; groundwater serves as the only source of drinking in both Kakuma and Kalobeyei. Additionally, taking into account the hydrogeological conditions of the area and the associated impacts, drilling the large number of required boreholes is not sustainable; not only are sufficient groundwater yields questionable, but the higher salinity of groundwater versus surface water poses long term salinity risks from irrigation;
- The analysis shows that significant surface water resources are available, albeit highly seasonal and available only in short duration runoff events. The pertinent issue is therefore not the availability of surface water resources, but the infrastructure required to store the water so that it can be used for water supply or irrigation purposes. Possibilities are provided by water pans and other small storage devices. The analysis shows that there is plenty of land (133 km^2) suitable for water pan development. However, the most promising development for large scale irrigated farming is the implementation of the Tarach dam on the Tarach lagga (ephemeral watercourse). Further study into the feasibility and optimum size of the potential dam on the Tarach lagga is required as the present proposal for a 11 m dam height underestimates the actual potential, which with a 14 m dam height as an example, might sustain an irrigated area of about 650 ha. An assessment of the sediment load shows, though, that substantial catchment conservation efforts would need to be implemented to ensure the long-term reliability of the Tarach Dam;
- Groundwater resources can be used for the development of small agribusiness, with the most promising options found in the shallow alluvial (<35 m bgl) and medium depth (35<80 m bgl) aquifers,

with sufficiently good water quality. Effort should be made, though, to ensure that the present water supply to the refugee settlements is not negatively affected. The deep groundwater aquifer, which was presented as a promising resource in the study of RTI (2013), is likely saline and only more detailed study can disclose whether this aquifer should still be considered for exploitation;

- The cost implications of borehole drilling, operation and maintenance vis-a-vis the profit margin could be unsustainable despite a ready market of the groundnuts. Opportunities for further research could address alternative agricultural products whose water requirements are low and could provide additional sources of income for the community.

In addition, the following points should be taken into account when developing water resources for agribusiness:

- The shallow alluvial aquifer is the main reliable source of potable water. It spans approximately 4 km wide at both sides of the axis of Tarach lagga. The medium-depth sedimentary aquifer extends to about 10 km from the axis of the Tarach lagga and its smaller network of ephemeral tributaries;
- The most favourable sites for well field development are to the north west of Kakuma town adjacent to the Tarach lagga;
- Proposed boreholes are recommended along the Tarach lagga, targeting shallow alluvial aquifers (<35 m bgl) and medium depth aquifers (35<80 m bgl); this is where significant borehole data to inform the groundwater availability were available;
- Careful siting, drilling and design of the boreholes should be done to ensure optimum yields and quality are obtained;
- Appropriate sanitation facilities should be designed and developed to avoid contamination of the shallow aquifer;
- A well field should be set in a low-density residential area to avoid contamination through leakages and broken water infrastructure;
- For a proper assessment of the groundwater resources, beyond the scope of the present study, a modern, wide area, comprehensive regional geophysical exploration program characterizing the top 120 m should be carried out;
- There are potential long-term concerns on climate change, surface water being a major source of groundwater recharge;
- Groundwater has been treated here as an isolated resource, i.e. the connection with the groundwater and the possibility of conjunctive use could not be taken into account in this study due to insufficient data. This is important, because the alluvial aquifer is considered as the highest yielding aquifer, and promoting recharge to make use of surface runoff will be crucial;
- It is recommended to study the benefits of conjunctive use, using groundwater modelling in combination with the recharge from surface water whenever more data become available by additional and dedicated study using geophysical methods.

Other recommendations in the field of social and legal aspects include:

- The potential for large irrigation schemes exists as the communities are slowly adapting sedentary lifestyles and are more receptive to the concept of agriculture. Despite the interest demonstrated by the communities towards expanding agricultural livelihoods for refugees and host communities alike, inadequate water to support irrigated farming and livestock use is a major limitation. Hydroponic farming and vertical works are emerging technology being promoted to intensify agricultural production and water conservation. Large-scale investment in water supply has been identified as an important pathway to enhance refugee self-reliance (UNHCR, 2019).
- Consultations with the Turkana County Government (Director, Physical Planning) indicated two approaches to enable a private commercial entity to be able to lease land for a specified period, namely:
    - A private investor makes a proposal to the County Government, which after obtaining approval from CEC Lands and CEC Agriculture, would engage the community to obtain community consent;
    - A private investor negotiates and secures community willingness to release land for commercial enterprise and subsequently seeks County Government approval.
- The past efforts mainly support dryland agricultural production through the use of in-situ soil conservation practices such as trapezoidal bunds, spate irrigation and conservation agriculture. The experience provides local experience and knowhow on farming within the harsh climate of the Kakuma-Kalobeyei area. Recent trials by the Turkana County Government, FAO and Egerton University on farming groundnuts indicate the significant potential for upscaling.

  It is clear that the climatic conditions make reliable production difficult without irrigation, but the development of pans linked to irrigation systems and the use of hydroponics indicates that there is potential that can be developed. Furthermore, the local population (host and refugee) provide a ready market for fruit and vegetables.
- The legal framework for water development in the Kakuma-Kalobeyei area is generally well defined through the Constitution, which provides certain responsibilities for the national and county governments. These responsibilities are reflected in the prevailing legislation, most notably the Water Act, 2016 and the EMCA, 1999. Institutional capacity weakness means that certain aspects of the legislative framework have yet to be fully implemented.
- As a final remark it should be mentioned that this report, especially the Volume 2 - Annexes, has brought together a massive amount of material about water resources in the area of Kakuma and Kalobeyei and should serve as a resource for further water supply programs.

Introduction 1

On 5 March 2020, a contract was signed with the International Finance Corporation (IFC) to start the project "*Feasibility Study on Quality and Quantity of Water for Commercial Use in Kakuma Refugee Hosting Area, North-western Kenya*". Subsequently, a telephone kick-off meeting was held on the 23 March 2020. The objective was rescheduling several activities that have become difficult or impossible to implement within the initial stage of the project implementation due to the COVID-19 pandemic. The coronavirus outbreak impeded many activities worldwide, starting in winter of 2020. The results of this meeting can be summarized as follows:

- Set a break in the project implementation, with a distinction made between activities that can be done from "home office" and those that require a field visit (at time of project implementation nearly impossible due to the corona crisis);
- Setting that the first phase will run till 30 June 2020;
- Definition of an intermediate or 'pre-final' report at the end of the first phase;
- Agreement to discuss the final phase of the project at the end of June, or anytime earlier when the process of the corona pandemic allows for making plans for the second (final) phase. The second phase of the project included a field visit;
- Deadline for the delivering of the Inception Report set on 17 April 2020.

Although an important activity of the study, a field reconnaissance, could not be carried out due to the covid-19 pandemic, previous ample field experience of the various team members in the Kakuma / Kalobeyei region proved sufficient to be able to interpret literature and global data sources for the study. Checking of conflicting information, such as the number of boreholes in the region, could, however, not be carried out.

The division into activities and the consequences for the implementation of the project are discussed in Chapter 2. This chapter is a short summary of the full description given in the Inception Report. As a result of the reorganization of the project activities, the deadline for the delivery of the "Pre-Final Report" was set at 30 June 2020. However, the lack of basic information crucial for the judgement on the validity of conflicting information in various reports made it necessary to postpone this deadline till 30 September 2020, and the final deadline of the project to 31 January 2021.

1.1 Background Information

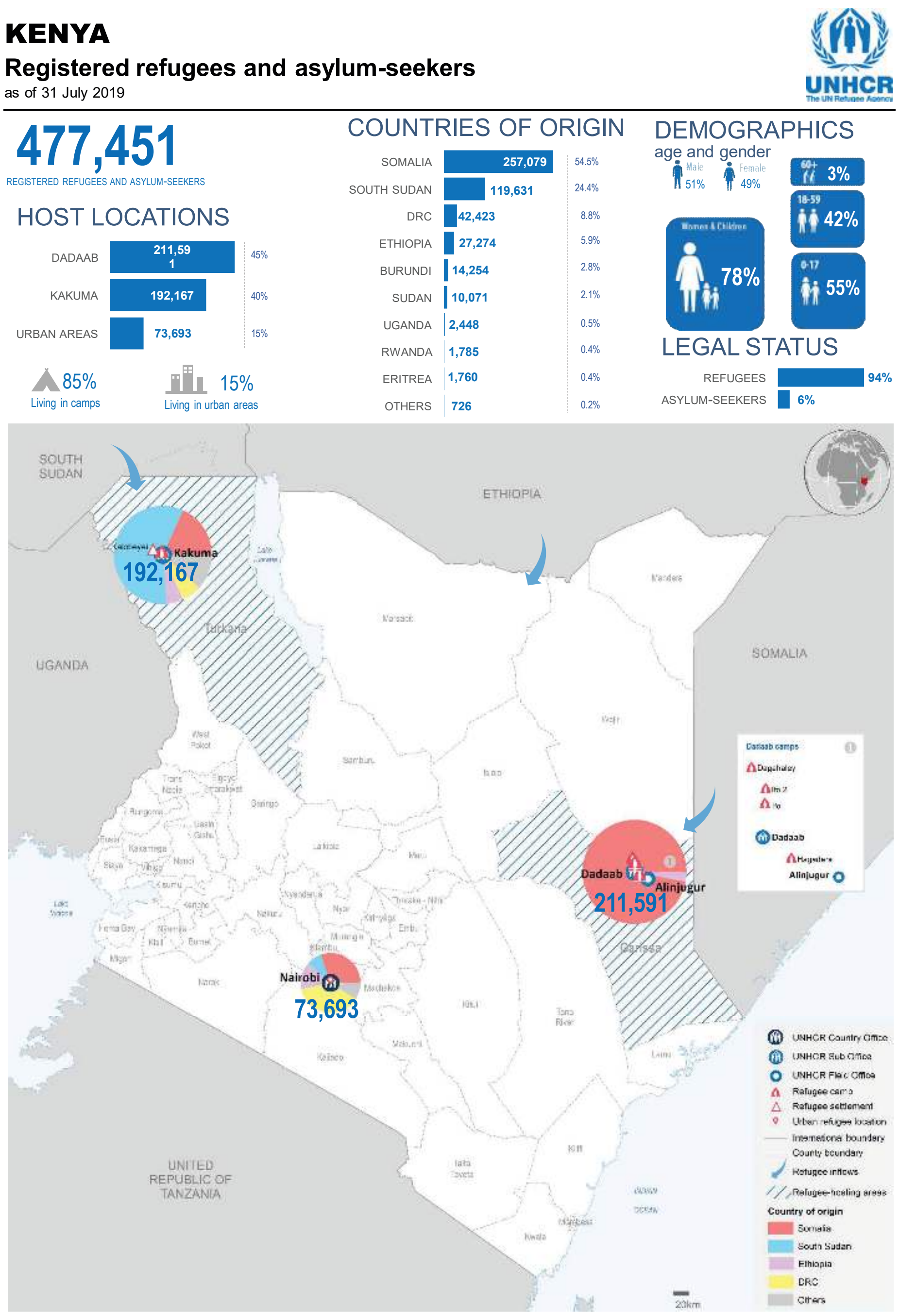
The International Finance Corporation (IFC), a member of the World Bank Group, intends to set up the Kakuma Kalobeyei Challenge Fund (KKCF) in Kenya. The Fund aims at empowering better economic integration and independence of the displaced population and their hosts through enabling private sector interest in the region. Among other key priority sectors, IFC is exploring the opportunity to attract agribusinesses to launch activities in the area. One of the critical hindrances recognized during the scoping missions is the absence of information on whether there is accessible water of adequate quality and quantity, and, if so, how to access it for commercial use, including for groundnut production. The reliable supply of water would positively impact the livelihoods of both the host population and the refugees.

1.2 Refugee Context in Kenya

Kenya had become the fifth-largest refugee-hosting country in Africa by 2019 (KNBS, 2019). Conflicts in the neighbouring countries of South Sudan and Somalia have resulted in the forced displacement of people who, consequently, have sought asylum in the Kakuma and Dadaab refugee camps in Turkana and Garissa counties, respectively.

According to the World Bank study "*Yes, in my backyard*" (2016), Kakuma refugee camp has contributed to an increase in the county's Gross Regional Product (GRP). The study estimates an increase of 2.6 % in the short-term, and 3.4 % in the medium- to long-term. Additionally, the complete economic integration of the refugees could lead to a 15.1 % increase in GRP. The government of Kenya has started exploring models for a different development response to forced displacement after recognizing the limitations of humanitarian response in the region. Figure 1 -1 shows the state of the refugees and asylum-seekers in Kenya by the end of July 2019. At the end of September 2020, the number of inhabitants in Kakuma and Kalobeyei settlements has been registered as resp. 155,685 and 39,623 persons[1].

Figure 1-1: Registered refugees and asylum-seekers in Kenya (July 2019)[2]



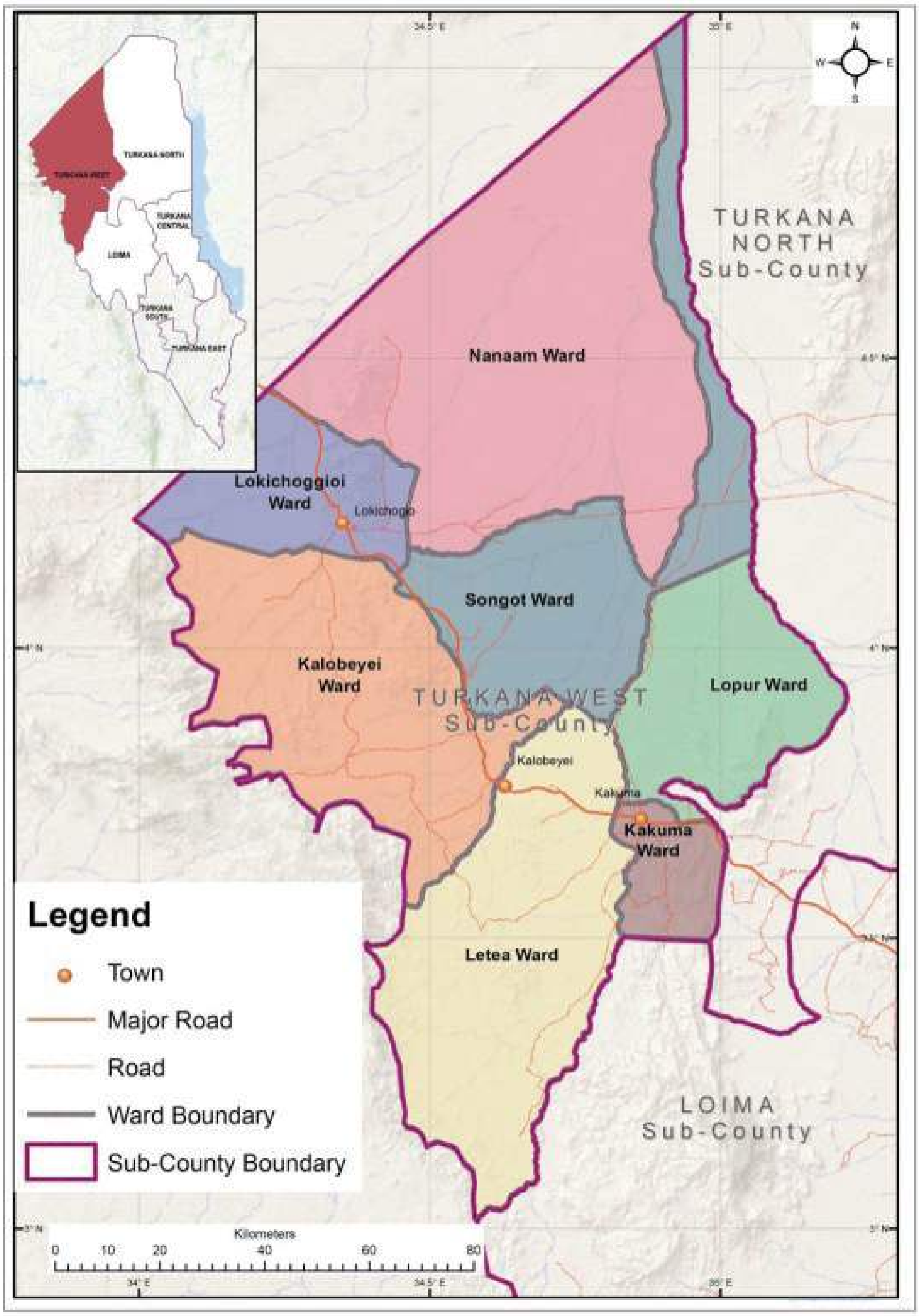
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Sources: UNHCR Kenya. Statistics based on UNHCR's Refugee Registration System, *proGres* **Author:** UNHCR Kenya - Data Management Unit Nairobi **Feedback:** kennaodm@unhcr.org

[1] UNHCR: "Kakuma & Kalobeyei Population Statistics", 30 September 2020.
[2] Source: Kenya Comprehensive Refugee Programme | 2019-2020.

1.3 Objectives of the Assessment

The objective of this study is to conduct a comprehensive analysis of the current water situation in Kakuma area and provide practical recommendations and actionable steps for agribusiness development within the present legal and regulatory environment. Specifically, this report compiles existing hydrological and other water studies on the Kakuma and Kalobeyei area, based on literature studies and stakeholder consultations. Due to the COVID-19 pandemic, field visits in the region of the study had to be replaced by in-depth desk study and oral questionnaires—online engagement and communication with relevant stakeholders supported data collection. Figure 1-2 shows the location of Kakuma and Kalobeyei within Turkana County.

Figure 1-2: Location map of Kakuma and Kalobeyei in Turkana County[3]



3 Source: FAO (2018). Feasibility Study on Agricultural Viability and Water Access for Dryland Agriculture in Kalobeyei and Kakuma. Turkana West Sub-County. Final Report.

2 Setup and Phasing of the Study

2.1 Setup

In the Inception Report, three project goals have been distinguished:

Goal 1 – Context analysis (present situation)

Determine the overall circumstances for agribusiness development in the Kakuma / Kalobeyei region in terms of water availability and social/legal situation.

Goal 2 – Room for development

Determine the room for development for agribusiness in the region, with emphasis on groundnuts.

Goal 3 – Assessment of possible measures

Determine which measures might be taken to mitigate observed limitations in terms of water resources and social/legal situation.

These project goals structure the outline of the study and the layout of this report.

The Final Report is divided into two volumes:

- Volume 1 – Main Report;
- Volume 2 – Annexes.

The Main Report gives the overall results, conclusions and recommendations and can be read without consulting the Annexes, which give more detail on the background and all the details of the data used in the study.

All reports and other publications referred to in this report are referenced in the list of documents consulted for this study in Volume 2, Chapter 5.

2.2 Project Phasing

2.2.1 Initial project phasing

In the Technical Proposal, the initial setup defined three phases:

1. Inception Phase;
2. Assessment Phase;
3. Recommendations and Final Reporting.

In the present report, the results are presented of the phases 2 and 3.

2.3 Summary of the Inception Phase

2.3.1 Redefinition of research questions and definition of project goals

During the Inception Phase, the original research questions, as defined in the ToR, were rewritten and organized into the three groups ('Goals') already introduced above in 2.1.

2.3.2 Consulting rounds

Consultations were held with all relevant stakeholders with the objective of gathering information on the present status of the water sector in the region of study and their involvement in either ongoing or future (planned) activities, e.g. with supplying water or use of water for irrigation.

The stakeholders consulted included national government departments and agencies, county government departments, utilities, multi-lateral humanitarian agencies, local and international NGOs, and research institutions. It also involved the private sector, including agribusiness and other firms with interests in the Kakuma-Kalobeyei area.

Table 2-1 summarizes the main points elicited during the stakeholder consultation process. In Volume 2, Chapter 2.8 (Annex 1), additional notes and contacts of the person consulted are given.

Table 2-1: Summary of stakeholder consultations

Stakeholder	Key Points Captured from Consultations
Government Departments	
Ministry of Water, Sanitation and Irrigation (MoWSI)	• Several boreholes have been drilled by NGOs in Kakuma, Kalobeyei and Turkana County. These boreholes supply water to urban and rural areas; • Poor groundwater potential zones are noted in some parts of Turkana West sub-county; • Groundwater in some areas has high salinity. Therefore, treatment is necessary for drinking water and crop production. Another alternative is growing salt-resistant crops; • MoWSI, supported by UNESCO and JICA, undertook GW mapping of Turkana North. They used space-based radar technology based on a proprietary methodology. USGS is currently mapping Turkana South; • MoWSI was not involved in any exploratory deep drilling in Lotikipi; • MoWSI is very interested in the outcome of this study.
Water Resources Authority (WRA)	• Deep drilling in Lotikipi done by RVWSB as per RTI recommendations. Brackish to saline water encountered; • GW Mapping study carried out by Rural Focus Ltd covering Turkana County; • UNHCR and Tullow recently installed some data loggers in some boreholes in Kakuma and in Turkana; • WRA has a borehole database, but many borehole completion records are very poor quality.
Water Sector Trust Fund (WSTF)	• WSTF is rolling out WASH and water for livelihood programs in Turkana West sub-county. They partner with Oxfam, AAH-I, AMREF, NRC and World Vision.

Stakeholder	Key Points Captured from Consultations
Turkana County Government (TCG)	• Turkana County Water Act 2019 has been gazetted, and it shall regulate water resources use in the county; • JICA is currently supporting the TCG in development of a database for water sources within Turkana County. This database will provide details of all boreholes within the county and their current status; • The County Government is currently supporting the running of Kakuma Water Supply in collaboration with KATOWASE (an interim management structure), while measures are being put in place to have a legally registered WSP to run the water supply; • The County Government is responsible for wells installed with hand pumps. • The County implements several irrigation projects including 12.5 acres in Lokiririet in Lokichoggio. The source of water will be borehole and irrigation method by a drip system; • The County Government is implementing a project with FAO and Egerton University on different dryland crop varieties - including various varieties of groundnut. It plans to upscale this work in Turkana West and other parts of Turkana County.
Multi-Lateral Agencies	
IFC	• KVDA/IFC - PPP water project pre-feasibility study done for Turkwel Dam in association with Tullow oil; • Composite water source from the dam and targeted boreholes to serve the resident communities, and Lokichar wellfield and urban water supply; • Not yet implemented.
UNHCR	• Water supply to Kakuma and Kalobeyei from 26 boreholes; • UNHCR has data available as well as a status report; • UNHCR shared two technical reports.
FAO	• They are supporting agricultural activities in collaboration with TCG; • They are conducting trials on groundnut production in Turkana West sub-county, in collaboration with WFP, Egerton University and TCG. • Trials at three sites: – Kakuma (near refugee camp) under rainfed, but later supplemented with irrigation (bucket system) using groundwater; – Kalobeyei (near Kalobeyei settlement) under rainfed supplemented with drip irrigation using water from a water pan; – Loima under furrow irrigation using water from Turkwel Lagga. • Supplementary irrigation meets irrigation water demand by about 60%; • Preliminary results on the quality show that protein content was about 30% and 0% aflatoxin. Aflatoxin is a family of toxins produced by particular fungi. This fungus affects various agricultural crops such as maize, rice, wheat, groundnuts, cottonseed and tree nuts. The fungi poison people and animals, sometimes with fatal outcomes; • WFP is implementing five water pans recommended supporting irrigation in Kalobeyei area. One is complete and operational, and the second one is almost complete; • They are supporting drip/bucket irrigation of 3 – 4 ha acres in Kalobeyei settlement, implemented under the KISDEP I Program which currently involves 400 – 600 farmers; • The water pans since commissioning have adequately served the irrigation projects and, hence, are an indication that floodwaters can be harvested to support irrigation; • Livestock water sources are mainly scoop-holes, hand-dug shallow wells, boreholes and water pans; • There is an increasing demand for irrigated agriculture using drip irrigation; • There is commercial poultry farming in the Kakuma area under the National Agriculture and Rural Inclusive Growth (NARIG) Project; the source of water is the Kakuma Town Water Supply.

Stakeholder	Key Points Captured from Consultations
WFP	• Two pans developed for horticulture. The project goes accordingly to the plan; • The open farming area under spate irrigation/trapezoidal bunds has struggled because of lack of fencing; • Existing pans fill very quickly and remain near full; • Plan to add additional water pans.
Research Institutions	
University of Neuchatel (Dr. Ellen Milnes)	• They coordinated the water supply studies for UNHCR in Kakuma; • Last study was done in collaboration with Earth water Ltd; • The reports are available on the UNHCR Website.
Egerton University (Prof. Paul Kirmuto)	• Currently implementing groundnut trials using 3 varietals: – Egerton Groundnut 1 (big seeded and spread (runner)) – Egerton Groundnut 2 (Red and early maturing) – Hybrid (local groundnut mainly planted in Kerio Valley) • Soil analysis was done, and some sites had high, but acceptable salinity levels; • Preliminary findings indicate 8 bags to 10 bags of 100 kg (800 – 1,000 kg) depending on the variety per acre = 2000 – 2500 kg/ha; • There are concerns about irrigation using high salinity groundwater on saline soils which will make soils too saline for crop production. Need to use low salinity water for irrigation; hence, surface water is preferred; • Groundnut production to be done on a rotational basis with the identified crops (dual-purpose cowpeas, indigenous vegetables, sorghum, finger millet); • Groundnut production to be carried out under supplementary irrigation such that it is planted at the onset of long rains so that the rains provide 25-30% of total CWR; • At the end of the rainy season; irrigate using surface water from pans (surface water irrigation to provide 50% of total CWR). When the water from the pans is depleted, irrigate using groundwater (25% of total CWR); • This is because the borehole water salinity levels are highly variable; • During the wet season between May and June, the levels are (405 – 8,460) µS/cm, e.g. at Kakuma BH 5 recorded EC value of 1,450 µS/cm during the wet season (35 mm); • During the dry season (0 mm) between December and January, a higher EC level of 1,520 µS/cm was recorded (UNHCR, 2012-2014 Monitoring data); • Looking at the long-term sustainability, the use of groundwater for irrigation should be maintained at a maximum of 25% of total crop water requirement; • Groundnuts will be planted during long rains and rotation crops planted during short rains under dryland agriculture or supplementary irrigation, but preferable using surface water from pans; • Plan with one season of groundnut production per year.

Stakeholder	Key Points Captured from Consultations
NGOs	
NRC	• Water supply in Kakuma camp faces difficulties due to the dilapidated pipeline network. It leads to a 35% water loss due to frequent leaks and bursts. To address this, NRC is replacing the dilapidated pipes and extending pipeline including drilling and equipping three boreholes. This project is financially supported by WSTF; • Water connections of commercial enterprises within the Kakuma camp remain illegal and unmonitored. This problem can be addressed by implementing a pipeline from the Kakuma Town Water Supply for supplying water to commercial enterprises within the camp; • There are cases of high fluoride levels in most boreholes. Attempts to treat water through reverse osmosis were unsuccessful as water demand was much higher than the rate of treatment. Furthermore, the cost of operation of the RO system was high; • Latrine coverage is still low as the latrines get filled up quickly, and some are prone to flooding. Installation of UDDTs in flood-prone areas aims to address this problem; • Other sanitation technologies have been piloted specially to address issues of flooding. These technologies include UDDTs and Container-based toilets (Sanivation toilets); • Sanivation toilets were decommissioned in 2019. The technology was not financially sustainable without donor support. • Supply to Kalobeyei is being increased by equipping a borehole at Kangura settlement and connecting it to Kalobeyei tanks and construction of an elevated tank and water kiosks.
Kenya Red Cross Society	• Undertook Feasibility Study on the Tarach Dam. • Ongoing work in Turkana West with WSTF. • They have the mandate to support government agencies on disaster response, including droughts, floods, disease.
World Vision	• They have implemented several irrigation projects, including drip irrigation. • Works mainly with the community groups; • Has observed that the refugee community are keener on crop production than the host community. • A lot of capacity building is needed, especially for the host community to adopt crop production as a livelihood activity. • There is an increasing demand for hydroponics technology in the region. That technology is mainly offered by Hortipro Ltd and Hydroponics Kenya. • Source of water for irrigation in Turkana West sub-county is boreholes. Most of water pans are within the grazing areas, except for the ones constructed in Kalobeyei settlement. • Most boreholes are equipped with solar-powered pumps. • Plastic storage tanks are mainly sourced from Kitale. • Some hotels in Lokichoggio town like Kate Camp and Trackmack grow their own vegetables under drip irrigation in shade nets. They also keep their own poultry for hotel supplies. The source of water is the Town Water Supply.
Africa Action Help International (AAH-I)	• With support from DfiD, AAH-I collaborated with FAO to assess agricultural feasibility for Kalobeyei Integrated Settlement Scheme in 2017 – 2018. • Undertake model irrigation farm in Pokotom area using GW. • Ongoing project with WSTF will involve implementation of dams, pans and WASH interventions.
Oxfam	• Oxfam has been engaged in WASH in Turkana County for over 20 years. • They are currently implementing a project in Turkana West with support from WSTF.

Stakeholder	Key Points Captured from Consultations
KDRDIP	• They are developing community action plans, water pans, boreholes and poultry farming.
SNV	• They are implementing a Renewable Energy Project through a market-based energy access model in Kakuma and Kalobeyei refugee camps. • Have Clean Cooking and Solar Clean lighting energy components.
DDNK-ASAL	• Drilled 2 BHs; • They are mapping WQ in Turkana County under ECORAD, in collaboration with JICA.
Private Sector	
SunCulture	• SunCulture has worked in Turkana County through NGOs. • Products are drip-irrigation systems, climate-smart rainmaker and associated equipment and fittings; • Has no plans to set up business in Turkana market because of uncertainties in the market. • Willing to set up an outlet in Turkana if there are 100% donor-funded projects. Then, SunCulture can take the role of technology and knowledge provider. They can also further conduct market research to ensure product fit, market size and purchasing capacity. • However, financial support is needed to set up the sales and service center. There is also a need for financing support for hiring staff and/or a percentage subsidy/incentive to lower the PAYG risk and ensure product affordability.
Hydroponics Kenya	• Hydroponics have had activities in Turkana County since December 2018. • Main activities within the county operate in Lodwar, Kakuma and Lokichoggio. • Hydroponics Kenya has an office in Lodwar with two agronomists and a store for stocking supplies. • Hydroponic systems have been installed for the host community and refugees, especially the household units. • The technology being implemented in Turkana County is simple: local materials are used as much as possible. • The technology does not involve any form of mechanized water circulation and recirculation as with most of the hydroponic systems. • A unit can feed one household. The measures are 4 m x 3 m, with a vertical set-up and costs about Ksh. 15,000/-. • There is an increasing demand for hydroponics. That was noted since the first pilot in Turkana as individuals (without donor support). Demand is especially located in Lodwar; • Main crops grown under hydroponics are capsicum, tomatoes, kales, spinach, cowpeas and now onions.
Davis & Shirtliff	• They have the main operational office in Lodwar; • Supplies water pumps (solar-powered & electric), water treatment equipment, generator systems and solar power system; • Major clients are NGOs, Turkana County Government and National Government; • There is an increasing demand for their products/services, especially on solar-powered pumping systems; • Have installed several solar-powered pumps to support irrigation activities; • There is limited demand for water treatment equipment (Reverse Osmosis equipment) and generators.

Stakeholder	Key Points Captured from Consultations
Irrico International	• Irrico conduct activities in Turkana County under the name HORTIPRO Limited; • Mainly deal with small irrigation kits, greenhouses/tunnels and shade nets. • The main clients are Kenya Red Cross, World Vision and Missionaries Community of St. Paul the Apostle. In the past, they supplied goods to TCG and FAO; • HORTIPRO Ltd purchased land for construction of offices in Turkana and has a field officer stationed in Turkana who takes orders and provides technical services to the clients in Turkana County; • Currently, their supplies are from Nairobi stores, but there are plans to construct storeroom in Lodwar; • The area is suitable for grapes, oranges and dates if water can be made available; this is the potential that is driving Irrico International to invest in the region.
Amiran Kenya	• Ventured in Turkana through Kenya. Red Cross is the main client in the region; • They have worked with KRCS for four years in carrying out the land survey, design of irrigation systems, soil analysis, seedling preparation, installation of irrigation systems, and supply of chemicals and fertilizers. • Drip irrigation in shade nets is preferred; • Does not have an office or outlet in Turkana; supplies are done from Nairobi; • No plans to set up an office/outlet in Turkana as the current arrangement works well for them. Materials are transported monthly to Turkana for KRCS projects.
Insta Products	• They are interested in buying groundnuts from Turkana County because trials indicate that Aflatoxin levels are very low; • There is a ready market for the groundnuts; • Willing to mobilize groups to grow groundnuts; • Shall share a detailed plan with the consultant.
Tullow Oil	• Water resources assessment studies carried out by Tullow Oil for oil extraction; • Instruments installed – BH monitoring; river gauging on Turkwel; • Tarach basin extends to the Lotikipi basin. Lies outside Tullow Oil Oil Block. Block owned by SEPSA which drilled one deep oil well north of Kakuma. This was not successful; • Two wells drilled in Lotikipi by RVWWDA. One very saline (deep) and the other fresh to brackish. Dried up later and so was not successful; • It is known that Tullow is minimizing activities in Turkana.
Others	
Arava / Furrows in the Desert	• Recommends net houses and not plastic-covered greenhouses since net houses are windproof; • If professionally guided, they can be insect proof, and save some 20-30% of the water consumption. The yielding potential is 150-200% of the open field crops; • Identifies dates as a very suitable crop to the region but need good training and supply of selected planting material. • States that check dams (referred to as "Liman") for spate irrigation need careful hydraulic planning and planting combination of fruit trees and annual crops to be planted post rain. • Believes the project can be scaled up and had made a proposal to implement the same in Kakuma.

2.3.3 In-depth desk reviews

Several studies have been carried out within and around Kakuma in the past years to delineate groundwater potential, water quality and its socio-economics, as shown in Volume 2, Section 5. They include geological and natural resources mapping in the whole of Turkana County. In the past decade, there has been a lot of interest in the hydrogeology of the Kakuma and Kalobeyei area to supply water to the refugee camp and the host communities. This review discusses each study in a snippet in reference to different years, purpose, and findings. The different projects carried out in Kakuma and Kalobeyei on water studies have been classified into two broad categories as presented below. An overview and discussion of these studies are given in Volume 2 – Chapter 2.1.

2.4 Existing Data from Previous Studies

Several sets of groundwater data from different studies in the Kakuma area have been obtained. There has been a resurgence in interest in the quality and quantity of water available for use in the Kakuma refugee hosting area. A summary of the data from previous studies is discussed in volume 2, Chapter 2. References to all reports and documents used in the study can be found in Volume 2, Chapter 5.

2.4.1 General observation on data sources

Data were collected from various relevant institutions. An overview of the most important sources is given in Table 2-2.

Table 2-2: Data sources

No.	Name of institution	Data type
1	Ministry of Water Sanitation and Irrigation	BCR, Water quality data
2	Water Resources Authority	Abstraction data, water quality and river gauging
3	Rift Valley Water Service Board	Deep borehole data
4	UNHCR	Monitoring data
5	Action Africa Help International - AAH-I	Well data
6	Norwegian Refugee Council	Borehole data and water quality
7	Lutheran World Federation	Borehole data and water quality
8	Turkana County Government	County Development plans

This collection of data is a universal problem in Kenya and for that reason it is important for the Water Resource Authority (WRA) to ensure that completeness of the data in the BCRs is achieved. For that reason, it is not guaranteed that the existing gaps in the current database would be closed upon additional data acquisition. We would like to stress that only an extensive field campaign in the Kakuma and Kalobeyei areas might give insight in the actual number of wells in the region, and their status. Such an inventory would require massive resources and was not only unfeasible during the project implementation due to the covid-19 pandemic situation but most fundamentally it is beyond the scope of the project. The existing data cited from previous studies have conflicting borehole statistics based on the objectives and the scope of the work defined by the respective studies.

From the data collected, we analyse and examine the groundwater availability in the study area. The analysed data are the only available data for the area of study. Likewise, the data had some limitations in terms of spatial distribution, whereby the majority of the data are concentrated in the Kakuma refugee camp area. It is also worth noting that the content of the different data sets is for specific purposes. Then, its comprehensiveness is focused on the purpose of the studies at different times.

Characterization of the aquifers in Kakuma and Kalobeyei area rely on conservative assumptions to get the range of values for aquifer parameters. The available data for water quality analysis and aquifer parameters are not distinctive for different aquifers. However, some conclusions can be drawn for parameters of specific aquifers at different depths.

An alternative approach was engaged to characterize the aquifers given missing data. It consists of extrapolating correlated borehole logs and data within a specific homogeneity of hydrogeological zones to achieve the purpose.

In conclusion, all the data that is available for the Kakuma-Kalobeyei area has been exhaustively collected, and we feel that this is a true reflection of the hydrogeological conditions as is presently known. In this process, noting that the study area was not clearly defined within the Kakuma-Kalobeyei area, a total of **115** boreholes have been collated from the analysis of all the datasets from various sources within a radius of 25km.

3 Context Analysis – Water Availability and Storage

The first Project Goal consists of five activities:

Goal 1 – Context analysis (present situation)

Determine the overall circumstances for agribusiness development in the Kakuma / Kalobeyei region in terms of water availability and social/legal situation

- **Water availability**
- **Water storage**
- Water demand
- Water balance
- Social and legal context

In this Chapter, the first two activities are discussed: water availability analysis (divided into surface water and groundwater), and water storage. They set the boundary conditions of the natural resources for possible future implementation of agribusiness in the area of study.

3.1 Water Availability

Goal: Determine overall water availability for both surface water and groundwater

3.1.1 Rainfall and climate

Evidently the climate, and particularly the rainfall and evaporation, have a major impact on the choice of the crops that can be grown in the region, either as rainfed-crops, or with the support of irrigation. In this Paragraph, the climatic conditions in the region of study are discussed. It is clear that given the existing and anticipated level of investment in the Kakuma-Kalobeyei area, proper rainfall (and climate) data are essential.

The discussion below shows that the rainfall is insufficient to support reliable rainfed agricultural production without irrigation and/or the application of in-situ soil conservation farming practices.

3.1.1.1 Rainfall data

Accurate, observed rainfall data are preferred over rainfall data derived from remotely sensed information. However, for the Kakuma area, observed daily rainfall data are scarce, implying that remotely sensed rainfall estimates are required to gain an understanding of the rainfall pattern. The observed data and remotely sensed data are presented below.

Historic, observed daily rainfall data for Kakuma (Catholic Mission KMD station nr. 8634005) were obtained for the period of October 1965 to December 1988. This data set has many gaps, which cannot be filled in using observational rainfall data due to the lack of other datasets.

The second set of observed rainfall records were provided by Dr. Ellen Milnes of the University of Neuchatel, Switzerland. These data were collected during the MSc research study of Sottas (2013)[4] for three different points around Kakuma. These data covered the period from January 2011 to May 2013, with additional data for January to May 2014.

From the limit amount of direct measurements, it can already be concluded here that the Kenya Meteorological Department and the Turkana County Government should collaborate to establish at least three good quality automatic weather stations in the Kakuma-Kalobeyei area.

4 Sottas, J. (2013). *Hydrogeological Study of the Aquifer System of Kakuma, Kenya*. University of Neuchatel, Switzerland.

Due to the historical nature and limited time period of the observed rainfall records, alternative rainfall data were obtained from two sources, namely:

1. Climate Hazards Center, University of California, Santa Barbara[5]. The Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data is a 30+ year quasi-global rainfall dataset. Daily rainfall data were obtained for the period 1981 – 2019 for Kakuma, Kalobeyei Center and Tarach Dam locations;

2. Princeton Africa Flood and Drought Monitor (AFDM)[6]. AFDM was developed to track drought conditions across Africa, using satellite datasets and current hydrological modelling technologies. Daily rainfall data were obtained for the period 1980 – 2018 for Kakuma, Kalobeyei Center and Tarach Dam locations.

Further details on these data sources are presented in Volume 2, Chapter 1.

Annual rainfall

Table 3-1 presents the mean annual rainfall for different locations and different data sources. There are significant differences between the various sources. For the common data period (2011-2012), the CHIRPS data set reports 42% less rainfall than Sottas (2013), and the Princeton data set reports 20% more than Sottas. For the data period, 1981 – 2019, CHIRPS reports an average annual rainfall of 230.3 mm, whereas Princeton data reports 443.8 mm/yr or 92% more.

Clearly, there is a degree of uncertainty regarding the long term mean annual rainfall. *The data indicate that a reasonable estimate is approximately **320 mm**, and this value is used in this report for all further calculations on recharge and the water balance*.

Table 3-1: Annual rainfall for different stations (in mm)

	Observations	Sottas	CHIRPS	Princeton
Data Period	1967 - 1988	2011 – 2012	1981 - 2019	1980 - 2018
Kakuma Center	312	583	231.3 SD = 72.7	438.0 SD 164.2
Kalobeyei Center			317.1	512.5
Tarach Dam			415.3	564.0

The spatial distribution of the rainfall in the area of study is shown in Figure 3-1. Kalobeyei center has approximately 24% higher rainfall than Kakuma center and Tarach Dam has approximately 46% higher rainfall than Kakuma center.

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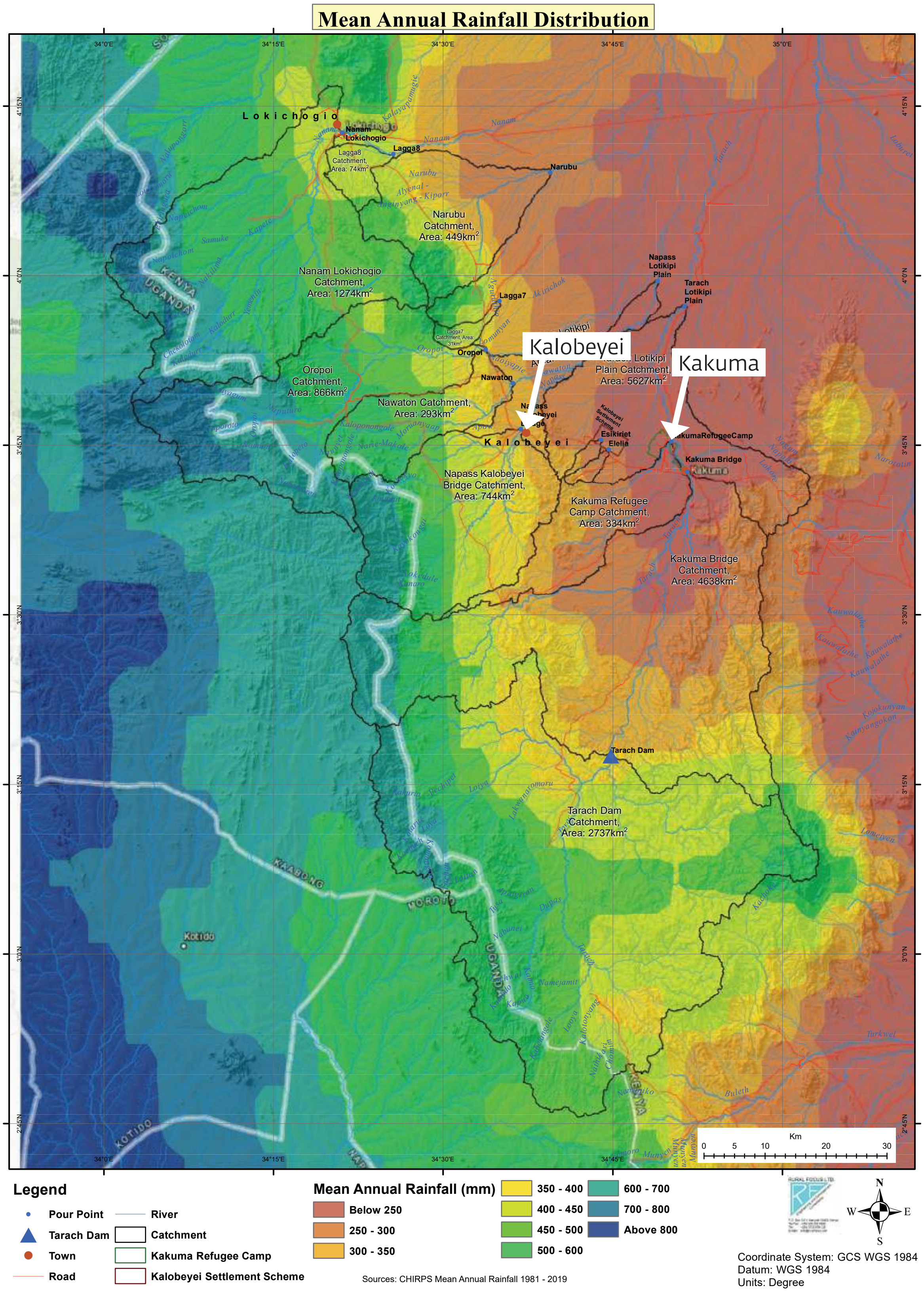
5 http://chg.geog.ucsb.edu/data/chirps/
See also: Funk, C., P. Peterson, M. Landsfeld, D. Pedreros, J. Verdin, S. Shukla, G. Husak, J. Rowland, L. Harrison, A. Hoell & J. Michaelsen. "*The climate hazards infrared precipitation with stations — a new environmental record for monitoring extremes*". Scientific Data 2, 150066. doi:10.1038/sdata.2015.66 2015.

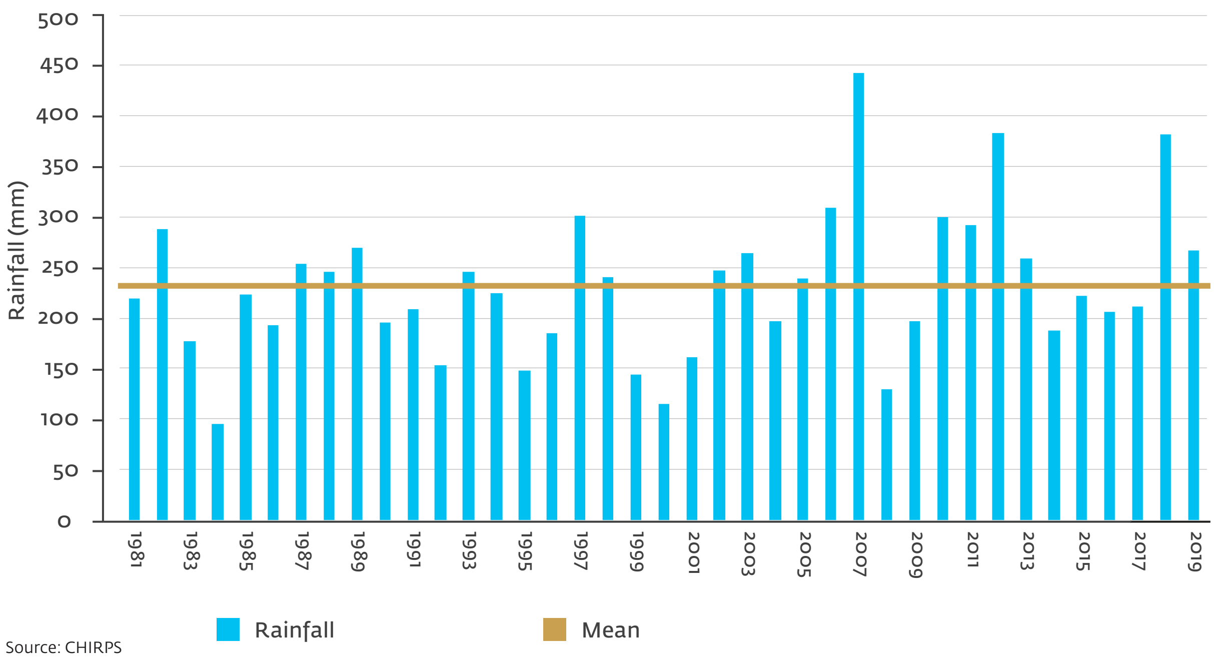
6 http://stream.princeton.edu/AWCM/WEBPAGE/interface.php?locale=en.

Figure 3-1: Rainfall distribution in Kakuma-Kalobeyei area



The CHIRPS annual rainfall time series for Kakuma is presented in Figure 3-2, which shows significant interannual variability.

Figure 3-2: Annual rainfall, Kakuma, 1981 – 2019

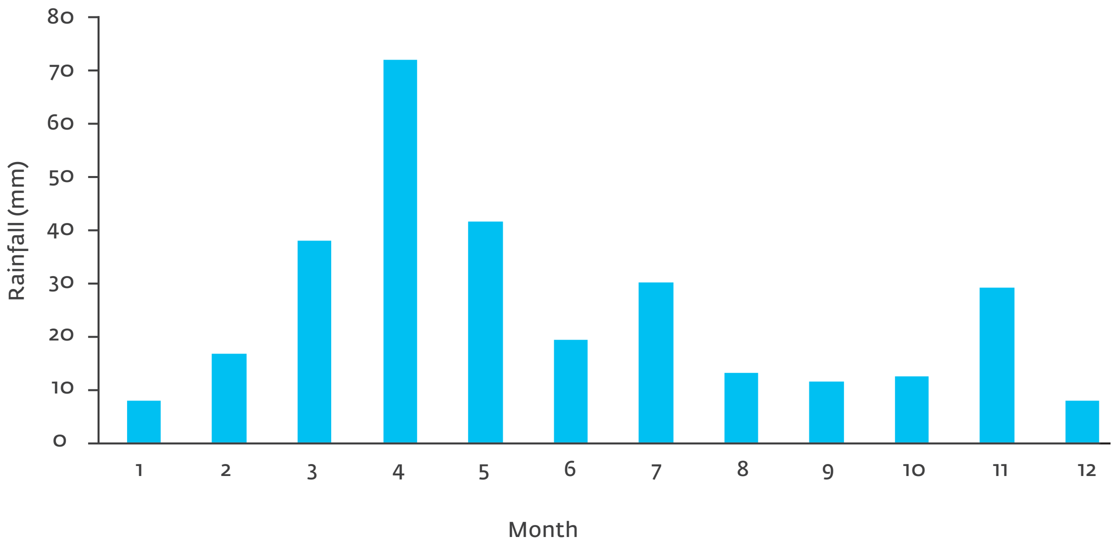


Source: CHIRPS

Monthly rainfall pattern

Mean monthly data are presented in Figure 3-3 for the observed historical data, which show the maximum rainfall season occurs from March through April to May ("long rains"). It accounts for 50% of the mean annual rainfall with a second shorter rainy season ("short rains") occurring between October and November.

Figure 3-3: Kakuma mean monthly rainfall, 1967 – 1988

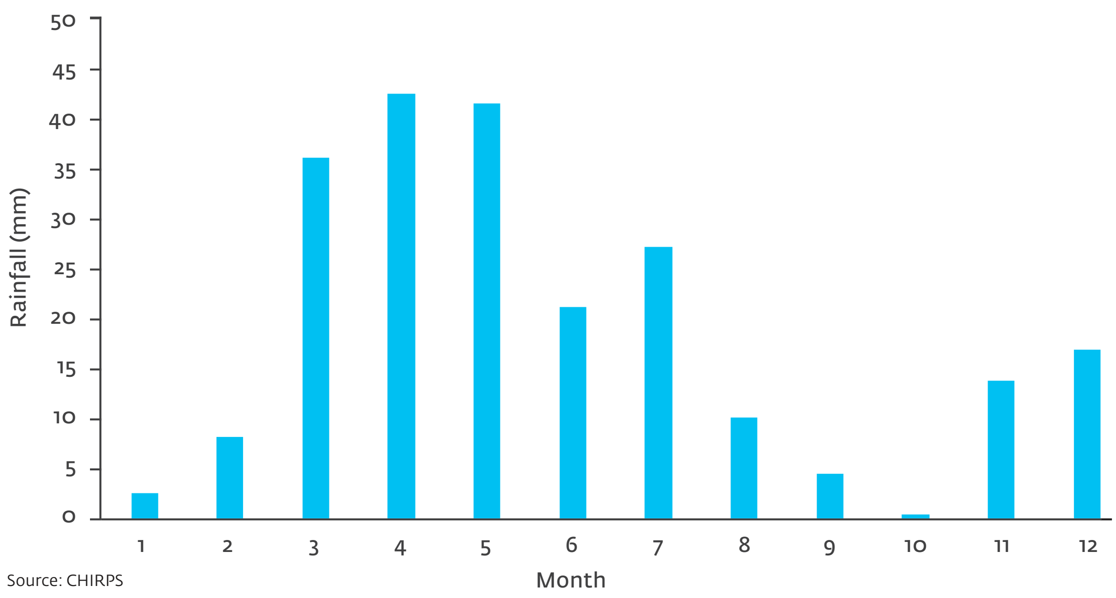


Source: Observations

The CHIRPS monthly rainfall pattern (Figure 3-4) indicates that 75% of the annual rainfall falls across the months of March to July with 50% across the "long rains" in March to June.

This implies that the main growing season is the "long rains" in which rainfed production with supplemental irrigation as needed may be the best approach for reliable crop production. The "short rains" in contrast are unlikely to be sufficient for crop production, and irrigation will be required for reliable crop production.

Figure 3-4: Mean monthly rainfall, Kakuma, 1981 – 2019



Source: CHIRPS

Rain days

A review of the rainfall data indicates that the area can experience long periods (6 - 9 months) with very low recorded rainfall. Figure 3-5 presents observed daily rainfall for a sample period from the end of 1967 to early 1969 to illustrate the fact that the area can experience long periods with very few rain days. Figure 3-6 presents the number of rainy days for daily rainfall greater than 1mm based on the CHIRPS data with a mean of 30 rain days per year. The implication is that rainfed agriculture will be unreliable unless appropriate measures are taken to ensure sufficient soil moisture for a successful harvest, either by using soil water conservation techniques or through using irrigation.

Figure 3-5: Kakuma daily rainfall for sample period, 01/11/1967 – 31/01/1969

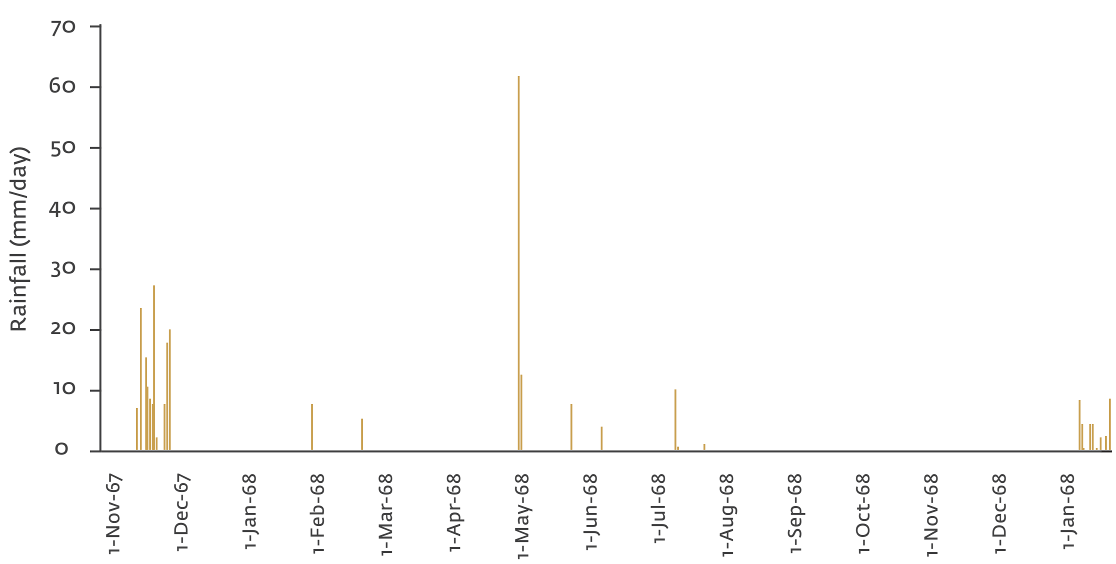
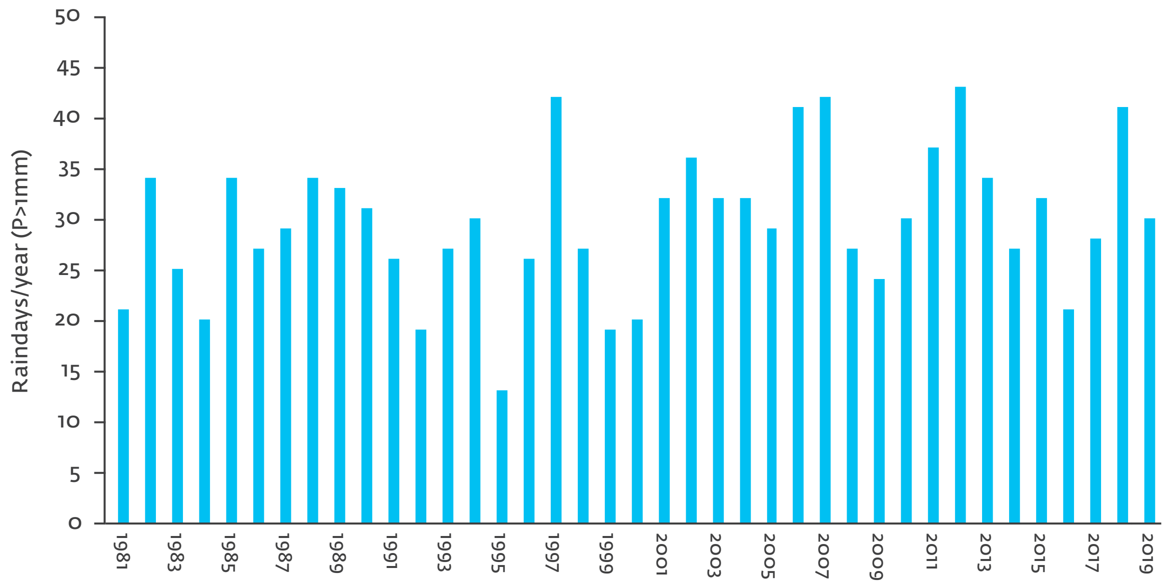


Figure 3-6: **Kakuma raindays for rainfall greater than 1 mm, 1981 – 2019**



Source: CHIRPS

In Volume 2, Chapter 1, a comparison between the remotely sensed and observed monthly rainfall is presented, which illustrates the uncertainty in the rainfall data.

