SUPPLY PRESSURE AND QUALITY OF WATER ALONG DISTRIBUTION NETWORK OF SMALL SUPPLY SCHEME:

A CASE OF MUKONO DISTRICT, UGANDA

BY

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APPROVAL

The undersigned certify that the supervisor and co-supervisor have read and hereby recommend for submission to the Directorate of Research and Graduate Training of Kyambogo University, a dissertation entitled: supply pressure and quality of water along distribution network of small supply scheme, in fulfilment of the requirements for the award of Master of Science in water and sanitation Engineering degree of Kyambogo University.

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DECLARATION

I, Ntumwa Jamiru, hereby declare that this submission is my own work and that, to the best of my knowledge and brief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the next and reference list.

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LIST OF ABBREVIATIONS/ACRONYMS

AC	Asbestos cement
AS	Australian Standard 2419
EC	Electrical conductivity
DI	Ductile Iron
GS	Galvanized steel
H.D.P.E	High Density Polyethylene Pipes
KKN	Kabembe-Kalagi-Naggalama
MS	Micro Soft
MPH	Minimum pressure head
NTU	Nephelometric Turbidity Units
NWSC	National water and Sewerage Corporation
PE	polyethylene
P.V.C	Poly Vinyl Chloride
UBOS	Uganda Bureau of Statistics
UPVC	un-plasticized polyvinyl chloride
WHO	World Health Organization
WDS	Water distribution system

ABSTRACT

The main objective was to assess the variation of water quality with water pressure along the supply network in small water systems in Mukono District. To achieve this, an assessment of the variation of pressure was done, water quality along the supply chain was assessed, and the relationship between water pressure and quality variation was validated. A sample of 95 questionnaires were distributed. Water pressure and water quality samples were collected at the same points created on the network specifically at the production wells, transmission and distribution and at the customer meter points. Eight water quality Parameters were selected and tested during the study (i.e. Potential of Hydrogen, Dissolved Oxygen (PH), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Coliforms (TC), Apparent color, Turbidity, and Residual Chlorine).

The results showed that, all the water quality parameters indicated quality variation as water traveled into the supply system. However, some had significant increase, decrease and others had insignificant variation with water pressure. PH, DO, TDS, EC, TC, Apparent color, Turbidity and Residual Chlorine recorded; 0.765 & 0.255, 0.655 & 0.23, 0.577 & 0.492, 0.592 & 0.492, 0.53 & 0.08, 0.951 &0.0311, and 0.841 & 0.932 significant values in Nakifuma and KKN network systems respectively. PH, Total Dissolved Solids, Electrical Conductivity, and Total Coliforms recorded negative correlation with pressure (i.e.-0.184 & -0.63, -0.339 & -0.411, -0.327 & -0.411, and -0.327 & -0.411), whereas Dissolved Oxygen, Turbidity, and Apparent color showed positive correlation (i.e. 0.96 & 0.51, 0.038 & 0.912 and 0.402 & 0.964) in both Nakifuma and KKN) small water systems respectively varying with water pressure. Residual Chlorine recorded negative correlation in KKN (i.e. 0.125) and positive correlation in Nakifuma (i.e. -0.499). In order to attain an equilibrium of water residual pressure and safe quality water in small water system, water quality parameters should be maintained in the desired ranges, i.e. PH = (6.5-8.8)mg/l, Dissolved Oxygen = (6.5 – 8)mg/l, Total Dissolved Solids = < 300mg/l, Electrical Conductivity = < 400µs/cm, Turbidity = < 1NTU, Apparent Color = 5<15(PtCo), Total Coliforms = <0.0(Cfu/100m/l), residual chlorine = (0.2<0.5)mg/l. Water pressures supplied should be above 10<160m and maintained to prevent pressure variations causing intrusion of contamination into the water system due to occurrence of network failures.

Key words: Water Pressure, Water quality, Variation, Mukono District, Nakifuma, Kabembe-Kalagi-Naggalama.

CHAPTER ONE: INTRODUCTION

Chapter overview

Chapter one covered the background of the study, problem statement, the purpose, objectives of the study, research questions, hypotheses, scope, conceptual framework, significance, justification and operational definitions of terms and concepts.

1.1 Background to the study

Water is an essential need for life and for major activities of human society, both economic and social development, maintenance of human health. Societies are entirely dependent on constant access to adequate safe quality water (Chenoweth, 2008). Under large water distribution systems, water travels long distances for long residence time, hence affecting the water quality (Hossein *et al.*, 2013a). It may be due to multiple reservoir storages, insufficient dis infection, and insufficient pressure in the system or occurrences of network failures like leaks and bursts, caused by pressure change in the water distribution network (Hossein *et al.*, 2013b).

Research has been carried out to assess the effects of pressure change in the distribution system and the results revealed that, if we want to increase quality, water pressure should be ideal (Mustonen *et al.*, 2008). Unstable pressures and velocity could increase turbidity and corrosion in the distribution systems, a factor which affects water quality in the network (Hossein et al., 2013a). Formation of biofilms in the network due to bacteria entering the system caused by negative pressures cause deterioration of water quality in a distribution system (Ulanicki *et al.*, 2000).

The location of quality water supplied shapes the geographic distribution of population, culture and quality of life. Adequate supply of water quality is key to integrity of environment and the maintenance of the ecosystem (Perry and Vanderklein, 2009). It extremely contributes to social wellbeing and economic productivity of the human population. (Goldemberg *et al.*, 2018). United Nation Environment programme (UNEP) projected by year 2020 that, twenty percent (20%) and fifty percent (50%) respectively, of the world's population will lack safe drinking water and access to safe sanitation systems hence, leading outbreaks of waterborne diseases (Angoua *et al.*, 2018).

(Wood *et al.*, 2005) explain that, due rapid growth of population and changes in social economic activities, industrialization and Urbanization as well as intensive lifestyles, have greatly contributed to water crisis in Africa. As a result, fresh water and water resources are unevenly distributed in many regions in Africa including Uganda where water consumption and demand has increased as with increased industrialization. (Shrestha *et al.*, 2017) argued that, households should have indoor access to safe and reliable water sources in order to benefit from improve water supply.

According to UNICEF, a quarter of the population in East Africa travels not less than one hour to fetch water (Geere and Cortobius, 2017). In Uganda, millions of people including institutions like schools and hospitals have no access to safe drinking water. Even for those with access to improved water sources and supply systems, the sources are contaminated due to poor sanitation and other environmental activities. For example; Out of 45million people, 38 million people (83% of the population) lack access to reliable, safely managed sources of water and 7million people (17%) lack access to improved sanitation solutions (Water.org, 2023).

However, MWE, (2019), reported that, water services increased in coverage to 253 towns of Uganda, of which 79.1% growth in 2019 from 77% in June 2018 was registered in small and Large towns, covered by the mandated body of National Water and Sewerage Corporation to supply safe and clean water and sewerage services in Uganda. Despite the coverage, there are still a number of areas that are not covered yet, and for that reason they adopted to using small water systems as their main source to match their demand.

1.2 Statement of the problem

Good quality of water supplied at households is important for ecosystem services and social economic development. Development growth has raised daily demand by 43.65% thereby creating a deficit yet to be determined. It results in increased water demand in relation to reduced access to improved water supply in the area (Bakamwesiga *et al.*, 2021). It is noted that, lack of access to improved safe water is a greater cause of public health problems.

United Nation sustainable development goal target 6.1, calls for universal and equitable access to safe and affordable drinking water. Half the world’s population currently rely on small water supplies with calls made for their greater focus to improve economies and health to meet the basic human rights to water and sanitation (Bain et al., 2014). Yet, studies relating to performance challenges of small piped water supplies, used in smaller settlements or peri-urban areas, are limited. Available information for small piped water supplies, often based on fast growing rural centers and towns, show that flow velocities in some areas are below the recommended minimum with some pipes not running full bore (Dadebo et al., 2023). Moreover, Small piped water supply schemes are noted to be ‘disproportionately problematic’ (Gunnarsdottir et al., 2020; Herschan et al., 2023) and are more often associated with waterborne disease outbreaks compared to larger water supply schemes (Moffatt and Struck, 2011).

Supply of high-quality water is gradually diminishing in most parts of Uganda including Mukono District (Bakamwesiga et al., 2022). This is partly due to low water pressure which leads to increased water contamination in the water supply system. Sufficient residual pressure should be maintained in water distribution systems, public standpipes, undulating terrain as well as in hydraulically remote and highly demanding sections (MWE, 2013). According to MWE (2013), in water distribution system, Sufficient residual pressure of not less and more than 10m (1bar) and 25m (2.5 bars) respectively for public stand pipes, 150m (15bars) in undulating terrain, 15m for (1.5bars) firefighting and at least 60m (6bars) in the water mains is required and should be sustained in a hydraulically remotest and highly demanding systems. To avoid occurrences of negative pressures in the system to prevent collapse of mains, failure of fittings which may lead to contamination of water supplied.

This research study attempted to address the call and the requirements of SDG 6.1 and it provided the opportunity to gather ground data in Uganda and produce outputs which heightened attention needed at all levels to overcome the various challenges facing small water supplies and to realize the full benefit of safe water.

1.3 Objectives of the study

1.3.1 Main objective

To assess the variation of water pressure and the quality of water supplied in small water distribution systems in Mukono District.

1.3.2 Specific objectives

i) Assess the variation of water pressure along the supply chain.

ii) Assess the variation of water quality along the supply chain.

iii) Assess the relationship between water pressure and quality variation in the Network

iv) To develop a suitable frame work for safe water and adequate residual pressures.

1.3.3 Research Questions

i) What is the water pressure distribution along the supply chain?

ii) How is water quality varying along the supply chain?

iii) What is the relationship between pressure and quality variations in the network in comparison with an old and a new small water supply system?

iv) What is the suitable Framework to apply in attaining safe and adequate residual pressures in an indirectly supplied systems at households?

1.4 Significance

The study provided a sufficient model appropriate for optimizing safe water and residual pressure supplied by small piped-water systems. It will prevent likely health risks that may arise due to undesirable water quality and residual pressure in the pipe network due to network system failures and water scarcity. Desirable water pressure will ensure water reaches every intended household. It will as well maintain safe water quality in the network. As a result, water borne disease outbreaks will be prevented, and mortality rate in the region and country. Therefore Sustainable Development Goal 6.1 will be achieved. Hence government will save expenditures incurred in fighting waterborne disease and outbreaks that may arise as a result of insufficient access to clean water. The research is a guide in achieving Vision 2040 and the National Development Program III. It is also a guide in decision making before any water connection(s) and expansion is made.

1.5 Scope of the study

The study was limited to piped small water systems in Nakifuma and Kalagi areas under Mukono districts leaving out, NWSC network, focusing on the quality of water and pressure as well as the characteristics of transmission, storage and distribution systems from the treatment plants to households. This study was carried out in comparison with an old and a new small water system. The study was done from July 2021 to October 2022.

1.6 Conceptual framework

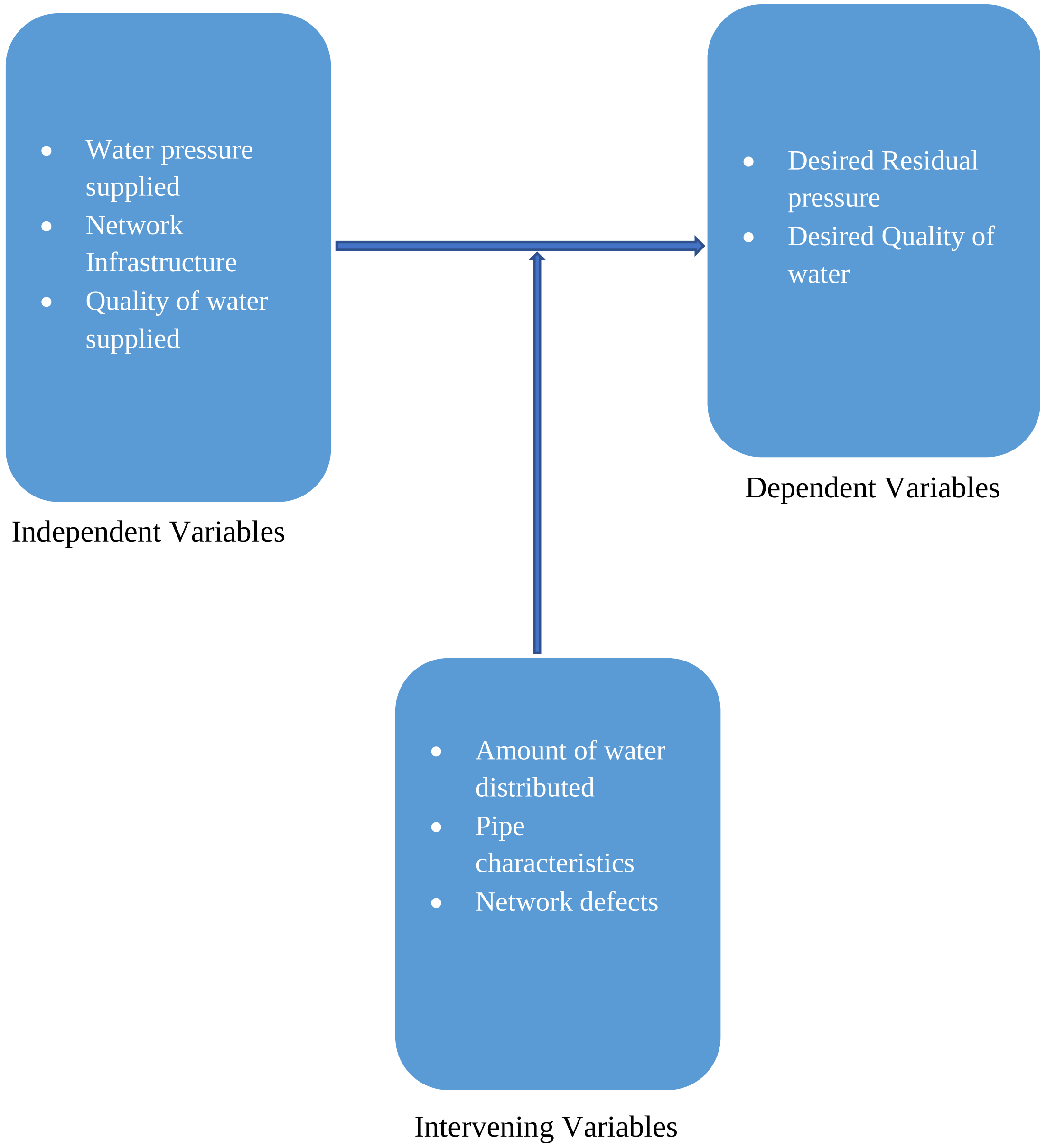

Figure 1.1: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Relevant literatures related to the research topic are investigated under this chapter in order to seek for a wider picture. It expounds literature based on the study objectives and theoretical reviews.

