University of Nairobi

School of Engineering

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

Evaluation of the efficiency of Water Supply and Distribution Systems in Kakuma Refugee Camp

OSCAR WESONGA NABISWA

F56/67872/2013

A Thesis submitted in partial fulfilment for the Degree of Master of Science in Civil Engineering (Water Resources Engineering), in the Department of Civil and Construction Engineering of the University of Nairobi

AUGUST 2021

DECLARATION

This research project is my original work and has never been submitted for an award of a degree in any other university.

15th August 2021

…………………………..……………… ………………………………….

Nabiswa, Oscar Wesonga Date

Name of Student

This research project has been submitted for examination with our approval/knowledge as university supervisors.

Dr. Simeon Dulo

14th August 2021

Signature Date

Prof. Patts Odira

16th August 2021

Signature Date

UNIVERSITY OF NAIROBI

DECLARATION OF ORIGINALITY

This form must be completed and signed for all works submitted to the University forExamination.

Name of Student **OSCAR WESONGA NABISWA**

Registration Number **F56/67872/2013**

College **ARCHITECTURE AND ENGINEERING**

Faculty/School/Institute **SCHOOL OF ENGINEERING**

Department **CIVIL AND CONSTRUCTION ENGINEERING**

Course Name **Master of Science in Civil Engineering (Water Resources Engineering)**

Title of the work **Evaluation of the efficiency of Water Supply and Distribution Systems in Kakuma Refugee Camp**

DECLARATION

1. I understand what Plagiarism is and I am aware of the University's policy in this regard
2. I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work, or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi'srequirements.
3. I have not sought or used the services of any professional agencies to produce this work
4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work
5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with the University Plagiarism Policy

Signature 

Date: **15th August 2021**

DEDICATION

I dedicate this work to my parents Mr. and Mrs. Nabiswa who have been a constant source of encouragement and guidance for me in the pursuit of my dreams. My beloved wife Isabellah Moraa in recognition of her unwavering support and love, my children Rhysglen, Trevis and Ivan.

ACKNOWLEDGMENT

I would like to acknowledge my supervisors Dr. Simeon Dulo and Prof. Patts Odira for their guidance and patience during this research project. I would also like to acknowledge my lecturers Prof. Nyangeri, Dr. Oonge, Prof. Odira and Dr Dulo for their input and guidance during my study for the Degree of Master of Science in Civil Engineering. I am greatly indebted to them and thankful and for their time. I also acknowledge the University of Nairobi for granting me the opportunity to pursue my Degree of Master of Science in Civil Engineering. I wish to thank my employer, The United Nations High Commissioner for Refugees for according me the necessary time and chance to conduct this study. Lastly, I would wish to acknowledge my fellow students and colleagues for their encouragement, support and useful contribution to this study.

ABSTRACT

Kakuma refugee camp was set up in 1992 to host the lost boys of South Sudan who fled war, and initially intended to host 100,000 refuges but over the years, the camp has grown to accommodate 192,167 refugees from over 20 nationalities. The United Nations High Commissioner for Refugees (UNHCR) together with other stakeholders established mechanisms to ensure effective use of the water resources. Studies indicating an average supply of 17 l/p/d for the entire camp, lower than the recommended minimum quantities of 20 l/p/d. It is against this background that the study sought to evaluate the efficiency of the water supply and distribution system in the Camp. The research prioritised the following specific objectives: Production characterisation of the boreholes, determination of water losses, analysis of water at source, water transmitted to reservoirs, water distributed to tapping points and water available at household level and use of Internet of Things (IoT) in monitoring. To achieve this, the study was guided by technology acceptance theory. The study adopted a mix of quasi-experimental and descriptive survey designs where the experimental survey design sought to use smart devices for real time monitoring of the water supply and distribution system. On the other hand, descriptive research design was essential for collection of descriptive data and relate the same with the research themes. Through the study, seven boreholes were mapped along Tarach River serving Kakuma 2, 3 and 4. A household survey to determine the water access levels at household level was done. The production characterisation of boreholes provided their current status. Computation of losses arising from water transmission from boreholes to water storage reservoirs made it possible to determine the frictional head losses that was used to determine the expected flow at the inlet of water storage reservoirs. From the analysis, the losses ranged from 1.25% to 43.55% with an average of 14.82%. Through real time monitoring by use of ultrasonic water level sensors, the actual water flow into the water reservoirs was determined. This flow was compared with the expected flow at the reservoir inlet. The difference ranged from 1.2% to 53.5% with an average of 23.6% for the various reservoirs/tanks. The disparity between the expected flow and actual flow at reservoir inlet was 8.78% (23.6%-14.82%). This is the unaccounted-for water. The difference between water produced at the borehole using the NRC (Norwegian Refugee Council) borehole logs with the real time monitoring data for the months of January to May 2020 ranged from 2.9% to 59.4% with an average of 38.6%. The NRC puts this figure at 35%. Losses in the water storage system

(elevated steel tanks), were also computed and averaged 5%. The per capita water use at household level ranged from 9.22 l/p/d to 20.38 l/p/d with the average at 13.35 l/p/d. This is a measure of the equitable distribution of water. The household KAP survey on water access at household level yielded a per capita of 23.55 l/p/d. In view of the above findings, the study concluded that there were system inefficiencies in Kakuma Refugee Camp's water reticulation system that resulted to water losses and wastages. To rectify the anomalies, it was recommended that UNHCR carries out a comprehensive hydraulic modelling of the entire system. A new test pumping for all the boreholes was recommended to determine their current yields. Installation of real time aquifer monitoring devices in the boreholes was recommended to monitor the aquifers. The study concluded that real time monitoring presented an effective, scientific way for collecting, transmitting, storing and analysis of data. This provides an effective platform for monitoring of provision of WASH and other interventions that can make use of Internet of Things (IoT) for effective monitoring.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ABBREVIATIONS AND ACRONYMS

CRRF	Comprehensive Refugee Response Framework
DFID	Department for International Development
EST	Elevated Storage Tank
FRC	Free Residual Chlorine
GPS	Global Positioning System
INGO	International Non-Governmental Organisation
IoT	Internet of Things
KAP	Knowledge Attitude and Practices
LoRaWAN	Long Range Wide Area Network
NACOSTI	National Commission for Science, Technology & Innovation
NGO	Non-Governmental Organisation
NRC	Norwegian Refugee Council
RTM	Real Time Monitoring
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children Education Fund
USAID	The United States Agency for International Development
WASH	Water Sanitation and Hygiene
BH	Borehole
UFW	Unaccounted for Water
TDH	Total Dynamic Head
ICRC	International Committee of the Red Cross
IEBC	Independent Electoral and Boundaries Commission
KRB	Kenya Roads Board
NCCK	National Council of Churches of Kenya

DEFINITIONS

Efficiency	The study adopted the technical definition of efficiency to mean the ratio of useful performance of the water distribution system to supply sufficient water to the households.
Per capita	This was used to mean for each person
Real time monitoring	This is the continuous streaming of data and information
Refugee	A person who has been forced to leave his/her country in order to escape ware, persecution or natural disaster
Water distribution network	These are components that carry potable water from a centralized place to consumers to satisfy their consumption needs.
Water loss	The amount of water distributed that does not reach the Consumers

CHAPTER 1 : INTRODUCTION

1.1 Background of the study

Supply of potable water for domestic use in refugee camps is one of the main mandates of the United Nations High Commissioner for Refugees with a recommended per capita of 20 litres for each person in a day (Sphere standards, 2018). Globally, there are close to 82.4 million forcibly displaced people out of which 48 million are internally displaced people (Internal displacement monitoring Centre, IDMC,2021) and 26.4 million are refugees (UNHCR, 2021) and only 43% of this refugee population can access a per capita of 20 litres of water for each person in a day (UNHCR, 2019). The per capita water consumption per person in a day is 20 litres as per Sphere 2018 standards. Despite this achievement, the per capita water access in this refugee camps is way below the average amount of water consumed in European Union and the United States of America which stand at 128 l/p/d and 300 l/p/d respectively.

Supply of water to refugees has not escaped the wrath of climate change which has hugely affected the ambition of UNHCR to ensure sustainable water supply at the recommended standards to restore dignity to the refugees and those affected by displacement. In Bangladesh for example, unpredictable monsoon rains hugely affect the quality of water accessed by the over 900,000 Rohingya refugees in 36 camps (UNHCR, 2019). Water supply and distribution is highly solarised, and the refugee community plays a key role in terms of monitoring the water distribution to reduce wastage and regular maintenance of the water reticulation system. Jordan hosts close to 1.4 million refugees from Syria (UNHCR, 2014a). This population is seeking refuge in an already water stressed country with an annual per capita of 129 m^3 with water rationing strategies put in place to ensure sustainable water distribution to households at least twice a week in Amman.

Lake Chad Basin, once one of Africa’s largest freshwater bodies and in North Africa hosting 2.5 million refugees has been a source of livelihood for about 30 million people, is vanishing fast. The water body has diminished by 90% since the 1960s due to overuse and climate change effects (UN, 2016)

This refugee population and the host community exerts pressure to this limited resource with UNHCR documenting a per capita of 14 l/p/d during the rainy season and 11 l/p/d in the driest period of the year (UNHCR, 2014a). The scarcity of this resource sometimes creates tensions especially in Kounougou refugee camp hosting refugees from Sudan. In 2013, UNHCR laid down five years' strategies one of which included establishment of WASH monitoring systems. In the same year, UNHCR successfully implemented innovative real time monitoring strategies including the use of satellites to monitor efficiency, and quality of water supply systems in 64 refugee camps globally (UNHCR, 2014b).

Kakuma Refugee camp was established in 1992 in Turkana County to serve refugees who had been displaced from South Sudan because of conflict. Over the years, the population in and around the camp has drastically increased to 192,167 refugees. This huge population is straining the limited water resources with an estimated average of 19 l/p/d in the refugee camp (UNHCR, 2019). This is despite the huge investment by UNHCR to sink and equip 19 boreholes pumping an average of 1,363.38 km^3 annually to the water distribution network leading to 1,089 communal and institutional tap stands. UNHCR estimates that 35% of the water pumped to the distribution network is lost through leakages, wastage and illegal water connection. This thus calls for change in strategy to implement effective water supply and distribution monitoring strategies. It is against this background that the study sought to pilot real-time monitoring technology in Kakuma refugee camp to establish the efficiency of the water supply and distribution network.

Figure 1.1 is a map of Kenya showing the location of Kakuma Refugee Camp while Figure 1.2 is a map of Kakuma Refugee Camp showing the four Sub-Camps of Kakuma 1,2,3 and 4. Figure 1.3 shows the drone map of Kakuma Refugee Camp

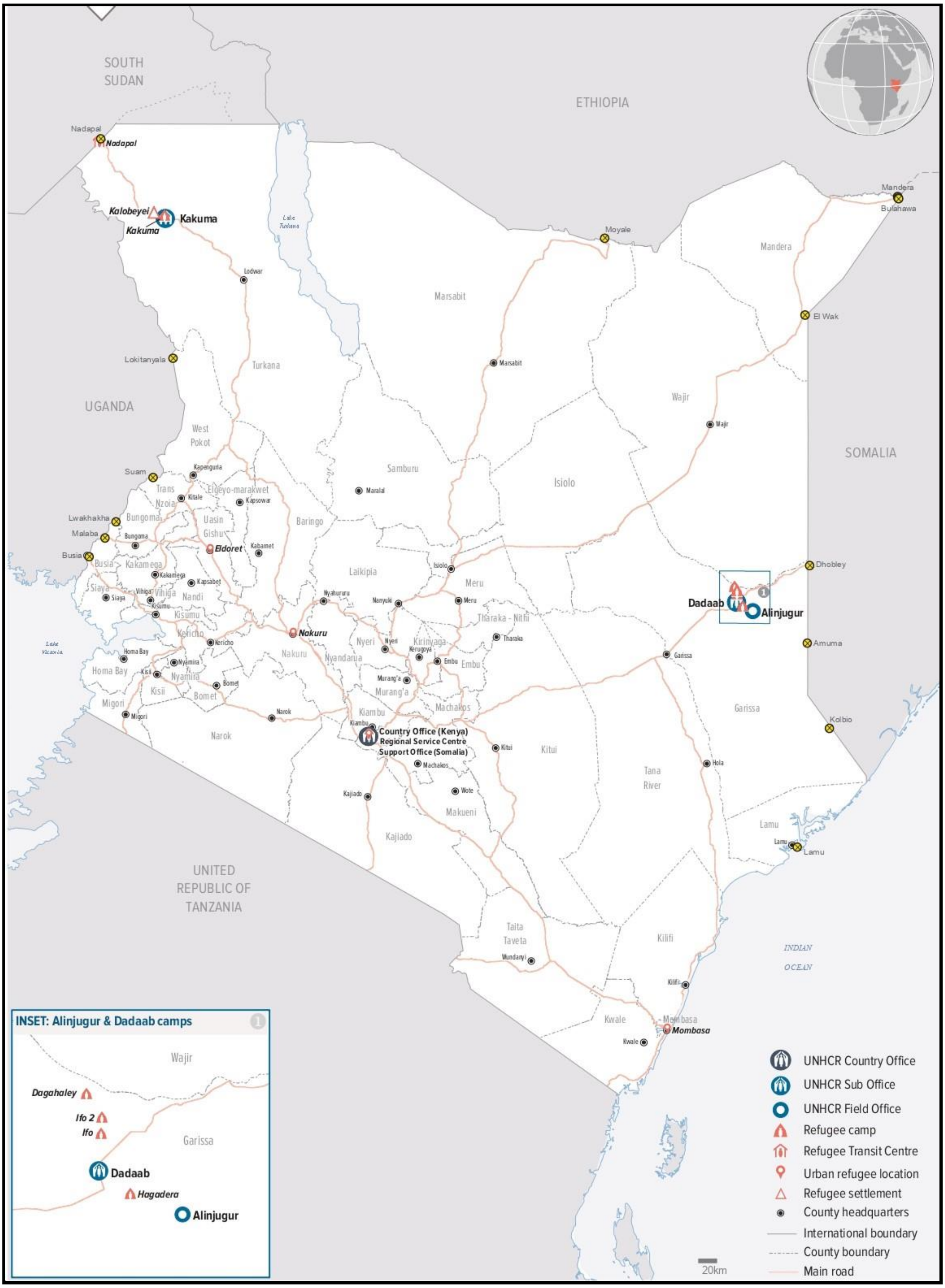


Figure 1.1 Map of Kenya showing location of Kakuma Refugee Camp

Source: UNHCR, UNCS, IEBC, KRB, ICRC

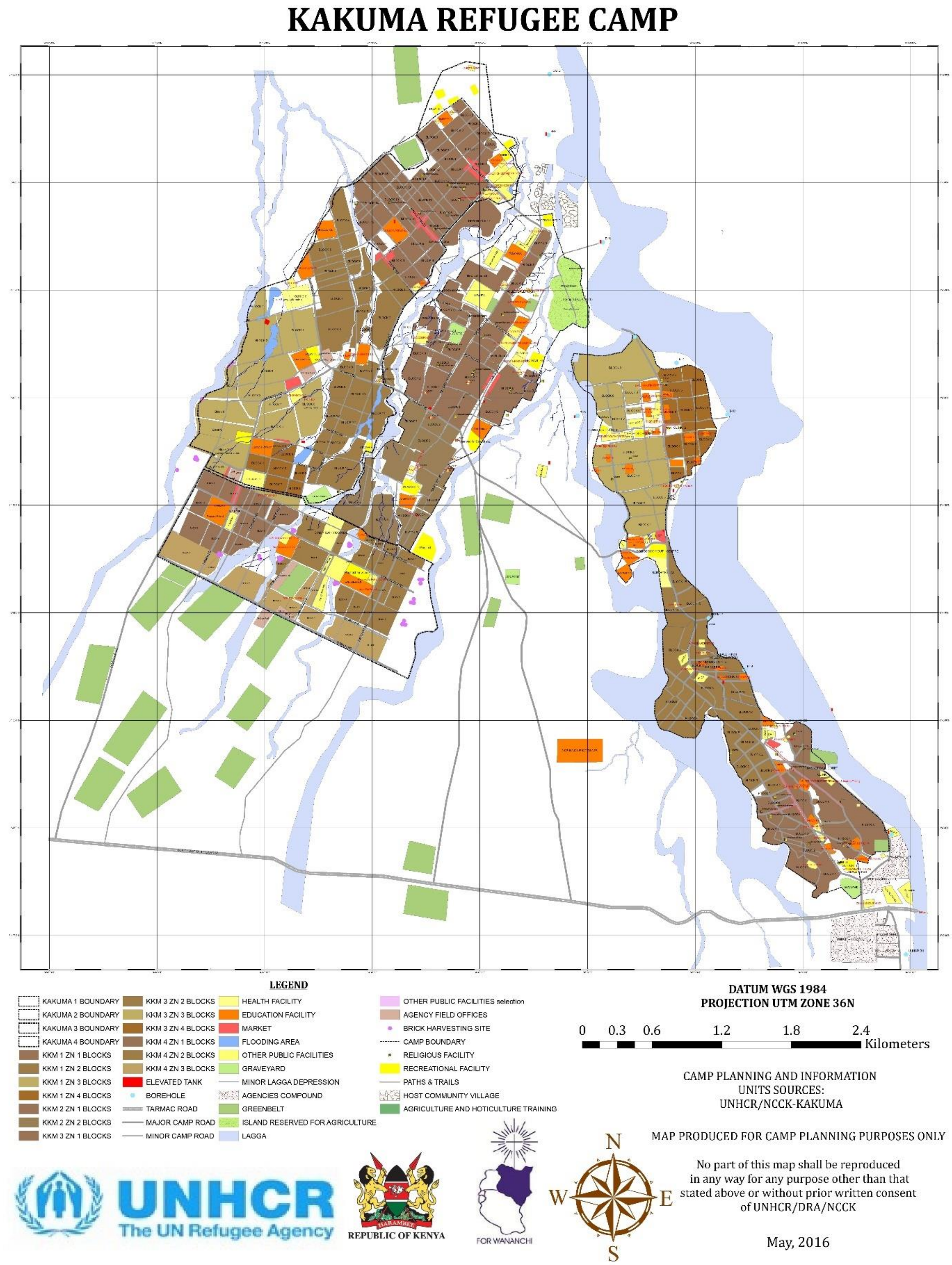


Figure 1.2 Map of Kakuma Refugee Camp

Source: UNHCR, NCCK Camp Planning Unit

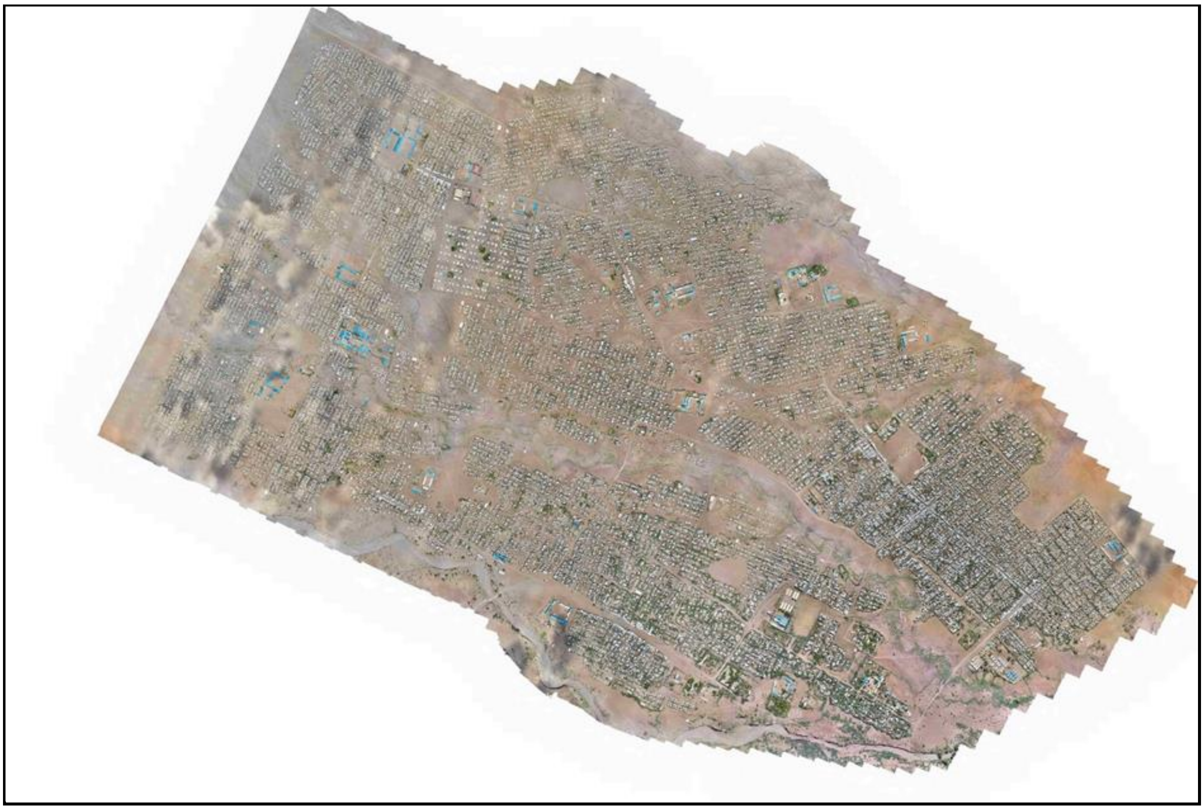


Figure 1.3 Drone Map of Kakuma Refugee Camp

Source: UNHCR, NCCK Camp Planning Unit

1.2 Statement of the Problem

Kakuma Refugee camp was designed in 1992 to provide asylum to 100,000 refugees. In 2014, Kakuma operation received a high influx of asylum seekers from South Sudan following the eruption of armed conflict in mid-December 2013 resulting to close to 192,167 refugees seeking assistance in Kakuma refugee camp. The huge population continues to strain the limited water resources available with the average water per capita use estimated at 19 l/p/d per person per day in the refugee camp (UNHCR, 2019). This has seen occasional conflicts among the refugees as they fight for the limited resource. Currently, UNHCR and partners determine the per capita by computing the amount of water pumped from boreholes and apply an arbitrary 35% as losses due to leakages and illegal connections. This has proved to be ineffective thus the need to come up with a reliable and verifiable mechanism that will depict the actual situation of water access by refugees. The study piloted an innovative real-time monitoring strategy in three of the camps in Kakuma that have experienced prolonged water challenge to assess the efficiency of the water supply and distribution network and generalize the same for Kakuma refugee camp.

1.3 Objective of the study

1.3.1 General Objective

The refugees in Kakuma Refugee Camp have continued to experience persistent water access challenges. It is against this background that the study sought to analyze the efficiency of water supply and distribution systems in Kakuma Refugee Camp focusing on Kakuma 2, 3 and 4 section of the camp that has been experiencing unending water supply crises.

1.3.2 Specific Objective

i. To perform a production characterisation of the boreholes in Kakuma refugee camp.
ii. To determine the losses arising from water transmission, storage and distribution in Kakuma refugee camp.
iii. To analyze the relationship between the water produced at the source, water transmitted to reservoirs and water distributed to tapping points and water available at household level in Kakuma refugee camp
iv. To determine the effectiveness of real time monitoring system in relation to the existing manual data capture and recording system in Kakuma refugee camp

1.4 Research Questions

i. What are the production characteristics of the boreholes in Kakuma refugee camp?
ii. How much water is lost from water transmission, storage and distribution in Kakuma refugee camp?
iii. What is the relationship between the water produced at the source, water transmitted to reservoirs and water distributed to tapping points and water available at household level in Kakuma refugee camp?
iv. How effective is real time monitoring in comparison with the manual recording and analysis system in Kakuma refugee camp?