3.1.1.2 Climate

The average annual temperature in Kakuma is 27.6 °C with a relatively uniform pattern over the year with a range of 2.5 °C (Source: Climate.org).

Woodhead (1968) presents reference evapotranspiration (ET_o) estimates for Lodwar (Table 3-2), which can be considered as a reasonable estimate of the conditions in Kakuma.

The mean annual ET_o is estimated to be 2714 mm (Table 4-3), and this value is used throughout this report. Using the UNEP Aridity Index (AI) of (P/PET) gives an AI of 14.6%, which indicates the climate to be arid. This situation is reflected in the vegetation/land cover condition.

Figure 3-7: **Kakuma temperature**

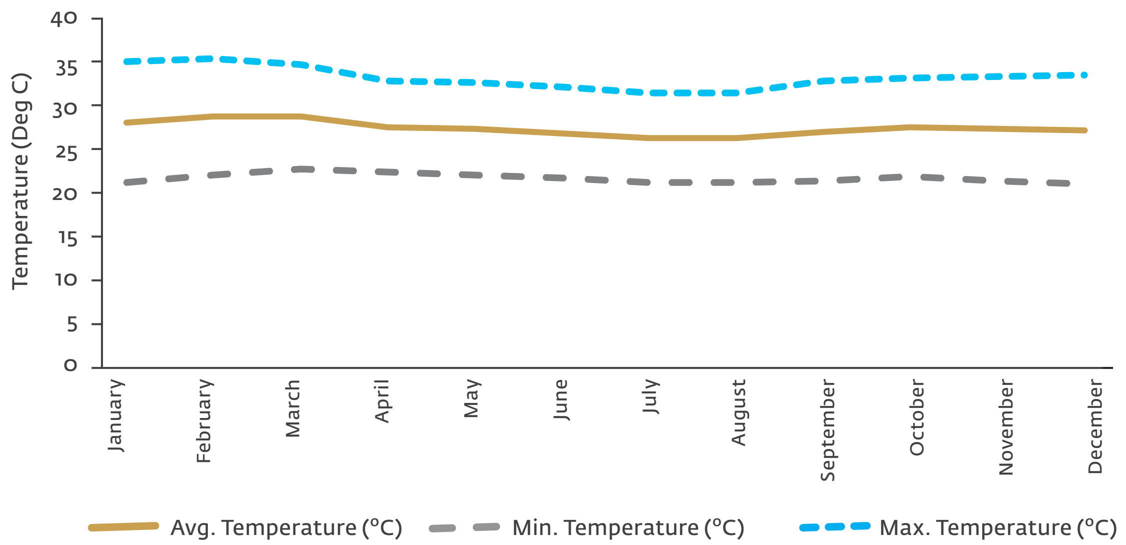


Table 3-2: Lodwar temperature and evaporation data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. temperature (°C)	28.2	28.9	28.9	27.7	27.5	27	26.4	26.4	27.2	27.7	27.5	27.3
Min. temperature (°C)	21.1	22.1	22.7	22.3	22	21.6	21.2	21.1	21.4	21.9	21.3	20.9
Max. temperature (°C)	35.3	35.7	35.1	33.1	33	32.4	31.6	31.7	33.1	33.5	33.7	33.8
Rainfall (mm)	6	18	40	76	36	19	30	21	12	17	32	14
Et_0 (mm/month)	227	210	232	204	235	221	221	226	239	255	220	224

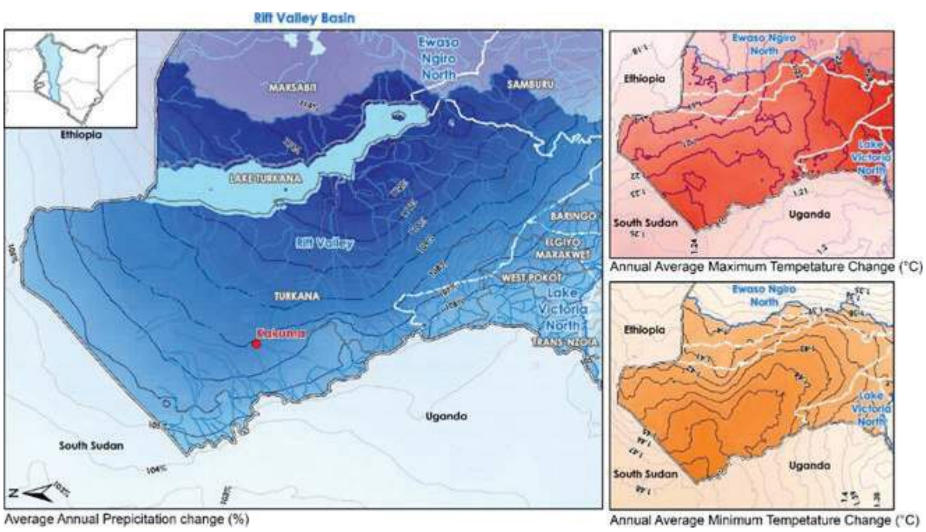
Source: Woodhead, 1968

Climate change

The Rift Valley Basin Plan (Aurecon et al., 2020) presents an analysis of the expected climate changes as a result of anthropogenic forcing factors. Based on the Intergovernmental Panel on Climate Change (IPCC) scenario RCP 4.5, which assumes greenhouse gas (GHG) emissions to stabilize from 2040 and decrease thereafter. The annual precipitation in the future (2040 – 2060) is expected to increase 4 – 12% (see Figure 3-8) with a significant increase in rainfall in February, March and October and decreasing rainfall in May-June and November-December. Generally, this implies a shift of the long and short rains to start earlier in the year. The shift in the onset of the rains has a bearing on crop planting. The reduction in rainfall in the months of May and June implies that there may be an early cessation of the long rainy season, thereby affecting crop growth to maturity. It is also expected that there will be higher rainfall intensities, implying that soil cover conditions will be more important to reduce runoff and erosion and enhance soil infiltration.

Day and night temperatures in the basin are expected to increase by up to 1.24°C and 1.46°C respectively by 2050 (RCP 4.5) (see Figure 3-8), resulting in increases in evapotranspiration. This implies that ground conditions for crop production are likely to become more stressful for the crop and efforts to reduce evapotranspiration, such as windbreaks, shade, mulching and minimum tillage, in conjunction with crop selection, will become important to ensure reliable crop production.

Figure 3-8: Expected future changes in mean annual rainfall and mean annual minimum and maximum temperatures



Source: Aurecon 2020 Rift Valley Basin Plan. Water Resources Authority.

Further details on the climate change analysis, including details on expected changes to mean monthly rainfall, are presented in Volume 2, Chapter 1.

3.1.2 Surface water potential

The aim of the surface water analysis is to develop reasonable estimates of the surface water potential in the catchments and ephemeral watercourses (*laggas*) in proximity to the Kakuma-Kalobeyei area, because this can form an important source of water for irrigated agriculture.

There are only two permanent streams in Turkana County, namely Turkwel River and Kerio River, that traverse the central and south-eastern parts of the County. There are, however, numerous seasonal rivers (*laggas*) that flow only during the rainy season and usually only in response to intense rainfall events. Consequently, the flow is often turbulent and marked by heavy sediment loads. Where the stream beds are made up of sandy alluvial sediments, water is retained in the sediments and forms a source of water that can be accessed through hand-dug scoop holes.

Drainage pattern

In the Kakuma-Kalobeyei area, the drainage pattern is dominated by various watercourses that drain the highlands along the western boundary of Kenya. Most water courses are ephemeral, i.e. they only have water during certain periods of the year, mainly after major rain events. These courses, the *laggas*, are shown in Figure 3-9. They drain northwards towards the Lotikipi Basin and include the Tarach, Napass, Natira and Nanam Laggas and drain the hills around the region of study. Some of these retain pools of water in their beds for part of the dry season. The elevation data presented in Figure 3-9 is drawn from a 30m Digital Elevation Model (DEM) derived from the Advanced Land Observation Satellite (ALOS)[7].

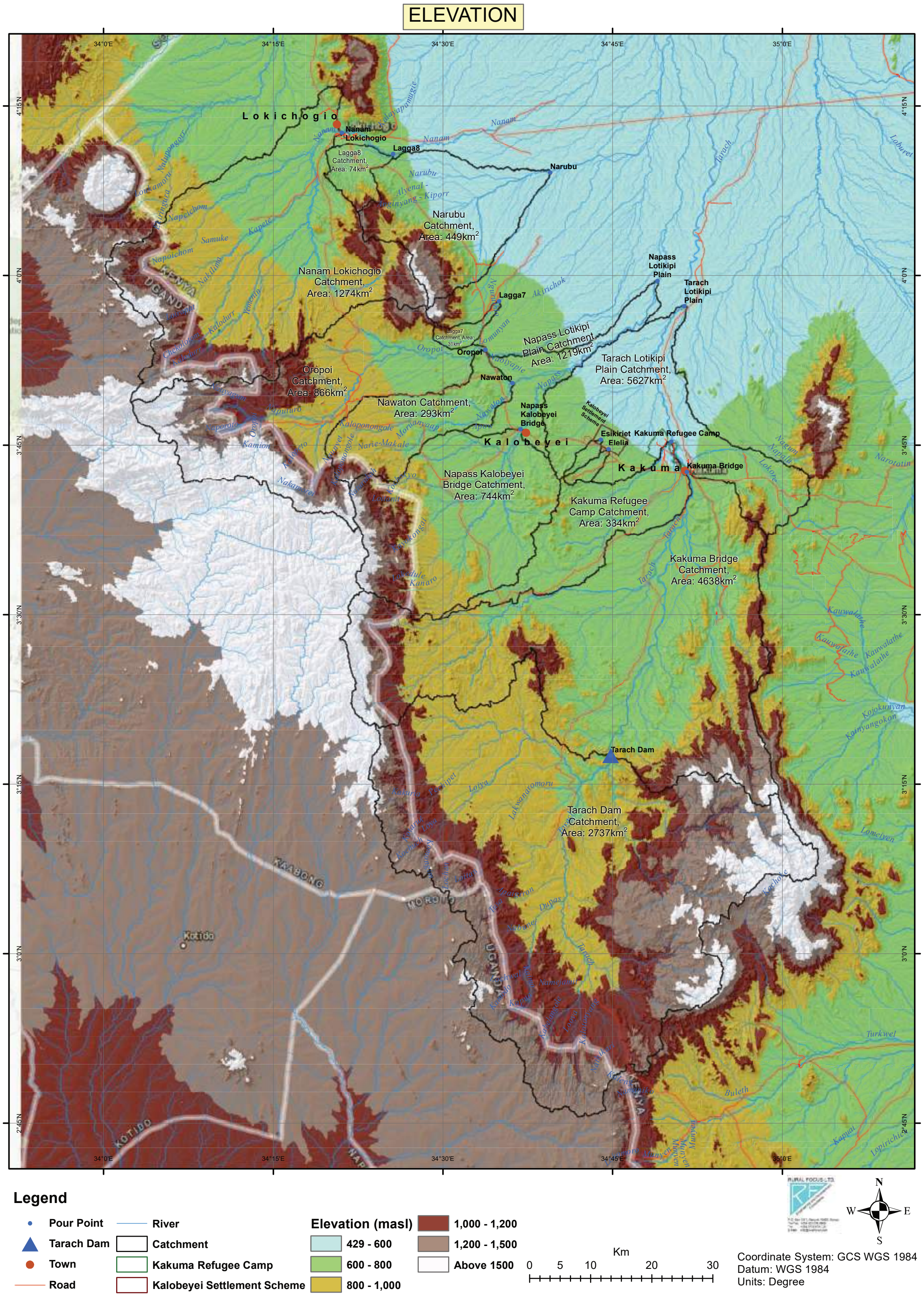
Figure 3-9 presents the catchment boundaries for different catchments of interest with catchment areas presented in Table 3-5. The points selected as the catchment outlets have been chosen because of a clear reference point (e.g. road crossing, potential dam site) or in relation to a potential supply area (e.g. Kalobeyei Integrated Settlement Scheme).

The Tarach lagga at Kakuma is a broad sand-gravel alluvium filled water course approximately 50 – 100 m wide, set about 2 – 5 m below ground level with steep alluvial sandy banks covered with riparian vegetation. This morphology is typical of the larger laggas in the area.

Within the Kalobeyei settlement area are two sand-gravel watercourses, which are approximately 30 m wide and are set 1 – 2 m below normal ground level. These *laggas* split into multiple channels in the northern part of the Kalobeyei settlement area, which is indicative of the flat terrain. These *laggas* are typical of the smaller catchments that flow and dissipate into the flat plains.

7 https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm.

Figure 3-9: Drainage basins and topography



Land use and slope

Land use / land cover and slope are two factors that have a significant bearing on the hydrological processes in terms of the extent of runoff and erosion.

Table 3-3 presents the land cover within the area of interest, based on data from the European Space Agency (2016)[8]. It can be seen that shrubland (±40%) and grasslands (±40%) dominate with forests (±10%) scattered in the higher elevations. The land use and slope information for the Tarach Lagga at Kakuma Bridge is provided in Table 3-3, with data for other catchments presented in Volume 2, Chapter 1. These data show that 22% of the catchment has slopes greater than 12%, implying that the conditions exist for significant runoff and soil erosion if the ground cover is not properly maintained. The extent of cropland is approximately 7 - 10%.

Table 3-3: Land use and slopes for Tarach Lagga at Kakuma Bridge

Catchment	% Area	Total Area (Ha)	Low	Moderate	High	Very High
Slope (Percent)			**<5**	**5 to 12**	**12 to 40**	**>40**
Land Use						
Forest	11.28	52,251.3	3,775.2	11,105.5	6,743.6	30,627.0
Shrubland	41.99	194,410.4	20,078.3	48,113.2	27,784.7	98,434.3
Grassland	38.62	178,839.5	35,581.6	56,712.2	20,924.8	65,621.0
Cropland	7.59	35,130.5	7,131.8	9,441.4	4,102.8	14,454.5
Aquatic Vegetation	0.00	0.1	-	-	0.1	-
Sparse Vegetation	0.48	2,224.6	821.6	1,128.3	165.1	109.6
Bare Ground	0.03	137.3	79.8	40.5	3.7	13.3
Built-up Areas	0.00	22.5	8.7	13.8	0.1	-
Water	0.00	0.5	0.1	0.3	0.1	-
Total	**100**	**463,016.9**	**67,477.1**	**126,555.2**	**59,724.9**	**209,259.6**

3.1.2.1 Streamflow based on regional runoff coefficients

The Water Resources Authority (WRA) reports that there are no river gauging stations on the Tarach lagga or any of the other watercourses in Turkana West sub-county. The only water level recording stations in Turkana County are on the Turkwel and Kerio rivers, plus Lake Turkana itself. It was reported that only the stations upstream of Turkwel Dam on the Suam river have good hydrological data[9].

The Rift Valley Basin Plan (WRA, 2020) developed a water balance model for sub-basins in the Rift Valley Basin, which was calibrated against observed streamflow data for specific sub-basins. The results (Aurecon, 2020, Annex B) for eight selected Turkana sub-basins (see Figure 3-10) are presented in Table 3-4. The mean annual precipitation and annual runoff coefficient is plotted on Figure 3-11. This shows that for rainfall of approximately 500 mm at Tarach Dam, the mean annual runoff should be approximately 2% to 3% of MAP.

8 European Space Agency Climate Change Initiative - S2 prototype Land Cover 20m map of Africa 2016. http://2016africalandcover20m.esrin.esa.int/.

9 *pers. comm* Dr. Sean Avery, Consultant Hydrologist for Tullow Oil.

Figure 3-10: Selected Turkana sub-basins for hydrological model calibration

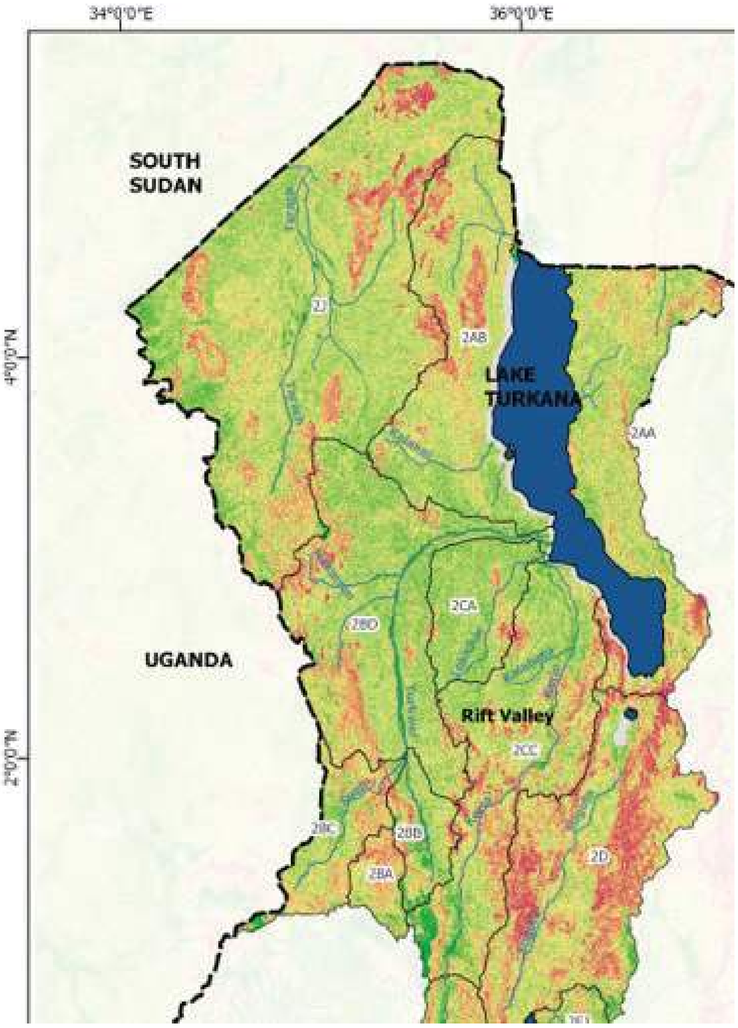
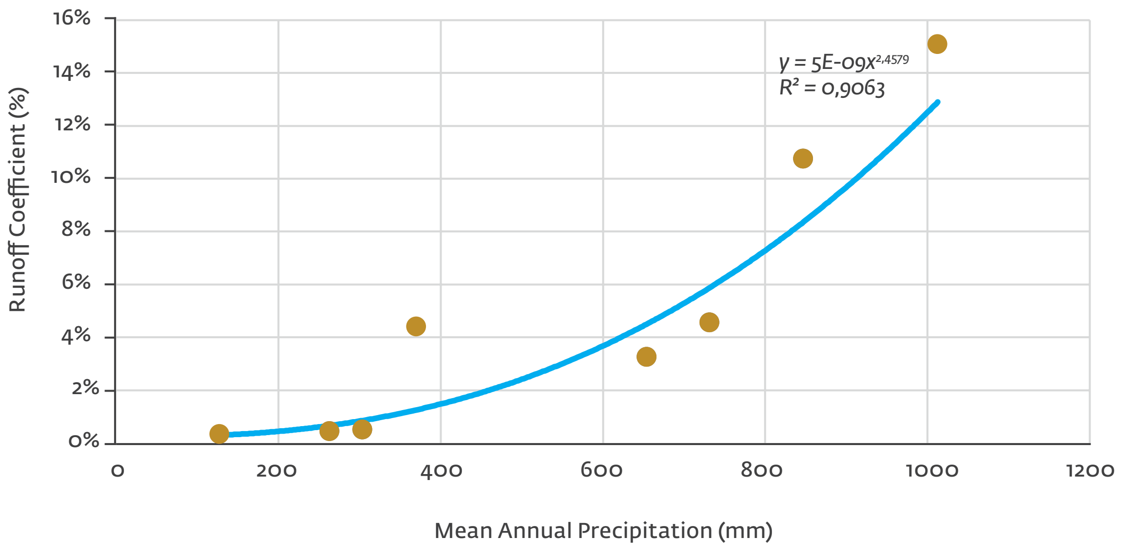


Table 3-4: Runoff coefficient for selected Turkana sub-basins

Sub-Basin	Area (km²)	MAP (mm)	MAP (MCM/a)	MAR (MCM/a)	Annual Runoff Coefficient (%)	Specific yield (l/s/km²)
2AB	13,041	255	3,325.5	6.7	0.2%	1.6
2BA	1,534	1,012	1,552.4	233.1	15.0%	481.8
2BB	2,466	728	1,795.2	78.4	4.4%	100.8
2BC	6,979	845	5,897.3	626.5	10.6%	284.7
2BD	15,894	296	4,704.6	12.5	0.3%	2.5
Turkwel	39,914		17275	957	5.5%	76.0
2CA	4,407	118	520.0	0.5	0.1%	0.4
2CC	13,517	363	4,906.7	206.6	4.2%	48.5
2J	8,927*	650	5,802.6	176.4	3.0%	62.7

* *Catchment area for 2J refers to Tarach lagga system, not entire 2J sub-basin*
Source: Aurecon et al., 2020

Figure 3-11: Annual runoff coefficient for selected Turkana sub-basins



We note that the National Water Master Plan (1992) indicates a mean annual runoff depth of less than 50 mm. This implies that runoff maybe 5-10% of mean annual rainfall (assuming insignificant groundwater-fed base flow, which is consistent with the ephemeral nature of the local *laggas*). Analysis of runoff as a portion of rainfall for the Turkwel lagga (NWMP, 1992, catchment area 2BD) estimates mean annual streamflow is 10.4% of mean annual rainfall. The 2030 National Water Masterplan (Nippon Koei 2013)[10], reports a runoff coefficient of 1.32% for sub-basin 2J, which is expected to rise to 2.08% by 2050 under climate change conditions particularly due to higher intensity storms. For Aurecon et al. (2020) the runoff coefficient for the Turkwel catchment (2BD) is 5.5% and for the Tarach (2J) is 3.04%.

There are two *laggas* (Esikiriet and Elelia) that originate in the Moru Itai hills to the south of the Kalobeyei settlement area and flow through the settlement area. In order to estimate streamflow in the *lagga*, reference is made to studies for smaller catchments in Kenya as summarized in Volume 2, Chapter 1, as there are no reports of more localized runoff studies. The results are transposed to the laggas in the region of this study.

The catchment most similar to the conditions in Kalobeyei is the Mukogodo catchment (Laikipia County) in terms of mean annual rainfall, soils and land use. The evapotranspiration in Mukogodo is less than in Kalobeyei given differences in elevation and temperature. Runoff, as a percentage of mean annual rainfall, was estimated at 7.5% for the Kalobeyei *laggas*, opposed to the 11% in Mukogodo.

This study has therefore adopted a conservative regional annual runoff coefficient of 4% for the larger catchments and 7.5% for the smaller catchments (<100 km²), recognizing a degree of uncertainty. The larger catchments have a higher proportion of flat land, which reduces the likelihood of runoff. The specific yield can be used to estimate the mean annual streamflow for various catchments, as shown in Table 3 -5, based on CHIRPS mean annual rainfall estimates.

It should also be noted that the runoff at a particular site for a particular storm may be much higher-perhaps as much as 40%, but when this is aggregated at a larger catchment size, the overall runoff is generally much less.

[10] Vol IV Sectoral 02_B Meteorology Hydrology.

Table 3-5: Surface water potential for selected catchments

River/Lagga	Catchment Area (km²)	Mean Annual Precipitation (mm)	Runoff Coefficient (%)	MAR (MCM/yr)	Specific Yield (l/s/km²)
Tarach Lotikipi Plain	5,626.5	400.5	4.0	90.127	0.51
Tarach at Kakuma Bridge	4,638.4	430.2	4.0	79.821	0.55
Tarach at Tarach Dam	2,736.9	478.7	5.0	65.514	0.76
Nanam Lokichoggio	1,274.5	558.7	5.0	35.607	0.89
Napass Lotikipi Plain	1,219.0	445.5	5.0	27.154	0.71
Oropoi	866.1	595.8	5.0	25.799	0.94
Napass Kalobeyei Bridge	744.5	471.3	5.0	17.543	0.75
Narubu	448.5	382.3	5.0	8.573	0.61
Kakuma Refugee Camp	334.4	286.4	5.0	4.790	0.45
Nawaton	293.4	476.1	5.0	6.985	0.75
Lagga8	73.8	434.9	7.5	2.409	1.03
Lagga7	30.5	432.9	7.5	0.990	1.03
Elelia	16.1	287.9	7.5	0.348	0.68
Esikiriet	13.7	285.1	7.5	0.293	0.68

Data: CHIRPS 1981 – 2019

3.1.2.2 Streamflow based on synthetic data

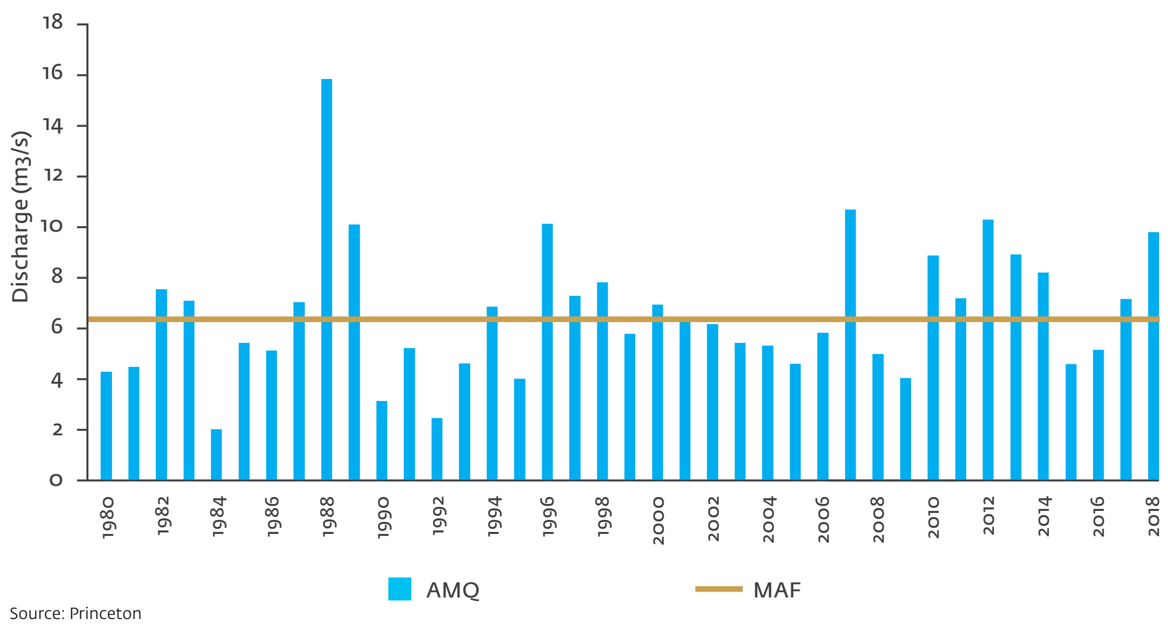
Since actual streamflow data are not available within the proximity of the study area, daily streamflow data were sourced from the Africa Flood, and Drought Monitor (AFDM) housed at Princeton University[11]. AFDM was developed to track drought conditions across Africa using satellite datasets and current hydrological modelling technologies. Further details on AFDM are presented in Volume 2, Chapter 1. AFDM data was obtained for the Tarach at Kakuma, Tarach at Tarach Dam and the Napas at the Kalobeyei Bridge for the period 1980 – 2018.

The daily streamflow time series was analysed to produce the mean annual flow series (Figure 3-12), the mean monthly flows (Figure 3-13) and the daily flow duration curve (Figure 3-14). Evaluation of this streamflow data against the AFDM rainfall data as shown in Table 3-6 indicates a runoff coefficient of 10% at the Kakuma Bridge and 2.2% at Tarach Dam. While these results are within the range of possibility, it is surprising that the Tarach Dam catchment has a lower runoff coefficient, given that the catchment has higher rainfall. We note that the proportion of the catchment area that has "very steep slopes" (>40%) is approximately equal in both catchments (48% for Tarach dam and 45% for Kakuma Bridge) and that the land use characteristics are similar for both catchments. These runoff coefficient values also support the analysis presented in Table 3-5 to use a runoff coefficient value of 4 % - 7.5%.

The validity of using the AFDM streamflow time series can only be determined once a proper river monitoring station has been established on the Tarach lagga and observed streamflow records obtained.

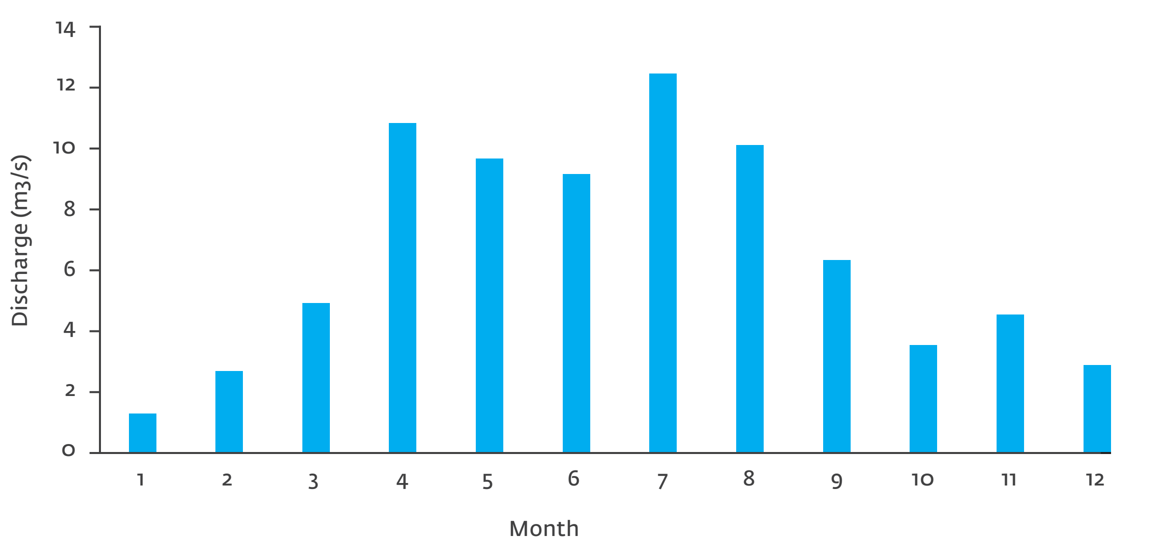
[11] http://stream.princeton.edu/AWCM/WEBPAGE/interface.php?locale=en.

Figure 3-12: **Mean annual discharge, Tarach Lagga at Kakuma Bridge, 1980 – 2018**



Source: Princeton

Figure 3-13: **Mean monthly flows, Tarach Lagga at Kakuma Bridge, 1980 – 2018**



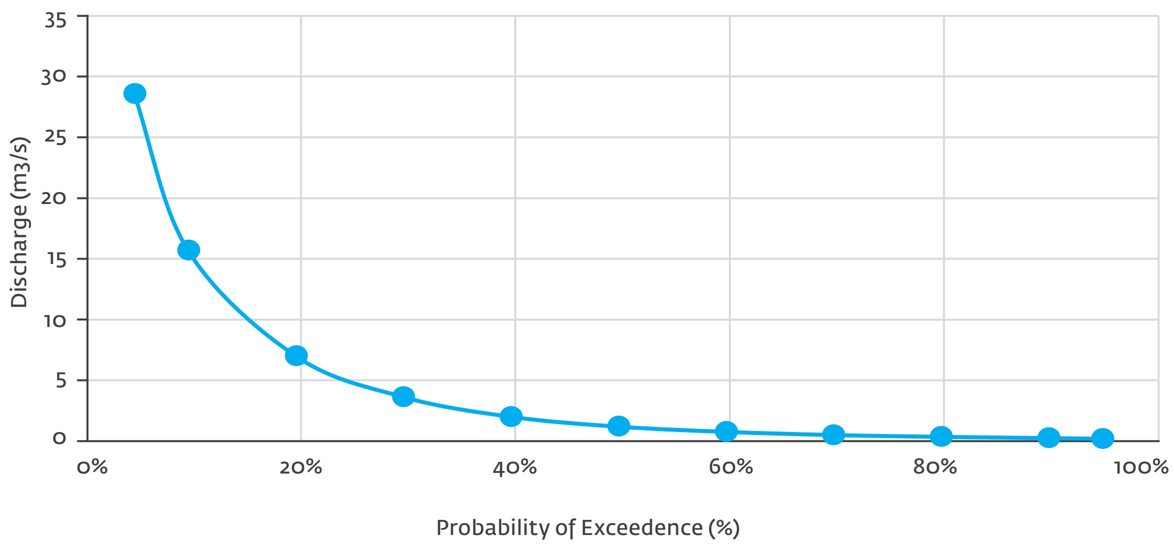
Source: Princeton

Table 3-6: **Runoff coefficient for Tarach Lagga catchments based on Princeton streamflow data**

Catchment Name	Catchment Area (km²)	Mean Annual Precipitation (MAP) (mm/yr)	Mean Annual Runoff (MAR) (m³/s)	Annual Runoff Coefficient (%)
Tarach Lagga at Kakuma Bridge	4,638	438	6.47	10.0
Tarach Lagga at Tarach Dam	2,736	564	1.09	2.2

Data: Princeton 1980 – 2018

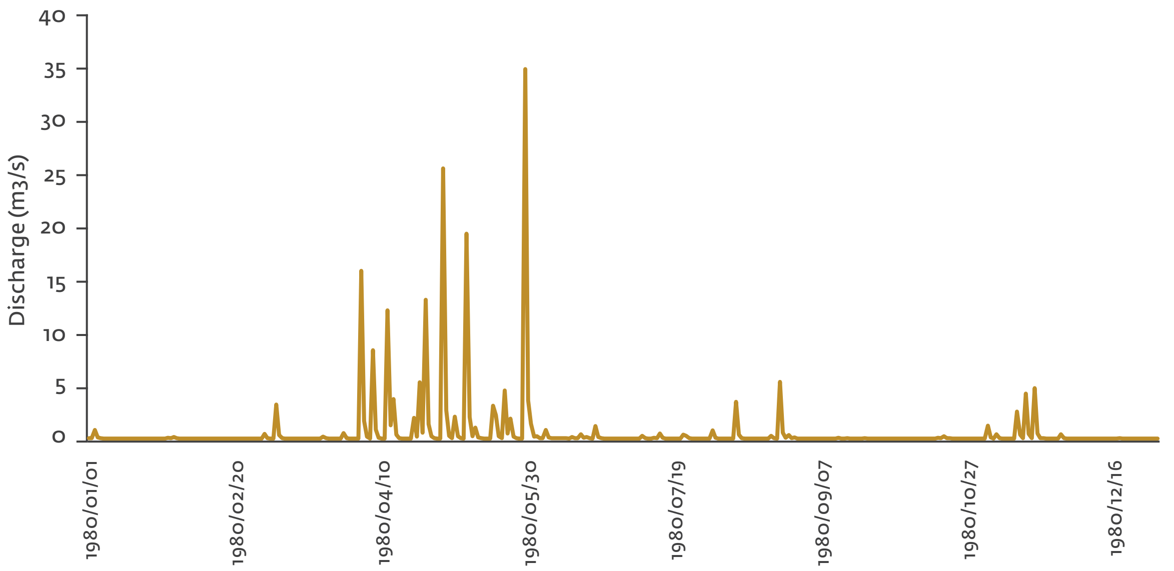
Figure 3-14: Daily flow duration curve, Tarach Lagga at Kakuma Bridge, 1980 – 2018



Source: Princeton

The analysis of the streamflow time series for the Tarach lagga at the Tarach Dam location are presented in Volume 2, Chapter 1. The daily streamflow hydrograph is presented for a sample year (1980) in Figure 3-15. This shows a hydrological pattern with short duration flash floods and otherwise long periods with very low flow. The Q_{95}[12], which is representative of a low flow condition, is 0.043 m³/s. While this indicates a perennial stream, which it is known that the Tarach lagga is not, this flow may approximate the flow underground within the alluvial material in the river bed.

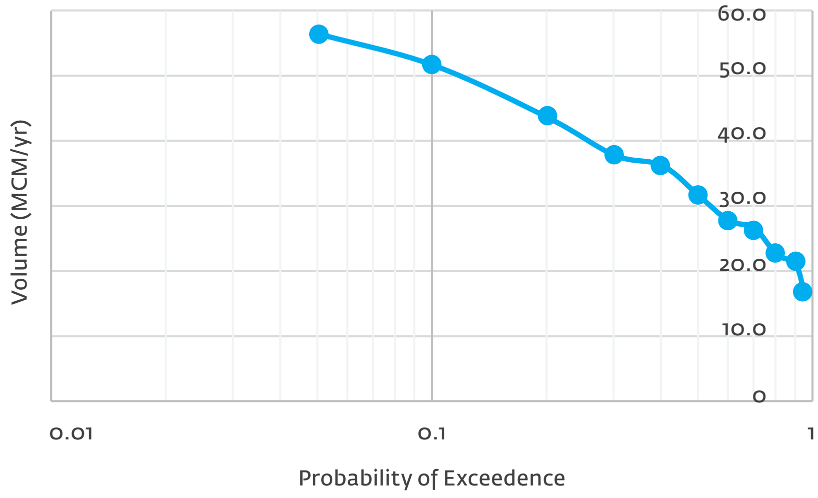
Figure 3-15: Daily streamflow hydrograph for Tarach Lagga at Tarach Dam, 1980



Of particular interest for the Tarach Dam location is the annual runoff volume. Figure 3-16 presents the probability of exceedance for annual flow volumes. The median value as shown in Figure 3-16 is 31.6 MCM/yr.

12 Daily flow that is exceeded 95% of the time.

Figure 3-16: Probability of annual runoff volume at Tarach Dam, 1980 – 2018



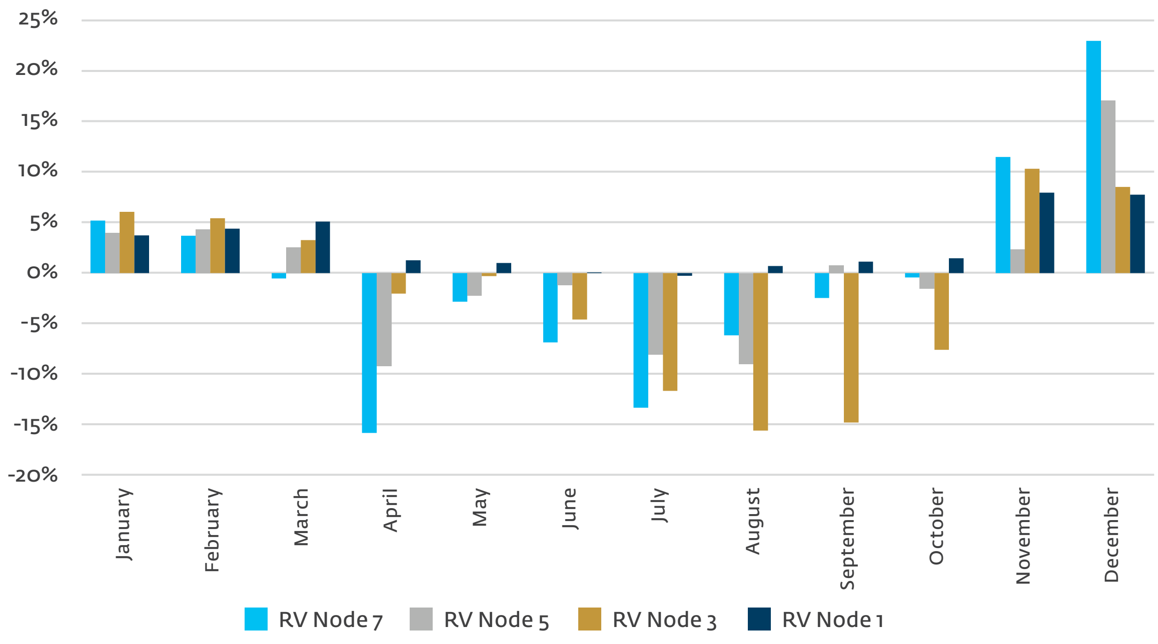
Prob. of Exceedence	Mean Annual Flow Vol (MCM/yr)
0.95	16.6
0.9	20.9
0.8	22.6
0.7	26.6
0.6	27.7
0.5	31.6
0.4	36.3
0.3	37.9
0.2	43.7
0.1	51.8
0.05	56.6

Source: Princeton

3.1.2.3 Anticipated streamflow changes due to climate change

The Rift Valley Basin Plan (Aurecon, 2020) superimposed the anticipated precipitation and climate changes derived from the most likely climate change scenario (RCP 4.5) on the hydrological model of the Rift Valley. It assessed the changes to the hydrological regime at various nodes, one of which is the Turkwel lagga (Node 7). Figure 3-17 shows the percentage change between historical naturalized flow and future flows under the climate change scenario. The results for the Turkwel (Node 7) indicate an increase in flows from November through to February and a decrease from April through to October. These changes signal the direction and scale of change that may be expected on the Tarach lagga. The changes and uncertainty surrounding future climate and streamflow implies that water storage and irrigation will become increasingly important for agricultural production in the Kakuma-Kalobeyei area.

Figure 3-17: Percentage change between current and future flows within the Rift Valley



3.1.2.4 Sediment yield

The Revised Universal Soil Loss Equation (RUSLE)[13] model is widely used to predict long-term rates of inter-rill and rill erosion from field or farm size units subject to different management practices. RUSLE is a lumped model which assumes spatially homogeneous hillslopes. A raster-based GIS soil erosion risk assessment tool for the Rift Valley Basin was developed as part of the development of the Rift valley Basin Plan (Aurecon et al., 2020) to establish the annual sediment yield for the Tarach sub-basin 2J. This value can be used on a pro-rata basis to provide an initial estimate of the sediment yield at the Tarach Dam site (Table 3-7), which is equivalent to approximately 1.39 MCM/yr[14]. This value implies a significant risk to the dam and indicates that substantial catchment conservation efforts would need to be implemented to ensure the long-term reliability of the Tarach Dam.

Table 3-7: Sediment yield in selected catchments

River/Lagga	Catchment Area (km²)	Potential soil loss (t/km²/yr)	Incremental sediment yield (t/km²/yr)	Cumulative sediment load (Mt/yr)
2J – Tarach sub-basin	27,798.0	3,001	660	18.347
Tarach at Tarach Dam Site	2,736.9	-	-	1.806

3.1.3 Groundwater

For the assessment of the groundwater, various factors that influence groundwater availability are put into consideration. A systematic approach and criteria for determining groundwater availability for cultivation of peanuts in the study area was followed. They are classified thematically based on geology, catchment boundary, climatic conditions and socio-economic factors. Groundwater often forms a reliable resource as the abstraction rate is less effected by fluctuations compared to surface water. However, water quality is an important factor to consider. For agribusiness, the shallow aquifer is interesting for reasons of relatively inexpensive access, but deeper aquifers can form a more reliable resource.

3.1.3.1 Approach

Data search and gathering of the existing information

Data from various sources as indicated in section 2.4, has been collected, collated, processed, and integrated to create an organized dataset for the area of study in Kakuma.

Data analysis

Precipitation data, lithology, soil type data and existing (historical) borehole database entries that have been collected are collated in one spreadsheet with one consistent format. This consistent format eases use during the subsequent geospatial analysis using GIS applications.

Synthesis of data

Water Strike Levels (WSLs), Static Water Levels (SWLs), Borehole logs, yields, aquifer lithology, water quality, test pumping and other parameters have been extracted from a total of 70 operational and 37 inactive boreholes. Precipitation data, surficial geology and catchment boundary has been embraced. The synthesis of all these information and data has aided in the determination of the aquifer occurrence and characteristics.

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13 Benavidez, R., Jackson, B., Maxwell, D. and K. Norton (2018): A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. Hydrol. Earth Syst. Sci., 22, 6059–6086.

14 Sediment density of 1.3 t/m³.

Reporting

This involves coalescing of the results that have been drawn from the overall analysis of data and synthesis of information gathered during the exercise. Ultimately, informing the way forward and the recommendations for water availability for the cultivation of peanuts.

Criteria for groundwater availability

Geology, soils and catchment boundaries, hydrogeological and climatic conditions and socio-economic factors have been used as the foundation at which the groundwater availability is based. This specific criterion is broken down into groups of data:

Hydrogeological and climatic factors

1. Geology and soils (Aquifer lithology);
2. Aquifer characterization (Areal extent and aquifer thickness);
3. Recharge;
4. Flux;
5. Aquifer storage;
6. Yield distribution;
7. Transmissivity;
8. Aquifer occurrence;
9. Catchment boundaries;
10. Water quality;
11. Precipitation;
12. Geospatial analysis of the above factors.

Socio-economic factors

1. Water demand and supply;
2. Legal and administrative issues.

3.1.3.2 Overall hydrogeology

Introduction

Based on the previous studies carried out in the area, Kakuma is located in a volcanic and sedimentary geological environment that forms a bimodal aquifer, i.e. consisting of two compartments[15]. The aquifer transmissivity varies considerably with aquifer lithology and structure. For instance, the fractured aquifer has lower transmissivity values than the sand aquifer, accounting for their low yields. It is noted that the water table elevation shows depressions at borehole sites, which exploits the fractured aquifers. This could be attributed to an inappropriate exploitation regime regarding the hydraulic parameters of this part of the aquifer, resulting in a constant minimal drawdown. In Kalobeyei, the main groundwater bearing formations are in the structures, low relief areas and where intense weathering processes have taken place. Generally, both Kakuma and Kalobeyei are located in low-medium groundwater potential zones.

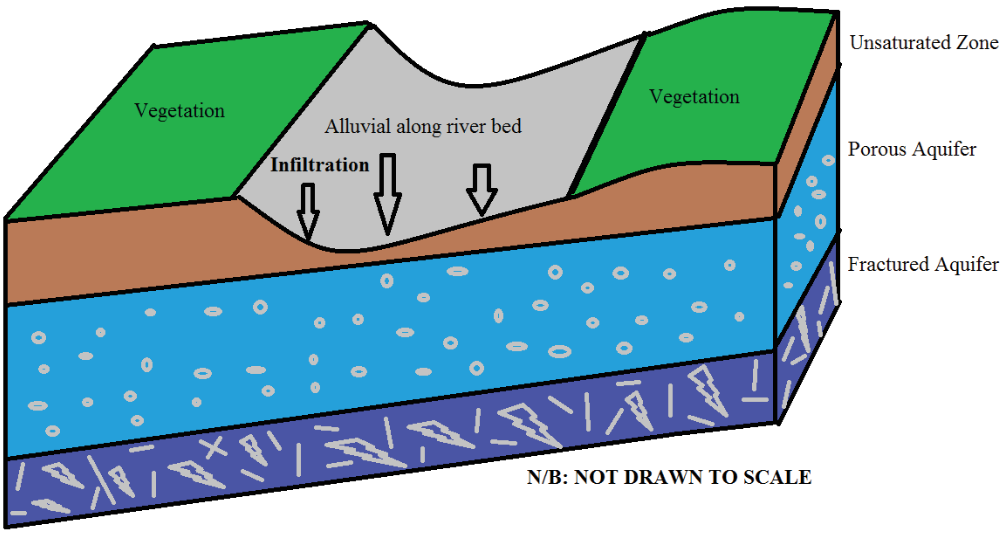
Delineation and characteristics of aquifers in Kakuma-Kalobeyei

Groundwater occurs mainly in the sedimentary and volcanic rock settings. In Kakuma, the volcanic rocks are close to the surface in the upstream part. It seems like it is then dipping northward, creating a zone underneath of sand with an increased thickness of sands and gravel layers. Hence, boreholes in this area are deep with low salinity at depths down to 120 m bgl. These rocks rise up in the northern part of the camp. In Kalobeyei, groundwater is mainly confined in fractures, joints and faults.

[15] The overall geology and soil types of the region of study are described in detail in Volume 2 – Chapter 2.

The structural geology of this region is described by Walsh and Dodson (1963)[16]. The subsurface lithology and these fault zones are also interpreted from the previous hydrogeological and geophysical investigations in the area, EWL (2015, 2016) and ERT line 10, 12 and 13 results (Bauman et al., 2016)[17]. Therefore, these fracture and fault zones are conduits for groundwater flow. From the analysis of the BCR data, boreholes drilled at depths >150 m bgl are bound to have poor water quality. Monitoring and piezometric data (derived from the analysis of borehole data, SWLs and elevation by EWL, see Figure 3-22) in Kakuma camp lead to the conclusion that the groundwater flows in a south-north direction. This is consistent with previous studies (Sottas, 2013 and E. Milnes, 2016). It shows that the water table tends to decrease during the dry season, with an increase in electrical conductivity values. However, rainfall and wadi runoff provide significant recharge, instantly raising the water table level. Furthermore, monitoring data demonstrate the actual active role of the laggas in the recharge process of Kakuma-Kalobeyei aquifers.

Figure 3-18: Schematic illustration of the aquifer system in Kakuma with two compartments



Source: Modified from Sottas (2013)

Classification of aquifers has been defined from boreholes in the area. Further delineation of aquifers using geophysics and correlation has been done in various previous investigations and studies. These aquifers are:

1. Tarach aquifers - both shallow and deep;
2. Lotikipi and the Lodwar aquifers;
3. Aquifers around Kalobeyei settlement and center.

They identified the main controlling factor as the type of rocks constituting the aquifer. Nippon Koei (2015) indicates that only 3% of the sustainable yield from the Kakuma basin is currently utilized.

[16] Walsh, J. and R.G. Dodson (1969): Geology of Northern Turkana. Min. Natural Resources, Geol. Survey Kenya, Report no. 82.

[17] Bauman, P., Ernest, E., Woods, L., MacLean, D., Shinduke, R., Alaistair McClymont, C. (Advasian: Wardey Parsons Group). Theran, A., Naama (IsraAID), (Geoscientists Without Borders) 2016, Surface Geophysical Exploration for Groundwater at the Kakuma Refugee Camp and the Proposed Kalobeyei Refugee Camp in Turkana County, Kenya, page 5.

3.1.3.3 Boreholes and groundwater level data

Borehole conditions

The borehole conditions vary considerably in the Kakuma and Kalobeyei areas. This is influenced by the structural controls in the case of the volcanic environment and alluvial deposits in (dry) river/ lagga courses. The presence of the water table at shallow depths in Kakuma has made possible the exploitation of productive boreholes having good quality water. However, as one moves to the NW i.e., towards the Kalobeyei location, sediments are thinner, and the volcanic environment sets in. Here, the boreholes drilled are mainly confined to fractures, joints, highly weathered basalts, inter-volcanic sediments and/or discordant contact between the Olivine and Augite basalts. At depths of about 70 m bgl, the water quality is good, but it deteriorates at greater depths through the basalts, which is associated with low yields. However, in case of a joint or fracture strike, the yields can be considerably higher compared to the yields in the weathered basalts. Figure 3-19 illustrates the boreholes within the area and their conditions, i.e. Inactive/non-operational and operational. The inactive boreholes are either dry, poor water quality, mainly with respect to salinity or were decommissioned due to frequent erosion and destruction by floods in the area along the laggas. The dry boreholes are either due to poor borehole construction or the existence of non-aquiferous geological formations in the sub-surface.

Boreholes in Kakuma and Kalobeyei locations that can be plotted in ArcGIS software (10.5 version) account for 115 in total, as per the available data records from various sources. A summary of the current condition of these boreholes is presented in Table 3-8.

Table 3-8: Summary of borehole conditions

Location	Operational	Inactive/non-operation
Kakuma-Kalobeyei	78	37

Figure 3-19: Borehole locations

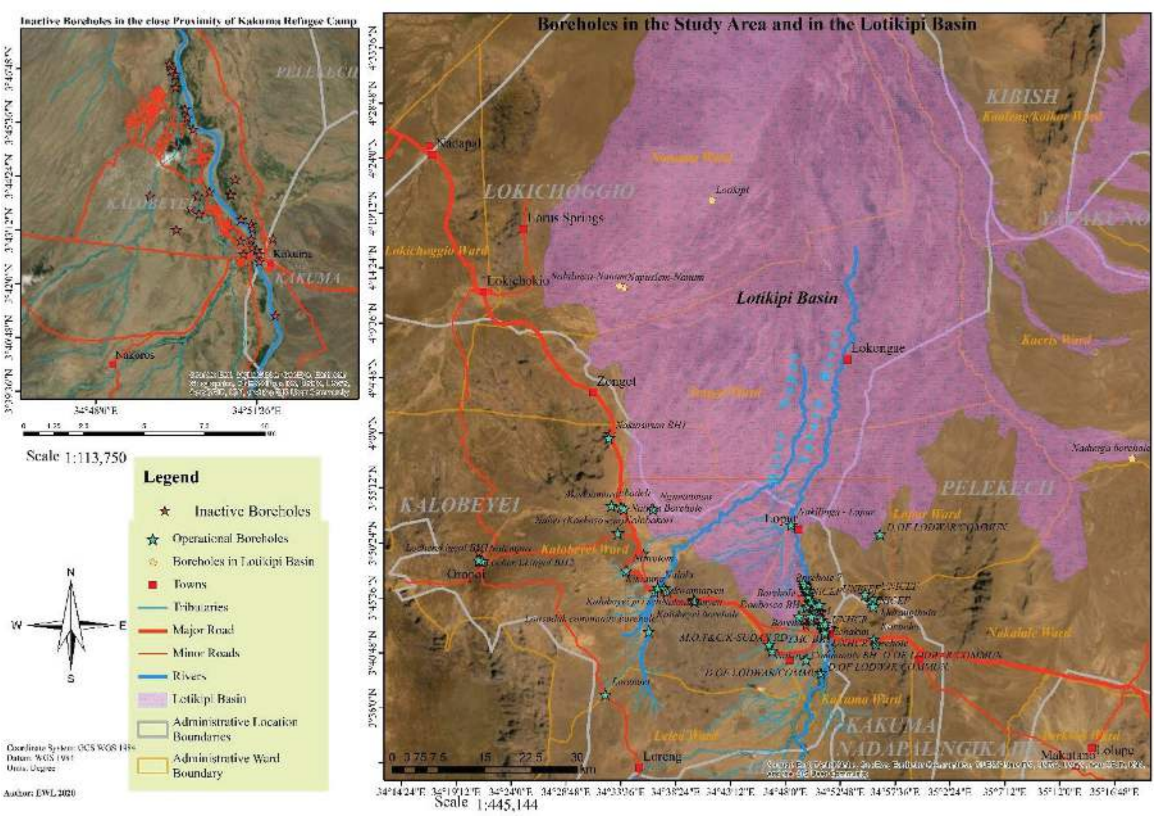
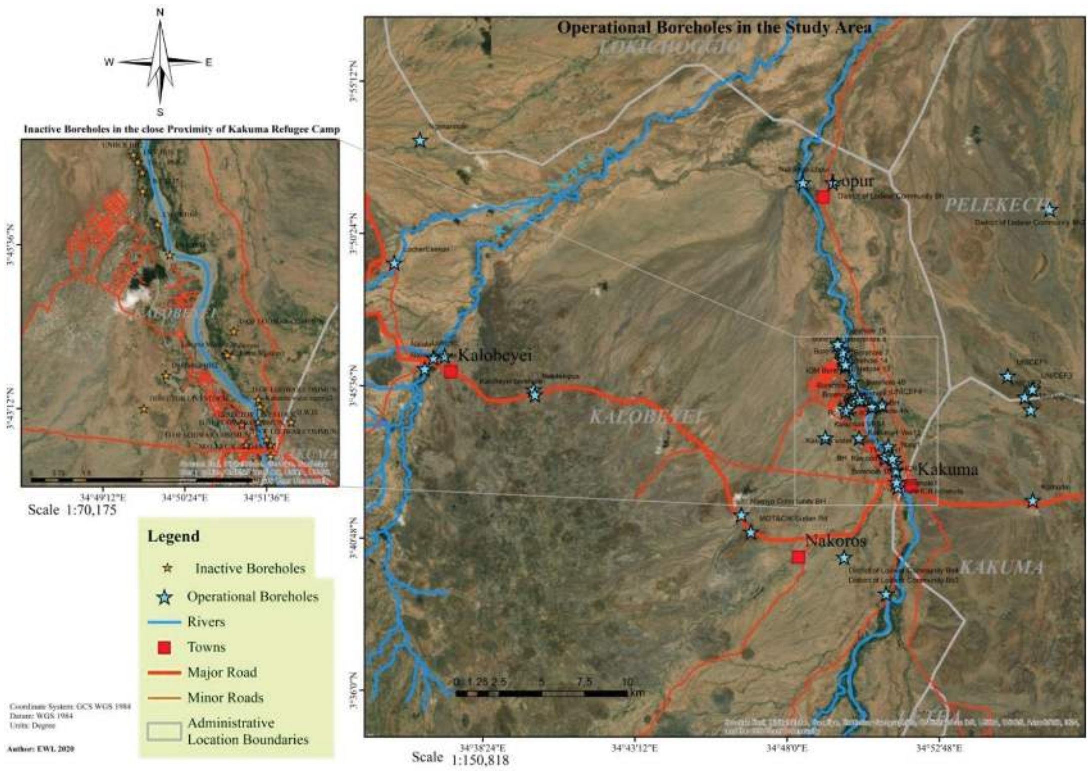


Figure 3-20: Borehole conditions



N/B: The borehole conditions described above apply to those that could be plotted. Other data exist for the whole County; however, some boreholes do not have coordinates for reference purposes. This calls for a detailed study to gather useful information about each borehole drilled which in turn will help in computing and calculating aquifer parameters of all identified aquifers.