2.2 Literature review

Important to note is that, water is one of the vital need of human race. 100 % of water supplies originate as rainfall, which reaching on earth. When it reaches on the earth, part of it is absorbed and held by top soil to support vegetation. The rest falls upon impervious surface and percolates through the earth. We therefore obtain water supplies from these two sources (Falkenmark *et al*., 2004). In spite of the increasing water coverage in developing countries, walking long distances in search and access for water is still a challenge. Gravity flow springs, protected wells, shallow wells and Protected Springs are the most common technologies used as rural water supply, whereas in small and large urban centers, small and large water piped supply systems are used. Those with no access to improved water sources depend on unsafe sources such swamps, unprotected wells, lakes and rivers, yet its raw water is unsafe for human consumption. Water borne diseases is a major cause to infant mortality and it’s an indicator of poor access to water quality. Access to water quality sources of water varies significantly across the country amongst districts i.e., from 12% to 95% (Walekhwa *et al.*, 2022).

2.3 Water Demand

Water demand is the amount of water required in an area at a given period of time. It is divided into domestic, commercial, institutional/Government and public stand posts/ urban pro poor consumer categories. Consumption is estimated and projected in each category independently (MWE, 2013). Water demand estimation of an area is one of the major first step taken during design of a water distribution system.

Developing countries in the world face noteworthy encounters in managing growing demand for urban water, because of urbanization, industrialization and probable impacts of global warming on freshwater (Varis and Vakkilainen, 2001). Water scarcity in urban areas can be addressed through demand-side and supply-side solutions. The conservative answer to scarcity of water is to pursue new water sources of supply, whereas others prefer demand –side management with conventional approaches (Inman and Jeffrey, 2006).

2.4 Water quality

All sources of water are, prone to contamination, and can gather contaminants from rocks, ground or air. Some contaminates containing pathogens are harmful to human health whereas others are not when consumed in low levels, such as; minerals. The quality of water supplied must be acceptable by the community as well as the treatment methods used. Some water quality parameters are easy to treat, like, Turbidity whereas others are very hard i.e., high Fluoride levels (Almedom and Odhiambo, 1994). Despite the scarcity of water, more efforts and mechanisms should be made to ensure good quality water is supplied in the current high-demanding-economy.

An effort has been made by the government of Uganda in providing safe water in the vicinity of the community and also reducing the walking distance to a water source which is a pre-liquisite for water usage. While the consumption is estimated at 20litres/ person / day, in some communities this is as low as 8-9litres/ person / day (Rosinger and Herrick, 2016). Some people take weeks without taking a shower and generally the hygiene is poor, this has led to spread of WASH Diseases like scabies and ringworm infections (Kamugisha, 2017).

2.4.1 Quality of water supplied

WHO guidelines for drinking water state that, water for consumption should be Should characterized by low turbidity and color (fairly clear), free from pathogens, fresh (not saline or salty), free from odor, incapable of not causing corrosion, and incapable of not staining clothes.

The following categories is used to describe drinking water quality;

- Physical (color, taste and odor, temperature, turbidity)
- Chemical (pH, Dissolved oxygen, chloride, Iron)
- Microbiological (coliform organisms)

2.4.1.1 PH

PH values of hydrogen ion concertation indicates the degree of acidity of the Water. The minimum and maximum allowable PH is 6.5-8.5 according to MWE (2013). Lower PH in water makes the water acidic where as a higher PH makes the water alkaline. Neutral PH is at 7 (MWE, 2013).

2.4.1.2 Turbidity

Turbidity test show the quality of waste discharge. It is measured in Nephelometric Turbidity Units (NTU) which links how light is scattered in a water sample compared to the amount of light scattered in a solution. Turbidity of safe quality water should be less than 1 NTU and fairly less than 5 NTU (WHO, 1984).

2.4.1.3 Electrical Conductivity (EC)

Electrical conductivity (EC), is the measure of dissolved materials in aqueous solutions and its ionic process of a solution that enables it to transmit current. An increase in ions concentration enhances the EC of water and the amount of dissolved solids in water indicates Electrical conductivity. For safe water, EC should not to exceed 400µS/cm (Meride and Ayenew, 2016)

2.4.1.4 Dissolved Oxygen (DO)

Dissolved Oxygen is the amount of oxygen concentration in water. It is measured in milligrams per liter (mg/l) and the acceptable range for health consumption is 6.5-8 mg/l according to WHO standards for safe drinking water.

2.4.1.5 Total dissolved Solids (TDS)

TDS values less than 300mg/l is considered excellent, between 300 and 600mg/l is good, 600mg/l to 900 mg/l is fair, 900mg/l to 1200mg/l is poor whereas TDS more than 1200 is unacceptable (El-Dakar, 2016).

2.4.1.6 Residual Chlorine

Chlorine is used widely in disinfection of drinking water to kill possible harmful organisms which may affect public health. Residual chlorine is the amount of chlorine which stays in the distribution system as water is transported to the consumer to encounter any possible contamination of water. 0.2mg/l – 0.5mg/l is the allowable range of Residual chlorine in safe quality water for public consumption (El-Dakar, 2016).

2.4.1.7 Total Coliform

Presence of Total coliform in water is an indicator for presence of pathogens in drinking water which renders its consumption unsafe. Safe quality water for consumption should have absence of TC or less than 1 Cfu/100ml in public drinking water. Its measured in colony-forming Unit per 100mls (Cfu/100ml) (Meride and Ayenew, 2016).

2.5 Water pressure

Water pressure is the force measured that drives water through water mains and pipe. It is measured in bars. 1 bar is the force needed to raise water to a height of 10 meters. Minimum pressure is required in the water distribution system (WSD) to ensure customer satisfaction. Very low pressure head is not acceptable and could lead to operation and maintenance problems due to equipment failure hence customer dissatisfaction and complaints. Water pressure in a water distribution system is minimum when the flows and head losses in the pipes are at maximum (peak demand). Water pressure is maximum when the flow is at a minimum (Jacobs and Strijdom, 2009).

One of the most important component in management of the hydraulic system in a WDS network is sustaining adequate pressure. Insufficient pressure caused by system failure may cause inadequate supply and intrusion of contaminated water into the water system (Glennon, 2004). On the other hand, high pressure increases wear on fittings, valves, and increases network failures (pipe leaks and bursts) which threatens the quality of water through intrusion and contamination (Walski *et al.,* 2003).

2.5.1 Residual Pressure

Residual pressure, is the amount of pressure which remains in the pipe network during water flow in the distribution system. It is the force applied on walls of the pipe as it flows inside the water pipe (Sacci *et al.*, 2021). Residual pressure is the minimum requirement for water supply to prevent negative pressure and collapse of pipe network (Nolan, 2011). The minimum pressure head (MPH) is the lowest pressure under maximum demand at the most critical demand node in a water distribution system. Critical low pressure nodes are relatively at high elevations and far from the supply points.

2.5.1.1 Pipeline pressure requirements

The minimum pressure in a pipeline section should not be less than 10m in consideration of the elevation of the area (MWE, 2013). According to MWE (2013) standards of the water distribution network, public stand pipes should contain a minimum pressure of 10<25 meter, 150m in undulating terrain, 15m for firefighting and at least 60m in the water mains (MWE, 2013).

Too much pressure surges create high water velocity fluctuations and may influence re-suspension of settled particles and biofilm detachments (Walski *et al.*, 2003).

The ability of the water system to sustain a desired water flow rate even during occurrence of defects, is normally accomplished by providing redundancy in the system, i.e. by creating backup sources and looping of pipe network (Walski *et al.*, 2003).

Various water quality parameters vary with length of time in the distribution system i.e. Residual chlorine reduces with increasing age of water and can even be lost completely, higher substance concentration may leach from pipe materials and lining when the water contact increases (Lee, 2008). High detention time caused by low water pressures reduces the ability to control corrosion effectively by affecting PH Management and Phosphate inhibitors. It is therefore important to reduce retention time of water is a supply system by improving the amount of water pressure to achieve safe quality of water distributed.

2.5.2 Pipe materials and deterioration

Aged pipes causes system failure defects such as leaks which affects maintenance of adequate pressures in a water system. Pipe materials are vulnerable to Physical and chemical deterioration which calls for rehabilitation and hence replacement (reference required).

The water pipe network condition is influenced by age, material type, pressure, procedure of installation, type of soils among others. It therefore makes it difficult to tell where the failure like leaks, will occur.

Water pipe networks worldwide are composed of different types of pipe materials and fittings, i.e. copper, steel, stainless steel, pre-stressed concrete cylinder, Cast iron, P.V.C, Ductile iron, Asbestos Cement, H.D.P.E, and Non Cylinder concrete (International Flow Technologies, 2018). The most used pipe materials in Uganda include; H.D.P.E, Galvanized steel, Ductile iron, steel, Un plasticized polyvinyl Chloride (MWE, 2013).

Table 2.1: Pipe sizes in the Uganda's pipe network system

Pipe type	Size (mm)
H.D.P.E	15, 20, 25, 32, 40, 50, 80, 90, 110, 125, 140
uPVC	63, 90, 110, 160, 200, 250, 315, 400
GS and steel	15, 20, 25, 32, 40, 50, 65, 80, 100, 150, 200, 250, 300, 500, 600, 700

(Source: Ministry of water and environment, 2013)

2.6 Small water supply systems

Under the safe drinking water act (SDWA), Small public water systems are systems characterised as systems serving 10,000 or less customers.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter gives and overview of the area of study, study design, sampling procedures, and population of study, samples, and instruments applied, data collection, data preparations, analysis and ethical considerations.

3.2 Research design

To achieve the stated objectives, qualitative and quantitative research approaches were conducted and used in this work under which; data was collected on the current water quality supplied, pressure, population, pipe characteristics in terms of sizes, length, pipe materials, age and the number of customers connected to the existing grid in the study area, and it was analyzed by making a comparison between the data from an old (located at Nakifuma) and a new (Located at Kalagi) small water supply scheme, so as to come up with a viable best solution (model) and recommendations. Below is an outline of the methods that followed to achieve it.

3.2.1 Data collection methods

3.2.1.1 Secondary data review

Literature in the form of research journals, reports, books, conference proceedings, unpublished materials was reviewed to extract information related to water pressure, focusing on water quality supplied through small water systems to households. Basically, information reviewed focused on water pressure, its design and implementation from different parts of the world and its cost benefit study was utilized to carry out the research as well as to support the results of the current study.

3.2.1.2 Primary Data

Primary data was acquired through site visits, questionnaires, sampling, interviews and tests and measurements**.**

3.3 Sampling procedure

Sampling was conducted at 2 levels; the first level was at the household and the second along the supply chain.

3.3.1 Selection of the Sample Size

According to UBOS 2014 census results, Nakifuma has eleven village with a total number of 44,689 households whereas Kalagi is a village under Kyampisi Sub County under Mukono district, a sub county with an average of 10486 households.

3.3.1.2 Selection of sample size from Nakifuma study area

The villages of Nakifuma were divided into four zones/Territories according to the management team of small water supply systems. Therefore, selection of sample areas was based on the Zone/Territory with the highest number of water meter connections. However the sample size was selected based on the village with highest number of water Connections in the Zone/territory.

3.3.1.3. Selection of sample size from Kabembe-Kalagi-Naggalama (KKN) study area.

Kabembe-Kalagi-Naggalama water supply system supplies 51 villages. The villages are divided into four territories. Therefore the selection of the sample area was based on the territory with the highest number of water connection and the sample size was based on considering the village with the highest number of connection with in the selected territory

3.3.1.4 Sampling size at household level

Sampling at household's level was done randomly by selecting households with water meters who receive along the distribution system and those towards the end of the distribution system. For this case therefore two (2) households located at different Altitudes were selected and samples taken for water quality and pressure. Water pressure Loggers and taps for providing the water samples were installed at the meter stands, at a point before the meter.

3.3.1.5 Sampling along the supply chain.

Sampling along the supply chain was done randomly by selecting points along the supply chain

The entire water network was divided into three sections, i.e.

i. Transmission
ii. Storage and,
iii. Distribution

The transmission system was considered from the point at which the water left the source/water collection tank to the point at which water enters the main reservoir, whereas the distribution system was considered from the point at which water leaves the main reservoir to the point at which water enters the customers' meter in the study Zone.

Sampling in Nakifuma area

Nakifuma area comprises of 11 villages. Out of the eleven villages, seven villages are connected to the Nakifuma piped water system and the rest are not connected. The seven villages all together have a total population of 122,315 people and 7,325 households as shown in the table 3.1 below).