1.5 Significance of the Study

The research was significant to WASH actors in that it provided reliable data in determination of the efficiency of water supply and distribution systems in Kakuma Refugee Camp. Findings from the study will help WASH practitioners to understand the characteristics of the boreholes and establish the exact per capita water use in Kakuma Refugee Camp. The study recommended ways of improving the water provision efficient and also recommended for potential avenues for advocating either an increase or standardization of the funding for the WASH sector.

By understanding the characteristics and attributes of water losses in the water distribution network, WASH actors and beneficiaries could be able to strategize on potential arears to tackle water losses.

As part of the project cycle management, donors would want to evaluate the outcome of their funding. This could be achieved through establishing the efficiency of water supply in Kakuma refugee camp. Kakuma Operation has in many years been unable to clearly explain the rationale of applying 35% as the amount of unaccounted for water. This has always led to donors being unsatisfied with the monitoring framework in place (The Humanitarian Aid Department of the European Commission-ECHO Mission Report, October 2017). With the pilot, it was possible to remotely monitor the efficiency of the water reticulation system by use of smart devices. Finally, the findings from the study provided enough literature in contributing to theory and practice which could be referenced by future scholars and researchers.

1.6 Limitations of the Study

In undertaking the study, challenges were encountered where the respondents especially the refugees who could have some expectations from the study to influence either an increase or decrease in the supply of water to their households. This could influence them to be biased in providing responses to the questionnaires. However, this challenge was overcome by explaining to the respondents that the study was meant for academic purposes only. In addition, the questionnaires were smartly developed to avoid leading questions. Through this, the challenges were avoided.

More time was spent in setting up the necessary infrastructure to collect, transmit and store data that could easily be interpreted. This involved installation, calibration and programming of the smart water level sensors, gateways and the dashboard for data viewing and interpretation.

The water reticulation system in Kakuma Camp is aged and dilapidated. This coupled with unplanned expansion of the systems could make it difficult to identify the specific water pipeline networks serving the various populations in the Camp. This was mitigated through detailed identification and isolation of the various pipelines.

The Seasonal variations of the Tarach River that recharges the boreholes might have an effect on ground water capacity for the various boreholes under study. This could lead to fluctuations of the borehole yields during the study period that could affect the water extracted from the boreholes.

1.7 Delimitation of the Study

The study was carried out in Kakuma refugee camp in Turkana County over a period of three months. Conducting the study in Kakuma was convenient in terms of saving time and finances as well as availability of diverse camps from which the gathered findings could be generalized for the refugee camps in Kenya. In addition, it is cognisable that the boreholes supply water to the entire camp but for the purpose of this study, only households in 3 camps were assessed. Finally, the study only analysed the efficiency of water distribution in Kakuma refugee camp.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

The chapter on literature review covered the following aspects: water distribution in refugee camps, water distribution monitoring methods, hydraulic modelling, real time monitoring, theoretical and conceptual framework, implications of the literature and knowledge gap.

2.2 Water Distribution in Refugee Camps

Water is transported from the source through a set of pumps, pipes, valves, reservoirs and taps to the consumer. This set forms the distribution network. Figure 2.1 shows the components of a distribution system.

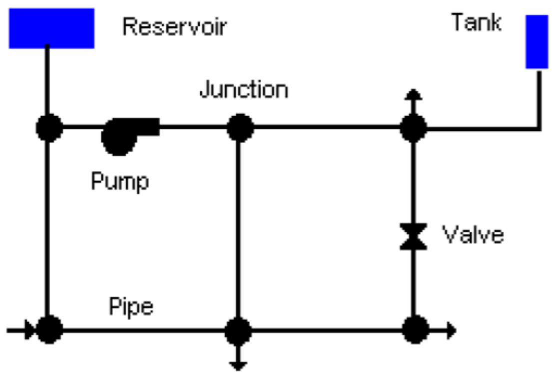


Figure 2.1 Physical components of a distribution system

Source: (Rossman, 2000)

A good and efficient water distribution system should be able to ensure durability of the water distribution pipes and supply the right amount of water with sufficient pressure to the intended locations. In addition, the system should be watertight with minimal losses. Until the last decade of the 20th century, unaccounted-for water was expressed as a percentage of the system output. This approach was not effective to account for water losses as it could not produce realistic figures. This approach is still adopted in many countries though the Water Loss Task Force in early 21st century recommended a more efficient way for calculating water loss using a non-revenue water which takes the difference between the quantities of water pumped to the distribution system and that billed to the consumers (Muhammetoglu, 2014). This yields real, apparent and unbilled authorized consumption losses. Even with this approach, data in most countries is not readily available and, in most instances, not reliable. For example, accounting for water lost when a pipe bursts normally looks at the flow rate only and, in most instances, fails to capture the leak run time.

In situations where there is large-scale movement of forcefully evicted people, water distribution takes various forms including water trucking in emergency situations to the use of a well-established and designed water distribution network for protracted situations. Water supply to formal refugee camps rarely meet the recommended standards due to challenges ranging from inability to cope with refugee influx to technical challenges (Dhesi *et al*., 2015). Refugees are particularly vulnerable and in need of rapid assistance. In addition, settling refugees in foreign land affects the host population who are required to share their resources with the refugees. In effect, there arises imbalances in establishing management structures to effectively manage water distribution. In response to this, UNHCR and other WASH partners set systems to professionalize management of the water distribution including engagement of public and private partners (Whaley and Cleaver, 2017). However, there is limited willingness among the private and public partners to work in humanitarian settings due to the limited revenue generation from this sector.

In Ethiopia for example, the Administration of Returnee and Refugee Affairs and UNHCR coordinate the distribution of water to over 830 refugees and 680 internally displaced persons (DFID, 2017). The plan is not adequately funded and as such it has a huge implication on management of water distribution especially in areas like Gambella that has huge refugee populations. Water in Gambella is sourced from boreholes along Baro River and pumped through a distribution network operated and managed by international NGOs. The networks cover close to 20km of water pipelines and this requires installation of boosters to increase pressure. Although the water distribution systems are managed by humanitarian agencies, Ethiopia in collaboration with UNHCR and UNICEF under the Comprehensive Refugee Response Framework have established rural utility model to facilitate management and monitoring of the water supply system through the Regional Water Bureaus (UNHCR, 2017). The model adopts employment of the non-revenue water approach in monitoring the water distribution framework.

In Lebanon, 78% of the refugee population access water from improved sources (UNHCR, 2019). However, the quantity and sustainability of the water supply is not guaranteed. This is in a country with limited water resources where the Bekaa Valley for example where majority of refugees are settled is overexploited. In addition, 50% of the water reticulation system is old and dilapidated contributing to huge water losses approximated to the 13% above the global average. However, it is not clear on which approach is adopted to calculate these losses as the water distribution in Lebanon especially to refugees is highly unregulated.

The distribution of water to refugees in South Sudan is inevitably in crisis attributed to the low coverage of water infrastructure, acute poverty and extremely difficult working environment. This means that possibilities of establishing water distribution management and monitoring is minimal. In Tanzania, the situation in refugee camps especially in the Kigoma sub-region, the coordination of emergency relief is overly easy. Water distribution networks are managed by INGOs. However, huge refugee populations in camps like Nduta, where water points are managed by volunteers, there is low level of ownership and persistent vandalism of the complicated and unplanned distribution network. This results in a lot of inefficiencies in the distribution of water to the households with huge operational costs. Although, the Tanzanian government and UNHCR through the CRRF have put in place mechanisms that will ensure adoption of sustainable models to manage the water distribution networks, the government later stopped its support for the CRRF ambition.

Like any other water reticulation system, Kakuma refugee Camp water distribution system comprises of links and nodes. Links refers to pipe section that can contain valves, bends and pumps. The nodes can be categorized as junction nodes which join pipes and are points of input or output of flow, and fixed–grade nodes such as tanks and reservoirs with fixed pressure and elevation. The system in Kakuma like in Nduta Camp in Tanzania is complicated due to unplanned expansion of the camp that was intended to serve 100, 000 persons but currently serves more than 192,167 refugees (Kakuma Camp WASH KAP Survey Report,2020). The level of ownership of the water resources by the refugees who manage more than 95% of the water reticulation system is relatively low and the system experiences spontaneous persistent vandalism especially along the pipelines. This results in huge undocumented inefficiencies in the supply of water to the refugees despite recommendations from previous studies.

2.3 Water Distribution Monitoring Methods

The different monitoring tools and strategies put in place in refugee camps including Kakuma to monitor water distribution are presented in this section.

2.3.1 Hydraulic Modelling

The two fundamental concepts of distribution network hydraulics are conservation of mass and energy. For energy, the Bernoulli equation applies and states that the sum of the elevation, pressure and velocity heads between two points must be constant (Ramesh, *et al*., 2011). Due to losses because of friction during flow through the pipe, this equation does not hold precisely in practice. Frictional head loss is accounted based on the following frictional head loss computation equations Hazen-Williams, Chezy-Manning or Darcy-Weisbach equations. The equations are shown in table 2.1:

Table 2.1 Frictional Head loss computation equations

Formula	*Resistance Coefficient (A)*	*Flow Exponent (B)*
Hazen-Williams	$4.727\ C^{-1.852}\ d^{-4.871}\ L$	1.852
Darcy-Weisbach	$0.0252\ f(\varepsilon,d,q)d^{-5}L$	2
Chezy-Manning	$4.66\ n^2\ d^{-5.33}\ L$	2

Notes: C = Hazen-Williams roughness coefficient
ε = Darcy-Weisbach roughness coefficient (ft)
f = friction factor (dependent on ε, d, and q)
n = Manning roughness coefficient
d = pipe diameter (ft)
L = pipe length (ft)
q = flow rate (cfs)

Material	*Hazen-Williams C (unitless)*	*Darcy-Weisbach □ (feet x 10^{-3})*	*Manning's n (unitless)*
Cast Iron	130 – 140	0.85	0.012 - 0.015
Concrete or Concrete Lined	120 – 140	1.0 - 10	0.012 - 0.017
Galvanized Iron	120	0.5	0.015 - 0.017
Plastic	140 – 150	0.005	0.011 - 0.015
Steel	140 – 150	0.15	0.015 - 0.017
Vitrified Clay	110		0.013 - 0.015

(Rahimi, 2008)

2.3.2 Epanet

EPANET is a software application globally used to model water distribution systems, design and size new water infrastructure, retrofit existing aging infrastructure, optimize operations of tanks and pumps, reduce energy usage, investigate water quality problems, and prepare for emergencies (https://www.epa.gov/water-research/epanet). The software is used for planning, designing, operations and management. The software can optimize designs, calculate energy use, flow and pressure and display the network data in graphics.

2.3.3 Knowledge Attitude and Practice (KAP) Surveys

Knowledge Attitude and Practice (KAP) surveys are periodic descriptive studies conducted at household level to measure achievement of set standards and targets. KAP surveys are essentially records of opinion and are basically declarative (USAID, 2011). These surveys measure the extent of known situation; confirm or disprove a hypothesis and provide new tangents of a situation's reality. In addition, they enhance the knowledge, attitude, and practices of specific themes; identify what is known and done about various health-related subjects. In effect they serve to suggest an intervention strategy that reflects specific local circumstances and the cultural factors that influence them; plan activities that are suited to the respective population involved.

KAP Surveys monitor standardized indicators derived from the Sphere Standard and the UNHCR minimum standards. Sphere standard is a product of the Sphere created in 1997 by a group of humanitarian non-governmental organizations and the Red Cross and Red Crescent Movement after the Rwandan genocide response. The aim of the Sphere then called Sphere Project was to enhance accountability in humanitarian response and as such settled in proposing the minimum standards of services that any humanitarian assistance including water supply standard access and quantity must adhere to (Sphere, 2018).

In understanding the inadequate water quantity and quality is the underlying cause of most public health problems in refugee crisis and protracted situations and the need to restore dignity, UNHCR has also put forth minimum water supply standard of quality and quantity. The standard requires that people have equitable and affordable access to enough safe water to meet their drinking and domestic needs. The indicators under this standard are presented in table 2.2.

Table 2.2 UNHCR WASH Indicators

Indicator		Emergency[1] Target	Post Emergency Target	Means of Verification
Water Quantity	Average # litres of potable[2] water available per person per day	≥ 15	≥ 20	Monthly Report Card
	Average # l/p/d of potable water collected at household level	≥ 15	≥ 20	Annual KAP
	% Households with at least 10 litres/person potable water storage capacity	≥ 70%	≥ 80%	Annual KAP
Water Access	Maximum distance [m] from household to potable water collection point	≤ 500m	≤ 200m	Mapping
	Number of persons per usable handpump / well / spring[3]	≤ 500	≤ 250	Monthly Report Card
	Number of persons per usable water tap[4]	≤ 250	≤ 100	Monthly Report Card
UNHCR WASH Standards for Communal Buildings				
Schools	Average 3 litres of potable water available per pupil per day 400 of pupils per usable hand pump/well 200 pupils per usable water tap			
Health Clinics / Nutrition Feeding Centre	Average 10 litres of potable water available per outpatient per day Average 50 litres of potable water available per inpatient/bed per day 1 separated water point per health facility			

Source: UNHCR WASH Manual 2018

2.3.4 Monthly Report Card

UNHCR uses an online WASH Monitoring System which is part of the wider Public Health Monitoring Platform called iRHIS (https://his.unhcr.org/collect/list/4?date_start=&date_end=

). The WASH Monitoring System is used to create WASH report cards for refugee sites that monitor trends in key water, sanitation and hygiene indicators at household and community levels. Water access indicators are monitored monthly and the results recorded in an online database. The monthly report card just like the KAP survey calculates the water per capita for the camps, and the water quality indicators including Free Residual Chlorine (FRC) levels and Faecal Coliforms in the water.

2.3.5 Real Time Monitoring

Water distribution systems monitoring is complicated. Conventional methods of monitoring the water distribution systems are in most instances inconsistent and as such not reliable for decision making. Automated real time monitoring (RTM) can continuously record data from multiple points of the network and stream it to the control centre (Karadirek, *et al*., 2014). These are on-site instruments that measure the hydraulic parameters and water quality indicator parameters. This system points at the exact location of for example pipe bursts or contamination. In Turkey for example, the city of Antalya uses real time monitoring for monitoring the distribution system (Muhammetoglu, 2014).

2.4 Theoretical Framework

Theoretical framework is the structure that can hold or support a theory of a research study. The theoretical framework introduces and describes the theory that explains why the research problem under study exists.

2.5 Technology Adoption Model

The study was guided by Technology Adoption Model (TAM) postulated by Davis in 1989. The model explains adoption of information technology because of user's perception but not real usage (Davis, 1989). Empirical studies done to validate the theory established that the TAM model causes between 40% and 50% combined with social influence experience and cognitive instrumental processes termed causes 60% of adoption of information technology (Venkatesh and Davis, 2000).

In the study, the adopters who were waters distribution actors in Kakuma refugee camp adopted the technology for real time water monitoring after evaluating perceived usefulness and ease of its use. They perceived the technology was likely to affect positively their ability to monitor water distribution and enhance efficiency of the water distribution network, thus the technology was adopted. The TAM was described by figure 2.2.

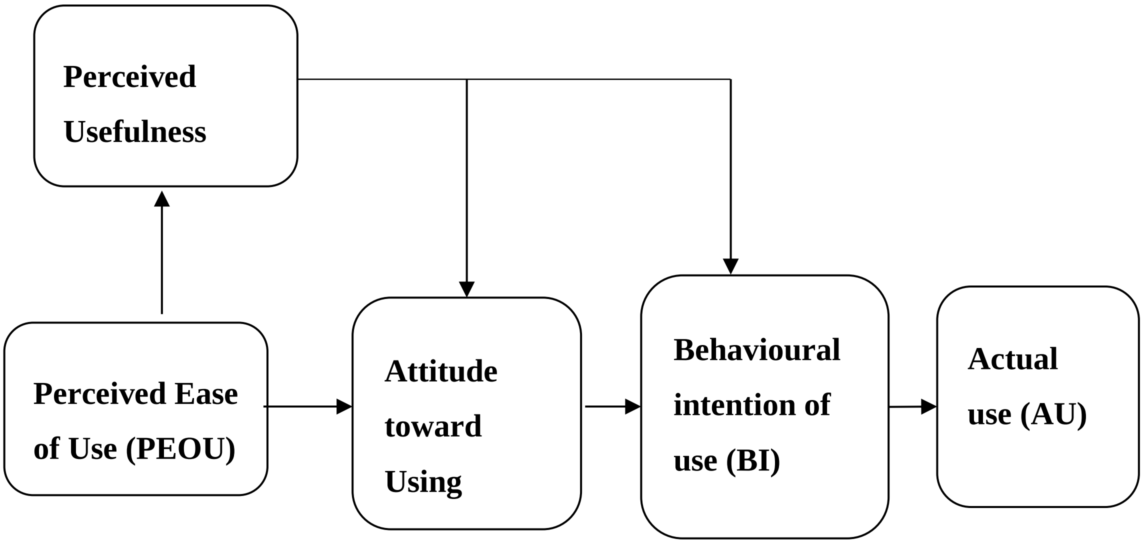


Figure 2.2 Technology Acceptance Model (TAM)

2.6 Conceptual Framework

The conceptual framework is the way the researcher perceives the relationship between variables in his study and how they interlink with each other (Mugenda & Mugenda, 2003). As such, it points out the required variables to the study. Figure 2.3 shows the relationship between Dependent and Independent Variables.

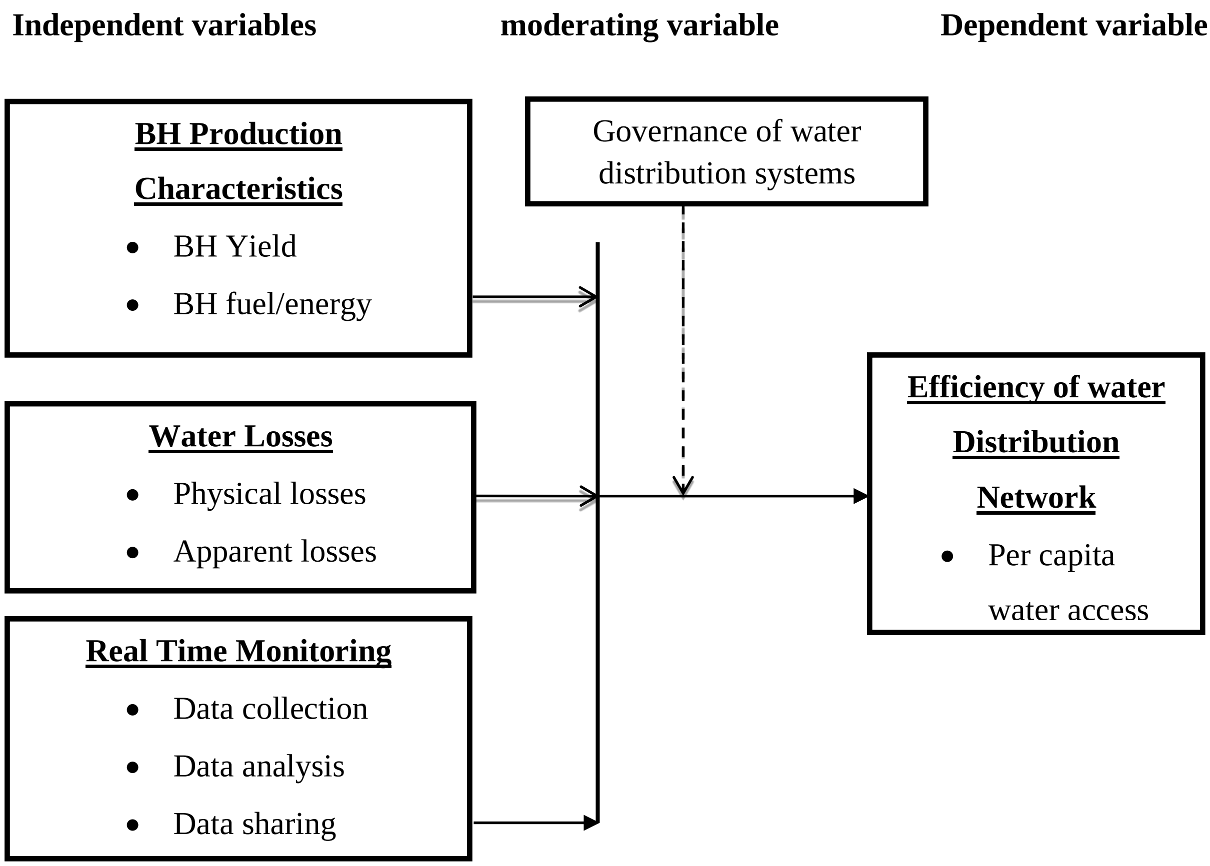


Figure 2.4 The Relationship between Dependent and Independent Variables

From figure 2.3, the study had three independent variables. The first variable was borehole (BH) production characteristics where the study looked at the yield of the BH, fuel/energy consumption and the recharge efficiency of the BH. Secondly, water losses were looked at in terms of physical and apparent water losses. Lastly the study looked at real-time monitoring in terms of data collection, analysis, sharing and archiving. In looking at the independent variables, the study analysed their relationship with the dependent variable, which is efficiency of water distribution network with regards to the average per capita. It is apparent that in trying to establish the relationship between the dependent and independent variables, there were other governance factors that affected the efficiency of the supply of water to the refugees.

2.7 Implications of Literature

Many studies have been done with regards to water supply and distribution in Kenya (Joseph Karanja, 2018) and around the world with good recommendations (Navid Rahimi, 2008). Some of the studies have looked at access, demand, and sourcing. This study sought to evaluate the efficiency of water supply and distribution in Kakuma refugee camp. Through the study, the existing gaps in available literature were filled and at the same time recommendations for solutions in the challenges faced in the distribution of water to refugees in Kakuma refugee camp were made.

2.8 Knowledge Gap

Table 2.3 presents a summary of the gap in existing literature.

Table 2.3 Knowledge Gap

Variable	**Author and Year**	**Findings**	**Knowledge Gap**
BH Production characterisation	Olago, (2018)	Key aquifers need urgent characterisation to reverse the current situation whereby development proceeds with insufficient aquifer knowledge.	The author focused on aquifer characterisation and not BH characterisation
Real-time monitoring	Kara, *et al*., (2015)	The integrated RTM system in Antalya proved to increase confidence in water services by improving water quality, decreasing operational costs, reducing water losses, and increasing energy efficiency.	The author failed to link the findings to efficiency of the water distribution to households but as the author concentrated on the importance of RTM in improving the general operational efficiency of the system in urban city.

CHAPTER 3 : METHODOLOGY AND MATERIALS

3.1 Introduction

This chapter contains the research methodology that was used in this study. It presents the basic assumptions of the study, research design, the target population of the study, the sample size and sampling techniques, research instruments, data collection methods and data analysis methods.

3.2 Basic Assumption of the study

The respondents provided correct and reliable information by answering the questionnaires honestly and factually. The respondents' feedback was not affected by expectations.

The real time monitoring system functioned fully without fail.

The smart devices performed optimally and generated data that could easily be analysed and interpreted. The smart devices read and transmitted data and did not experience system failures like internet access outage.

3.3 Research Design

The study employed a mix of quasi-experimental and descriptive survey research design. Quasi-experimental survey entailed the installation of ultrasonic water level sensors in thirteen storage tanks supplying water to Kakuma 2, 3 and 4 to collect readings and submit real time data to the central database (Kothari, 2008). On the other hand, descriptive research design enabled the collection of descriptive data from the households in Kakuma 2, 3 and 4 and relate the same with the research themes.

3.4 Target Population

Population for the proposed study consisted of heads of households or responsible persons above 18 years of age from 22,976 households in Kakuma 2, 3 and 4. In addition, one project officer from UNHCR and one project coordinator from NRC were included in the target population bringing the total population to 22,978.