Yield distribution

Most of the boreholes in the area have been drilled along the laggas, which act as a recharge zone for the shallow aquifers whose effects impact the deep aquifers through faults and fissures based on primary porosity of the rocks and soil types. This results in high yields in a significant number of boreholes. Along Tarach Lagga, borehole yields increase downstream towards the north of the Kakuma area.

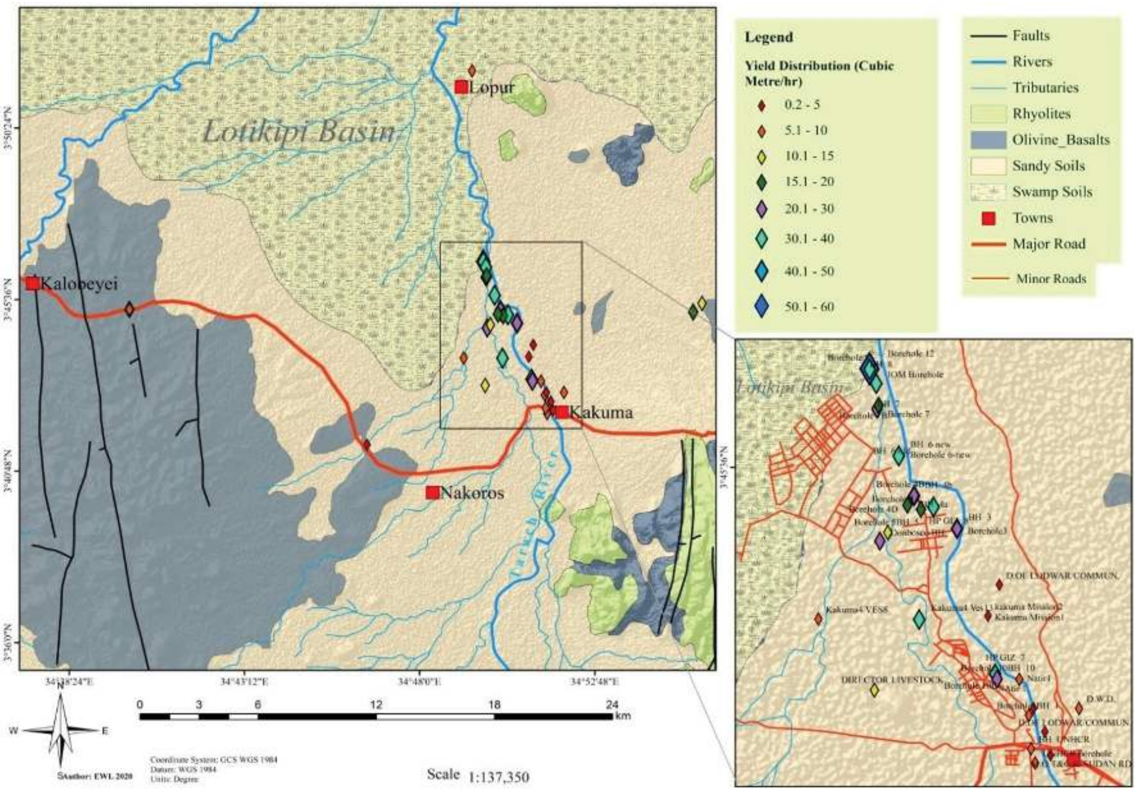
The Lotikipi basin, which is characterized by swamp and sandy soils (Walsh and Dodson, 1963[18]), extends further to the north of the Kakuma area. The topography is gently sloping, offering enough residence time for water to infiltrate and recharge the underlying aquifers. Based on this hypothesis, the boreholes in the north of the study area are postulated to have been drilled in the fringes of the Lotikipi basin to the south, where the aquifer is superimposed with Tarach Lagga basin. This basin is characterized by thicker sediments (alluvial sands and swampy soils) resulting in high yields, the highest being Borehole 12 with 60 m^3/hr as indicated in Figure 3-21.

Thickening sediments towards the North can be attributed to the periodic floods from the laggas upstream that deposit sediments downstream towards the Lotikipi basin forming a swamp that is a source of recharge in the aquifers below (WRA, 2020). From the borehole data in the location where the Tarach Lagga meet the Lotikipi basin, it can be premised that there exist shallow aquifers within the Lotikipi basin underlying the swamp soils. (see Figure 3-27). Perhaps recharging deeper aquifers further northwards in what can be the Lotikipi Aquifer (which was suggested by the RTI, 2013 study), though the extents of these aquifers are yet to be determined due to insufficient borehole data in this region. In contrast, the lowest yielding boreholes are the ones located upstream to the south, Kakuma Mission 1, M.O.T & C / Kakuma-Sudan Rd, District of Lodwar and Nakoyo Community Boreholes with yields of 0.24, 0.78, 1.14 and 1.97 m^3/hr, respectively. In general, the area has fairly moderate to high yielding boreholes with an estimated average of 17.56 m^3/hr.

It should, however, be noted that the reported yields of the boreholes are the tested yields and do not necessarily coincide with the aquifer yields. This, therefore, means that the yield distribution, in this case, is a subjective indicator of the aquifer capacity.

18 Walsh, J. and R.G. Dodson (1969): Geology of Northern Turkana. Min. Natural Resources, Geol. Survey Kenya, Report no. 82.

Figure 3-21: Yield distribution



Borehole logs

Sottas (2013) & Earth Water Ltd (2004, 2016) analyzed the borehole logs within Kakuma and Kalobeyei area with the results showing that:

- The aquifer within Kakuma consists of two sub-units:

1. Porous sedimentary deposits (mostly sands and gravels);
2. Fractured to severely altered volcanic bedrock underlying the sands, partially outcropping in some areas especially in the upstream direction to the south, while it deepens towards the north as the overlying sediments thicken. Therefore, it can be referred to as an "*aquifer system*" as shown in a schematic section in Figure 3-23;

- In Kakuma, the volcanic formation consisting of rhyolites underlain by basalts is close to the surface in the upstream. It seems like it is then dipping northward, creating a zone underneath with an increased thickness of sands and gravel layers and hence the boreholes in this area are deeper with low salinity effects. These rocks rise up in the northern part of the camp. However, perched aquifers and the unconsolidated units from the paleo-salts deposits that are saline can be encountered at shallow depths, (Sottas, 2013[19]);
- There is a shallow aquifer to depths as low as 6 m from the WSLs consisting of silts, sands and gravel, which is the one from which abstraction takes place in most shallow wells. In this study, shallow aquifers are defined up to the depth of 35 m bgl, in some cases, the aquifers are continuous down to medium depths (35-80 m bgl) which can be referred to as the intermediate-depth aquifers. It serves as a deep groundwater recharge buffer;
- The main alluvial aquifer consisting of coarse sands, gravels and cobbles lies at depths between 12 m and 30 m and most boreholes within the camp are tapping this aquifer;

[19] Sottas, J. (2013): *Hydrogeological Study of the Aquifer System of Kakuma, Kenya*. University of Neuchatel, Switzerland.

- In some boreholes, fractured basalts are encountered at depths beyond 30 m.

Observation of drill logs from boreholes located in the camp shows the presence of about 20-40 m of sedimentary formation (comprising of Silts, sands and gravel) on volcanic rocks as presented in Volume 2, Chapter 2.8 (Annex 2).

The deep borehole data at our disposal is only for one borehole. The details are presented in Table 3-9. The EcoRAD study reported an EC value of 7,000 µS/cm, contradicting the EC reported in the borehole records by WRA Turkana sub-regional office of 690 µS/cm, indicating that it is fit for human consumption. This sharp difference calls for exploratory drilling to confirm the correct values. From the UNESCO Kenya Groundwater Mapping Programme (2014), the aquifers of Lodwar and Lotikipi were confirmed through exploratory drilling.

The five aquifers, Lotikipi, Lodwar (confirmed) and Kachoda, Nakalale, and Gatome (to be confirmed) all require drilling, hydrogeological investigation and aquifer characterization, including quantity and quality. According to JICA (2015)[20] "*boreholes were drilled by UNESCO to confirm the existence of the deep aquifers in North and Central Turkana*". These boreholes are *Napuu3* in Lodwar aquifer and *Lotikipi borehole* in the Lotikipi basin aquifer. Lotikipi borehole is recorded to have a yield of 11 m³/hr and an EC of 7000 µS/cm, measured during test pumping.

It is too salty for drinking water and generally unfit for dairy cattle and young cattle. The report further added that saline water could be found in deep boreholes. No further detailed information is given for the Lotikipi borehole, including the coordinates, in the entire report (coordinates were later made available by UNHCR). Therefore, geophysical survey and exploratory drilling to confirm the correct borehole parameters is necessary.

Table 3-9: Lotikipi borehole data

Name of Site	GPS coordinate	Depth drilled (m)	Q m³/hr	WSL (m)	WRL (m)	Temp (°C)	Cond µS/cm	pH	Radial Dist. from Nasinyono (Km)
Lotikipi	36N 687889 479788	330	21	42-72, 124-216, 246-280	90.1	37.8	690	9.5	4.311

Source: WRMA Turkana sub-regional office – Drilled by UNESCO 2013 for RTI

The WRA database describes Lotikipi borehole as Lotikipi UNESCO & Lotikipi RVWSB, and both share similar GPS coordinates location. The data for the two boreholes has been summarized in the table below and could not fully help in the conclusion of the water quality analysis for deep aquifer characterization due to the discrepancy in EC and yield values in comparison with other data sources for the same borehole.

Table 3-10: Lotikipi borehole data (WRA)

Name of Site	Completion date	GPS coordinate	Depth drilled (m)	Q m³/hr	WSL (m)	WRL (m)	PWL (m)	Temp (°C)	Cond µS/cm	pH
Lotikipi (RVWSB)	2014	36N 687977 479400	350	35.98	178, 254	87	141.03	40.7	9060	7.96
Lotikipi (UNESCO)	-	36N 687977 479440	-	-	-	-		-	-	-

Source: WRA

20 JICA (2015): Water Potential Study in Turkana County, Annex E.

The primary data for Lotikipi borehole, whose accuracy cannot be disputed, was obtained from Rift Valley Water Service Board (RVWSB), who commissioned the borehole, and is tabulated below.

Table 3-11: Official Lotikipi borehole data (RVWSB)

Name of Site	Completion date	GPS coordinate	Depth drilled (m)	Q m^3/hr	WSL (m)	WRL (m)	PWL (m)	Temp (°C)	Cond µS/cm	pH
Lotikipi Community BH	6/12/2014	-	350	35.98	86, 214, 244-258	89	141.45	25	8640	7.3

Source: Rift Valley Water Service Board

The drill logs for this borehole show that the aquiferous layers consist of fractured pebbles (84-90 m bgl), weathered course pebbles (210-244 m bgl) and fractured fine sand (244-258 m bgl). The general stratigraphy depicts the basement system is overlain by differentiated volcanic rocks with different degree of weathering and younger sedimentary formations overlying the Volcanics conformably. Screening of multiple aquifers and a single well having interconnecting screen intervals in different zones are common good designs in the area, hence presenting a challenge in correlating and determine the relative contribution of the bedrock in contrast to the sedimentary aquifer (Bauman et al., 2016)[21]. The geological logs for this borehole are annexed in Volume 2 (Chapter 2.8, Annex 2).

In view of this contradictory and confusing information of the deeper borehole data from Lotikipi basin. For instance, both low and high EC values being 690 µS/cm and 7,000 - 8,640 µS/cm), (which can be attributed to errors related to secondary data transfer/entry and/or typing errors) respectively among other discrepancies for the same borehole from the contractor, WRA and RVWSB. We highly doubt the authenticity and validity of any other data that might be available. However, official Lotikipi borehole data provided by the custodian (RVWSB) and the regulatory authority (WRA), which is unequivocal, is taken as the legitimate data.

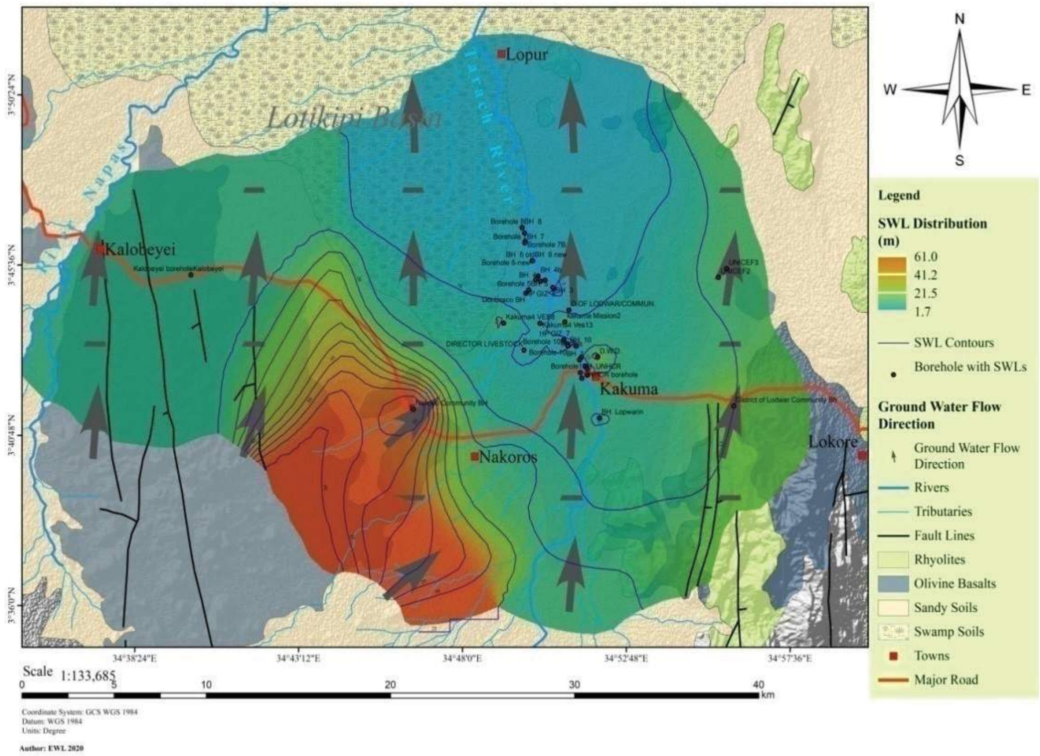
Piezometry

The topography of the study area generally slopes to the north. The highest elevation is 845 m amsl at the hills in the southern region; the lowest is 543 m amsl in the north towards the Lotikipi plains. Several data sets were collated and analysed. This includes data from UNHCR, Sottas, EWL, JICA, WRA and NRC, LWF, as well as other previous studies. The data were assembled into MsExcel and GIS databases and analysed. The static water levels of the boreholes reduce consistently with altitude, and the distances away from the laggas/rivers greatly influence the water table. The deepest SWL is 61 m bgl at the Nakoyo community borehole in the south of the study area, and the shallowest SWL is 0.4 m bgl at borehole 3.

The piezometric level is lowest (shallowest) in the boreholes near the Tarach Lagga and is highest (deepest) in the Nakoyo borehole. This suggests that the general groundwater flow is to the north towards the Lotikipi plains, as shown in Figure 3-22. However, it should be noted that the lithological heterogeneity of the region and variation of geology with depth greatly influence the potentiometric pressure. This, together with the fact that there is interval screening of aquifer zones in some areas and multiple aquifer screening can pose a challenge in determining the localized groundwater flow as indicated by Sottas (2013). Accuracy of the reported data is also in some areas uncertain.

[21] Bauman, P., Ernest, E., Woods, L., MacLean, D., Shinduke, R., Alaistair McClymont, C. (Advasian: Wardey Parsons Group). Theran, A., Naama (IsraAID), (Geoscientists Without Borders) 2016, Surface Geophysical Exploration for Groundwater at the Kakuma Refugee Camp and the Proposed Kalobeyei Refugee Camp in Turkana County, Kenya, page 5.

Figure 3-22: Piezometry



Conceptual considerations regarding the regional groundwater flow and quality

The aim of this section is to synthesize the field observations and to describe the main findings in relation to the geological and hydrogeological profiles, which have been compiled from the available borehole logs and which are presented in Volume 2, Chapter 2.8 (Annex 2). Those findings are:

- The profile shows high variability in the geological material and may suggest very irregular groundwater flow patterns. Vertically, the profile has been subdivided into a bedrock domain and a superficial sedimentary aquifer (sand/silt and gravel). This suggests that it is likely that the upper unconsolidated aquifer may be more permeable than the lower bedrock aquifer, which is mostly related to weathered volcanic rocks (generally less permeable than gravel/sand).

- With regard to the groundwater quality, the subdivision into a shallow unconsolidated aquifer and a deeper bedrock aquifer suggests that the water quality may be better in the upper aquifer, which is characterized by a different lithology, due to higher water flux and more direct groundwater recharge. This can be the reason why the fluoride level is low in this shallow aquifer. However, the proximity to the surface and the shallow water table makes the upper aquifer more vulnerable to man-made contamination (e.g. bacteriological contamination) than the lower bedrock aquifer level, which is probably more prone to geogenic contamination (e.g. fluoride and trace element).

Monitoring data – level recording

Monitoring data for boreholes in Kakuma refugee camp has been retrieved from previous studies due to a lack of current monitoring systems in the study area. The monitored boreholes included: Borehole 1, Borehole 3, Borehole 4a, Borehole 5, Borehole 6 (New), Borehole 10 and UNHCR Borehole. The monitoring data ranges from November 2012 to April 2014. The data has been presented in the form of graphs showing the varying water levels, electrical conductivities and rainfall.

From the monitoring hydrographs, it is clear that when the rainfall is low, the water levels decline, and this results in increased EC values. In the months of April and May 2013, the area received high amounts of rainfall, which led to increased water levels and decreased EC values in the boreholes. This shows that there is a direct connection between the amount of rainfall received in the area and groundwater recharge in the shallow unsaturated zone. However, the evapotranspiration rate is high and as the dry season approaches, most of the water in these shallow alluvial formations is lost. Hence most of the recharge in the shallow unsaturated zones comes from occasional flooding of the laggas. Increased or decreased water levels due to recharge changes have significant effects on water chemistry. When the groundwater recharge is high, the water quality in the aquifers is good and vice versa. This is because when water levels increase, the concentration gradient of the dissolved ions is low and vice versa. The graphical representation is given in Volume 2, Chapter 2.8 (Annex 9).

Monitoring data - available test pumping data analysis

Lotikipi Borehole (Hydro Water Wells)

- From the test pumping data, a drawdown of 52 meters was experienced over a period of 24 hrs, and a 73% recovery was obtained to a depth of 102.6 m for a period of 26 hrs. More time should have been given for recovery to attain the 75% recommended recovery.

Kakuma boreholes (Team & Team International)

- From the test pumping data, the five boreholes (coordinates not provided) show a drawdown range of between 4 and 6 m. Recovery in all the boreholes is within 18 minutes, though it is not in all the boreholes where the static water level goes back to the original level before pumping, but at least there is over 75% recovery by the end of test pumping. It can therefore be concluded that the boreholes are tapping from the same aquifer, which has homogeneous aquifer properties and recharge is high in all the tested wells.

IOM- BH 8

- Step-test: The fourth step (51 m^3/hr) is the pump's maximum flow rate at the given head. Hence, flow-rate for CRT was selected at the pump's limit;
- The recovery after the test took only 8 minutes;
- The observable change in water level from 10.26 m bgl to 10.23 m bgl between the 21st and 24th hour during recovery is due to the stopping of pumping at Borehole 8 for 2 hrs hence, with the cone of influence regarded, a full recovery would be observed when pumping in both Borehole 8 and IOM borehole is stopped;
- With only the first aquifer partially tested, it is possible that the well's production yield is in excess of 55 m^3/hr and is estimated at 55-60 m^3/hr.

BH 6B

- Drawdown took only 5 minutes with recovery taking 10 minutes;
- In the graph of drawdown vs yield during the Step Test, the second intersection point between the two curves gives the constant (flow) rate (35 m^3/hr) for the 48-hr constant rate test.

BH 4D

- Recovery was achieved in 8 minutes.

3.1.3.4 Groundwater recharge

Groundwater recharge zones / sources

For the estimation of the groundwater availability and the sustainability of water abstraction, it is important to estimate the groundwater recharge. Without sufficient recharge, the aquifers are mined, and the abstraction cannot be sustained in time. Groundwater recharge typically occurs in the upper aquifer and part of the water can flow downwards to the middle and deeper aquifers.

Several factors influence groundwater recharge of an area and include:

- Geology and physiography;
- Climatic;
- Land use and land cover/vegetation;
- Soil type;
- Drainage conditions of an area.

The possible recharge mechanisms are direct recharge through the infiltration of rainwater at the surface and overland runoff from the West South West, indirect recharge via faults and lateral recharge through the primary porosity of the underlying volcano-sediments.

Kakuma and Kalobeyei are also widely favourable for indirect recharge from flows in the laggas into the ground through porous and fractured geological formations, and partly, there is direct recharge from rainfall through the infiltration of precipitation into the shallow unsaturated zones.

Previous groundwater recharge estimates

Sottas (2013) concluded that as annual potential evapotranspiration exceeds annual rainfall, arid and semi-arid areas, groundwater recharge relies mostly on intense, short-term rainfall events, causing diffuse direct and local indirect recharge. The movement of the water within the aquifers follows gravity, so groundwater flows from the South and West to the North and percolates through successive formations northwards due to the existing hydraulic gradients.

IsraAID et al. (2016) noted that aquifer recharge at Kakuma camp was likely associated with indirect recharge from Tarach Lagga during flooding events (i.e. the laggas flood and aquifers are recharged from the laggas). Ellen Milnes (2016) shows this in the piezometric levels versus rainfall versus water levels in laggas.

Rural Focus (2018) noted that recharge occurs through direct (soil layers) and indirect (Tarach Lagga flooding events) processes. Sottas (2013) further presents a rough conservative recharge estimate of 32 MCM/yr based on a catchment area of 5,011 km^2, 2% infiltration and 350 mm/yr annual rainfall. Additionally, he provides a further estimate of the recharge within a restricted zone of Kakuma to be 3.7 MCM/yr. The recharge estimate does not include the recharge process from flows within the *lagga*. Nippon Koei (2015) estimated that annual abstraction within the Kakuma area is 3% of sustainable recharge. The estimated annual groundwater abstraction of 1.2 MCM/yr (Rural Focus, 2018) can be evaluated against the annual recharge estimates.

According to IGRAC (2014) review paper on the RTI study, the reported recharge rates appeared unrealistically high, as compared to what had been discussed in the previous work by various consortiums. They further fortified earlier reports on recharge in Kakuma and Kalobeyei as follows: studies by Bouwer (1989)[22] and Andersen (2008)[23] show that average regional recharge may be as low as 1% of the annual precipitation since evapotranspiration captures most of the water entering the soil and recharge occurs only during extreme rainfall events (Pilgrim et al., 1988)[24]. Green et al. (2012)[25] estimated recharge rates for seven different regions with semi-arid climates within the US, ranging from 2% to 7% of the annual precipitation.

Groundwater recharge estimates in this study

In view of the literature aforementioned, direct and indirect recharge methods have been used to calculate recharge in the study area based on the surface runoff.

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22 Bouwer, H (1989): Effect of Water Depth in Groundwater Recharge Basins on Infiltration. Journal of Irrigation and Drainage Engineering, Vol. 115, Issue 4.

23 Andersen, F.H. (2008): Hydrological modelling in a semi-arid area using remote sensing data, Doctoral Thesis, Department of Geography and Geology, University of Copenhagen, Copenhagen.

24 Pilgrim, D. H., T.G. Chapman & D.G. Doran (1988): Problems of rainfall runoff modelling in arid and semiarid regions (Problèmes de la mise au point de modelés plui écoulement dans les régions arides et semi-arides), Hydrolog. Sci. J. 33: p. 379–400.

25 Green, R.T., F.P. Bertetti, & M. Hernandez (2012): Recharge Variability in Semi-Arid Climates. Nature Education Knowledge 3 (10): p. 34.

The area is mainly dominated by ephemeral rivers/ laggas that run dry during the dry spells. Therefore, the catchment water yield (the rainfall that occurs as surface water flow after evapotranspiration and losses to soil or groundwater is calculated using the formula:

Catchment Water Yield = C * A * P, with

C= runoff coefficient (permeability of the land cover material),

A= area of the catchment (km^2),

P= precipitation (mm).

Runoff coefficients are taken from Table 3-5, which also illustrates the recharge values per specific catchment. The total recharge estimated from all the catchments in the study area using the above method is **$2.61*10^8$** m^3/yr. (**261 MCM/yr**). When the evapotranspiration rate (Et) is factored in this computation, the recharge values are negative since the Et rate is higher than average annual precipitation.

Another approximate method that introduces the elements of the sum of the change in water storage in the unsaturated zone, and the difference in the groundwater in and outflow in the water balance equation is applied estimating the recharge to be **$2.59*10^8$** m^3/yr (**259 MCM/yr**). The recharge calculations using Darcian flow are given in Section 4.2.1 (*Groundwater Flux*) and in Volume 2, Chapter 2.4 (*Groundwater Flux*).

3.1.3.5 Aquifer storage

Shallow aquifers (0-35 m bgl)

The shallow aquifers of Kakuma and Kalobeyei are composed of unconsolidated material (silts, sands and gravel) and complex multi-layered weathered volcanic formations and grits overlying a shallow basement. This complex and heterogeneous geologic context presents a challenge to estimating the potential storage of such aquifers at the regional scale. The study found out that localized studies need to be done for targeted alluvial aquifer units in order to achieve such an estimate. However, from the available data, the following estimates have been done:

The areal extent of shallow aquifers within Kakuma and Kalobeyei area is estimated at $5.14*10^8$ m^2, based on GIS spatial analysis, correlation and interpolation of the borehole data (WSLs, Logs and yields), soils and lithology spatial distribution. From the borehole logs and WSL data of 8 boreholes, mostly along the Tarach Lagga, an aquifer thickness of 6 m is taken as the average, although this is considered as the least value that is assumed to avoid exaggerating the aquifer storage. It therefore follows, the estimated aquifer storage of the shallow aquifers in the area is $3.09*10^9$ m^3*10% aquifer porosity = **$3.09*10^8$ m^3** (**309 MCM**).

Medium aquifers (35-80 m bgl)

From further analysis, medium aquifers have been classified to range between 35-80 m bgl. Borehole data indicate an aquifer thickness of 6 m on average, whereas the total areal extent of the aquifer is $7.16*10^8$ m^2. The total estimated aquifer volume is **$2.15*10^8$ m^3** (**215 MCM**), taking into consideration a 5% porosity of the aquifer material.

The above figures for the two aquifer categories have been arrived at taking into consideration the aquifer material porosities and the analysis of borehole data collated. However, localized aquifers are not well delineated due to insufficient data.

Deep aquifers (>80 m bgl)

The deep aquifer is not properly characterized in terms of hydrogeological conditions, geometry and water quality. The aquifer has not been adequately penetrated to provide a well-distributed spatial borehole data to deduce the groundwater availability (both the quantity and the quality). RTI, 2013 survey hypothetically propose a significant prospect for groundwater in the area with an estimated cumulative storage volume of 248 BCM. This over-estimation is unjustified and unqualified as commented by numerous reviews by among others, the UNESCO and IGRAC 2013. Water quality is also a matter of concern since later exploratory studies revealed high salinity levels.

Two exploratory boreholes were drilled to confirm the existence of deep aquifers in Lodwar and Lotikipi basin, which are more than 100 km apart, (UNESCO (2014)). According to the JICA (2015) Report, these boreholes are Napuu3 in Lodwar aquifer and Lotikipi borehole. Official data from RVWSB (Table 3-11) shows that Lotikipi community borehole has an EC of 8640µs/cm, which indicates that the deep aquifer is saline. Nevertheless, it is unlikely that all the aquifers have uniform water quality i.e. similar EC values and chances are that the water quality is varying with depth in different aquifers, this information is not available since specific data logging for these zones was not done.

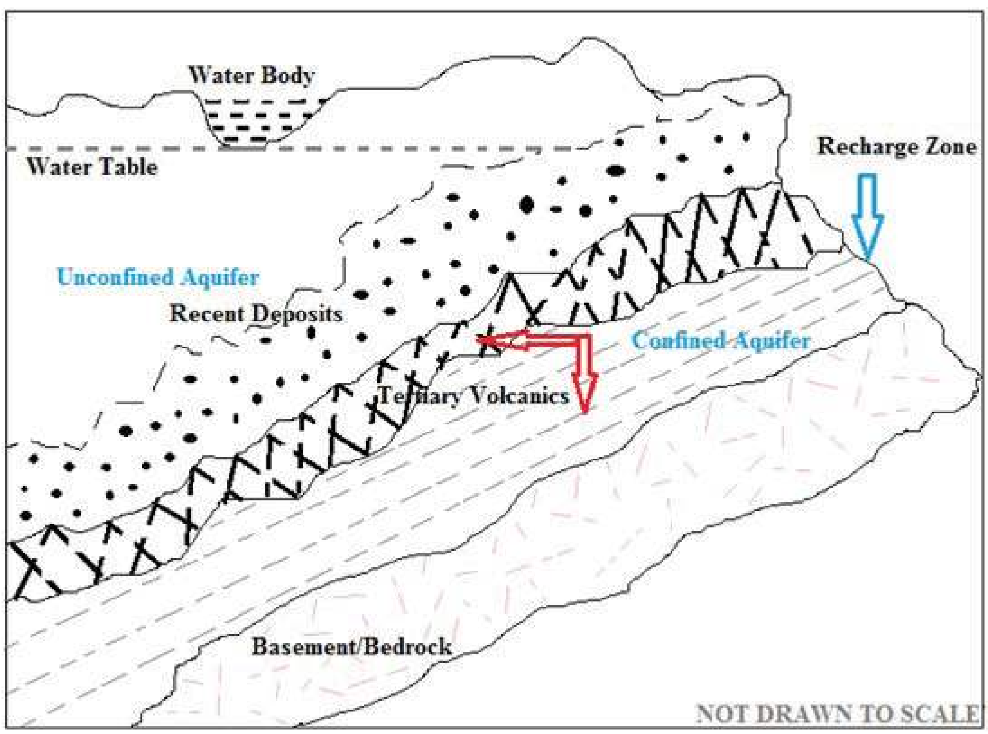
From our own observations, the elevation of the Lotikipi borehole and Lake Turkana is 505 m amsl and 360 m amsl respectively. The elevation of water strike level for the deep aquifer (259 m amsl) reported in Lotikipi borehole is lower than the surface-water level of lake Turkana (360 m amsl), with an average depth of up to 80 m. This indicates that the bottom of the lake is still above the WSL of the deep aquifer for the Lotikipi borehole. Hence the water column in the Lake, which is saline with higher density, has a great impact on the piezometric pressure in the regional surrounding hydrogeological systems, which have lower piezometric baseline levels like the Lotikipi basin. For this reason, we are persuaded to conclude that the deep aquifer is saline, justified by the EC of 7,000 µs/cm recorded during the JICA study.

Lake Turkana, being the regional piezometric base level, must be influencing regional groundwater systems like the deep aquifer in Lotikipi via the Turkana grits, which outcrop near the western shores of Lake Turkana. These observations are consistent with the regional piezometry of the area.

3.1.3.6 Groundwater occurrence

Groundwater occurs in two environments, depending on the geologic conditions surrounding the aquifer material. It is either in confined or unconfined aquifers. Both of these aquifer types are present in Kakuma and Kalobeyei as noted from previous studies (Sottas, 2013, RTI, 2013, & EWL, 2013). A schematic cross-section is illustrated in Figure 3-23.

Figure 3-23: A schematic cross-section showing confined and unconfined aquifers



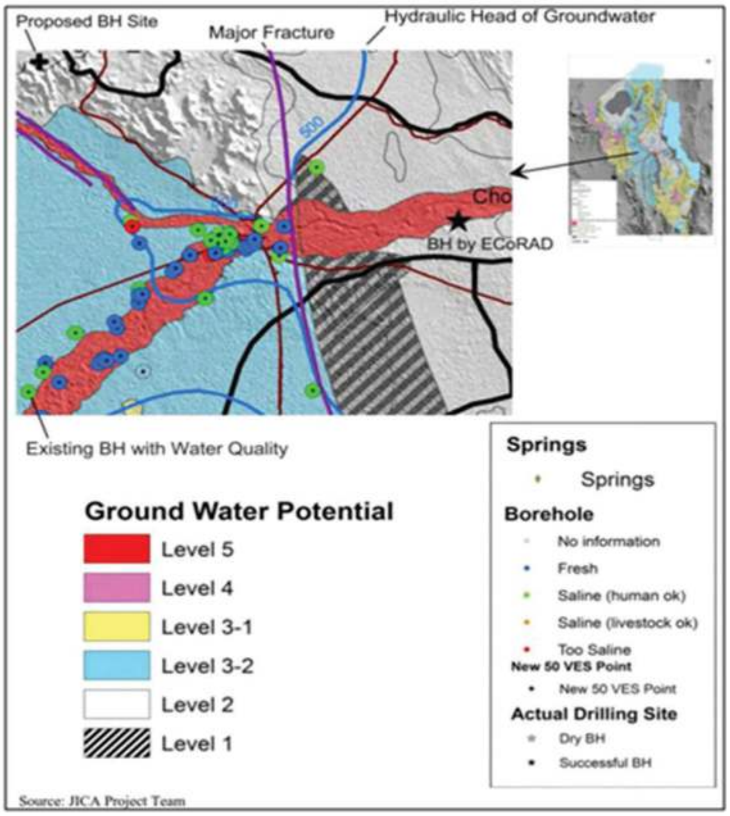
N/B: The borehole conditions described above apply to those that could be plotted. Other data exist for the whole County; however, some do not have coordinates for reference purposes. This calls for a detailed study to gather useful information about each borehole drilled, which in turn will help in computing and calculating aquifer parameters of all identified aquifers.

3.1.3.7 Assessment of groundwater availability

Groundwater potential zonation

The findings from previous studies have generalized the groundwater potential of the whole County of Turkana. The Tarach Lagga bed has features that are controlled by a major N-S fault which is recut by N45° and N160° faults, observed as part of a "Horse Tail" shearing-distensive system. However, inferences have been made from these findings in reference to Kakuma and Kalobeyei regions by reviewing the 3R Map analysis and Groundwater potential zonation by the JICA (2015) Study and RTI (2013) studies, and as presented in Figure 3-24. Studies carried out by EWL (2017) within the study area indicate the presence of good groundwater potential in the Kalobeyei area where faults are prevalent. These faults could be deep-seated with a connection to the Lotikipi basin alluvium formations.

Figure 3-24: Groundwater potential



Map level classification (Figure 3-24)

Level	Area	Description
5	River and Major Laggas Area	Potential is high. Water struck level may be shallow, and yield may be high. The water should be fresh.
4	Surround Area of Level 5	Potential is relatively high. The recommended site is along laggas. Freshwater is expected.
3-1	Volcanics and Basement Rocks Area	Potential is medium. Groundwater struck level is less than100m. The recommended site is along laggas. The water quality may be mildly saline in Volcanics.
3-2	Sediments Area	Potential is medium. Development target is limited along laggas. The water is fresh-saline.
2	Surround Area of Level 1	Potential is relatively low. Groundwater struck level may be more than 100 m. The water may be saline.
1	Basin and Lake Turkana Coastal Area	Potential for hand pump is low. Groundwater struck level in Basin Area is more than 100 m, and hydraulic head may be low for a hand pump. The water quality could be saline. Groundwater could be struck at shallow depth in Lake Turkana Coastal Area. However, the water could be saline.

Source: JICA Project Team

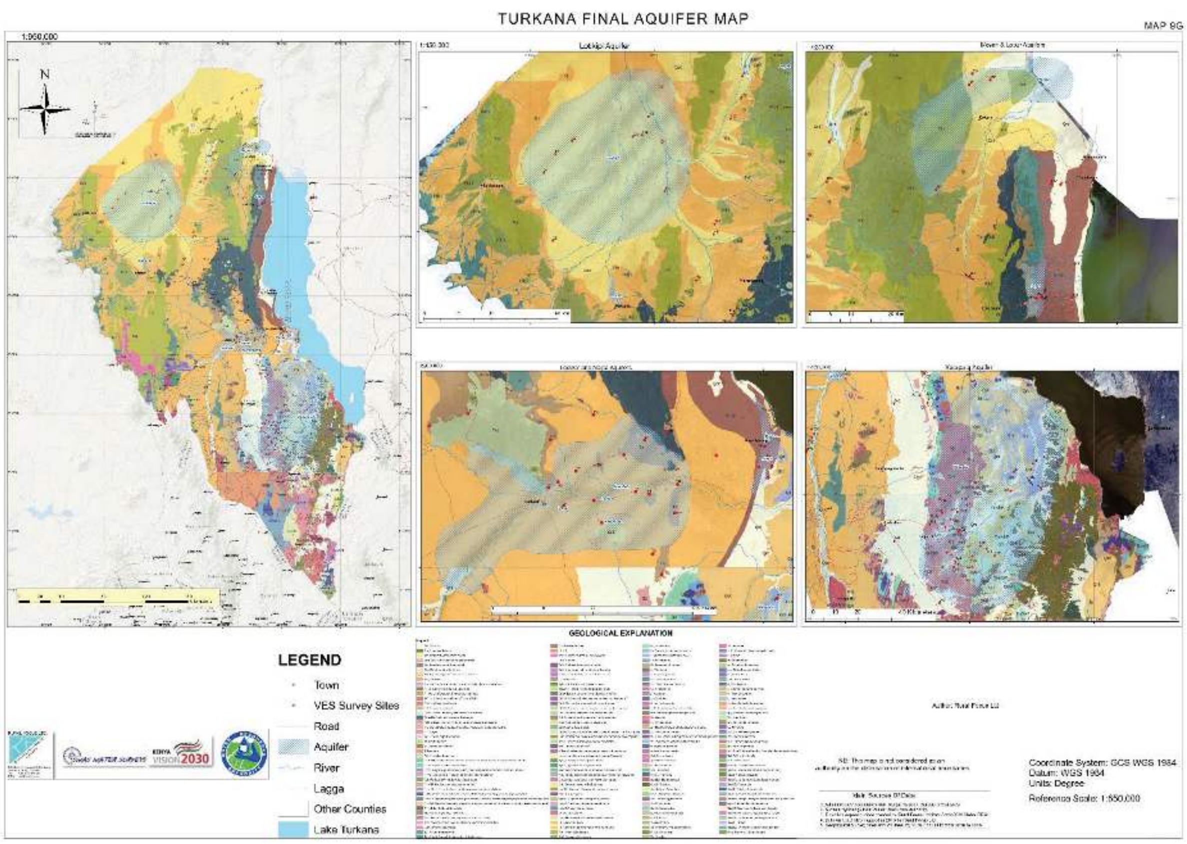
Kakuma exploits its water mainly from shallow boreholes (<100 m) within the fracture corridor of the Tarach Lagga. It's a location to the Lotikipi Basin Aquifer 25 km south of the southern portion of the large Lotikipi Basin Aquifer (Lotikipi South), could be a good site to explore for groundwater. Mike Thomas et al. 2018, postulated that the Kakuma aquifer system consists of two layers, one shallow porous aquifer made up of sedimentary material and one underlying fractured aquifer made of volcanic rocks.

The shallow alluvial aquifer is generally associated with high yields and greater storage, lower EC and fluoride concentrations but greater vulnerability to bacterial contamination. The deeper, fractured volcanic rock aquifer is associated with lower yields, higher EC and fluoride concentrations but lower vulnerability to bacteriological and anthropogenic pollution. Rural Focus (2016) data indicates 52 boreholes and shallow wells within a 10 km radius of Kakuma. This clearly illustrates the level of effort to exploit the groundwater resources and the importance of groundwater as a reliable water source.

Aquifers in the fractures and weathered rhyolites have high fluoride levels. This can be attributed to various factors. One of them is the genesis of rhyolites and mineralization. Fluorite (CaF_2) occurs in the hydrothermal veins and fractures, including in volcanic rocks. Rhyolites contain alkali feldspars (sanidine and sodic plagioclase); as it decomposes, Na^+ ions replace calcium in the fluorite and releases sodium fluoride (NaF), which readily dissolves in groundwater. Weathering of biotite in the rhyolites into clays and chlorite (which react with Na^+) reduces hydraulic conductivity in the fractured aquifers, increasing fluoride levels further and salinity respectively.

From a study conducted by WRA (2020) on Hydrogeological Mapping of Turkana aquifers, seven aquifers were delineated at a regional scale in Turkana County. The aquifers are Kakuma aquifer, Lotikipi aquifer, Lodwar aquifer, Meyan aquifer, Naipa aquifer, Napuu aquifer, Kalapata aquifer and Lopur aquifer. These aquifers are shown in the figure below.

Figure 3-25: Turkana aquifers



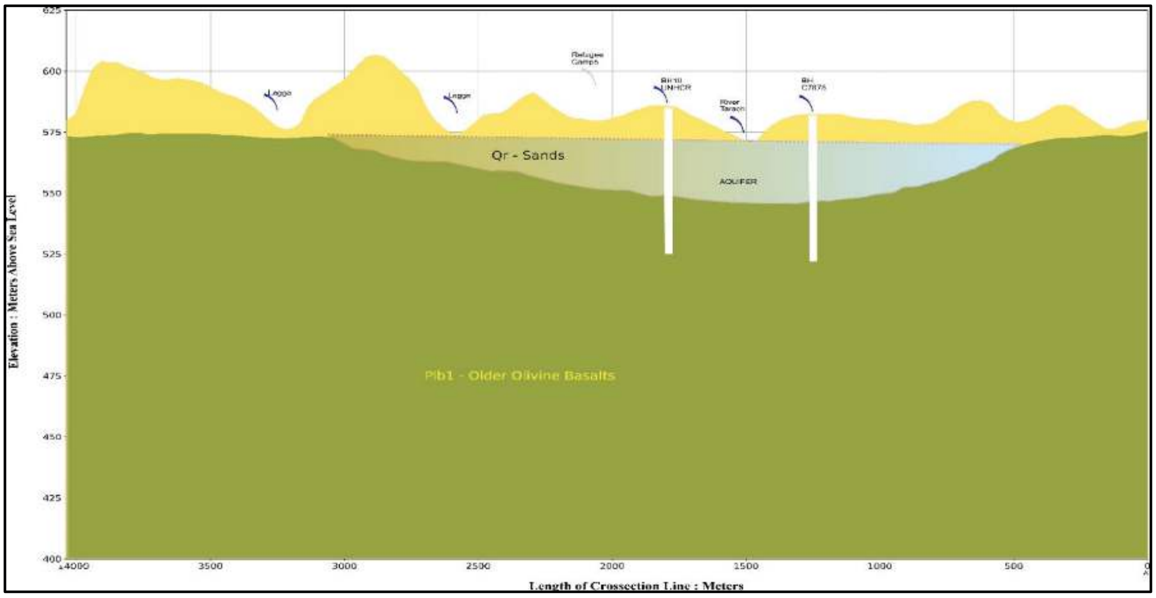
Source: WRA, 2020

In this study, Kakuma aquifer was described as a strategic alluvial aquifer of 20-70 m depth overlying volcanic rhyolites and olivine basalts. It is the main source of water in the refugee camp; the aquifer yield and quality deteriorate with increasing distance from the lagga. The cross-section for the aquifer is shown in the figure below from coordinates shown in the table below.

Table 3-12: Kakuma aquifer cross section coordinates

Name	Start line (Datum WGS 84)		End line	
	Lat	Long	Lat	Long
Kakuma	3.723501317	34.86850656	3.721010629	34.82972366

Figure 3-26: Kakuma aquifer cross-section



Source: WRA, 2020

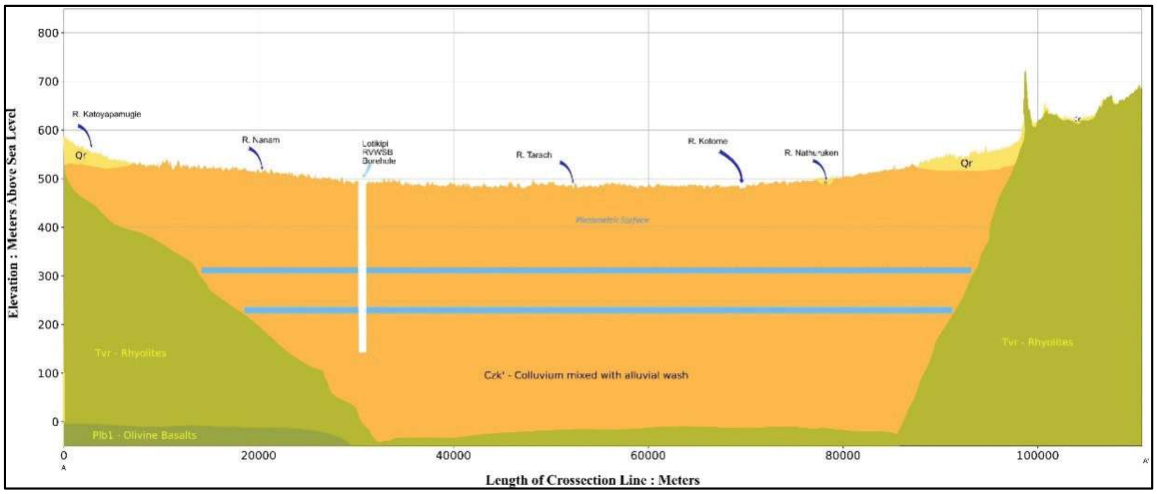
Lotikipi aquifer was identified and described by UNESCO as a vast aquifer in the Lotikipi basin. However, exploratory drilling of one borehole confirmed water quality in the aquifer is unsuitable for domestic, livestock or irrigation purposes without treatment. This could be due to the fact that the basin was a former extension of Lake Turkana and the highest percentage of recharge is through the Turkana grits, which extends all the way to the lake, which is saline. The geology of this area is characterized by alluvial sediments and clayey soils, with Turkana grits and rhyolite beds at a greater depth.

The sample collected for water quality analysis indicates the water is very saline with excess levels of sodium, bicarbonates, nitrates, sulphate, boron, chloride and fluoride. The aquifer depth starts at 178 m and continues to 254 m as determined from the RVWSB exploratory borehole drilled. No abstractions have been made yet from this aquifer, except in Nasinyono and Nanam communities, where the water quality is better. Recharge for this aquifer is estimated at 60.77 MCM/yr (RTI 2013) with possible groundwater storage of 129.24 BCM (WRA, 2020). This is an over-estimation considering only the single borehole. The aquifer cross-section is presented in the figure below from coordinates shown in Table 3-13.

Table 3-13: Lotikipi aquifer cross section coordinates

Name	Start line (Datum WGS 84)		End line	
	Lat	Long	Lat	Long
Lotikipi	4.364981608	34.42583483	4.245132916	35.48264864

Figure 3-27: Lotikipi hydrogeological aquifer cross-section



Source: WRA, 2020

Shallow groundwater potential

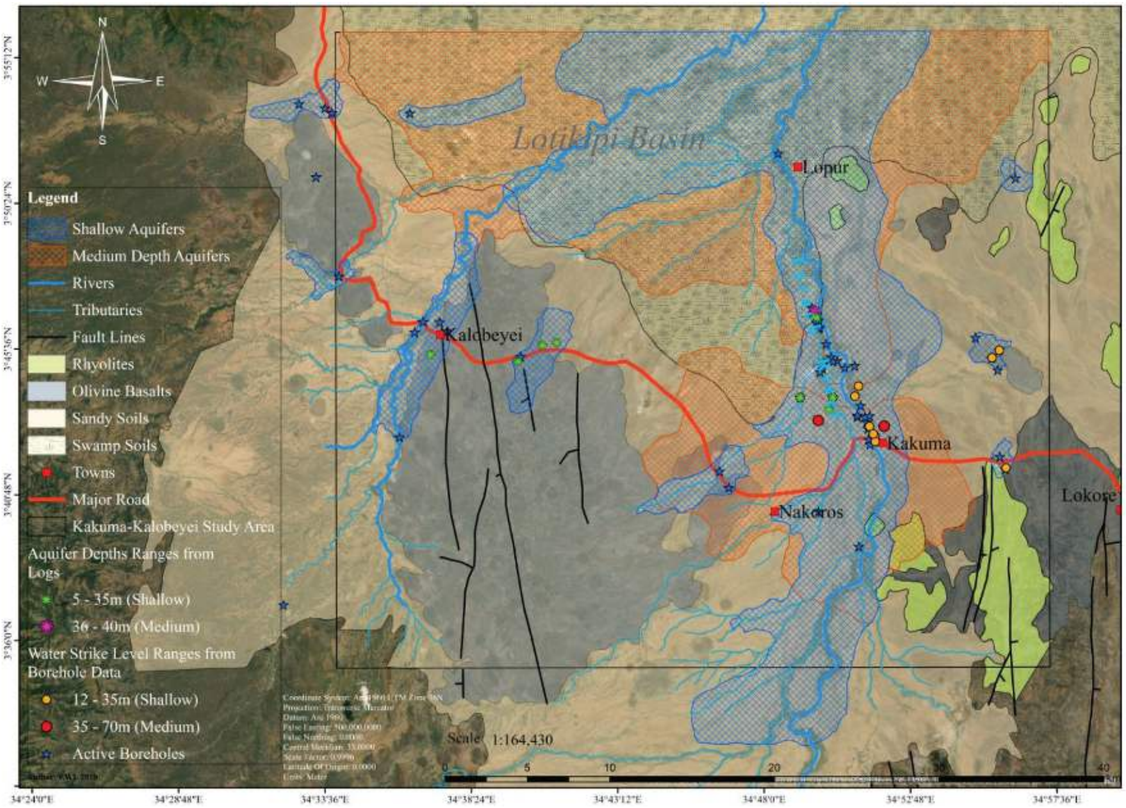
From several studies carried out by Earth Water Ltd, a shallow aquifer is present as evidenced by shallow wells which are in some cases used for small scale agriculture by the refugee community and scoop holes dug by both the refugee and the host community in the Tarach Lagga bed during the dry seasons. In May 2016, three high-yielding boreholes surveyed by Earth Water Ltd were drilled by UNHCR in the alluvium and tested at sustainable flows of 29 m^3/hour, 40 m^3/hour, and 45 m^3/hour. Water quality in each well showed low salinity and low fluoride concentrations.

Medium groundwater potential

From the desk studies and calibrating with the existing geo-structural, borehole logs, geophysical (from EWL and Advisian/IsraAID/GWB 2016 report[26]) and borehole data, we have classified the aquifers into two i.e. shallow aquifers up to 35 m bgl and medium aquifers from 35-80 m as shown in Figure 3-28. A geological correlation exists between the shallow and the deep Lotikipi borehole. It describes its geology as mature endorheic delta that consists from a surface to 300 m of coalescent palaeo-channels rich in quartz gravels and sands. Boreholes drilled beyond 30 m tap this aquifer, and the water quality is questionable in some of the boreholes at this depth.

[26] Bauman, P., Ernest, E., Woods, L., MacLean, D., Shinduke, R., Alaistair McClymont, C. (Advasian: Wardey Parsons Group). Theran, A., Naama (IsraAID), (Geoscientists Without Borders) 2016, Surface Geophysical Exploration for Groundwater at the Kakuma Refugee Camp and the Proposed Kalobeyei Refugee Camp in Turkana County, Kenya, page 5.

Figure 3-28: Shallow and medium depth aquifers



Deep groundwater potential

Models have been developed to understand the deep-seated aquifers in the area, and from the findings by RTI (2013) five major deep structures are mapped and assessed. The discovery of the five structures was a very significant result for hydrogeological investigations. The models were developed to represent groundwater regimes that were, in general, stored in confined or semi-confined formations in permeable geologic material from 80-100 m to an approximate depth of 3 km or more. The findings are presented in Figure 3-29.

Figure 3-29: Five deep-seated structures in Northern-Central Turkana County (RTI, 2013)

Lotikipi aquifer remains largely uncharacterized due to lack of enough and spatially distributed borehole data to define it. However, from our analysis of the deep Lotikipi borehole that was drilled by RVWSB in 2014 and the water quality from the borehole. We are tempted to conclude that the deep aquifer beyond 80 m bgl is saline and unusable for both irrigation and domestic purposes unless proved otherwise by a more specific investigation (both geophysical and sub-sequent aquifers exploratory drilling) in Lotikipi basin.

3.1.3.8 Aquifer occurrence in Kakuma and Kalobeyei

Hydrogeological characteristics

Comparing and correlating water levels from the available borehole data, water strike levels and piezometric levels in the alluvial deposits (unconsolidated formations) do not vary significantly, neither do they have a trend which can distinguish the sandy formations underlying the alluvium or occurring further from the axis of the lagga basin. Therefore, it is unlikely that these sandy formations form compact sedimentary rocks such as sandstones. Along the Tarach Lagga in Kakuma, alluvial sediments are underlain by rhyolites, and some of the outcrops are evident. A bit further, the sandy soils are underlain by basalts.

A. Hydrogeological characteristics of Tarach aquifer

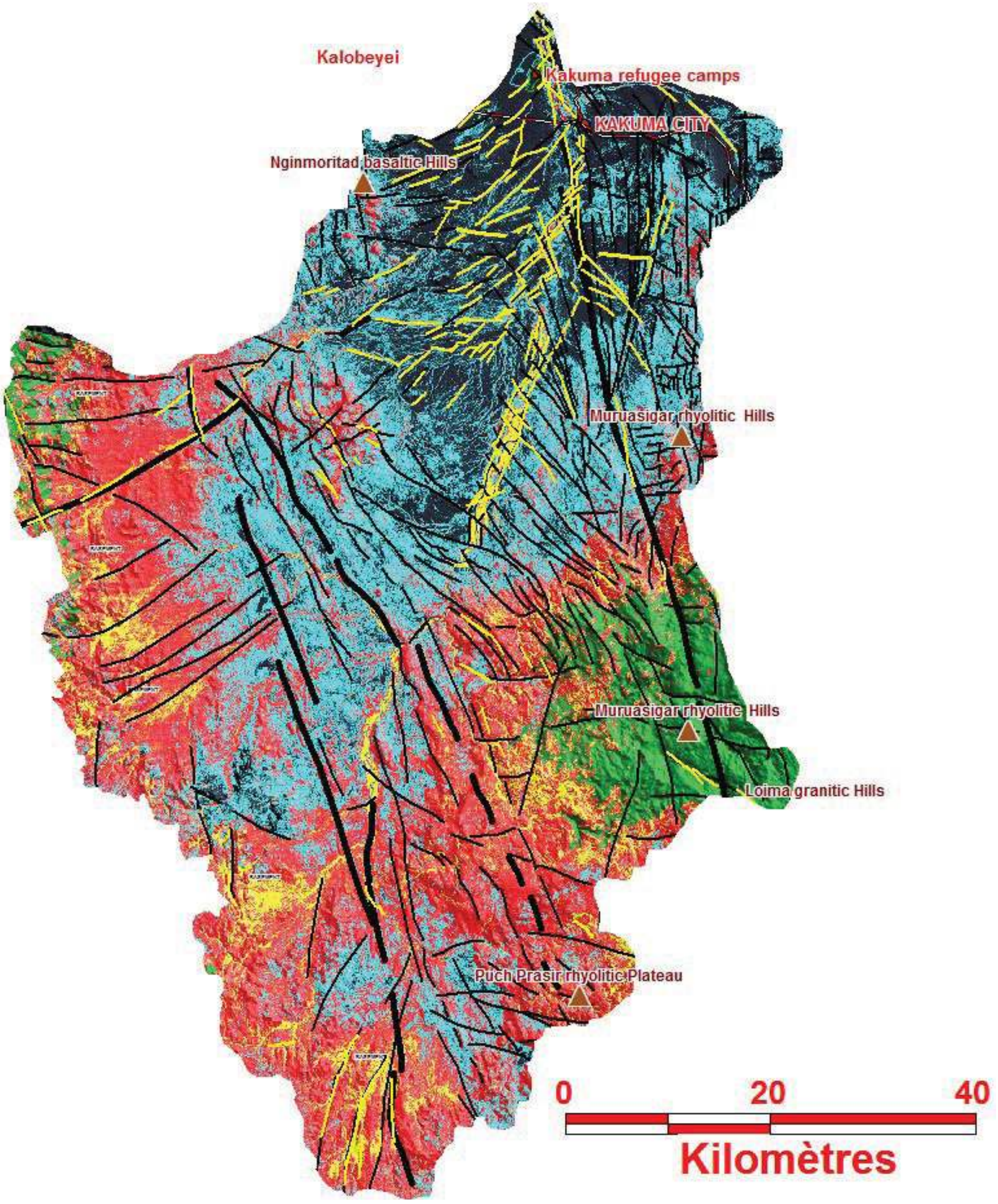
Thomas, et al. (2018) described Tarach-Kakuma sub-watershed (catchment area 5,168 km²) located in an area of highlands at an elevation ranging from 600 m to 1,400 m. Most of the water in the watershed flows towards Kakuma town in a north-north easterly direction from the silica-rich granitic escarpment of Uganda, the Puch Prasir rhyolitic plateau in the south and the Muruasingar rhyolitic hills southeast of Kakuma.

The Tarach Lagga bed has features that are controlled by a major N-S fracture which is recut by N45° and N160° fractures, observed as part of a "Horse Tail" shearing-distensive system. The two rhyolitic volcanoes in the area that they noted were the Pelekech and Muruasigar hills.

The basement in the Kakuma area is relatively shallow, ranging from 100 m to 150 m. Significant volumes of water infiltrate downstream through the Tarach Lagga and its tributaries, which converge at Kakuma.

RTI (2013) noted that the aquifers reached by the boreholes within the vicinity of the Kakuma refugee camp were considered to be dynamic aquifers, with a general water flow oriented towards the north. The half-graben structure located in the north filled with Plio-Pleistocene fluvio-deltaic deposits. Being steadily fed by the Tarach Lagga course through vertical recharge, this half-graben structure is considered to be a renewable aquifer with high potential. The water level in this structure is estimated to be at a depth of 100 m or more. This structure can be confirmed by drilling deep boreholes approximately 20 km north of Kakuma BH08.