Table 3.1: Villages of Nakifuma town connected on Nakifuma small water system

S/N	Village	Population	Households
1	Bubiro	430	110
2	Nankulabye	1095	640
3	Nenyodde	1600	500
4	Nakifuma East	3400	1500
5	Nakifuma west	3400	1555
6	Kizungu	2290	600
7	Kaama	110,100	2420
	Total	**122315**	**7325**

(Source: Nakifuma local council, 2021)

To easily manage the water system in Nakifuma, the operating body divided and zoned the seven villages into four Zones, i.e. Kaama, Kizungu, Nankulabye and Nenyodde Zone. Kaama Zone constituted of three villages, Kizungu constituted of one village, two villages in Nankulabye and one village in Nenyodde zone. Kaama zone had the most number of villages, highest population, households and the most number of water connection, Consisting of three villages, 116900 people, 5475 households and 87 number of water connections respectively, followed by Kizungu Zone as shown in the table 3.2 below.

Table 3.2 Nakifuma water Zones with their populations, households and the number of water connections:

S/N	**Water Zones**	**Villages in the Zones**	**Population (number)**	**Total population in a zone (number)**	**Households (number)**	**Total Households in a Zone (number)**	**Total Number of water meter connections per zone (number)**
1	Kaama	Nakifuma East	3400	**116,900**	1500	5475	**87**
		Nakifuma west	3400		1555		
		Kaama	110,100		2420		
2	Kizungu	Kizungu	2290	**2290**	600	600	**78**
3	Nankulabye	Bubiro	430	**1525**	110	750	**59**
		Nankulabye	1095		640		
4	Nenyodde	Nenyodde	1600	**1600**	500	500	**61**
	Total number		**122315**	**122315**	**7325**	**7325**	**285**

(Source: Nakifuma local council and Nakifuma water system operating office, 2021)

The selection of a sample area was based on the Zone/Territory with the highest number of water meter connections. However the sample size was selected based on the village with highest number of water connections in the Zone/territory.

The sample size was calculated using Yamane formula of sample determination size as shown below;

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

Where
n = sample size
N = population size
e = margin of error at 95% confidence level

Equation …… 1

Calculation of the sample size

From the collected data and presented in table 3.2, N=87 water meter connections, and e=0.05, Using equation 1;

$$n = \frac{87}{1 + 87 (0.05^2)}$$

n= 71.467, Approximately 72 sample.

Sampling in Kabembe-Kalagi-Naggalama (KKN) area

KKN has 51 villages supplied by the small water system. The 51 villages are divided into four Zones/Territories, i.e. Kabembe, Kalagi, Kiyunga/Namirembe and Naggalama territories. They have a population of 667, 789, 548 and 283 of water connections respectively, as shown in the table below.

KALAGI TERRITORY

S/N	Village	Number connections
1	Kalagi TC	102
2	Kakola	51
3	Kyabakadde	61
4	Kirwanyamuli	72
5	Nakanyonyi	23
6	Dundu	34
7	Bengazi	16
8	Nakasajja	48
9	Kalagala	12
10	Bulijjo	21
11	Kandikwa	10
12	Bulimu	33
13	Kasenene	8
14	Nkonge	34
15	Bunyiri	40
16	Nabiyagi	17
17	Nkakwa	22
18	Kirwanyamuli	80
19	Kitanda	23
20	Kikabys	16
21	Nsamere	7
22	Kyampisi	39
	Total numbe	**769**

NAGGALAMA TERRITORY

S/N	Village	Number connections
1	Kazinga	32
2	Gwendidde	25
3	Gomba	41
4	Nabaale	19
5	Kiwebwa	34
6	Naggalama TC	76
7	Wabikokoma	56
	Total number	**283**

KABEMBE TERRITORY

S/N	Village	Number connections
1	Kabembe TC	123
2	Katega	71
3	Mabuye	40
4	Kanganda	68
5	Miggo	57
6	Lugamba	91
7	Kikandwa	57
8	Kyewanise	23
9	Katete	34
10	Kalebera	61
11	Mbaliga	42
	Total Number	**667**

KIYUNGA TERRITORY

S/N	village	Number connections
1	Kiyunga TC	123
2	Namirembe *	56
3	Lukuusi	78
4	Mulajje	42
5	Kibuye	53
6	Kito	14
7	Kasayi	33
8	Lugali *	136
9	Naro	5
10	Namulaba	8
	Total Numbe	**548**

Figure 3.1: Kabembe-Kalagi-Naggalama water Zones showing the number of water connections per zone and villages.

(Source: Kabembe-Kalagi-Naggalama water system operating office, 2021)

From the data collected, Kalagi territory has the highest number of water connections and within the territory, Kalagi trading center has the highest number of connections with in the territory, with 102 water connections, hence the population size.

Calculation of sample size

From the data collected and presented in table 3.2, N=102 water meter connections, and e=0.05. Using equation 1;

$$n = \frac{102}{1 + 102(0.05^{2})}$$

$$n = 81.274$$

Approximately 81 sample.

Note: Basing on the values calculated from the Yamane formula, From Nakifuma and KKN water supply area, an average of 80 sample size was taken.

3.4. Administering of questionnaires

Structured questionnaire (see appendix) for household interviews was prepared and administered randomly to eighty (80) households with connections on the piped small water supply system and eighty (80) households not connected to the water network system, including fifteen (15) supervisors, and technical operators of both the supply schemes, to collect primary data on impact of water pressure on water quality in selected households in Nakifuma and Kalagi small water supply systems under Mukono district. The field study included visiting households, organizations and expert consultations plus site observations which was conducted for a period of one month.

Besides household interviews in the field, water network infrastructure was seen to vary according to information received from respondents

3.5 Water pressure measurement

Water pressure measurements was done by installing water pressure Loggers on the pipe network including the points at which water enters and leaves the treatment plant(s), collection tank and reservoir, as well as at the customer meter points.

Figure 3.2: water pressure Loggers that was used to measure pressure in the water supply network

3.5.1 Water pressure-sampling criteria

i. Sampling at the household

A tee connection point was created at the meter stands at the meter points of the selected households. Water pressure loggers were installed at the created points in the morning, when samples were to be collected and removed in the evening of the same day.

The collection of pressure data was done three times at every point on three different days and times. In some occasions by skipping either one or two days from the time of sampling.

Figure 3.3: pressure Logger installed at the customer's meters to measure pressure

ii. Sampling along the supply chain

Pressure measurements along the supply \chain was done by creating sampling points on the pipe network, by either drilling and installing pipe saddles on the pipes or by creating tee connections on the already existing tapings on the pipe network.

Figure 3.4: point created on the DN100 pipeline with a pressure logger installed and tap point to collect water sample

It should be noted that only the transmission lines, main reservoir and the distribution lines that supply the selected study Zones were considered during collection of data. For example; under Nakifuma water supply scheme, the main reservoir Located at the hill of Nakifuma town plus the distribution lines to Kaama supply Zone was considered, and for KKN water supply scheme, the transmission line to Nkonge main Reservoir located at Nkonge hill and the distribution line to Kalagi town were considered.

On the transmission line, two (2) points were considered, i.e. at the point at which water leaves the water source (production well)/ collection tank and the point at the point at which water enters the reservoir (Nakifuma and Nkonge reservoirs).

On the distribution system, four (4) points were considered, i.e. at the point at which water leaves the main reservoir on the distribution line, at a point far away from the tank along the distribution line but in the study zone and at two (2) water meter stand points at which water enters the meters at the households. The coordinated for each point were recorded and plotted as indicated on the figures below.

Nakifuma Small water system

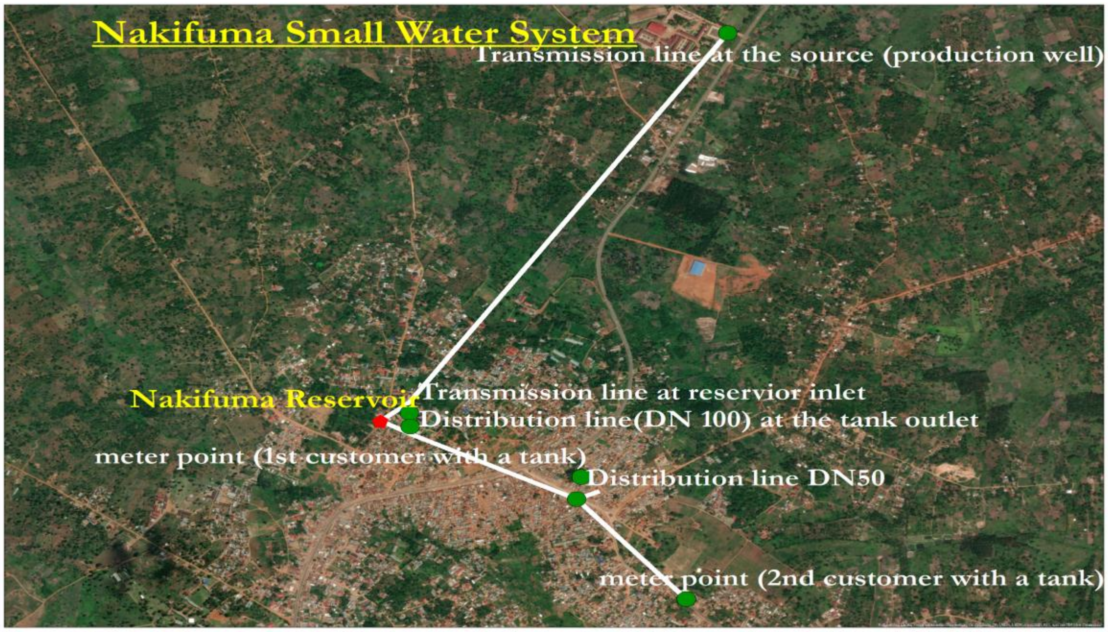

Figure 3.5: map showing Nakifuma and the points on the water supply system where the pressure and water quality samples were collected.

Kabembe- Kalagi -Naggalama small water supply system

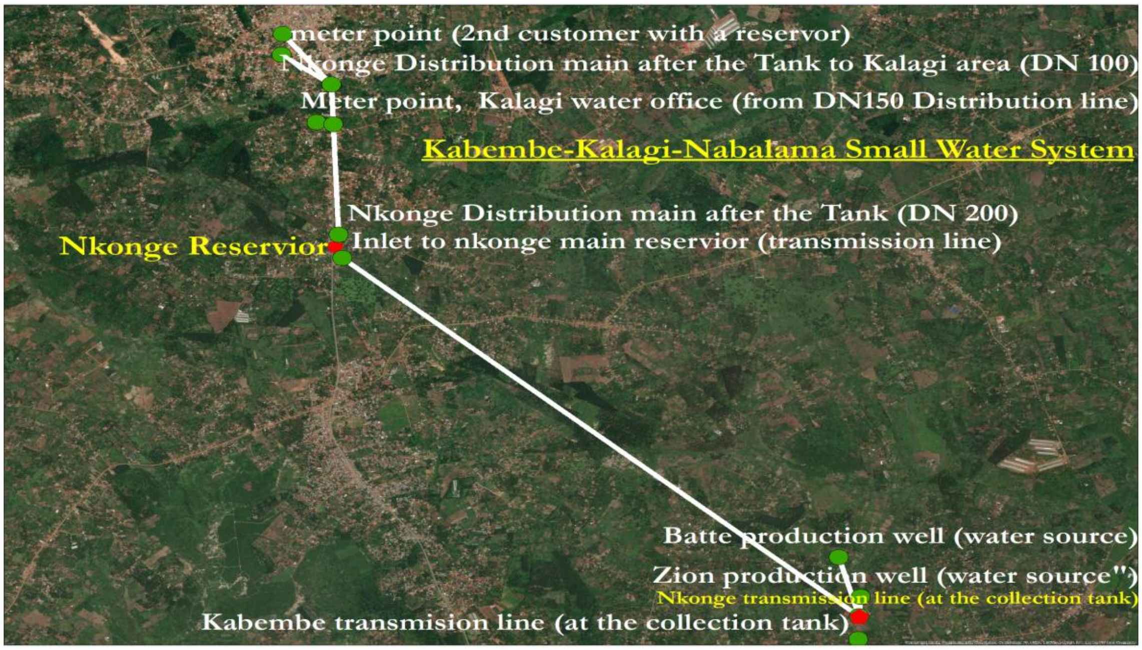

Figure 3.6: map showing Kabembe-Kalagi-Naggalama and the points on the water supply system where the pressure and water quality samples were collected

3.5.2 Pressure data analysis

Data recorded on pressure loggers was extracted to a computer, using “Radwin view version 4.84” software and analyzed using Microsoft office applications. Tables and graphs were drawn and analyzed using statistical methods to identify pressure variations in the network.

3.6 Water quality measurement

Water quality testing was carried out by identifying and installing sampling points in the sections created on the network chain and households, from the point at which water enters and leaves the treatment plant(s), collection tanks, and reservoir and up to the customers’ meter point. Water Quality sampling was done at every point where the pressure measurements was done in the network. The water samples were tested for common water quality parameters known to affect human health if consumed in water. Such parameters included; PH, Turbidity, Total Coliform, Total Dissolved Solids, Apparent Color, Dissolved Oxygen, Electrical Conductivity and Residual Chlorine. Sampling was done on three different days of the week, once a day, during the day, but on different hours of the day, which included, morning, afternoon and evening**.**

The samples were collected in a sterilized plastic bottles, were kept in a mobile freezer containing ice, and transported to the lab using a vehicle to the lab in less than 6(six) hours.