3.5 Sample Size and Sampling Procedures

The sampling design and procedures that were adopted in the study to get the desired sample size are described in this section.

3.5.1 Sample Size

The study objectively selected a unit from the population also known as a sample size (Kombo, & Tromps, 2006). Sample size was defined using Slovin's formula (1960). By applying the formula, using an error margin of 5%, a sample size of 393 was studied. The number of respondents to be studied per camp were identified by relating the number of respondents under each camp in relation to the entire population.

Slovin's formula is:

$$n = \frac{N}{1+N(e^2)}$$

Equation 3-1

Where n = number of samples, N = total population and e = error margin / margin of error.

$$n = \frac{22{,}976}{1+22{,}976(0.05^2)} = 393$$

In addition, two specialists were purposefully targeted as key informants bringing the total sample for the study to 395 as described in Table 3.1.

Table 3.1 Sample Size

Location	Population	Proportion	Sample size
Kakuma 2	11,488	50%	197
Kakuma 3	5,055	22%	86
Kakuma 4	6,433	28%	110
UNHCR WASH Project officer	1		1
NRC WASH Project coordinator	1		1
Total	**22,978**	**100%**	**395**

3.5.2 Sampling Procedure

The study proportionately clustered the size of the sample to each location after which the respondents were systematically interviewed at random. The WASH project officer and coordinator were selected purposefully since the information sought from them was specific to their job specialization.

3.6 Research Instruments

The study collected primary data from the households using structured and semi-structured online administered questionnaires. Primary data was also sought from key informants using interview guides. In addition, primary data was collected from the boreholes using a checklist. Secondary information was sought from existing reports at UNHCR and NRC using checklists.

3.6.1 Questionnaire

The questionnaire had items aiming at answering the study questions that met the research objectives. Questionnaires were preferred for collection of data from the households since they would provide a high degree of data standardization and adoption of generalized information amongst the population (Orodho, 2005). Structured questionnaires were used to collect data. These questionnaires were uploaded to a mobile data collection platform called KoboCollect. The closed ended questions were used for easy coding and analysis while the open-ended questions were used to elicit more information from respondents to complete any missing links. The close ended questions were accompanied by a list of possible alternatives, from which respondents were required to select the answer that best described their situation.

3.6.2 Interview schedule

Primary data was collected from key informants including the UNHCR project officer and NRC project coordinator using interview guides. The interview guides consisted of open-ended questions. The open-ended questions enabled the collection of qualitative data. This was used to gain a better understanding and possibly enable better and more insightful information on the objectives of the study (Kothari, 2008).

3.6.3 Quasi Experiments

Primary real time monitoring data was collected using quasi experiments where LoRaWAN (Long Range Wide Area Network) enabled ultra-sonic water level sensors were installed in thirteen water storage reservoirs in Kakuma 2, 3 and 4. The data was transmitted to the UNHCR real-time WASH monitoring system (portal) and analysed. By installing water level sensors in each of the thirteen reservoirs, it was possible to determine the fill up rate, emptying rate and fill up/emptying frequencies of the reservoirs.

3.6.4 Pilot Testing of the Descriptive survey data collection instruments

A pilot study was carried out over 37 households in Kakuma 1 that did not participate in the final study. Cronbach's alpha was calculated from the pilot findings to establish reliability of the descriptive survey data collection instruments.

3.6.5 Validity of the Research Instruments

Validity is concerned with the integrity of the conclusions that are generated from a piece of research. Validity is the degree to which an instrument measures what it purports to measure. It estimates how accurately the data in the study represents a given variable or construct in the study (Creswell, 2013). The study used test and retest through piloting to ensure content and construct validity of the research instruments.

3.6.6 Reliability of the instruments

The study used a test-re-test method on the pilot group from which reliability index was calculated with the aid of SPSS where a reliability index of 0.853 was obtained indicating that the instruments were reliable (Kothari, 2004).

3.7 Data Collection Procedure

An introduction letter from the institution was obtained. A total of 20 research assistants were engaged to assist with data collection through Kobo Collect tool. In addition, the study reviewed WASH records from the UNHCR and NRC to source for secondary data.

3.7.1 Household survey data analysis

Data was tabulated and statistically analysed using descriptive statistics such as percentages, frequencies and means. The purpose of descriptive statistics was to enable meaningfully description of the findings. Data was presented in tables, charts and narratives. Qualitative data was analysed and was presented in narratives.

3.7.2 Quasi experiment data analysis

Determination of losses in the water reticulation system forms an integral part in assessing the efficiency of the system. Meter readings were collected daily and recorded for analysis. The meter readings of the water meter installed on the well head and the flow computed through real time monitoring at reservoir inlet point was used to compute the losses during transmission. Computation of losses due to friction was done using the Hazen Williams equation 3-2.

$$h_f = 10.7\left(\frac{Q}{C}\right)^{1.852}\frac{l}{d^{4.87}} \quad \text{(SI units)}$$

Equation 3-2

Where:

hf = head loss due to friction(m)

Q= flow rate (m^3/hr)

C = Hazen-Williams Coefficient

d = pipe internal diameter (ID) (m)

l = length of pipe (m)

Through comparing the flow rates at source and delivery point in water reservoirs and by computing the frictional head losses, it was possible to isolate the unaccounted-for losses/usage. The real time flow monitoring devices provided information to buttress the analysis.

Water volume readings transmitted by the devices after filling up of the reservoirs and start of distribution of water to beneficiaries provided losses during storage which was linked to tank leakages and evaporation. To determine the rate of tank filling and emptying, Ultrasonic liquid level sensors were installed on each reservoir.

3.8 Realtime monitoring- Internet of Things (IoT)

The study piloted internet of things (IoT) to effectively capture, transmit and store the data for ease of analysis and interpretation. IoT was selected through setting up of a real time monitoring system. The study explored the possibility of monitoring the following parameters:

1. Quantity of water pumped
2. The frequency of filling and emptying of water storage reservoirs
3. The amount of water stored in a reservoir over a given time
4. The efficiency of water distribution system
5. Ground water table/aquifer monitoring
6. Free residual Chlorine monitoring

From the above parameters, the following was prioritized by the study:

1. The frequency of filling and emptying of water storage reservoirs
2. The amount of water stored in a reservoir over a given time
3. The efficiency of water distribution system
4. Quantity of water pumped

After exploring the different options available for developing real time monitoring by incorporating IoT, the study settled on Long Range Wide Area Network which is a media access control protocol for wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long-range wireless connections.

To set up a complete LoRaWAN communication protocol, the assistance of the UNHCR IT department was sought to support the research by setting up the following:

1. Devices, Node
2. Gateway
3. Network server
4. Application server.

The figure 3.1 demonstrates the set up:

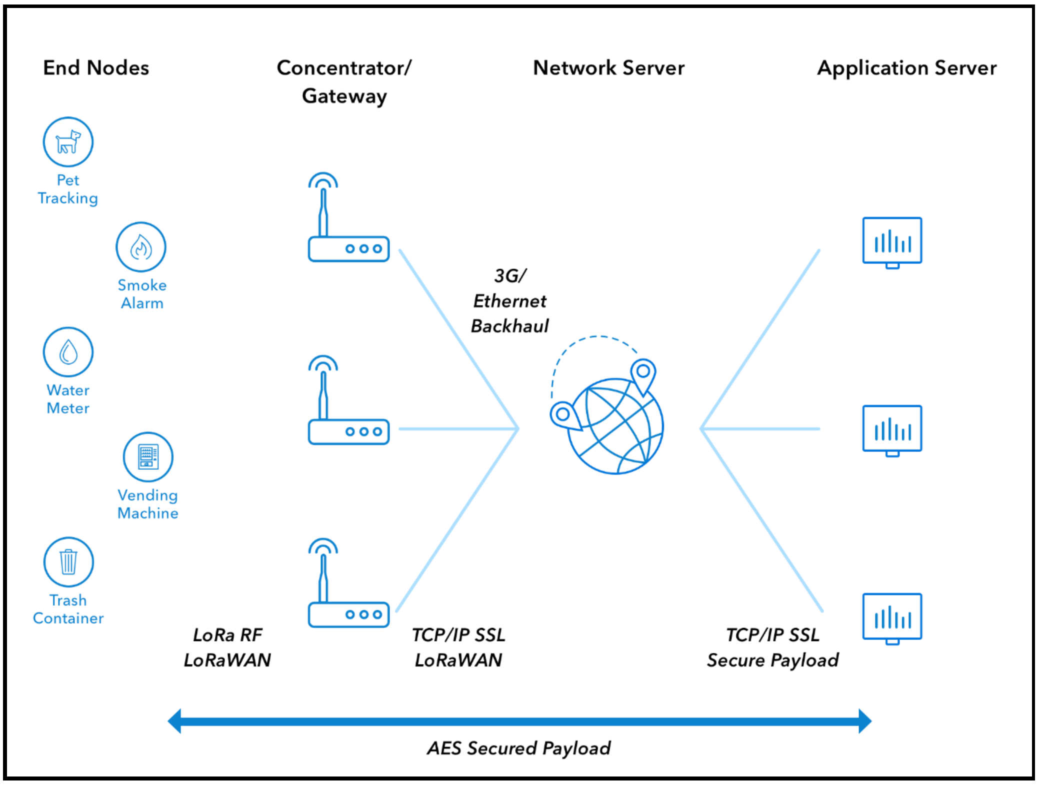


Figure 3.1 Real time monitoring set up

Source: https://www.thethingsnetwork.org/

3.8.1 Water Level monitoring in water reservoirs

The use of real-time monitoring commenced with identification of the devices able to collect data and transmit.

3.8.2 LoRaWAN Ultrasonic level sensor

The Tekelek Tek766 device was identified to be used in water level monitoring. Tekelek provides a range of reliable non-contact level Measurement Sensors utilising solutions for water level measurements.

The Ultrasonic LoRaWAN sensor in figure 3.2 is a flexible and configurable, battery operated ultrasonic level sensor with an integrated LoRaWAN radio. Thirteen water sensors were procured through https://tekelek.com/product/tek-aqua-lora-ultrasonic/

Figure 3.2 Ultrasonic LoRaWAN Sensor

The thirteen sensors were registered on the things network using their unique device ID/Identifiers. The registration was done through the url https://console.thethingsnetwork.org/applications/unhcr-kakuma-tek766-application . Figure 3.3 shows the installation of the water level sensors.

Figure 3.3 Installation of LoRaWAN Water level sensor

Thirteen LoRaWAN enabled Ultrasonic water level sensors were installed and registered on the Things Network using their unique device identifiers. The installation of the sensors was done on the roofs of 13 elevated steel tanks in Kakuma 2, 3 and 4 on 17th February. Table 3.2 presents the features of the LoRaWAN sensors installed.

Table 3.2 LoRaWAN Sensors installed on water tanks

Sn	Project	Device type	EUI	Name
1	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000002A7A	Nasibunda Big Tank
2	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000002B12	Phase 3 Tank
3	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000002CDC	EST 3 Hope Primary Tank
4	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000002D44	Clinix Six Tank
5	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000002E68	Reception Center Tank
6	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000003051	Phase 2 Tank
7	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000003087	EST4 Kakuma 4
8	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B00000030D6	Fuji Tank
9	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B00000031E4	ISSB Tank
10	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B000000324D	Somali Bantu Tank
11	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B0000003265	EST 2 Kakuma 4
12	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B00000033F4	Nasibunda Small Tank
13	Kakuma Refugee Camp WASH Monitoring	Tekelek Tek766	244E7B000000345C	Gambela Tank

Figure 3.4 shows the cloud-based interphase from which the collected data was transmitted.

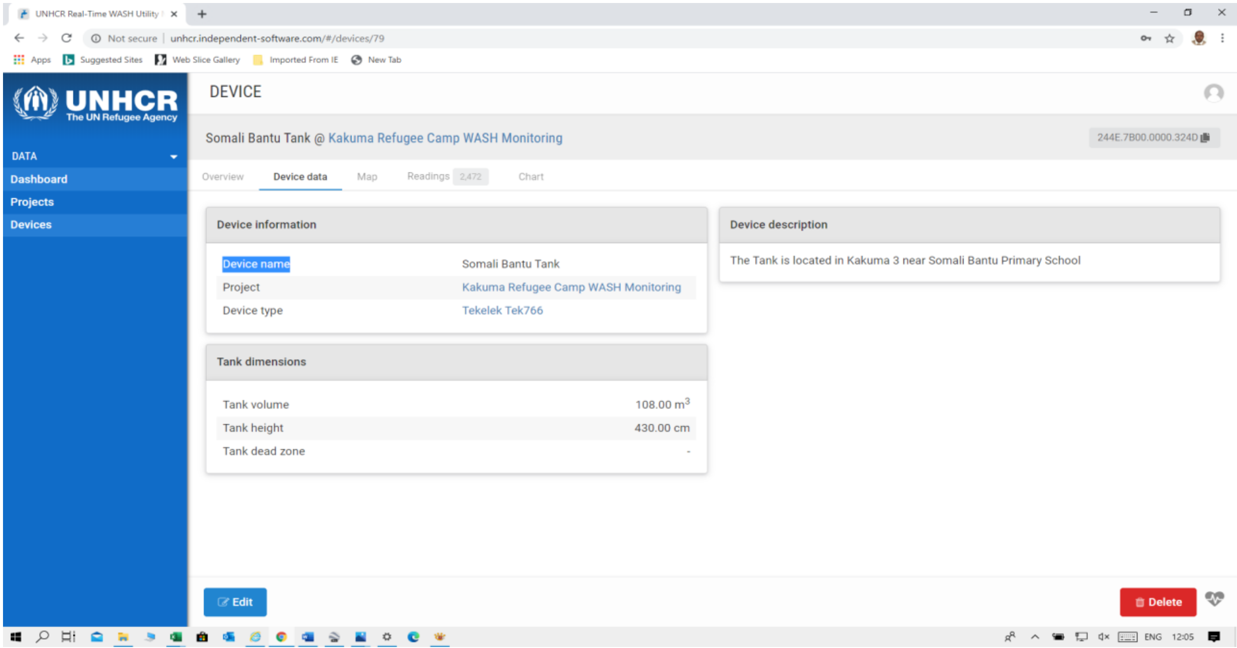


Figure 3.4 Real time monitoring interphase

3.9 Ethical Consideration

Ethical consideration is paramount for every study. Ethical issues apply to all research approaches and to every stage of research that is, in the identification of the research problem, data collection, data analysis and interpretation, and lastly in the writing and dissemination of the research (Creswell, 2009). Ethical issues involve matters of access, confidentiality and anonymity of the participants, the participants' consent as well as legal issues like intellectual ownership, confidentiality, privacy, access and acceptance and deception (Johnson & Christensen, 2008). All ethical considerations were adhered to in the during the study. A clearance was sought from the Ministry of education through the National Commission for Science, Technology and Innovation (NACOSTI). Consent was also sought from the University of Nairobi, UNHCR, Refugee Affairs Secretariat and NRC. Informed consent from the respondents was sought before collecting any information from them. They were assured that the information collected was intended for academic use and will be treated as such.

CHAPTER 4 : RESULTS AND FINDINGS

4.1 Introduction

This chapter presents results, findings and data analysis, interpretation carried out to analyse the efficiency of Water Supply and Distribution Systems in Kakuma Refugee Camp in Kenya. The main objective of the study was to evaluate the efficiency of Water Supply and Distribution Systems in Kakuma Refugee Camp.

The research adopted a mix of both quasi-experimental research and survey research designs. The findings have been analysed, combined and presented in tables, charts and narratives.

4.2 Response Rate

The study focused on selected heads of households from three sub camps of Kakuma Refugee Camp. The study interviewed 377 respondents across Kakuma 2, 3 and 4, where 377 questionnaires were issued. Of the 377, 370 questionnaires were returned of which 6 were incomplete. This narrowed down to 364 completed questionnaires indicating a response rate of 97% as summarized in table 4.1

Table 4.1 Response Rate

Questionnaire issued	Questionnaire returned	Incomplete Questionnaires	Complete Questionnaires	Response rate
377	370	6	364	97%

4.3 Background information of the respondents

This section presents the demographic characteristics of the respondents interviewed through household in depth interviews.

4.3.1 Gender of the respondents

Background information of the respondent provided relevant information as far as the sample population and the research topic was concerned. The following were the findings of the study as summarized in Figure 4.1. Out of the 364 respondents issued with questionnaires in the study, 164 were male while the remaining 200 were female. This accounted for 45% and 55% respectively.

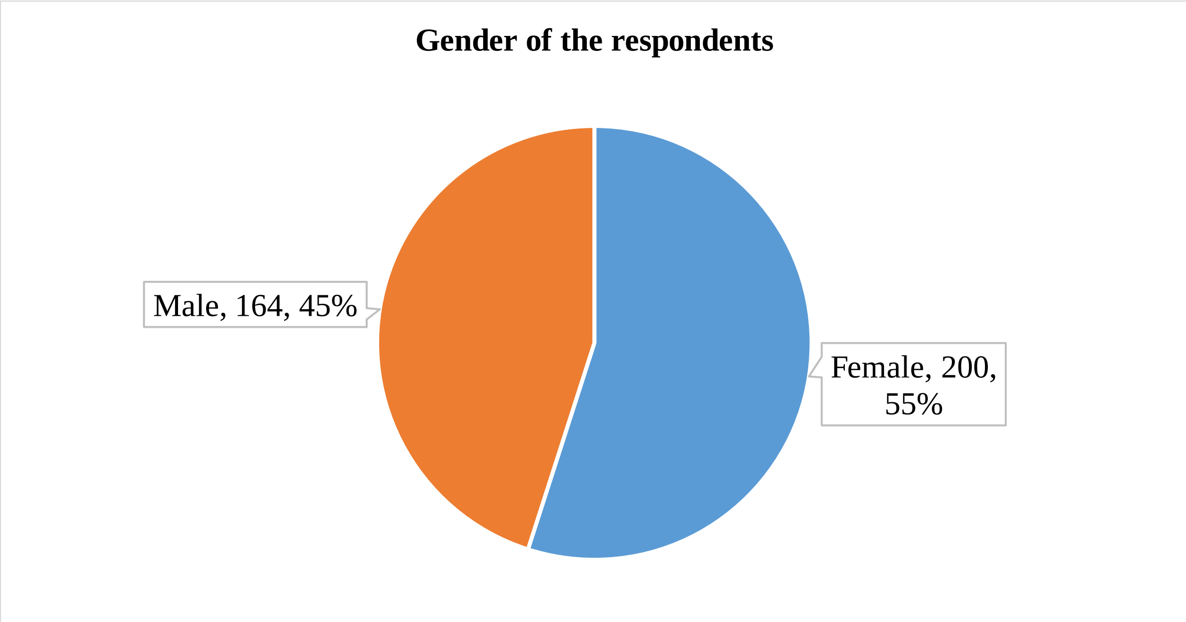


Figure 4.1 Gender of the respondents

4.3.2 Family size

The family size was operationally defined using two intermediate variables mainly total people who slept in the house the previous night and the number of children under 5 years that were in the household. There was no problem in the statement of the family size therefore all respondents disclosed this vital information. This information provided a good picture of the total water consumers in the household. The family size was analysed by establishing the measures of central tendency as shown in Table 4.2.

Table 4.2 Family size

	How many people slept in this house last night?	How many children less than 5 years old live and slept in this house last night?
Median	6	1
Mean	7	1
Mode	4	0

4.4 Descriptive analysis for the study Variables

The findings with regards to the research questions are presented below.

4.4.1 Production characterisation of the boreholes in Kakuma Refugee Camp

A total of seven boreholes located along Tarach River were visited. These boreholes supply water to Kakuma 2, 3 and 4. The boreholes were mapped and their characteristics with regards to depth, tested yield, static water levels, dynamic water levels and casing diameters recorded. The borehole locations were determined using a GPS receiver and uploaded on Google Earth. Borehole flow rates were determined using the water meters installed on the well head and a stopwatch was used to determine the time taken for the meter to record a certain flow. The static water levels and the pumping water levels were determined by inserting a dipper meter into the borehole through the airline pipe. The data was presented in table 4.3 and figure 4.2.

Table 4.3 Borehole features

BH ID	Longitude (W-E)	Latitude (N-S)	Tested Yield m3/hr	Elevation(m)	Casing diameter (mm)	Depth (mbgl)
BH-4B	34.83699	3.75486	32.3	603	152	40
BH-5	34.83235	3.74833	12.4	591	203	45
BH-6	34.83418	3.76202	37.2	598	203	100
BH-7B	34.83045	3.77047	16.0	587	203	85
BH-8	34.82917	3.77758	32.1	587	203	60
BH-12	34.82952	3.77639	41.0	593	203	100
BH-IOM	34.83032	3.77503	31.2	587	203	70

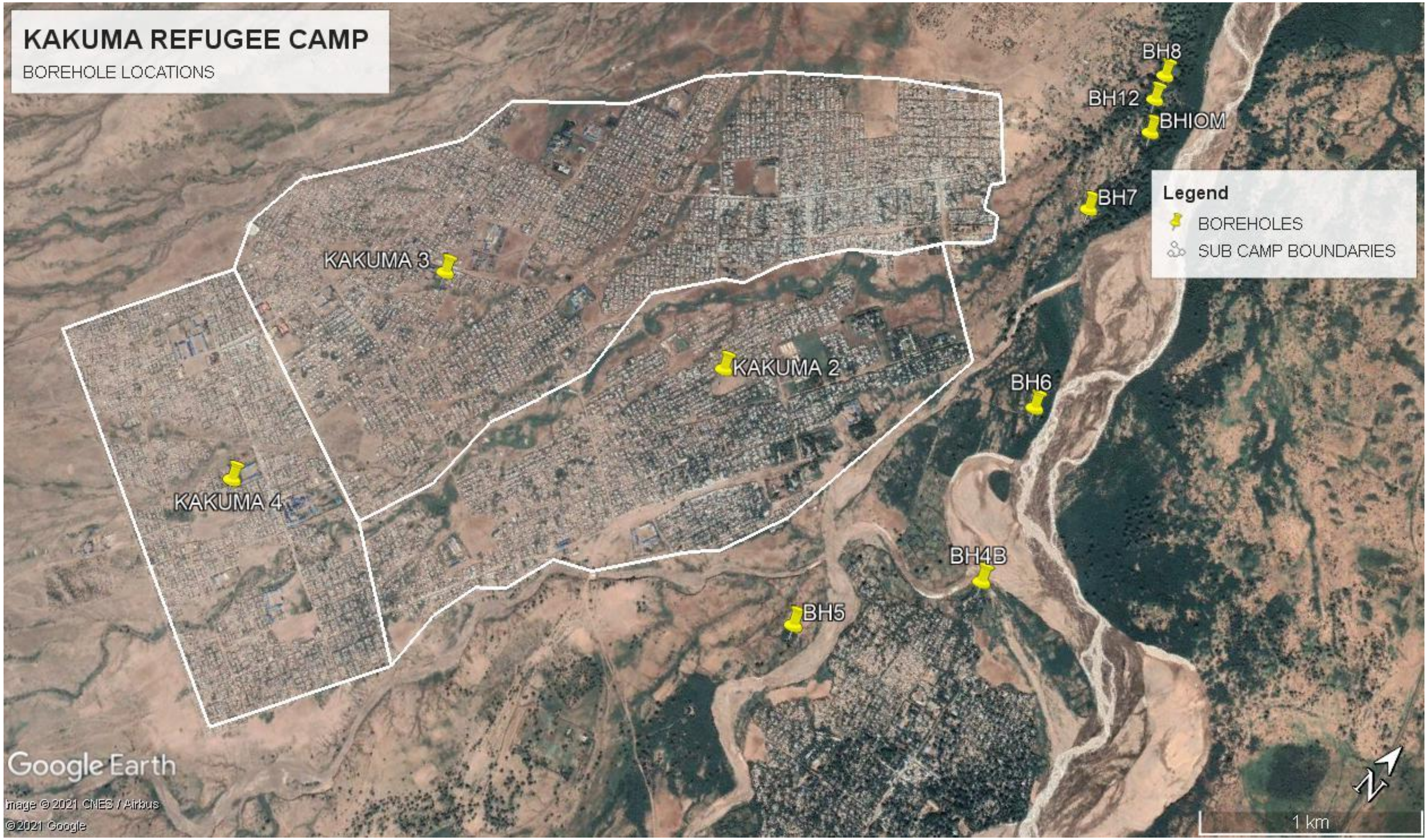


Figure 4.2 Borehole locations

4.4.2 Borehole Production

The borehole production records were extracted from the borehole logbooks at each of the seven boreholes. Data for January, February, March, April and May for year 2020 was collected and recorded. The data provided the total amount of water produced or pumped from the boreholes for the five months. The data was tabulated in Table 4.4.