Figure 3-30: **Kakuma watershed (After Thomas et al., 2018, based on RTI, 2013)**



In the Kakuma area, most aquifers occur at a shallow to moderate depth, often less than 50 m. These aquifers are situated amongst inter-volcanic layers and within fractured geologic formations initiated by the shallow granitic basement.

It is important to note that while most boreholes drilled in and along the alluvial systems of the Tarach Lagga may show tendencies of freshwater quality, drilling outside these systems may result in variations in groundwater quality resulting from the local alkaline volcanic context (rich in sodium bicarbonate) and different level of fluoride concentration. Several rhyolitic plugs in the Kakuma area and its environs (especially to the West of the Tarach) present a challenge to drilling in the area since water quality at some levels is not good, and great care should be taken to mitigate this. Drilling in the Kakuma area carries a high risk due to the pervasive, intrusive volcanic plugs, which are often not visible on the surface. In order to minimize risk, it is highly recommended to drill within the fracture corridor of the Tarach Lagga. Additional ideal areas for borehole drilling could be explored downstream of existing boreholes in the Kakuma refugee camp area.

In the Kakuma area, a dense web of deeply incised fractures and high flow rates of the lagga (during the rainy season) provide favourable conditions for directing runoff and groundwater infiltration at Kakuma. In addition, Kakuma's high potential for groundwater occurrence is enabled not only through the alluvial aquifer system, but more by the multi-layered aquifers found slightly deeper within the volcanic layers and grits recut by fractures and reworked by laggas. Such a combination of alluvial systems intersected by fractures is more reliable for large water supplies as compared to only considering fractures in these camps area.

There is a broad geosyncline (valley) between two distinct volcanic systems: the Ngimoritad basaltic hills in the West and the Pelekech rhyolitic Hills in the East, which is a potential zone for groundwater occurrence The Tarach riverbed itself is controlled by a shear distensive fractures corridor, which is injected with hardened magma, known as rhyolitic plugs. These plugs protrude to the surface and are visible along the Lokichoggio-Lodwar Road west of Kakuma and within the refugee camp near the Tarach riverbed. The basement, which can be reached at an average depth of 100 m, is overlaid by Turkana Grits (sandstones and conglomerates) and by weathered basalts and rhyolites layers intersected by deep-seated fractures. The structural system needs to be investigated for groundwater since it is clear that some boreholes tap water from the fractures system.

B. Hydrogeological characteristics of Lotikipi aquifer

The UNESCO through the RTI (2013) study suggested the existence of the large Lotikipi Basin aquifer system. An exploratory borehole drilled by RVWSB to a depth of 330 m encountered three interconnected aquifer layers with a cumulative aquifer thickness of 202 m. This coincides with the original hypothesis (although purely arbitrarily) of the RTI models of the existence of a mature endorheic delta that consists from the surface to 300 m of coalescent palaeo-channels rich in quartz gravels and sands. The study identified deep-seated aquifers but never documented its quality.

The second layer of the aquifer was observed from 250 m to 300 m, with quartz-rich layers. RTI estimated the porosity at over 20%. A distinctly different aquifer layer was observed at 300 m. Analysis of the geological cuttings taken from 330 m revealed fluvio-lacustrine, tuffs and brecciates. Seismic and gravimetry interpretation indicated a transition of seismic character to the formation with very continuous horizons.

The study concluded that the layer of the Lotikipi Basin Aquifer was an ancient sedimentary formation that began at 300 m depth and had a minimum thickness of 500 m. The Paleo Lake was expected to be the most water-saturated portion of the aquifer system and could store a volume even far greater than the shallower layers observed in the initial 330 m.

The water in this formation was likely to be much older than the shallower layers but may be less productive than the shallower layers due to its reduced permeability caused by a different shale-to-sand ratio and possible carbonated cement. There was a concern that water in this deep layer could be of lesser quality, but this could only be confirmed with deeper testing and dating.

C. Hydrogeological characteristics of aquifers around Kalobeyei settlement

The Kalobeyei sub-watershed begins in the highlands at an elevation of 1,750 m and extends northward towards Kalobeyei Township down to 710 m. It receives some 293 MCM of water/year, which is drained over the catchment area of 770 km², making it around ten times smaller in scope than the adjacent Tarach-Kakuma watershed. Most of the water is flowing from the silica-rich granitic highlands of Uganda. The main groundwater resources in the hills are hosted by conductive fractures with limited potential. The most important aquifers for Kalobeyei are hosted within the low-lying plains of the Kalobeyei (Napas) lagga, within alluvial aquifers covering a shallow basement (less than 100 m deep).

The geology and hydrogeology of the Kalobeyei area are very similar to Kakuma (EWL, 2015) comprising clayey alluvium overlying tertiary lavas, with sand lenses being present near the major *laggas*. EWL (2016) postulated that weathered rhyolites underlie areas of alluvium most of which are underlain by interbedded basalts, sedimentary rocks and Precambrian Basement.

Groundwater quality is affected by the alkaline volcanic context rich in sodium bicarbonate and locally affected by the presence of fluoride. The structuration of the Napas/Kalobeyei lagga is dissected by N45° and N160° *en echelon* fractures.

RTI (2013) described the conditions of Kalobeyei aquifers as mild potential alluvial aquifers with intra-basaltic layers. They further noted that although the volume of water was relatively high through recharge, the dispersion and distribution of shallow alluvial aquifers made it less favourable to support an influx of population in the area.

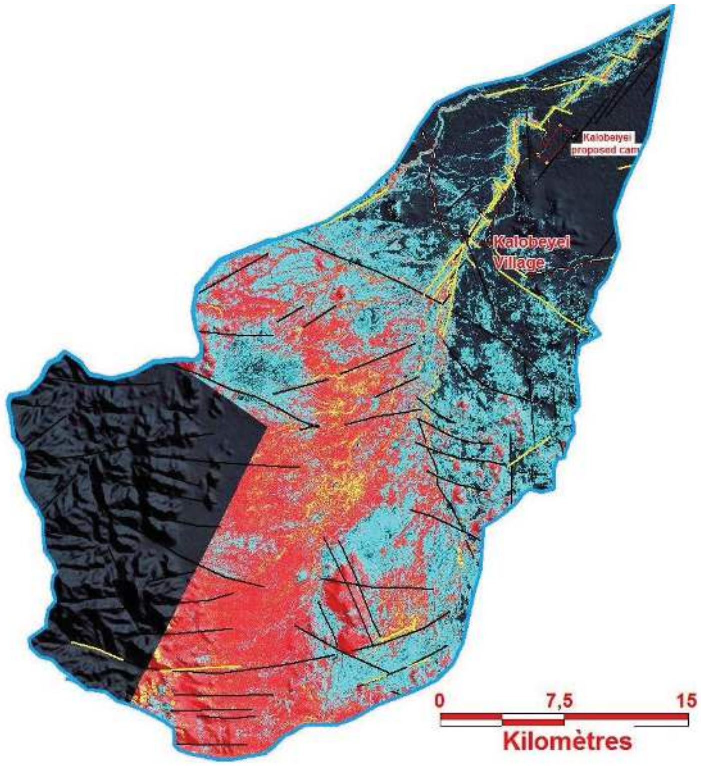
Thomas et al. (2018), reviewed Bauman (2016) and EWL (2015) and reported that the Kalobeyei borehole, drilled in 2011 to a depth of 68 m bgl, recorded a yield of 5 m^3/hr. The latter extensive geophysics within the Kalobeyei area was done, but the two most promising sites were drilled to 130 and 150 m bgl resulting in very low yields (< 1 m^3/hr).

EWL (2016) described the Kalobeyei area is located in a medium groundwater potential hydrogeological zone, consisting of superficial and alluvial deposits overlying volcanic rocks. The study concluded that the area is characterized by shallow and deep aquifers whereby the shallow aquifers occur at depths ranging from 20-50m bgl while the deeper aquifer is found to occur at depths >100m bgl. This study yielded the most recent boreholes (BH 13, 14 and 15), which are currently being abstracted. EWL (2015) revealed the existence of two aquifers: the shallow and the deep aquifers. The first aquifer is expected to have low yields and fairly lower levels of electrical conductivity favourable for domestic use. The deep aquifer is expected beyond 80 m bgl and the electrical conductivities may vary from 1000 to over 7000 µS/cm depending on the proximity to the recharge zone.

Bauman's (2016) rock description of the area to be close to the surface and that both the Elelia and Esikiriet *laggas* appeared to have low resistivity. Baumann recommended four potential drilling sites which had targeted faults, zones of thicker weathered/fractured material and areas showing low resistivity near to the existing Kalobeyei well.

In a study by Rural Focus (2016), the data set indicated eleven boreholes and shallow wells within a 10km radius of Kalobeyei center; this is a low level of groundwater exploitation in the Kalobeyei area compared to Kakuma.

Figure 3-31: Kalobeyei watershed (After Thomas et al. 2018, based on RTI, 2013)



D. Hydrogeological characteristics of Lodwar aquifer

The Lodwar aquifer is located astride the Turkwel lagga and with fairly good groundwater potential in areas near the lagga. The Lodwar aquifer is exploited by LOWASCO for water supply within Lodwar town. The Lodwar aquifer is confined to the banks of the Turkwel lagga and is recharged directly from the lagga through the alluvial sands. Boreholes drilled more than 100 m from the Turkwel lagga have been found to be low yielding and saline.

Lodwar aquifer also includes the following smaller isolated units:

- Napuu aquifer (hypothesized by RTI);
- Ayengyeng aquifer (not verified by exploratory drilling);
- Chokchok aquifer (hypothesized by RTI).

The Lodwar aquifer covers an area of approximately 992 km^2 and is mostly concentrated along the Turkwel lagga; the aquifer is rich where thick alluvial sands deposits overlie an impermeable rock layer.

The hydrogeology of this area is controlled by the Turkwel lagga, which flows though Lodwar town.

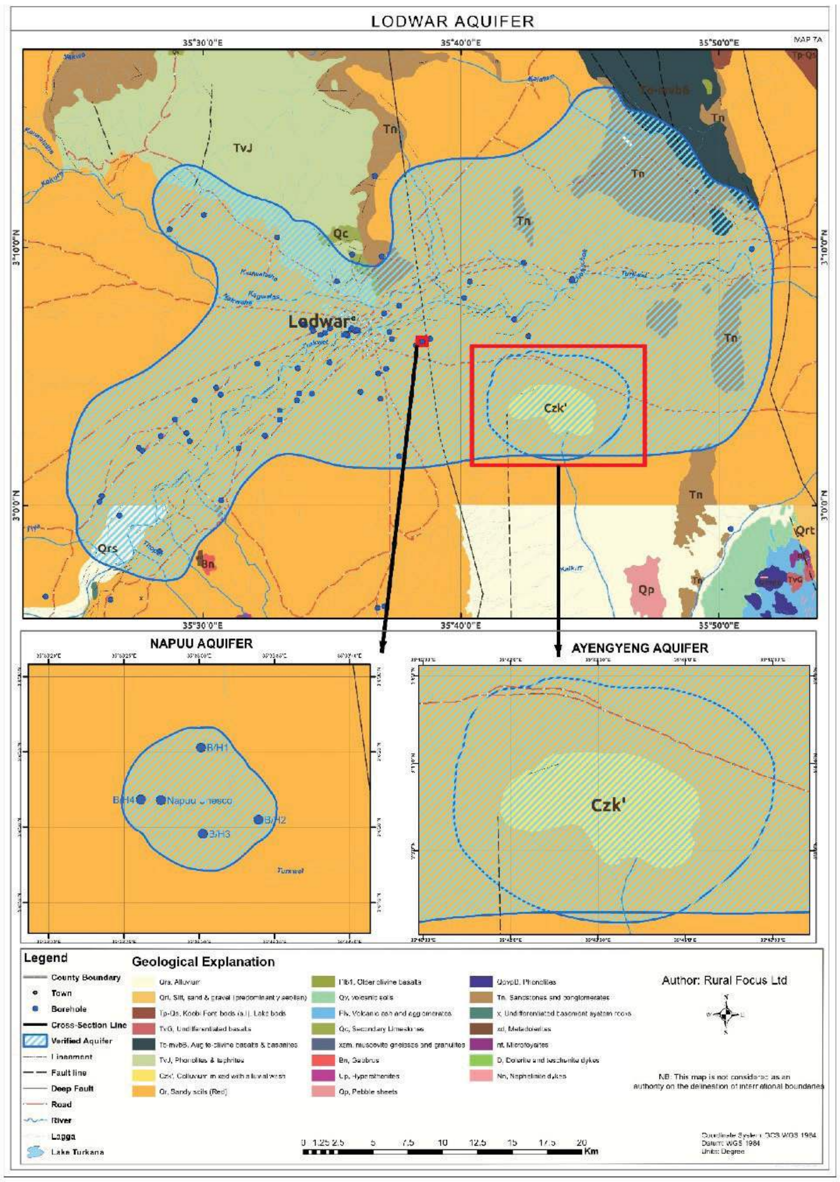
Most boreholes drilled along the lagga are very productive with yields ranging from 20 m^3/hr to 96 m^3/hr, while other areas further from the lagga have significant yields values ranging from 2 m^3/hr to 12 m^3/hr. The Lodwar aquifer is mostly encountered in the sediments and sands which overlie a semi-permeable volcanic layer. The aquifer within the weathered and fractured volcanic rocks are more saline than the alluvial sand aquifer.

Borehole depths vary with geology with alluvial sand aquifer depths ranging from 12 m to 40 m and the volcanic aquifer ranging from 40 m to 80 m in most areas. The deepest borehole is 160 m, at the Kenya Red Cross office within the rhyolites and phonolites formations. Transmissivity for aquifers away from the riparian area range from 0.4 m^2/day to 1.6 m^2/day, while boreholes close to Turkwel lagga indicate a higher T values of approximately 11.7 m^2/day.

Abstraction from this aquifer has been carried out at a small scale by individuals and institutions and at a larger scale by LOWASCO, which pumped 1.705 MCM in 2016/17, or an average of 4,671 m^3/d from 6 boreholes (WASREB, 2018).

Groundwater recharge for the Lodwar aquifer has been estimated to be 38.14 MCM/yr made up of 53% direct recharge and 47% lateral recharge based on a recharge factor of 4%. Aquifer storage has been estimated to be 13.9 BCM. Annual groundwater potential is 10% (USGS values) of the annual groundwater recharge at 3.8 MCM/year. Soils overlying the Lodwar aquifer are well-drained and provide a good substrate for rainwater infiltration (WRA, 2020).

Figure 3-32: **Lodwar aquifer showing Napuu and Ayengyeng aquifers (Aquifer mapping in Turkana County, WRA (2020))**



3.1.3.9 Impacts of abstraction on aquifers

Aquifer over-exploitation regards the situation in which, for some years, average aquifer abstraction rate is greater than or close to the average recharge rate. In water resources management, groundwater over-exploitation and aquifer over-exploitation are interchangeably used while hydrologists, hydrogeologists, managers and journalists use them when talking about stressed aquifers or some groundwater conflicts. The decision that a particular aquifer system is becoming or has become over-exploited is an economic and moral judgment.

The economic factors include the consideration of the relative value taking into account the issues of social equity and protection of the environment. It is in recognition of aquifer over-exploitation problems that the concept of a safe level of exploitation otherwise known as safe yield should be stressed. Several authorities define “safe yield of an aquifer” as the amount of water that can be withdrawn from the aquifer without producing an undesirable result. Although any significant abstraction will necessarily result in some environmental impact by reducing water levels, spring discharge or streamflow, it is important to differentiate the benefits of exploitation from the negative side effects of over-exploitation.

The concept of sustainability has become popular. It regards the level of development of groundwater that meets the needs of the present generation, without compromising the ability of future generations to meet their needs.

Summarizing, abstraction affects aquifer. In the next paragraphs, a number of potential negative impacts are described.

Subsidence

In all sediments, excessive groundwater abstraction results in compaction and subsidence. Subsidence is more probable in areas of compaction in which the entire thickness of the more 'unstable' section is preserved. Kakuma case study (believed to be in the southern tip of the Lotikipi basin) has this characteristic. The aquifer is situated along Tarach Lagga, and consists of fine to coarse sands, silts, cobbles and gravels underlying by volcanic formations.

Hydrogeological impacts

Despite the problem of defining 'over-exploitation' in a given aquifer setting, there are a number of well-known consequences of groundwater development that may not be desirable, which are summarized here. Groundwater level decline leads to a decrease in river baseflow and wetland area. Most aquifers show a water level decline as part of a natural cycle, even when not exploited, at least in some areas for part of the time. This may be seasonal, during a normal dry season, or it may be longer-term in response to a prolonged drought. During these periods, lagga and spring flows and discharge to wetlands are provided by the release of water from aquifer storage and, as a consequence water levels in the aquifer decline. Subsequent periods of recharge permit water levels to rise again as water is brought back into aquifer storage.

Likewise, when groundwater is exploited, water levels will decline and continue to do so until they either stabilize at a lower level or, if abstraction is persistently greater than recharge, the aquifer is dewatered. Extended declines can result in the drying-up of shallow wells, increased pumping costs, deepen or replace boreholes and deterioration in water quality.

In extreme cases the aquifer may be effectively dewatered, groundwater levels had become so severely depressed that the aquifer approaches exhaustion. Borehole yields are dramatically reduced, and wholesome abandonment may result. The resultant forced reduction in abstraction needs to be severe, beyond the long-term rate of recharge, for water levels to recover, and this may take many years or even decades to occur. Such impacts can have severe socio-economic consequences.

Changes in water levels

Abstraction over a long period of time may lead to the decline of the water levels in the aquifer system. Thus, it is expensive to exploit the deep zones that may pose a risk in groundwater potential in an area. The graphs showing the variation of the water levels in Kakuma boreholes are presented in Volume 2, Chapter 2.8 (Annex 9).

Impact on water quality

In our case study, this is observed during the dry seasons. During this time the borehole yields are low due to low recharge, as a result of this deep water which is saline is drawn into the wells and makes the water unfit for consumption. However, when the rains pick, and there is a good recharge the situation normalizes. Decreased water levels due to abstraction have significant effects on water chemistry, because this can lead to the intrusion of saltwater from the deep saline aquifers into the freshwater bearing aquifers due to the change in hydraulic gradient.

Boreholes yielding water from upper sand layers tend to have low EC values than the boreholes yielding from the Volcanics in Kalobeyei and Kakuma area. Most of the freshwater is present within the alluvium and also in the basaltic formations which underlie the rhyolites while saline water is located in the rhyolites underlying the alluvium. Two water salinities are found in the area:

1. Phenomenon salinity associated with the genesis of the geological formations; and
2. Salinity consequent from abstraction and salinization through salt water intrusion.

Hydrological impacts

Surface sources of water like marshes and lakes are supplied by the groundwater from aquifers and so as the water table continues to lower the surface water store is not supplied and will dry up. If a marsh dries up, then an important wetland site for many organisms has been lost. In our case, the Lotikipi basin which ordinarily is a swamp might experience drying up in case of over-abstraction of the Lotikipi aquifer. However, this is not the case at the moment since no substantial number of productive boreholes have been drilled in the basin.

Socio-economic impacts

Changes in flow pattern leading to deterioration in water quality resulting directly, or indirectly, from groundwater abstraction can be classed as over-exploitation. Such changes are only classified as over-exploitation if the changes have a negative effect on the socio-economic state of the resource. Such deterioration in quality can occur for a number of reasons. It includes saline intrusion, geochemical evolution of groundwater and induced pollution. The induction of flow of low-quality water into the aquifer as a result of a new hydraulic head distribution is perhaps the most common of these and requires detailed attention.

Extended declines can result in the drying-up of shallow wells, increased pumping costs, deepening or replacement of boreholes and saline intrusion. This has a socio-economic impact since other sources have to invented and of course at a cost. In refugee camps, this courses unrest since the population does not decrease during such seasons. In the event of dwindling groundwater resources in the area, the refugees would have to be re-located. Furthermore, irrigation projects would have to be re-design and adjusted to match the scenario obtaining in the area.

Ecological impacts

Plants with high water requirements are more affected by lower water tables as they can't access the water they need, if they begin to die out, then this will affect the whole food web.

Reduced supplies

When the rate of abstraction over takes the recharge rate then there will be a severely reduced supply and this directly affects the refugee and host population since Kakuma and its environs is solely dependent on ground water for both domestic and livestock uses Reduced supplies may result to human conflicts and consequently to wars among different population groups. This is evident in Kakuma study area especially during the dry seasons when the borehole yields fluctuate and this force regulating water supply or rationing the water in the camp and hence reduced per capita consumption.

3.1.3.10 Environmental impacts of irrigation

The environmental impacts of irrigation relate to the changes in quantity and quality of soil and water. These changes are the result of irrigation and the effects on natural and social conditions in the aquifers, laggas and downstream of an irrigation scheme. The impacts stem from the altered hydrological conditions caused by the installation and operation of the irrigation scheme.

Direct effects

An irrigation project that draws water from groundwater and distribute it over an area will lead to an increased evaporation, increased level of the water table due to groundwater recharge and an increase in flow in the irrigated area. Likewise, irrigation has immediate effects on the provision of moisture to the atmosphere, inducing atmospheric instabilities and increasing rainfall downwind, or in other cases modification to the atmospheric circulation, delivering rain to different downwind areas.

Indirect effects

Indirect effects are those that have consequences that take longer to develop and may also be longer-lasting. The indirect effects of irrigation include the following:

- Waterlogging;
- Soil salination;
- Ecological damage;
- Socioeconomic impacts.

The indirect effects of waterlogging and soil salination occur directly on the land being irrigated. The ecological and socioeconomic consequences take longer to happen but can be more far-reaching. Where the project is using groundwater for irrigation, the overall water level decreases. This may cause water mining, land/soil subsidence, and, along the coast, saltwater intrusion.

Lost land-use opportunities

Irrigation projects may reduce the opportunities of the original population and the grazing opportunities for cattle. The livestock pressure on the remaining lands may increase considerably because the ousted traditional pastoralist tribes will have to find their subsistence and existence elsewhere, overgrazing may increase, followed by serious soil erosion and the loss of natural resources. When more groundwater is pumped from wells than replenished, storage of water in the aquifer is being mined and the use of that water is no longer sustainable. As levels fail, it becomes more difficult to extract water and pumps will struggle to maintain the design flow rate and consume more fuel energy per unit of water. Eventually it may become so difficult to extract groundwater that project will have to be halted.

Reduced downstream drainage and groundwater quality

The downstream drainage water quality may deteriorate owing to leaching of salts, nutrients, herbicides and pesticides with high salinity and alkalinity. There is threat of soils converting into saline or alkali soils. This may negatively affect the health of the population at the tail-end of the basin and downstream of the irrigation scheme, as well as the ecological balance.

3.1.3.11 Water quality

Geology and groundwater quality in Turkana County have a very close relationship because most of the groundwater resides in rock fractures, fissures and general rock formations and a large number of dissolved substances exist in the groundwater due to the long retention time.

Electrical conductivity

The main problem of water quality is salinity. The general salinity map of boreholes in Turkana County is shown in Figure 3-33.

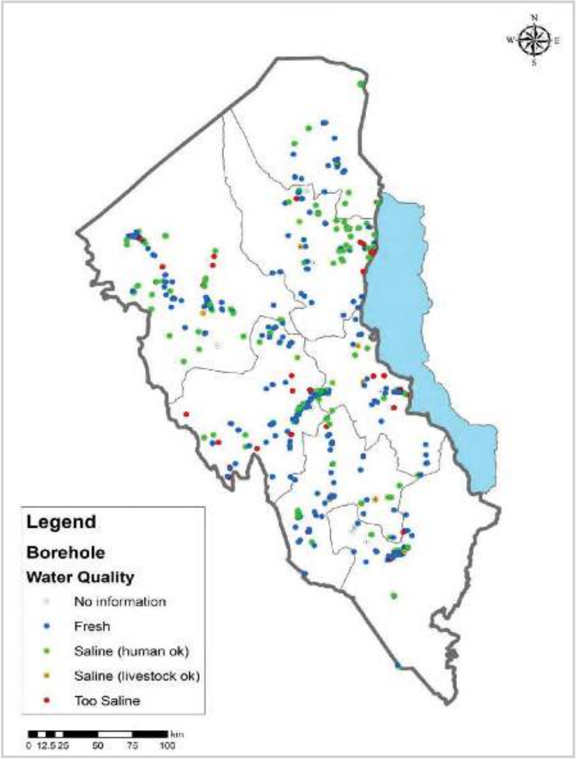


Figure 3-33: Turkana boreholes with their water quality (Source: JICA, 2015)

Data for EC of groundwater in the area was analysed from several sources including EWL, UNHCR, NRC, KRCS, WRA, JICA, NWMP, UNICEF, RVWSB and LWF. The EC values of the recorded boreholes in the study area range between 405 µS/cm and 8,640 µS/cm. From the data, Lopwarin borehole has the highest EC value of 5,270 µS/cm in Kakuma refugee camp area. Borehole 3 has the lowest EC value of 405 µS/cm. Lopwarin borehole is located 2 km upstream of the borehole UNHCR, which has an EC value of 656 µS/cm. Considering the extremely high EC levels compared to the neighbouring boreholes, Lopwarin borehole could be partly disconnected from the surrounding aquifer. This could have resulted from the clogging of the screens since the borehole is an unexploited and abandoned. Boreholes yielding water from upper sand layers (shallow aquifer) tend to have lower EC values than the boreholes yielding from the volcanic. Generally, the EC values upstream are high compared to the values downstream. Natirı borehole is yielding water from basaltic layers, and the moderate EC values suggest influence from upper sand layers. Kalobeyei borehole is located approximately 20 km west of UNHCR borehole, the surface geology is composed of olivine basalts, and it has a moderate EC value of 930 µS/cm.

From the available borehole data, the EC values in Kalobeyei area range between 550 to 1,448 µS/cm. This suggests that the water quality in Kalobeyei based on salinity is generally good. The Lotikipi RVWSB borehole has the highest EC value of 8,640 µS/cm. The borehole is yielding water from the deep saline Lotikipi aquifer, which elucidates the high EC values. The EC trend for various years in the selected boreholes is presented in the bar graph shown in Figure 3-34. The EC distribution in the study area is shown in Figure 3-35.

Figure 3-34: EC trend analysis

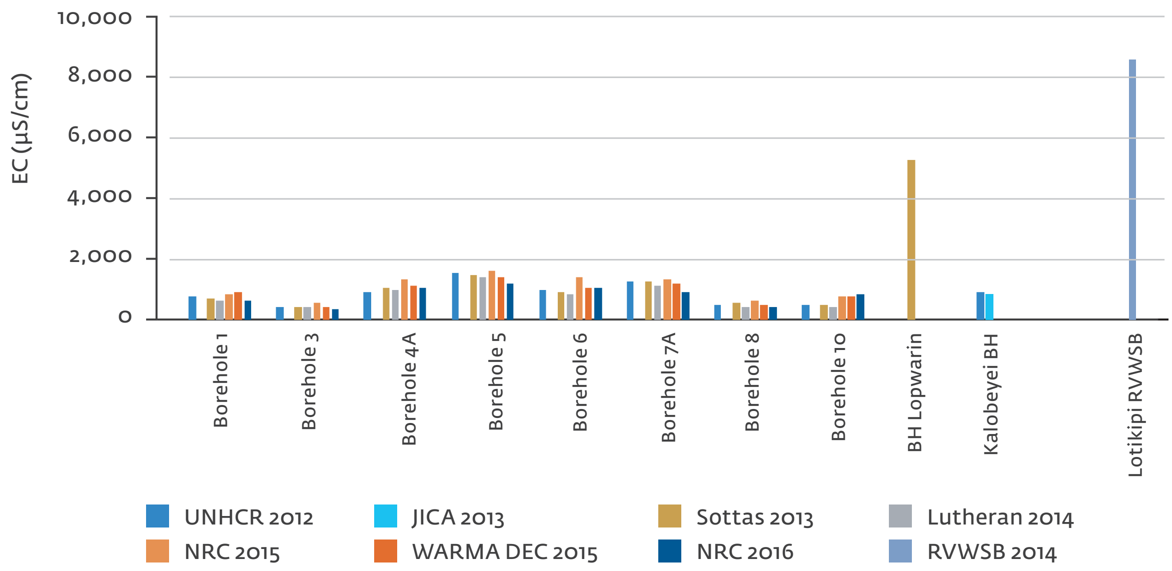
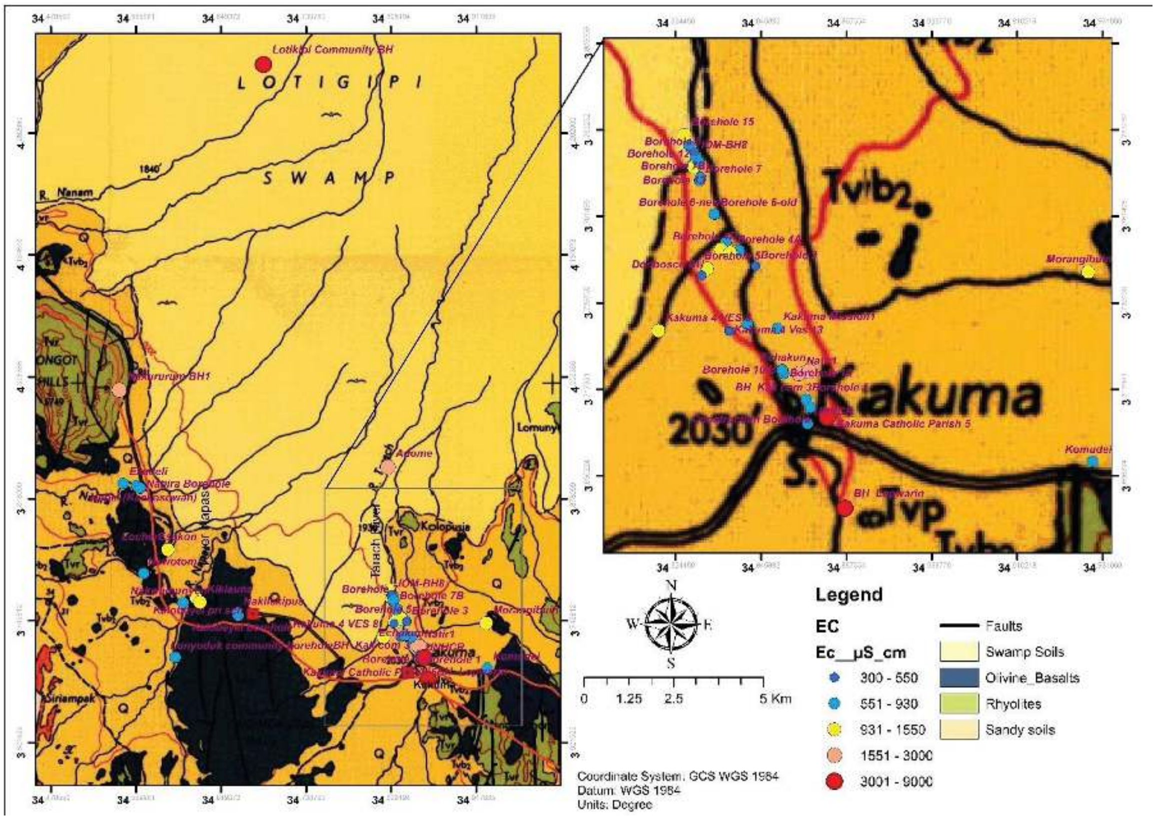


Figure 3-35: EC distribution



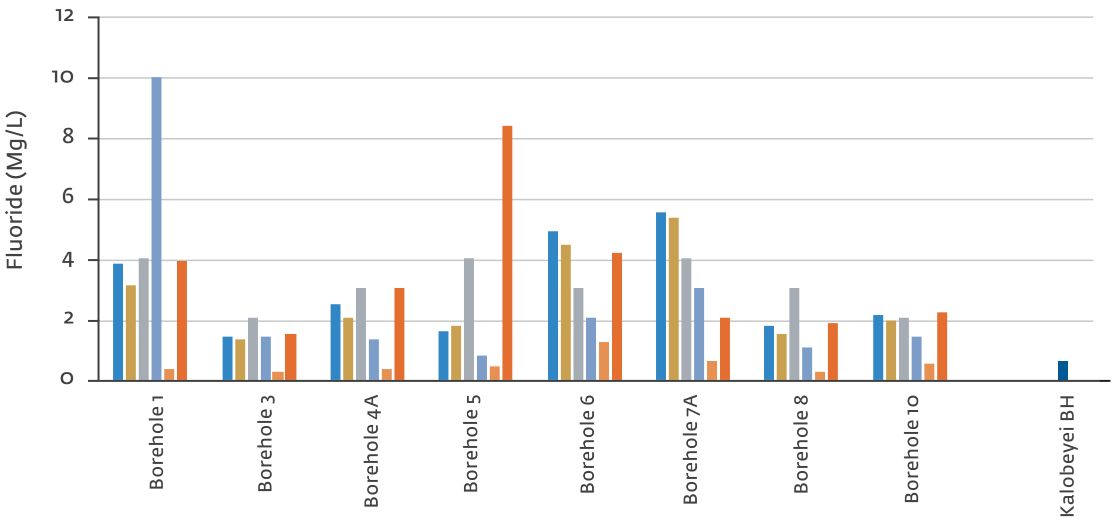
Fluoride

Fluoride levels in groundwater usually vary depending on the minerals in the rock and ores in which the water passes through. Fluoride is formed when fluorite minerals dissolve in water. Other minerals associated with the formation of fluorite include apatite and mica. Fluorite is the principle fluoride mineral in igneous rocks. This is the reason why groundwater in volcanic settings contains notable concentrations of fluoride.

According to the previous studies, notable high concentrations of fluoride are distributed in the boreholes. The average fluoride concentrations in the examined boreholes range between 0.04 and 10 mg/l. The UNHCR field mission in 2012 revealed that the Kalobeyei borehole had the lowest fluoride concentration levels of 0.04 mg/l.

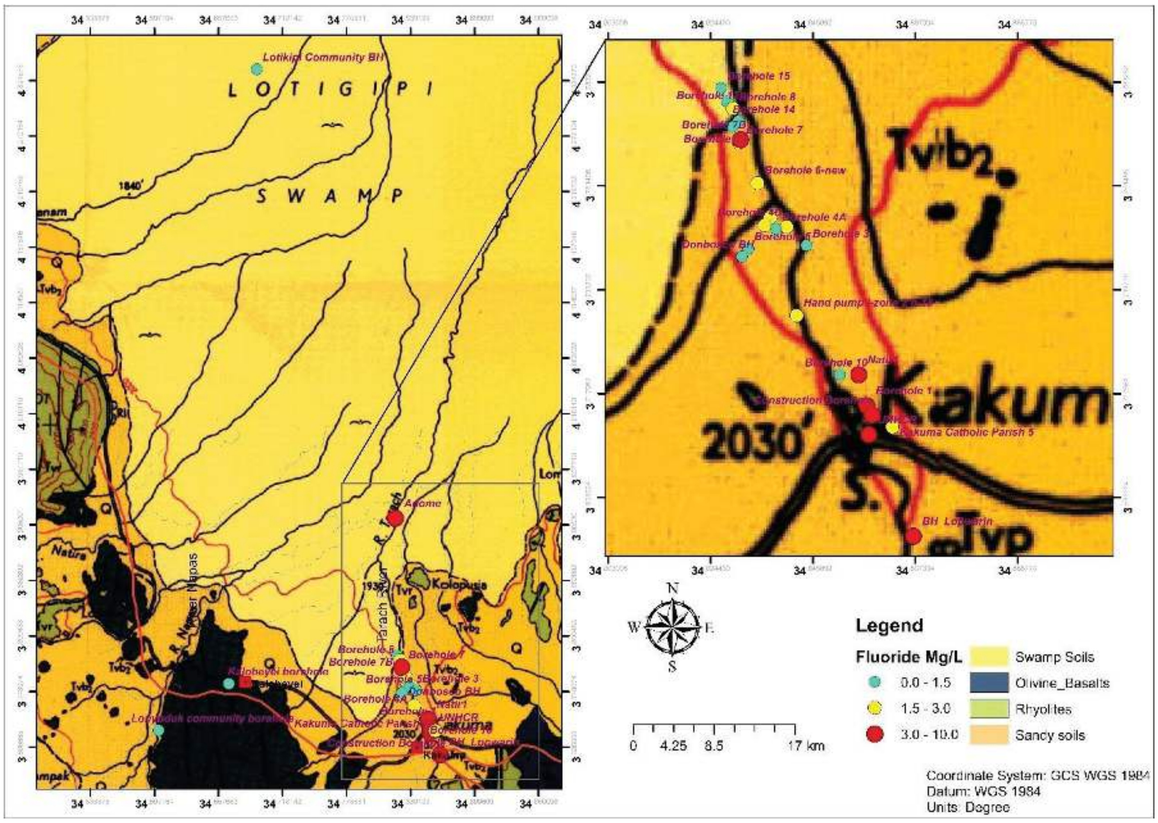
In the year 2013, UNHCR borehole had the highest fluoride concentration of 6.54 mg/l, and Kalobeyei borehole with the lowest fluoride concentration of 1.01 mg/l. In 2014, water quality results showed that the highest fluoride concentration recorded in the examined boreholes was 4 mg/l, and the lowest was 2 mg/l. In 2015 a study conducted by NRC revealed that borehole 1 had the highest fluoride concentration of 10 mg/l and that Borehole 5 had the least fluoride concentration of 0.5 mg/l. The varying fluoride concentrations in the boreholes over the years can be attributed to changes in the water levels at different seasons. These trends are summarized with a graph, as shown in Figure 3-36.

Figure 3-36: Fluoride concentration



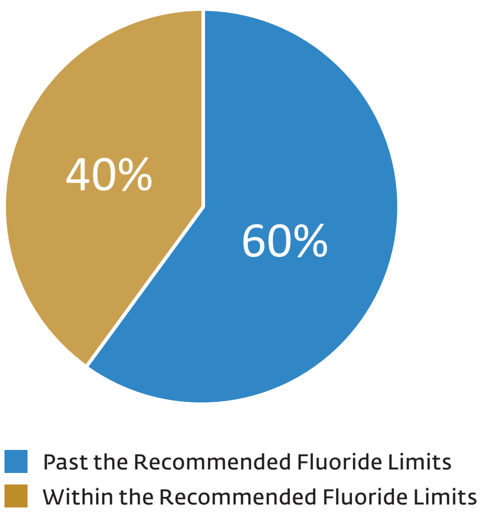
The fluoride concentrations in the study area are slightly higher than the KEBS recommended standards of (<1.5). Fluoride causes dental and skeletal fluorosis with concentrations higher than 3mg/l. The area around Kalobeyei has lower fluoride levels compared to the area around the Kakuma refugee camp. The average fluoride distribution within boreholes in the study area is shown in Figure 3-37.

Figure 3-37: Fluoride distribution



On average, 60% of the boreholes in the study area have fluoride concentrations exceeding the KEBS recommended levels, while 40% of the boreholes have fluoride concentrations within the KEBS standards. This is presented in the pie chart on the next page (Figure 3-38).

Figure 3-38: Fluoride analysis (Mg/l)



Iron concentration

Iron is a mineral that is common in many igneous rocks. The igneous rocks in the study area include basalts and rhyolites. Basalt is an iron-rich, very dark colored extrusive igneous rock. Presence of these rocks in our area of the study explains why most of the water supplies in the area contain iron. Water may also dissolve iron upon contact with the metal well casings, pump parts and pipes.

From previous studies, water quality data was analyzed, and the iron content was found to range between 0 and 0.04 mg/l. Kalobeyei borehole has an iron content of 0.04 mg/l, which is the highest of all the boreholes examined. Iron content in some of the boreholes was not detected. The iron concentration trend in the examined boreholes is shown in Figure 3-39.

The average iron concentration from the examined boreholes within the Kakuma refugee camp is 0.077 mg/l. This shows that the iron content in Kakuma area is within the acceptable recommended levels (<0.3). Iron concentration levels in Kalobeyei are expected to be a little higher when compared to the Kakuma area. This is because the geology of Kalobeyei is composed of basalts, which are usually rich in iron content. The iron distribution in the different boreholes in the study area is presented in a map shown in Figure 3-40.

Figure 3-39: Iron concentration trend analysis

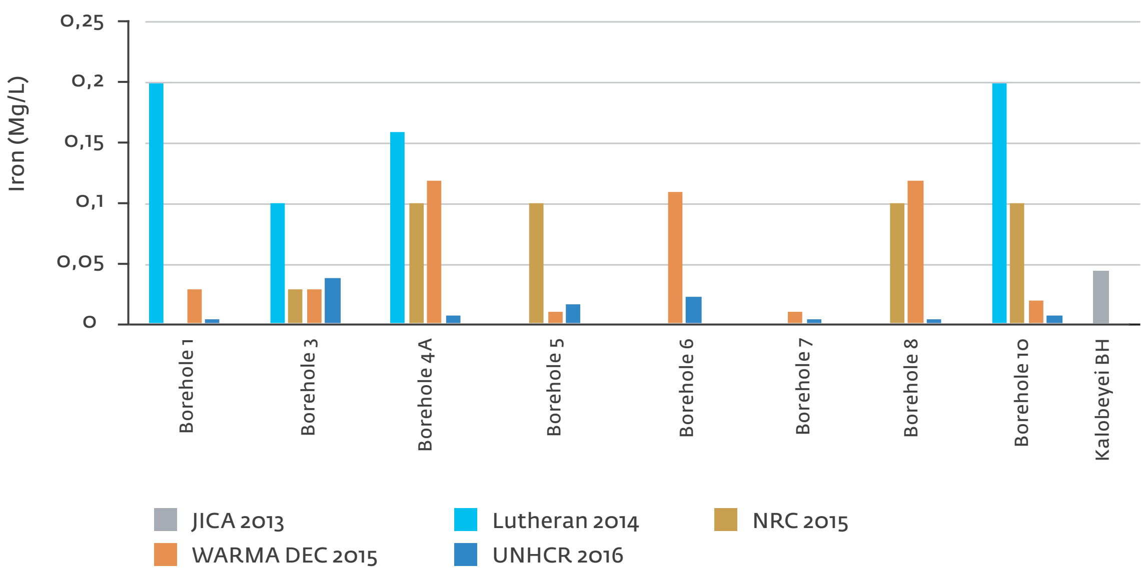
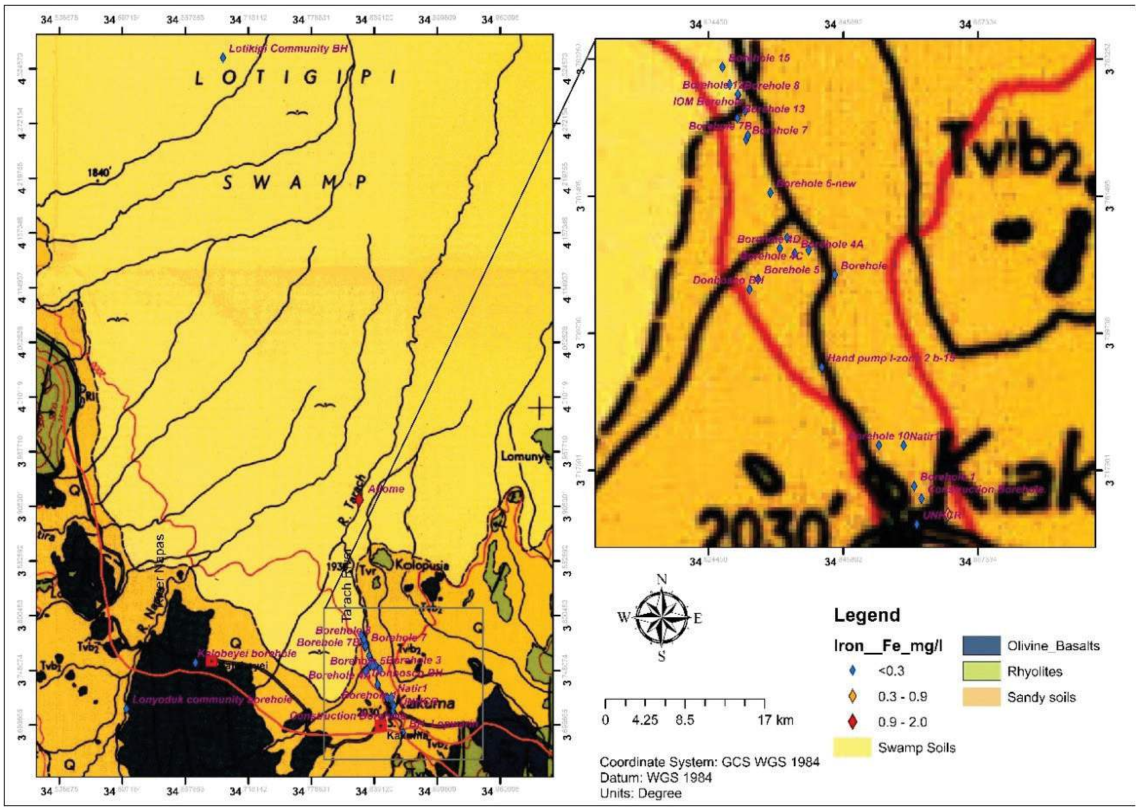


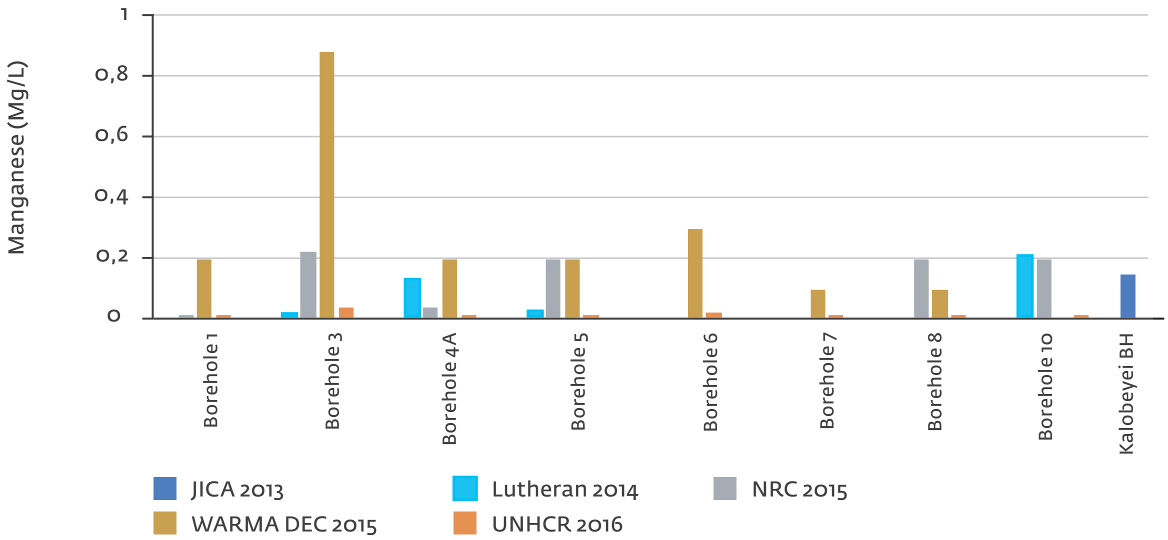
Figure 3-40: Iron concentration



Manganese concentration

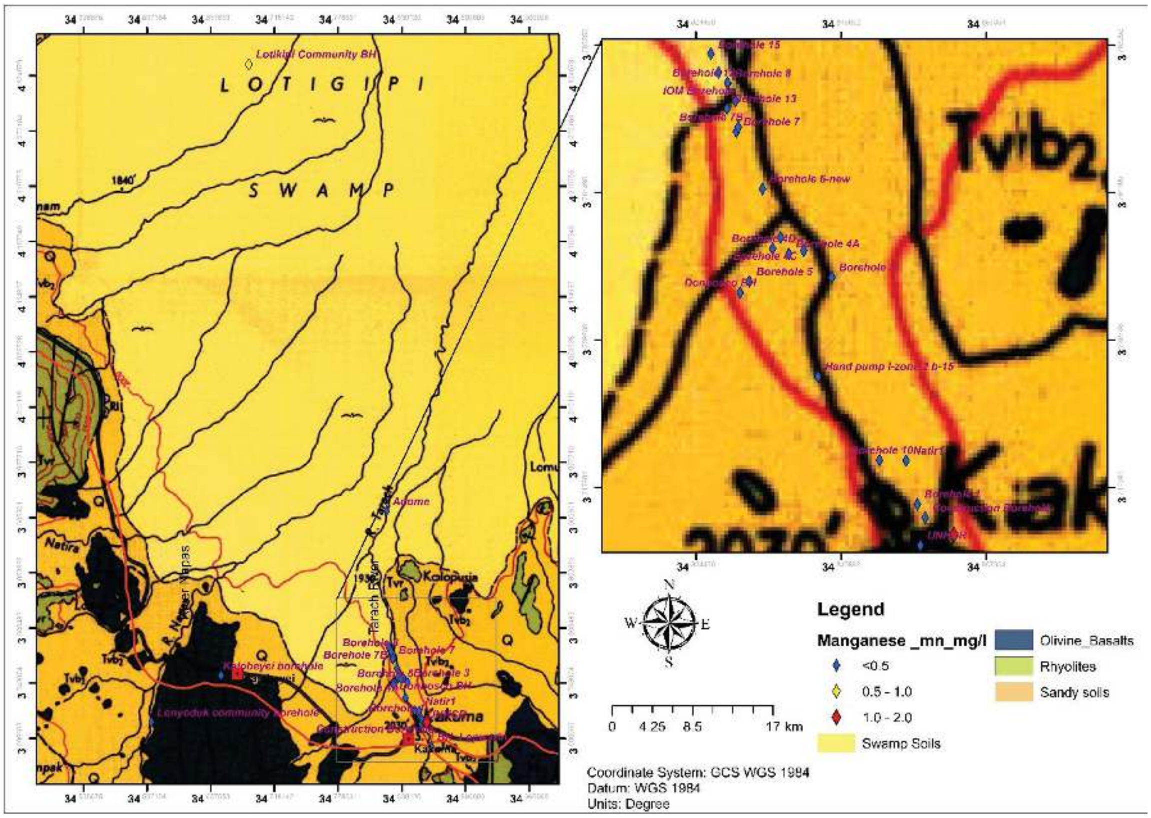
Manganese occurs as soluble manganese bicarbonate, which changes into insoluble manganese hydroxide when it reacts with atmospheric oxygen. It occurs as oxides in volcano-sedimentary deposits, sedimentary, igneous formations and in association with iron deposits. From the previous studies, borehole 3 has indicated a significant rise of manganese concentration levels. The manganese concentration ranges from 0 to 0.9 mg/l. This range falls within the acceptable recommended levels by KEBS (<0.5) except for the case of Borehole 3, which had a manganese concentration of 0.9 mg/l as reported in December 2015 by WARMA. The manganese concentration trends for the years 2014 and 2015 are presented in a graph, as shown in Figure 3-41.

Figure 3-41: Manganese concentration trend analysis



Manganese was not detected in some of the boreholes for both years e.g. in the case of borehole 6 and 7. In the case of borehole 1 and 8, manganese was not detected in 2014 by Lutheran water quality analysis, but in 2015 manganese concentration levels in the two boreholes were 0.01 and 0.2 mg/l respectively based on NRC analysis report. This can be attributed to the use of fertilizers in small scale farming that is going on in the area. The manganese distribution in the examined boreholes is shown in Figure 3-42.

Figure 3-42: Manganese concentration



Water quality for peanut cultivation

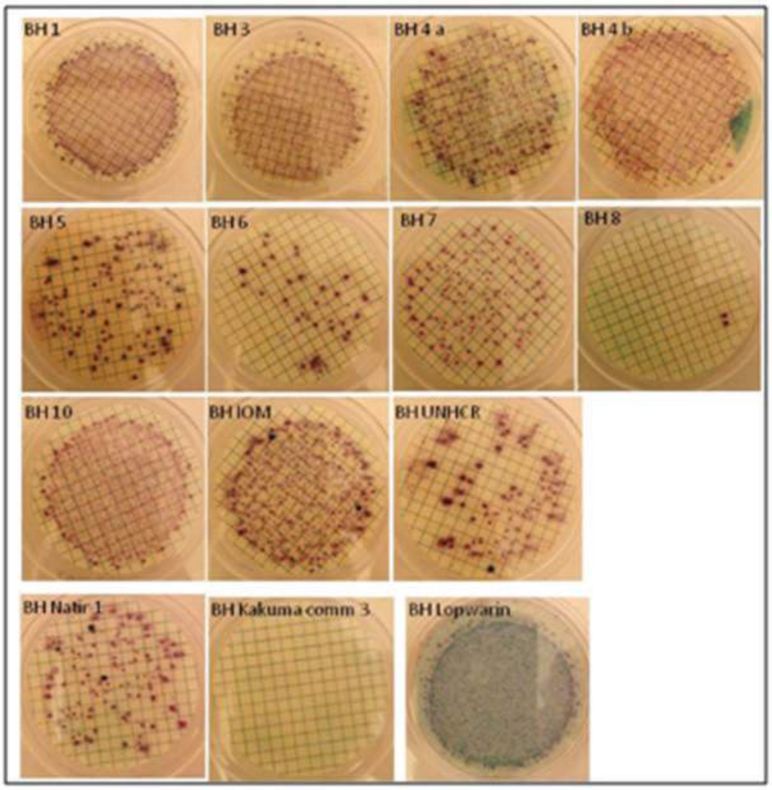
Different plants have specific accepted levels of chemical elements in the water required for irrigation. The requirements for peanut should be determined through testing of the water samples from the area of study in the laboratory. Sodicity (sodium and chloride levels) irrigation water from laggas and streams may contain excess sodium (Na) and chloride (Cl). Na and Cl can be directly toxic to plants, may contribute to raising the soluble salts (EC) level of the growing medium, or may inhibit water uptake by plants. Plant problems include injury from excess soluble salts, growth reduction, and increased susceptibility to disease. Foliar chlorosis caused by high Na and Cl is similar in appearance to that caused by deficiencies of nitrogen, iron, and magnesium.

Bacteriological analysis (coliform tests)

E.Coli bacteria are rod-shaped gram-negative none-spore forming bacteria which can ferment lactose with the production of acid and gas when incubated at 35-37 °C. They are used as bacteria indicators of acceptable water quality. In the study area, bacteriological analysis results were obtained from a previous study conducted in Kakuma area by Sottas in the year 2013. From this study, the results of the bacteriological test show the presence of total coliforms in all of the boreholes. The presence of coliforms shows the hydraulic connection of the groundwater with the surface water.

This connection established that the main source of recharge of the aquifer units is surface water which is polluted by human/animal defecations. Lopwarin borehole had the highest coliforms (100 CFU). This can be explained by the fact that the borehole was abandoned. The bacteriological load of the boreholes is shown in Figure 3-43.

Figure 3-43: **E.Coli test**



Pollution risks

As seen in the bacteriological analysis results pollution, especially on the shallow aquifer is prevalent, and this is as a result of human activities such as defecation and agricultural activities where chemicals are used in small-scale irrigation projects.

3.1.4 Summary of water availability

Although it is recognized that the surface water and groundwater resources are interconnected, here we present the total water availability of the two sources separately. Only during a more in-depth study, it may be possible to identify the quantitative value of the interaction between the two sources, taking into account that the surface water. In general, is not a perennial source and recharge from the surface water to the groundwater will take place primarily during flood events.

a) Surface water

The surface water availability was discussed in the foregoing section, and the total amount for selected catchments is presented in Table 3-5. The surface water potential for the Tarach Lagga at Kakuma Bridge is estimated at **79.8 MCM/yr**.

b) Groundwater

Taking into consideration the aquifer porosities, the total aquifer volume within Kakuma and Kalobeyei aquifers is **$5.23*10^8$ m^3** (**523 MCM**). These values are based on areal extent and aquifer thickness of the medium and shallow aquifers. However, WRA 2007 rules stipulate that for aquifers, the Reserve Quantity shall be 40% of the aquifer flux in the case of aquifers whose recharge rate has been determined by the Authority. Therefore, **$3.14*10^8$ m^3** (**314 MCM**) is the amount of storage that can be used for other purposes including domestic, livestock and irrigation purposes.

These estimates are only approximate as many factors are assumed to be favourable leading to uncertainties in the stated values for the different aquifers i.e. surficial and weathered volcanic aquifers.

3.2 Water Storage

Goal: Determine which options exist for water storage

The surface water analysis has reported on the fact that the laggas in the area are seasonal and flow only in response to rainfall events. Indeed, the earlier discussion showed that there is significant surface water potential to support agribusiness. However, in order to make use of the surface water, the runoff water would need to be stored. In general, there are a number of conceptual approaches which can be considered, namely:

1. Large dam(s) on the main watercourses;
2. Small distributed structures, either dams or pans in the low hills and flatter areas;
3. Small farm ponds;
4. Sand dams and sub-surface dams;
5. Rainwater harvesting;
6. In situ soil water conservation technologies including spate irrigation.

Various water storage technologies are discussed below and the extent to which the technology is currently being applied in Turkana West sub-county.

3.2.1 Larger storage structures

Typically, a well-sited large dam can offer an attractive storage option as the unit cost of water stored is less than for smaller structures. If the dam is located in a place of higher elevation, gravity can be used to supply water to the demand areas. Water quality, being composed of runoff water, can generally be described as fair as heavy sediments are deposited in the still water of the reservoir. In addition, the scale of the project can attract and sustain technical expertise to meet multiple demands, such as domestic water supply, irrigation, hydropower and potentially flood management.