3.6.1 Testing criteria of water samples

The water samples were tested for physical, chemical and biological parameters. Some water parameters were tested from the field (i.e. PH, Dissolved Oxygen, Electrical Conductivity, Total Dissolved Solids, and Turbidity) using mobile gargets, were as some were tested from the Laboratory (the public health and Environment Engineering Laboratory- Makerere University) (i.e. Apparent Color, Total Coliform and Residual Chlorine).

PH was measured using a 3510 PH meter, Turbidity measured in NTU SI units using an electronic hand-held meter (2020weTurbidmeter) LaMatte make, Electrical Conductivity measured in µS/cm SI units and Total Dissolved Solids measured in mg/l SI units was detected using a Portable Electro conductivity meter (ELE international make), Dissolved Oxygen was measured and recorded in MG/l SI units using a Hydro check meter (type HC1000), A photometer 7500- make was used to measure Residual Chlorine in Mg/l SI units, Platinum-Cobalt standard methods was used to measure Apparent color in PtCo SI Units, whereas Total Coliforms were tested in the Laboratory using Spread plate method, all in accordance to Standard method for water and waste water.

3.6.8 Determination of variations.

The techniques that were utilized include;

i. Desk study, which comprised review of documents like Action Plan and Reports.

ii. Household interviews; here the study formulated household and institutional structured questionnaires.

iii. On-site observations were conducted to determine the extent of water quality supplied in households

iv. Photography was used to gather on-site proof of the study problem.

v. Water pressure and quality tests were carried both in the field and laboratories to understand their behaviours.

vi. The variation was determined by using the statistical soft wares, use of person's correlation efficiency, and plotting of the pressure and Water quality parameters on graphs.

3.7 Data collection instruments

Development of data collection instruments was based on the study objectives with a basis of finding out the effect of residual pressure on the quality of water supplied to households in a small water supply systems, variation of water pressure along the supply chain, variation of water quality along the supply chain, the relationship between water pressure and quality variation in the network and the determinants to develop a suitable model that ensures safe water and adequate residual pressures.

3.8 Data processing and presentation

During data processing, software like; SPSS, Microsoft excel, was used to process the collected data.

3.9 Data analysis

Raw data obtained from the questionnaires was entered and processed using SPSS software to get the mean, frequency, and percentage of questionnaire response and compute and presented using Microsoft word.

The water pressure and water quality data collected from both the field and laboratory was entered, analysed and graphs/curves plotted using Microsoft excel. To get the variation levels of Water pressure and Quality, correlation and significance levels were calculated/processed using Person's correlation coefficient.

The data was then analysed using simple statistical Formulas such as; frequency, mean and percentage. The results were presented using MS Word.

Formulas used;

Mean "μ" $= \frac{\sum fx}{n}$, n = ∑f Equation….2

Where;

f = frequency

x = Mid-interval value of each class

n = Total frequency

∑f = Sum of products of mid- interval values and their corresponding frequency

3.10 Attaining a suitable framework to optimize quality with water pressure

To attain a suitable Model/frame work for optimization of good water pressure and quality, different related literatures were revised (i.e. using WHO standards), came up with optimization figures and values. The Optimization frame work was presented in form of a flow chat.

CHAPTER FOUR: RESULTS AND DISSCUSSION

4.1 Introduction

This chapter explains how the sample sizes were taken, the results from the field exercise, both from questionnaires, water quality and pressure tests. It relays the discussion of the outcome from the field results using statistical tools. The solution to optimize and have a safe system is also proposed.

4.4.1 Water pressure distribution along the supply chain

4.4.1.1 Pressure variation in Nakifuma small water system.

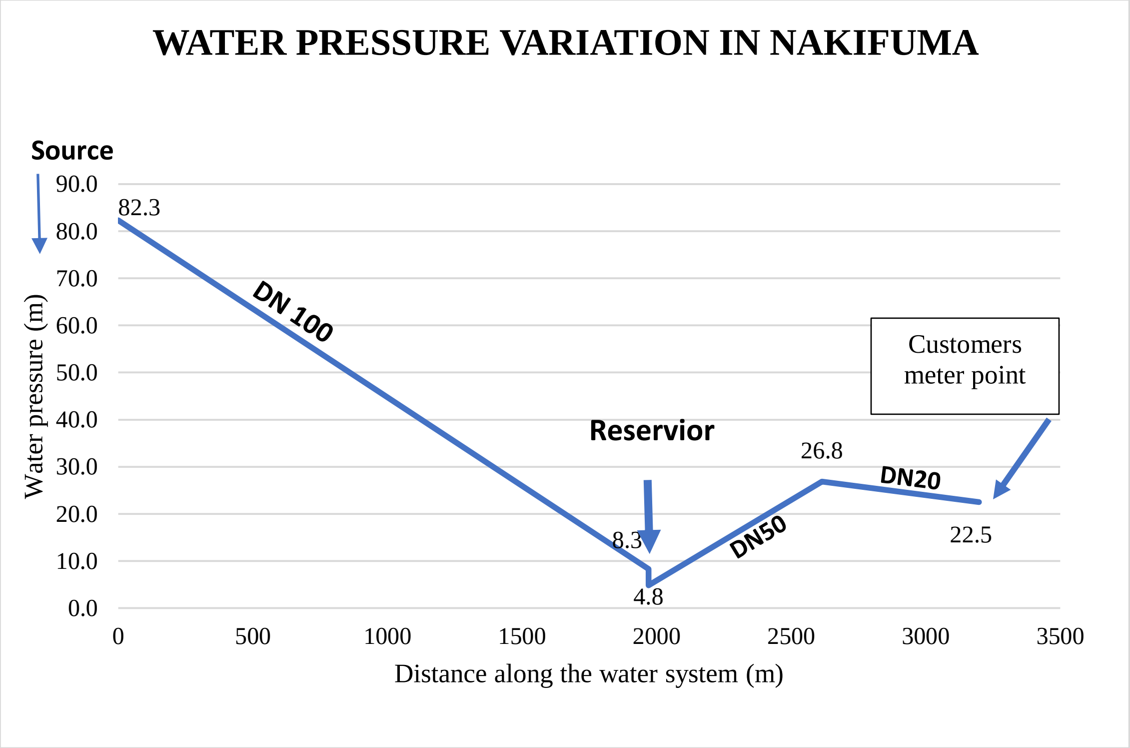

Figure 4.1*: Variation in water pressure distribution along the supply chain of Nakifuma small water system*

From the figures 4.1 above, Nakifuma small water supply system comprises of DN100 HDPE transmission line stretching 1971m from the source to the water reservoir, water leaves the water source at 82.3m water pressure and reaches the reservoir at 8.3m water pressure head. Water leaves the tank and enters the distribution network at 4.8m pressure head in a DN100 HDPE pipe and later reduces to DN50 HDPE pipe. A point 644m away from the water reservoir in the distribution network on DN50 pipe registered 26.8m pressure head and reduced to 22.5m head as water reached the customer's water meter, 3199m away from the reservoir in a DN20 HDPE pipe.

4.4.1.2 Pressure variation in Kabembe-Kalagi-Naggalama (KKN) small water system.

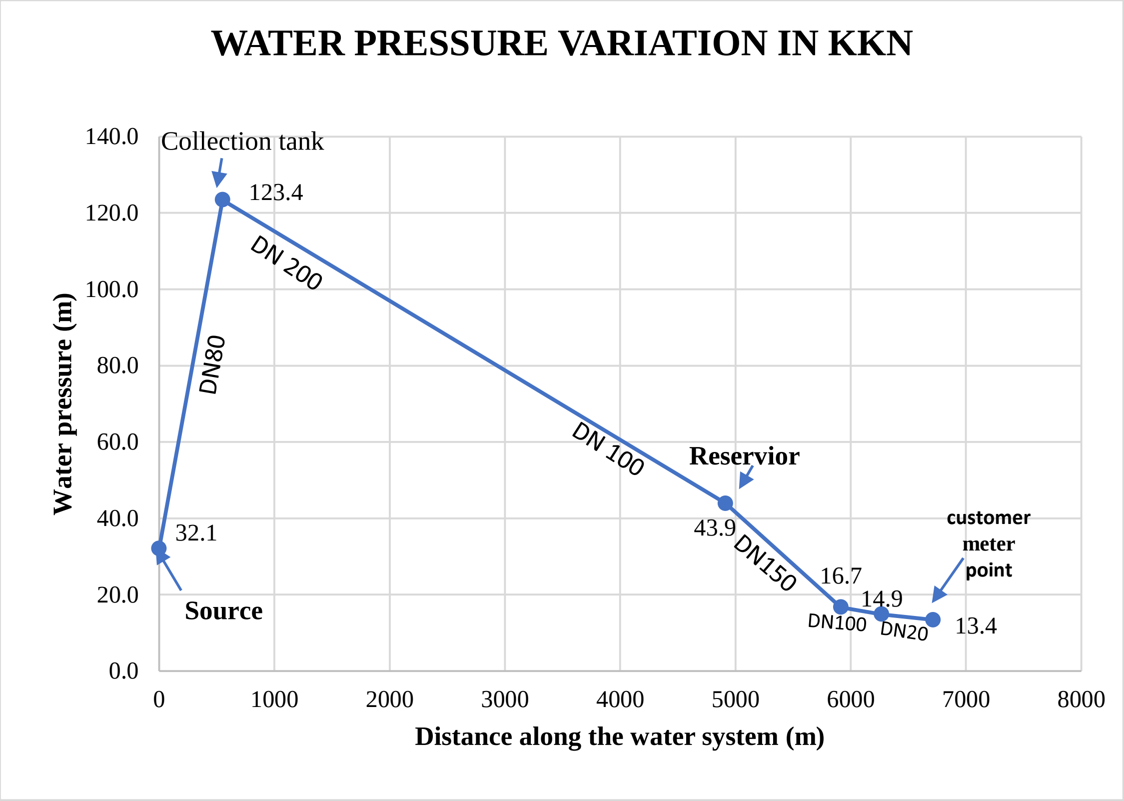

Figure 4.2: Variation in water pressure distribution varies along the supply chain of Kabembe-Kalagi-Naggalama small water system

From the figures 4.2 above, from the water source under Kabembe-Kalagi-Naggalama small water system, water is transported through DN80 pipe at 32.1m water pressure head to a water collection tank 551m length from the furthest source. From the collection tank, water is pumped at 123m pressure head through DN200 UPVC transmission main and reaches Nkonge reservoir 4915m away in a DN100 UPVC pipe at 43.9m water pressure head. Water from the main reservoir enters the distribution network through DN200 and reduces to DN150 UPVC pipe. 1000m length away from the reservoir, 16.7m water pressure was registered in a DN150, then later reduces to 14.9m head 1354 meters away from the reservoir in DN100 UPVC pipe. At the customers' water meter, 1801m away from the reservoir, water reached at 13.4m water pressure head in a DN20 HDPE pipe.

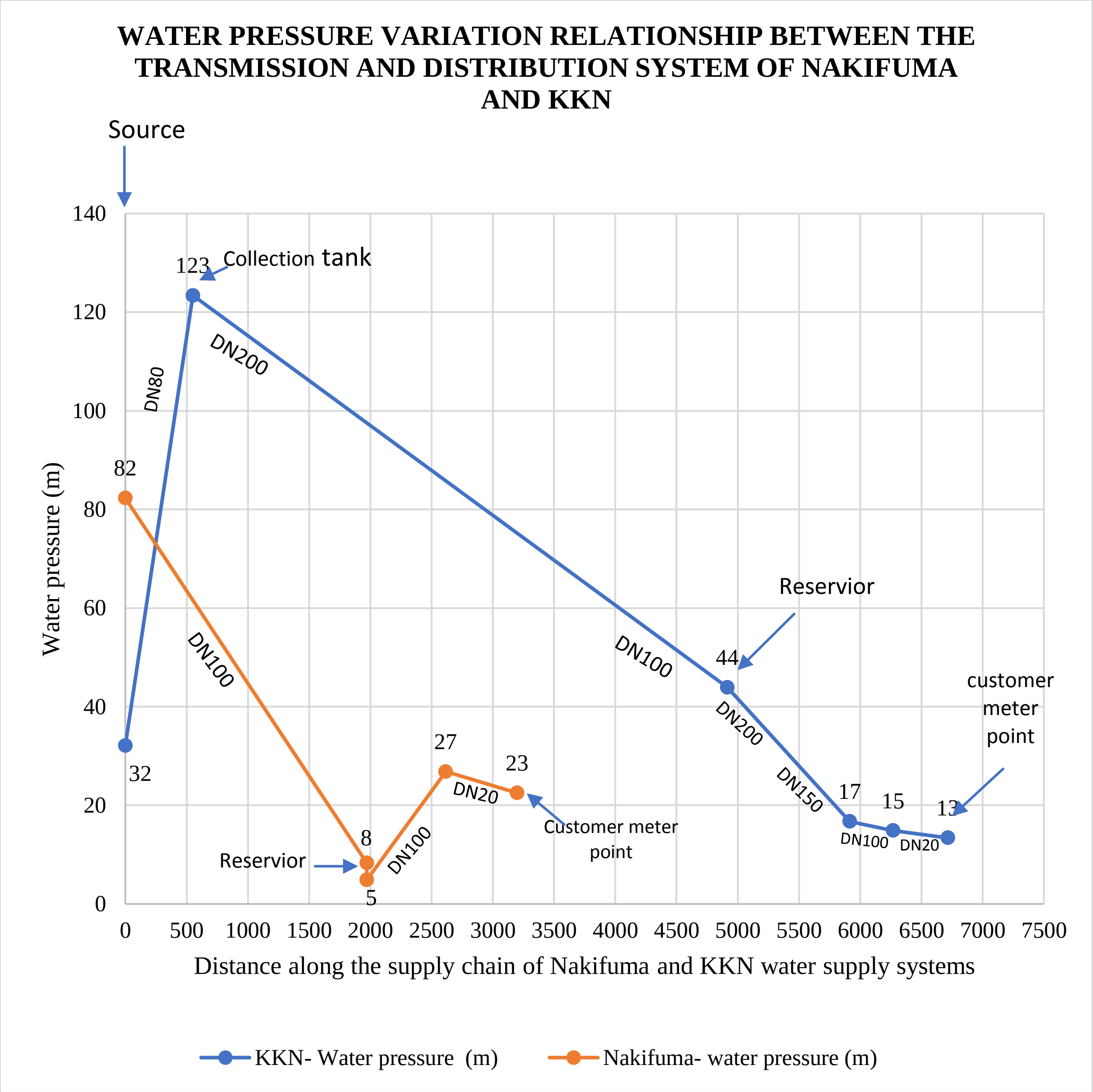

Figure 4.3: Water pressure relationship variation between Nakifuma and KKN small water systems