Table 4.4 Borehole Water Production Data

BH ID	Borehole Yield m^3/hr	Total Monthly Borehole Water Production in m^3					
		Jan-20	Feb-20	Mar-20	Apr-20	May-20	Total
BH-4B	32.3	15,652	15,621	18,054	19,064	16,748	85,139
BH-5	12.4	5,413	4,617	5,700	5,733	5,390	26,853
BH-6	37.2	13,254	11,283	14,099	13,717	14,096	66,449
BH-7B	16.0	6,041	5,090	6,339	5,551	5,887	28,908
BH-8	32.1	12,161	10,977	12,327	13,628	18,000	67,093
BH-12	41.0	21,648	21,521	21,737	26,761	27,655	119,322
BH-IOM	31.2	15,752	13,206	16,637	17,921	16,349	79,865
Total Monthly Production		**89,921**	**82,315**	**94,893**	**102,375**	**104,125**	**473,629**

4.4.3 Storage of water and distribution in Kakuma Refugee Camp

A mapping exercise to determine the type, location and capacity of the water storage capacity for the research area was carried out. The water storage type consisted of pressed steel panel tanks on an elevated steel tower. The tower heights ranged from 9-15m high. The water tanks were rectangular and their capacities were computed by measuring their dimensions and computing the volume.

The location of the tanks was determined by taking the GPS coordinates and recording the data. Thirteen tanks supply water to refugees in the study area. The total storage was found to be 1,287m^3 as presented in table 4.5.

Table 4.5 Water tanks features

SN	Tank Name/ID	Capacity m^3	Coordinates		Borehole/Water Source
			Latitude	Longitude	
1	Nasibunda Big Tank	108	3.763800	34.818440	BH-IOM
2	Phase 3 Tank	90	3.757800	34.826500	BH-6
3	EST 3 Hope	108	3.740028	34.805027	BH-4B
4	Clinix Six Tank	108	3.755810	34.808680	BH-8
5	Reception Center Tank	108	3.765910	34.825930	BH-7B
6	Phase 2 Tank	90	3.749030	34.821240	BH-6
7	EST 5	108	3.736260	34.807360	BH-4B
8	Fuji Tank	108	3.749610	34.817220	BH-5
9	ISSB Tank	108	3.746770	34.810460	BH-12
10	Somali Bantu Tank	108	3.753600	34.815670	BH-8
11	EST 2 Kakuma 4	108	3.740277	34.808080	BH-12
12	Nasibunda Small Tank	27	3.763800	34.818440	BH-IOM
13	Gambela Tank	108	3.741472	34.817306	BH-4B
	Tatal storage capacity m^3	**1287**			

Figure 4.3 was developed by marking the coordinates of the tank locations on Google earth. From the map Kakuma 2 has a total of 4 tanks, Kakuma 3, 5 tanks and Kakuma 4, 5 tanks.

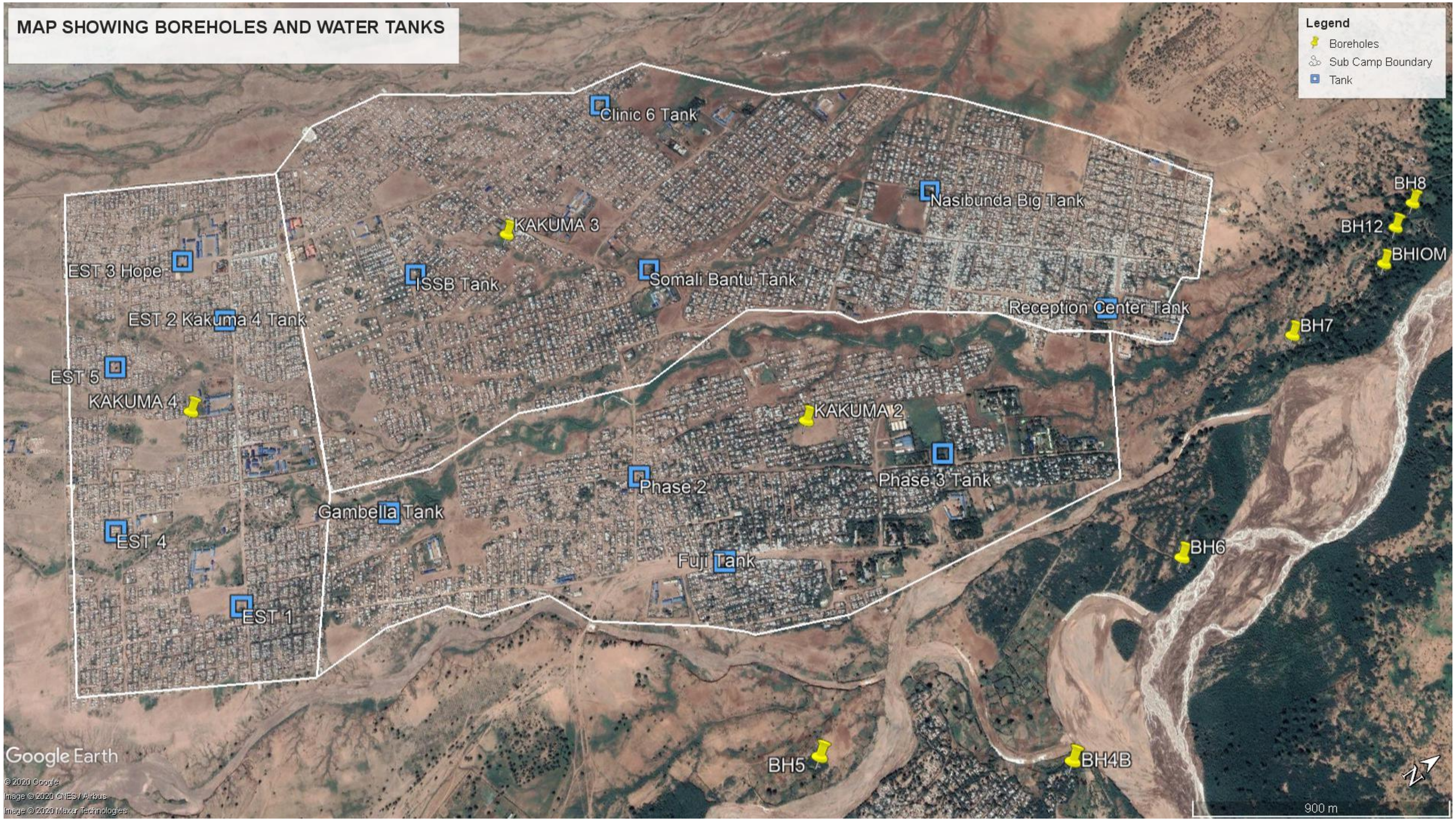


Figure 4.3 Location of tanks in the camp

4.4.4 Water available at household level in Kakuma Refugee Camp-Boreholes' data

The study sought to compare the two methodologies of calculating per capita water access. First, the study adopted the status quo methodology where total monthly production was divided by the days in a month. The net water production per day was then divided by the total population of the study area. Table 4.6 shows the computations of the per capita for the respective months using this methodology.

Table 4.6 Household water per capita

BH ID	Borehole Yield m^3/hr	Total Monthly Borehole Water Production in m^3					
		Jan-20	Feb-20	Mar-20	Apr-20	May-20	Total
BH-4B	32.3	15,652	15,621	18,054	19,064	16,748	85,139
BH-5	12.4	5,413	4,617	5,700	5,733	5,390	26,853
BH-6	37.2	13,254	11,283	14,099	13,717	14,096	66,449
BH-7B	16.0	6,041	5,090	6,339	5,551	5,887	28,908
BH-8	32.1	12,161	10,977	12,327	13,628	18,000	67,093
BH-12	41.0	21,648	21,521	21,737	26,761	27,655	119,322
BH-IOM	31.2	15,752	13,206	16,637	17,921	16,349	79,865
Total Monthly Production		**89,921**	**82,315**	**94,893**	**102,375**	**104,125**	**473,629**
Average Daily Production in m3		2,900.68	2,838.45	3,061.06	3,412.50	3,358.87	
Average Daily Production in Liters		2,900,677.42	2,838,448.28	3,061,064.52	3,412,500.00	3,358,870.97	
Unaccounted For Water(UFW) 35%		1,015,237.10	993,456.90	1,071,372.58	1,194,375.00	1,175,604.84	
Net production		1,885,440	1,844,991	1,989,692	2,218,125	2,183,266	
Refugee Population Kakuma 2,3 ,4		89,430	89,430	89,430	89,430	89,430	
Per capita(L/P/D		21.1	20.6	22.2	24.8	24.4	

Figure 4.4 shows the variation of the per capita during the months of January to May 2020.

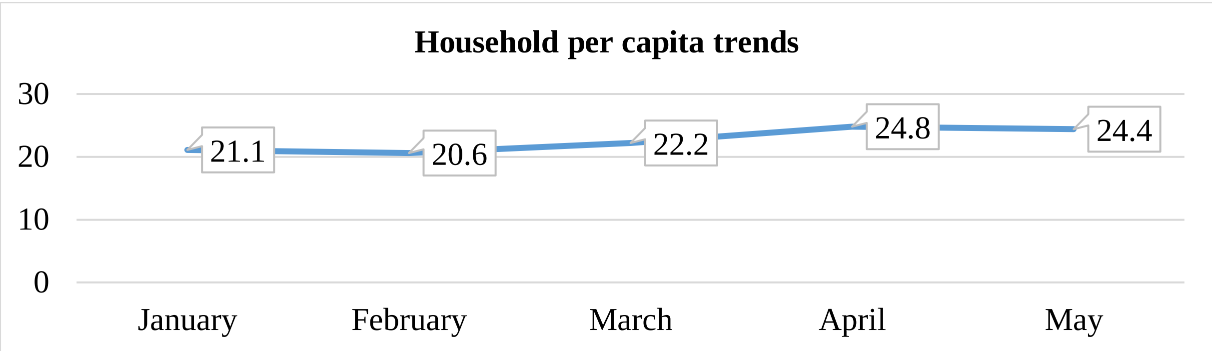


Figure 4.4 Household per capita water access trends

Based on the statistics above, the average per capita was 22.62 l/p/d.

4.4.5 Water available at household level in Kakuma Refugee Camp-KAP Survey

Table 4.7 presents the findings from the KAP survey based on the administered questionnaire.

Table 4.7 KAP Survey Results

What is the main source of water for this household?		
Water location	Frequency	Percentage
Communal/household tap-stand	363	99.77%
Traditional source (scoop hole, lagga, dry river bed)	1	0.23%
How far is the main water collection point from the household?		
Value	Frequency	Percentage
Less than 200m	296	78.47%
More than 200m but less than 500m	75	19.91%
Over 500m	6	1.62%
How much time does it take you to fill your jerrican?		
Time	Frequency	Percentage
30 min and below	258	70.83%
Over 30 min	106	29.17%
What type is/are the drinking water storage container/s? (Observe/Multiple entry)		
Type of mouth	Frequency	Percentage
Narrow mouth and covered	228	62.73%
Narrow mouth but not covered/lid	109	29.61%
Wide but covered	17	4.85%
Wide mouth and not covered	10	2.81%
What is the condition of the drinking water storage container? (observe)		
Condition	Frequency	Percentage
No visible dirt and covered	187	51.39%
Visible dirt and not covered	76	20.84%
Visible dirt and covered	69	18.96%
No visible dirt and not covered	32	8.81%
What is the most common mode of transporting water from the collection point to the household?		
Means of Transporting water	Frequency	Percentage
Direct carrying (head, shoulder etc)	318	87.27%
Hand cart/wheelbarrow	36	9.95%
Foot/rolling/pulling on ground	9	2.55%
Bicycle	1	0.23%
Have you experienced or heard of water conflicts/quarrels at the fetching point in the last one month?		
Conflicts / Quarrels	Frequency	Percentage
Yes	211	57.87%
No	153	42.13%

Table 4.8 presents a statistical summary on the measures of central tendencies of the water availability at household level as collected from the household survey.

Summary of water availability in the households

Table 4.8 Summary of water availability in the households

	Number of containers	Collected water(liters)	Per capita(l/p/d)
Average	5	102.0988	23.55419
Mode	4	80	40
Median	4	80	17.5

4.4.6 Real time monitoring interphase

The real time monitoring portal which had been set up by feeding it with the relevant data including the names of the reservoirs, their capacities and the heights, provided an interphase for viewing, analysis and downloading of the data captured by the ultrasonic water level sensors. Their coordinates were also incorporated.

The real time monitoring portal was accessed through the link http://unhcr.independent-software.com/#/projects/10. Figure 4.5 shows the online portal with the thirteen water reservoirs. From the portal, it was possible to visualize the total amount of water available in the reservoirs at a particular time. This was given as a volume and also as a percentage of the total storage capacity.

By clicking on the individual tanks, it was possible to determine, the current volume of the water at a given time. It was also possible to analyze the various graphs depicting the filling up and emptying of the tanks. The rate of filling up and emptying could also be computed.

In order to check on the rate at which the devices were communicating with the gateway and the server, it was possible to check the last time the devices were online thus transmitting the data.

It was also possible to determine the frequency at which the various tanks were filled and emptied with water.

The portal had a provision for calibrating the level sensors/devices to conform to the actual parameters in relation to the installation heights. This parameter was important since it determined the level of accuracy in providing the actual amount of water in the tank. A negative volume indicated that the device reading height was not well calibrated.

Figure 4.5 shows the number of readings carried out by the sensors. It also shows the volume of water in the reservoirs. The curves could be zoomed to show data for the last 24hours, 3 days, 1 week or one month.

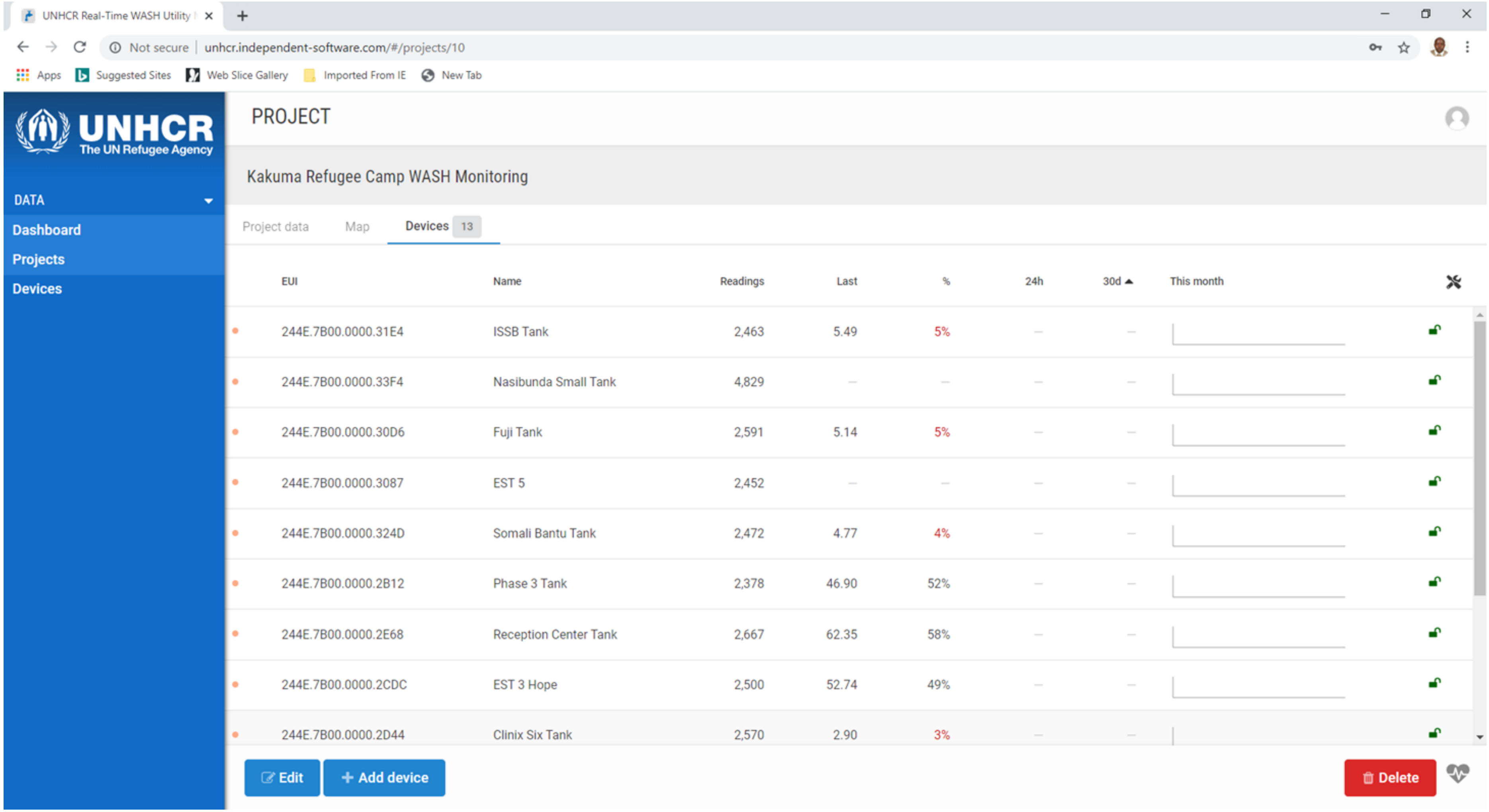


Figure 4.5 Real time monitoring Interphase

The real time portal had a provision for downloading data captured by the level sensors. The data was downloaded as an image (chart). The data downloaded was for the period from 17th February to 17th April 2020 as shown in Figures 4.6 to Figure 4.15.