The drawbacks on structures of this size are capital cost, requiring significant investment by the exchequer and potential environmental and social hazards that would need to be analysed and mitigated. With respect to the Kakuma-Kalobeyei area, the potential impact of upstream dams on the hydrology of the Tarach Lagga would need to be analysed to determine the potential impacts on recharge of the Kakuma aquifers, because the Kakuma water supply relies heavily on the groundwater resources in the vicinity of Kakuma town.

It should be noted that an upstream dam, capturing runoff and releasing it slowly over a period of time may actually enhance groundwater recharge. Indeed, this concept has been exploited in various arid counties. For example, Oman has developed 43 recharge dams storing 93.4 MCM (Oman Water Society[27], Abdalla & Abdallah, 2013[28]) specifically for groundwater recharge.

At present, there are no large dams[29] in the Kakuma-Kalobeyei vicinity. The Feasibility Study for the Tarach Dam (KRCS, 2019) considers the possibility of a dam on the Tarach Lagga approximately 40 km upstream of Kakuma town. This is discussed further in Chapter 9.1. The Kakuma Spatial Development Plan (Turkana County Government, 2020) has identified the Tarach Dam as a long-term project.

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27 http://www.omanws.org.om/en/page/dams.

28 Abdalla, O. and Abdallah, S. (2013): Groundwater recharge dams in arid areas as tools for aquifer replenishment and mitigating seawater intrusion: example of AlKhod, Oman. Environmental Earth Sciences, volume 69, pages 1951–1962.

29 WRM Regulations (2007) sets out criteria for different dam classes. A large dam is considered to be class C.

3.2.2 Small dams and pans

Small dams and pans are typically storage structures that are less complicated, less capital intensive, address a local water demand and generally pose lower environmental or social risks than large storage structures. The distinction between a dam and pan is that a pan is primarily an excavation structure in which water is stored below normal ground level. This necessitates arrangements to pump the water from the reservoir area. Pans are typically located in flat or gently sloping (slope<3%) area and are typically located in very small watersheds (less than 5 km²) or are located adjacent to the water course for a larger catchment area. Pans are typically constructed to provide 5,000 to 100,000 m³ of storage although they rarely exceed 200,000 m³. Pans have been used extensively in Kenya particularly in the ASAL for livestock and domestic water and, as lined structures, within the horti-floricultural sector in other parts of Kenya. Many pans involve a combination of both excavation and a retaining wall.

Figure 3-44: Example of existing pan 3.5 km south of Kakuma

A dam implies a structural wall designed and built to retain water above normal ground level. Small dams can be up to 15 m in height and 1 MCM in capacity[30] but are typically less than 10 m in height as the cost and complexity of a structure increases with dam height. Dams are typically located on a watercourse at a suitable point of constriction in the valley. Being online (on the watercourse), dams have to be designed to safely pass floods. Consequently, the size and cost of the spillway is a function of the catchment area and risk profile of the dam. In addition, an online dam will capture a significant proportion of the sediment travelling down the watercourse. Effectively this means that small dams are located on smaller catchments.

JICA (2015) reports 148 water pans in Turkana County of which 112 were operational, and at least 35 were located in Turkana West sub-county.

The Tarach Dam Feasibility Study (Finix, 2017) evaluated options for larger pans (2,000,000 m³) located at various sites within Kalobeyei, below Kakuma refugee camp and or near the Tarach Lagga, but they concluded that the Tarach Dam was a more suitable option than large pans.

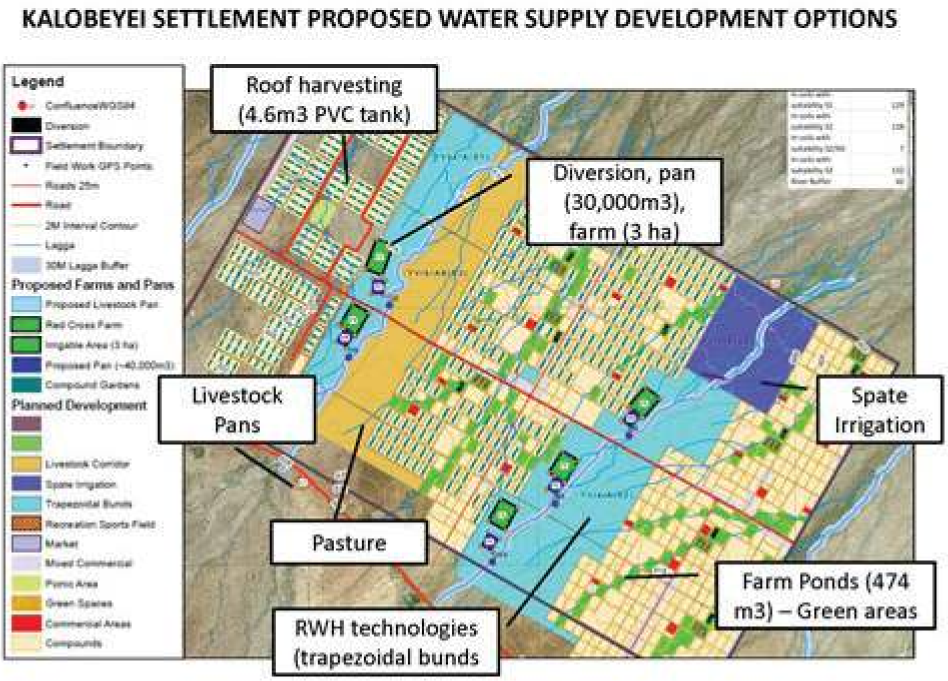
Thomas & Gikone (2018) investigated dam sites within the Moru Itai Hills to the south of the Kalobeyei Settlement Scheme and concluded that there were limited prospects for dams within these hills. The report, therefore, analysed the water resource availability. and proposed the construction of No.5 lined 30,000m³ pans to be excavated adjacent to the two *laggas* that transect the Kalobeyei Settlement

30 WRM 2007 Rules.

Scheme with each pan serving a 3ha irrigated farm. The pans would be filled by constructing diversion structures across the *laggas* to enable surface water to enter a canal/furrow that directed water into the pan. The furrow would have a silt trap to reduce the silt load into the pan. The estimated cost of each pan was $204,270, which included the diversion structure, earthworks, fencing and lining with 1mm HDPE synthetic liner.

It is reported (*pers. comm*. Eng. Maingi of WFP) that two 30,000 m³ pans were constructed under the KISDEP I program and lined with compacted clayey material. The water has been used successfully to irrigate small gardens for 600 farmers on land around one of the pans. It is proposed to build an additional two pans under KISDEP II.

Figure 3-45: Potential pan locations within Kalobeyei Settlement Scheme



Thomas & Gikone (2018) also recommended the development of 2 No. pans for livestock on the periphery of the Kalobeyei Settlement Scheme of which the Kangura Dam (estimated capacity 100,000 m³) was developed.

Under the WSTF project, six additional water pans (capacity 30,000 – 50,000 m³) are proposed, primarily for domestic and livestock use within Turkana West sub-county. The Turkana County Annual Development Plan (CADP) 2021/2022 has also proposed the construction of various water pans within the Kakuma-Kalobeyei area, e.g. Pokotom Water Pan.

3.2.3 Sand dam and subsurface dam

Sand dams are water retaining structures that are typically less than 5 m in height, built on sandy watercourses with suitable rock bar and riverbank stability. The alluvial sand is deposited behind the retaining wall offering 25 – 30% void space that can be filled with water, which is not subject to full evaporation loss as would be the case for open water. Water storage is typically in the range of 2,500 to 10,000 m³. Extraction of the water is either by a pipe through the wall or a shallow well built adjacent to the sand dam. In the absence of these options, hand-dug wells are excavated into the body of the sand/water reservoir. The sand dam technology has been widely adopted in Machakos, Kitui and Makueni Counties but has also been applied elsewhere in other ASAL counties.

Application of the sand dam technology requires careful investigation and analysis of the site conditions and appropriate designs. This analysis aims to identify possible failure, which is typically caused by bank erosion around the wall, leaks through or under the wall, and erosion undermining the downstream toe of the wall leading to overturning. The technology can, however, provide good quality water through an extended dry season typically for livestock and domestic uses. The latest Kakuma Spatial Development Plan (Turkana County Government, 2020) indicates a plan to develop ten sand dams within the vicinity of Kakuma town.

Subsurface dams are conceptually similar to the sand dam in that the water is retained within a body of sandy alluvial material in the watercourse. The distinction is that the wall is excavated and built into the alluvial lagga bed to form an impermeable barrier to flow within the sediments. The net result is a structure that may not be exposed above ground level. Extraction of the water is typically by an adjacent shallow well or by hand-dug wells in the river bed. Suitable sites for sub-surface dams are watercourses with deep sandy/gravel alluvial material with rock bars that provide anchorage for the wall and prevent erosion around the wall. Identifying a suitable site requires detailed geotechnical and geophysical site investigations, including geophysical surveys.

JICA (2015) reports 43 subsurface dams in Turkana with 29 of them being operational. A detailed site investigation within the Kakuma-Kalobeyei area is required to identify suitable sand dam and subsurface dam sites.

3.2.4 Rainwater harvesting

Rainwater harvesting is a broad term that refers to a system in which the rainfall is captured on a surface (usually a roof) and stored in tanks. However, there are different options in terms of the catchment surface and the storage structure. The most typical is to harvest water from a roof, typically corrugated iron sheets, with gutters to direct water to a tank or multiple tanks which might be PVC or masonry. Tank sizes are typically in the range of 2.5 to 15 m^3 for PVC tanks and up to 50 m^3 for masonry.

Alternative arrangements include rock catchments, where a bare rock surface provides an impermeable surface, typically larger than a roof from which water can be harvested and directed to tanks. JICA (2015) reports seven operational rock catchments in the Songot area. There are also runoff harvesting structures where ground runoff is directed in a small pond or underground masonry tank (*Berkad*).

These structures are designed to serve one homestead or -at best- a small collection of homesteads. However, rainwater harvesting systems have a number of potential advantages:

- The structure may be located at or near the house significantly reducing the time and effort to collect water; a burden that is disproportionately carried by women and girl-children;
- The water quality may be poor (rock catchments, *Berkads*) to fair (roof harvesting) depending on the condition of the catchment surface and tank (whether covered or not);
- The scale of the system makes it more affordable to single households;
- The management and operation of the structure are typically in the hands of one or a few households making it easier to make decisions.

The principle drawback is size and cost as the unit cost of water for rainwater harvesting systems is typically higher than can be obtained from larger-scale structures (dams and pans). In addition, rainwater harvesting structures are dependent on local rainfall, and as in the case of Kakuma-Kalobeyei where rainfall can be very localized and extended dry spells may span 6 – 8 months. The reliability of the system can be a problem, and alternative backup water sources are required. The smaller scale of the system can also restrict whether there is sufficient water for irrigation use. However, there are many examples of rainwater harvesting systems being used successfully for small kitchen gardens.

Thomas & Gikone (2018) reviewed the potential for rainwater harvesting from roofs within the Kalobeyei Integrated Settlement Scheme, where household roof sizes are typically about 31.5 m^2. Given the potential rainfall catch over a single rainy season, the report recommended a gutter and tank system (4.6 m^3 PVC tank) for a unit cost of approximately $620 per household. It notes that such a system has limited potential to meet irrigation water demand for any but a very small kitchen garden or specific fruit trees.

The rainwater harvesting system has been adopted at many schools and institutions which have large roof sizes and so can expect to fill a 10 or 15 m^3 tank over a small number of rainfall events. The rainwater tanks also serve as a point of storage when water is being trucked from an alternative source as may be required during an extended dry period or drought.

Due to the sporadic nature of rainfall in the Kakuma area, the adoption of the rainwater harvesting technology is primarily restricted to institutions and has been adopted less in private households. It should also be noted that the rainwater harvesting technology cannot be applied with the traditional housing structures within the Turkana community (a grass/reed covered hut known as a "*tukul*") which will limit widespread adoption.

3.2.5 In-situ soil water conservation

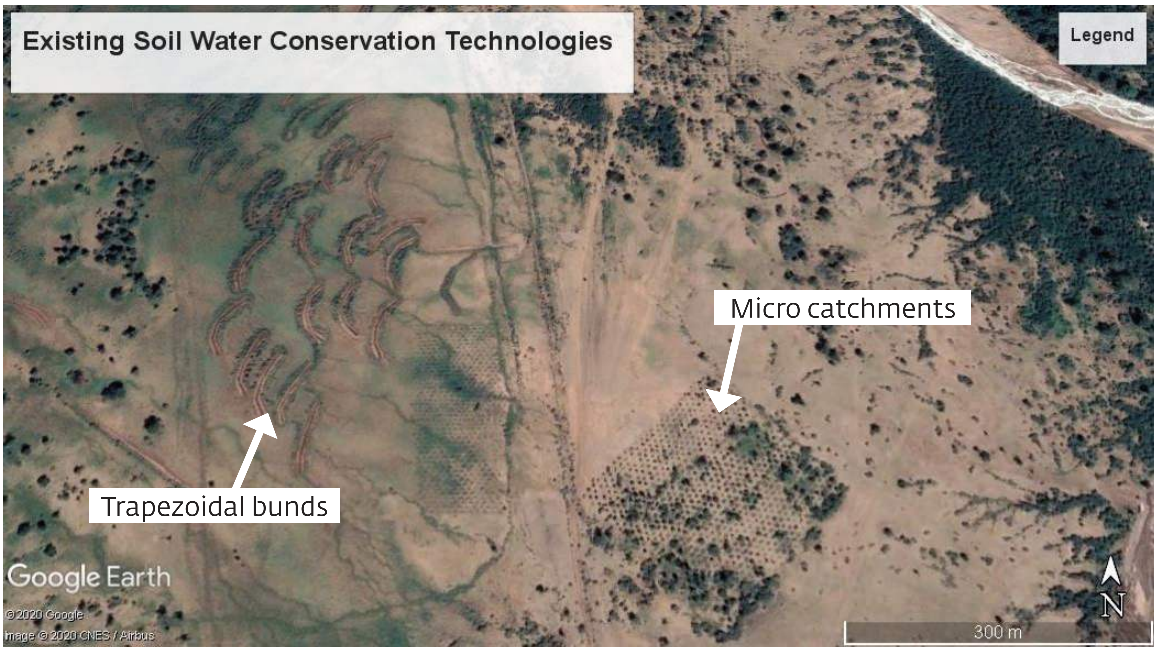
In-situ soil water conservation technologies create conditions suitable for rainwater retention in the soil and concentrate the runoff towards the cropping area. There are therefore various components to in-situ soil water conservation technologies which include:

1. Preventing runoff. This can be achieved through terracing or creation of bunds, thereby enhancing the infiltration into the soil;
2. Concentrating runoff to the cropping area thereby enabling sufficient soil moisture to sustain a cropping cycle;
3. Ensuring soil conditions suitable for water infiltration. This may include activities such as mulching, minimum tillage, etc. which diminish evapotranspiration and enhance soil health (physical and nutrient properties) for better infiltration and robust crop growth.

The application of these principles has resulted in a number of typical structures or approaches which have been used within the Kakuma-Kalobeyei area, as shown in Figure 3-46. These include:

- Trapezoidal or contour bunds;
- Zai pits;
- Micro-catchments;
- Conservation agriculture;
- Spate Irrigation.

Figure 3-46: **Existing soil water conservation structures 10km north of Kakuma**



A. Trapezoidal or contour bunds

Trapezoidal bunds are efficient water harvesting structures for crop production in the arid and semi-arid lands with an annual rainfall of 200-500 mm, good soil and ground slopes of 0.25-1.5%. Trapezoidal bunds are used to enclose large areas of up to 2 hectares in order to impound water for crop production. The layout of these bunds is designed to concentrate the runoff to the lower part of the bunded area which, within the Kakuma area, is typically planted with sorghum and millet. The layout results in a honeycomb effect (Figure 3-47), in which the three-sided bunds are offset from one another.

This arrangement channels the water from the catchment area to the production area and allows for the discharge of excess water. This technology has been applied extensively in Turkana West sub-county with variable success. The success is probably a function of seed quality, land preparation, planting time and rainfall.

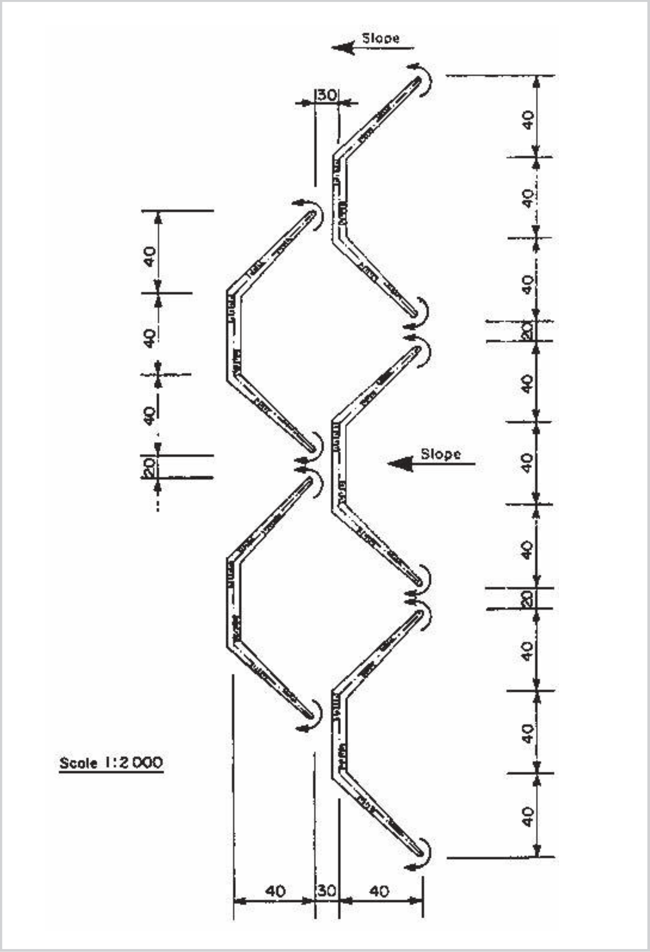
Contour bunds are similar to the trapezoidal bund in shape, but the layout differs in that the bund follows the contour and contains runoff in the cropland upslope of the bund.

An example of the trapezoidal bund technology can be seen in 24-acre farm in Lopur Ward established by AAHi. The farm targets 100 members of the host community who are growing sorghum, cowpeas, pumpkins, green grams and watermelons using trapezoidal bunds. It is reported that yields are 5 to 7 @90kg bags or 1125 – 1575 kg/ha of sorghum per season.

B. Zai pits

These pits have been extensively used in the Sahelian parts of West Africa with good outcomes and have been recently promoted in Kenya by NDMA, various NGOs across the ASALs. The technology involves the excavation of a pit approximately 60 cm x 60 cm x 60 cm. Manure and other vegetation matter are mixed with the bottom layer soil material to improve the soil fertility before the top-soil is returned. The runoff is channelled towards the pit which is planted with maize or sorghum. The aim is to improve the soil fertility as well as concentrating the runoff towards the production area. The zai pit technology has been tried within the Kakuma area but has not been adopted as a wide-scale practice.

Figure 3-47: Trapezoidal bund: field layout for 1% ground slope



C. Conservation agriculture

Conservation agriculture (CA) takes a slightly different approach to the others in that it is less focused on the development of structures and more focused on soil fertility and soil cover. The approach uses a minimum tillage concept in which the soil is only disturbed where and when the seed is planted. The soil is otherwise maintained with a mulch cover (to reduce raindrop impact, evaporation and to improve the micro-climate for plant growth). The Ministry of Agriculture is currently promoting conservation agriculture in the ASALs to see if crop yields can be improved without the need for more elaborate structural measures. The CA approach can be used in combination with the trapezoidal or contour bunds or with forms of terracing.

D. Spate irrigation

Spate irrigation can be considered an in-situ soil water conservation technology as it focuses on raising and storing water in the soil. However, it tends to involve more infrastructure than is normally associated with in-situ technologies. Spate irrigation conceptually involves establishing an offtake structure across a watercourse (weir) and a furrow/canal to channel a portion of the flood flow from the watercourse during a runoff event to the cropping area. Crops are typically planted after the initial flooding of the land to enhance the soil moisture. One of the advantages of spate irrigation is that it can take advantage of rainfall and runoff originating away from the cropping area and so enlarges the area that can contribute water to the cropland. However, spate irrigation systems face a number of challenges, one of which is controlling the quantity of floodwater into the cropland. Without proper control, crops can actually suffer from flooding or waterlogging.

Spate irrigation is being promoted in the County by TCG and currently 550 acres are under spate irrigation in Lomidat, Nasinyono and Loyaal in Turkana West sub-county. An additional 200 acres is being developed at Nakinakiyar in Nanam by AIC Health Ministries. The county has identified other potential places for spate irrigation sites which include Kalobeyei, Lokichoggio, Lokipoto, Wapet and Moruangibuin. The actual acreage for these potential sites has not been established. The crops grown under spate irrigation are field crops which include maize, sorghum and cow peas.

Other organizations that have supported spate irrigation include WFP and AIC Health Ministries. WFP supported spate irrigation at Natira among others under Food for Assets program for pasture production while AIC Health Ministries supported Nasinyono and Nanam spate irrigation projects (funded by JOHANNITER International and GIZ).

An additional example of a spate irrigation project is the Kajujuk project under the GIZ Drought Resilience in Northern Kenya Programme (DRP) Phase II. This project is being implemented in Kaaleng-Kaikor Ward in Turkana North sub-county. It involves construction of weirs across dry river beds (*laggas*) to harvest and divert flash floods to farms. Approximately 50 acres has been put under crop on group farms. Currently the yields are low at approximately 1200 kg/ha mainly because of the inadequate technical capacity of the farmers but with training and experience the yields can be substantially increased.

The above serves to illustrate the high potential of runoff harvesting for irrigation production. The same is applicable in the Kakuma/Kalobeyei areas which have higher rainfall and therefore larger volumes of runoff. Green gram is particularly viable because it is a high value dryland crop with a ready local market. Sorghum, especially varieties with high brewing quality, has a high potential because of the growing demand by the brewing industry.

4 Context Analysis – Water Demand and Water Balance

The first Project Goal, reproduced below, is achieved by five Activities:

Goal 1 – Context analysis (present situation)

Determine the overall circumstances for agribusiness development in the Kakuma / Kalobeyei region in terms of water availability and social/legal situation

- Water availability
- Water storage
- **Water demand**
- **Water balance**
- Social and legal context

In this Chapter, the next two activities of Goal 1 are discussed: water demand and water balance.

4.1 Water Demand

Goal: Make an inventory of the water demand of the various demand sectors

For the present situation, the demand sectors assessed include:

- public water supply for both the refugee and host populations,
- livestock, and
- crop water demand, including rainfed crops and irrigated agriculture.

4.1.1 Domestic water demand

The water demand has been estimated as per the Design Manual for Water Supply in Kenya (2005) published by the Ministry of Water and Irrigation and hereinafter referred to as "*the Water Design Manual*".

Population

For this analysis, the project area has been defined as the whole of Turkana West sub-county in order to capture the water demand for the host community.

The human population within Turkana West-sub-county has been analyzed, as shown in Table 4-1. The data show discrepancies in the figures presented and further scrutiny of the numbers are necessary in order to establish a realistic population figure.

Table 4-1: Population data and sources for Turkana West sub-county

Source	Population	Record Year	Remarks
KISEDP Strategic Overview	506,000	2018	186,000 refugees + 320,000 host population
Kenya Population and Housing Census, 2009	245,327	2009	Population Census data
Kenya Population and Housing Census, 2019	239,627	2019	2% decrease in population from 2009 census data (10 yrs)
Turkana County CIDP (2013 – 2017)	409,490	2017	Projected population from 2009 census data

Kenya Population and Housing Census, 2019[31] (KPHC) indicate that the total population in Turkana West sub-county is 239,627 as of August 2019. The UNHCR record[32] of refuge population within Turkana West sub-county as of 31st August 2019 was 191,500 (both Kakuma camp and Kalobeyei settlement). This implies that the total population of the host community in Turkana West sub-county is 48,127 people, according to KPHC (2019). This is however very unlikely because the 2009 Kenya Population and Housing Census data indicate a population of 245,327 in Turkana West sub-county. The refugee population at the time of census was 45,638 (UNHCR, 2009). This translates to a local population of 199,689 in 2009 within Turkana West sub-county.

In this study, it has therefore been assumed that the figures for Turkana West sub-county, as presented in KPHC (2019) data, do not include the refugee population. Therefore, the annual population growth rate for Turkana West sub-county from 2009 census works out at 1.84%, which is still below the national average of 2.2% annual population growth rate reported in KPHC (2019).

All analysis of the total population assumes that the KPHC (2019) record does not include the refugee population. In addition, the study has adopted urban population analysis as presented in the draft Water Supply and Sanitation Services Masterplan for Kakuma Town, Kakuma Camp and Kalobeyei Settlement (GIZ, 2020) since the 2019 Population and Housing Census data provides a 28% reduction in Kakuma urban population without explanation for the declining growth. The review of several documents reveals discrepancies in the estimated population in Kakuma town. The figure presented in the draft Water Supply and Sanitation Masterplan gives a fair estimate of the population in Kakuma town compared with other documents. Table 4-2 shows the urban population in Kakuma town as presented by various sources.

31 Kenya Population and Hosing Census, 2019.

32 Practice Manual for Water Supply Services in Kenya, 2005.

Table 4-2: Urban population of Kakuma town

Source	Urban Population	Record Year	Remarks
Kakuma as a Market Place (IFC, 2018)	60,000	2018	An estimate based on discussions with UNHCR
Draft Water and Sanitation Masterplan for Kakuma Town, Kakuma Camp and Kalobeyei Settlement	44,478	2019	Projected from Population and Housing Census data, 2009 using 3.35% annual growth rate
Kenya Population and Housing Census, 2009	31,992	2009	Population census data of 2009
Kenya Population and Housing Census, 2019	22,984	2019	Population census data of 2019 showing a 28% reduction in Kakuma urban population
Turkana County CIDP (2013 – 2017)	53,350	2017	Projected from Population and Housing Census data, 2009 using 6.4% annual growth rate
Turkana County CIDP (2018 – 2022)	48,047	2020	Projected from Population and Housing Census data, 2009 using 3.36% and 3.34% annual growth rate for male and female population respectively

The rural population has been computed from the KPHC (2019) and the projected Kakuma town population as presented in the draft Water Supply and Sanitation Master Plan. The total population in Turkana West sub-county as documented in KPHC (2019) is 239,627, while the projected urban population in 2019 as presented in the draft Water Supply and Sanitation Masterplan is 44,487. Thus, the rural population in 2019 is 195,149 (239,627 - 44,487).

This figure compares well with the KPHC (2019) data, which indicates that the rural population from 5 years old and above in Turkana West sub-county is 176,268 (KPHC, 2019). It is therefore obvious that the total rural population, including children below five years of age, is higher than 176,268. Hence, the figure of 195,149 people is realistic. This study adopts 1.84% annual population growth rate for the rural population, based on the analysis of KPHC 2009 and 2019 population data. Table 4-3 presents population estimation growth.

Table 4-3: Population analysis for selected areas within Turkana West sub-county

Description	Year	Kakuma Town	Kakuma Camp	Kalobeyei Settlement	Rural Host Population	Total
Population growth rate		3.35%	2.50%	2.50%	1.84%	
Population Census	2009	31,992				
Population Census	2019	44,478	153,593	36,099	195,149	429,319
Population Projected	2020	45,968	157,433	37,001	198,740	439,142
Population Projected	2022	49,100	165,403	38,875	206,121	459,499
Population Projected	2027	57,894	187,138	43,983	225,795	514,810
Population Projected	2030	63,909	201,527	47,365	238,489	551,290

Source: Water Supply and Sanitation Masterplan & Computation for Rural Host Population based on KPHC (2019)

Domestic water demand has been analyzed separately for Kakuma town, Kakuma camp, Kalobeyei settlement and the rural host population in Turkana West sub-county. The draft Water Supply and Sanitation Masterplan provides detailed analysis of water demand in Kakuma town, Kakuma camp and Kalobeyei settlements and these figures shall be adopted in this study.

Computation of water demand was based on the following assumptions as established in the study:

Kakuma town:

- Percentage of people fetching water from household connections (IC) was 25.4%;
- Average per capita water consumption for households with individual connections was 32 l/c/d;
- The ratio of IC (mostly yard connections) to non-household connections (NC) was 25.4 : 74.6;
- Average per capita consumption for the population served by water Kiosks was 18.74 l/c/d;
- High potential rural area characteristics exhibited in the initial year and low housing urban area realized after ten years as per MWI Practice manual, 2005.

Kakuma camp:

- A rate of 20l/c/day was adopted for both for IC and NC. This is based on both the current provisions and the SPHERE manual recommendation (within the range of 15-30 l/c/d).

It is however noted that actual water consumption varies with time. Higher rates of 20.8 l/p/day to 22.7 l/p/day was reported by UNHCR in 2017 from actual field data.

Kalobeyei settlement:

A rate of 40 l/c/day was adopted as it is a mixed settlement and previous studies have used the same rate.

The computed water demand for Kakuma town, Kakuma camp and Kalobeyei settlement as presented in the draft Water Supply and Sanitation Masterplan is presented in Table 4-4. These figures have been adopted in this study.

Rural host population

Table 4-4: Domestic water demand for Kakuma town, Kakuma camp and Kalobeyei settlement

Year	Domestic Water Demand (m^3/day)			
	Kakuma Town	Kakuma Camp	Kalobeyei Settlement	Total
2020	1,018	3,149	820	4,987
2022	1,191	3,308	943	5,442
2027	1,671	3,743	1,269	6,683
2030	2,201	4,031	1,705	7,937

The rural part of Turkana West sub-county can be classified as a rural region with low potential for agricultural development due to the climatic conditions. The Water Design Manual (2005)[33] indicates that per capita water demand for people with individual connections in the low potential rural area is 40 l/person/day and 10 l/person/day for people without individual connections. On the other hand, Sphere standards recommend a minimum of 15 l/person/day. However, research indicates that 20 liters per capita per day is the minimum quantity of safe water required to realize minimum essential levels for health and hygiene[34] (WHO, 2013). Therefore, a per capita water demand of 20l/person/day has been adopted for the rural population, without individual connections and 40l/person per day for the rural population with individual connections.

The Water Design Manual (2005) provides the following guidelines for the projection of in-house (IC) and non-in-house (NC) connections (Table 4-5). The guidelines for the low potential rural area has been adopted for the projection of water demand in the rural area of Turkana West sub-county. The Manual defines the initial year as 0-5 years of preliminary design, future year as ten years and ultimate year as 20 years from the initial year. In this study, the design period is up to 10 years, and therefore the numbers have been adjusted accordingly such that the year 2030 is the future year as per the manual with a projected ratio of 10:90 for IC:NC. A value of 0.5% annual increment in individual connections has been adopted as presented in Table 4-6.

Table 4-5: Projected ratio of IC to NC

	IC %			NC %		
Rural Area	Initial	Future	Ultimate	Initial	Future	Ultimate
Low potential	5	10	20	95	90	80

Source: Extract from The Water Design Manual, 2005

Table 4-6: Projected water supply service levels for the rural population

Year	Population	% IC	Population with IC	% NC	Population with NC
2020	198,740	5%	9,937	95%	188,803
2022	206,121	6%	12,367	94%	193,753
2027	225,795	8.5%	19,193	91.5%	206,602
2030	238,489	10%	23,849	90%	214,640

The computed domestic water demand for the rural population in Turkana West sub-county is shown in Table 4-7.

Table 4-7: Domestic water demand for rural population

Year	Population with IC	Water Demand for IC (m^3/day)	Population with NC	Water Demand for NC (m^3/day)	Total Water Demand (m^3/day)
2020	9,937	397.5	188,803	3,776.1	4,174
2022	12,367	494.7	193,753	3,875.1	4,370
2027	19,193	767.7	206,602	4,132.0	4,900
2030	23,849	954.0	214,640	4,292.8	5,247

33 Practice Manual for Water Supply Services in Kenya, 2005.
34 WHO technical Notes on Drinking Water, Sanitation and Hygiene in Emergencies, 2013.

Total domestic water demand for Turkana West sub-county

The total domestic water demand for Turkana West sub-county is presented in Table 4-8.

Table 4-8: Total domestic water demand in Turkana West sub-county

Year	Domestic Water Demand (m^3/day)				
	Kakuma Town	Kakuma Camp	Kalobeyei Settlement	Rural Population	Total
2020	1,018	3,149	820	4,174	9,161
2022	1,191	3,308	943	4,370	9,812
2027	1,671	3,743	1,269	4,900	11,583
2030	2,201	4,031	1,705	5,247	13,184

Institutional water demand

Institutional water demand within Kakuma town, Kakuma camp and Kalobeyei settlement as documented in Water Supply and Sanitation Masterplan is presented in Table 4-9.

Table 4-9: Institutional water demand

Year	Institutional Water Demand (m^3/day)			
	Kakuma Town	Kakuma Camp	Kalobeyei Settlement	Total
2020	53	504	297	854
2022	62	529	313	904
2027	87	599	354	1,040
2030	120	645	381	1,146

Source: Water Supply and Sanitation Masterplan

We note that the registered student population in public primary and secondary schools in Turkana West sub-county is 32,734 according to Turkana County records of June 2020. The Water Design Manual, 2005 recommends at least five liters of water per student per day. Institutional water demand in public primary and secondary schools within Turkana West sub-county is therefore 164 m^3/day. Reviewing the information in Table 4-9, therefore indicates that the institutional water demand estimates cater for all other public institutions such as health facilities.

Commercial water demand

The draft Water Supply and Sanitation Masterplan report that the water utility in Kakuma town (KATOWASE) had 25 commercial connections by February 2020. The Masterplan further states that the current water consumption from commercial enterprises is about 31 m^3/day (as established through meter readings) mainly from hotels and guest houses. Using the same rate of increase as the domestic water demand, the Masterplan projects commercial water demand as presented in Table 4-10.

Table 4-10: Commercial water demand in Kakuma town

	2020	2022	2027	2030
Commercial Water Demand (m^3/day)	31	36	50	69

There also exist several commercial enterprises within Kakuma camp that need water. However, due to the lack of guidelines on supply and payment for water for commercial purposes, there are no records on water demand for commercial enterprises within the camp. It is therefore assumed that this demand is covered by the domestic water demand.

A study by IFC (2018)[35] shows that there are potential and interest of the refugee population for doing business. Of the population interviewed on interest in business, 11% expressed interest in food stalls, 6% in restaurant/cafeteria and 4% in salon/barbershop. The operation of these businesses requires a reliably supply of water.

It is therefore important to anticipate commercial water demand in the camp. Due to lack of documentation on the extent of water demand for commercial purposes, this study has made a basic assumption that commercial water demand in the camp is 50% of the commercial water demand reported in Kakuma town. The total commercial water demand estimate is presented in Table 4-11.

Table 4-11: Total commercial water demand

Commercial Water Demand (m^3/day)	2020	2022	2027	2030
Kakuma Town	31	36	50	69
Kakuma Camp	15.5	18	25	34.5
Total (m^3/day)	**46.5**	**54**	**75**	**103.5**

4.1.2 Livestock water demand

Livestock water demand has been computed based on livestock population within Turkana West sub-county. Livestock population data were obtained from the Turkana County Government, Directorate of Livestock Production for December 2019. The livestock population was converted into livestock units following the Water Design Manual, 2005, with a per capita demand of 50 l/day per livestock unit. Table 4-12 presents the livestock population and livestock water demand for Turkana West sub-county.

Table 4-12: Livestock population and water demand for Turkana West sub-county

Livestock	Population	Conversion Factor to Livestock Units	Livestock Units	Water Demand (m^3/day)
Cattle	355,811	3	118,604	5,930
Goats	931,258	15	62,084	3,104
Sheep	616,872	15	41,125	2,056
Camels	136,570	2	68,285	3,414
Donkeys	90,621	5	18,124	906
Total			**308,222**	**15,411**

Total water demand for Turkana West sub-county (human and livestock)

The total water demand for domestic, institutional, commercial and livestock has been computed and presented in Table 4-13. Attention is drawn to the fact *that livestock water demand consists of over 50% of the total water demanded throughout the design period and is actually 60% of the total demand in the initial year*.

35 IFC (2018): Kakuma as a Market Place.

Table 4-13: Combined total water demand for Turkana West sub-county

Type of Demand	Combined Total Water Demand in m³/day			
	2020	2022	2027	2030
Domestic	9,161	9,812	11,583	13,184
Institution	854	904	1,040	1,146
Livestock	15,411	15,411	15,411	15,411
Commercial	47	54	75	104
Total	**25,473**	**26,181**	**28,109**	**29,845**

4.1.3 Irrigation water demand

This section focuses on the irrigation water demand for groundnuts. The method adopted herein to compute irrigation water demand takes a reasonably conservative approach which is appropriate for planning purposes. More detailed analysis can be undertaken for a specified crop, cropping calendar, irrigation method and soil types which may indicate a lower irrigation water demand.

It is recognized that groundnut production would be undertaken under a system of crop rotation with other crops which are discussed in Volume 2, Chapter 3.2. Information on crop water demand for other crops is provided in Volume 2, Chapter 3.3.

A. Types and varieties of groundnuts

There are two main types of groundnuts, namely the bunch type and runner type, with various varieties under each type. Generally, the bunch type matures early (60 -75 days[36]; 90 to 100 days[37]) compared to the runner type (120 – 150 days)[38] depending on altitude and therefore temperature. The runner types are large-seeded and mainly used for oil extraction, while the bunch types are small to medium seeded and normally used for roasting and peanut butter (ICRISAT, 2016). Some of the recommended varieties are CG7 (red large-seeded for commercial production), ICGV-SM9991 (medium size for roasting and commercial), ICGV-SM 12991 (for peanut butter)[39].

B. Ecological requirements

Groundnuts do well in the warm tropics and sub-tropics below 1500m asl with the optimal temperature being 27 – 30°C [40,41,42]. The crop requires 500 – 600 mm[43] of rainfall that is well distributed within the growing season.

Cognizant of the fact that there exist different figures on climate for the study area, for the irrigation water requirement, we have chosen to work with modelled climatic parameters for Kakuma and Kalobeyei as presented in Table 4-14 and Table 4-15, derived from the IMWI Climate portal, as these values are conservative for irrigation water demand estimation. The mean annual rainfall is low (about 260 and 325 mm for Kakuma and Kalobeyei, respectively) and has a poor temporal distribution with an average of 70 days with rainfall in a year. The P_{75}[44] rainfall is very low (110 mm for Kakuma and 150 mm for Kalobeyei). The mean annual temperature is 27°C with January and February being the hottest months. This, coupled with the high wind speeds (mean 3 m/s), accounts for the high mean monthly and annual (6.4 mm/day)[45] evapotranspiration and low moisture availability index (mean annual MAI is zero). Cumulatively these climatic conditions make rainfed crop production difficult. However, the high-intensity nature of rainfall causes flash floods, presenting an opportunity for runoff harvesting.

36 OXFAM organic.
37 Farmlink Kenya.
38 Farmlink Kenya.
39 KALRO.
40 ICRISAT Nigeria.
41 OXFAM Organic.
42 Farmlink Kenya; Prasad et al.
43 Farmlink Kenya; OXFAM Organic; Prasad et al.
44 Rainfall with a 75% probability of exceedance.
45 FAO Irrigation and Drainage paper 56 gives a mean ET_o of 6 – 8 mm/day for warm arid and semi-arid regions.

Table 4-14: Climatic data – Kakuma

Month	Rainfall (mm/month)		Days with Rain	Temp (°C)	Wind (m/s)	Moisture Availability Index (MAI)	Penman ETo (mm/day)
	P50	P75					
Jan	3.75	0.68	2.2	27.2	3.1	0	6.96
Feb	9.16	2.79	3.5	28	3.2	0	7.35
Mar	26.13	11.89	5.3	28.4	3.4	0.1	7.22
Apr	61.61	37.64	9.1	27.8	3	0.2	6.24
May	40.46	21.17	7.7	27.3	3.1	0.1	5.99
Jun	19.36	6.13	5.7	26.7	3.1	0	5.79
Jul	31.38	10.43	6.7	26	3.2	0.1	5.57
Aug	24.02	7.78	6.2	26.3	3.1	0	5.89
Sep	9.62	1.83	5.5	27.1	3.1	0	6.46
Oct	9.38	3.02	6.1	27.5	3.2	0	6.53
Nov	17.88	5.76	5.8	27	3.1	0	6.31
Dec	6.09	0.93	3	26.8	2.9	0	6.45
Total	258.84	110.05	66.8				
Mean				27.18	3.13	0	6.40

Source: Generated from IWMI Online Climate Service Portal

Table 4-15: Climate data – Kalobeyei

Month	Rainfall (mm/month)		Days with Rain	Temp (°C)	Wind (m/s)	Moisture Availability Index (MAI)	Penman ETo (mm/day)
	P50	P75					
Jan	3.39	0.62	2.2	27.3	3	0	6.9
Feb	9.47	2.98	3.5	28.2	3	0	7.19
Mar	27.81	13.03	5.7	28.6	3.2	0.1	7.08
Apr	62.69	38.91	9.4	27.9	2.8	0.2	6.05
May	49.64	27.61	8.4	27.4	2.9	0.2	5.77
Jun	29.01	11.02	6.5	26.7	2.9	0.1	5.54
Jul	45.56	18.74	7.5	26	3	0.1	5.29
Aug	38.25	15.56	7.2	26.3	2.9	0.1	5.66
Sep	18.87	5.47	6.4	27	2.9	0	6.14
Oct	13.67	5.04	6.8	27.5	3	0	6.29
Nov	20	6.86	6.1	27	2.9	0	6.07
Dec	6.73	1.18	3	26.9	2.7	0	6.25
Total	325.09	147.02	72.7				
Mean				27.23	2.93	0.1	6.19

Source: Generated from IWMI Online Climate Service Portal

C. Yield potential

Farmer recorded yields vary greatly from as high as 3500 kg/ha to as low as 400 kg/ha mainly based on the agronomic practices. The runner types generally have a higher yield than the bunch types. Some reported potential yields are:

Source	Yield (kg/ha)
ICRISAT 2016:	2000 – 3000
ICRISAT Nigeria:	2000 – 3000
Legume Development Trust (Malawi)[46]:	2000 – 2500

Other yield values reported in Prasad et al., 2010)[47] for different regions are: Africa 800 kg/ha; Asia 1600 kg/ha; S. America 2500 kg/ha; USA 3500 kg/ha, World 1500 kg/ha.

For the purpose of this assignment, a mean of **2000 kg/ha** has been adopted on the assumption that the high yielding commercial varieties and appropriate agronomic practices will be adopted. This compares well with the preliminary results of groundnut trials in Turkana giving an estimated yield of 2000 kg – 2,500 kg/ha under recent trials by FAO and Egerton University.

D. Reference crop evapotranspiration (ET_o)

This is the evapotranspiration rate from a reference surface that is not short of water and expresses the evaporative demand of the atmosphere at specific places and time. It is independent of crop type, stage of crop development and soil type and only dependent on climatic factors. Various methods exist for computation of ET_o including the evapotranspiration (ET) measurement, pan evaporation method and FAO Penman-Monteith method which is the recommended as the standard method. However, due to the complexities of these methods, average ET_o figures are available for different agroclimatic regions. For the ASAL Turkana County with a warm to and hot climate the ET_o is 6 – 8 mm/day which in conformity with ET_o generated with the IWMI Online Climate model (Table 4-16). It should be recognized that ET_o is expected to rise with the anticipated temperature increases under the climate change scenarios.

Table 4-16: Simulated mean Penman ET_o (mm/day) for Kakuma and Kalobeyei

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean*
Kakuma	6.96	7.35	7.22	6.24	5.99	5.79	5.57	5.89	6.46	6.53	6.31	6.45	6.40
Kalobeyei	6.90	7.19	7.08	6.05	5.77	5.54	5.29	5.66	6.14	6.29	6.09	6.25	6.12

Source: Tables 1 and 2 *computed

E. Crop coefficients

Crop coefficients (K_c) give a measure of the level of evapotranspiration and vary with crop type, stage of crop development and climatic conditions, especially humidity and wind speed. For any particular crop, the K_c changes with respect to the plant growth stage with a low K_c initial when the plant is germinating, rising to a peak during the mid-season stage (K_{cmid}) and falling again during the late season/harvest stage. For planning purposes, the crop water requirement (CWR or ET_c) and subsequently irrigation water requirement (IWR) can be estimated conservatively using the peak K_{cmid} value. For groundnuts the initial K_c during germination is 0.40, rising to 1.15 mid-season and dropping to 0.6 at harvest[48]. This results in a time-averaged K_{cavg} for groundnuts, using the FAO CropWat values for K_c over the growing cycle, of 0.85 which is applied for this assignment.

46 Harmonized Groundnut Production Manual for Malawi.
47 Prasad, P.V., V.G. Kakani & H.D. Upadhyaya (2010): Growth and Production of Peanut. In book: Encyclopaedia of Life Support Systems. Publisher: EOLSS Publishers, Oxford, U.K.
48 Source: FAO Irrigation and Drainage Paper No. 56 page 111.

F. Length of the growing period

The length of the growing period varies with varieties and climatic conditions with bunch type varieties having 90 to 100 days and runner types 120 to 150 days[49]. For the purpose of this planning, an average of **120 days** is used.

G. Effective rainfall (P_e)

Effective rainfall (P_e) is the fraction of rainfall (P) received in an area that is available to the crop and is usually taken into account when computing irrigation water requirement.

The P_e is estimated based on the site monthly rainfall data using the "FAO dependable rainfall formula" which adopts a conservative estimate of effective rainfall. For the purpose of this assignment, the mean p50 monthly rainfall for Kakuma is used (Table 4-14), although the p75 value would result in a more conservative estimate of irrigation water requirements. It should be noted that the effective rainfall is significantly lower than actual rainfall and in reality it is only in the months of April, May and July where rainfall will contribute towards meeting the crop water requirement (CWR or ET_{crop}) which must otherwise be met from irrigation

Table 4-17: Mean monthly rainfall and effective rainfall for Kakuma

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P50 Mean (mm/m)*	3.75	9.16	26.13	61.61	40.46	19.63	31.38	24.02	9.20	9.38	17.88	6.09
Pe**	-7.75	-4.50	5.68	26.96	14.28	1.78	8.83	4.41	-4.48	-4.37	0.73	-6.35
Adopted Pe (mm/m)	0	0	6	27	14	2	9	4	0	0	1	0

*Source: Table 4-14; **Computed

H. Crop water requirements (CWR or ETcrop)

Crop water requirement (CWR or ET_{crop}) is the amount of water required to compensate for evapotranspiration from a cropped field and is what the crop should absorb from the soil to meet growth needs. Crop water requirement is a function of the crop and the evaporative demand of the atmosphere.

Table 4-18: Crop water requirement (CWR) for groundnut in Kakuma

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean ET_o (mm/day)*	6.96	7.35	7.22	6.24	5.99	5.79	5.57	5.89	6.46	6.53	6.31	6.45
Kcavg **	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Mean CWR (mm/day)	5.9	6.2	6.1	5.3	5.1	4.9	4.7	5.0	5.5	5.6	5.4	5.5
Mean CWR (mm/month)	183	176	190	159	158	148	147	155	165	172	161	170

*Source: Table 4-14 **Source: FAO Irrigation and Drainage Paper No. 56, page 111

49 Farmlink Kenya 2017 and OXFARM ORGANIC; FAO Irrigation and Drainage paper 56, page 104, table 11.

I. Irrigation application efficiency

Irrigation efficiency is a measure of the fraction of the total amount of supplied irrigation water that is eventually available to the crop. Hence, it is a function of the soil type and irrigation water application method. The application efficiency is factored in the computation of the irrigation water requirement (IWR). Table 4-19 presents typical irrigation application efficiencies used in planning for drip, sprinkler, furrow and basin systems.

Table 4-19: Indicative irrigation application efficiencies

Irrigation Method	Field Application Efficiency (%)
Surface (border, furrow, basin)	60
Sprinkler	75
Drip	90

Source: Brouwer et al, 1989: Irrigation Water Management: Irrigation Scheduling, training Manual No. 4

J. Irrigation water requirement (IWR)

Irrigation water requirement (IWR) is the amount of water that should be delivered to the irrigated plot to meet the crop water requirements. It takes into account the area to be irrigated, effective rainfall and the field application efficiency. IWR is computed on a monthly basis, but for planning purposes, the month with the peak demand (March) is used. This is the quantity of water that this assignment seeks to inform whether it is available for the proposed project.

Table 4-20: Irrigation water requirement for groundnuts in Kakuma

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean CWR*	183	176	**190**	159	158	148	147	155	165	172	161	170
Adopted P_e (mm/m)**	0	0	6	27	14	2	9	4	0	0	1	0
CWR – Pe	183	176	184	132	144	146	138	151	165	172	160	170
Ea (Surface)%***	60	60	60	60	60	60	60	60	60	60	60	60
Ea (Sprinkler)%***	75	75	75	75	75	75	75	75	75	75	75	75
Ea (drip)%***	90	90	90	90	90	90	90	90	90	90	90	90
IWR (surface) mm/m	306	294	**307**	220	240	243	230	252	275	287	267	283
in mm/day	10	10	**10**	7	8	8	8	8	9	10	9	9
IWR (Sprinkler) mm/m	245	235	**246**	176	192	194	184	202	220	229	213	227
in mm/day	8	8	**8**	6	6	6	6	7	7	8	7	8
IWR (Drip) mm/m	204	196	**205**	147	160	162	153	168	183	191	178	189
in mm/day	7	7	**7**	5	5	5	5	6	6	6	6	6

Table 4-18; * Table 4-19

K. Irrigation water demand for proposed project (commercial groundnut)

Computation of the irrigation water demand for the proposed commercial groundnut project is premised on the following:

- High yielding commercial groundnut varieties;
- Confirmed annual groundnut demand of 6,000 tons (6,000,000 kg)[50];
- Peak irrigation water demand which is in March (Table 4-20);
- Estimated yield of 2000 kg/ha;
- Length of the growing season of 120 days (4 months).

Irrigation area (ha)

- Theoretically, there can be three irrigation seasons in a year (12 months / 4 months per season). In practice, there are two seasons because time is required in-between seasons for operations like harvesting and land preparation. In practice the groundnuts will actually be grown in rotation with other crops;
- Production per irrigation season is 3,000 tons (3 million kg) i.e. is 6,000 tons / 2 seasons;
- Required irrigation area per season is 1,500 ha i.e. 3,000,000 kg/season ÷ yield per ha (3,000,000 kg ÷ 2,000 kg/ha).

Table 4-21: Irrigation water demand to produce 6000 t/yr of groundnuts

Irrigation method	mm/day	l/s/ha*	m³/ha/day*	Total m³/day (for 1,500ha)	Total m³/season (120 days)
Surface	10	1.137	98.05	147,077	17,649,188
Sprinkler	8	0.910	78.44	117,661	14,119,350
Drip	7	0.758	65.37	98,051	11,766,125

L. Implications of crop rotations on irrigation water requirements

It is recommended that groundnuts be grown in rotation with other crops, especially cereal crops like maize, sorghum and millets and cassava, sweet potato and sunflower.

Groundnuts also give higher yields on fields that have been fallowed hence one of the best crop rotation systems is one in which a grass fallow, especially a commercial grass fodder crop, is followed by groundnuts. As a rule, other legume crops, tobacco, tomato and cotton, should not be included in a rotation program with groundnuts because of common pests and diseases, namely nematodes and soil-borne diseases.

Since groundnut is the principal crop; it is proposed that 50% of the land in any one given season be under groundnuts and the remainder of 50% distributed among the other groups based on their gross margins as dictated by prevailing production costs and market prices.

The crop water requirement (CWR) for sorghum and finger millet in the driest month (March) is 166 mm compared to 190 mm per month for groundnuts. This means that rotating groundnuts with cereal crops will result in a lower water demand of about 13%, which is significant for ASAL areas. However, the inclusion of sunflower in the rotation will not change the irrigation water demand significantly because sunflower has similar water requirement to groundnuts.

50 IFC TOR.

M. Other potential crops

There are many other crops being cultivated in the various parts of the County under various technologies that would be suitable for the Kakuma-Kalobeyei area, based on the suitability of the soils and relatively higher rainfall compared to other parts of the country.

Vegetable crops including tomato, kales and spinach can be grown under shade nets to reduce the evaporation water loss. These are being promoted by the WFP through the Kalobeyei Integrated Development Project. Dry bulb onion and garlic have a huge potential owing to the high suitable soils (sandy loams and loams) that are deep and friable and therefore readily allow for bulb expansion. They are also high-value vegetable crops, and domestic demand is high.

Dryland crops are the drought-tolerant crops grown in various parts of the county including Turkana West. These include green grams, cowpeas and sorghum grown using in-situ soil water conservation technologies.

N. Technologies and management practices to reduce irrigation water demand

Deficit irrigation

Groundnuts, green grams, cowpeas and sorghum have substantial levels of drought tolerance, and therefore, deficit irrigation can be used during the non-sensitive growth stages (vegetative and ripening) with minimal reduction in crop yield. This would make water available for the increasing area under irrigation.

Supplementary irrigation

Irrigation water demand can be reduced by scheduling the planting season to coincide with the onset of the rainy period. This will ensure maximum utilization of rainfall and only supplementary irrigation applied as necessary. This way rainfall can meet 25-30% of the crop water demand, with the balance being provided by irrigation.

Shading and wind breaks

The high evapotranspiration in the Kakuma area is a function of high temperatures and wind speeds. Various technologies can be used to reduce the evapotranspiration by reducing temperature and or wind over the crops. These include use of greenhouses, windbreaks and shade nets. Windbreaks are typically developed using a perennial plant (e.g. Napier grass, bushes or trees) which do not interfere with the crop growth.

4.2 Water Balance

The assessment of the feasibility to introduce new water demand sectors, such as agribusiness, is mainly based on the study of the surface water and groundwater availability. In this paragraph, an effort has been made to set up a water balance, but such an effort is hampered by the problem of delineation of the region to which the balance applies.

At the same time, there are major uncertainties in both the water demand and the water availability assessments, which does not allow at present for the presentation of a reliable water balance. Nevertheless, some results are presented here, and details of the calculation are given in Volume 2, Chapters 2.5 and 2.6.

The summary of aquifer storages is tabulated in the table below.

Table 4-22: Aquifer storages in the study area

Aquifers	Areal Extent (m^2)	Depth (m bgl)	Storage (m^3)
Shallow Aquifers (Tarach and Kalobeyei Aquifers)	$5.14*10^8$	0-35	$3.09*10^8$ / 309 MCM
Medium Depth Aquifers (Lotikipi and Volcanic Aquifers)	$7.16*10^8$	35-80	$2.15*10^8$ / 215 MCM
Deep Aquifers	?	>80	?

4.2.1 Groundwater flux

Groundwater flux is the Darcy velocity which represents the flow per unit cross-sectional area of the porous medium. Since there is the porous media, the water must move through the pores around the solid particles, at a speed greater than the flux. This is useful in the process of quantifying the individual processes, bringing water into or out of the system to define the water balance or water budget of an aquifer system.

The common inflows and outflows of water in groundwater systems in the study area comprise either one of these or both:

1. Inflows of water to groundwater systems
    - Infiltration through the vadose zone that is not intercepted by evaporation, transpiration or bound in the unsaturated zone. Thus, it becomes recharge
    - Groundwater flow from other regions outside the region of interest.
2. Outflows from groundwater systems
    - Evaporation and/or transpiration (evapotranspiration)
    - Water withdrawal by pumping from wells
    - Natural groundwater flows or discharge at springs or seeps or to surface water bodies.

Determination of the groundwater flux is not a straight forward calculation, especially where the aquifer is not clearly defined and fully characterized, and there are no proper monitoring systems. However, from the analysis of 43 boreholes, some hydraulic parameters for Tarach alluvial aquifer and the intermediate depth aquifers in Kakuma-Kalobeyei area can be deduced. The full derivation is given in Volume 2, Chapters 2.5 and 2.6. The final balance of the groundwater recharge from groundwater flux comes from the difference between the lateral inflow and lateral outflow, the latter being only a fraction of the inflow:

Estimated retained water in the aquifer:

$$\textit{Inflow}\ (Q_{on}^{gw}) - \textit{Outflow}\ (Q_{off}^{gw})$$

$8.03 * 10^7 - 1.06 * 10^5 = \mathbf{8.03 * 10^7}$ m³/yr

This is equivalent to $2.2 * 10^5$ m³/day.

4.2.2 Groundwater recharge mechanism

An important component in the water balance is the groundwater recharge, that was discussed in paragraph 3.1.3.7. Recharge can be provided by the following equation:

$$\textit{Recharge} = P - ET \pm Qs$$

Where P is the Precipitation, ET is the actual Evapotranspiration and Qs is inflow or outflow from rivers/laggas and springs. From this equation, it is possible to calculate the volume of the groundwater recharge in case accurate information is available on precipitation, evapotranspiration and inflow and outflows of a given region. When precipitation and ET are comparable, direct recharge is an unlikely mechanism of replenishment. From the water balance calculations presented in Volume 2, it turns out that the balance has a negative value of $\mathbf{-1.037 * 10^9}$ m³/yr, indicating little to no direct recharge into groundwater occurs from precipitation. This can be attributed to the high value of evapotranspiration (ET) in the region compared to the rainfall (resp. 2714 mm and 320 mm).

Kakuma and Kalobeyei are covered by the two main rock types, i.e. volcanic intrusions and sedimentary rocks. Therefore, there are two possible types of groundwater recharge mechanisms for the aquifers: direct recharge through the infiltration of rainwater at the surface and overland runoff, and indirect recharge (Sottas, 2013) via faults and lateral recharge through the primary porosity of the underlying volcanic-sediments.