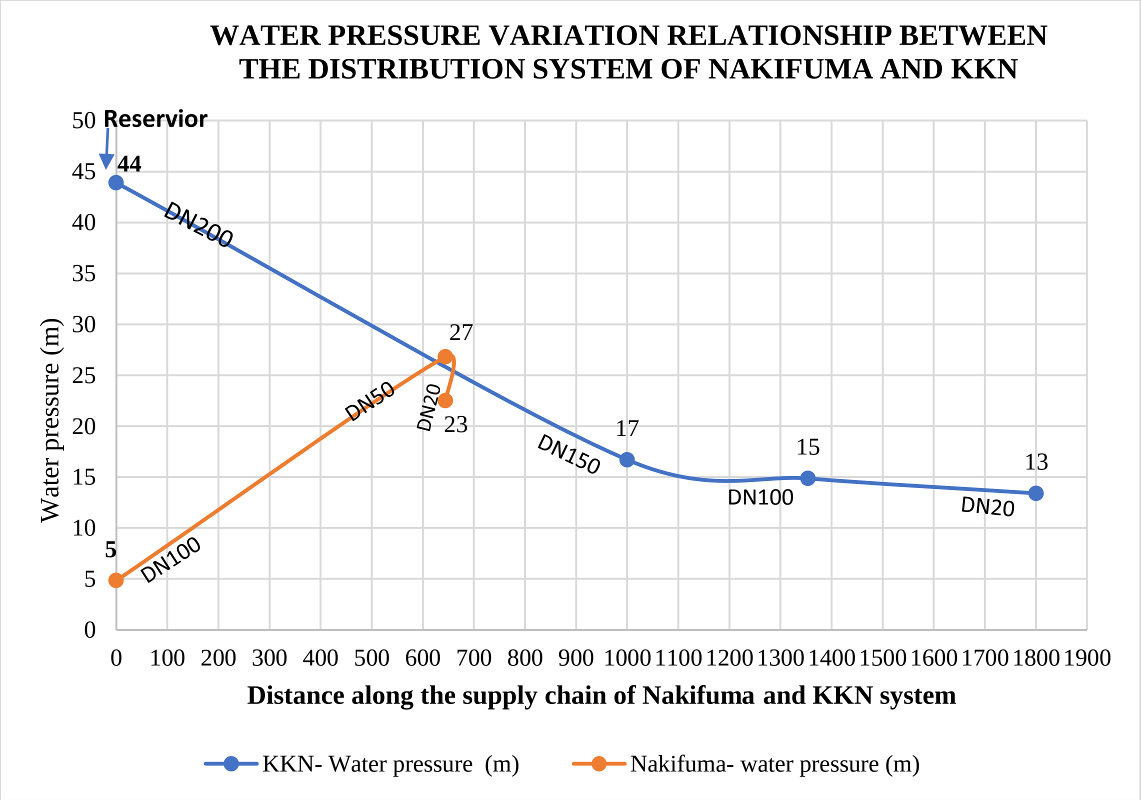

Figure 4.4: shows water pressure relationship variation between Nakifuma and KKN Distribution small water systems.

The Analysis in comparison with the new system (KKN) and Old system (Nakifuma) as shown in figures 4.3 and 4.4 above shows that the older system performed better than the new system in terms of pressure delivered to the final consumers. The rate of pressure loss in the system is estimated to be 16.07m/km for the KKN main and 37.5m/km for the Nakifuma main. The difference in pressure loss could be attribute to the distance from the reservoir, the size of system, type of pipes, and the elevation. Both systems delivered residual pressure are within the acceptable minimum range of not less than 10m (1bar).

To ascertain the performance of the system, response from consumers in each system were captured as indicated in the section below.

Water supply status (questionnaire results)

Table 4.1 Response rate on water supply status from households with water connections in Nakifuma and KKN small water systems:

Response on water supply status from households with water connections								
Area	**Supply on all the time**		**Supply not on all the time**		**No response**		**∑f**	**∑%**
	Frequency (f)	%	Frequency(f)	%	f	%		
Nakifuma	24	46.2	20	38.5	8	15.3	52	100
KKN	6	9.5	57	90.5	0	0	63	100

Source: Field Survey (July 2021)

Table 4.2 Response rate on water supply status from the operators of Nakifuma and KKN small water system:

Response on water supply status from the operators								
Area	**Supply on all the time**		**Supply not on all the time**		**No response**		**∑f**	**∑%**
	Frequency (f)	%	Frequency (f)	%	f	%		
Nakifuma	1	20	1	20	3	60	5	100
KKN	4	57.1	2	28.6	1	14.3	7	100

Source: Field Survey (July 2021)

From the results presented in table 4.1 above, it depicts that in Nakifuma water supply is more reliable than Kabembe-Kalagi-Naggalama water supply area. i.e., 46.2% of customers with water connections in Nakifuma compared to 9.5% in KKN confirm that supply is on all the time where as 38.5% and 90.5 in Nakifuma and KKN respectively say water supply is intermittent. Whereas the results from the operators (Table 4.2) of the system responded otherwise from both systems. In Kabembe-Kalagi-Naggalama. i.e., 57.1% responded, water is on all the time where as 28.6% shows that supply is not on all the time. In Nakifuma, water supply is on most times (20%) and the responses equal with those that said it is on all the time (20%). Pressure Results as shown in the corresponding figures 4.1 and 4.2 above, where customers in Nakifuma and KKN receive 22.5 m and 13.4m pressures respectively at their meter, directly reflects what the public with water connections say and it may be the linked as to why the public perceive there is water all the time in Nakifuma and less in KKN.

4.4.2 Water Quality distribution along the supply chain of Nakifuma and Kabembe-Kalagi-Naggalama small water system

4.4.2.1 How water Quality and dissolved oxygen varies along Nakifuma small water system supply chain

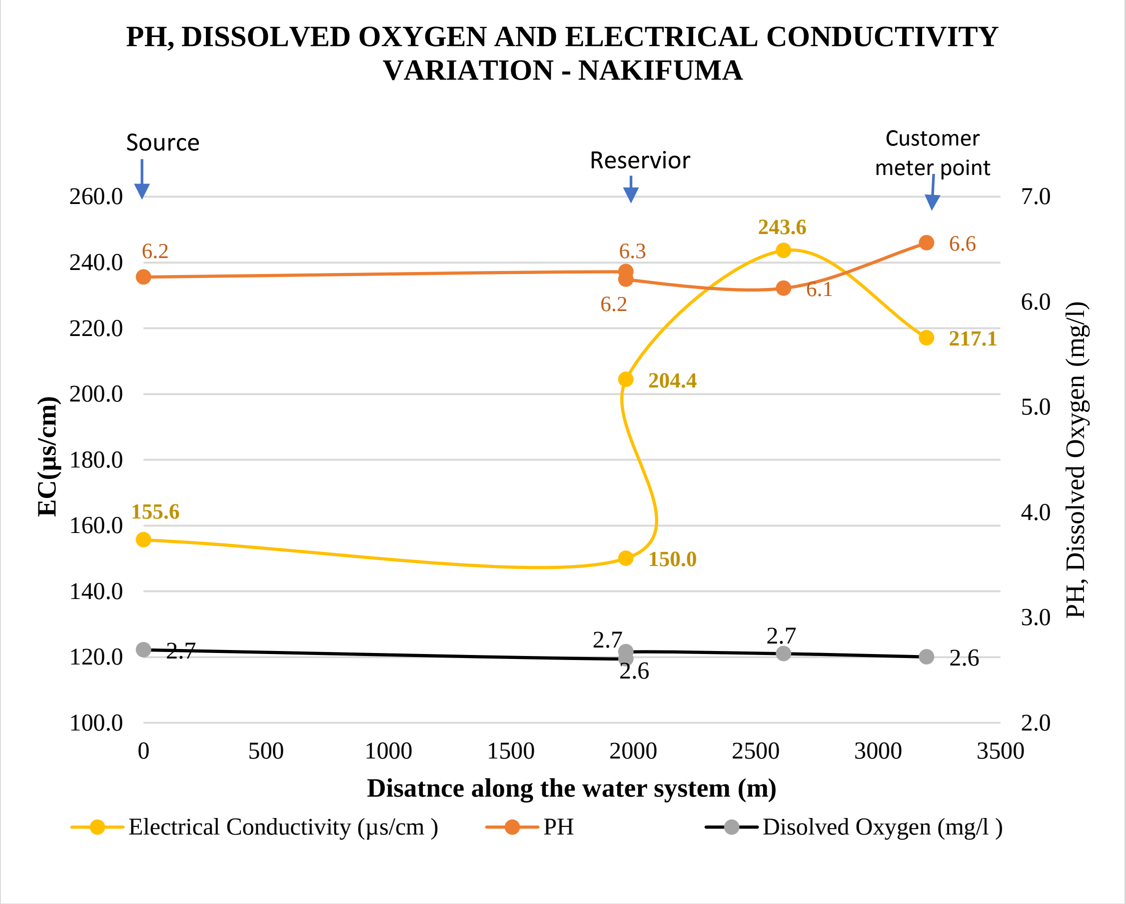

Figure 4.5: PH, Electrical conductivity and dissolved oxygen variation along the supply chain of Nakifuma small water system

From the figure 4.5 Above, PH slightly increase and Dissolved Oxygen reduces as well slightly along the supply chain of Nakifuma small water system, from the source to final consumer. The oscillation value of PH and Dissolved Oxygen is averagely 0.2mg/l a minimal value, causing less impact. On the other hand Electrical Conductivity increase as water is distributed along the water system with an increase in distance until water reaches the final consumer as shown in figure 4.3 above. The findings are in line with the recommended EC valued by WHO, (i.e., should not exceed 400 µs/cm).

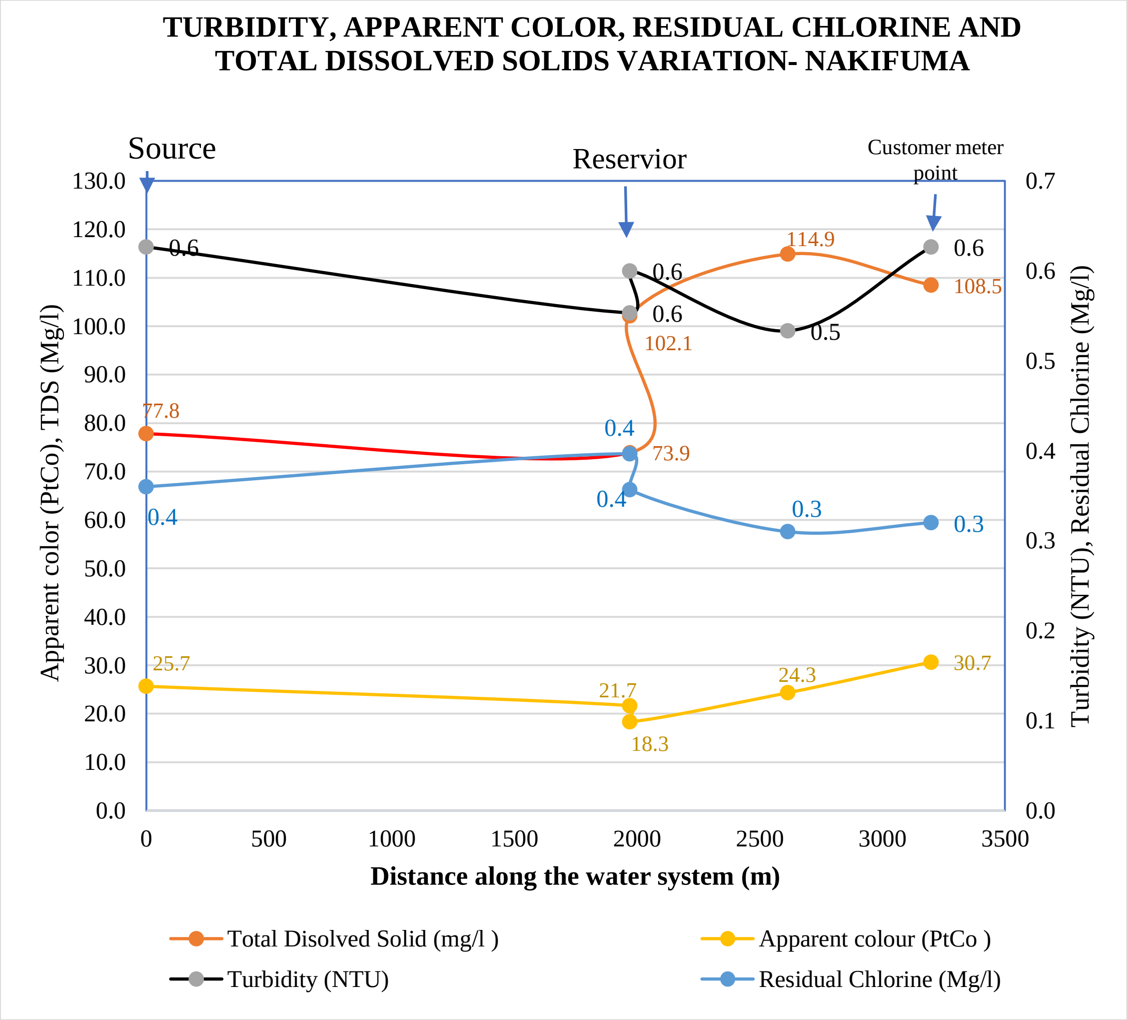

Figure 4.6: Apparent color, Total dissolved Solids, Turbidity and Residual chlorine variation along the supply chain of Nakifuma small water system

Apparent color and TDS increases in the supply chain of Nakifuma small water system as water is distributed with increase in distance whereas Residual Chlorine varies relatively constantly. The above figure 4.6 shows that, TDS and Turbidity values oscillates with in the acceptable range of less than 300mg/l and <1NTU as guided by WHO standards.