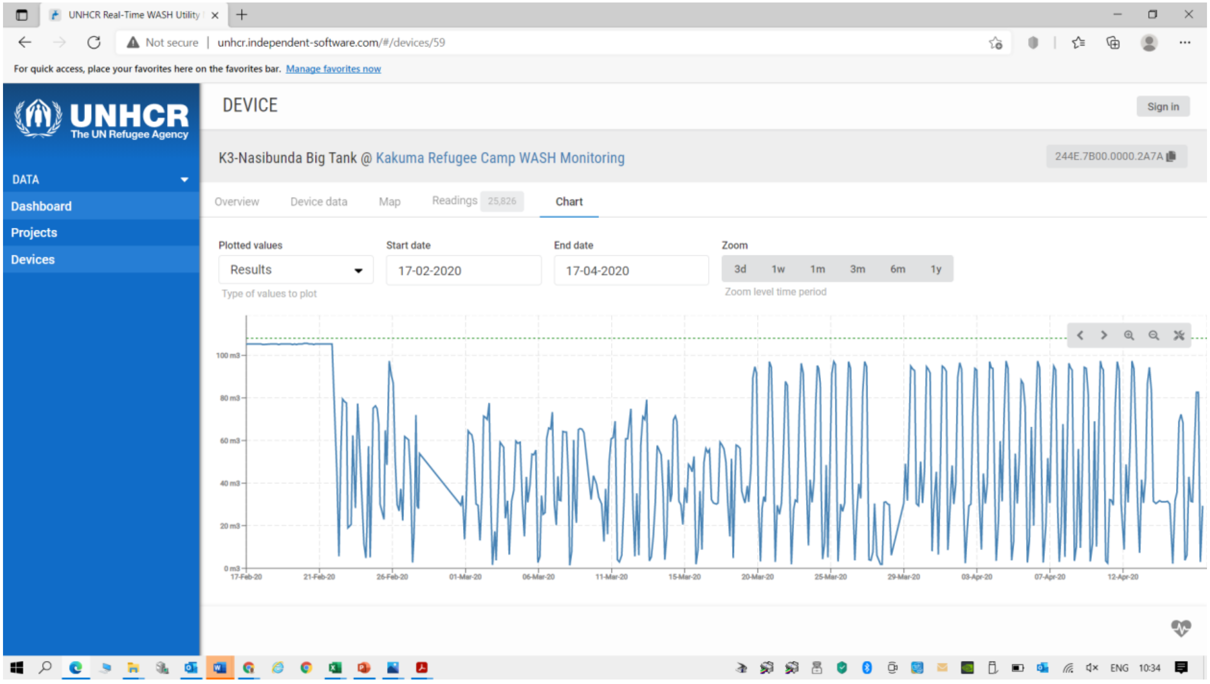


Figure 4.6 Nasibunda Big Tank

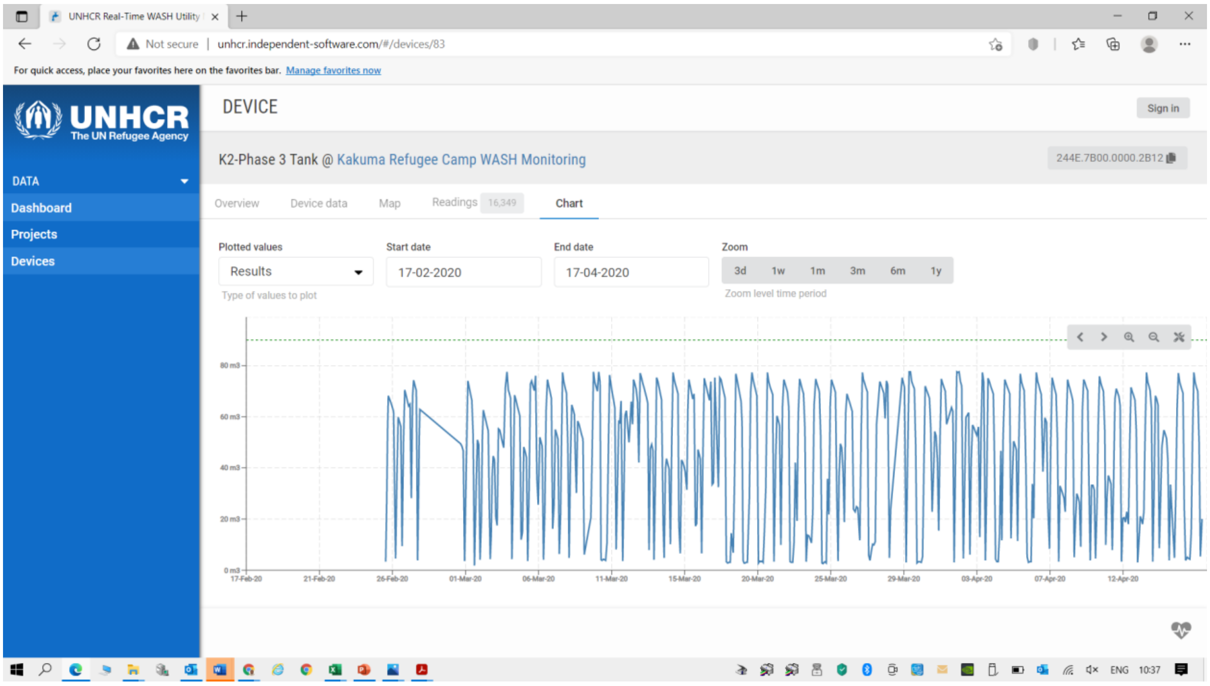


Figure 4.7 Phase 3 Tank

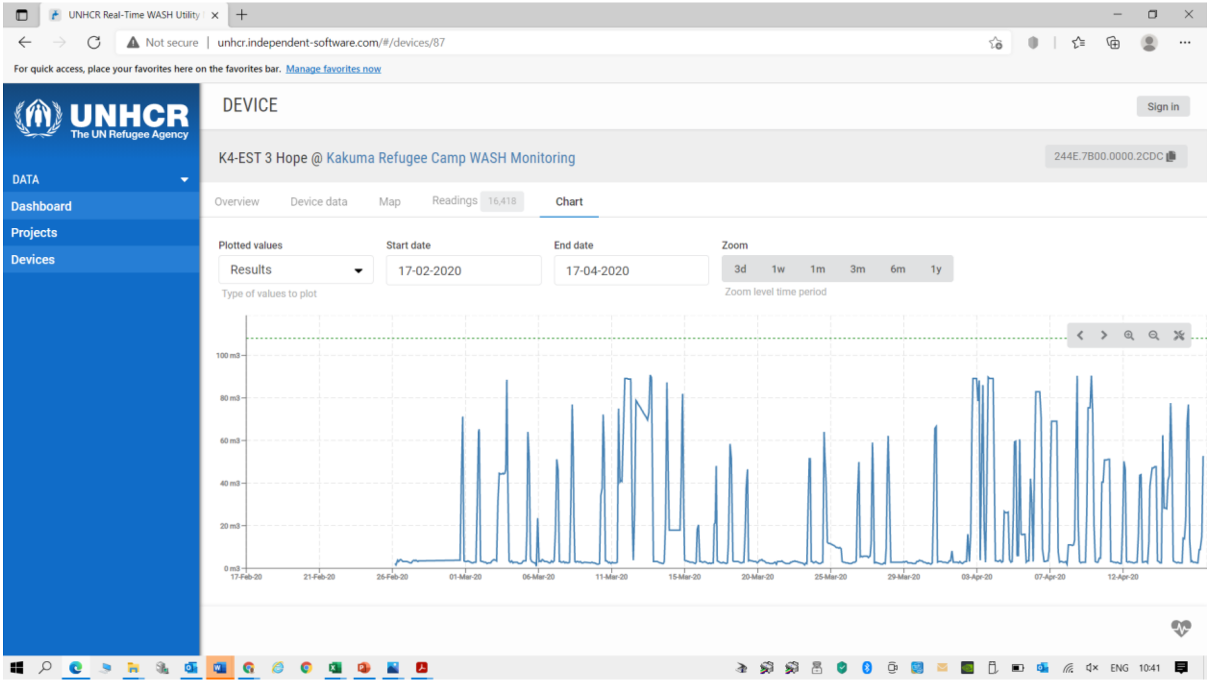


Figure 4.8 EST 3 Hope Primary Tank

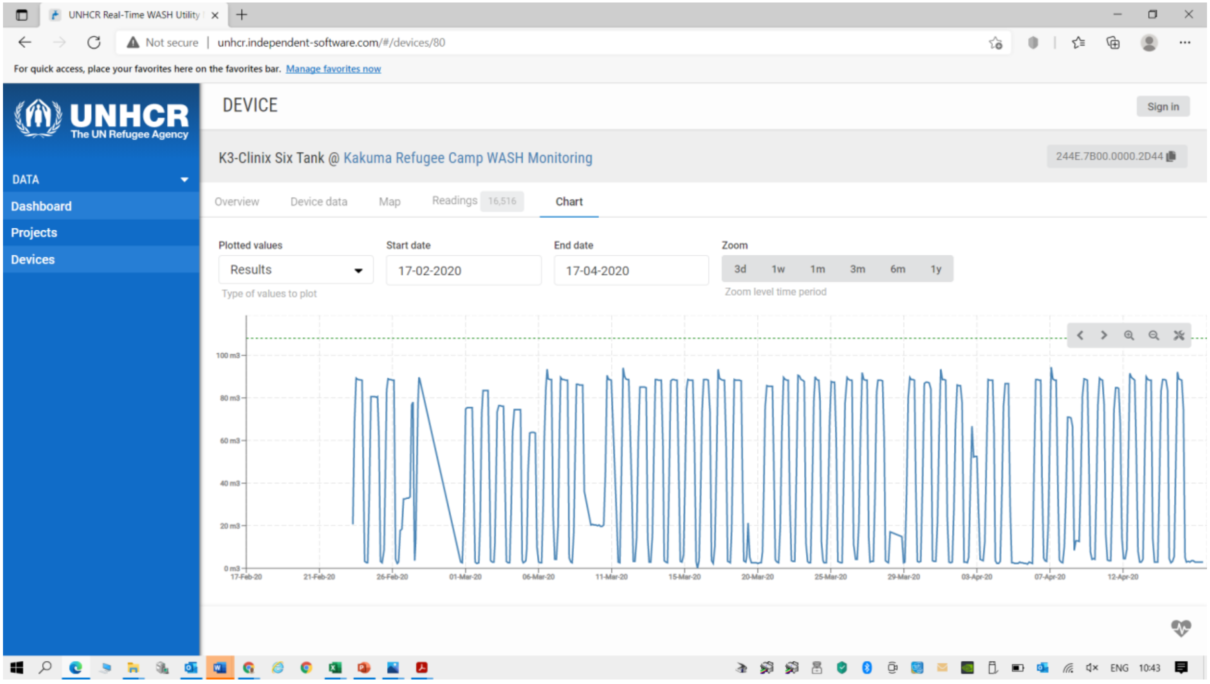


Figure 4.9 Clinic Six Tank

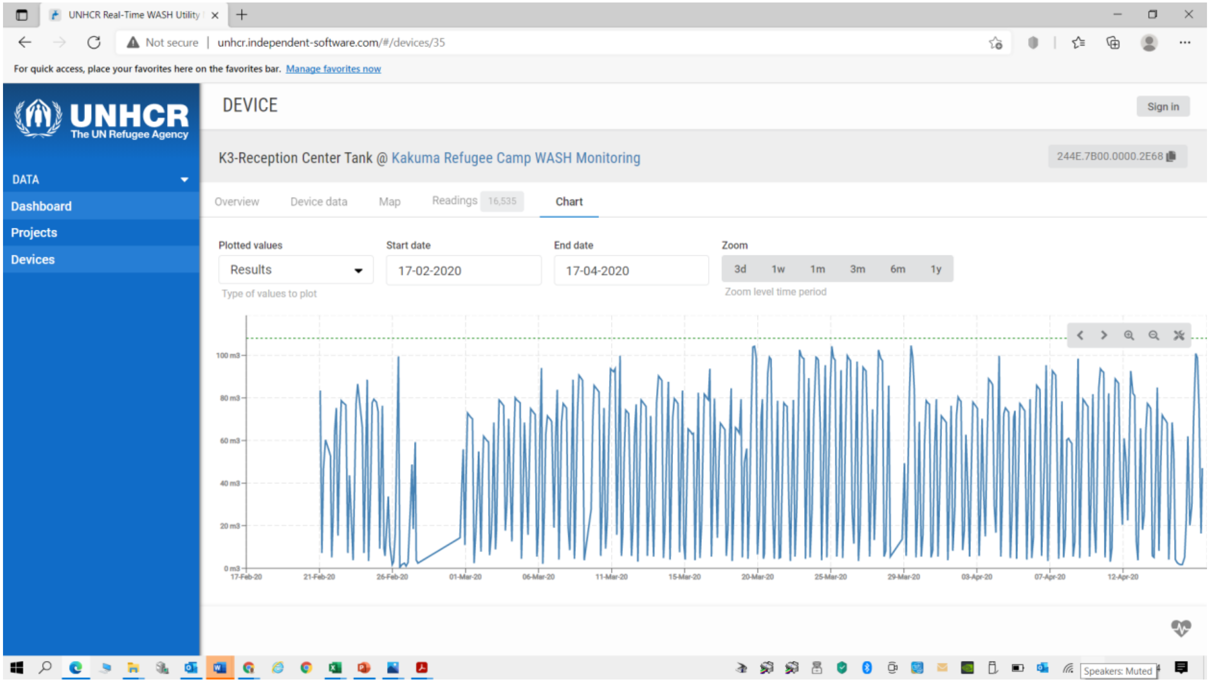


Figure 4.10 Reception Center Tank

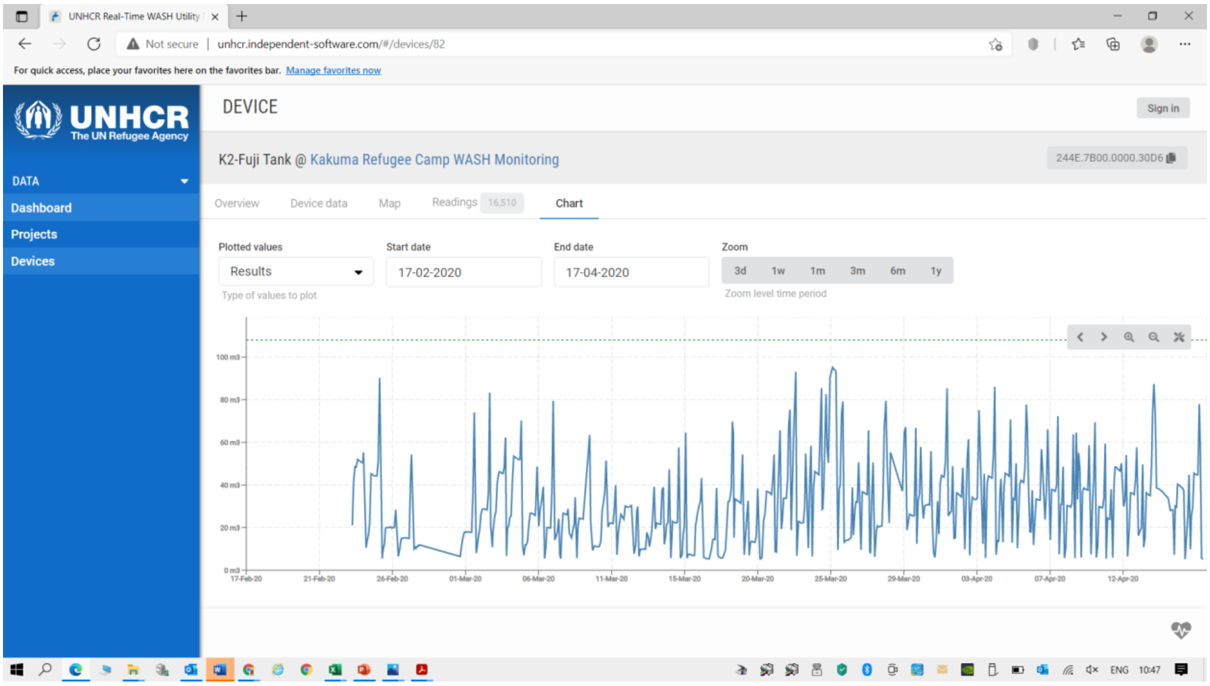


Figure 4.11 Fuji Tank

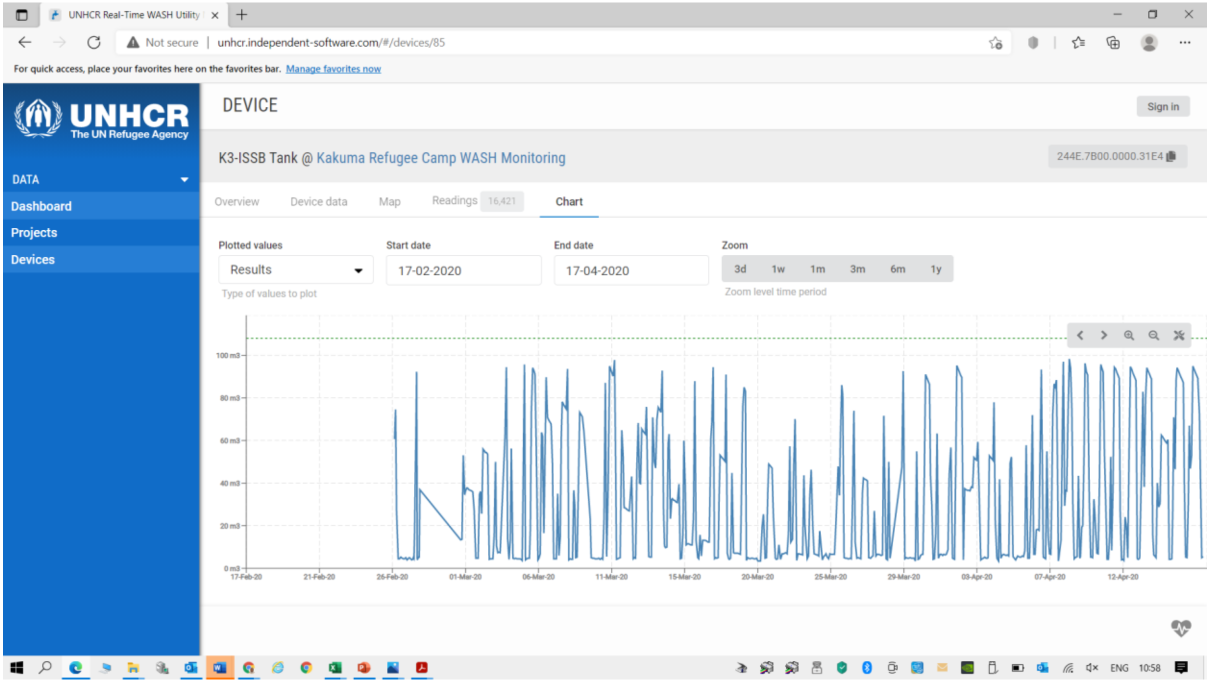


Figure 4.12 ISSB Tank

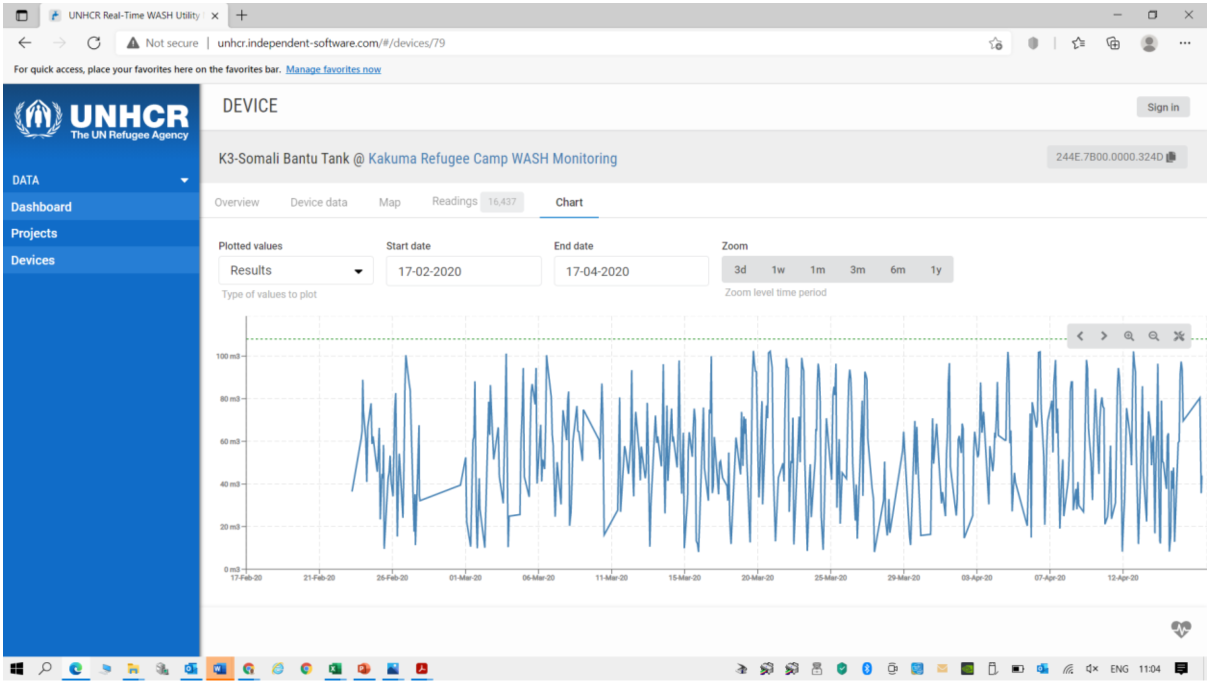


Figure 4.13 Somali Bantu Tank

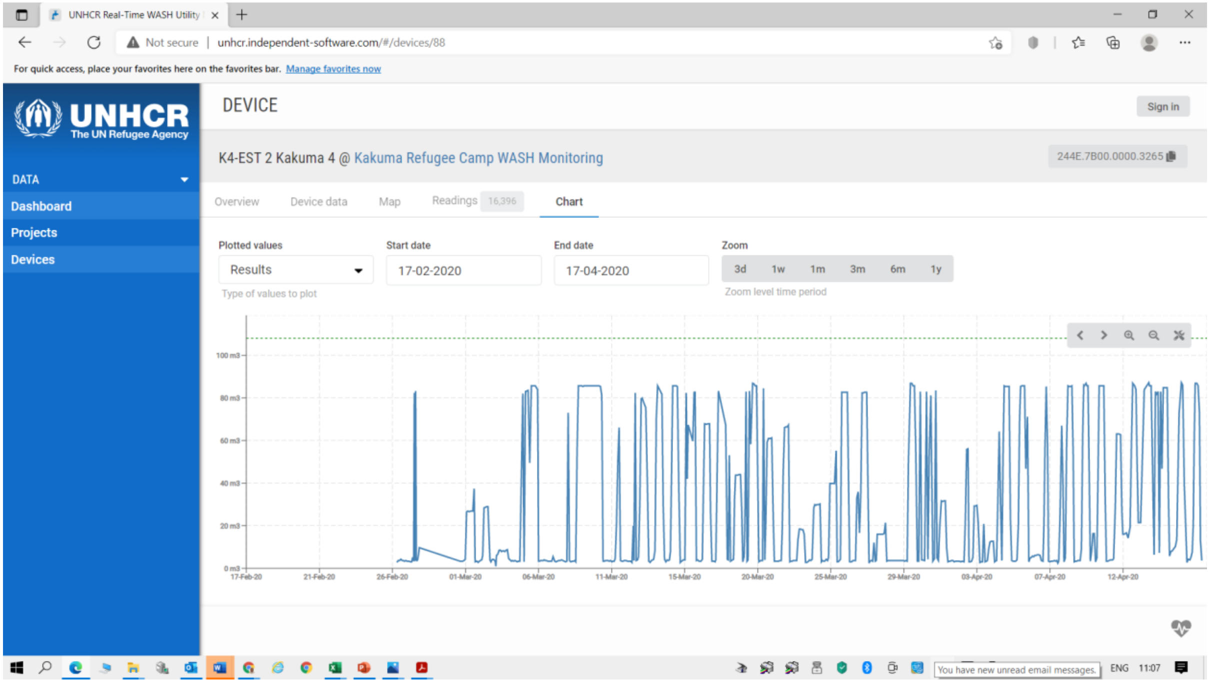


Figure 4.14 EST 2 Kakuma 4

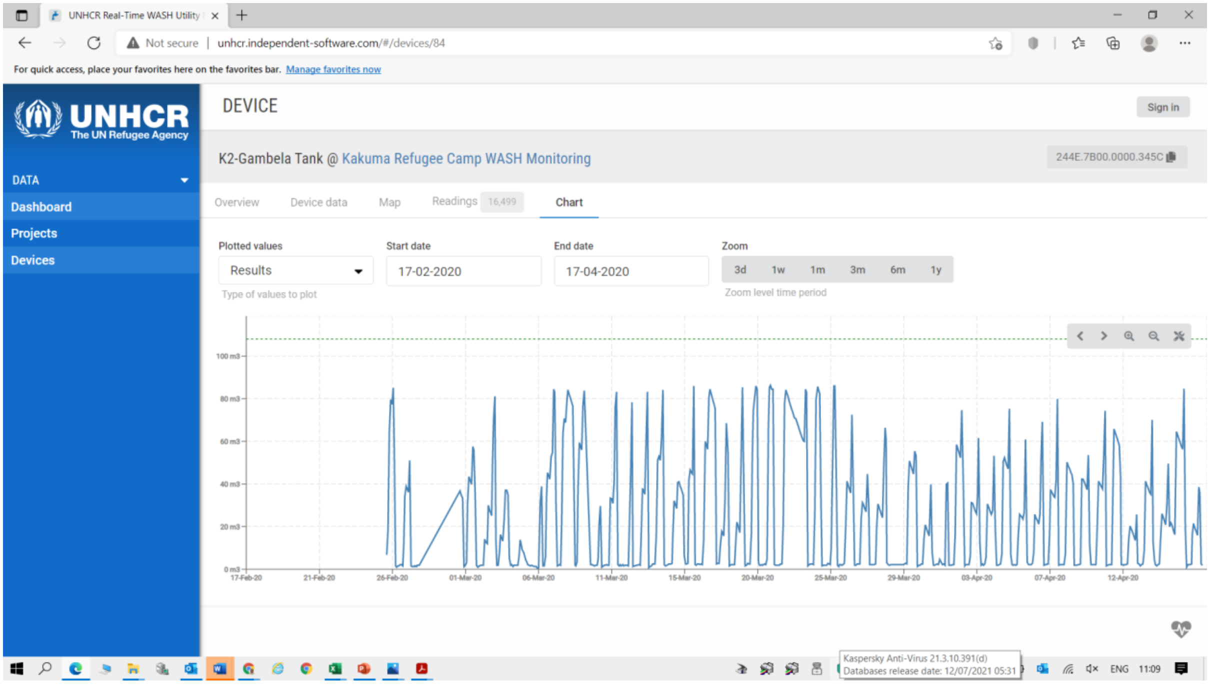


Figure 4.15 Gambela Tank

The individual tanks were analysed by determining the amount of water pumped into the tanks and the duration. The tank fill-up rate was computed and tabulated. An analysis was also carried out to determine the water distribution time for each tank and a tank emptying rate computed and tabulated. To determine the storage losses, the difference in volume between the fill up volume and the emptying time was computed. Data from three tanks, Phase 2, EST5 and Nasibunda Small Tank was not captured due to inability of the level sensors to measure the water levels during the data collection period. These was omitted from the analysis. The table 4.9 presents survey findings from the real time monitoring data.