Since direct precipitation hardly contributes to groundwater recharge, groundwater flux is therefore considered to be the main reliable source of groundwater recharge in the aquifers within Kakuma-Kalobeyei area. However, in those areas where there are fractured/weathered volcanic, direct recharge into the fractures is possible from the water seeping through the overlying sediments or directly into the crevices and fractures. Another potential route is the infiltration along the lagga valleys during flood events, e.g. by the Napas, Nanam and Tarach Laggas among other minor seasonal lagga valleys.

Recharge from the groundwater flow and the increase in the water stored in the unsaturated zone gives the maximum recharge values attained during the wet season.

$R = (Q_{on}^{gw} - Q_{off}^{gw}) + \Delta S^{UZ}$

$R = (8.03 * 10^7 - 1.06 * 10^5) + 1.78 * 10^8$

$\mathbf{= 2.59 * 10^8}$ **m³/yr (259 MCM/yr)**

4.2.3 Water deficit / surplus

Climatic water deficit is the amount of water by which the potential evapotranspiration (PET) exceeds the actual evapotranspiration (AET, Stephenson (1998)). The water surplus is where the actual evapotranspiration exceeds the potential evapotranspiration. In a simple way, a water surplus is a point where there is more than enough water, and the deficit is where there isn't enough. Generally, semi-arid to arid places have a water deficit.

An illustrative water balance was made for the areas of both Kakuma and Kalobeyei, based on the already existing data on various parameters like precipitation and the conservative estimates of recharge with a hydrological influx per year of:

- Average Precipitation: 320 mm/yr;
- Evapotranspiration: 2714 mm/yr.

Based on conservative recharge estimates of about 656,9*10^3 m^3/yr, the water demand for irrigation cannot be met using sustainable groundwater abstractions.

When the higher estimates of the recharge values are used, a more positive figure is found:

- Recharge: 6.5 mm/year (3.74*10^6 m^3/yr) (2% of precipitation)

This value is higher than the current human and livestock water demand. However, in order to gain a more robust groundwater supply, it is recommended that water supply is augmented by rainwater harvesting, managed aquifer recharge and surface water storage.

4.2.4 Recharge, abstraction and demand relationship per aquifer

The following assumptions are made:

- Abstraction period is 12 hrs/day;
- Water consumption rate is 0.01 m^3/day per location;
- The human population is calculated based on the population densities per constituents stipulated in the KNBS data;
- Average yields are 17.56 m^3/hr.

The host community is projected to be 90,044 people, whereas the refugees are 192,167. From these figures, water demand translates to:

- (90,044+192,167) * 0.02 (Per Capita Water Demand of 0.02 m^3/day);
- The total water demand is 5,644.22 m^3/day (2,060,140.3 m^3/yr);
- Recharge 655,934.76 m^3/yr.

The total standardized Livestock unit was used to establish the livestock demand in the area in reference to a per capita rate of 50 liters per LU/day/livestock units as per the Design Manual guidelines. The arising total livestock demand is 150 m^3/day or 558,732 m^3/year. The water demand for the entire lifespan peanut period (3-4 months) is between 6.3 and 12.5 Mm^3/season. Water demand for the entire lifespan (3-4 months) of the targeted (6,000 tonnes) peanut production is between 6.3 and 12.5 Mm^3.

Based on the borehole abstraction data gathered during the study, the overall abstraction presents a water surplus of about 1.1 Mm^3/yr of approximately a third of the human and livestock water demand for the current year (2020). However, if 8% of the 67 wells are abstracted daily with 5 m^3/day (WRA) abstraction, the overall water demand will present a water deficit of about 0.7 Mm^3/year.

The current supply can only smoothly support domestic demand and livestock with great challenges during the dry seasons. Irrigation demand for 6,000 tonnes of groundnuts cannot be met at present unless additional groundwater exploration and exploitation is done. In addition, surface water could also be exploited to augment the deficit.

4.2.5 Groundwater reserve

The Reserve Quantity is that part of the resource that is inviolable and being reserved for basic human needs, including both current and future and ecological needs.

This can indeed be difficult to define. However, in establishing the Groundwater Reserve, the following factors are the guidance:

- Ecological vulnerability;
- The vulnerability of local population dependent on that water resource;
- Local observations with respect to the naturalized flows or water levels of minimum values observed during periods of prolonged droughts;
- In all instances where water flow is known to be normally perennial, the reserve quantity shall be sufficient to ensure perennial flow;
- Consultations with the WRA.

The WRA Rules (2007) describe the Reserve, but with no definition. It has been described as comprising of one element related to the quantity of the resource and the respective probability associated with that quantity, and a second element related to the quality of the resource. In order to define the Reserve, some of the principal parameters include the reservoir storage, recharge volume, anthropogenic abstraction and natural discharge. Although no set criterion is available for the quantification of these parameters, this can best be done using water balance calculations.

For aquifers, the Reserve Quantity shall be 40% of the aquifer flux in the case of aquifers whose recharge rate has been determined by the Authority. For aquifers whose recharge rate has not been determined by the Authority, the Reserve Quantity for each point of abstraction shall be 40% of the tested yield based on test pumping analysis. If the Authority considers that the Reserve Quantity and or Quality is threatened, it shall cause to be placed in or near the water resource or in a public place frequented by the water users of a particular resource a legible signboard displaying the current condition of the resource and action required by the water users to safeguard the Reserve.

4.3 Water Supply and Sanitation

KPHC (2019) documents the sources of drinking water in Turkana West Sub-county. It reports that 32.5% of the population get their drinking water from public standpipes and 29.6% get drinking water from streams or laggas (unprotected sources). The data are specifically for drinking water and does not include other domestic water uses. However, the data give an indication of main water sources for domestic use within the sub-county.

Water Supply in Kakuma town, and the Kakuma camp and Kalobeyei settlement has been covered in detail in the draft Water Supply Masterplan, 2020 and is summarized below.

4.3.1 Water supply to Kakuma town

The town has two boreholes located near the Tarach lagga and three shallow wells. One is located at Kakuma, another near the distribution center and two at Ong Kong near Kakuma Two. There are no treatment plants in the town, and people have to treat the water individually.

The water service provider in Kakuma town is Kakuma Town Water Services (KATOWASE) supported by the Turkana County Government. KATOWASE was established about a year ago to take over water supply services in Kakuma town following the disbandment of the previous water service provider. KATOWASE is not yet a legally registered entity and hence is an interim management arrangement with the objective to ensure that there is continuous water supply in Kakuma town as the County Government is working on proper structures for efficient management of the water supply scheme.

KATOWASE supplies water to the residents of Kakuma town through individual connections and water kiosks. The sources of water consist of 6 boreholes. In March 2020, there were 715 individual connections and 17 operational water kiosks. In addition, 98% of the individual connections were metered, and only 7 out of the operational 17 kiosks were metered[51].

Water billing is on metered consumption for the metered connections and on a flat rate for the unmetered connections. The tariff for metered connections is graduated. Water is sold at the kiosks at Ksh 5 per 20-liter jerrican.

Water is supplied only during the day for about 12 hours. The total available storage is 550m³. It is estimated that KATOWASE serves 25.4% of the population via individual connections and 11% via water kiosks.

In terms of water quality, the water source is groundwater which has endogenic properties depending on the geology of the area. Salinity is a common problem with groundwater in the area. However, all boreholes operated by KATOWASE have freshwater except one The water supply is chlorinated before distribution, but due to frequent bursts and leaks, the supply may become contaminated periodically.

Apart from the KATOWASE boreholes, there are six private boreholes that supply water to part of the population. In addition, Kakuma town is also served by shallow wells fitted with hand pumps. These are mainly found along the Tarach lagga and are community-managed but supported by the Turkana County Government in case of major repairs. There are nine hand pump wells serving an estimated population of 1,320[52], which translates to about 3% of the population. Some other sources include the Tarach Lagga that traverses Kakuma town, and unprotected hand-dug wells/scoop holes and two water pans (Awarnapar and Loyaal water pans). These sources are, however, unprotected and hence do not form part of water supply coverage. The water pans are meant to support agricultural activities. Water vendors complement the KATOWASE system by distributing water from different sources.

KATOWASE is faced with several challenges like inadequate institutional and operational capacity. In addition, not all connections are metered, resulting in poor monitoring of scheme performance, especially on non-revenue water. It has, however, been observed that scheme performance improved with the establishment of KATOWASE and metering of connections. More connections can be realized with 100% metering ratio and management of illegal connections.

4.3.2 Water supply to Kakuma camp and Kalobeyei settlement

Water supply to the Kakuma camp and Kalobeyei settlement is managed by NRC as mandated by UNHCR. Kakuma camp and Kalobeyei settlement are entirely served by boreholes. In total, there are 18 boreholes, ten of which are on a hybrid power system (Solar and diesel generator) and the rest are only on diesel generators. The total combined yield for the Kakuma camp is 380.8 m³/hr and 90 m³/hr for the Kalobeyei settlement.

Water production from the NRC managed boreholes in the Kakuma camp is estimated at 4,615 m³/day. It is also estimated that the unaccounted-for-water is 35%. Thus, the water supplied to Kakuma camp is on average 3,000 m³/day. Water production in Kalobeyei settlement is estimated at 856 m³/day, and with an estimated 15% losses (unaccounted for water), the average supply is 728 m³/day. Total available storage at Kakuma camp and Kalobeyei settlement is 2,500 m³ and 1,300 m³ respectively.

Water quality deteriorates during the dry season when fluoride and salinity levels increase beyond the Kenyan standards for drinking water (1.5 mg/l for fluoride). This mainly happens following an extended dry period of about 5-6 months, according to NRC. Two boreholes, one serving the UNHCR quarters and one serving the host community have higher fluoride levels, and there were previous attempts to treat the water at the UNHCR quarters through reverse osmosis, but this was abandoned when the rate of treatment could not cope with demand and the cost of running the equipment was high. UNHCR has recently drilled another borehole whose fluoride level is within WHO standards (pers. comm., September 2020). Disinfection of all the water is carried out before distribution.

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51 Draft Water Supply and Sanitation Masterplan for Kakuma Town, Kakuma Camp and Kalobeyei.

52 Ibid.

There are strict guidelines for water supply for humanitarian support. Thus, water demand by commercial enterprises within the camp is usually ignored as there is no policy to guide connections to commercial enterprises. This means that the supply to commercial enterprises remains illegal and unmonitored. The problem with this is that illegal connections may undermine efforts by NRC to offer efficient services to the refugee population. Having a policy of proper monitoring of commercial connections in the camp is necessary to realize accountability.

4.3.3 Water supply to rural host community

Turkana CIDP 2013-2017 states that 88% of the county residents depend on surface and sub-surface dams, which in most cases do not hold water for long due to high evapotranspiration rates. The Turkana County Water and Sewerage Services Sector Policy 2018 states that 61% of the rural population rely on unimproved water sources with the majority relying on unprotected wells and stream.

This means about 39% are served by improved water sources, mainly groundwater (boreholes and handpump wells). JICA (2015)[53] documents that Turkana West sub-county had 13 boreholes, 35 water pans, three rock catchments, 87 shallow wells and 3 springs. JICA further studied the water supply in Turkana County, and the report for Turkana West sub-county has been summarized in Table 4-23.

Water points in the rural area are mainly managed by the community through a water management committee. These committees are supported by the Turkana County Government as they lack the capacity to effectively manage the water points. Major repairs on the water points are carried out the county government. Due to inadequate capacity on the management of the water points, the services are usually unreliable.

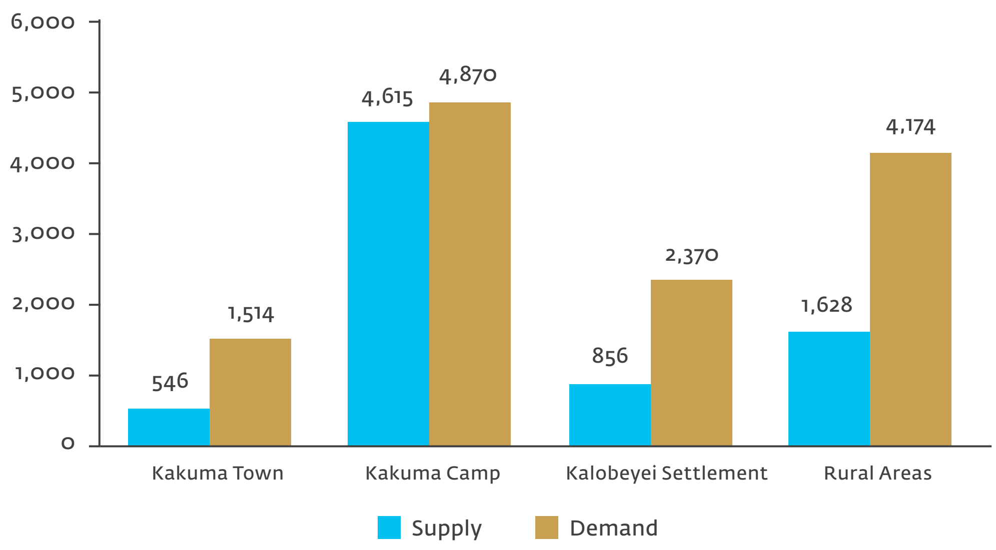
Table 4-23: Present condition of water resources in Turkana West sub-county

Sub-Location	Sources of Water	Water Quality	Remarks
Lokichoggio	5 boreholes located along Nanam lagga bank 2 boreholes supplying Lokichoggio town	Generally good	
Lokariwon sub-location	No developed water supply		A pan that was constructed by GoK is not functional due to poor design
Nanam sub-location	Shallow wells along Nanam Lagga	Contaminated	There were 4 dry boreholes and one non-operation borehole with an estimated yield of 0.6m³/hr Residents depend on scoop holes
Oropoi sub-location	Three boreholes	Generally good	High demand for livestock water, therefore domestic water is only collected at night
Kalobeyei sub-location	One borehole Two functional shallow wells and 3 non-functional shallow wells	Generally good for human consumption	Borehole water is adequate to meet domestic water demand
Loreng sub-location	1 dry borehole 1 dry hand dug well	Generally poor water quality	
Nadapal sub-location/ Kakuma	Several boreholes and shallow wells	Generally good but the quality deteriorates in the dry season	There is a decline in yield during the dry season

53 JICA (2015): Water Potential Study in Turkana County, Annex E.

The draft Water Supply and Sanitation Masterplan has analyzed the current water supply against water demand for Kakuma town, Kakuma camp and Kalobeyei settlement. For the rural area, an assumption has been made based on the records that the rural water supply service level is at about 31%. The current water supply and demand in Turkana West sub-county is, therefore, as presented in Figure 4-1.

Figure 4-1: Current water supply vs water demand in Turkana West sub-county



4.3.4 Proposed water supply development plans

Efforts are currently being made to order to address challenges associated with supply as follows:

A. Kakuma town supply

The following are currently being undertaken by the key stakeholders:

- Hydraulic modelling for Kakuma town water supply;
- Drilling and equipping 2 No. new boreholes to boost production;
- Solarization of 3 No. boreholes (2 No. new boreholes and 1 No. rehabilitated (broken down windmill -BH5 or capped borehole at Nakwangat);
- Construction of 3 No. new steel elevated tanks each of capacity of 200 m^3;
- Construction of 1 No. masonry tank reservoir;
- Overhaul/Rehabilitation of 14 km pipeline extension for rising main and distribution network for Kakuma water supply;
- Construction of six smart water kiosks within Kakuma town;
- Establishment of Kakuma Water Company in line with County water and national government legislation with the engagement of third-party partner for capacity building of the company.

The interventions are expected to improve the service delivery and meet the current domestic water demand in Kakuma town.

Under the ISUDP programme, the proposed water projects are tabulated below:

Sector	Project	Estimated Cost (Kshs)	Time-Frame	Implementers	Remarks
INFRASTRUCTURE					
Water Supply	Additional boreholes (5No.) & water reticulation	25 million (@Ksh. 5m)	Short Term	TCG & WARMA	
	New sand dams (10 No.) & pumping/ equipment &reticulation	100 million (@Ksh.10m)	Medium Term	TCG & Relevant Sewerage & Water Co.	
	Construction of a dam on the Tarach Lagga	5 billion	Long Term		
Water Tanks	Provision of storage water 20 No. (50 m³ each)	200 million	Short Term		
Water Treatment Plants	Provision of safe potable water	500 million	Medium Term		Centralized
Sanitation	Sewerage Treatment System	500 million 32,000 m³/ day	Medium Term		Along R. Tarach Low-rate, anaerobic treatment
	Dumpsite	25 million	Short Term	TCG	

Source: TCADP 2020

B. Kakuma camp and Kalobeyei settlement

The following actions aim at addressing the challenges related to the water supply to Kakuma camp and Kalobeyei settlement:

- Drilling and equipping of 3 No. new boreholes in Kakuma camp;
- Solarization of three drilled boreholes to reduce pumping costs;
- 8 km Pipeline extension to overhaul existing and integration to new supply within Kakuma camp;
- Construction of 6 No. new pump houses at the Kakuma camp;
- Rehabilitate and repaint 4 No. leaking steel elevated tanks at Kakuma camp;
- Repair and rehabilitation of 50 tap stands at Kakuma camp;
- Water quality/aquifer monitoring;
- Hydraulic modelling of Kakuma camp water supply;
- Rehabilitation (Solarization) of Kalobeyei borehole for Kangura village supply and connection to Kalobeyei settlement;
- 15,200m pipeline extension to 80 units (1120 households for both refugees and host population within the settlement);

- Installation of 4No. 100m³ steel elevated tanks at Kalobeyei settlement;
- Installation of 80-yard taps at Kalobeyei settlement.

C. Rural host community

In order to address the water supply gap within the host community in Turkana West sub-county, the following activities are currently being undertaken:

Kalobeyei/Kangura water supply:

- Rehabilitation (Solarization) of Kalobeyei borehole for Kangura village supply;
- 3 km HDPE PN12 pipeline extension to Kangura village;
- Installation of 108 CM steel elevated tank;
- Construction of 2N water kiosk with 5 CM overhead tank;
- Construction of 2 No. standard cattle troughs.

Lokichoggio town water supply:

- Hydraulic modelling of Lokichoggio town supply;
- Rehabilitation of 3 boreholes (Akoros I, Epool and ICRC) and solarization;
- 7.5 km pipeline extension for rising main and distribution network;
- Construction of 4 No. water kiosks with 5 m³ overhead tanks;
- Installation of 2 No. 50 m³ Steel elevated tanks;
- Rehabilitation of 4 No. boreholes and equipped with hand pumps;
- Construction of aprons with animal troughs in the grazing zones of Lochoreamoni, Natumamon I, Natumamon II and Iria.

Lopur Ward:

- Drilling and equipping of Lopuski borehole and equipping with the solar system;
- Installation of 48 m³ steel elevated tank;
- 7000 m pipeline extension;
- Construction of 2 No. water kiosks and construction of 2 No. animal troughs;
- Rehabilitation of 8 shallow wells - equipping with hand pumps;
- Construction of aprons for domestic and small-scale agriculture water supply.

Songot Ward:

- Napeikar borehole improvement/rehabilitation;
- 8 km pipeline extension from Napeikar borehole to Nakururum (village, school and dispensary): Installation of 48 m³ steel elevated tank,
- Construction of 2 No. standard water kiosks installed with 5 m³ overhead tanks,
- Construction of school and dispensary tap stands,
- Installation of plastic storage tanks of 10 m³ for the two institutions;

- Construction of 2 No. animal troughs;
- Equipping of Lomonyenakirionok or Nakulumei capped borehole (1 No. targeted after preliminary tests) with solar pumping system;
- 5km pipeline extension;
- Installation of steel elevated tank of 54 m^3 capacity;
- Construction of 2 No. water kiosks with overhead storage of 5 m^3;
- Construction of 2 No. animal troughs.

4.3.5 Sanitation

Although sanitation is not among the primary topics of this study, proper measurements to ensure that sanitation is well-established has a direct impact on the water availability, especially in those circumstances where drinking water is obtained from surface water or shallow wells. Currently, there is no sewer system in Kakuma town. It is reported in the draft Water Supply and Sanitation Masterplan that about 65% of the population in Kakuma town practice open defecation. It is also reported that about 16.3% use pit latrines, mostly unlined. Use of unlined latrines and open defecation in the area is now becoming a major concern as the high level of e-coli have been observed in shallow wells/scoop holes; and even boreholes in the area especially during the rainy season. This shows the importance of addressing the sanitation as part of the overall improvement of the provision of drinking water in the region of study. Further details are given in Volume 2, chapter 2.7.

5 Context Analysis – Social and Legal Context

The first Project Goal, reproduced below, is achieved by five Activities:

Goal 1 – Context analysis (present situation)

Determine the overall circumstances for agribusiness development in the Kakuma / Kalobeyei region in terms of water availability and social/legal situation

- Water availability
- Water storage
- Water demand
- Water balance
- **Social and legal context**

In this Chapter, the last activity is discussed: the social and legal context. This provides the social and legal environment that any potential agribusiness development should take into account.

5.1 Social Context

Goal: Assess the social and legal context of possible new agribusiness

5.1.1 Study methodology

Desk review was the main methodology through which data relevant to the feasibility study was gathered. For data gaps identified in addressing the key study questions, qualitative data was elicited through the application of key informant interviews. Key informants (community members and development organizations) identified at the desk review phase were contacted either by phone or email and informed about the objective of the study. Further, in the wake of the Covid-19 pandemic (year 2020) and the resultant social distancing and the travel restrictions imposed by the government, the potential respondents were explained to why "one on one" interviews were not possible.

A structured checklist (guiding questions) was prepared to target different respondents. The interviews were conducted via phone and by sharing the checklist with the respondents in case email addresses were available. The latter was for those who could handle the checklist in terms of time availability and comprehension of the issues sought. A major limitation occurred when no response was forthcoming even after showing interest in the study and a willingness to participate. As shown in Volume 2, Chapter 2.8 (Annex 1), the targeted respondents from Sanivation and Action Africa Help International (AAH-I) were not responsive, even after several attempts were made to have the checklist returned. Nevertheless, the information sought from them was addressed through responses received from other stakeholders.

5.1.2 Social context

5.1.2.1 General socio-economic characteristics of the refugees and host communities

Local livelihoods are turning diversified with the rise of small urban centers such as Kakuma town. However, over 40% of the population in the Sub County practice nomadic pastoralism. This means that pastoralism is a key livelihood of the population, and water for the livestock an important issue. Therefore, nomadic pastoralism takes a major part of the water demand alongside other associated activities such as fodder production. The latter integrates water conservation measures for an adaptation to climate change.

Farmers are the largest component of the county population, and they remain vulnerable to natural disasters. This fact poses a significant social and economic challenge. Severe drought strikes the area approximately every three to five years, causing significant losses.

Such devastating disasters push already vulnerable pastoralists and agro-pastoralists into poverty and push the already poor into destitution. In this line, poverty rates in Turkana are extreme, with more than 79% of people living in poverty (World Bank, 2019). Turkana County alone accounts for close to 15% of the extreme poor in Kenya, and it also ranks highest in terms of food poverty, with 66% being food insecure. In Turkana West Sub County, 84% of the population lives below the poverty line (World Bank, 2018). Against this background, it would be imperative that the project and other players in water development develop a dynamic water use plan. Such a plan should strategically ensure that the water available meets domestic and water for the livestock needs as well as for commercialization of the groundnut farming.

Frequent disasters associated with drought and poor preventive and preparedness initiatives at community level notwithstanding, the presence of the refugee camp has emerged as an important source of income for the host community (World Bank, 2019). In Turkana, host community members sell firewood or charcoal to refugees, they work in the refugee camps as construction workers, domestic servants, security guards, livestock producers/sellers, and some also staff refugee businesses. Agriculture seems to play a more limited role due to the arid climate, scarcity of water, and poor soil quality, with a small number of households farming millet, maize, sorghum, and legumes. This practice underlines the need for the intensification of hydroponics and vertical farming technologies for reduced water demand.

The presence of refugees has created a demand for agricultural products. Numerous studies have highlighted that the livelihood options for refugees are closely intertwined with co-existence and relationships with the host communities. The priority sectors outlined in the current Turkana CIDP (2018-2022), including energy, water, and agriculture, highlight key linkages with the refugee economy for potential integration through sectoral priorities. Therefore, agriculture presents an opportunity to improve both refugees and host communities' livelihood. However, according to the Turkana CIDP II (2018-2022), agricultural production is mainly at the subsistence level with limited commercial production. Only about 30% of the County's soil is suitable for crop production, and farming is mainly practiced through irrigation along the Turkwel and Kerio Rivers, and through rainfed production around Kakuma and Lokichoggio. This underlines the importance of this present project on the possible development of agribusiness.

5.1.2.2 Water source, use and sanitation

In relation to water resources, Turkana West Sub County is a water scarce area. Only about 16 to 17% of the households accessed water from boreholes, which are considered to be safe sources (KDRDIP, 2020; KIHBS, 2016). Information from the Sub County Water office shows that there a total of 132 boreholes, 50 water pans/ dams and 2 natural springs in the sub-county. While these water points are reliable during the wet season, water availability worsens during the dry spell with drying of water pans while a number of boreholes also get dry. The distance to water sources ranges from 0.1 to 8 km. The estimated water demand for domestic is about 9,000 m^3 per day while that for livestock is about 15,000 m^3 per day (see Table 4-13). The estimated yield from boreholes stands at 5,112 m^3 per day, while that from water pans and the natural springs is unknown. Currently, the following projects are being implemented:

Table 5-1: Water projects under implementation

Project name & location	Implementing partners	Status
Development of Lotikipi aquifer	RVWSB, TCG, UNHCR	On-going
Construction of Tarach dam	KRCS, TCG, UNHCR	On-going
Development of Lorus Borehole	World Vision	On-going

Source: Turkana West Sub County data, 2020

Kakuma town and the immediate peripheral areas are served by Kakuma Town Water Supply Company under the County Government. Formerly, Kakuma Water and Sewerage Company had close working relationships with Oxfam who strengthened it to grow from a small water user association to a mid-level water company. The water company was handed over to the county government as per the provisions of the Water Bill 2019. Oxfam is currently assisting in drilling three boreholes and in the rehabilitation of the water supply distribution lines within Kakuma town. Urban residents and the business communities are connected to the supply system and water meters installed. Households drawing their water from the public kiosks are charged 20/= per 20-liter jerrican. In the refugee camps, water is sourced from boreholes which are solar-powered.

Some of the rural areas get their water from boreholes or hand pump. Communal points/ kiosks have been put up where pastoralists pay 5/= for a 20-liter jerrican. The cost may rise to between 10 and 30/= depending on the locality from the communal water point due to transport-related costs usually by use of donkeys. Most of the rural community members resort to accessing their water from alternative water points, mainly from laggas rather than paying the set amount. The concept of **water for sale** is yet to be embraced especially among the rural communities. Still, there is need to integrate the capacity building in KAPs (Knowledge, Attitude and Practices) for the rural community to establish the willingness to pay for water considering the need for financial sustainability and hygiene.

The water from these laggas is unsafe, as the water is not only muddy, but also contaminated. Laggas are also used as human waste disposal points (latrines) by the communities. Environmental considerations need to be taken into account in the development of the water infrastructure. Information from the Sub County office shows that latrine coverage is about 20% in the sub-county. Interviews held with community members affirmed the poor latrine coverage situation. For instance, interviews with the representatives of Nanam Youth Group showed that there were no latrines in the community area apart from the ones at the local health center.

The poor sanitation conditions in the study area were affirmed by Mr. Alfred Kapoko, a former MCA who noted that "*around trading centers, the toilet coverage was about 10%, but in the rural there were none*". World Health Organization and UNICEF's Joint Monitoring Program (JMP) have defined standards for "improved sanitation". Latrines and toilets are not considered "improved" when they are public or shared between by two or more households. The JMP standard on "improved sanitation" is the official standard used for monitoring progress towards having access to sanitation. The Ministry has launched a total sanitation community-led strategy, focusing on behavioural change to empower community for making make villages free of open defecation. Nevertheless, the disposal of solid waste remains to be a challenge in the area.

The rural community members interviewed stated that they are not charged for livestock water use. During extreme drought periods, communities migrate towards the hills of Tarach in Oropoi division and behinds the hills of Lokore in Kakuma division to search the water for the livestock. The population in Lokore is especially adversely affected by the scarcity of water, and many have migrated to areas like Kakuma town and Tarach to settle. Table 5-2 presents water sources for domestic and water for the livestock in the project area, whereas Volume 2, Chapter 4.3 presents water points in Turkana West.

Table 5-2: Main sources of household water for domestic and livestock uses

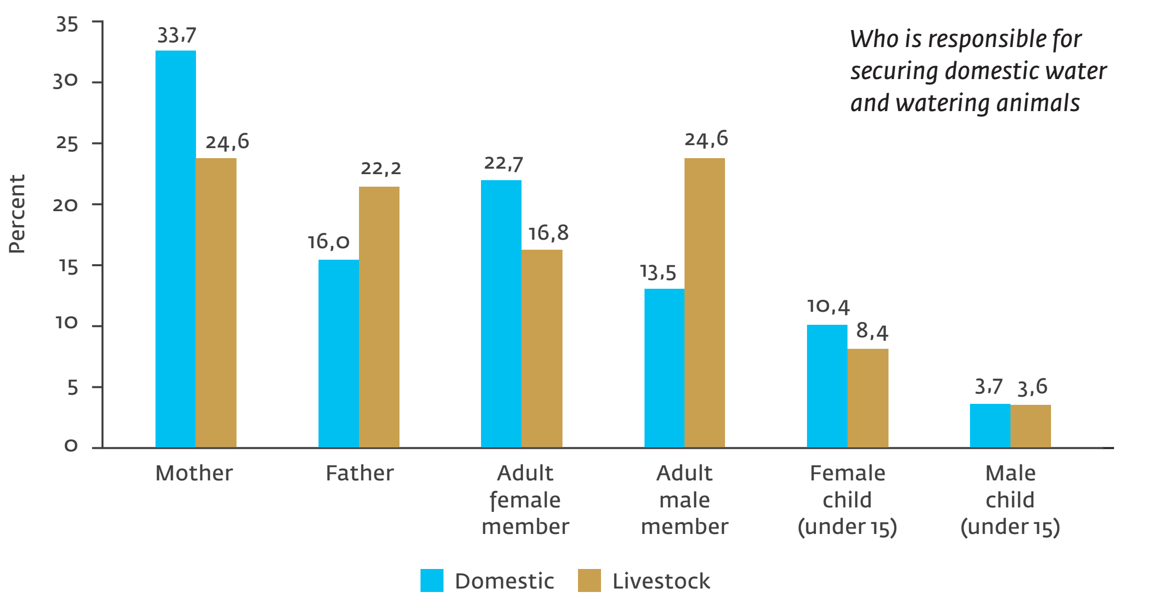
Water Sources	Domestic	Livestock
Borehole	16%	20%
River / Lagga/ Sand dam	32%	50%
Piped into public tap outside compound	27%	6%
Well	5%	6%
Tanker/ trucker	9%	2%
Piped into compound/yard	2%	1%
Piped water into dwelling	3%	0
Water pan	4%	7%
Rainwater	0	3%
Open/ unprotected spring	0%	3%
Other Sources	0	2%
No response	2%	0
	100%	100%

Data Source: Modified from KDRDIP Baseline Survey, 2020

The 27% household respondents who indicated to have piped water accessed at a public tap belong to communities in the urban centers along the tarmac road Songot, Kakuma and Kalobeyei, the Kakuma refugee camp and the Kalobeyei settlement.

On the division of labour related to household water, women are more (66.9%) involved in securing water for domestic use as compared to their male counterparts (33.1%). On watering of the animals, there exists a very thin difference as men account for 50.3% (fathers, adult male and male children), whereas women represent 49.7% (mothers, adult female and female children) as illustrated in Figure 5-1.

Figure 5-1: Division of water related labour by gender



Data Source: Extract from KDRDIP Database, 2020

5.1.2.3 Management of the water infrastructure

Water infrastructure (i.e. boreholes, wells and pans) are essentially managed by community groups and/ or associations commonly known as 'Water Users Associations" some of which are inactive. The water users' associations have 9 to 15 committee members, the majority of whom are men (2/3). Most of the water user associations are weak, as those interviewed indicated to have received minimal or no training in management, and most have no technical know-how on water infrastructure repairs. As such, the O&M work is mostly done by the County water department or partner organizations, like Oxfam.

This presents a big challenge limiting the optimal realization of benefits from the existing water supplies. UNHCR and partner agencies are piloting a model that seeks to improve the efficiency of the water supply. An example is an initiative by Oxfam in partnership with LeFil Consulting Company, which together seek to contribute to a paradigm shift on how rural water infrastructure is installed, managed and paid for in Kakuma West Sub County. The concept revolves around bundling a number of rural water schemes in a region, contracting a private operator to perform their O&M, and instituting a dedicated public fund to pay for O&M expenses.

5.1.3 Livestock and crop production in the project area

5.1.3.1 Livestock production

Livestock keeping is the mainstay of the community members in the project area, accounting for 70%, while agro-pastoralism represents 22% of the area population. Livestock production is purely nomadic or semi-nomadic. In a few pockets of highlands and riverine areas scattered over the project areas, agro-pastoralism is increasingly being practiced as a strategy to avert pastoral related risks. Livestock kept include cattle, goat, sheep, camels, donkeys and poultry (mainly chicken).

Most of the breeds are indigenous but are a few dairy goats (Toggenberg), Galla goats and dorper rams. KDRDIP (2020) observed that although livestock played a central role in people's livelihoods, the current livestock population trend showed a decrease in livestock holding as a result of frequent loss associated with drought. According to the study, 68% of the households earned on average about Kshs 73,154 and Kshs 30,470 annually during normal and drought periods from livestock production.

5.1.3.2 Crop production and other non-traditional livelihood activities in the project area

Crop farming in the project area is limited by several factors ranging from very unreliable rainfall to infertile and shallow soils, from inappropriate planting materials to poor farming methods, to mention but just a few. Severe and frequent drought episode strikes the area rendering rainfed agriculture a high-risk enterprise if no irrigation is done. Subsistence farming of mixed crop mainly consisting of sorghum, millet, maize, beans, and potatoes is being tried through rainfed. According to the sub-county office, the following areas have the potential for crop production:

- Kakolonyo-very productive area;
- Nasinyoro-high potential for expansion;
- Nanomtor Koyar- fertile soils with a high potential for beans and maize farming;
- Lokipotom and Namoton, high potential;
- Nanam Lokipiki- plain area with floods from Tarach Lagga;
- Lomidat (65 acres just opened by County Government are doing well);
- Lokiririet in Lokirchogio - Songot, Lokichogio, Nanum wards;
- Lokangai, maize production-High yielding boreholes in high potential areas.

Table 5-3 shows crop farming details of Turkana West. Farmers are organized into 74 farmer groups made up of 11,459 farmers. They are already working with partners (Turkana County Government, FAO, WFP, KRCS, GIZ, LWF, Juanita-AICHM, AAH-I, DRC, LOKADO, TADO, USAID-ADF and JICA) to commercialize crop production.

Table 5-3: Crop farming details in Turkana West sub-county

	WARD	No. of Farm sites	Approx. Area (Ha)	Total No. of farmers	Male farmers	Female farmers	Main crops and Water source
1	Kakuma	27	1,976	3,990	933	3,057	Sorghum, Green grams, Cow peas (***rain-fed***); Kales, Spinach, Okra, Amaranth, Tomatoes (***Borehole & drip irrigation***)
2	Songot	11	446	1,522	372	1,150	Sorghum (***rain-fed***); Maize, Kales, Cowpeas, Watermelon (***flood based***)
3	Letea	11	727	1,431	371	1,060	Sorghum, maize, watermelon (***rain-fed & drip irrigation***)
4	Lopur	4	260	483	87	396	Sorghum, maize (***rain-fed***)
5	Nanam	3	219	545	97	448	Sorghum (***rain-fed***); Kales, Spinach, Tomatoes (***Borehole & drip irrigation***)
6	Lokichogio	7	572	1,409	291	1,118	Sorghum, maize (***rain-fed***)
7	Kalobeyei	10	660	1,279	198	1,081	Sorghum, maize, Cow peas (***rain-fed & borehole drip irrigation***)
	Kalobeyei Settlement	1	180	800	124	676	Sorghum, Cow peas (***rain-fed***)
	Total	**74**	**5,040**	**11,459**	**2,473**	**8,986**	

Data Source: Turkana County's Department of Agriculture, 2019

Interview with the Sub County Agricultural Officer indicated that women constitute 70% of the population engaged in farming activities. Only a few youths participated in agricultural activities due to exposure to trading with refugees. This corroborates the findings by the KDRDIP (2020) that showed that women accounted for 72% of the population engaging in farming activities.

5.1.3.3 Irrigated agriculture

Rainfed farming is the most practiced form of agriculture in the area, but there exists irrigated agriculture in scattered pockets of land along riverine and flood zones, where high-value crops, including horticultural crops (kales, tomatoes, spinach, okra and cowpeas) and fruit trees are grown. Spate (flood) irrigation is mainly practiced in the Lokipiti plains which are fed by Tarach Lagga. According to the department of agriculture, close 500 acres are currently irrigated using different irrigation technologies, namely:

- Drip irrigation (in Kalobeyei, 7.5 acres; and Kakuma, 20 acres);
- Shade nets measuring 8 * 15 meters (GIZ, 2; LWF, 4; and Worldvision, 4);
- Spate irrigation 465 acres (Lomidat, 165 acres; and Nasinyno, 300 acres).

Insta Products and other partners (FAO, Egerton University, and local community among others) had undertaken a trial in Kalobeyei, Natiira and Nanyee (an irrigation scheme along the Turkwel river, with the Turkana Community, in Loima Sub County). The trial was guided into testing the adaptability of a number of groundnuts varieties from Egerton University. Egerton University, a leading institution in the country pertaining to Agricultural researches and development of new seed varieties, were brought on board by Food and Agricultural Organization (FAO). Insta was directly involved in the collection of data, evaluation and monitoring of the trial project. Among other objectives was the need to find out how different varieties perform in the few selected sites and whether a form of agricultural practice like intercropping would work and to establish the aflatoxin levels.

One of the findings was that rain-fed farming in this part of Turkana is highly unreliable without supplemental irrigation. The idea of utilizing underground water for irrigation was challenging as borehole water was found to compete with other water needs and were serving as the only source of drinking in both Kakuma and Kalobeyei. Additionally, taking into account the geological conditions of the area and the associated impacts, drilling of boreholes was not sustainable combined with the salinity level of water, it was not highly recommendable to turn to underground production.

According to Insta's experience, water pans have recently proven to hold a greater potential success in reserving water for Irrigation. This is after a massive project funded by the World Food Programme (WFP) registered impressive success and has provided water to irrigate small vegetable plots in Kalobeyei. Water pans, therefore, can be ideal sources of water for irrigation.

Further findings showed that spate irrigation is another possibility to irrigate some farms in Kalobeyei, next to village 2, an area set aside for farming. It can be done by directing floodwater into the farms. This would be an ideal way of reserving water pans water during the rainy season. Drip irrigation would be a comparatively better option to start with as other forms of irrigation like spate, and trapezoidal irrigation are tested.

Within the refugee camps, an NGO Action Africa Help International (AAH-I) with the support of UNHCR, UKAID, NRC, DRC, FA, WFP and FAO are working with the communities on agribusiness development and linkages to microfinance and agriculture for food production. So far, there are proposals for the implementation of several agricultural activities in Kakuma, Kalobeyei and Pokotom. Also, they have established a 3-acre demonstration farm and have assisted in the establishment of kitchen gardens. A capacity-building strategy for farmer organizations has been developed through which two vegetable host community farmer groups have been identified for support to sell vegetables with Kalobeyei and Kakuma traders.

The potential for large irrigation schemes exists as the communities are slowly adapting sedentary lifestyles and are more receptive to the concept of agriculture. Despite the interest demonstrated by the communities towards expanding agricultural livelihoods for refugees and host communities alike, inadequate water to support irrigated farming and livestock use is a major limitation. Hydroponic farming and vertical works are emerging technology being promoted to intensify agricultural production and water conservation. Large-scale investment in water supply has been identified as an important pathway to enhance refugee self-reliance (UNHCR, 2019).

5.1.3.4 Non-traditional livelihood activities

Other non-traditional livelihood activities include trading of natural resources (i.e. building materials), casual labour, sale of charcoal, small scale businesses, fish and honey trade.

5.1.4 Rangeland resource use and land ownership dynamics

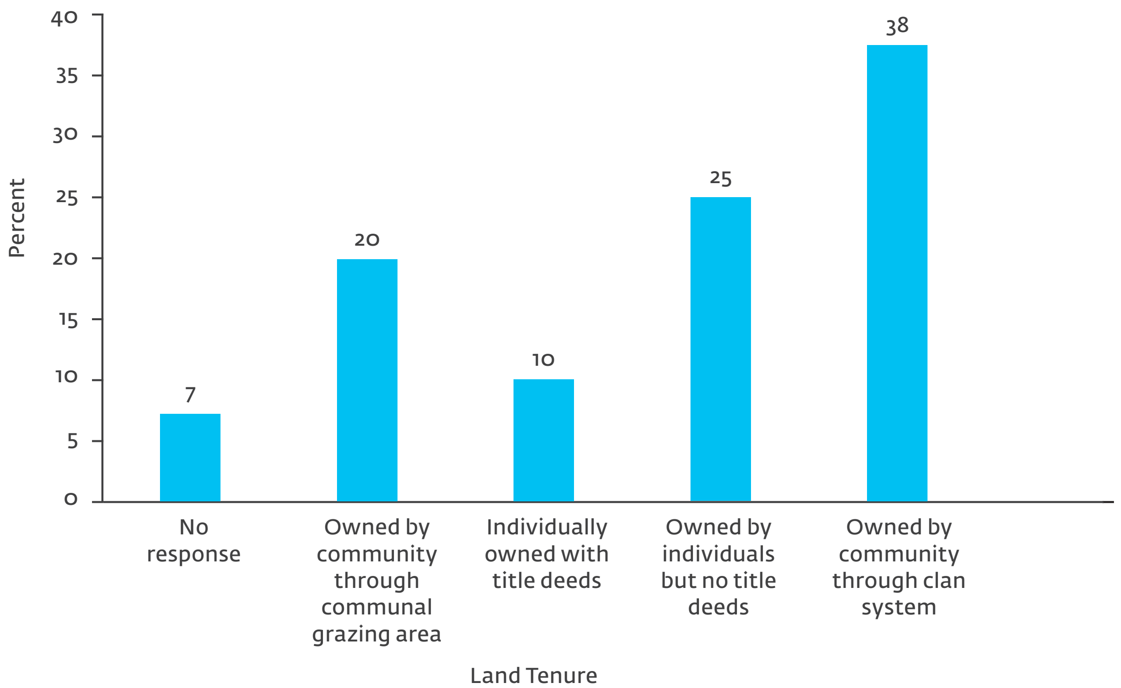
The land is a key resource supporting primary production of the pastoralist. Over the years, the management of the rangeland resources within the study area has faced great challenges posed by overgrazing, rangeland degradation and shortages in rangeland resources due to unsustainable utilization. This study established that the management of pasture resources through zoning of the pastureland into dry and wet grazing areas, which had been introduced through the Kenya Livestock Grazing Programme in mid 1970s, collapsed when the programme came to a closure early in 1990s.

The ASAL programme that followed was to build on the initial success of this programme. To achieve the grazing zonation, the programme had embarked on the installation of supportive infrastructure for livestock production in the rangeland. It includes the construction of boreholes and dams to sustain livestock during the dry seasons. The management of seasonal grazing was regulated by Block Grazing Committees who invoked the Chief's Act to enforce the regulations.

This contributed to weakening the traditional grazing control system which is blamed for the deterioration of pasture and natural vegetation (both in quality and quantity). In reality the change in rangeland management structures has been coupled with periodic droughts, excessive soil erosion due to floods and overgrazing. All these factors have continued to negatively affect the quantity and quality of the pastures available in the project area.

The land in the project area is essentially rangeland supporting livestock production with limited irrigated farming using underground and/or flood water. Land tenure is mainly communally owned through the clan system, although some respondent indicated they have individualized ownership rights. The claim of individual land ownership with or without title was attributed to the on-going county intention to issue pastoralists with letters of ownership. Figure 5-2 presents information from respondents.

Figure 5-2: Land tenure system



Data Source: Extract from KDRDIP Database, 2020

According to the Kenyan Constitution, any unregistered community land shall be held in trust by county governments on behalf of the communities for which it is held. The Community Land Act, 2016 gives effect to article 63 (5) of the Constitution in order to provide for the recognition, protection and registration of community land rights; management and administration of community land and to provide for the role of county governments in relation to unregistered community land and for connected purposes.

From the stakeholder analysis described above, it has become clear that *in case a new agribusiness needs to be established, it would be imperative for the project to have open discussions with key stakeholders, including the host community, refugees and the county government*, due to the attachment that the community has to the land resources. This would go a long way towards managing any disenchantment that may arise among the parties early enough at the outset of the project.

5.2 Legal Context

In this paragraph, a brief summary of the salient points is presented. Chapter 4.1 in Volume 2 provides a more detailed description of the legislative context for agribusiness development in Turkana West sub-county.

5.2.1 Constitution of Kenya

The Constitution of Kenya provides for the establishment of Turkana County as a devolved unit and creates its governing structure in the County Executive and County Assembly.

The Fourth Schedule sets out the distinct functions of the national government and those of the county governments. In part 1 of the Fourth Schedule, the national government is responsible for the protection of the environment and natural resources with a view to establishing a durable and sustainable system of development, which includes, in particular:

(a) Fishing, hunting and gathering;

(b) Protection of animals and wildlife;

(c) Water protection, securing sufficient residual water, hydraulic engineering and the safety of dams; and

(d) Energy policy.

As per Part 2 of the Fourth Schedule, the functions of county governments include:

(i) Agriculture including crop and animal husbandry;

(ii) County public works including water supply and sanitation services;

(iii) Implementation of specific national government policies on soil and water conservation;

(iv) Ensuring and coordinating community participation in governance at the local level.

The constitution requires government at each level, and different county governments to cooperate in the performance of functions and exercise of powers, and for that purpose, to set up joint committees or joint authorities.[54] This provision is pertinent to this task which requires a comprehensive analysis of the current water situation in Kakuma area and provides practical recommendations and actionable steps on how to navigate legal and regulatory environments for commercial water access.

Article 43 provides a human right to clean drinking water in adequate quantities to all persons in Kenya. This right is extended to refugees as it is not limited to citizens. This applies to the human right to reasonable standards of sanitation. It is important to note that these rights create a concurrent duty of fulfilment on both the national government and the Turkana County Government.

5.2.2 Water Act, No.43 of 2016

The Water Act 2016 regulates water resources management; water harvesting and storage; and water supply and sanitation services. The Act recognizes that water-related functions are a shared responsibility between the national government and the county government. Hence, the Act defines roles and responsibilities for the management, development and regulation of water resources and water services in the country.

54 Constitution of Kenya, article 189.

Water resources regulation and management

The mandate for water resources regulation is vested in the WRA, which is responsible for various functions, including determining water allocation criteria, issuing water permits, collection of charges for permits, data and water use, collection of hydrological data, and flood management. Water permits are required for abstraction, water storage structures, drainage of wetlands and effluent discharge, whether from ground or surface water sources. The process of obtaining a water permit is set out in the Water Resources Management Regulations (2007) and involves public consultation, payment of fees, and proof of legal access to the land on which the water infrastructure is to be developed. Water use charges, currently set at Ksh 0.75/m^3 for water for irrigation, must be paid to WRA. The Act also provides for the establishment and participation of Water Resources User Associations (WRUAs) in the management of the water resources.

The Water Act and the Water Resources Management Regulations (2007) set out the priority for water allocation; the Reserve will encompass water for environmental purposes and basic requirements for downstream users; domestic water has priority over other forms of water use, namely livestock, agriculture or industry.

Water harvesting and storage

The Water Act establishes the National Water Harvesting and Storage Authority (NWHSA), which succeeded the former National Water Conservation and Pipeline Corporation. The NWSHA is responsible for developing infrastructure, mainly dams, for water harvesting and storage for the national government. It is also responsible for developing the capacity to provide water during drought emergencies across Kenya.

This mandate does not, however, preclude county governments, the county water service provider, or private and community entities from developing water infrastructure, such as dams or boreholes, for water harvesting and storage, including rainwater harvesting. This means that the county government can invest in water harvesting and storage structures.

Water services and sanitation

The Water Act upholds the constitutional provisions that vest water and sanitation services on county governments, with the exception of the setting and regulation of service standards and tariffs. These functions are undertaken by the Water Services Regulatory Board (WASREB) as part of the national government obligation for consumer protection.

The Water Act allows each county government to establish county water service provider(s) (WSP), either as a limited liability company or through another legal form, with approval of WASREB to provide potable water. These county WSPs are licensed and regulated by WASREB, which also approves the tariffs, and issues licences that set standards of key service delivery indicators.

A county WSP may develop water sources (river intakes, boreholes, treatment plants) directly or it can obtain bulk water from a provider licensed by WASREB. At present, most bulk water provision nationwide is undertaken by Water Works Development Agencies (WWDAs) established under the Water Act. For Turkana County, this is the North Rift WWDA established in February 2020 after the split of the Rift Valley WWDA into two agencies.

Domestic water supply services in areas currently not served by a WSP (e.g. rural areas) can be served by an individual, institution or community group which should operate under the sanction of the WSP. However, this is rarely the case for rural areas, and most water supplies in the rural areas are poorly regulated.

Water for livestock or irrigation does not fall under the same regulation as domestic water and can be developed by any entity, subject to obtaining a water use permit and complying with any other relevant legislation.

5.2.3 Irrigation Act 2019

Irrigation activities are regulated by the 2019 Irrigation Act. This law, at the county level, empowers the Turkana County Government to set up a county irrigation unit that would guide the development of publicly funded irrigation activities.

5.2.4 Environment Management and Co-ordination Act 1999

Environmental Management and Co-ordination Act (EMCA) Cap 387 is the principal act guiding environmental management in Kenya. It establishes the National Environment Management Authority (NEMA) to be the principal agency in the management and coordination of environmental considerations in regard to the development and use of natural resources. Part VI of the Act requires the undertaking of an Environmental Impact Assessment for projects described in the Second Schedule and as amended by Legal Notice 31 and 32 of 2019 to be submitted to NEMA for approval.

The risk category of a project, whether involving water abstraction, storage or agricultural development will determine the complexity and timeframe for the EIA process. The EIA process incorporates requirements for public consultation.

Effectively this means that any project involving water abstraction, boreholes and/or storage will need to comply with both the Water Act requirements for a permit and EMCA for an EIA license, prior to development.

As part of evaluating the potential environmental and social impacts, IFC commissioned the *Strategic Environmental and Social Assessment for the Kakuma Kalobeyei Challenge Fund* (IFC, 2020) which has reviewed the legal framework, baseline conditions and risk and mitigation measures for potential activities under the KKCF.

5.2.5 Land Act 2012, Land Registration Act 2012, Community Land Act 2016

The Community Land Act provides for the management of community land as well as promotes proper land-use practices, which uphold the unique nature of the community. As much of the land within the Kakuma-Kalobeyei area has not been demarcated for private ownership and remains as community land, any agricultural development will need to seek authority from the county government and the local community.

Consultations with the Turkana County Government (Director, Physical Planning) indicated two approaches to enable a private commercial entity to be able to lease land for a specified period, namely:

1. A private investor makes a proposal to the County Government, which after obtaining approval from CEC Lands and CEC Agriculture, would engage the community to obtain community consent;
2. A private investor negotiates and secures community willingness to release land for commercial enterprise and subsequently seeks County Government approval.

In either approach, the social, economic and environmental benefits to the community must be clearly set out, and commitments agreed.

There are currently no examples of private investors obtaining land leases in Turkana West although there are examples from other parts of Turkana County, notably in Katilu along the Turkwel lagga.

5.2.6 Turkana County Water Act 2019

The Turkana County Water Act entry into force in May 2019. It is intended to:

- Govern water supply and sanitation services;
- Regulate water use rights;
- Coordinate stakeholders;

- Promote public participation;
- Govern the management of public-private partnerships;
- Coordinate waterworks development.

Importantly the county law recognizes the right of every person to clean and safe water in adequate quantities, and reasonable standards of sanitation. The Act provides for the priority of water use rights in the county, giving livestock water a higher priority than irrigation water, reflecting the importance of livestock production for livelihoods in Turkana County.

The county water law gives power to the county government to allow the establishment of private water service providers, and to issue them with permits and provides a framework for community-owned water operators to manage and operate rural water facilities under permit.

The Act also provides for public-private partnerships, enabling the county-owned WSP or the department responsible for water to enter into partnerships with any person for the development and maintenance of waterworks, in accordance with the procedure stipulated by the 2013 Public-Private Partnerships (PPP) Act. This law requires either the relevant department at the national level or county to prepare a proposal and feasibility report, for approval by the PPP Unit at the National Treasury.

Where a county government proposes a PPP investment and the investor requires a sovereign guarantee, article 212 of the Constitution requires the consent of the national government, which is through the National Treasury together with the approval of the county assembly.

6 Room for Development

Goal 2 – Room for development

Determine the room for development for agribusiness in the region, with emphasis on groundnuts

- Agribusiness
- Enhanced water availability
- Water storage potential

Goal: Determine the unit crop water demand for various crop types, among which groundnuts and the expected total water demand for the introduction of new agribusiness.

6.1 Agribusiness

This section reviews the business sector encompassing farming and farming-related commercial activities. Agribusiness involves all the steps required to send an agricultural product to market, including production, processing and distribution.

6.1.1 Crop production

Due to the ASAL nature of Turkana County, conventional farming methods based on rainfed agriculture has led to frequent crop failures or low production. This led to the introduction of dryland agriculture and various methods of irrigation including spate irrigation, drip irrigation, furrow irrigation and even bucket irrigation. Several stakeholders have supported crop production-related activities in the area, and they include Turkana County Government, WFP, FAO, AAH-I, LWF, GIZ, World Vision, AIC Health Ministries and AMREF. Different methods and technologies for crop production have been adopted, and a brief summary is presented below.

A. Dryland agriculture

Agencies that have promoted dryland agriculture in Turkana West include the WFP, Turkana Rehabilitation Program (TRP), Turkana County Government, NDMA and various local and international NGOs. WFP and TCG, using a Food for Asset (FFA) approach, have implemented 4,800 hectares under dryland agriculture in several parts of Turkana West sub-county. The technologies applied included zai pits, sunken/raised beds and bunds. The scale of farming is mainly for subsistence/livelihood.

AAH-I financed by DANIDA has reclaimed 30 acres of land which has been put under dryland agriculture. The crops grown are sorghum and cowpeas. *Peace with Japan* is planning to support households in setting up kitchen gardens using zai pit technology.

In-situ soil water conservation can significantly improve the reliability and yield of cropping in ASAL areas. For example, MKKL (2016) indicates that in Laikipia smallholder agricultural returns can increase by a factor of 2 to 3 times where conservation agriculture is practiced.

B. Drip irrigation

Drip irrigation is gaining popularity in the region. Several organizations have been involved in establishing drip irrigation in Kakuma-Kalobeyei area.

Under KISEDP I, FAO (Technical Support), WFP (infrastructure development) and TCG (Extension Services) have implemented irrigation of 7.5 acres under drip irrigation in Kalobeyei area. The source of water is a water pan. Water is pumped to an elevated tank using solar power then distributed to the farms. Drip irrigation is done under shade nets. The drip irrigation technology met some challenges with the farmers as they were unfamiliar with this form of technology. It was recognized that additional training is required to familiarize the farmers with how to use drip irrigation technology.

Crops grown include kales, tomatoes, spinach, cowpeas and amaranth. Trials are being conducted on onions. The yield is about 5-6 tonnes per season, and the product is supplied to Kakuma town and Kakuma camp. There are plans to do an additional 7.5 acres upon completion of the second water pan. This is likely to be commissioned in December 2020.

AAHI has implemented 30 acres under a micro-irrigation project in Kakuma. The source of water is eight shallow wells equipped with hand pumps and one borehole. However, the borehole was decommissioned as it became an environmental hazard due to frequent flooding of the borehole site. Water from the handpumps is pumped to troughs from where the farmers use portable pumps to pump water to elevated tanks that serve the drip lines. Irrigation is done throughout the year, and crops grown are mainly vegetables (cowpeas, kales, spinach, amaranth, okra) for sale in Kakuma town and the refugee camp. When the borehole was operational, the total revenue per week from the 30-acre farm was Ksh 200,000/-. However, this has gone down to Ksh 70,000/- per week with the decommissioning of the borehole.

World Vision has supported several drip irrigation projects under shade nets within Turkana West sub-county. They have installed two units in Teremukus, 2 units in Nanam, two units in Lokichoggio town and are yet to install 2 units in Kangura in Kalobeyei Ward. A unit is composed of 8m x 15m shade nets and drip lines. Apart from Kangura where the water source is the Kangura dam, the rest are supplied with water from boreholes equipped with solar pumps.

Lutheran World Federation (LWF) has also supported drip irrigation in the area. In Lokangai, it has done three-shade nets under drip irrigation using water from a borehole. The borehole has good water quality (Kenya drinking water standards). In Lotikipi, LWF has implemented drip irrigation in open fields where they are irrigating vegetables on 5 acres using water from a borehole. The borehole is high yielding and has good water quality (Kenya drinking water standards). In Nakoyo, LWF has installed three shade nets with drip irrigation system. The total irrigated area in Nakoyo is one acre of which part of it is irrigated by bucket system. A shade net is 8 m by 15 m. LWF is also planning to 3 shade nets in Agis, Kakuma and has set aside 1 acre of land for drip irrigation. However, the borehole has high salinity. LWF procures the shade nets and drip irrigation units from Nairobi.

There are plans by the TCG to develop 12.5 acres in Lokiririet in Lokichoggio, where the source of water will be a borehole and irrigation will be by a drip system.