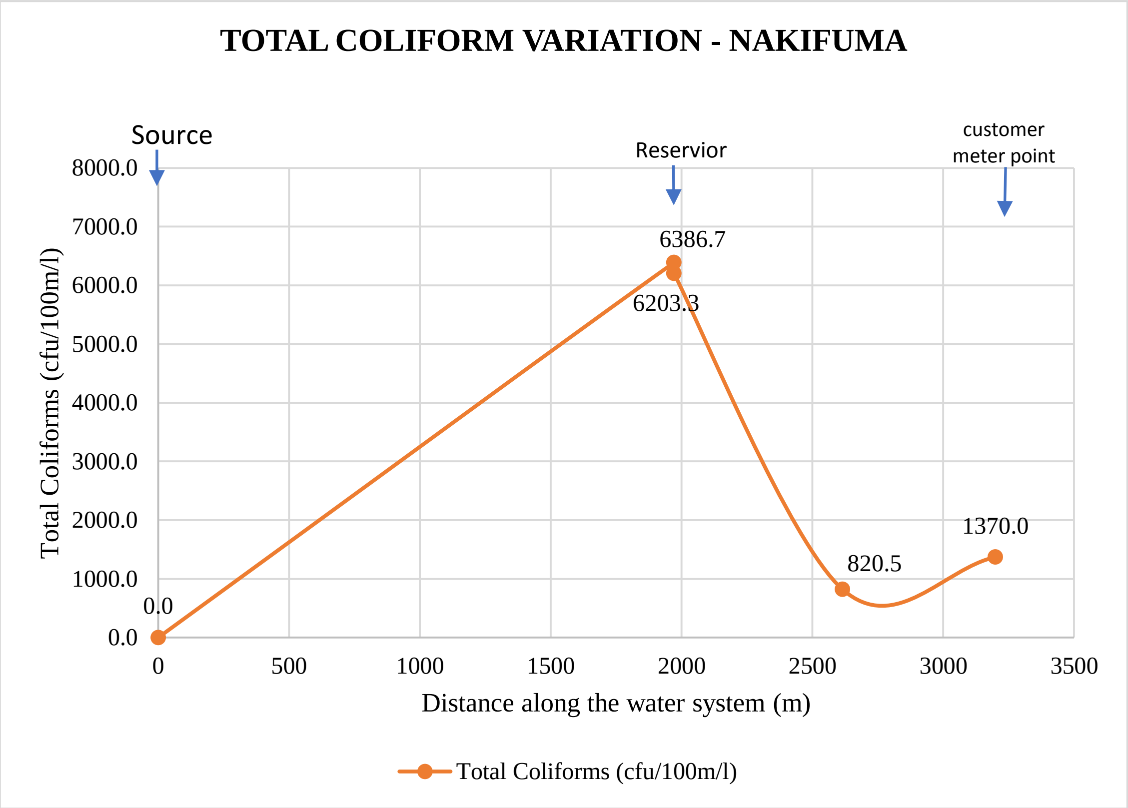

Figure 4.7: Total Coliforms variation along the supply chain of Nakifuma small water system

Total coliform increases in the transmission main to 6386.7 and reduces to 1370 Cfu/100m/l in the distribution along the supply chain of Nakifuma small water system as shown in the figure 4.7 above. The values attained are far above what was quoted by Meride & Ayenew (2016) that, WHO and Ethiopian drinking water guidelines require the absence or less than 1 colony-forming unit per 100mls (Cfu/100 ml) of total coliform in public drinking water supplies.

4.4.2.2 How water Quality varies along Kabembe-Kalagi-Naggalama water supply chain.

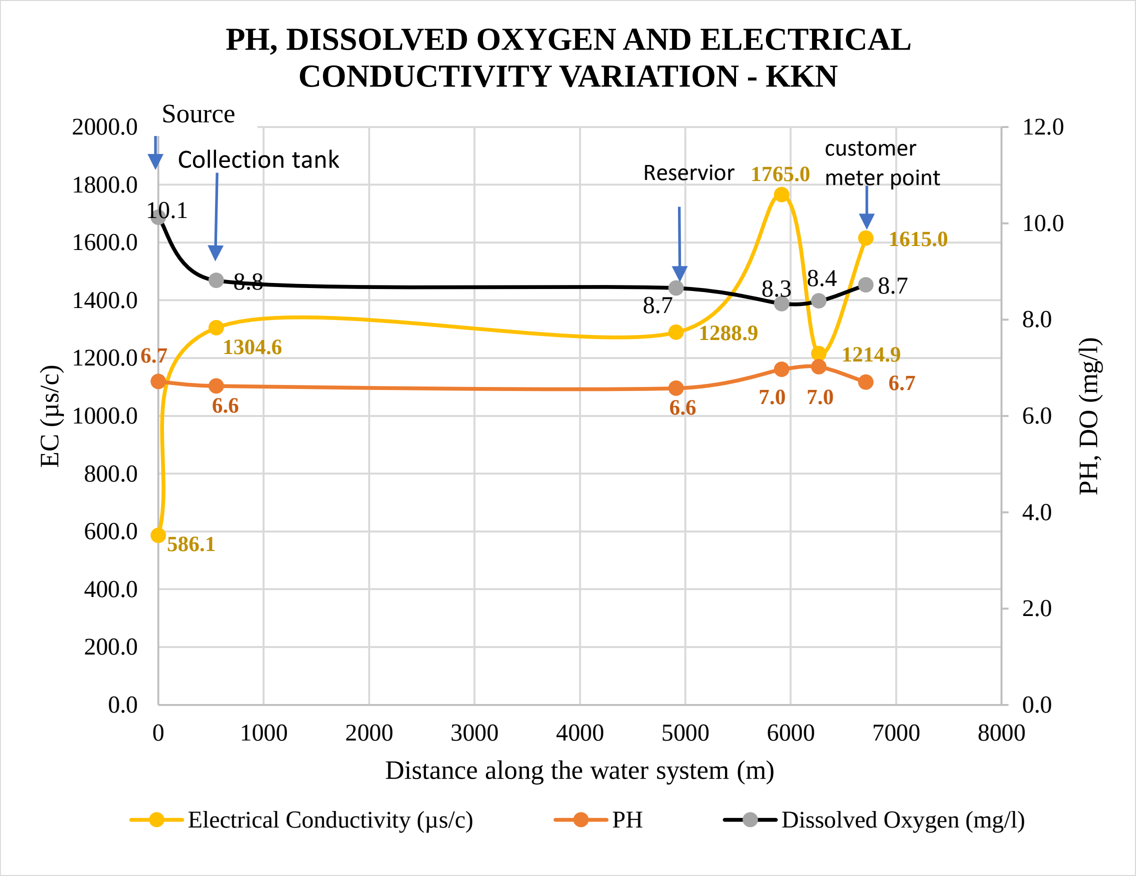

Figure 4.8: PH, EC and Dissolved Oxygen variation along the supply chain of Kabembe-Kalagi-Naggalama small water system

From the figure 4.8 above, Electrical conductivity increases with an increase in distance and reduction in the pipe size as water is supplied in the supply Chain of Kalagi-Kabembe-Naggalama small water system. It increases beyond the acceptable value (400µS/cm) for drinking water according to WHO standards. PH and Dissolved Oxygen slightly increases and decreases respectively, but their values oscillates within the acceptable range as water is distributed to the final consumer.

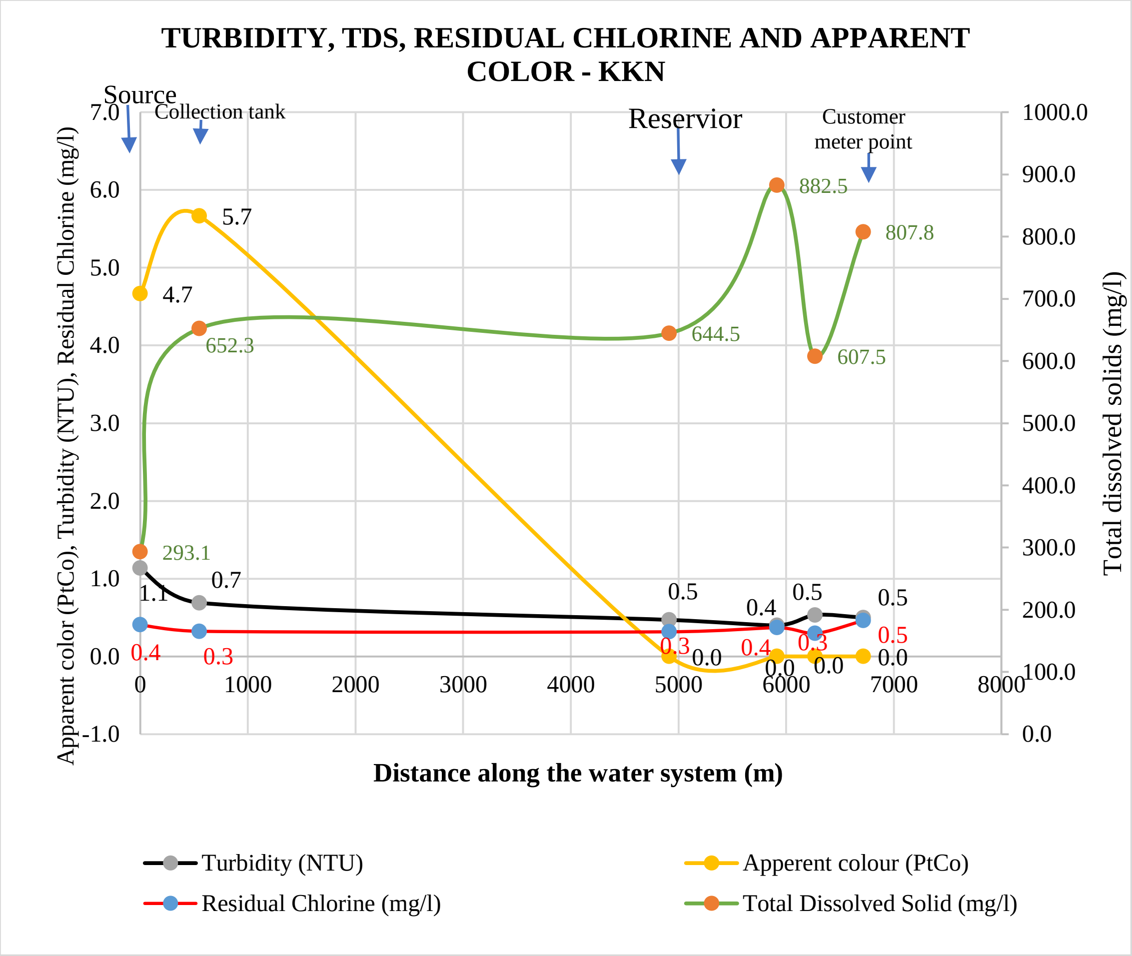

Figure 4.9: Turbidity, Residual Chlorine, Total Dissolved Solids and Apparent color variation along the supply chain of Kabembe-Kalagi-Naggalama small water system

Residual chlorine changes slightly with change in distance as water is distributed. Turbidity slightly reduces in smaller margins as water is distributed in the supply chain of Kabembe-Kalagi-Naggalama small water system. Apparent color drastically decreases from the collection tank as water is transmitted through Nkonge transmission, distribution to the consumers. Whereas, El-Dakar (2016) claimed that total dissolved solids values less than 300 mg/l is considered as excellent, between 300 and 600 mg/l is good, 600-900 is fair, 900 to 1200 is poor and that more than 1200 mg/liter is unacceptable, the study is revealed that TDS in the network was higher and increased with distance as shown in the figure above 4.9.