Table 4.9 Real time monitoring data

SN	Tank Name/ID	BH ID	Filling Up Tanks							Emptying of the Tanks(Consumption)						
			Start time	End Time	Filling Time (Hrs)	Volume Start (m^3)	Volume End (m^3)	Difference /Pumped (m^3)	Calculated Fill up rate (m^3/hr)	Start time	End Time	Emptying Time (Hrs)	Volume Start (m^3)	Volume End(m^3)	Difference /Consumed (m^3)	Calculated Emptying rate (m^3/hr)
	Nasibunda Big Tank	BH-IOM	31/03/2020 20:57	01/04/2020 02:56	5.98	4.27	97.07	92.80	15.51	01/04/2020 08:27	01/04/2020 11:27	3.00	92.53	1.87	-90.66	-30.22
1	Nasibunda Big Tank	BH-IOM	01/04/2020 13:27	01/04/2020 17:55	4.47	1.87	60.00	58.13	13.01	01/04/2020 17:55	01/04/2020 20:57	3.03	60	4.53	-55.47	-18.29
	Phase 3 Tank	BH-6	01/04/2020 20:29	01/04/2020 23:59	3.50	3.04	75.8	72.76	20.79	02/04/2020 08:58	02/04/2020 11:00	2.03	73.27	3.04	-70.23	-34.54
2	Phase 3 Tank	BH-6	02/04/2020 11:00	02/04/2020 14:00	3.00	3.04	60.08	57.04	19.01	02/04/2020 19:00	02/04/2020 19:58	0.97	60.08	4.82	-55.26	-57.17
3	EST 3 Hope	BH-4B	03/04/2020 20:39	04/04/2020 00:10	3.52	2.83	89.79	86.96	24.73	04/04/2020 07:41	04/04/2020 11:09	3.47	89.16	3.45	-85.71	-24.72
4	Clinix Six Tank	BH-8	03/04/2020 18:36	04/04/2020 00:06	5.50	5.48	88.66	83.18	15.12	04/04/2020 08:06	04/04/2020 11:04	2.97	88.33	3.55	-84.78	-28.58
5	Reception Center Tank	BH-7	01/04/2020 19:58	02/04/2020 00:58	5.00	3.41	81.09	77.68	15.54	02/04/2020 08:28	02/04/2020 09:58	1.50	77.68	3.41	-74.27	-49.51
	Reception Center Tank	BH-7	02/04/2020 10:58	02/04/2020 16:26	5.47	4.43	97.44	93.01	17.01	02/04/2020 16:26	02/04/2020 17:57	1.52	97.44	1.7	-95.74	-63.13
6	Phase 2 Tank		No data collected by device													
7	EST 5		No data collected by device													
	Fuji Tank-1st Pumping	BH-5	03/04/2020 20:12	03/04/2020 23:15	3.05	5.66	40.85	35.19	11.54							
8	Fuji Tank-2nd Pumping	BH-5	04/04/2020 07:13	04/04/2020 10:15	3.03	43.2	86.14	42.94	14.16	04/04/2020 10:15	04/04/2020 12:15	2.00	86.14	7.2	-78.94	-39.47
9	ISSB Tank	BH-12	01/04/2020 21:02	02/04/2020 01:03	4.02	4.18	98.32	94.14	23.44	02/04/2020 08:02	02/04/2020 10:32	2.50	89.69	3.92	-85.77	-34.31
	Somali Bantu Tank 1st Phase	BH-8	05/04/2020 00:43	05/04/2020 05:42	4.98	11.8	101.97	90.17	18.09	05/04/2020 07:14	05/04/2020 08:45	1.517	101.97	39.68	-62.29	-41.07
10	Somali Bantu Tank 2nd Phase	BH-8	05/04/2020 08:45	05/04/2020 10:13	1.47	39.68	70.33	30.65	20.90	05/04/2020 10:13	05/04/2020 12:15	2.033	70.33	22.1	-48.23	-23.72
	Somali Bantu Tank 3rd Phase	BH-8	05/04/2020 12:15	05/04/2020 15:44	3.48	22.1	46.21	24.11	6.92	05/04/2020 15:44	05/04/2020 18:13	2.483	46.21	24.36	-21.85	-8.80
11	EST 2 Kakuma 4	BH-12	04/04/2020 21:05	05/04/2020 00:33	3.47	3.62	85.68	82.06	23.67	05/04/2020 08:32	05/04/2020 10:34	2.033	85.68	3.62	-82.06	-40.36
12	Nasibunda Small Tank		No data collected by device													
	Gambela Tank	BH-4B	02/04/2020 20:32	02/04/2020 23:05	2.55	2.14	32.12	29.98	11.76							
13	Gambela Tank	BH-4B	03/04/2020 07:03	03/04/2020 10:04	3.02	25.39	68.84	43.45	14.40	03/04/2020 10:04	03/04/2020 12:03	1.983	68.84	2.14	-66.7	-33.63
	Total (m^3)							**1094.25**							**-1057.96**	

A comparative analysis between the borehole yield and flow computed using real time monitoring data was done. The results were presented in table 4.10.

Table 4.10 Comparative analysis of the borehole production and reservoir real time monitoring data

SN	Tank Name/ID	Capacity m^3	Coordinates		Borehole/ Water Source	Yield m^3/hr	Computed Flow Rate m^3/hr from Level Sensors	Flow as a % of borehole yield	Fill Up Time in Hours(Full Tank Capacity)
			Latitude	Longitude					
1	Nasibunda Big Tank	108	3.763800	34.818440	BH-IOM	31.2	15.51	49.7%	6.96
2	Phase 3 Tank	90	3.757800	34.826500	BH-6	37.2	20.79	55.9%	4.33
3	EST 3 Hope	108	3.740028	34.805027	BH-4B	32.3	24.73	76.6%	4.37
4	Clinix Six Tank	108	3.755810	34.808680	BH-8	32.1	15.12	47.1%	7.14
5	Reception Center Tank	108	3.765910	34.825930	BH-7B	16	15.54	97.1%	6.95
6	Phase 2 Tank	90	3.749030	34.821240	BH-6	37.2			
7	EST 5	108	3.736260	34.807360	BH-4B	32.3			
8	Fuji Tank	108	3.749610	34.817220	BH-5	12.4	11.54	93.1%	9.36
9	ISSB Tank	108	3.746770	34.810460	BH-12	41	23.44	57.2%	4.61
10	Somali Bantu Tank	108	3.753600	34.815670	BH-8	32.1	20.9	65.1%	5.17
11	EST 2 Kakuma 4	108	3.740277	34.808080	BH-12	41	23.67	57.7%	4.56
12	Nasibunda Small Tank	27	3.763800	34.818440	BH-IOM	31.2			
13	Gambela Tank	108	3.741472	34.817306	BH-4B	32.3	14.4	44.6%	7.50

4.5 Determination of water transmission Losses

Computation of the losses through the water transmission pipeline formed an integral part in determining the efficiency of the water reticulation system. The determination of the losses was done using the Hazen Williams equation.

First, the pipeline lengths were mapped and determined from the boreholes to the elevated steel tanks. The pipe type, outside diameters and class was also determined and presented in table 4.11. The camp pipe network consists of class D PVC pipes.

Table 4.11 Pipeline characteristics

SN	Tank Name/ID	Capacity m^3	Coordinates		Borehole/Water Source	Pipe length from Borehole to Tank (m)	Pipe Size mm	Pipe Type	Pipe Class
			Latitude	Longitude					
1	Nasibunda Big Tank	108	3.763800	34.818440	BH-IOM	2,009	90	PVC	D
2	Phase 3 Tank	90	3.757800	34.826500	BH-6	998	90	PVC	D
3	EST 3 Hope	108	3.740028	34.805027	BH-4B	4,699	110	PVC	D
4	Clinix Six Tank	108	3.755810	34.808680	BH-8	3,588	90	PVC	D
5	Reception Center Tank	108	3.765910	34.825930	BH-7B	712	90	PVC	D
6	Phase 2 Tank	90	3.749030	34.821240	BH-6	2,156	90	PVC	D
7	EST 5	108	3.736260	34.807360	BH-4B	4,533	110	PVC	D
8	Fuji Tank	108	3.749610	34.817220	BH-5	854	75	PVC	D
9	ISSB Tank	108	3.746770	34.810460	BH-12	3,992	110	PVC	D
10	Somali Bantu Tank	108	3.753600	34.815670	BH-8	3,269	90	PVC	D
11	EST 2 Kakuma 4	108	3.740277	34.808080	BH-12	4,804	110	PVC	D
12	Nasibunda Small Tank	27	3.763800	34.818440	BH-IOM	2,009	110	PVC	D
13	Gambela Tank	108	3.741472	34.817306	BH-4B	2,920	110	PVC	D

Table 4.12 provides the PVC pipe specifications for the various pipe diameters. The table was used to compute the pipe internal diameters (ID) for frictional head loss calculation.

Table 4.12 PVC pipe specifications

NOMINAL DIAMETRE (mm)	OUTSIDE DIAMETRE (mm)	WALL THICKNESS (mm)				PER 6 METRE EFFECTIVE LENGTH				IMPERIAL SIZE (inch)
		CLASS B	CLASS C	CLASS D	CLASS E	CLASS B	CLASS C	CLASS D	CLASS E	
D25	25.2			1.6	1.8				1.2	3/4
D32	32.0		1.6	1.9	2.35			1.6	1.9	1
D40	40.2		1.8	2.4	2.85		1.9	2.5	3.0	1 1/4
D50	50.2	1.6	2.2	2.9	3.5	2.1	3.0	3.8	4.6	1 1/2
D63	63.2	1.9	2.8	3.6	4.45	3.3	4.7	6.1	7.4	2
D75	75.2	2.2	3.3	4.2	5.15	4.6	6.7	8.5	10.2	2 1/2
D90	90.2	2.7	3.9	5.1	6.2	6.7	9.6	12.2	14.8	3
D110	110.2	3.3	4.8	6.1	7.55	10.0	14.3	18.4	22.2	4
D160	160.3	4.7	6.8	8.9	10.95	29.5	42.2	54.9	66.4	6
D200	200.3	5.2	7.6	10.0	12.3	37.6	53.7	69.1	83.9	7

NOTE: Maximum Pressure Ratings: Class B = 6 Bar, Class C = 9 Bar, Class D = 12 Bar, Class E = 15 Bar

4.5.1 Frictional Head Loss Computation- BHIOM to Nasibunda Tank

By applying the equation below:

$$h_f = 10.7\left(\frac{Q}{C}\right)^{1.852} \frac{l}{d^{4.87}} \quad \text{(SI units)}$$

Where Q = Pumped flow rate from the borehole submersible pump (m^3/sec)

C = Hazen Williams Coefficient, 150 for PVC pipes

d = Pipe internal diameter in m = 90-2(t) where t is the pipe wall thickness

L = Pipe length in m=2009m

$H_f = 10.7(0.008667/150)^{1.852} * 2009/0.0798^{4.87}$

H_f = **67.67m**

The same approach was used to compute the frictional head loss for the rest of the pipelines and tabulated in Table 4.13

In computing the total dynamic head (TDH), the frictional head loss was summed with the tank height, pumping water level (PWL), and the residual head to generate the table for the different boreholes and reservoirs.

TDH=Frictional Head losses+ Tank Height+ Pumping Water Level +Residual Head

TDH=67.67+15+12.67+5

= **100.34m**

The above computation was replicated for the remaining boreholes and reservoirs and tabulated in Table 4.13.

Table 4.13 Total dynamic head computation

Item	Nasibunda Big Tank Line from IOM BH	Phase 3 Tank from BH6	EST3 Hope from BH4B	Clinic Six Tank from BH8	Reception Centre Tank from BH7B	Fuji Tank from BH5	ISSB Tank from BH12	Somali Bantu Tank from BH8	EST 2 Kakuma 4 from BH12	Gambela Tank from BH4B
Rising main Pipe Diameter OD mm	90	90	110	90	90	75	110	90	110	110
Rising main Pipe Diameter ID m	0.0798	0.0798	0.0978	0.0798	0.0798	0.0666	0.0978	0.0798	0.0978	0.0978
C Hazzen Williams Coefficient	150	150	150	150	150	150	150	150	150	150
Pipe Length, L, Meters	2009	998	4699	3588	712	854	3992	3269	4804	2920
Flow at Borehole	31.2	37.2	32.3	32.1	16	12.4	41	32.1	41	32.3
Flow Rate Q m^3/s	0.00867	0.01033	0.00897	0.00892	0.00444	0.00344	0.01139	0.00892	0.01139	0.00897
Frictional Head Loss, H_f at Tank Inlet, m	67.669	46.560	62.674	127.390	6.962	12.565	82.815	116.064	99.660	38.946
Tank Height,m	15	15	15	15	12	12	15	15	15	15
Residual Head at Tank Inlet,m	5	5	5	5	5	5	5	5	5	5
Pumping Water Level,m	12.67	54.03	29.8	7.42	7	7.3	13.35	7.42	13.35	29.8
Total Dynamic Head,m	**100.34**	**120.59**	**112.47**	**154.81**	**30.96**	**36.86**	**116.16**	**143.48**	**133.01**	**88.75**

4.5.2 Determination of the flow rate from Pump Curves

To determine the actual flow rate based on the computed total dynamic head (TDH), the pump curves for the various pumps installed in the boreholes were read. The data for the pumps installed in the boreholes was obtained from NRC and is shown in table 4.14.

Table 4.14 Borehole pump data

BH ID	Longitude (W-E)	Latitude (N-S)	Tested Yield m3/hr	Elevation(m)	Casing diameter (mm)	Depth (mbgl)	Installed Pump	Pumping water level m
BH-4B	34.83699	3.75486	32.3	603	152	40	SP30-13	29.8
BH-5	34.83235	3.74833	12.4	591	203	45	SP14-11	9.81
BH-6	34.83418	3.76202	37.2	598	203	100	SP30-13	54.03
BH-7B	34.83045	3.77047	16.0	587	203	85	SP14-8	7
BH-8	34.82917	3.77758	32.1	587	203	60	SP30-17	7.42
BH-12	34.82952	3.77639	41.0	593	203	100	SP46-12	13.35
BH-IOM	34.83032	3.77503	31.2	587	203	70	SP30-13	12.67

The curves were obtained from the pump manufacturer, Grundfos. As an illustration, BH-IOM supplies water to Nasibunda Big Tank. The borehole is equipped with Grundfos submersible pump model SP30-13 whose performance curve is shown in Appendix V1. From the curve, at a total dynamic head of 100.34m as computed above, the pump had a capacity to deliver a corresponding 29m^3/hr of flow. This was obtained by reading the figure where the 100.34m head intersects with the SP30-13 curve and reading the corresponding flow rate. This was done for the remaining boreholes and tabulated in Table 4.15.

Table 4.15 Flow rate and pump curves

Item	Nasibunda Big Tank Line from IOM BH	Phase 3 Tank from BH6	EST3 Hope from BH4B	Clinic Six Tank from BH8	Reception Centre Tank from BH7B	Fuji Tank from BH5	ISSB Tank from BH12	Somali Bantu Tank from BH8	EST 2 Kakuma 4 from BH12	Gambela Tank from BH4B
Rising main Pipe Diameter OD mm	90	90	110	90	90	75	110	90	110	110
Rising main Pipe Diameter ID m	0.0798	0.0798	0.0978	0.0798	0.0798	0.0666	0.0978	0.0798	0.0978	0.0978
C	150	150	150	150	150	150	150	150	150	150
Pipe Length, L, Meters	2009	998	4699	3588	712	854	3992	3269	4804	2920
Flow at Borehole	31.2	37.2	32.3	32.1	16	12.4	41	32.1	41	32.3
Flow Rate Q m^3/s	0.008667	0.01033	0.00897	0.00892	0.00444	0.00344	0.01139	0.00892	0.01139	0.00897
Frictional Head Loss, H_f at Tank Inlet, m	67.669	46.560	62.674	127.390	6.962	12.565	82.815	116.064	99.660	38.946
Tank Height,m	15	15	15	15	12	12	15	15	15	15
Residual Head at Tank Inlet,m	5	5	5	5	5	5	5	5	5	5
Pumping Water Level,m	12.67	54.03	29.8	7.42	7	7.3	13.35	7.42	13.35	29.8
Total Dynamic Head,m	**100.34**	**120.59**	**112.47**	**154.81**	**30.96**	**36.86**	**116.16**	**143.48**	**133.01**	**88.75**
Pump installed(Model)	SP30-13	SP30-13	SP30-13	SP30-17	SP14-8	SP14-11	SP46-12	SP30-17	SP46-12	SP30-13
Flow Rate at computed TDH, (Expected flow at inlet of water reservoir), m3/hr	29	21	25	24	15.8	12.1	40	28	30	31
Difference between flow at borehole and flow at TDH m3/hr	2.2	16.2	7.3	8.1	0.2	0.3	1	4.1	11	1.3
% Difference between flow at borehole and flow at TDH(Expected flow at inlet of water reservoir)	7.05%	43.55%	22.60%	25.23%	1.25%	2.42%	2.44%	12.77%	26.83%	4.02%
Calculated flow (From sensors) Actual flow at Reservoir inlet m3/hr	15.51	15.12	24.7	20.9	15.54	11.54	23.44	20.9	23.67	14.4
UFW m^3/hr	13.49	5.88	0.3	3.1	0.26	0.56	16.56	7.1	6.33	16.6
UFW %	**46.5%**	**28.0%**	**1.2%**	**12.9%**	**1.6%**	**4.6%**	**41.4%**	**25.4%**	**21.1%**	**53.5%**

The difference between the flow at TDH and the flow calculated at the reservoir inlet based on the level sensor readings was also computed and tabulated as a percentage. The percentage refers to the unaccounted-for water (UFW). It ranged from 1.2% to 53.5% for BH4B. The average was 23.6%. This was based on the expected flow rate at the computed total dynamic head. A graph comparing the various flow rates which consisted of flow at the borehole, flow at computed TDH and flow from sensors was plotted as shown in figure 4.16.

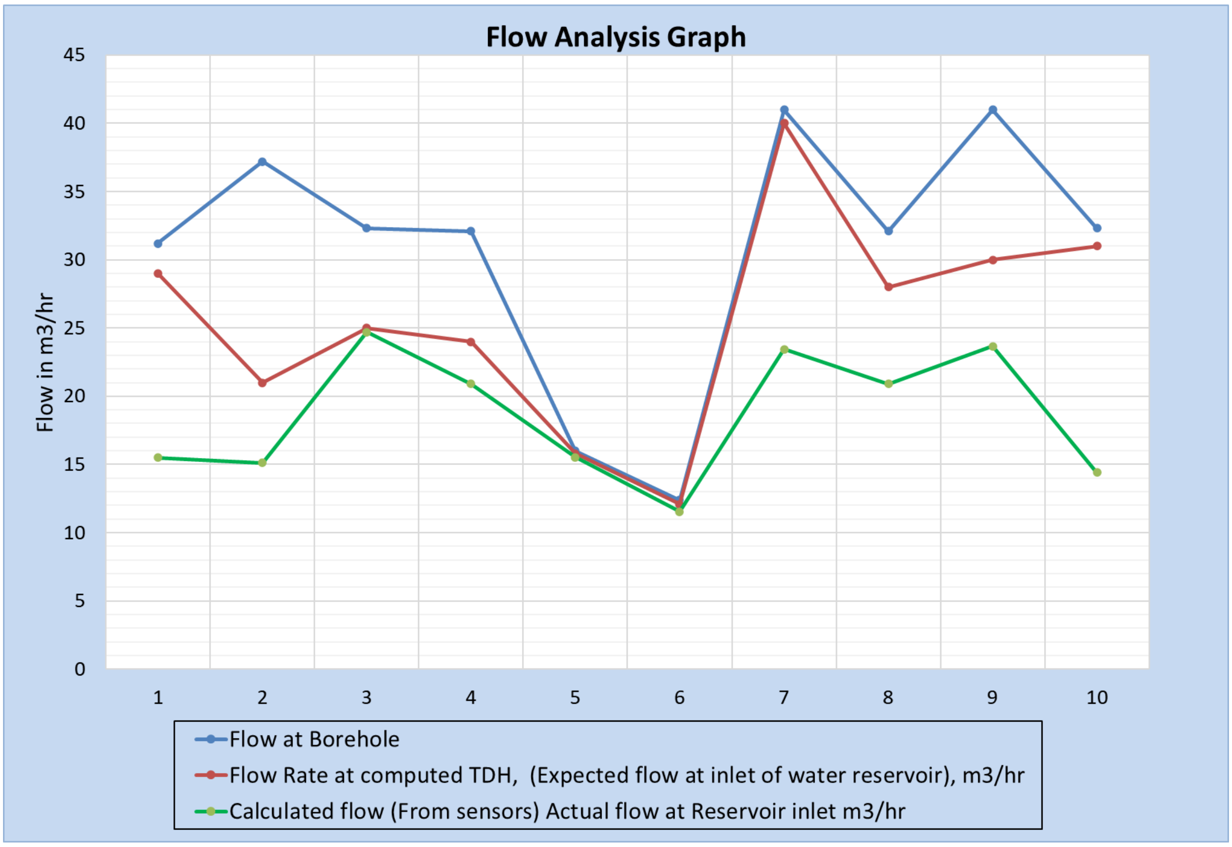


Figure 4.16 Comparison between borehole pumping yield, Flow computed at TDH and Flow computed using real time level sensors (Reservoir inlet).

4.6 Determination of Water storage Losses

An analysis of the losses arising because of water storage inefficiencies was done. This was attributed to leaking water reservoirs or leaking gate/sluice valves. Individual reservoirs were monitored from the time the reservoir was filled with water and the time distribution commenced. The difference in the quantity of water was considered as storage losses. It was not possible to determine water losses during pumping/filling of the tanks. Reception tank real time monitoring graph was used for analysis. The figure 4.17 was analysed to determine the water storage losses.

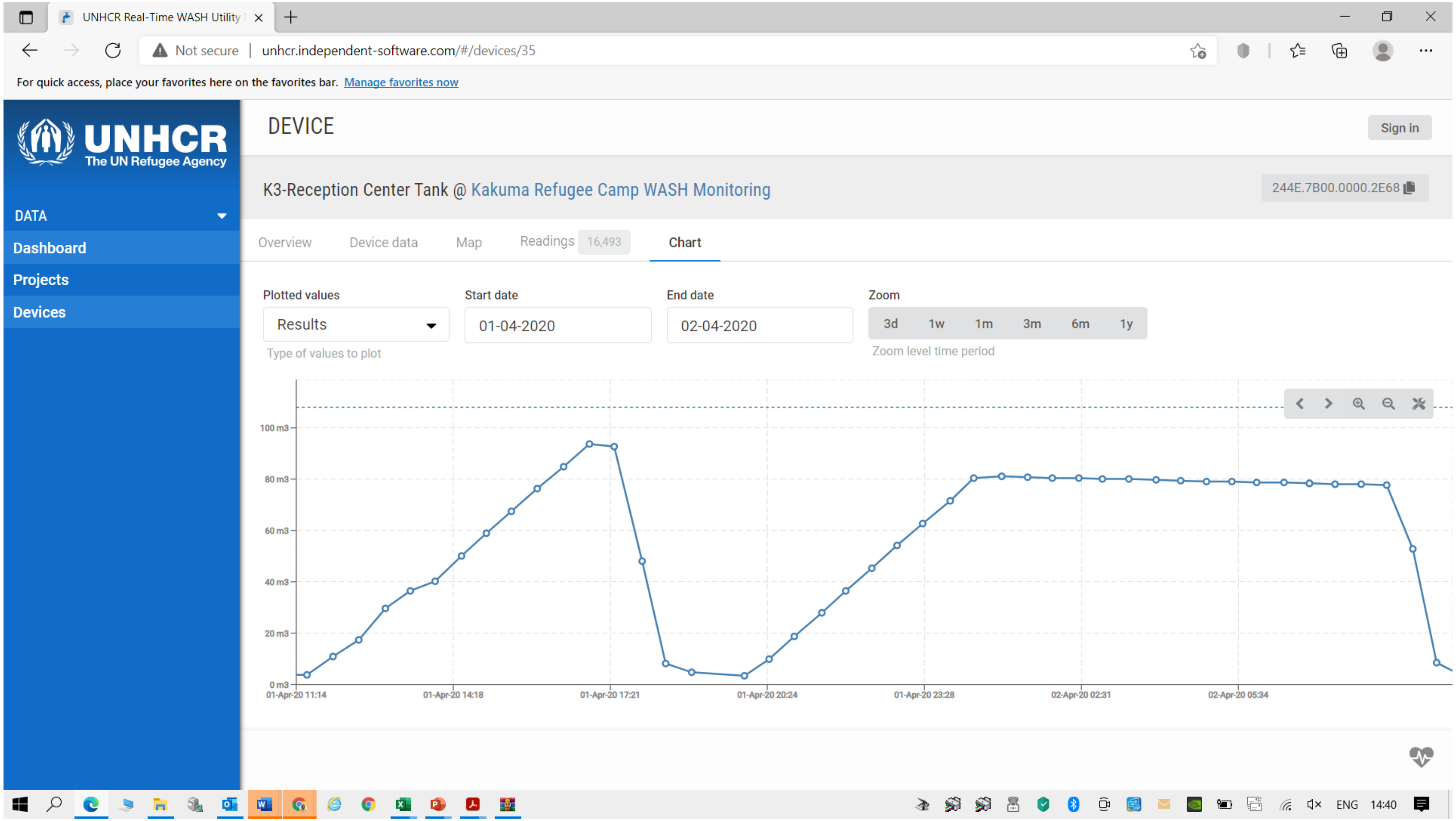


Figure 4.17 Water Losses During Storage

From figure 4.17, filling of the tank begun with a starting volume **of 3.41m^3** on **01/04/2020 at 19:58:00**. The tank received water for a duration of 5hours until **02/04/2020 00:58:00** when the volume was **81.09m^3** when pumping stopped. The amount of water pumped was **77.68m^3** (81.09-3.41).