C. Bucket irrigation

Bucket irrigation projects have been supported by several stakeholders including LWF, World Vision and AAH-I. Part of the 30-acre land under micro-irrigation implemented by AAHI is under bucket irrigation.

AMREF supported the implementation of bucket irrigation in Lokichoggio. The project started with 2 acres but has now expanded to 10 acres. The irrigation project is managed by a CBO. The source of water is two boreholes. Water is pumped using solar power to a tank then distributed to standpipes where farmers collect water using buckets or watering cans for irrigation. Crops grown are mainly vegetables which are sold in Lokichoggio town.

Bucket irrigation is also happening around the water pan in Kalobeyei settlement. It is estimated that about 9.5 acres of land are being irrigated using the bucket system by both the refugees and the locals.

D. Hydroponic technology

Hydroponic technology was introduced in Kakuma as a pilot project by GIZ but is now gaining popularity in the area. Main crops grown under hydroponics are capsicum, tomatoes, kales, spinach and onions.

GIZ is currently piloting hydroponic technology in Turkana West sub-county. The technology is being implemented under a fully automated greenhouse. GIZ has installed two hydroponic units in Kakuma Ward (one near Kakuma Ward Administrator's office and another near the Kakuma Youth Multipurpose Hall) and one hydroponic unit in Kalobeyei Ward. The source of water for the Kakuma units is Kakuma Town Water Supply, while the Kalobeyei unit is supplied with Kalobeyei Settlement Water Supply. Crops grown are high-value vegetables. The hydroponic units were supplied by Miramar International.

I Choose Life – Africa is also piloting hydroponic farming technology in Lokichoggio and has established one shade net under hydroponics where they are piloting production of tomatoes. They have been working with Hydroponics Kenya who supplies simplified hydroponic units. A unit that can feed a household measuring 4 m x 3 m in a stacked vertical set-up costs about Ksh. 15,000/-.

E. Storey gardens or "guni" farming

The construction of a storey garden or "*guni*" garden involves creating a more porous chimney up the middle of the gunny sack or *gunia* to enhance water and airflow into the core of the bag. The periphery and top of the bag are filled with good soil. Notches are cut into the side of the bag where seedlings are planted. The bag is irrigated by pouring water onto the top of the bag. Typical crops grown in storey gardens are kale and amaranth. Storey gardens are suitable for residential environments as they enable multiple plants to be grown in a small space which can also be protected from livestock damage.

Danish Church Aid (DCA) is supporting refugees and host community in setting up storey gardens.

F. Groundnut production

The county is planning to pilot groundnut production under dryland agriculture in Loyaal, Nasinyono, Ejem, Mitiran in Kalobeyei, Lo Lotikipi Kipoto, Nabek and Arot in Lokichoggio. These areas were selected due to soil suitability (sandy loam soils) and rainfall amounts. Each area will have 20 acres of groundnuts under dryland agriculture bringing the total acreage under groundnut production to 140 acres in Turkana West sub-county. The plan is to pilot using trapezoidal bunds and then apply lessons learnt for upscaling.

The initial pilot of groundnut variety was conducted by *TCG* in collaboration with FAO, Egerton University and *Insta Foods Ltd*. Two varieties were tested under furrow irrigation, drip irrigation and bucket irrigation supplemented with rainfall. Yield analysis shows that 1 acre of land can produce between 800kg and 1,000kg of groundnuts. In terms of quality, the groundnuts had about 30% protein and 0% aflatoxin, which makes the product highly desirable in the market.

WFP and FAO are considering groundnut production in Kalobeyei settlement using supplementary irrigation.

6.1.2 Private sector involvement in agribusiness

A. Farm inputs/supply

Private sector involvement in the supply of farm inputs like seeds, pesticides, tools etc. has been a major challenge as for a long time there was no agrovet store in Kakuma. Farm inputs have always been sourced from Kitale, Eldoret and Nairobi. However, *FIDAI Agrovet* has now established an outlet in Kakuma.

B. Pumping equipment

This market is dominated by *Davis & Shirtliff*, which has an office in Lodwar that serves the region. Davis & Shirtliff supply pumps. In addition, they supply solar panels and associated fittings, generators and are responsible for the installation and maintenance of equipment. Solar power has gained popularity in the region and this has led to a significant decrease in the purchase of generators which in the past was the main source of power for water pumps. Most boreholes that were previously powered by genset are now being solarized.

SunCulture has also supplied solar-powered water pumping equipment (rainmaker) to Turkana through NGOs but does not have an office in Lodwar or within Turkana County.

C. Shade nets and drip kits

Shade nets and drip kits are mainly supplied by *HORTIPRO Ltd (Irrico)* and *Hydroponics Kenya* who have established offices in Lodwar. However, *Amiran Kenya* also supplies drip kits to NGOs in Turkana County from their Nairobi office.

D. Hydroponic technology

Automated hydroponic units have been supplied to GIZ by *Miramar International*. Hydroponics Kenya is also dealing with simplified non-automated hydroponic technology and have supplied *I Choose Life - Africa* with some units.

E. Market for the agricultural produce

Hotels and restaurants are major buyers of the horticultural produce in the area. *Insta Products* has expressed interest in buying groundnuts from the sub-county.

6.1.3 Livestock production

Livestock rearing is the main economic activity in Turkana West sub-county. The sub-county has the highest livestock population in the county. As of December 2019, the total livestock population was as shown in Table 6-1. Livestock rearing is mainly undertaken by nomadic pastoralist, which involves migration from one place to another in search of pasture and water.

Sustained livestock sub-sector growth is critical to uplifting the living standards of pastoralist as well as generating rapid economic growth. However, the livestock sub-sector is faced with challenges, especially water and pasture scarcity leading to low productivity. The current water sources for livestock are scoop holes inside laggas; hand-dug shallow wells, water pans and boreholes. There is high water demand from these sources, especially during the dry season leading to conflicts.

Table 6-1: Livestock population in Turkana West sub-county

	Livestock Type	Population
1.	Cattle	355,811
2.	Goats	931,258
3.	Sheep	616,872
4.	Camels	136,570
5.	Donkeys	90,621

Considering that livestock production is the main economic activity in the area, the county government in collaboration with other partners have come up with a plan of activities to improve the livestock sub-sector. The activities have been discussed below.

A. Rehabilitation and operationalization of the Lomidat abattoir

The Lomidat abattoir is the largest abattoir in Turkana County. It has a capacity of 50 cattle and 200 goats and sheep in a day. It was implemented by UNDP. It used to supply raw materials to the Lodwar tannery. Rehabilitation of the Lomidat abattoir is being done under the National Agricultural and Rural Inclusive Growth (NARIG) project, and it mainly targets the sheep and goat value chain.

There are discussions on the business model and management of the Lomidat abattoir with suggestions that it should be run by a private investor under a PPP arrangement. Details on this are yet to be finalized. Rehabilitation of Lomidat abattoir will lead to re-opening of Lodwar tannery. The tannery is currently being managed by the Livestock Marketing Council, but if it has to be operated on a business model, then the council can evaluate, recommend and adopt a business model of operation.

The source of water supplying the Lomidat abattoir is a borehole which has sufficient water. The borehole is installed with a solar-powered pump which pumps water to an elevated tank for distribution. The same borehole supplies water to the army barracks. Water is collected from the borehole using water bowsers and delivered to the army barracks for domestic use.

Revival of Lomidat abattoir will therefore not require additional development of a water source.

B. Lodwar tannery

The Lodwar tannery was also implemented by UNDP. Activities at Lodwar tannery became minimal due to an inadequate supply of raw materials following the closure of the Lomidat abattoir. The tannery is still in good condition, and once Lomidat abattoir becomes operational; it will also start operating at full capacity. There exists a borehole which is the water source for the tannery.

Products from the tannery are mainly sold in Nairobi with only a small portion sold locally. UNDP was responsible for looking for the market of finished products. The products include shoes, belts, wallets, hats and ornaments (bangles, earrings, and necklace).

C. Kakuma abattoir

This was constructed by NDMA and handed over to the county government. It is mainly serving Kakuma town and Kakuma refugee camp. The source of water is a borehole.

D. Breed improvement of goats and sheep

Breed improvement is being made by the county government in collaboration with AAHI. The objective is to improve the local breeds for improved production. Galla goat (buck) is being used to upgrade the local breed as it is bigger in size and can withstand harsh climatic conditions.

E. Donkey rearing

Donkeys are important in traditional households as a means of transporting water and materials. Lack of animal breeders in the area has affected the operation of the Lodwar donkey abattoir as there were concerns that the donkey abattoir was implemented without careful consideration of the donkey population and reproduction. It was reported that the rate at which the donkeys were being slaughtered was much higher than the rate of reproduction. A donkey's hide was fetching Ksh 10,000/- while a live donkey was selling at 8,000 Kenya shillings. This made slaughtering and sale of donkey hide attractive.

Clearly, there is an opportunity for a donkey breeder in the area as the local population is familiar with the husbandry of donkeys and the donkey is a hardy animal that can withstand the conditions in Turkana County.

F. Poultry production

Poultry production was introduced in the county by the county government in collaboration with other stakeholders. This was done through women and youth groups. The initial poultry that was introduced was layers and broilers. However, this was faced with several challenges including access to feed, unreliable and inadequate water supply and lack of veterinary services.

Feeds were being sourced from Kitale or Eldoret, pushing the cost of production up due to the high cost of transportation. The lack of agrovets and the complexity of transporting vaccines requiring a cold chain from 300 km away had its challenges. The lack of a nearby reliable water source meant that the groups had to go far looking for water. This became stressful to the groups, and the business collapsed.

Based on the lesson learnt from the initial trial of poultry farming in the county, the county government in collaboration with stakeholders opted to bring month old improved indigenous chicken for the groups, sourced from KALRO, Naivasha. The groups were also issued with starter mash that would last a month or two and were trained on feed formulation so that they could make chicken feeds locally.

FIDAI Agrovet established an outlet in Kakuma and stocks chicken feeds, vaccines and medicine. This has brought down the cost of chicken production, and several households are currently embracing poultry farming as a livelihood activity.

Poultry production is being supported by Turkana County Government, NARIG Project, Danish Refugee Council (DRC) and FAO. FAO bought 2,500 improved indigenous chicks (1-month-old) and constructed 5-6 poultry units. In Kakuma camp, households were given 6 chicks each while groups were given 100-200 birds depending on the number of group members.

Some groups have incubators (solar-powered) that they use to hatch chicks for sale. However, the solar-powered incubators sometimes have challenges leading to low efficiency. The chicks are still sourced mainly from *KALRO Naivasha* and *Kukuchic Ltd*, in Eldoret.

Poultry farmers have formed a cooperative society with the objectives of bulk purchase of feeds and marketing of poultry products for better prices. A rooster (mature cock) retails at Ksh 1,500-2,000/- depending on the live weight, a cockerel retails at Ksh 1,000-1,200/- while an egg retails at 20 Shillings. The chicken is sold locally with the main market being Kakuma town and the refugee camps.

The Turkana County Government, livestock department, report that water supply remains a major challenge for poultry farming, especially within the host community.

G. Beekeeping

Beekeeping was introduced in the county by GIZ in collaboration with TCG as a way of diversification using women groups. Beekeeping is being practiced in Oropoi, Letea and Nalapatui. Beekeeping is being done using both modern hives (Langstroth and Kenya Top Bar) and local log hives.

The water source is an important factor that must be considered when siting a bee hive. GIZ supports the groups in assessment and identification of suitable sites for beekeeping with access to water.

The major challenge with beekeeping is a lack of equipment for honey harvesting and processing. The groups therefore sell unprocessed honey locally in recycled containers. 1kg of honey retails at Ksh 800/- but can be lower depending on the quality of honey (amount of impurities).

With value addition, prices and demand is expected to increase. There exists the opportunity in investing in honey processing and packaging, which can be done by an individual entrepreneur or groups.

H. Pasture production

Pasture production was piloted in a 5-acre piece of land in Kalobeyei area in 2009 but failed due to poor management. The project was implemented by several stakeholders, each taking responsibility for a particular item. The pasture was produced under irrigation (partly furrow and partly sprinkler). The source of water was a borehole installed with a solar-powered pump.

The farm was taken over by a local NGO (*LOKADO*) who are now farming vegetables.

Pasture production under rainfed agriculture has been introduced in Songot area by GIZ, Lokore area by JICA and Komdei area by TCG. This is being implemented through groups. One acre of land can produce 180 bales of hay (15 kg weight) and a bale costs between 250 – 350 Ksh depending on the season. The bails are purchased locally by NGOs and NDMA who in turn provide the bales to the community during drought.

Some groups also do pasture seed bulking. One kilogram of pasture seed fetches Ksh 1,000/-. The seeds are sold locally to NGOs and TCG for reseeding of rangelands.

It is noted that pasture production in the county is still on a small scale. Bales of hay are still sourced from Kitale and Eldoret to meet the demand. The County is thinking of pasture production under spate irrigation to increase production.

I. Marketing of livestock products

TCG, in collaboration with other stakeholders, has developed sale yards with specific days for trade in livestock. However, a lot still needs to be done in terms of marketing. Previously, Nairobi was a major market for livestock from Turkana. This is no longer the case. The County is therefore looking for a market for meat, especially with the planned opening of the Lomidat abattoir.

There is an opportunity for the private sector to invest in a meat processing factory within Turkana West sub-county, especially near Lomidat abattoir which has a permanent water source with adequate water supply. The business could involve processing, packaging and branding of meat. Meat from Turkana is desirable as it is considered to be tasty.

6.1.4 Private sector involvement in livestock production value chain

Currently, there is minimal private sector involvement in the livestock production value chain. It is reported that some hotels in Lokichoggio have opted to rear poultry (broilers) to meet demand in the hotel. These include *Kate Camp* and *Track Mack*. Due to unreliable supply, the hotels decided to rear broilers for their own use.

However, several opportunities have been identified that can be bridged by the private sector. They include:

- Providing veterinary services (diagnosis, treatment and drugs);
- Managing of Lomidat Abattoir under PPP;
- Animal breeding;
- Value addition in honey production (refinery, packaging and branding);
- Value addition of meat products.

6.2 Enhanced Water Availability

Assess what options exist to enhance the present water availability

In order to allow for a larger development in agribusiness, the possibilities are studied for enhanced water availability, both in surface water and in groundwater.

6.2.1 Surface water

The surface water analysis in Chapter 3.1.2 has reported on the fact that the laggas in the area are seasonal and flow only in response to rainfall events. The analysis shows that significant surface water resources are available, albeit highly seasonal and available only in short duration runoff events. The pertinent issue is therefore not the availability of surface water resources, but the infrastructure required to store the water so that it can be used for water supply or irrigation purposes. Further study into the feasibility and optimum size of the potential dam on the Tarach lagga is required. This is discussed in the next paragraph on water storage potential.

Catchment conservation is widely adopted as an approach to enhance streamflow and to reduce hydrological extremes by creating good ground cover conditions for improved infiltration to enhance dry season flows and reduce extreme runoff and soil erosion. Catchment conservation includes aspects of lagga bank and riparian protection and restoration, arresting and restoring erosion gulleys, controlling runoff from roads and tracks, among others.

The greatest threat to the condition of the catchment and riparian areas is overgrazing and deforestation for charcoal and firewood production. In many places, an invasive species of *Prosopis* (known locally as "Mathenge") has invaded the riparian and lowland areas. While the bush is hardy and has potential utility as a source of wood for charcoal and fodder for livestock (highly nutritious seed pods), the bush inhibits grass and can leave soil bare and exposed to the deleterious effects of severe runoff.

Catchment conservation requires a coordinated program initiated by the County government and implemented with local WRUAs and environmental conservation groups, focusing on identified high priority areas (for example the catchment specific to a small dam or pan).

6.2.2 Groundwater

For groundwater, the focus was placed on the drilling of addition boreholes.

From previous studies, a number of areas have been selected having promising potential for groundwater development. Earth Water Ltd (2016) carried out hydrogeological surveys in the Kakuma-Kalobeyei area and recommended drilling sites based on ERT results as presented in Table 6-2 and the site location map for the profiles is presented in Volume 2, Chapter 2.8 (Annex 4).

Table 6-2: Potential drilling sites within Kakuma-Kalobeyei area (ERT 2016, EWL)

Priority	Profile No.	Drilling Location			Min Depth (m)	Max Depth (m)
		Location	N	E		
1	KAK07	80m east of the concrete marker KBH 1	414635	684940	130	160
2	KAK06	110m west of the concrete marker KCT 2	414498	682611	130	160
3	KAK09	Location of concrete marker TR 1	421867	702103	60	100
4	KAK08	20m west of the concrete marker NAPAS 1	416383	679697	130	150

Bauman (2016) used seismic refraction and ERT geophysical methods to target paleo-channels connected to the large laggas in which the periodic flash floods would be the mechanism for recharge with low salinity and low fluoride water. Seismic refraction data identified a few deep paleo-channels while ERT differentiated high-resistivity freshwater saturated sands and gravels from low resistivity clays or saltwater-saturated alluvium. He suggested that further investigations on the potential sites (Table 6-3 and Volume 2, Chapter 2.8 (Annex 3)) within the Northern Well Field should be carried out.

The potential interest for irrigation purposes for either Kalobeyei Settlement Scheme or for more local farms is less likely to threaten existing domestic boreholes. The site west of Kakuma 1 is also of interest but no grid reference was provided for this site.

Table 6-3: Potential drills sites within northern wellfield

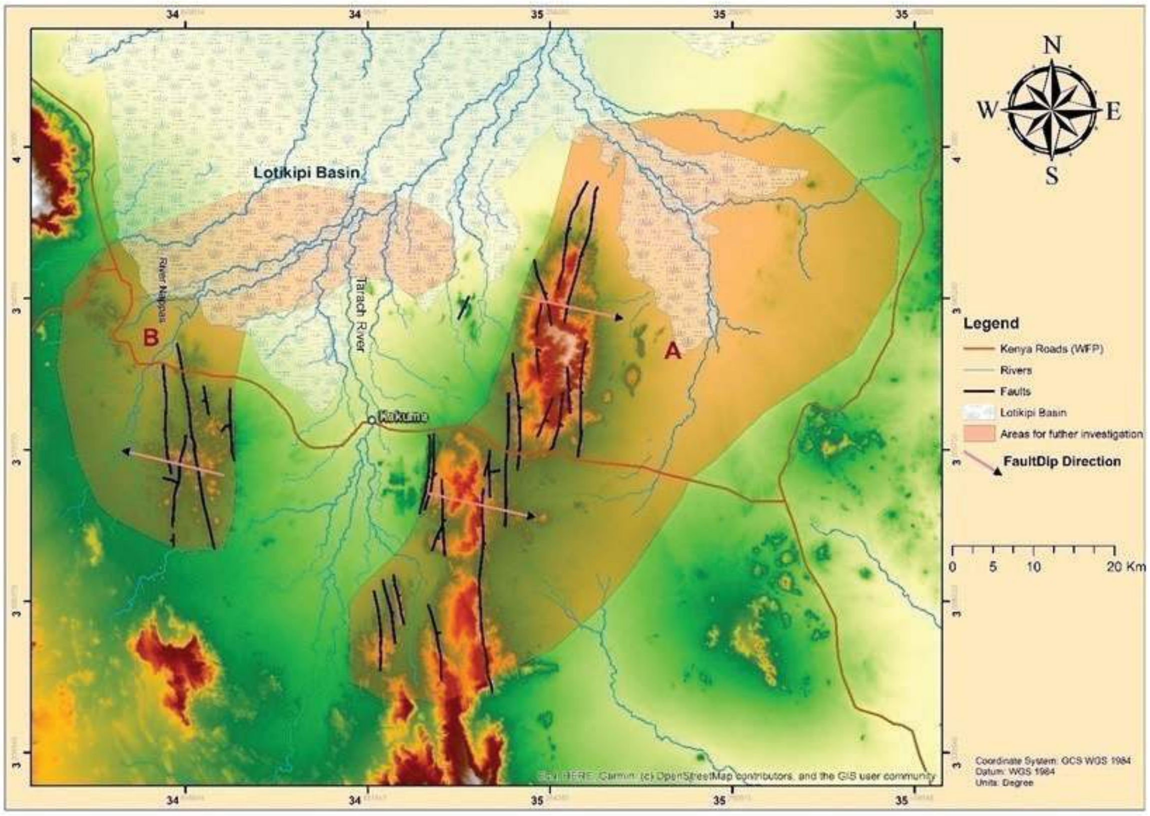
ERT No.	Latitude	Longitude	Target area	Description
ERT7	3.77845	34.82906	Area Between BH 8 and BH 9, West of Bh 8 and Bh IOM	Granular overburden
ERT7	3.776108	34.82906		Thick overburden
ERT7	3.775411	34.82918		Thick overburden
ERT7	3.774082	34.82914		Seismic velocity low and granular overburden
ERT7	3.772952	34.82919		Seismic velocity low and granular overburden
ERT4	3.771159	34.83038	The Area between Bh 4 and Bh IOM	Thick, granular overburden and weathered bedrock
ERT4	3.771846	34.8304		Thick, granular overburden and weathered bedrock
ERT4	3.772244	34.83037		Thick, granular overburden and weathered bedrock
ERT4	3.774024	34.83108		Thick, granular overburden and weathered bedrock

Based on the structural geology of Kakuma-Kalobeyei, further investigation areas are recommended as follows:

- The area to the East of Kakuma town (Zone A in Figure 6-1): Faults in this area (Pelekech hills) are striking N-S and dipping towards the East and therefore investigations should be focused further east of the faults;
- The area of Kalobeyei extending towards the Lotikipi basin (Zone B in Figure 6-1). The Strike of the fault is N-S and the dip is towards the West, and hence investigations should be done targeting this zone and extending towards the Lotikipi basin.

The actual number and spacing of these boreholes should be determined on the basis of detailed on-site geophysics and additional hydrogeological investigations. Environmental, engineering, economic and O&M considerations should also be taken into account.

Figure 6-1: Recommended further investigation sites



6.3 Water Storage Potential

Assess the possible locations and volumes of additional water storage

This section provides a brief analysis of potential surface water storage options.

6.3.1 Large dams

The only large dam under consideration at the moment for which background information available is the Tarach Dam (sometimes referred to as the Tulubalany Dam). Finix (2017) provides an analysis of the Feasibility of the Tarach Dam. The proposed dam site is located in a gorge 40 km upstream of Kakuma town at grid reference 36N 694,118.92m E 364,049.00 N. The site is 2 km downstream from the confluence of two major streams and one tributary from the Loima hills, Letea and Lokiriama respectively. The site has a catchment area 2,737 km^2 [55], which extends over into north-eastern Uganda to an altitude of 1200 masl.

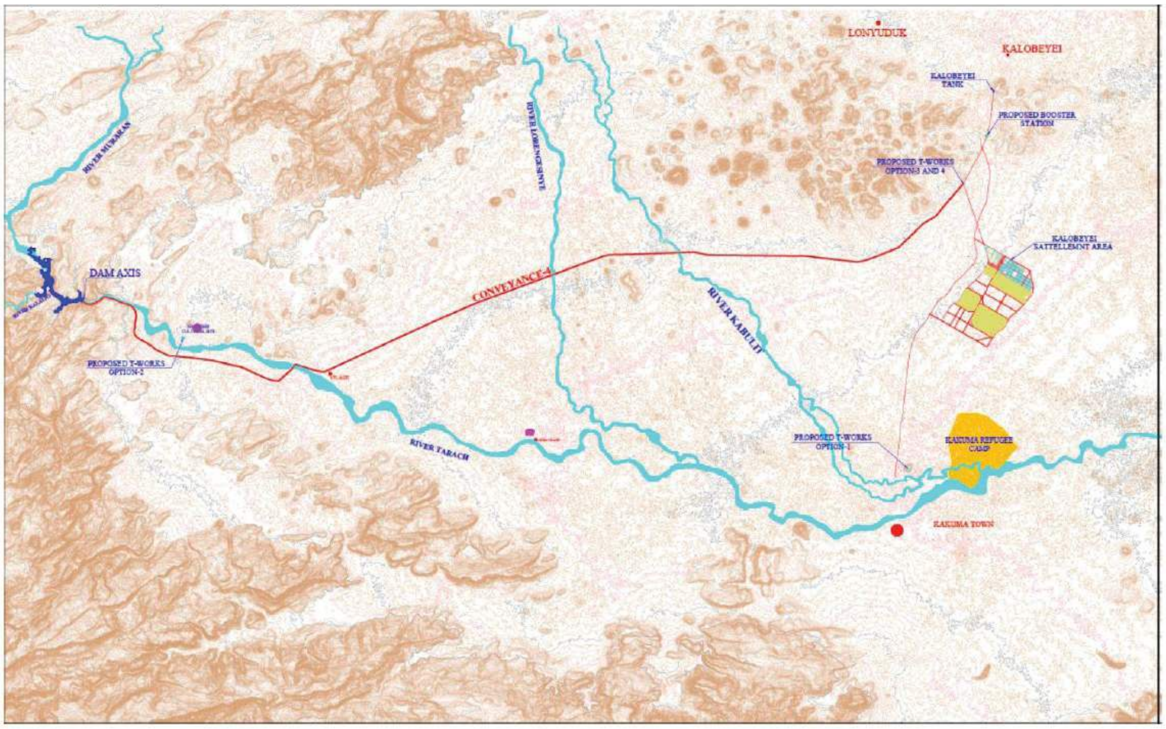
The report proposes a concrete/rockfill dam with a spillway height of 11 m and a crest height of 14 m. The storage capacity would be 4 MCM.

The report states that the proposed dam location seems suitable for the intended purpose. There is sufficient water to supply Kakuma town and the refugee camp, and the Kalobeyei Settlement Scheme by gravity flow and to Kalobeyei center through a booster pump system located at a sump to the west of the Kalobeyei Settlement Scheme (see Figure 6-2). The analysis indicates that the dam could meet a future domestic and livestock water demand of 8,392 m^3/day and 1,530 m^3/day respectively and support 150 acres (60 ha) of irrigated agriculture.

Various advantages of this site are:

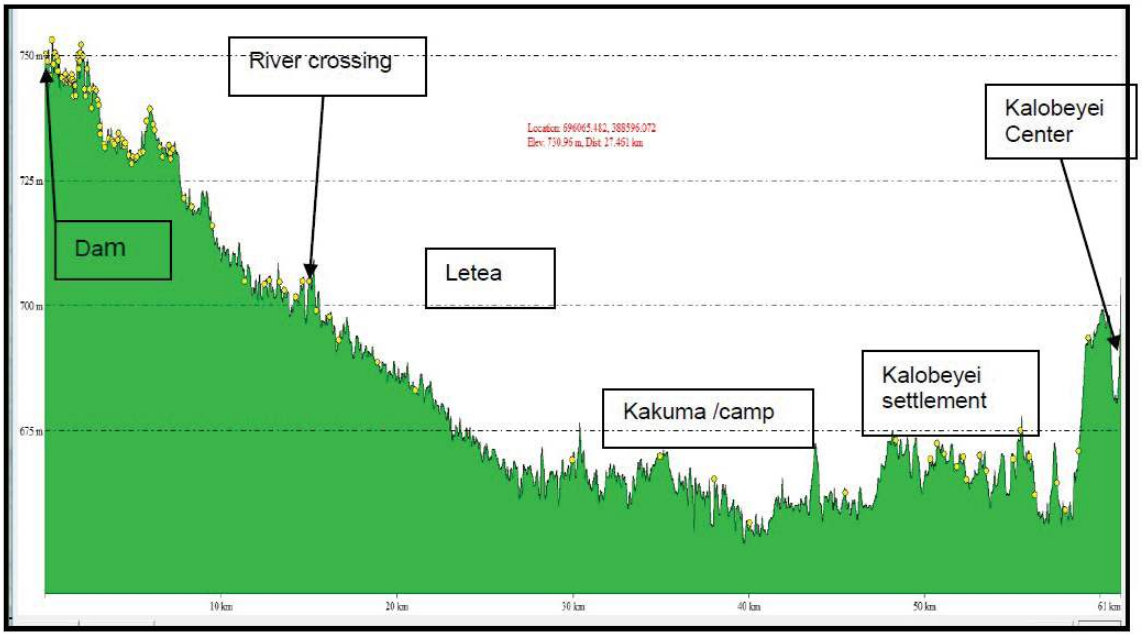
- Pollution is not a factor as the catchment area has very low settlement;
- Resettlement is not likely to be an issue as the reservoir area does not have permanent settlement;
- There is minimal risk to the property as there is no infrastructure within the reservoir area, and habitations and other structures are located a significant distance downstream of the site. The EIA process would also provide an opportunity to fully assess the risks and propose mitigation measures;
- The topography of the site provides a net storage ratio that makes the site attractive;
- Gravity supply to the demand areas is possible (see Figure 6-3);
- Construction materials are locally available.

Figure 6-2: Pipeline route from Tarach Dam to Kalobeyei



55 Finix 2017 reports a catchment area of 2,594 km^2. The discrepancy with our analysis is attributed to differences in the DEM, and has not practical consequences for the study.

Figure 6-3: Topographical cross section from Tarach Dam to Kalobeyei



Issues of concern or which require further investigations include:

- the O&M challenges for the 60km long pipeline including lagga crossings, potential vandalism, etc;
- the sediment load into the dam;
- the foundation suitability;
- the potential impact on the recharge of the Kakuma aquifer.

There are various components to the overall proposed project with associated costs as shown in Table 6-4.

Table 6-4: Tarach Dam water supply project cost

	ITEM	USD
1	Dam	4,000,000
2	Pipeline	9,561,802
3	Treatment Works	700,000
4	Project Administration and Management	700,000
5	Overall Contingencies	538,198
	Grand Total	**15,500,000**

Review of Tarach Dam yield analysis

As there are no streamflow data for the Tarach Lagga, the Feasibility Study for the Tarach Dam (Finix, 2017) made use of the synthetic streamflow data provided by the African Drought and Flood Prediction Model. This information provided a mean annual volume of 34.4 MCM/yr. The Consultants opted to use 10% of the mean annual volume to guide the sizing and potential yield of the dam. As this study is interested in the potential of the Tarach dam to support a greater irrigation demand, it was considered appropriate to review the yield analysis for the dam.

The approach adopted was to set up a reservoir water balance simulation model, as described in Volume 2, Chapter 1.4 to test a range of irrigation demand scenarios.

Various scenarios were established to explore the potential yield of the dam. These were:

- Spillway height of 11 m and 14 m. A review of the HVA curve (see Volume 2, Chapter 1.4) indicates that a 11 m spillway height does not take advantage of the site topography in which the storage increases significantly above 11 m depth. A value of 14 m height is taken as an *arbitrary value* to explore the gain made by increasing spillway height. The crest length only changes from 130 to 162 m;
- Irrigation demand based on 70 m^3/ha/day for irrigation area ranging from 60 to 700 ha.

The environmental compensation flow of 3,715 m^3/day (Q_{95}) and the combined domestic and livestock demand of 9,922 m^3/day were held constant for the different scenarios.

The reliability results are presented in Figure 6-4 and Figure 6-5, in which the minimum reliability across all months is the metric displayed. These demonstrate that a 14 m spillway height results in significantly better performance than a dam height of 11 m, with potentially as much as 650 ha of irrigation being met with an 80% monthly reliability. The site cross-section indicates that a higher wall is also possible and should be investigated.

This analysis is not exhaustive. But it does point to various conclusions:

1. The reservoir yield may be significantly greater than indicated in Finix (2017) especially as the synthetic streamflow data used is a conservative estimate (annual runoff coefficient of 2.2 %);
2. The need for accurate rainfall and streamflow data cannot be under-estimated;
3. Further analysis of the Tarach Dam in terms of different heights, yields and potential environmental impacts is warranted.

Figure 6-4: Reliability of meeting domestic and livestock demand for different spillway heights

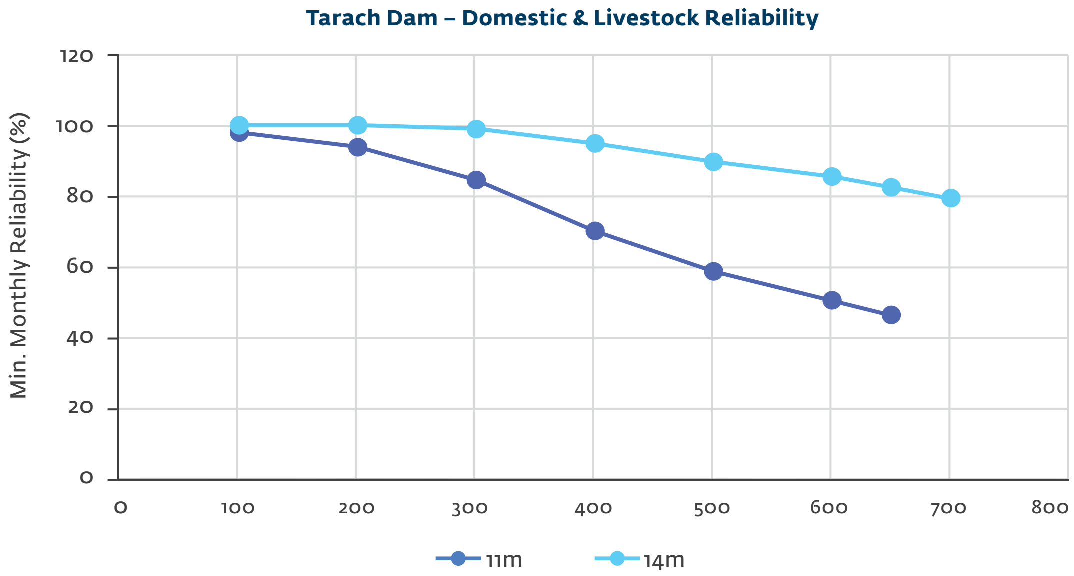
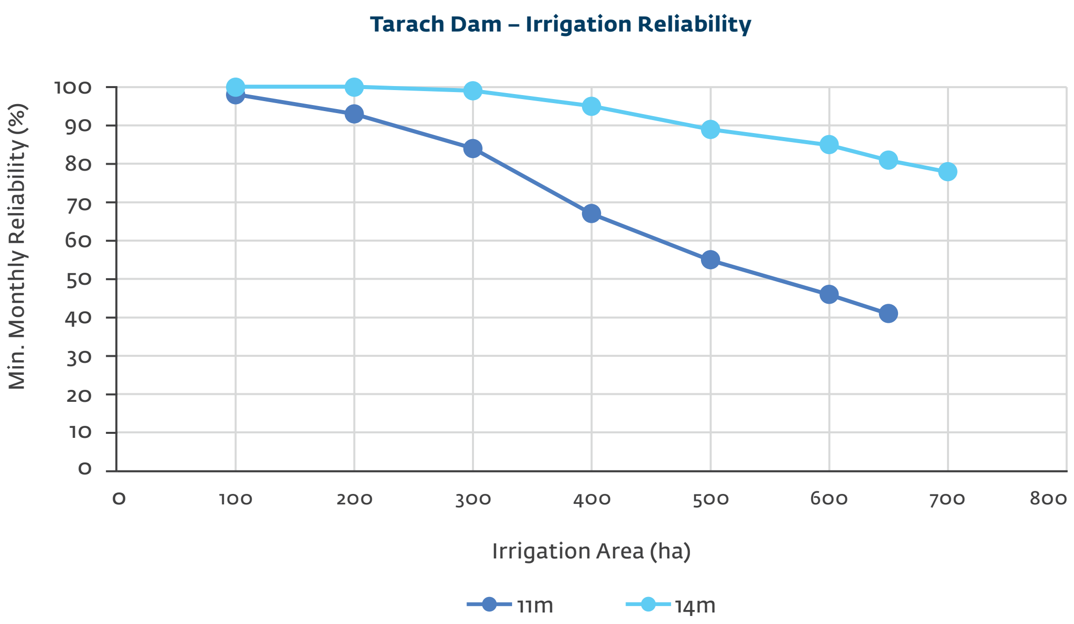


Figure 6-5: Reliability of meeting irrigation demand for different spillway heights



6.3.2 Small dams and pans

Essentially while the development of dams is very site-dependent, there is more flexibility on where to develop pans as they are located offline from the watercourse. This study has replicated a GIS-based analysis described in JICA (2015) and presented in Volume 2, Chapter 1.5, which aims to identify areas suitable for pan development based on a number of criteria, namely:

- Rainfall;
- Land slope;
- Proximity to a watercourse;
- Soil suitability for agricultural production.

The result is the map presented in Figure 6-6 and Table 6-5, which indicates the extent to which the pan technology can be applied across the Kakuma-Kalobeyei area and even further afield. Essentially this shows that the potential to develop pans is not restricted by land availability.

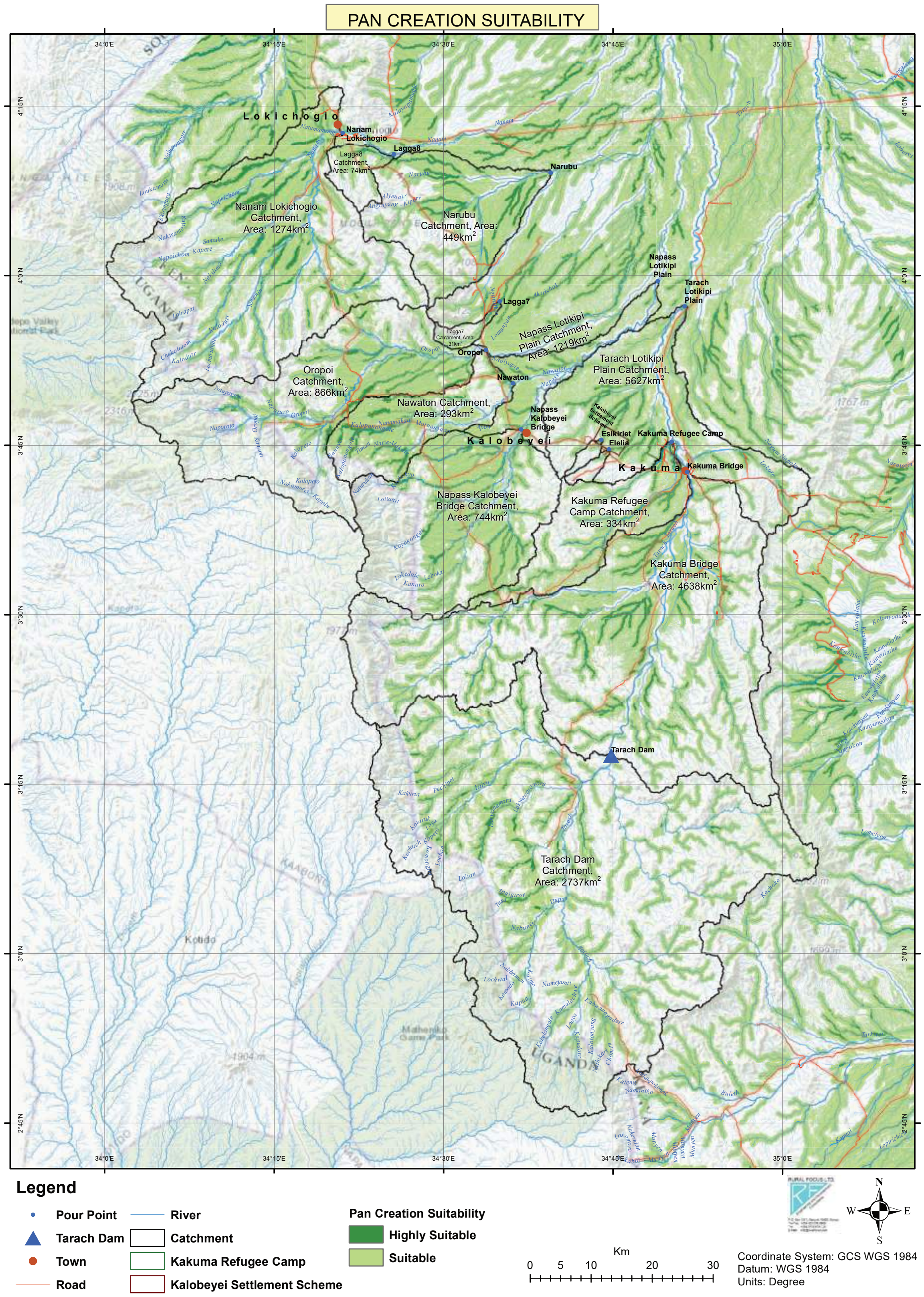
It should be noted that pans will need a catchment of sufficient size to reliably fill the intended size of pan to suit the intended area to be irrigated. This level of site-specific investigation and analysis is required for each proposed pan site.

Table 6-5: Land suitability for pan development

	Area Suitable for Pans	
Catchment	Highly Suitable (km²)	Suitable (km²)
Tarach Lotikipi Plain	138.96	2,072.24
Kakuma Bridge	103.44	1,546.20
Napass Lotikipi Plain	60.01	677.22
Nanam Lokichoggio	59.06	584.36
Tarach Dam	42.03	822.46
Narubu	31.24	238.47
Napass Kalobeyei Bridge	29.98	383.38
Oropoi	29.22	292.98
Nawaton	24.62	177.27
Kakuma Refugee Camp	13.35	182.78
Lagga8	1.86	34.07
Lagga7	0.93	16.28
Elelia	0.19	3.19
Esikiriet	0.17	3.09

Note: data only shows land within Kenya

Figure 6-6: Potential location of small dams and pans



6.3.3 Farm ponds

Small farm ponds of 50 – 500 m^3 capacity can be used to store roof or ground runoff water which can then be used to irrigate a small kitchen garden, fodder or fruit trees. The scale of this type of infrastructure is suitable for a single-family or small group of farmers. This type of pond generally involves the following aspects:

- Manual or machine-assisted excavation in an area of flat or gently sloping land;
- Excavation of furrows to channel runoff into the pan;
- Excavation of a spillway channel to discharge excess water;
- The lining of the pond may be required in porous soils, which can be expensive (typically ≈ $ 2.0 - 3.5 per m^2 depending on thickness and quality of lining material);
- Provision of a gate and fencing of the structure to control access in order to minimize the risk of drowning;
- A system of extracting the water for use. This may be a bucket and rope, treadle pump, small electric solar (e.g. sunflower SF1) or petrol pump. The SF1 pump can produce 0.9 m^3/hr against a 6 m head which is ample. As the pump is portable, one pump could be shared by a number of farms;
- It would be possible to cover the pond with shade netting to reduce evaporation. The merits of this option, given the windy nature of the area, should be investigated.

Thomas and Gikone (2018) recommended the development of these ponds within the Kalobeyei settlement area, specifically along with the small watercourses within the "green spaces" (which total approximately 77 ha across the entire settlement scheme) to capture runoff water. Each farm pond would then need to be associated with a small farming area. The allocation of land would need to be carefully managed. The technology can be offered to host and refugee community members. The critical component is that the land for both the pond and farming area is available, there is potential for runoff to be directed into the pond, and the pond and farming area can be properly fenced. However, none of these structures has yet been developed.

It should also be noted that the introduction of open water storage within the settlement area introduces a hazard as it may act as a breeding ground for mosquitos, raising the risk of malaria. In addition, to minimize the risk of drowning the ponds must be well fenced to control unauthorized access.

A vegetable garden of 20 m x 20 m irrigated with 10 mm/day would require approximately 4 m^3/day of water or 280 m^3 for a 70-day growing season.

A pond of 30 m x 30 m x 2.5 m water depth would have a capacity of about 474 m^3. Approximately 200 m^3 is lost to evaporation over a 70-day growing period, so approximately 270 m^3 is left for irrigation, which would be sufficient to support the proposed cropping area of 400 m^2 or 20 m x 20 m. The study anticipates that initially this vegetable garden would be irrigated using furrow/basin irrigation fed by a pump and 50 m PVC hose pipe.

Thomas and Gikone (2018), Annex C, presents a preliminary design, BOQ and drawings for the farm pond. The preliminary design indicates that a pond of 474 m^3 would cost approximately USD 12,520, inclusive of fencing and shade netting over the pond and farming area to reduce evaporation.

6.3.4 Sand dams and subsurface dams

The sand dam and subsurface dam technology is appropriate to ASAL areas in watercourses with sandy/gravelly alluvial material but requires site-specific identification and investigation to develop robust structures. Sand dams and sub-surface dams can be used to enhance local shallow aquifers from which water can draw from shallow wells. The technology can provide good quality water, although typically the limited water storage volumes constrain the supply to be domestic and livestock uses only.

6.3.5 Rainwater harvesting

The small-scale nature of rainwater harvesting systems typically provides water for domestic use and rarely is sufficient to cover any significant irrigation applications, except potentially small kitchen or storey gardens, or household fruit trees. In addition, in an ASAL climate such as in Kakuma-Kalobeyei area, the rainfall is erratic, which means the systems cannot provide a high level of reliability. Backup water sources are generally required.

6.3.6 In-situ soil water conservation

In-situ soil water conservation technologies focus on enhancing soil moisture sufficient to ensure a successful cropping cycle, without significant infrastructure requirements. There are various arrangements, but all of them focus on minimizing runoff, concentrating runoff to the cropping area, minimizing evapotranspiration and enhancing soil health, plus crop selection and opportunistic farming to suit the climate and seasonal conditions. These technologies have been promoted for many years in Turkana West sub-county with good success in places. It does not offer the reliability of crop yields that may be gained from an irrigated crop but can significantly enhance the reliability and yield under near-normal conditions.

The potential to expand cropland using in-situ soil water conservation or dryland farming practices is large. Careful selection of the sites is required in consultation with technical staff, county government officers and the local community.

7 Assessment of Possible Measures

Goal 3 – Assessment of possible measures

Determine which measures might be taken to mitigate observed limitations in terms of water resources and social/legal situation

- Water availability measures
- Water demand measures
- Social and legal measures
- Economic feasibility

7.1 Water Availability Measures

Goal: Make an inventory of possible measures that might improve the limitations on agribusiness development posed by water availability

7.1.1 Surface water

Surface water availability for agribusiness development can be enhanced through addressing the following constraints.

7.1.1.1 Rainfall and climate data

Accurate meteorological data is important for agricultural development and crop production. KMD, in collaboration with WRA and the County Government, should design and establish a meteorological monitoring network that can support agricultural production within Turkana West sub-county.

7.1.1.2 Streamflow and sediment yield data

Streamflow and sediment yield data are critical to the analysis and design of the Tarach Dam and generally to the better understanding of the hydrology within Turkana West sub-county. WRA, in conjunction with the Turkana County Government, should establish a river gauging station on the Tarach lagga. It is recognized that watercourses with unstable channels and lagga banks, such as the Tarach, present challenges for streamflow measurements; targeted efforts and fieldwork should be undertaken to identify a suitable site with appropriate instrumentation. The data collected can be used to calibrate a hydrological model to develop a better estimate of streamflow.

7.1.1.3 Water storage

The limitations to water storage are partially dependent on the scale of infrastructure proposed. The discussion is focused primarily on structures that can make a significant impact on the scale of agricultural production. Details of the possibilities for extended water storage facilities are already discussed in paragraph 6.3.

Large dams

Large dams require detailed technical investigations, including fieldwork. While there is a proposed dam on the Tarach lagga, there are no documented studies covering other watercourses in the area, namely the Napas, Nanam, and Oropoi laggas.

Small dams and pans

Identification of sites suitable for small dams requires fieldwork which can be undertaken by suitably qualified engineers. These should be undertaken within the foothill areas adjacent to the flatlands where agricultural activities can be conducted. As a basic guide, one hectare of irrigated land may require 10,000 – 15,000 m^3 of stored water to cover a 90-day growing season, allowing for seepage and evaporation.

Sites suitable for pans are easier to identify, but specific attention is needed to make sure the pan can fill, that the depth does not go into rock, this can be easily checked with geophysics and geotechnical surveys (expensive to excavate) and that there is a suitable material to line the pan where well-drained soil conditions exist.

A deliberate effort is required to build capacity within the Turkana County Government water and/or agricultural departments to be able to site, design and develop small dams and pans in line with the MWI Practice Manual for Small Dams, Pans and other Water Conservation Structures.

In-situ soil water conservation structures

While in-situ soil water conservation technologies use minimal infrastructure, there are certain requirements for tools, machinery, farmer training, group organization and even incentives to initiate the development of cropland using these dryland farming techniques. The principal constraint to the establishment of dryland farming areas is financial resources as the land, and technical know-how within the county government exists.

Specific technologies such as spate irrigation will require the identification of suitable sites and the design and development of infrastructure. This will require capacity building to enable local technical government officers to confidently develop spate irrigation schemes, in addition to training farmer groups on the operation and maintenance of the infrastructure.

7.1.2 Groundwater

7.1.2.1 Groundwater studies

The lack of sufficiently detailed and reliable information on groundwater in the region of study implies that further study is necessary. Several issues are relevant.

Geophysics

Geophysical investigations carried out previously in the area to identify groundwater sites have encountered some challenges including identifying the position and elevation of the surface of the volcanic rock as the presence of magnetite interferes with the electrical signals of ERT, thus making their interpretation difficult. Sottas (2013) notes that the use of non-electrical geophysical methods is recommended. Geophysical data as it stands currently and from previous studies, is insufficient for aquifer parametrization. The combination of resistivity and seismic refraction (Bauman, 2016) clearly identified the top of Volcanics. It is recommended an all-inclusive geophysical method be done by combining TDEM, ERT, VES, NMR, Seismic, Magnetics and AMT to unearth the sub-surface conditions for groundwater suitability.

Aquifer characterization

From the various drilling carried out, the characterization of the aquifers in the area has not been carried out. Even very basic characterization using the EC or other physical and chemical aquifer parameters has not been done. This creates a major constraint in clearly defining water use of available water. It must be pointed out that in some instances, 2 or 3 aquifers are reported with defined thicknesses and depths, e.g. the deep borehole of 330 m. The EC is reported to be 690 µS/cm. This value does not specify the EC of the individual aquifers. The reported value could be the average EC or for the upper or deeper aquifer. This is a major limitation in deciding the design parameters for the project. It is, therefore, necessary to carry out detailed monitoring of basic physical and chemical parameters during drilling to enable vertical aquifer delineation.

The characterization of aquifers has been discussed by in most of the previous studies. However, these studies give ranges in terms of aquifer geometries which are acceptable, but the storage and recharge by RTI (2013) have been criticized in equal measure by other consortiums poking holes on the highly exaggerated groundwater recharge estimates, and aquifer storage considering the high evapo-transpiration rates in the area. It is, therefore, suggested that a clear framework be put in place to understand the estimates and work out realistic values. This will help in future groundwater development by different partners like IFC who are interested in commercial production of peanuts in the area. Field surveys are paramount to augment the remote sensing and GIS mapping findings of the exact aquifer extent.

Artificial groundwater recharge

Due to the cyclic floods in the area along the main laggas, underlain by thick alluvial sediments, it is evident that large volumes of water are transported as run-off during the floods and baseflow thereafter. Artificial groundwater recharge should be implemented in promising zones along the floodplain, and suitable groundwater recovery points identified where drilling of shallow boreholes can be undertaken.

The application of AGWR will minimize the direct impacts of lowering groundwater levels and consequent saline intrusion.

7.1.2.2 Additional measures

In view of the issues exposed in the chapter 3.1.3 on groundwater, rafts of recommendations and way forward are proposed as follows, most of them focusing on waste management:

- Monitor possible anthropogenic pollution still in the unsaturated zone in order to prevent eventual future pollution of the aquifer;
- With approximately 200,000 refugees using latrines situated on top of the aquifer, the alluvial aquifers and likely the Volcanics will remain contaminated. Treatment with chlorine will always be mandatory;
- A comprehensive larger scale hydro-chemical study related to the geological specificities of both watersheds reaching Kakuma should be investigated;
- Ensure water from the hand pumps and scoop holes are not used as drinking water as it presents a significant load of pathogen bacteria unless treatment is done;
- Enhanced partnerships with Wash actors to emphasize hygiene and sanitation guidelines is highly recommended.

Fabreau et al. (2019) suggest the expansion of safe waste management to public health systems. They recommend a robust waste management system which includes; monitoring supply, consumption and destruction of syringe waste, creating the infrastructure of public health waste management, latrine setups, linking regulatory and procurement mechanisms that control waste choices and establishment of leadership, commitment and country planning to link waste management budgeting to medical supply services that generate waste.

In view of these findings, it is clear that Kakuma and Kalobeyei areas have an underdeveloped waste management system exposing the general public to water-borne ailments in case of leakage into groundwater.

7.1.2.3 Groundwater supply

Most boreholes in the study area have been drilled along the rivers / laggas, which act as a recharge zone for the shallow aquifers whose effect further reaches the deep aquifers through faults and fissures. This results in high yields in a significant number of boreholes. From the analysed boreholes, an average yield of 20 m^3/hr (for a 10 hr/day pumping regime) has been used in the calculation of the proposed water supply.

The production of groundnuts viz a viz groundwater supply irrigation scheme is subject to a number of considerations for aquifer management which is subject to WRA laws and regulations. A commensurate water allocation plan must also be done to ascertain the actual water available for the project and identify other critical needs.

The WRA 2007 rules stipulate that for aquifers, the Reserve Quantity shall be 40% of the aquifer flux in the case of aquifers whose recharge rate has been determined by the Authority. The calculated values are based on areal extent and aquifer thickness of the medium and shallow aquifers assuming the aquifer is saturated as the draft (abstraction rate is not surpassing the recharge.

In view of this, 60% of the remaining storage is considered for use as follows:

40% * 523,162,645 m^3/yr = 2.09*10^8 m^3/yr (209 MCM/yr)

(Reserve as an environmental practice on groundwater conservation).

60% = 3.14*10^8 m^3/yr (314 MCM/yr).

Therefore, 3.11*10^8 m^3/yr (311 MCM/yr) is the amount of storage that can be used for other purposes, including domestic, livestock and Irrigation purposes. Taking total demand for human, livestock, commercial and institutional use of 2.9*10^6 m^3/yr, the available surplus stands at 3.08*10^8 m^3/yr (308 MCM/yr). For this an allocation plan is paramount and has to be negotiated with WRA.

We propose an allocation of 2% of the estimated available water storage (surplus) from the aquifers to serve irrigation purposes i.e. 6.16*10^6 m^3/yr, this translates to 16,876 m^3/d. This must be negotiated with other stakeholders including WRA and the deficit be augmented with water from other sources like surface water harvesting.

NB: To meet the calculated minimum daily demand of 135,000 m^3/day for groundnut agricultural production by drip irrigation, more water than the available calculated from the available surplus is needed, and this calls for adjustment of the allocation percentage of 2% of the available surplus for irrigation purposes and hence this will further increase the number of boreholes, but this is only through consultation with the stakeholders. Otherwise if we take 2% of the available surplus then the remaining demand i.e. 118124 m^3/day has to be sought from surface water. The only option to reducing the number of boreholes is getting the available surface water for irrigation, this way we can complement the two sources and probably reduce the number of boreholes.

Based on the daily irrigation demand of 135000 m^3/day and assuming a groundwater supply only, the calculations of the boreholes needed to meet the demand is explained below.

To sustain the proposed 2% of the total abstractable storage for irrigation, about 84 Boreholes yielding 20 m^3/hr and pumping for 10 hrs a day is required. This % abstraction can be increased to fit the demand, but only upon consultation with stake holders, and this may increase the number of boreholes and consequently an increase in estimated capital and O&M costs.

Table 7-1: Summary of groundwater storage allocations

Allocation	Storage m³/y
Total aquifer storage (b * areal extent) - medium and shallow aquifers	$5.23*10^8$
40% of storage (5.23×10^8 m³/yr)	$2.09*10^8$ (Reserve)
(60%) Total available for use	$3.14*10^8$
Less Human and livestock demand	$2.9*10^6$
Remainder (to be considered for irrigation)	$3.08*10^8$
2% allocation of the remainder for irrigation	$4.3*10^6$

7.2 Water Demand Measures

Make an inventory of possible measures that might decrease the present water demand of existing sectors

The influx of refugees into Kakuma and Kalobeyei regions has exerted pressure on the limited groundwater resources which is the primary resource for domestic water supply to the Kakuma refugee camp, Kalobeyei Settlement Scheme, Kakuma town and the host community. The increased demand means over-exploitation of the shallow and medium aquifers could be in play, which harbours fresh water. This is a risk in terms of water quality deterioration, eventually rendering the aquifers unfit for human and crop use. It is then recommended that a safe yield pumping regime be initiated through an elaborate wellfield development.

7.2.1 Water use

It is imperative that water use efficiency is exercised for all uses. Conservative approaches in irrigation is very important, considering the high evapotranspiration losses in the area. In the event of dwindling groundwater resources in the area, the refugees would have to be re-located. Furthermore, irrigation projects would have to be re-designed and adjusted to match the scenario obtaining in the area. For this reason, water-saving, conservation and preservation measures should be put in place. These include the recharge, re-use and re-cycle. This 3R principle should be embraced by all stakeholders.

7.2.2 Irrigation water demand

Various measures can be utilized to reduce irrigation demand. These include:

- Monitoring irrigation water use;
- Monitoring soil moisture to determine irrigation requirements;
- Using drip irrigation systems which are more efficient than sprinkler or furrow-based irrigation systems;
- Creating wind breaks around farmland;
- Shading cropped areas using shade net;
- Adopting a cropping calendar that is timed to take advantage of rainfall;
- Selecting crops that can handle local climatic conditions and a certain level of drought stress.

7.3 Social and Legal Measures

Assess the possible measures that may be taken to eliminate possible social and/or legal limitations for the introduction of agribusiness

7.3.1 Social measures to mitigate limitations for the Introduction of agribusiness venture

Capacity building

Capacity-building amongst the pastoral is envisaged in two fronts:

1. Capacity development geared towards equipping the pastoral communities with skills and knowledge for irrigated crop farming and in particular groundnut cultivation. This will give them capacity and skills to better husbandry practices, including the introduction to water and soil conservation (soil and water management, runoff harvesting, build cut-off drain, terraces, etc.). This measure will ensure that the pastoral community acquire capacities to run farming enterprise in ASAL context.