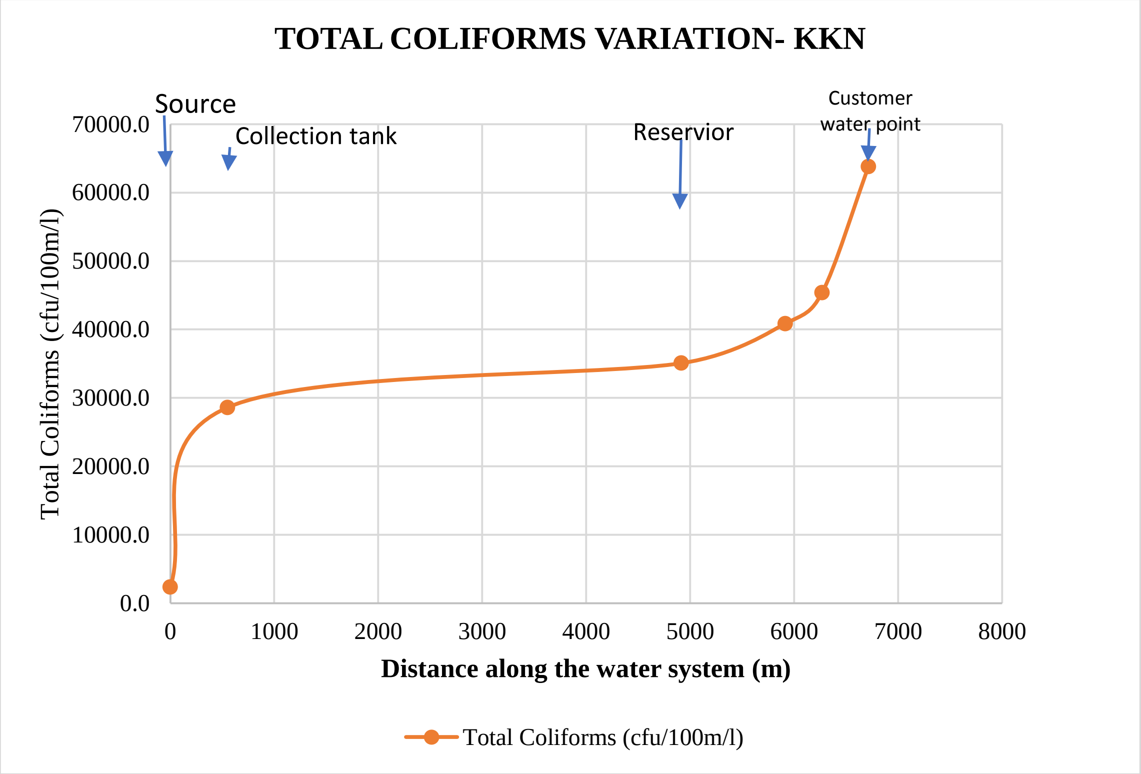

Figure 4.10: Total Coliforms variation along the supply chain of Kabembe-Kalagi-Naggalama small water system

Total coliform greatly increases with distance as water is distributed in the supply chain of Kabembe-Kalagi-Naggalama small water system as shown in the figure 4.10 above.

Water quality comparison between Nakifuma and KKN small water supply systems.

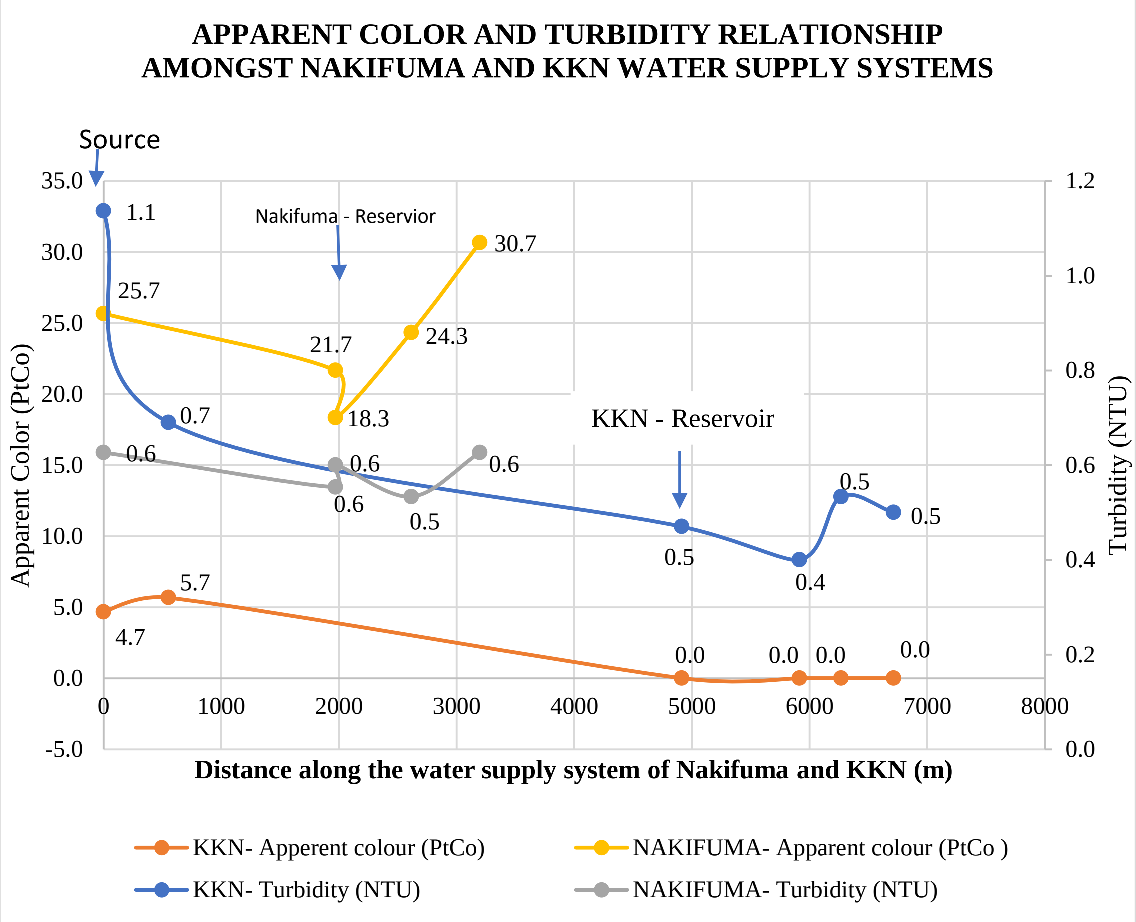

Figure 4.11: Behavior of Turbidity and Apparent color of Nakifuma and KKN small water supply systems.

Turbidity and Apparent Colour in both systems have relatively similar behaviours in both systems. In both systems, Turbidity falls below the acceptable range, i.e., below <1 NTU. However the for Apparent Colour, KKN values fall under the acceptable range of 5PtCo whereas for Nakifuma, the values are far above the permissible limit of 15PtCo and the higher values were seen to originate from the source throughout the entire system as shown in the figure 4.11 above hence rendering the waters unsafe for consumption compared to KKN water system.

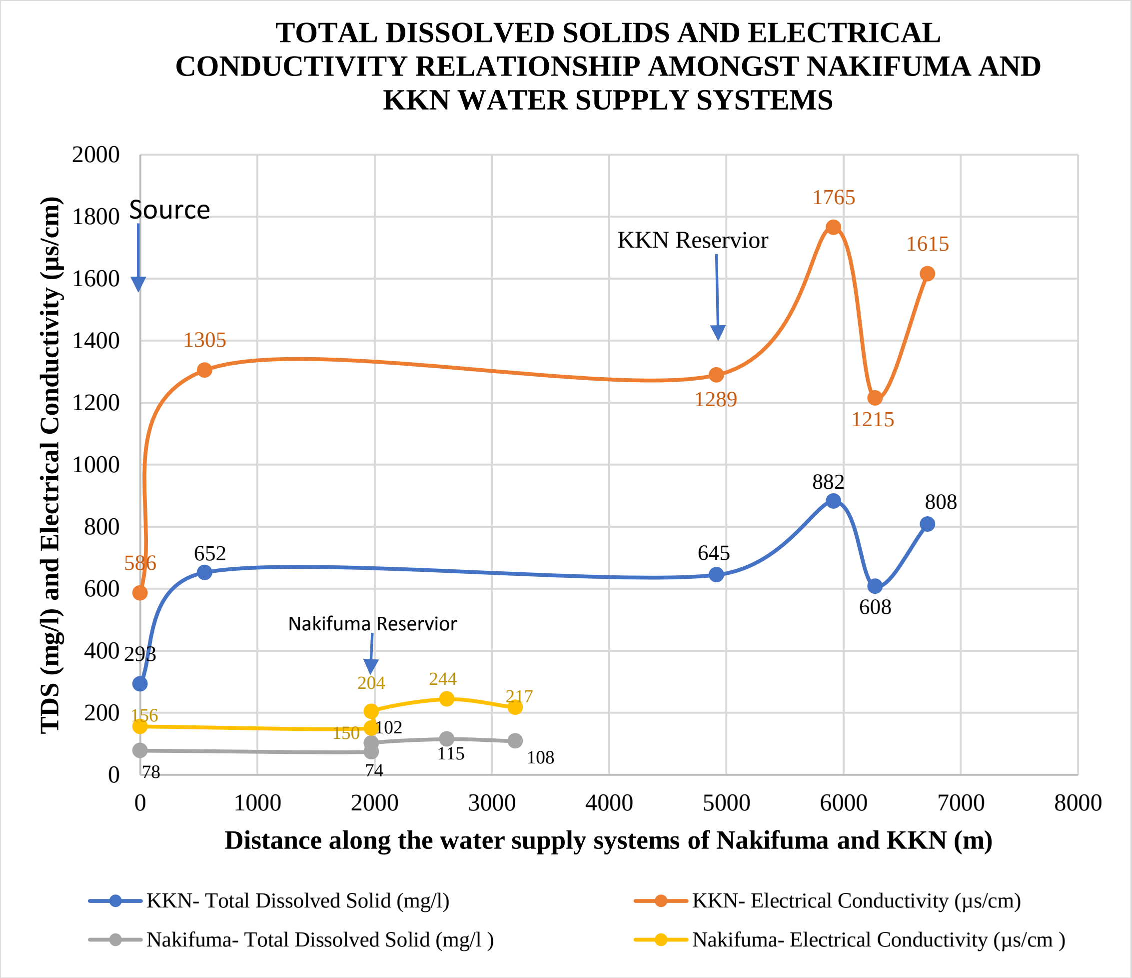

Figure 4.12: Behavior of Total Dissolved Solids and Electrical Conductivity of Nakifuma and KKN small water supply systems.

Electrical Conductivity and TDS Oscillates in the same direction, i.e., an increase or decrease in the quality values of one parameter increases or decreases the other parameter respectively as shown in Figure 4.12 above. Nakifuma water system had fair TDS and EC values which fall below the acceptable values according to WHO requirement for drinking water, i.e., EC<400 µs/cm and TDS<300mg/l whereas, the values for KKN are far above the acceptable range making the waters supplied through this system un safe for drinking in terms TDS and EC.

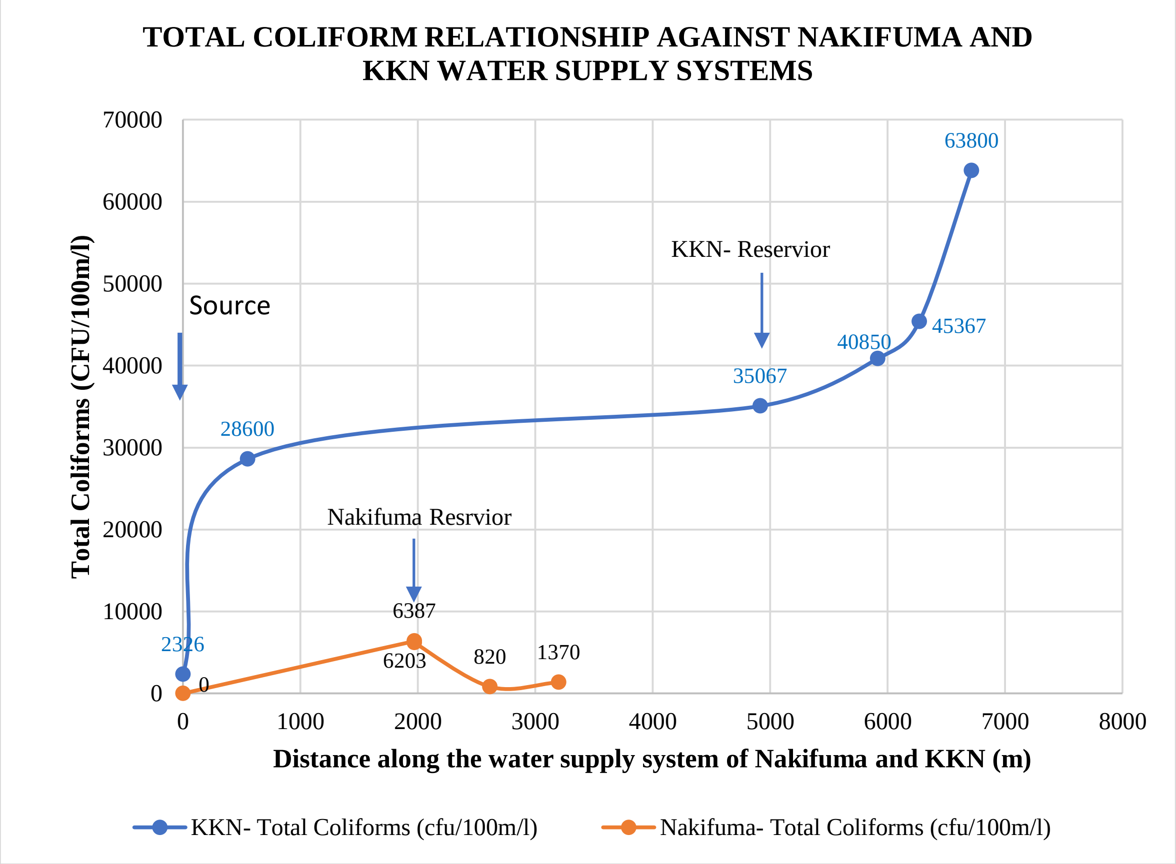

Figure 4.13: Behavior of Total Coliforms under Nakifuma and KKN small water supply systems.