Distribution or emptying of the reservoir started on **02/04/2020 at 08:28:00** when the volume had fallen to **77.68m^3**. The distribution proceeded for 1.5hours until **02/04/2020 09:58:00** when the volume was **3.41m^3**. The amount of water distributed was **74.27m^3** (77.68-3.41).

During the time, the water was in storage, **02/04/2020 00:58:00** to **02/04/2020 at 08:28:00,** the volume reduced by **3.41m3** which accounts for storage losses**.** This translates to **4.6%**

4.7 Determination of Per Capita water access

4.7.1 Per capita calculation using real time water monitoring devices' UFW

The study compared the per capita water as per NRC monthly water production data and flow rate computed as per data captured by water level sensors.

This was done by computing the daily pumping hours of each borehole. The hours were then used to compute the total amount of water based on the real time monitoring devices data. The unaccounted-for water was then computed for each of the boreholes. This ranged from **2.9%** for BH7B to a maximum of **59.4%** for BH6 with an average of **38.6%.** Table 4.16 shows the results obtained after computation of the average monthly per capita water available through manual and real time monitoring approaches from January to May 2020. The total monthly water production was calculated based on the meter readings at the borehole. This was compared by computing the monthly water production using the flow rates at the inlet of the reservoirs which was measured by the water level sensors. The total monthly water production was divided by the total refugee population of 89,430.

Table 4.16 Computation of average monthly per capita water available through manual and real time monitoring approaches

BH ID	Borehole Yield m^3/hr	Actual Flow Rate m3/hr as computed using Real Time Monitoring	Borehole Water Production Characteristics															Unaccounted for Water %
			Jan-20			Feb-20			Mar-20			Apr-20			May-20			
			Hrs	Monthly Production (NRC Data) m3	Actual Monthly Production (m3)	Hrs	Monthly Production (NRC Data) (m3)	Actual Monthly Production (m3)	Hrs	Monthly Production (NRC Data) (m3)	Actual Monthly Production (m3)	Hrs	Monthly Production (NRC Data) (m3)	Actual Monthly Production (m3)	Hrs	Monthly Production (NRC Data) (m3)	Actual Monthly Production (m3)	
BH-4B	32.3	24.73	15.6	15,652	11,984	16.68	15,621	11,960.0	18.0	18,054	13,822.77	19.67	19,064	14,596	16.73	16,748	12,822.85	**23.4%**
BH-5	16.0	11.54	10.9	5,413	3,904	9.95	4,617	3,330.0	11.5	5,700	4,111.13	11.94	5,733	4,135	10.87	5,390	3,887.54	**27.9%**
BH-6	37.2	15.12	11.5	13,254	5,387	10.46	11,283	4,586.0	12.2	14,099	5,730.56	12.29	13,717	5,575	12.22	14,096	5,729.34	**59.4%**
BH-7B	16.0	15.54	12.2	6,041	5,867	10.97	5,090	4,943.7	12.8	6,339	6,156.75	11.56	5,551	5,391	11.87	5,887	5,717.75	**2.9%**
BH-8	32.1	20.90	12.2	12,161	7,918	11.79	10,977	7,147.0	12.4	12,327	8,025.99	14.15	13,628	8,873	18.09	18,000	11,719.63	**34.9%**
BH-12	41.0	23.67	17.0	21,648	12,498	18.10	21,521	12,424.4	17.1	21,737	12,549.14	21.76	26,761	15,450	21.76	27,655	15,965.70	**42.3%**
BH-IOM	31.2	15.51	16.3	15,752	7,831	14.60	13,206	6,564.9	17.2	16,637	8,270.51	19.15	17,921	8,909	16.90	16,349	8,127.34	**50.3%**
Total Monthly Production, m3				**89,921**	**55,389**		**82,315**	**50,956**		**94,893**	**58,667**		**102,375**	**62,929**		**104,125**	**63,970**	**38.6%**
Total Monthly Production, Liters				**89,921,000**	**55,388,502**		**82,315,000**	**50,956,012**		**94,893,000**	**58,666,849**		**102,375,000**	**62,929,137**		**104,125,000**	**63,970,147**	**38.6%**
Daily water production in liters				1,885,440.32	1,786,725.88		1,844,991.4	1,757,104		1,989,691.94	1,892,479		2,218,125	2,097,638		2,183,266.13	2,063,553	
Refugee Population in Kakuma 2,3,4				89,430	89,430		89,430	89,430		89,430	89,430		89,430	89,430		89,430	89,430	
Per capita, l/p/d				**21.08**	**19.98**		20.631	19.65		22.25	21.16		24.80	23.46		24.41	23.07	

4.7.2 Equitable Distribution of Water: Per capita water access computation at Block Level

The study analysed the equitable distribution of water across the study area by computing the per capita water available for specific blocks within the Camp served by the water reservoirs installed with real time monitoring devices. The population data for the blocks was obtained from UNHCR, department of Protection (Data Management).

NRC provided the data relating to the populations served by individual reservoirs at block level.

Through the use of water level monitoring data from Table 4.9 and checking from the curves the frequency of filling and emptying of the reservoirs, it was possible to compute the total amount of water pumped into the reservoirs daily. This was then divided by the total population served by the reservoir to get specific per capita for different tanks in the study area.

It was also possible to determine the frequency at which the reservoirs were filled and the duration of filling.

It was noted that due to difference in populations per block, some reservoirs served more people than others. The per capita ranged from 9.22 l/p/d to a maximum of 20.38 l/p/d with an average of 13.35 l/p/d for Kakuma 2, 3 and 4.

Also, by interpreting the graphs for various reservoirs, it was possible to determine how regular the water tanks were filled and emptied thus affecting water access to refugees. Some water Tank Operators respected the schedule provided by NRC while others did not.

From Figure 4.19, Clinic Six tank was a good example of a well operated reservoir with the Operator respecting the filling up time and the distribution time while Fuji tank’s operation was erratic and did not follow the NRC schedule. This mode of operation could result in unequitable distribution of water leading to intermittent water shortages in the areas served by the reservoir.

Table 4.17 shows the per capita water access at block level for various blocks across the camp.

Table 4.17 Per capita water access calculation at block level

Borehole ID	Tank/Reservoir ID	Area Served	Block	Population of beneficiaries per Block	Total Population	Water Distributed in Liters	Per Capita in Liters/Person /Day
BH7B	Reception Centre Tank	K3	1	2430	14,696	170,010	**11.57**
			2	6410			
			3	4215			
			4	1641			
BH IOM	Nasibunda Big Tank	K3	7	2,236	7,170	146,130	**20.38**
			6	1,547			
			5	1,599			
			15	400			
			14	589			
			16	799			
BH8	Somali Bantu Tank	K3	8	3,730	9,451	132,370	**14.01**
			9	2,912			
			10	2,809			
	Clinic Six Tank	K3	1	2,448	9,200	84,780	**9.22**
			2	2,680			
			3	2,067			
			4	2,005			
BH6	Phase 3 Tank	K2	5	1,165	6,846	126,000	**18.40**
			7	2,521			
			8	932			
			9	716			
			10	1,104			
			11	408			
BH12	ISSB Tank	K3	11	2,094	7,574	85,770	**11.32**
			12	2,212			
			13	3,268			
	EST 2 Kakuma 4	K4	1	2970	8,248	82,060	**9.95**
			2	2440			
			3	2838			
	EST 3 Hope	K4	1	2995	6674	85,710	**12.84**
			2	1986			
			3	1693			
BH4B	Gambela Tank	K2	1	2,430	5,669	66,700	**11.77**
			2	1,641			
			3	1,599			
BH 5	Fuji Tank	K2	4	2430	5618	78,940	**14.05**
			5	1641			
			6	1547			
					81,146	**1,058,470**	**13.35**

Figure 4.18 is a graphical presentation of the block level per capita water access.

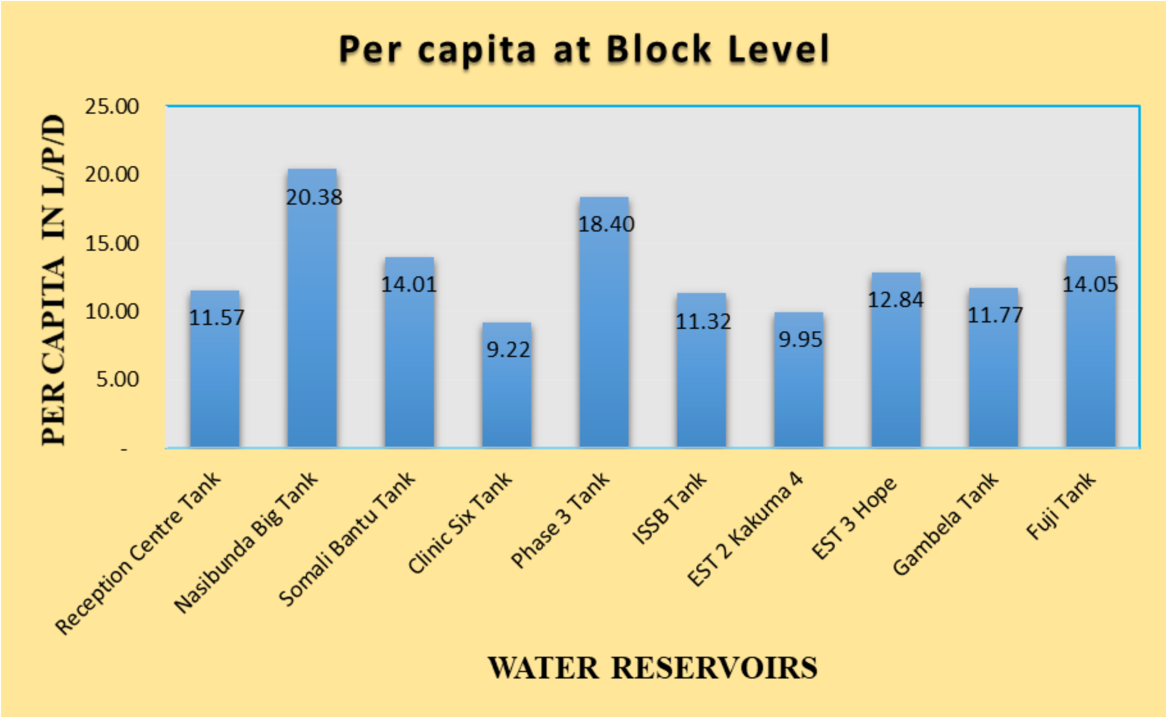


Figure 4.18 Per Capita water access at block level

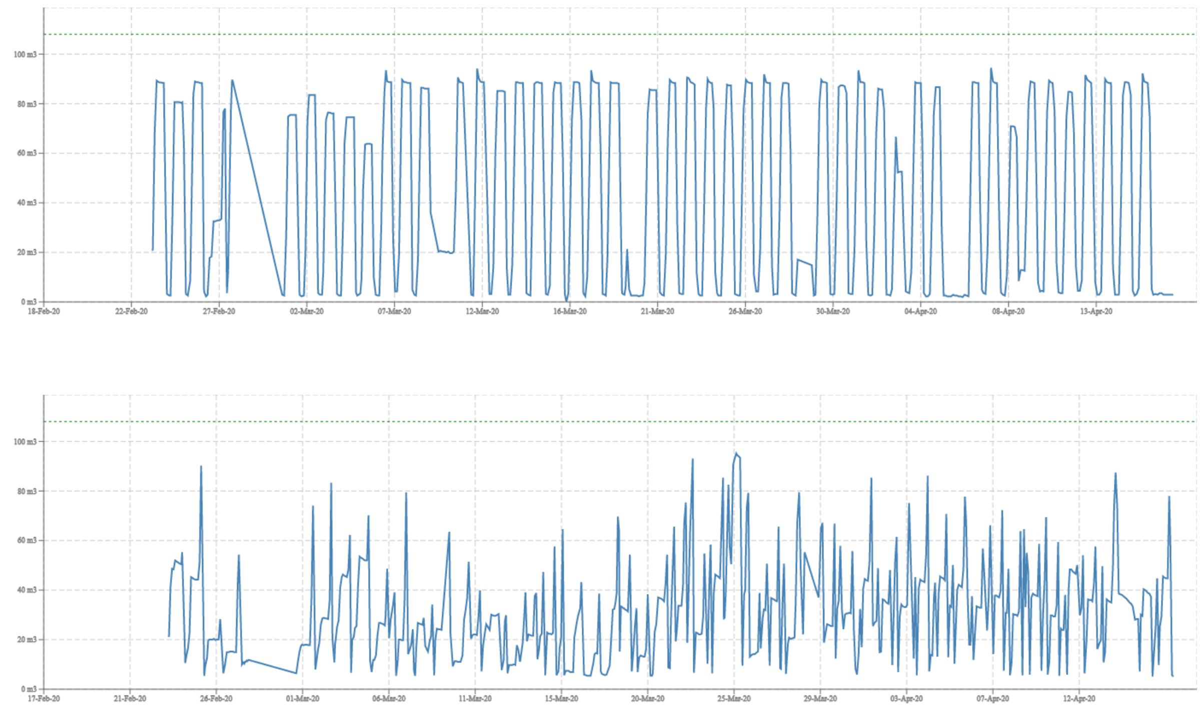


Figure 4.19 Clinic Six and Fuji Tank Curves

CHAPTER 5 : DISCUSSIONS

5.1 Introduction

This chapter presents the discussion of results in relation to existing literature and theories from the research.

5.2 Production characteristics of the boreholes in Kakuma Refugee Camp

The mapping exercise to determine the production characteristics of the boreholes serving the study area provided extremely useful information. Information ranging from the borehole location, tested yield in m^3/hr, borehole depth, borehole casing diameter was collected.

The pumps installed in respective boreholes was also determined. It was noted that most of the boreholes have similar pump model Grundfos SP30-13. When consulted NRC indicated that this is the most common pump that matches most of the boreholes. But after analysing the pump performance curves vis a viz the borehole test pumping reports, it was noted that the pump was not suitable for some boreholes and in some instances the duty point was outside the pump curves or operating at very low efficiencies.

5.3 Losses arising from water transmission, storage and distribution

Kakuma refugee Camp having been in existence since 1992 has undergone increase in population from the initial design population of 100,000 to the current 192,000.

The water reticulation system has aged over time and its efficiency compromised. The system is prone to breakdowns, leakages and illegal connections.

Through the study, it was possible to compute water losses during transmission, storage and distribution.

By using the Hazen Williams frictional head loss computation formula, it was possible to determine the frictional head losses that was used to determine the flow rates at consumption points. From the analysis, the losses ranged from 1.25% to 43.35%. The losses are attributed to inappropriately sized water pumping mains from the borehole to the reservoirs leading to high frictional head losses. BH 6 supplying Phase 3 tank through a 998m long, 90mm PVC pipeline had a loss of 43.55% with the flow reducing from 37.2m^3/hr to 21m^3/hr. Similarly, BH12 delivering water to EST2 Kakuma 4 tanks through a 4804m long, 110mm pipeline had its flow reduce from 41m^3/hr to 30m^3/hr resulting to 26.83% frictional head losses.

Losses in the water storage system (elevated steel tanks), were also computed and averaged 5%. It was also noted that the losses increased if water was stored in the reservoirs for a considerable period.

5.4 Relationship between water produced at the source, water transmitted to reservoirs and water distributed to tapping points and water available at household level

The study analysed the amount of water produced at the source by the boreholes, water transmitted to reservoirs and water distributed to tapping points and household level per capita.

The losses between the boreholes and the inlet of reservoirs as a result of friction were computed and ranged from 1.25% for BH7B and 43.55% for BH6 with an average value of 14.82%. This was done by comparing flow at the borehole and flow at TDH (Expected flow at reservoir inlet). An analysis was done between flow at TDH and flow as computed with the real time monitoring method. This ranged from 1.2% to 53.5% with an average of 23.6%. The comparison using the frictional head loss method and the real time monitoring method was aimed at giving a realistic way of estimating the losses. With the frictional head loss averaging 14.82%, while the real time monitoring method averaging 23.6% as losses, the huge disparity of 8.78% translated to unaccounted-for water.

The difference between water produced at the borehole using the NRC (Norwegian Refugee Council) borehole logs with the real time monitoring data for the months of January to May 2020 ranged from 2.9% to 59.4% with an average of 38.6%. The NRC puts this figure at 35%.

Through computation of the water per capita at block level, it was determined that the per capita water available ranged from 9.22 l/p/d to 20.38 l/p/d with the average at 13.35 l/p/d. The analysis provided an indication on how water is equitably distributed within the study area. Some sections of the Camp enjoyed high per capita rates as opposed to the rest. This has been a recurring problem over a considerable period of time but could not be determined through the method employed in computing per capita that gives a single per capita for the entire Camp. The inequitable distribution of water resulted to conflicts related to water supply with refugees fighting for water while others had a surplus supply.

The household KAP survey on water access at household level yielded a per capita of 23.55 l/p/d. It was also noted that 99% of the respondents collected water from communal taps, 78.4%

walked less than 200m to the water point and 70.83% spent less than 30minutes to collect the water. 87.27% directly carried the water from the water point to the house.

5.5 Comparison of the effectiveness of real time monitoring with the manual recording and analysis system

For the first time, the use of real time monitoring in refugee settings was piloted in Kakuma Camp. The results from the pilot clearly showed that system of monitoring was reliable as opposed to the manual system.

During the pilot phase, data was collected with the use of the water level sensors and transmitted to the gateway that in return re-routed the data to the UNHCR real-time monitoring portal where the data was stored. Accessing the data was by the click of a button where data could be downloaded in a form that made it easier for analysis purposes. The portal is still undergoing development to be more user friendly.

By analysing the data collected through real time monitoring, it was possible to determine the level of water access to the refugees at a given instant. This was more effective unlike the manual system where data was recorded in logbooks after which it was manually analysed. It was not possible to determine water distribution frequencies and time of distribution from the manual data.

The real-time monitoring method avoided errors in instances where the data collectors had literacy challenges like in Kakuma Refugee Camp.

The method also eliminated situations where calculation of water access (per capita) was based on estimates. It was possible to compute the actual water per capita.

Kakuma Operation has in many years been unable to clearly explain the rationale of applying 35% as the amount of unaccounted for water. This has always led to donors being unsatisfied with the monitoring framework in place. With the pilot, it was possible to monitor the efficiency of the water reticulation system. The pilot will form a basis for other Operations or Countries to learn from and replicate the same in their contexts.

CHAPTER 6 : CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Computation of losses arising from water transmission from boreholes to water storage reservoirs made it possible to determine the frictional head losses that was used to determine the expected flow at the inlet of water storage reservoirs. From the analysis, the losses ranged from 1.25% to 43.55% with an average of 14.82%.

Through real time monitoring by use of ultrasonic water level sensors, the actual water flow into the water reservoirs was determined. This flow was compared with the expected flow at the reservoir inlet. The difference ranged from 1.2% to 53.5% with an average of 23.6% for the various reservoirs/tanks.

From the above analysis, the study concluded that not all the water produced by the boreholes is utilised by the refugees but 8.78% is unaccounted-for.

The difference between water produced at the borehole using the NRC (Norwegian Refugee Council) borehole logs with the real time monitoring data for the months of January to May 2020 ranged from 2.9% to 59.4% with an average of 38.6%. The NRC puts this figure at 35%.

Losses in the water storage system (elevated steel tanks), were also computed and averaged 5%.

The per capita water use at household level ranged from 9.22 l/p/d to 20.38 l/p/d with the average at 13.35 l/p/d. This is a measure of the equitable distribution of water. The household KAP survey on water access at household level yielded a per capita of 23.55 l/p/d.

From the above findings, it was thus concluded that the current method underestimates the amount of unaccounted-for water by 3.6% which results to an erroneous water capita value.

This discrepancy is huge and thus indicates that a lot of water is unaccounted when calculating the actual per capita of the camp water supply. In view of this, the study concluded that the real time monitoring system presented an effective scientific way for establishing the water per capita for the camp.

The study also concludes that there are system inefficiencies in Kakuma Refugee Camp's water reticulation system that resulted to water losses and wastages.

6.2 Recommendation

The study was able to isolate and analyse the water flow from the boreholes to the reservoirs and at household level. The study proposed the following recommendations.

There was need to ascertain the current borehole status. It was therefore recommended that a new test pumping for all the boreholes be carried out to determine the current yields. Borehole Camera inspection be done to visualize the status of the borehole casing that will also determine the pump installation point. Several boreholes did not have borehole completion reports (BCRs) thus making it difficult to effectively utilize the borehole. It was also recommended that UNHCR scales up installation of real time aquifer monitoring devices in the boreholes to monitor the borehole performance characteristics. This will provide information whether the boreholes were being over abstracted thus depleting the aquifer.

Some boreholes were running on undersized or oversized generators leading to pumping inefficiencies. A good number of boreholes were solarized but still running on diesel powered generators. UNHCR to explore drilling of additional boreholes that will lead to reduction in pumping hours for the boreholes to operate fully on solar which is available for 7hours a day.

Most boreholes had inappropriately sized submersible pumps in relation to the borehole characteristics. It was recommended that proper sizing of the pumps be done to improve pumping efficiency. The sizing to be done based on the results of the test pumping exercise.

It was also noted that due to the ad hoc expansion of the refugee camp, the existing water supply infrastructure is poorly designed thus leading to inequitable distribution of water and system inefficiencies.

To rectify the above anomalies, it was recommended that UNHCR carries out a comprehensive hydraulic modelling of the entire Camp and re-design and construct the water system by replacing old infrastructure. The new system should be equipped with real time monitoring facilities to monitor the system efficiency.

It was also recommended that the water pumping and distribution schedule be adjusted so that pumping was not done overnight. Water to be dispensed during daytime. It was also recommended that the aging and leaking water tanks be rehabilitated by replacing worn out panels and control valves.

The study piloted real time monitoring of service provision. The results from the study confirmed that real time monitoring is a new system that could yield reliable and verifiable data for analysis.

It was therefore recommended that the study could form a strong basis to encourage other operations not only in refugee camps, to use the system to monitor service levels.

Other than water access monitoring, internet of things can be used in monitoring water trucking, aquifer monitoring and water quality monitoring.

6.3 Further Study

The study focussed on evaluating the efficiency of the water supply and distributions system in Kakuma Refugee Camp.

Areas for further study could entail determination of the factors that constitute or contribute towards unaccounted for water.

Also due to inequitable distribution of water across the research area, it will be important to carry out further research on effective water allocation.

REFERENCES

Action Contre La Faim (2005), *Water and Sanitation for Populations at Risk*. 2005 HERMANN ÉDITEURS DES SCIENCES ET DES ARTS, 6 RUE DE LA SORBONNE, 75005 PARISACF, Paris.

Ackah, M. Agyemang O, (2011). *Assessment of groundwater for drinking and irrigation: The case study of Triman-Oyarifa community, GaEast Municipality, Ghana*; proceedings of international Academy of Ecology and Environmental sciences, 1(3-4):186-194.