2. Water Management: Community will be trained on self-reliance in the operation and maintenance of water infrastructure. Sustainable capacity development requires building organizational capacities, to help develop and apply internal mechanisms, arrangements and procedures which is necessary to deliver the water user associations' mandate as spelt out in the Water Act 2016. The capacities to be strengthened amongst the water user associations should enable them to organize, to plan, coordinate and undertake simple O&M activities.

Water access and equity

According to UNDP[56] "*There is more than enough water in the world for domestic purposes, for agriculture and for the industry. The problem is that some people notably the poor are systematically excluded from access by their poverty, by their limited legal rights or by public policies that limit access to the infrastructure that provide water for life and for livelihoods*". In line with this observation, the water feasibility study has revealed that most of the rural communities hardly access safe water and have to rely on the water sourced from laggas. Those who try to run rainfed agriculture reported frequent crop failure due to inadequate rainfall. The project should promote a pro-poor strategy geared towards ensuring access to water by poor households.

Tariff setting

Deprivation in water has a major negative impact, especially to women who are responsible for securing household water. Further, the majority of farmers are women. Women spend a substantial amount of their time in search of water, which translates into significant opportunity cost and health implications. While considering the sustainability of the water supply system, the tariffs and user charges should be set while considering the inability of the poor to afford the cost of water. A subsidy could be worked out so as to improve access to water by the poor households.

Inclusivity in securing land for investment

This report has revealed that land matters are emotive and need to be well negotiated, bringing together all the stakeholders. The project should be anchored around the existing county laws for the project to access the land for commercialization of the groundnuts. Conflict resolution body made of stakeholders, including community elders and leaders, should be created and strengthened to manage conflicts that may occur.

[56] UNDP, 2017.

7.3.2 Social and legal measures

7.3.2.1 Social measures

From the social perspective, we propose that any new project that will be implemented in the region should adopt an integrated approach in the design and implementation of the project to achieve protection of the fragile ecosystem and to spur economic development, either through commercialization of the groundnut farming, or any other crop that is being implemented.

On the socio-economic front, the intervention should seek to improve the livelihoods of the local communities and the local economy through employment creation and increased incomes. The project should also work towards improving the status of the natural resources for posterity. Indeed, to be sustainable, 'development' must meet the needs of the local people. The following measures are proposed:

- ***Community Participation***: Involvement of local communities in the formulation, designing, implementation and operationalization phases of the project should be a priority consideration so as to inculcate the sense of belonging and positively identify with the project;
- ***Conflict Resolution and Land-Use Planning***: Access and control of land are emotive issues not only in Turkana County but generally in the Kenyan context. The project should be anchored around the existing county laws for the project to access the land for commercialization of the groundnuts. Conflict resolution body made of stakeholders, including community elders and leaders, should be created. This body should manage other conflicts that may directly or indirectly be associated with the project. In addition, the project should make use of the lessons learnt from the acquisition engagement process which was supported by FAO, WFP, UNHCR, and the Turkana County Government with leaders and members from the host and refugee communities, through which the Turkana County Government allocated 1,500 hectares of land in Kalobeyei for settlement of refugees under the KISEDP approach;
- ***Promotion of Agricultural Activities***: Being a non-traditional activity, the project proponents should take deliberate action to sensitize, and build capacity in pastoral communities on modern ways of farming with low environmental impact but high returns. The learning from the projects and replication tendencies should be guided so that farming activities are not practiced anywhere. They should be carried out in designated areas to maintain the balance between the commercial venture and environmental wellbeing. Learning from elsewhere has found that farmers with little knowledge of ASAL try farming activities anywhere regardless of ecological suitability neither growing appropriate crops resulting in frequent crop failure. In addition, the project should attempt to generate progressively sustainable economic earnings from farming without disrupting the social, cultural and environmental integrity of the community on which it depends. The low investment costs, modest prices and almost immediately return to the community are three factors integral to the success of the project;
- ***Gender Mainstreaming in the Project***: The project should strive to ensure the farming venture expands economic welfare for both men and women (e.g. that do not unfairly benefit one cultural group or gender). At the same time productivity in labour markets (and leads to the emergence of labour markets) could consider focusing on market-driven approaches to improve the effectiveness, impact and sustainability of the intervention. Management of the water infrastructure should strongly integrate women as they are more involved in water management as well as in crop farming activities;
- ***Controlled Land Use***: Controlled land use and buffer zone creation to prevent human encroachment to fragile habitats/ ecosystems;
- ***Ensuring Sustainable Agricultural Practices***: Balance economic, social and environmental issues through the promotion of water conservation practices and sustainable agriculture, i.e. application of hydroponics and vertical farming works for intensified production yet reduced water demand;
- ***Focus on Achieving Twin Beneficial Outcomes***: The integration of environmental considerations into development planning and management of the project.

7.3.2.2 Social feasibility measures

The social feasibility component should blend organically with other components and not in any way minimize the importance of technical, economic and operational feasibilities but play a complimentary in determining the viability of the project. This social feasibility looks into the following key measures:

- Acceptability and willingness of the local communities to participate in the project;
- Equitable Distribution of benefits;
- Gender Dimensions;
- Child Labour;
- Agrichemicals effects.

Acceptability and willingness of the local communities

The community in the project area (host and refugee) are generally pastoralists. Crop production is one of emerging non-traditional livelihoods being adopted as a strategy to avert pastoral related risks and build household resilience. Moreover, changing the lifestyle of the nomadic pastoralism to sedentary settlement pattern will allow people to engage in farming activities. This study has demonstrated that communities are slowly adapting and are more receptive to the concept of agriculture.

However, the knowledge and skills of the communities to engage in agriculture is weak. Therefore, the project needs to undertake a great deal of capacity building, sensitization and encourage local participation. Indeed, the project can have improved outcomes by working towards local acceptance and ensuring more active local participation.

Equitable distribution of benefits, gender mainstreaming and pricing for water use

This will involve the project working out a framework for determining how it can benefit local communities and other stakeholders and promote local ownership and support for the project. The fundamental objective of the project towards promoting equity will be how to organize the beneficiary communities in order to obtain continuing joint benefit to achieve sustainable socio-economic development. The WASREB tariff structure provides guidelines on how different costs of water and sanitation services are charged to different customers to ensure affordability. This structure should be applied while considering putting in place "pro-poor" policies that allow for the provision of a lifeline tariff for poor households.

Gender dimensions

This study has shown that women play a central role in securing domestic and watering livestock. It has also revealed that women are more involved in agricultural activities as compared to their counterpart male. Towards ensuring the sustainability of the project, it is imperative that women be more involved in the governance and management of agricultural activities. By engendering project development through promoting gender equity, will also impact positively in poverty reduction in the project area, since large gender disparities in basic human rights in resources and economic opportunity as well as in political voice are inextricably linked to poverty.

Mainstream the gender perspective in the project is not only a globally recognized fundamental human rights and social justice, but it is a growing awareness that equality is a pre-condition for sustainable development and sustainable use of development facilities as well as resources. Equality means - equal rights, opportunities and responsibilities for men and women. Moreover, the gender dimension objective can be achieved through the application of a rights-based approach (RBA) by the project.

RBA provides for the inclusion of the rights of women into the development process. Using an RBA ensures that women are involved in making decisions, project identification and implementation. The inclusion of youth is also important, and they should be actively engaged for they are more energetic. RBA also advocates for consideration of the elderly and those living with disabilities. The definition of the right to water and sanitation is provided by the General Comment 15[57]: The Right to Water adopted by the United Nations Committee on Economic, Social and Cultural Rights and the Guidelines for the Realization of the Right to Drinking Water Supply and Sanitation adopted by the UN Sub-Commission on the Promotion and Protection of Human Rights. A human rights approach to water and sanitation means that individuals and communities are entitled to demand that laws, policies and practices respect and promote human rights standards. In the study area, communities have three main concerns with water: access, cost and quality.

Child labour

Projects of such a high magnitude in many instances have child labour sourced where there is insufficient workforce. The Kakuma-Kalobeyei area is dominated by a culture where women and children are the sources of labour. This forces children to drop out of school and hence the illiteracy levels persist. Whereas the short-term income gains may impact positively and appreciated by the beneficiaries, this causes consequent under-development in such marginalized areas in the long-term.

Agrichemical effects

The scale of this project is big and the use of chemicals is foreseen. Prolonged use of chemicals has negative effects on the environment. This affects the biotic and abiotic factors negatively and should therefore be regulated. Monitoring of effluent from irrigated areas and the impacts should be done.

7.3.3 Legal measures

The water and environmental legislation are generally clear, and the administrative systems are well developed. However, capacity at different levels to implement the legislation is still weak. Specific areas that require extra support include:

- Supporting WRA to develop a holistic surface and groundwater allocation plan for the Tarach catchment, encompassing the essential aquifers for the Kakuma water supply. That plan should ensure that commercial development requiring water resources can be undertaken in which domestic and livestock water supplies are safeguarded;
- Development of water resource user associations (WRUAs) within the area to provide structures for community engagement in water resource management. This will become increasingly significant as more surface, and groundwater resources are committed for commercial uses and structures like large dams built that can change the natural hydrology;
- Tighter regulation of rural community-managed water sources to ensure more reliable services are delivered and proper investments are made in the operation and maintenance of the infrastructure;
- A land-use plan, agreed with stakeholders, for the wider Kakuma-Kalobeyei area, will clarify which areas are available for agricultural development and which areas are set aside for livestock grazing and other uses (residential, commercial zones).

7.4 Economic Feasibility

Determine the economic feasibility of the introduction of agribusiness with attention to the costs of possible measures that need to be taken

Economic analysis is used for evaluating the effectiveness of the proposed introduction of agribusiness in the project area in terms of the potential measures, while not conducting an extended analysis. Therefore, economic feasibility will particularly look at:

- Costs of enhanced water supply for agribusiness;
- Costs of water treatment in case of deficient water quality for irrigated crops.

57 Committee on Economic, Social and Cultural Rights General Comment 15: The right to water (articles 11 and 12). See: http:// www.unhchr.ch/html/menu2/6/gc15.doc.

After review of the economic and social aspects, the growing of peanuts may contribute to improving the lives of the refugee and the host community. However, water sourcing could be a challenge since the actual volume that can be abstracted for agricultural use is still unclear. Therefore, more geophysical investigations in the recommended target areas need to be done. This should be followed by exploration drilling to determine the quantity and quality of the available water. Similarly, the intended purpose (groundnuts irrigation) should also follow the same approach where few boreholes should be done initially for project testing and more added progressively to avoid huge capital costs losses. The success or failure of the initial phase should determine the project future. Opportunities for further research could address alternative sources of income for the proposed facility.

7.4.1 Surface water options

Thomas and Gikone (2018) set out cost estimates for different water supply development options to support agricultural production. These costs are compared in Table 7-2, and indicate that spate irrigation provides the cheapest cost per ha followed by the development of a 30,000 m³ pan and associated diversion works.

Table 7-2: Cost estimates for water development options

Item	Detail	Qty	Unit Price Water Supply (USD)	Farming Area (ha)	Irrigation Setup Costs (USD)	Total Cost (USD)	Cost per Farmed Area (USD/ha)	Comments
Spate Irrigation	Gabion structure, lateral embankments	1	21,130	32	-	21,130	660	
Diversion works, pan	Gabion structure, 30,000 m³ pan	1	197,777	3	63,460	261,237	87,079	
2No. Tarach BH & delivery pipe (farm adjacent to river)	2No Bhs, 1No 500m³ GS tanks, pumping systems, 2km piping	1	309,400	3	63,460	372,860	124,287	Reliable Supply
Tarach Dam	Tarach Dam[1]	1	155,000,000	650	137,497	155,137,497	238,673	Reliable supply plus domestic water
2No. Tarach BH & delivery pipe (farm located in Kalobeyei)	2No Bhs, 2No 500m³ GS tanks, pumping systems, 10km piping	1	784,640	3	63,460	848,100	282,700	Reliable Supply
Farm Pond	474 m³, PE liner, SF1 pump	1	12,520	0.04	0	12,520	313,000	SF1 pump shared between 2 farms
Roof harvesting	4.6m³ PVC tank, gutters, downspout	1	620	0.0012	0	620	516,667	

Notes:
1. The Tarach Dam and associated infrastructure is estimated at KES15.5 Billion

7.4.2 Groundwater options

7.4.2.1 Estimated costs

All costs in this paragraph are expressed in Kenyan Shillings (Kshs or KES).

Groundwater investigations and borehole drilling cost

The cumulative cost for the hydrogeological surveys for the 84 boreholes is estimated at approximately Kshs 17,084,745. The initial capital cost for the project is Kshs 575,029,308. Total annual operation and management cost is Kshs 35,715,263. The Ultimate Capital Cost for the Design Period of 25 yrs is estimated at Kshs 660,912,168, while the Ultimate Operations & Maintenance Costs for 25 yrs is estimated at Kshs 694,407,728. The tabulation is given in Volume 2, Chapter 2.8 (Annex 11).

Environmental impact assessment forms part of such projects and is therefore advisable to have a complete assessment before project kick-off. An approximate cost of Kshs 500,000 is foreseen for the environment impact assessment for the project.

Note: These values are crude estimations overview prior to the implementation stage. The actual values can only be ascertained upon kick-of confirmation and the following procedure can apply:

1. Confirmation of project site upon approval by the County and National governments
2. Determination of approximate groundwater volumes required in the supply system (out of the total supply volume required per day)
3. Geophysical survey in the targeted recommended sites after authorization by the local and County governments to ascertain the exact drilling locations and depths
4. Reporting with BOQs appended
5. Exploration to drill authorization by WRA.

Drilling and installation

From water availability assessment, the projected water needed to run the project for 3 seasons equates to an average of 28.2 Mm^3/yr. A proposed allocation plan of 2% abstraction for irrigation purposes from groundwater is insufficient to meet this demand. Therefore, to abstract the proposed amount of water 84 boreholes would have to be developed, and additional other water sources need to be availed to augment the need. 84 boreholes, each yielding 20 m^3/hr is estimated at a cost of Kshs 218,169,000 (US $ 2181690).

Operation and maintenance

Training of the operations personnel and local counterparts is paramount at the start of the project to ensure a skilled approach to the O&M. This includes pumps and engines, plumbing, pipefitting, bookkeeping and water supply management.

The main aspects of being considered in the assessment of O&M costs are:

Regular operation of the system i.e.

- Manpower
- Power consumption (fuel)– Genset
- Power consumption -Grid electric power
- Support services

Need for regular preventive maintenance and monitoring i.e.

- Servicing of pumps and equipment
- Replacement of parts and items
- Technical advice and guidance

Need for periodic overhaul and replacements

- Pumps
- Water treatment (Guided by the results of exploratory drilling results)
- Structures e.g. intake tanks
- Improvements foreseen during designing

Sustainability

Post-construction monitoring is necessary to keep track of the status of the boreholes. During one year of operation, it will be necessary to occasionally review the water supply system, operation and maintenance plans and costs to find out whether they match the design plan.

Capital investments

The major capital investments include:

- Cost of Boreholes Drilling and installations (presented in Volume 2);
- Storage Facilities Costs (Presented in Volume 2);
- Reticulation system and installation.

Foreseen operation and maintenance costs

Operation and maintenance

The estimated O&M costs will apply as presented in the table below:

The estimated Capital, Ultimate, O&M costs will apply as presented in the table below. Full calculations table is presented in Volume 2, Chapter 2.8 (Annex 11).

Table 7-3: Estimated capital, ultimate and O&M costs for the project

Component	Capital Costs (KES) total	Ultimate Capital Cost for the Design Period (25yrs) (KES)		Annual Operations & Maintenance Costs total (KES)	Ultimate Operations & Maintenance Costs (25yrs) (KES) for 1	Ultimate Operations & Maintenance Costs (25yrs) (KES)
Boreholes	218,169,000.00	218,169,000.00		10,908,450.00	920,981.00	77,362,412.00
Pumps	42,000,000.00	73,750,000.00		2,100,000.00	625,000.00	52,500,000.00
			Monitoring personnel	2,181,690.00	649,312.00	54,542,250.00
			Environmental	654,507.00	194,793.00	16,362,674.00
			Management and operators	2,181,690.00	649,312.00	54,542,250.00
Instruments and testing apparatus (monitoring)	2148,837.00	7,546,511.00		654,507.00	194,793.00	16,362,675.00
Pipeline (Initial purchasing and installation)	99,627,906.00	87,470,930.00		3,985,116.00	1,186,046.00	99,627,906.00
			Running costs	996,279.00	296,511.00	24,906,976.00
			Salaries	996,279.00	296,511.00	24,906,976.00
			Repairs	996,279.00	296,511.00	24,906,976.00
			Infrastructure maintenance	996,279.00	296,511.00	24,906,976.00
			Pipeline security	996,279.00	296,511.00	24,906,976.00
Access Roads	29,302,325.00	51,453,488.00		879,069.00	261,627.00	21,976,744.00
Storage tanks 250m³ (59 No)	139,953,488.00	139,953,488.00				
			Tank cleaning	996,279.00	296,511.00	24,906,976.00
			Salaries for tank attendants	996,279.00	296,511.00	24,906,976.00
			Repairs	996,279.00	296,511.00	24,906,976.00
Generators (59No)	42,000,000.00	147,500,000.00		2,100,000.00	625,000.00	52,500,000.00
			Repairs and Servicing	420,000.00	125,000.00	7,375,000.00
Environmental Impact Assessment	500,000					
Miscellaneous	1,327,749.00			1,680,000.00		42,000,000.00
Total	**575,029,308.00**	**660,912,168.00**		**35,715,263.00**	**7,803,961.00**	**694,407,728.00**

NB: The actual cost can only be established once the design and drilling phase has been completed.

Calculation of O&M costs

The main aspects considered in the assessment of O&M costs are:

Table 7-4: Calculation of O&M costs for the project

Regular operation of the system	Manpower Power consumption (fuel) – Genset Support services Administration cost
Need for regular preventive maintenance and monitoring	Servicing of pumps and equipment Replacement of parts and items Technical advice and guidance Water treatment (only to be verified upon drilling)
Need for periodic overhaul and replacements	Pumps Structures e.g. intake tanks Improvements foreseen during designing
Operational personnel	
Operators-in-charge	Assistant operators/Meter readers Pumps Plumbers/fitter Line Patrol men/Laborers Watchmen

Project viability based on recovery costs

Possible management hypothesis

Once sufficient water quantities are achieved and a water supply system designed, an appropriate management option should be adopted to ensure proper running of the system.

8 Summary and Conclusions

8.1 Rainfall and Climate

Due to the lack of observed rainfall records, rainfall estimates are based on the remotely sensed information. These indicate a mean annual rainfall in Kakuma of 280 – 320 mm rising to 380 mm towards Kalobeyei center and rising with elevation in the highlands to the south of Kakuma to a mean of 500 – 550 mm per year. An average value of 320 mm was used for most of the calculations in this study.

For the annual evapotranspiration, a value of 2714 mm was used throughout the study.

Climate change analysis indicates an increase of 4 – 12% on mean annual rainfall, a shift in rainfall pattern with an earlier onset of the long rains and the short rains, with less rain in the dry season between, and a reduction in the number of raindays. Temperatures are likely to rise by 1.5°C. Uncertainty in the future climatic conditions implies that water storage and irrigation will become increasingly important for a reliable agricultural development.

8.2 Surface Water Potential

The catchments within Turkana West sub-county have been delineated based on a 30 x 30 m DEM to explore surface water potential across different catchment sizes and in different locations, as rainfall and soil conditions vary.

The surface water analysis is based on synthetic streamflow data from AFDM and published regional values. These indicate an annual runoff coefficient of 4 – 7.5% for large to smaller catchments. The results indicate significant availability of surface water across the different catchments. For example, the mean annual runoff volume on the Tarach lagga at the Kakuma bridge is estimated at **79.8 MCM/yr**. Most streams, are, however, ephemeral and storage devices are necessary to make practical use of surface water for e.g. irrigated agriculture.

8.3 Water Storage Options

8.3.1 Large dams and Tarach Dam

The only large dam currently under consideration within Turkana West sub-county is the Tarach Dam located about 40 km upstream of Kakuma town. The Feasibility Study for the dam evaluated alternative options and concluded that the dam presented the best option to meet the domestic and livestock demands with sufficient yield for 60 ha of irrigation.

This study has undertaken a basic yield analysis for different scenarios related to dam height and irrigation area and concludes that an irrigation area of 650 ha may be possible with a dam height of 14 m, i.e. higher than the present plan for 11 m. Further yield analysis is required to refine this estimate. However, the analysis indicates that further investigations of the Tarach Dam are warranted, including exploring higher wall heights, which may create an opportunity for a significant area under irrigation and investigating the potential sediment capture in the dam.

The environmental impacts of a potential Tarach Dam need to be explored in detail as the dam could have a negative or positive impact on the recharge of the Kakuma aquifer on which the current water supply for Kakuma town, Kakuma refugee camp and Kalobeyei Integrated Settlement Scheme depend. It is noted, though, that there is a catchment area on the Tarach lagga of about 1,900 km² downstream of the Tarach dam, which would continue to provide natural flows towards the Kakuma aquifer.

8.3.2 Small dams and pans

Small dams are site-specific, and therefore, only detailed fieldwork would reveal suitable dam sites. Investigations undertaken for FAO (Thomas & Gikone, 2018) indicate a low potential for dams in the Moru Itai Hills to the South of the Kalobeyei Settlement Scheme.

However, the potential for water pans to support agricultural (and livestock) development is extensive as the structures can be located in reasonable proximity to watercourses, where the topography is reasonably flat, and the land is suitable for agricultural production. Analysis for this study indicates 133 km^2 of land within the Tarach (Kakuma Bridge) and Napas (Kalobeyei bridge) catchments that is considered highly suitable for pan development. It should be noted that specific site conditions should be investigated, and water resource analysis should be undertaken for each site.

8.3.3 Sand dams and subsurface dams

The sand dam and subsurface dam technology is appropriate to ASAL climate areas such as in Kakuma-Kalobeyei in watercourses with sandy/gravelly alluvial material but requires site-specific identification and investigation to develop robust structures. The technology can provide good quality water, although typically the limited water storage volumes constrain the supply to domestic and livestock uses only.

8.3.4 Rainwater harvesting

Rainwater harvesting covers a range of systems in which rainwater is captured from roof, rock surfaces or impermeable surfaces and channelled into tanks. This technology can offer good quality water in close proximity to homesteads, thereby reducing the burden of fetching water; a burden that is disproportionately carried by women and girl-children. The small-scale nature of these systems typically provides water for domestic use and rarely is sufficient to cover any significant irrigation applications. In addition, in an ASAL area, the rainfall is erratic, which means the systems cannot provide a high level of reliability. Backup water sources are generally required.

8.3.5 In-situ soil water conservation

In-situ soil water conservation technologies focus on enhancing soil moisture sufficient to ensure a successful cropping cycle, without significant infrastructure requirements. There are various arrangements, but all of them focus on minimizing runoff, concentrating runoff to the cropping area, minimizing evapotranspiration and enhancing soil health, plus crop selection and opportunistic farming to suit the climate and seasonal conditions. These technologies have been promoted for many years in Turkana West sub-county with good success in places. It does not offer the reliability of crop yields that may be gained from an irrigated crop but can significantly enhance the reliability and yield under near-normal conditions.

8.4 Hydrogeology

- The geology and hydrogeology are clearly quite complex resulting in a mix of high yielding, low EC boreholes and low yielding, high EC boreholes;
- Three distinct aquifers can be distinguished in the area: shallow, medium and deep;
- Groundwater has been extensively exploited in the Kakuma-Kalobeyei area with more than 61 currently operational existing boreholes. There are over 115 boreholes in the study area. However, the conditions for almost half of them is unknown;
- This assessment concludes that there is a promising potential for further groundwater exploitation within the Tarach lagga corridor, Kalobeyei area and the region to the East of Kakuma for the intended groundnuts farming. However, there is insufficient information on the safe yield of the aquifers present in targeted areas;

- The exploitation of the groundwater requires prior comprehensive geophysical investigations and careful and competent drilling. A regional, extensive, and state-of-the-practice geophysical survey should be carried out, investigating to a depth of say 200 m. This would map out aquifers, structures, depth to rock, and near-surface alluvial bodies. Surface, airborne or drone-based, and borehole geophysics should all be considered;

- Groundwater exploitation is unlikely within the new Kalobeyei re-settlement area due to high salinity levels, unless the water is sourced from far north towards the Lotikipi basin along the Tarach lagga course;

- The fractured volcanic aquifer has lower transmissivity values than the sandy aquifer. Therefore, boreholes yielding water from such volcanic are less productive;

- The water table elevation shows depressions at the locations of boreholes exclusively exploiting the fractured aquifers;

- Monitoring data, consisting of joint observations of the water table elevation data with electrical conductivity variations, confirm the existence of at least two aquifer units with little information about the deep aquifer. This monitoring data highlights the difference in water production between these units and confirm the existence of recharge processes through the laggas beds. Long-term monitoring data for boreholes is not available;

- There is a constant decrease in the respective maximum daily water table elevation for all the boreholes until a substantial rain event in the area or upstream flow is experienced;

- Upstream boreholes (BH-UNHCR and BH1) are characterized by the highest standard deviation in mean maximum and minimum water table elevation;

- The alluvial aquifer comprises sands and sandy soils, gravels, and even boulders. These aquifers are highly transmissive; hence, it is postulated that the lateral flows from the adjacent hydrogeological systems are the main source of recharge for these aquifers;

- Production boreholes drilled by UNHCR in 2016 wells targeted the alluvial aquifers at shallow depths of 56 to 74 m bgl. The resulting yields vary between 45-29 m^3/hr. Most of the yield comes from the gravels, and most of the fluoride comes from the Volcanics.

8.4.1 Recharge

- Recharge into the unsaturated zone, and the shallow alluvial aquifer occurs through direct infiltration by rainfall and run-off along the major laggas during the periodic flooding seasons. The average change in the piezometric levels during different seasons is estimated to be 0.41 m. This indicates that precipitation and direct infiltration has got meagre impacts on the groundwater storage;

- Recharge into the medium-depth, and deep aquifers occur mainly through lateral flows from adjacent aquifer systems and/or deep percolation enhanced by structural controls and favourable hydraulic conditions, although there is currently little or no evidence apart from the structural lineaments in the western part of the area and a few individual borehole test pumping data within Kakuma refugee settlement area;

- Total annual recharge has been estimated at $2.59*10^8$ m^3/yr (259 MCM/yr). This is achieved by determining the difference in groundwater inflow and outflow (balance from the groundwater flux and change in storage in the unsaturated zone) in Kakuma-Kalobeyei area of interest.

8.4.2 Aquifer storage

From the available abstraction data and the estimated recharge values, it is considered that the draft does not surplus the rate of recharge, hence the assumption that the whole volume of the aquifer is saturated.

- **Shallow aquifers**

  Depths of up to 35 m bgl (the medium aquifer extends even beyond these levels, but it is not certain whether this is alluvial or whether those are faults that provide the recharge). The areal extent of shallow aquifers within Kalobeyei and Kakuma area is $5.14*10^8$ m^2. Aquifer thickness of 6 m is taken as the average and the porosity of the water bearing sediments is taken to be 10%. Total estimated aquifer storage is $3.09*10^8$ m^3 (309 MCM).

- **Medium aquifers**

  Depth of between 35-80 m bgl (from BH logs and previous geophysical interpretations). Aquifer thickness of 6 m on average, total areal extent of the aquifer is $7.16*10^8$ m^2. The total estimated aquifer volume taking into consideration a 5% porosity of the aquifer material equals to $2.15*10^8$ m^3 (215 MCM).

  The total aquifer volume within Kakuma and Kalobeyei for the shallow and medium-depth aquifers is **$5.23*10^8$ m^3** (523 MCM) and hence the volume of available water stored in the aquifers.

  The above two calculations have been made from primary data from BCRs.

- **Deep aquifers**

  The thickness of the deep aquifer was only estimated based on data from 1 borehole. The estimated aquifer storage by RTI (2013) is 248 BCM, taking into account 200 m of water column. This data cannot be fully relied on and hence ground truthing is necessary. The water is probably saline, but data are not conclusive.

Summary of aquifers in Kakuma-Kalobeyei area

The area is characterized by three aquifers i.e. the Shallow aquifer, Medium aquifer and the Deep aquifer. The summary of the respective aquifer characteristics is given in the table below.

Table 8-1: Summary aquifers in the study area

Aquifers	Areal Extent (m^2)	Lithology	Depth (m bgl)	Thickness (m)	Storage (m^3 / MCM)	Postulated Water Quality
Shallow Aquifers (Tarach and Kalobeyei Aquifers)	$5.14*10^8$	Alluvium	0-35	6	$3.09*10^8$ / 309 MCM	Fresh water
Medium Depth Aquifers (Lotikipi and Volcanic Aquifers)	$7.16*10^8$	Tertiary Volcanics	35-80	6	$2.15*10^8$ / 215 MCM	Fresh to saline water
Deep Aquifers	-	-	>80	-	-	Saline water

8.4.3 Water balance

Evapotranspiration (Et) rate is extremely high (2714 mm/yr) as compared to the annual average precipitation (P) value (320 mm/yr), most of the water is lost into the atmosphere and little to nothing is left for the groundwater recharge. However, Et doesn't affect the deep groundwater zones, this groundwater flows through deep percolation. Using the Darcian flow method, it is estimated there is a significant amount of groundwater. The recharge of **$2.59*10^8$ m^3/yr** (**259 MCM/yr**) is what remains when the water balance in both side of the equation is struck. Hence, this value should be a benchmark, and it should not be exceeded when abstracting groundwater.

The above recharge value has been used to calculate and estimate the number of boreholes (i.e. 84 boreholes, each with an average estimated yield of 20 m^3/hr.) that could be used to abstract water for irrigation of peanuts.

8.4.4 Water quality

Water quality data in all the cases is an average of all the aquifers penetrated in all the sampled boreholes; the logging and water quality monitoring did not consider the individual aquifers struck during drilling. Units were not hydraulically isolated or discretely sampled.

Electrical conductivity

- The water quality in the area based on EC is generally good apart from a few boreholes drilled beyond the alluvial formation;
- Moderate EC values for boreholes in the area suggest influence from upper sand layers;
- Boreholes in Kalobeyei area show EC values that range between 550 µS/cm and 1,448 µS/cm which are within the WHO's and KEBS drinking water standards.

Fluoride

- Fluorite is the principle fluoride mineral in igneous rocks and is the reason why groundwater in volcanic settings contains high fluoride concentrations;
- Fluoride concentrations in the boreholes yielding water from the alluvium are low while those yielding water from the volcanic have high fluoride concentrations;
- The fluoride concentration levels in the study area range between 0.5 and 10 mg/l, which means the levels are slightly higher than the KEBS recommended levels of <1.5 in some of the boreholes.

Iron

- The iron concentration levels in the study area range between 0 to 0.04 mg/l, which are within the acceptable recommended levels by KEBS (<0.3). In the Kalobeyei area, iron concentration levels are expected to be a little higher when compared to the Kakuma area. This is also seen in the Kalobeyei borehole, which has the highest iron concentration of 0.04 mg/l. This is because the geology in the Kalobeyei area is mostly composed of basalts and basalts are iron-rich rocks. Corrosion of the steel pipes and casings could also attribute to the presence of the iron, bearing in mind that the supply system in Kalobeyei is basically via galvanized iron pipes.

Manganese

- From the examined boreholes, the manganese concentration ranges from 0 to 0.23 mg/l. This range falls within the acceptable recommended levels by KEBS (<0.5);
- The use of fertilizer with manganese bound compounds by the small-scale farmers in the area could be the reason why manganese was detected in some of the boreholes that previously had zero manganese concentration, although there are no nitrates elevations noted.

Bacteriological analysis

- Coliforms were present in all the boreholes. The presence of coliforms shows the hydraulic connection between the groundwater with the surface water. This connection helps us to establish and conclude that the recharge of the aquifer units is surface water, which is polluted by human/animal defecations.

8.4.5 Water treatment

Water treatment has been practiced in the study area, especially in the refugee camp, by chlorination of domestic water supply in the UNHCR programmes. However, there are no water treatment facilities outside the camp and raw water is consumed. This could pose health risks to consumers.

Water treatment for agricultural use in the study area could be un-economical bearing in mind that the application of methods such as defluorination and desalination is very expensive and even where they are practiced, it is basically strictly for drinking water only. The various methods of water treatment are outlined in Volume 2, Chapter 2.7.2.

8.4.6 Economic feasibility

The cost implications of borehole drilling, operation and maintenance vis-a-vis the profit margin could be unsustainable despite a ready market of groundnuts. Opportunities for further research could address alternative agricultural products whose water requirements are low and could provide additional sources of income for the community. Upon successful exploratory drilling to determine the quality and quantity of the water in the targeted aquifers (alluvial, volcanic and the deep aquifer) then their feasibility will be determined.

8.4.7 Impacts of abstraction on aquifers

- Groundwater is the principal source of water in the study area (Kakuma);
- Abstraction monitoring has not been practiced efficiently, and hence the state of the aquifer is not clear;
- The Kakuma aquifer is at risk of over-exploitation since there is no other water source being utilized. Inefficient abstraction regimes that can lead to overexploitation could result in saline water intrusion into fresh water-bearing aquifers, especially when the amount of abstraction exceeds the recharge rate from laggas/rainfall, hence limiting the groundwater usage purpose for peanut cultivation;
- From the deep Lotikipi borehole data and other available data, it is concluded that there is a layer of saline water below depths ranging above 80 m in most areas. The depth of saline interface interactions with the overlying layers is not clearly defined. The unavailability of this key information deters the estimation of the safe yield. This leaves room for doubt on how much water should be abstracted and how the current abstraction is affecting the upconing of the saline layer.

8.5 Potential for Agricultural Production and Agribusinesses

The past efforts mainly support dryland agricultural production through the use of in-situ soil conservation practices such as trapezoidal bunds, spate irrigation and conservation agriculture. The experience provides local experience and know-how on farming within the harsh climate of the Kakuma-Kalobeyei area. Recent trials by the Turkana County Government, FAO and Egerton University on farming groundnuts indicate that there is significant potential for upscaling. It is clear that the climatic conditions make reliable production difficult without irrigation, but the development of pans linked to irrigation systems and the use of hydroponics indicates that there is potential that can be developed. Furthermore, the local population (host and refugee) provide a ready market for fruit and vegetables.

8.6 Social Issues

- Livestock production, which is a purely nomadic or semi-nomadic system, defines the livelihoods of the project area's population. The capacity of the pastoral communities to manage livelihood shocks and risks have been disrupted by climate change and the cyclic and frequent occurrence of droughts. Livelihood options outside livestock production are narrow, and in the event of shocks and risks, livelihoods are rendered vulnerable. Owing to challenges faced in pastoral production, agro-pastoralism is increasingly being practiced as a strategy to avert livelihood related risks. Crop farming was mentioned as one of the emerging activities for gaining livelihoods. Whereas rainfed agriculture is the most common agricultural form used, the potential for large irrigation schemes exists as the communities are slowly adapting sedentary lifestyles and are more receptive to the concept of agriculture. UNHCR and partners have made substantial efforts in activating farms along the laggas around the Kakuma area and in the Lokipoto area along Tarach lagga, with small irrigation systems;
- Land is a key resource supporting primary production of the pastoralist. Land tenure is mainly communal owned through the clan system. According to the Kenyan Constitution, any unregistered community land shall be held in trust by County governments on behalf of the communities for which it is held;

- Women are responsible for securing household water needs and also play a significant role in watering livestock, especially the young ones who are left behind as the rest are grazed away from homesteads. However, only a third of water management committees (WRUAs) are women. Most of the water user associations are weak, have received minimal or no training in management, and most have no technical know-how on water infrastructure repairs.

8.7 Legal and Administrative Issues

The legal framework for water development in the Kakuma-Kalobeyei area is generally well defined through the Constitution, which provides certain responsibilities for the national and county governments. These responsibilities are reflected in the prevailing legislation, most notably the Water Act, 2016 and the EMCA, 1999. Institutional capacity weakness means that certain aspects of the legislative framework have yet to be fully implemented. These include:

- The development of Water Resource User Associations (WRUAs) to enable better engagement of communities and stakeholders in water resource management;

- With the rising demand for the water resources, the need for clear water allocation and development plans with full stakeholder support and engagement are needed;

- Tighter regulation on water resources development is needed. This applies to the siting, drilling and development of boreholes, as well as surface water development. One obvious aspect to tighter regulation is the acquisition of data by WRA to populate the water resources information database;

- The rural landscape has numerous community-managed water supplies that function poorly and remain outside regulatory structures. Tighter regulation would ensure that this infrastructure is better managed and able to provide more reliable services.

8.8 Existing Data from Previous Sources

This study showed that important data gaps are still present. An extensive field campaign in the region of Kakuma and Kalobeyei would be needed to physically validate the actual number of boreholes and shallow wells in the region, and their status. This would help in formulating a water allocation plan.

9 Recommendations

9.1 Overall Recommendations

The study of the possibility for the development of agribusiness in the Kakuma and Kalobeyei region shows that there is potential for implementation of irrigated agriculture in general. However, given the present stress on the water resources, particularly evident from the water supply to the refugee settlements, such a development requires investment in infrastructure. Both surface water and groundwater sources can be made available but need special attention in terms of more detailed assessments.

With regard to surface water, the erratic rainfall implies that a substantial storage is required to make irrigated agriculture feasible, i.e. a combination of low storage dams, water pans or, in case a larger region needs to be addressed, a major storage device like the Tarach dam. For pan development, the analysis here indicates that there are significant quantities of suitable land (133 km^2), but this requires site-specific study of the conditions and possibility to fill the pan by an off-take from a lagga. Small dams and sand dams provide in general only resources for water supply and livestock.

For the Tarach dam it is shown that the present design should be revised with a higher dam, e.g. +14 m instead of the 11 m in the present design. This dam may provide the most economical and reliable solution for water supply to the Kakuma-Kalobeyei area and offer the possibility of significant irrigation supply, possibly supporting as much as 650 ha under irrigation.

For groundwater, there is serious doubts regarding the deep groundwater that was supposed to be a promising source from a study of RTI (2013). Particularly the water quality is probably not suitable for irrigation because of high salinity levels, but this can only be determined by additional geophysical surveys in the recommended target areas followed by borehole drilling and water analysis. Concrete possibilities are posed in the shallow aquifer, particularly along the laggas, but here water quality needs special attention as contamination from sewage forms a threat to the water quality. In the deeper (middle) aquifer, fluoride levels need to be monitored closely. Evidently, there is a connection between the surface and groundwater and any further planning should pay attention to this connection to avoid negatively impacting the present groundwater abstractions for water supply. In terms of costs, preliminary estimates are provided in the report for both the Tarach dam extension and the implementation of new boreholes, with a total number of 84 boreholes as an example based on present knowledge of the groundwater potential.

The cost implications of borehole drilling, operation and maintenance vis-a-vis the profit margin could be unsustainable despite a ready market of the groundnuts. Opportunities for further research could address alternative agricultural products whose water requirements are low and could provide additional sources of income for the community. Upon successful exploratory geophysics and drilling to determine the quality and quantity of the water in the targeted aquifers (alluvial, volcanic and the deep aquifer) their feasibility can be determined. However, at all times the groundwater supply for drinking water in the area should not be negatively influenced by any further development.

In this report, both the option for the cultivation of groundnuts and other crops are being considered. In case a project is prepared to commercialize groundnut farming, it is important to note that the variety of groundnut to be planted will be key since highly therapeutic foods need to be produced that meet international standards, especially in relation to aflatoxins levels. For this reason, not all available types of seeds should be used, as protein, oil and other nutrients contents vary depending on seed type.

With respect to land ownership, private investors are unlikely to invest in agricultural production unless leases for land can be secured. This will require support from the County Government and local politicians to engage with the local community to enable land leases to be released to private investors.

Commercialization of groundnut farming presents a ready market opportunity to farmers, job opportunities to refugees and the host community, and the possibility of funding in the form of selling machines to farmers which could be organized through Insta Products.

More details on the recommendations are given in the following paragraphs.

9.2 Surface Water Potential

The surface water analysis is entirely based on synthetic rainfall and streamflow data as there are very few useable records of rainfall, climate and streamflow. It is highly recommended that KMD, WRA and the County Government design and install a hydro-meteorological monitoring network to inform the water resource assessment for the Tarach and other laggas within Turkana West sub-county. We note that the Turkana County Government has identified the need for weather stations within the Kakuma Spatial Development Plan 2020. It is also noted that the recent hydro-met design undertaken by WRA under KWSCRP does not anticipate a river gauging station on the Tarach lagga. It is recommended that this design is reviewed to include at least three daily rain gauges, one climate station, and at least one automatic river gauging station on the Tarach lagga at a site yet to be determined.

9.3 Water Storage Options

9.3.1 Large dams and Tarach Dam

The review of the yield analysis for the Tarach Dam indicates that the site is definitely worth further investigations in terms of the size of the dam, hydrology, yield analysis and geotechnical conditions with the option of a larger dam (greater than 11 m) being considered in the analysis. This dam may provide the most economical and reliable solution for water supply to the Kakuma-Kalobeyei area and offer the possibility of significant irrigation supply, possibly supporting as much as 650 ha under irrigation.

The O&M challenges associated with the pipeline from the dam site to Kakuma and Kalobeyei need to be investigated in detail as the terrain, lagga crossings and potential vandalism would pose certain risks to the pipeline.

A large dam on the Tarach Lagga upstream will change the hydrology of the lagga and potentially provide positive or negative impacts on the recharge of the Kakuma aquifer. Although there is a 1,900 km^2 catchment area on the Tarach Lagga downstream of the Tarach Dam which would provide natural flows to the Kakuma aquifer, potential impacts of the Tarach Dam on the Kakuma aquifer recharge need to be fully investigated.

9.3.2 Small dams and pans

The analysis here indicates that there are significant quantities of land (133 km^2) suitable for pan development where soil, topography, and proximity to water courses indicate that a pan could be developed. However, individual sites should be identified and fully investigated. The identification of specific sites would require fieldwork and site-specific analysis on the hydrology, soil, agronomic and geotechnical conditions, and site suitability for an offtake structure on the water course.

The potential for small dams is more limited due to the fact that dam sites are very site-specific and the structures require a higher level of technical investigation and design than for pans. Identification of suitable dam sites would require extensive fieldwork to map potential sites after which site-specific investigations would be needed on their feasibility for supporting irrigated agriculture.

9.3.3 Sand dams and subsurface dams

Sand dams and sub-surface dams are a technology suitable to ASAL areas and where conditions in the watercourses are appropriate. Given the sandy/gravelly nature of many of the *laggas* in the Kakuma-Kalobeyei area it would be appropriate to conduct desk and field investigations to identify suitable sites. However, this technology generally provides a water supply sufficient for domestic and livestock use, but rarely for irrigation uses. These technologies can be used to enhance groundwater recharge by increasing water storage within the alluvial river beds.

9.3.4 Rainwater harvesting

Rainwater harvesting systems are typically orientated towards domestic water supply and do not offer an economical and reliable solution for larger-scale irrigation. We do not recommend any further analysis for rainwater harvesting systems to support irrigated farming, but this technology can and should continue to be considered relevant to household and institutional water supply.

9.3.5 In-situ soil water conservation

In-situ soil water conservation practices provide significant benefits in terms of reliability and yield from cropping in ASAL areas. This technology is highly appropriate to the conditions in the Kakuma-Kalobeyei area and should be encouraged widely within the host and refugee communities.

9.4 Hydrogeology

- The Kalobeyei-Napas Lagga (and the area towards Lotikipi) and Tarach Lagga downstream of the refugee boreholes (towards the Lotikipi basin) should be targeted for drilling but spearheaded by geophysics and exploratory drilling to determine potential yield;
- The Kalobeyei refugee resettlement area should not be considered for drilling due to salinity issues;
- The center of interest should be the alluvial aquifers since they are high yielding and have fresh water, while the volcanic formations should be less of a target;
- Previous recommendations by EWL (2015, 2016) and Bauman (2016) suggest further investigations on the potential sites presented in Table 6-3 and Volume 2, Chapter 2.8 (Annex 3) within the Northern Well Field. These are of potential interest for irrigation purposes for either the Kalobeyei Settlement Scheme or for more local farms as they are less likely to threaten existing domestic boreholes. The area west of Kakuma 1 is also of interest and should be investigated;
- Safe yield determination from the abstraction should be considered for the sustainability of the documented aquifers through proper monitoring systems and correct borehole spacings;
- Inexpensive sensors ("smart" pump technologies) attached to electric and hand pumps with small and inexpensive telemetry systems could be used to collect observation data and send it to storage receivers, as earlier installed TRMC devices ceased working in April 2014 and hence real-time observation data is unavailable;
- A comprehensive hydro-chemical survey is recommended to determine the water quality status of the area. In addition, Kakuma based water testing abilities may be considered given the implications of especially fluoride and elevated salinity;
- No geophysics was done after the RTI (2013) study; therefore, a regional geophysical survey using combined methods (seismic, time-domain electromagnetics, nuclear resonance sounding and 2-D resistivity) is highly recommended to augment and confirm results of the previous studies in Kalobeyei and Kakuma area with structural features and also to target the deep aquifers at depths greater than 300m. Airborne methods may also be considered;
- Drilling of exploratory boreholes (including piezometers) to confirm the quality and quantity of all the encountered aquifers in the targeted drilling sites is forcefully proposed. Comprehensive test-pumping of the boreholes should be done in order to determine the aquifer parameters and optimize the wellfield design;
- Development of a well field incorporating sand and sub-surface dams should be considered at a distance downstream of boreholes in the Kakuma refugee camp along Tarach Lagga to increase recharge. This should also be considered in Kalobeyei, especially both up and downstream of the Napas lagga at the Kalobeyei Bridge past Kalobeyei town. This could be economical since the water can flow by gravity to the Kalobeyei re-settlement Camp, where agricultural activities are targeted. Detailed geophysical and hydrogeological studies are recommended in zones A and B as shown in Volume 2, Chapter 2.8 (Annexes 3, 4 and 8) from previous studies carried out in the area based on the groundwater structural controls;

- It is clear that the Kakuma and Kalobeyei areas have an under-developed waste management system exposing the general public to water-borne ailments in the case of leakage into groundwater; this should be looked into and developed;

- Artificial groundwater recharge through the construction of sub-surface dam and dams should be implemented in promising zones along the floodplain, and suitable groundwater recovery points identified where drilling of shallow boreholes (infiltration galleries) can be undertaken;

- A water allocation plan should be laid out by determining the supply potential versus the demand and laying out a water use plan balance;

- A plan must be laid out on the water allocation for the different water users;

- All data, including new data collected, should be placed in a centralized database and key stakeholders should discuss how this data can be managed for future use. The UNHCR or WRA database can be a starting point;

- Restoring functionality and dependability of existing non-operational wells in Kakuma and Kalobeyei is highly recommended (by use of borehole geophysical logging, observations using borehole cameras) as a rapid way of bringing more groundwater on line.

9.4.1 Recharge

- Detailed investigations and exploration of sand dam/sub-surface dam sites along the Tarach and Napas laggas to enhance groundwater recharge should be carried out;

- Exploring opportunities for artificial groundwater recharge in surficial sands and gravels along the Tarach and Napas laggas to increase the surface area of infiltration is recommended.

9.4.2 Aquifer storage

- Aquifers in the region are not properly characterized, further studies with objectives of mapping and assessing the groundwater resources is advised. This would include field expedition to clearly determine the aquifer areal extent, depth, porosity and the aquifer storage for each aquifer in Kakuma and Kalobeyei region;

- Exploratory drilling where comprehensive logging is done will help in ascertaining the aquifer thicknesses and hence estimate the storage capacity.

9.4.3 Water quality

- After completion of the exploratory boreholes in the recommended target sites, a comprehensive water test of 4-5 samples collected after at least 5 hrs of pumping should be done in an authorized water testing laboratory to qualify or disqualify the water for peanut irrigation purposes. Field real-time water quality testing can only be done upon project kick-off;

- Due to the lack of well-distributed data for correlation purposes, a comprehensive water quality investigation is necessary so as to fully understand the water quality status in the Kakuma and Kalobeyei area. This should be done in both the dry and wet seasons to enable identification of saline water-saturated zones;

- Water treatment and especially chlorination should be made a practice in all the water sources which utilize the shallow aquifer and to some extent the deep aquifers since the aquifers are interconnected;

- Large scale water treatment methods for agricultural use could be uneconomical bearing in mind the scale of production that is targeted, however methods such as desalination/deionization, and defluorination can be applied;

- A regular long-term monitoring of water quality should be instituted in dedicated boreholes in each identified aquifer unit;

- Drilling of alternative boreholes in areas of good water quality and piping water to the areas of poor water quality is highly recommended, especially along with the recommended target drilling sites;
- Currently, water quality is not specific to the individual aquifers due to the completion of multiple zones in each well. Exploratory drilling to fully explore the water quality should target, penetrate, and screen across individual aquifers. This should be done in the recommended target sites;
- Borehole construction should target the shallow alluvial aquifers for higher yields and low fluoride. Precautions should be undertaken for permanent installations during borehole construction to avoid groundwater pollution. Thus, a suitable sanitary seal must be installed above the screened section.

9.4.4 Water quality for irrigation

- Water quality should be tested at a laboratory that is equipped to test water for agricultural irrigation purposes to ensure it is acceptable for plant (peanuts) growth and to minimize the risk of discharging pollutants to surface or groundwater.

9.4.5 Wellfield design

- An optimized wellfield design and safe yield determination should be carried out for healthier aquifers;
- The actual number and spacing of these boreholes should be determined using an optimization model based on detailed on-site hydrogeological investigations and exploratory drilling to determine both the physical and chemical aquifer parameters;
- The wellfield design should also bear into consideration aquifer hydrogeological characteristics, environmental, institutional, engineering, socio-economics and O&M considerations;
- Considering the location of new projects are not yet clearly known, assuming the apparent hydraulic conditions of the sediments within Kakuma area, these boreholes should be spaced at around 2 km intervals apart to avoid interference of radii of influence between the existing and the boreholes to be developed.

In addition, the following points should be taken into account when developing groundwater resources:

- The shallow alluvial aquifer is the main reliable source of potable water. It spans approximately 4 km from the axis of Tarach Lagga. The medium-depth sedimentary aquifer extends to about 10 km from the axis of the Tarach Lagga and its smaller network of ephemeral tributaries;
- The most favourable sites for well field development are to the north west of Kakuma town adjacent to the Tarach Lagga;
- Proposed boreholes are recommended along the Tarach lagga targeting shallow alluvial aquifers (<35 m bgl) and intermediate aquifers (35<80 m bgl);
- Careful siting, drilling and design of the boreholes should be done. Appropriate sanitation facilities should be designed and developed to avoid contamination of the shallow aquifer;
- A well field should be set in a low-density residential area to avoid contamination through leakages and broken water infrastructure;
- Water treatment is of importance and should be reconsidered bearing in mind that some of the population scoops holes in the river bed to fetch water;
- A sewerage system should be considered since none exists in the Kakuma town. This is a health risk considering that most boreholes are drilled downstream of Kakuma town;
- Development of efficient water and solid waste management infrastructure is highly recommended.

9.4.6 Economic feasibility

- Since there is a ready market, the other factors involved should be analyzed in terms of groundnut production. The drilling of the boreholes should be in an exploratory approach in the recommended sites, and so the intended purpose (groundnuts irrigation) should also follow the same approach where few boreholes should be done initially for project testing and more added progressively;
- A preliminary estimate of costs for developing and operating 84 boreholes is provided. This should be used as an equivocal template prior to the feasibility and implementation phases.

9.4.7 Impacts of abstraction

- Embark on borehole data, document their characteristics if and where available, and develop a model for groundwater availability and usage;
- There should be special monitoring of aquifer usage in Kakuma; monitoring devices should be installed, and continuous monitoring carried out;
- Overexploitation problems can originate from excessive pumping at individual wells or due to interference from nearby wells; hence, safe yields should be determined so as to regulate pumping in the well field;
- Test pumping of all new boreholes should be done to ascertain the optimum yield of any new borehole;
- Models should be developed to project the impacts of abstraction;
- Monitoring boreholes should be done to access the behaviour of the aquifers in the most promising areas like Napas, and Tarach laggas;
- Crops are sensitive to salinity. In the event of subsequent studies, saline layer should be determined, and the proper test pumping process should be done to monitor the upcoming of saline layer:
- In particular, a well field downstream of the Tarach lagga and at the Napas lagga in Kalobeyei should be investigated to relieve the refugee area well field which is already stressed with no known safe yields.

9.4.8 Existing data from previous sources

- It is important that the Water Resource Authority (WRA) ensure completeness of the data in the BCRs is achieved for complete computation of aquifer parameters.
- An extensive field campaign in the region of Kakuma and Kalobeyei should be commissioned to give insight of the actual number of wells in the region, and their status.

9.4.9 Water development options

Based on the structural geology of Kakuma-Kalobeyei region, further investigation areas are recommended as follows:

- The area to the East of Kakuma town – Zone A in Volume 2, Chapter 2.8 (Annex 8): faults in this area (Pelekech hills) are striking N-S and dipping towards the East and, therefore, investigations should be focused further East of the faults;
- The area of Kalobeyei extending towards the Lotikipi basin – Zone B in Volume 2, Chapter 2.8 (Annex 7). The Strike of the faults is N-S and the dip is towards the West and hence investigations should be done targeting this zone and extending towards the Lotikipi basin;
- Artificial groundwater recharge should be considered, especially along the Tarach and Napas Laggas, after which infiltration galleries should be constructed to tap the recharge;
- Crude estimates from the analysis of the irrigation demand for peanuts v/s groundwater availability suggest the need of about 84 boreholes, pumping 20 m^3/hr.;

- Abstraction can be increased to a higher percentage of the groundwater available as long as 40% of the reserve is preserved. This can be pursued through negotiation and agreement with other stakeholders in the water resource sector.

9.4.10 Additional recommendations

- Fundamental changes in well construction should be considered to understand the causes of borehole failure and to enable water well surveys (borehole-geophysics, borehole camera surveys). For instance, replacing steel-cased wells with PVC-cased wells can facilitate borehole geophysical logging and monitoring;

- The earlier exploratory boreholes drilled by RVWSB do not give sufficient information on aquifer characterization. Therefore, a comprehensive exploratory program is recommended whereby three boreholes are drilled at different depths with the intention of monitoring the aquifer characteristics of shallow, medium and deep aquifers independently. Exploratory drilling supervision should be done by a qualified hydrogeologist.

9.5 Potential for Agricultural Production and Agribusinesses

- Development of a land-use plan for the wider Kakuma-Kalobeyei area is recommended as this will help to delineate areas where agricultural production can be implemented, and areas for livestock grazing can be set aside;

- A detailed soil survey will help to support the upscaling of agriculture within the region;

- Setting up of an information portal under the Kakuma-Kalobeyei Challenge Fund will allow sharing information on agricultural development and results.

9.6 Water Resources Management

- WRUAs should be formed and actively engaged in all aspects of water resource allocation and management;

- A multi-stakeholders forum is highly recommended for the Kakuma-Kalobeyei area to strengthen the planning and management of the water resources;

- All new meteorological, surface water and groundwater data collected should be placed on the centralized database at WRA, and key stakeholders should discuss how this data can be accessed;

- A detailed soil study is necessary to understand the dynamics of soil retention capacity which will aid in selecting suitable sites for dam construction and agricultural engineering practice;

- WRA should initiate a process with the County Government and other stakeholders to develop a water allocation plan for both the Tarach and Kakuma aquifers.

9.7 Social Issues

- Towards resilience building among the pastoral community in the project area, crop farming offers an important opportunity since the community members are already trying both rainfed and irrigated agriculture, albeit in a rudimentary fashion. This provides the project with leverage for intensification in farming practices to increase food security and income. This can be achieved through the promotion of irrigated agriculture and intensification in terms of husbandry practices. According to the Department of Agriculture in the Sub County, there is an opportunity for spate irrigation in the Lotikipi plain area with floods from the Tarach Lagga, Nasinyoro area (has high potential for expansion) and Nanomtor Koyar which has fertile soils with a high potential for beans and maize farming, for example;

- The study has revealed that women are more involved in crop production and are more responsible for securing and management of the household water resources. It is, therefore, prudent for the project to consider mainstreaming gender in all aspects of the project cycle. Community and stakeholders' structures and procedures should embody principles and practices of disaggregation of gender roles - the perspectives, roles and responsibilities of both men and women in the entire project cycle - there should be an elaborated process involved in stages of the project cycle from planning and design stages to implementation, monitoring and evaluation. A major factor is an inadequate capacity to internalize and integrate gender mainstreaming, but it is also the case that many individual professionals lack the commitment to the mainstreaming objectives;

- As the project prepares to commercialize groundnut farming, it is important to note that the variety of groundnut to be planted will be key since highly therapeutic foods need to be produced that meet international standards, especially in relation to aflatoxins levels. For this reason, not all available types of seeds should be used, as protein, oil and other nutrients contents vary depending on seed type. Agronomy activities are the key variable to good crop production, is thereby supposed to be correct. This is guided toward avoiding scenarios where the farmers' produce is rejected after raising his/her expectations of a ready market. Further, the project should invest in sufficient farmer training on agronomical activities to achieve aflatoxin free, or minimal levels;

- Commercialization of groundnut farming presents a ready market opportunity to farmers, job opportunities to refugees and the host community, and the possibility of funding in the form of shelling machines to farmers which could be organized through Insta Products.

9.8 Legal and Administrative Issues

- Any surface or groundwater developments must adhere to the land, water and environmental regulations including the acquisition of approvals by TCG, WRA and NEMA;

- Private investors are unlikely to invest in agricultural production unless leases for land can be secured. This will require support from the County Government and local politicians to engage with the local community to enable land leases to be released to private investors.

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