Ahamed A; (2013). *A comparative evaluation of groundwater suitability for drinking and irrigation purposes in Pugalur, Karur district, Tamilnadu, India*; archives of applied science Research:213-223

Davis J, Lambert R, (2002), *Engineering in Emergencies 2nd Ed*. ITDG, UK.

Ferron, Morgan, O'Reilly, (2007), *Hygiene Promotion*: A Practical Manual for Relief and Development.

Global WASH Cluster (2014), *'WASH information management guidance note'*, Global WASH Cluster, UNICEF, Geneva, Switzerland.

I.E. Karadirek, S. Kara, A. Muhammetoglu, H. Muhammetoglu, S. Soyupak, (2014). *Management of Chlorine Dosing Rates in Urban Water Distribution Networks Using Online Continuous Monitoring and Modelling*, Urban Water J.

John Hopkins and IFRC (2008), *Public Health Guide for Emergencies*.

Kombo, D. & Tromps, D. (2006*), Proposal and thesis writing: An introduction*, Pauline's publication, Kenya.

Kothari, C. R. (2008). *Research Methodology, Methods and Techniques* (2nd ed., pp. 109-110). New Delhi New Age Inter- national (P) Limited.

Krejcie, Robert V., Morgan, Daryle W (1970). *Determining Sample Size for Research Activities*

Mohsen, B (2013*). Suitability assessment of deep groundwater for drinking and irrigation use in the Djeffara aquifers (Northern Gabes south-eastern Tunisia*; open access at Springerlink.com Environmental earth science

Mona A. (2013). *Water quality assessment and hydrothermal characteristics of groundwater in Punjab, Pakistan*; IJRRAS 16(2); www. Airspace.com, vol 16 issue2

MSF (2010), *Public Health Engineering in Precarious Situations 2nd Ed*. Medecins Sans Frontiers, Muhammetoglu, (2014). *Investigation of the Renewable Energy Recovery Potential for Sustainable Water Supply Systems, TUBITAK* (The Scientific and Technological Research Council of Turkey) Project Proposal No: 114Y203,

Navid Rahimi (2008), *Modelling and mapping of Maela Refugee Camp water supply*, Massachusetts Institute of Technology,

Orodho J.A. (2005). *Elements of Education and Social Science Research Methods*. Nairobi: Masola.

Ramesh. K, Elango E; (2011). *Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India*; Environment Assess (2231-3),

Robert Pitt, Shirley Clark, and Alex Maestre, (2004). *A Step-by-Step Guide to EPANET 2.0 Simulations*

SPHERE (2018). Sphere Association. The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response, fourth edition, Geneva, Switzerland, 2018.

Sudhakar A. and Narsimba A. (2013), suitability and assessment of groundwater for irrigation purpose: A case study of Kushaiguda area, Ranga Reddy district, Andhra Pradesh, India; *advances in applied research*, 2013,4(6): 75-81

Taha H, Salim A (2009). *Groundwater quality of areas selected NE of Mosul City used for irrigation and drinking purposes;* Al-Rafidain Engineering Vol.17 No.3 2009

UNHCR (1992), *Water Manual for Refugee Situations*. UNHCR, Geneva.

UNHCR (2006), *Practical Guide to the Systematic Use of STANDARDS & INDICATORS in UNHCR Operations*, Second edition 2006

UNHCR (2006), *'Practical guide to the systematic use of standards and indicators in UNHCR operations'*, Office of the United Nations High Commissioner for Refugees (UNHCR), Geneva, Switzerland.

UNHCR (2006), *'The UNHCR tool for participatory assessment in operations'*, Office of the United Nations High Commissioner for Refugees (UNHCR), Geneva, Switzerland.

UNHCR (2007), *Handbook for Emergencies*, 3rd Ed. UNHCR, Geneva.

UNHCR (2014a), *'Emergency information management tool*kit ', Office of the United Nations High Commissioner for Refugees (UNHCR), Geneva, Switzerland.

UNHCR (2014b), *'WASH report card preparation using TWINE'*, Office of the United Nations High Commissioner for Refugees (UNHCR), Geneva, Switzerland.

UNHCR (2017), *UNHCR WASH Standards and Indicators for Refugee Settings"*. UNHCR, Geneva.

Venkateswaran, S, Vediappan S, (2013). Assessment of groundwater quality for irrigation use and evaluate the feasibility zones through Geospatial Technology in lower Bhavani Sub Basin, Caivery river, Tamil Nadu, India; *International journal of innovative Technology and exploring engineering* (IJITEE) ISSN :2278-3075, Vol-3, issue-2

WEDC (2007), *Excreta Disposal in Emergencies. Water, Engineering and Development Centre (WEDC*), Loughborough University, UK.

WHO (2011), *Guidelines for Drinking Water Quality* 4th Ed. World Health Organisation, Geneva.

APPENDICES

APPENDIX I: LETTER OF INTRODUCTION

OSCAR NABISWA

RE: RESEARCH DATA COLLECTION

I am a student pursuing a degree of Master of Science in Civil Engineering of the University of Nairobi. Undertaking a research project on, **"Evaluation of the efficiency of Water Supply and Distribution Systems in Kakuma Refugee Camp".** The data being collected is purely for academic purposes and a copy of findings will be availed to you upon request. Any information received will be treated with strict confidentiality and at no point will your name or that of your organization be mentioned in the final report.

Your cooperation will be highly appreciated.

Yours faithfully

OSCAR NABISWA

APPENDIX II: HOUSEHOLD QUESTIONNAIRE

Part A: Demographic Information

1. Name of Camp/Settlement
    a) Kakuma 2 ()
    b) Kakuma 3 ()
    c) Kakuma 4 ()
2. Gender of respondent?
    a) Male ()
    b) Female ()
3. Country of origin
    a) Burundi ()
    b) Democratic Republic of Congo ()
    c) Eritrea ()
    d) Ethiopia ()
    e) Rwanda ()
    f) Somalia ()
    g) South Sudan ()
    h) Sudan ()
    i) Uganda ()
    j) Other (Please specify) ()
4. If Country of origin is other, specify

____

5. What is the highest educational level that you attained?
    a) No formal education ()
    b) Primary school ()
    c) Secondary school ()
    d) Vocational training ()
    e) College/University ()
6. Can you read and write (not Quran)?
    Yes ()
    No ()
7. What is your marital status?

a) Married ()

b) Single ()

c) Widowed ()

d) Divorced ()

e) Separated ()

8. How many male persons slept in this household last night? (Including self?)

____

9. How many female persons slept in this household last night? (Including self?)

____

Part B: Water supply

10. What is the main source of water for this household?

a) Communal tap-stand ()

b) Traditional source (scoop hole, lagga, dry riverbed) ()

c) Others (specify) ()

11. If main source of water is other, specify.

____

12. How far is the main water collection point from the household?

a) Less than 200m ()

b) More than 200m but less than 500m ()

c) Over 500m ()

13. Do people queue (line up) at the water point to get water?

Yes ()

No ()

14. How much time does it take you to fill your jerrican?

a) Below 30 min ()

b) Over 30 min ()

15. Quantity of water collected

a) Please record NUMBER of water storage containers by their sizes (put zero if the listed size does not exist in the household)

Size of containers	**Number of containers**
5 Litres	
10 Litres	
20 Litres	

b) Please record NUMBER of times you used these containers to fetch water the last time you collected water (put zero if the listed size does not exist in the household)

Size of containers	**Number of times**
5 Litres	
10 Litres	
20 Litres	

16. What type is/are the drinking water storage container/s? (Observe/Multiple entry)

a) Narrow mouth but not covered/lid ()

b) Narrow mouth and covered ()

c) Wide but covered ()

d) Wide mouth and not covered ()

17. What is the condition of the drinking water storage container? (observe)

a) Clean and covered ()

b) Clean and not covered ()

c) Dirty and covered ()

d) Dirty and not covered ()

18. What is the most common mode of transporting water from the collection point to the household?

a) Direct carrying (head, shoulder etc) ()

b) Foot/rolling/pulling on ground ()

c) Hand cart/wheelbarrow ()

d) Bicycle ()

e) Other (Please specify) ()

19. If other mode of transport, please specify.

____

20. Have you experienced or heard of water conflicts/quarrels at the fetching point in the last one month?

Yes ()

No ()

21. If you have experienced conflict, what was the cause of the conflict?

____

Thank You!

APPENDIX III: INTERVIEW GUIDES FOR KEY INFORMANTS (UNHCR AND NRC WASH OFFICERS)

1. How long have you been working with this organization?
2. What is your observation on the efficiency of water distribution in Kakuma?
3. How about governance issues with regards to the water distribution in Kakuma?
4. How do you monitor water distribution system?
5. Have you employed any innovative ideas in monitoring the water distribution system? What are they?
6. Have you had any experience with real time monitoring? What has it been?
7. What do you think are the challenges of adopting innovative techniques in monitoring water distribution systems?

APPENDIX IV: NACOSTI LICENSE

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **217896**

Date of Issue: **05/June/2020**

RESEARCH LICENSE

This is to Certify that Mr.. Oscar Wesonga Nabiswa of University of Nairobi, has been licensed to conduct research in Turkana on the topic: Evaluation of the efficiency of water supply and distribution systems in Kakuma Refugee Camp for the period ending : 05/June/2021.

License No: **NACOSTI/P/20/5071**

217896

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

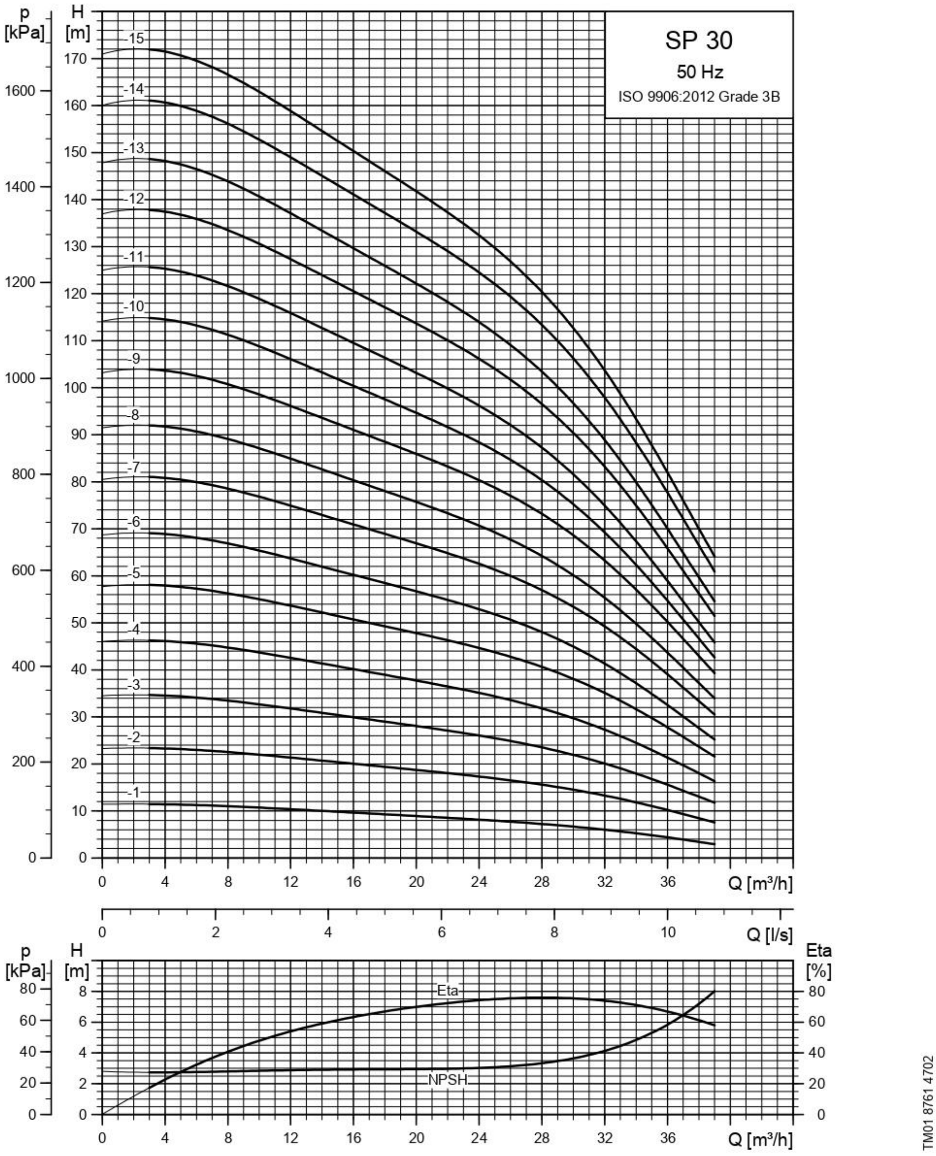
Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

APPENDIX V: GRUNDFOS SP30-13 PUMP PERFORMAMNCE CURVE

SP 30

Performance curves

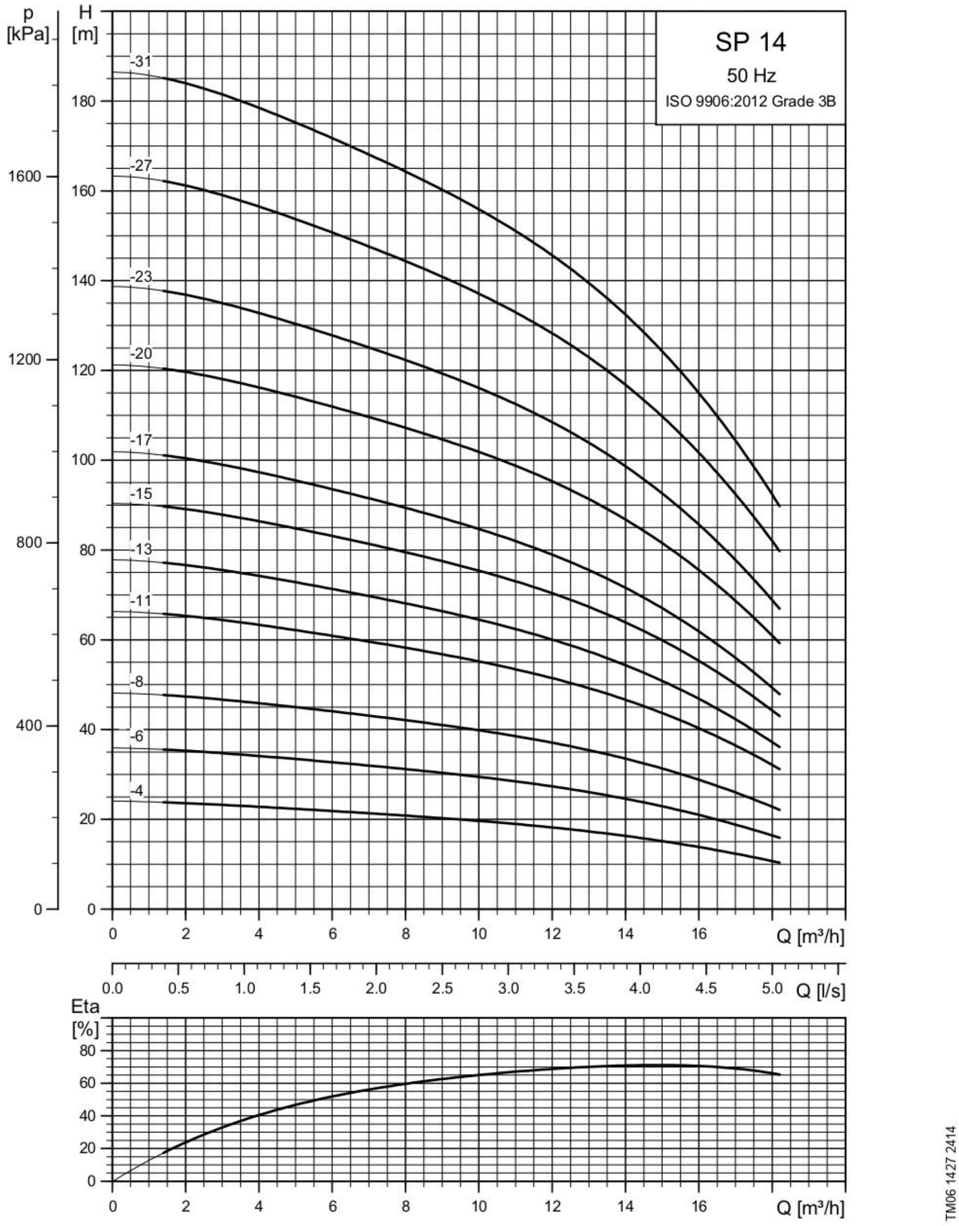


See also section *How to read the curve charts* on page 24.

APPENDIX VI: GRUNDFOS SP14-8/11 PUMP PERFORMAMNCE CURVE

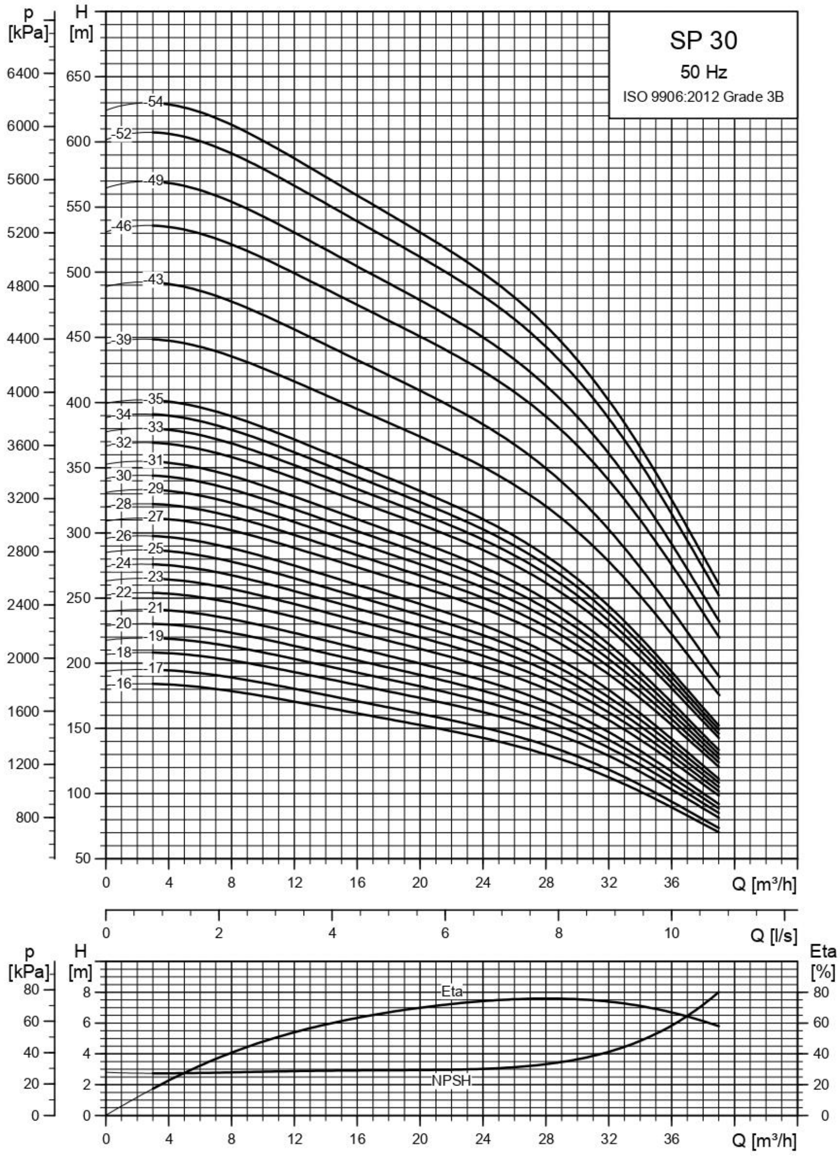
SP 14

Performance curves



See also section *How to read the curve charts* on page 24.
NPSH: Minimum inlet pressure 0.5 m.

APPENDIX VII: GRUNDFOS SP30-17 PUMP PERFORMAMNCE CURVE



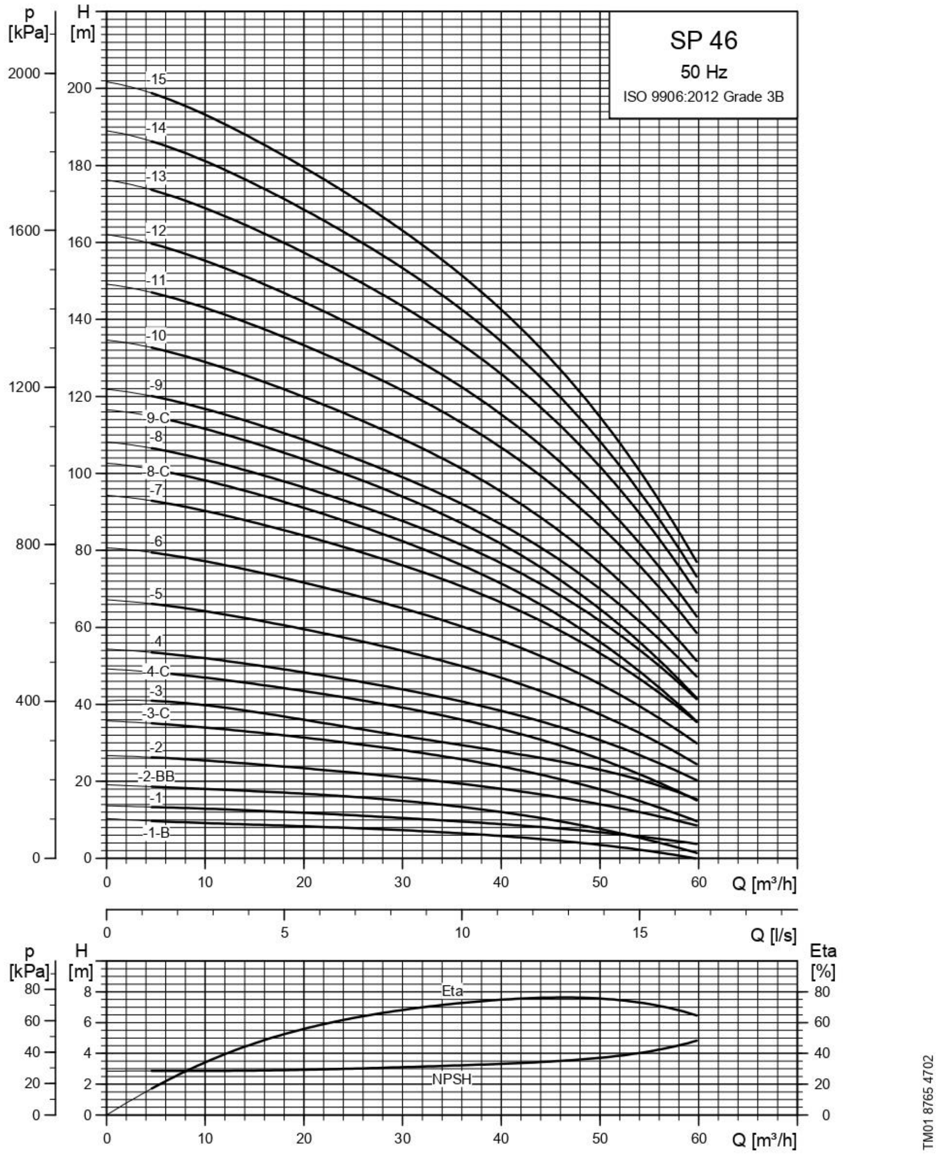
TM01 8762 4702

See also section *How to read the curve charts* on page 24.

APPENDIX VIII: GRUNDFOS SP46-12 PUMP PERFORMAMNCE CURVE

SP 46

Performance curves



See also section *How to read the curve charts* on page 24.