Figure 4.13 above shows that, both systems were tested to have total coliforms, however, KKN (the new system) had more Coliforms than Nakifuma. It was also observed that under Nakifuma system, Coliforms started surfacing at the reservoir area to the network until the customers’ meter. Whereas for KKN water supply system, it was observed right from the source.

4.5 Relationship between pressure and Quality Variations in Nakifuma and Kabembe-Kalagi-Naggalama small water system supply Network.

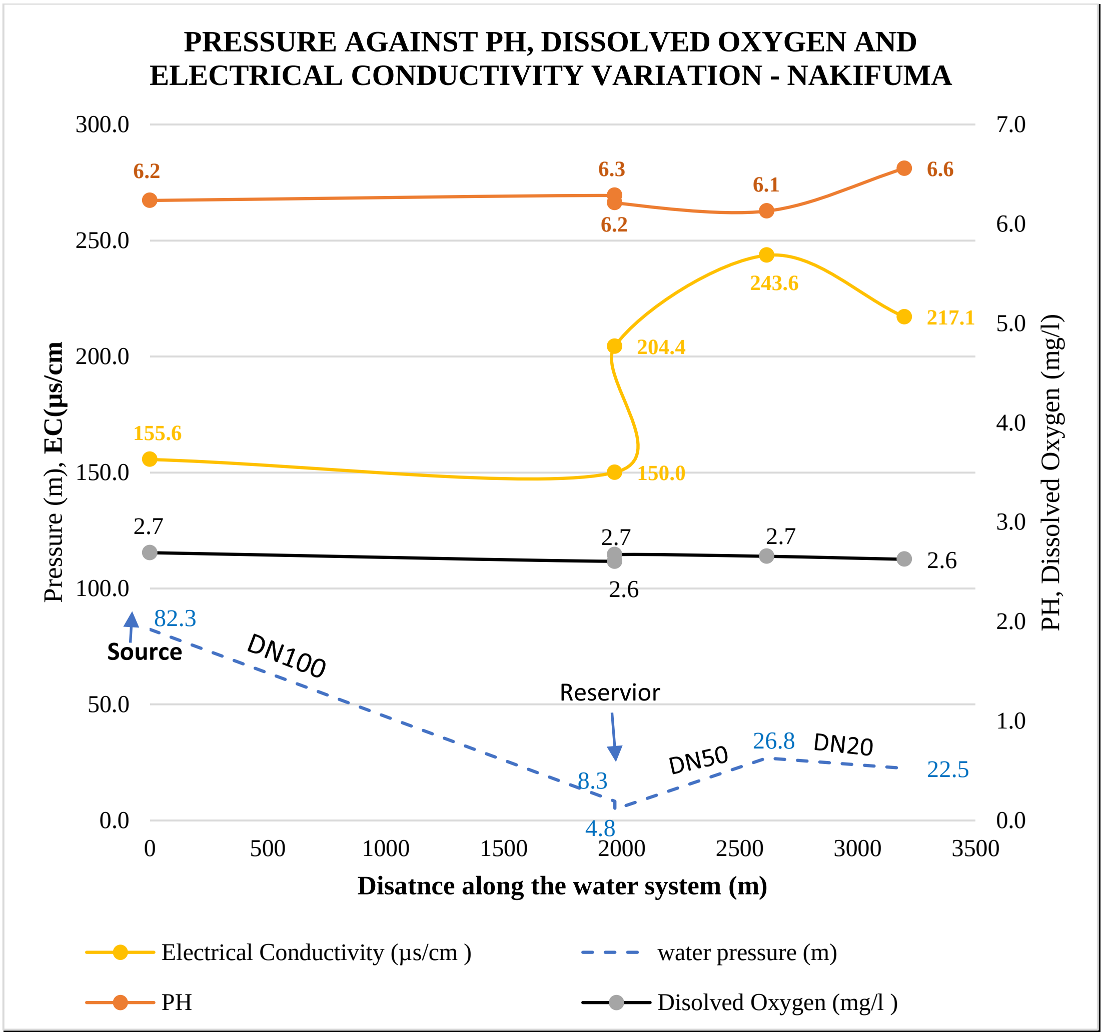

Figure 4.14: Water pressure variation with PH, Electrical conductivity and dissolved oxygen along the supply chain of Nakifuma small water system

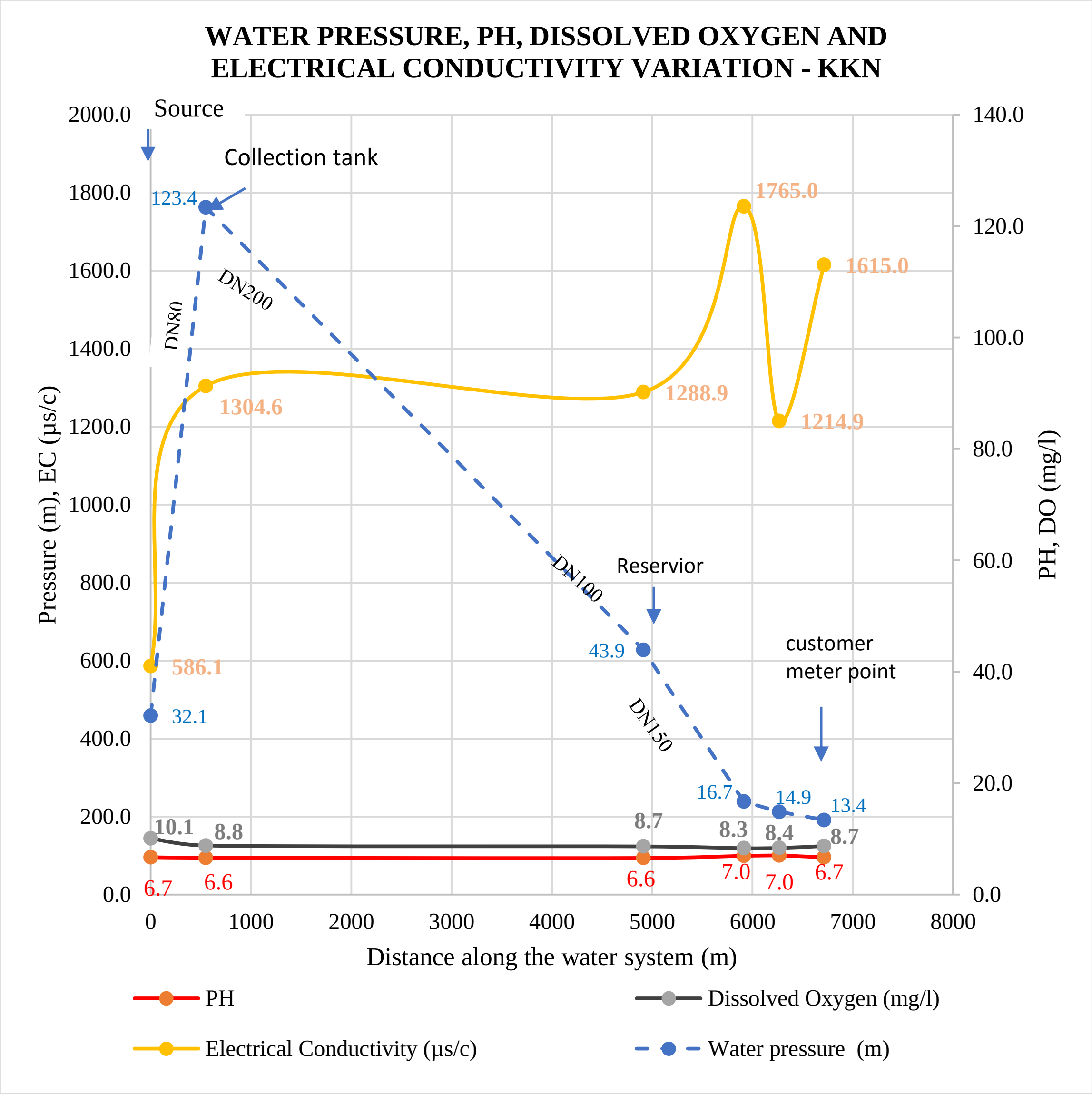

Figure 4.15: Water pressure variation with PH, EC and Dissolved Oxygen along the supply chain of Kabembe-Kalagi-Naggalama small water system

From the figures 4.14 & 4.15 above, Water pressure in the water distribution system of Nakifuma, started at 4.8m at pH of 6.2, 2.7mg/l DO, and Electrical conductivity of 204.4µs/cm in a DN100 HDPE pipe. The pressure then increased to 26.8m, recording a stagnation of 2.7mg/l Dissolved Oxygen, 0.1 reduction in pH to 6.1, and an increase in Electrical Conductivity to 243.6µs/cm at DN50 HDPE pipe. pH increased to 6.6, water pressure as well as DO and Electrical Conductivity reduced to 22.5m, 2.6mg/l, and 217.1µs/cm in a DN20 HDPE pipe respectively. Under KKN, water pressure registered from the water reservoir (Nkonge reservoir) into the distribution pipe was 43.9m, DO was 8.7mg/l, and Electrical conductivity was 1288.9µs/cm. As water was distributed into the system, water pressure and Dissolved Oxygen dropped to 16.7m and 8.3mg/l respectively but Electrical Conductivity increased to 1765µs/cm in a DN150 UPVC pipe. When water continued to travel in the distribution system, water pressure dropped further to 14.9m, DO increased by 0.1mg/l to 8.4mg/l and Electrical conductivity reduced to 1214.9µs/cm in a DN100 UPVC pipe. At the customers' meter pressure reduced to 13.4m, 8.7mg/l DO and an increase in Electrical Conductivity to 1615µs/cm was registered in a DN20 HDPE distribution pipe.

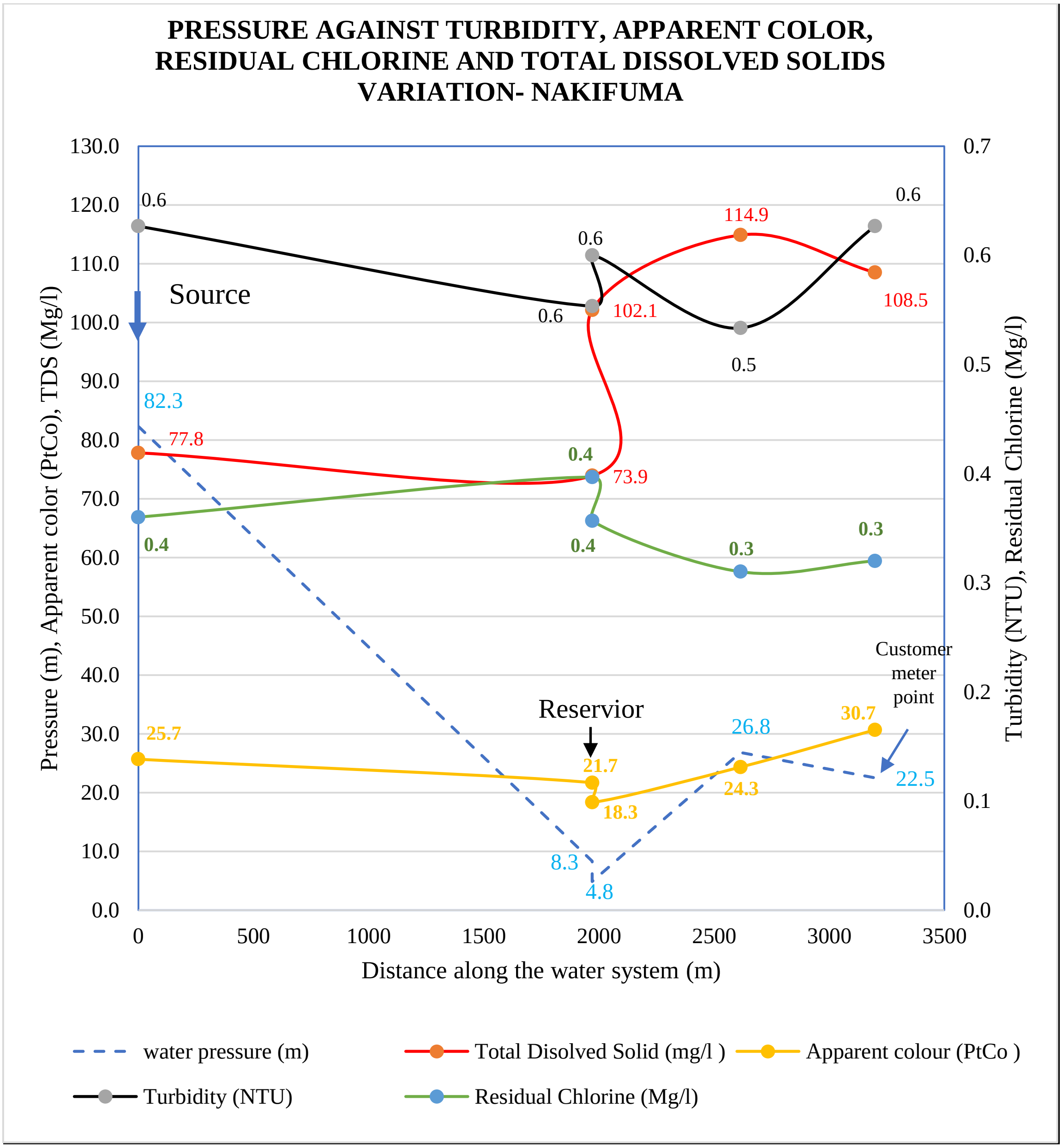

Figure 4.16: Water pressure variation with Turbidity, Residual Chlorine, Total Dissolved Solids and apparent color along the supply chain of Nakifuma small water system

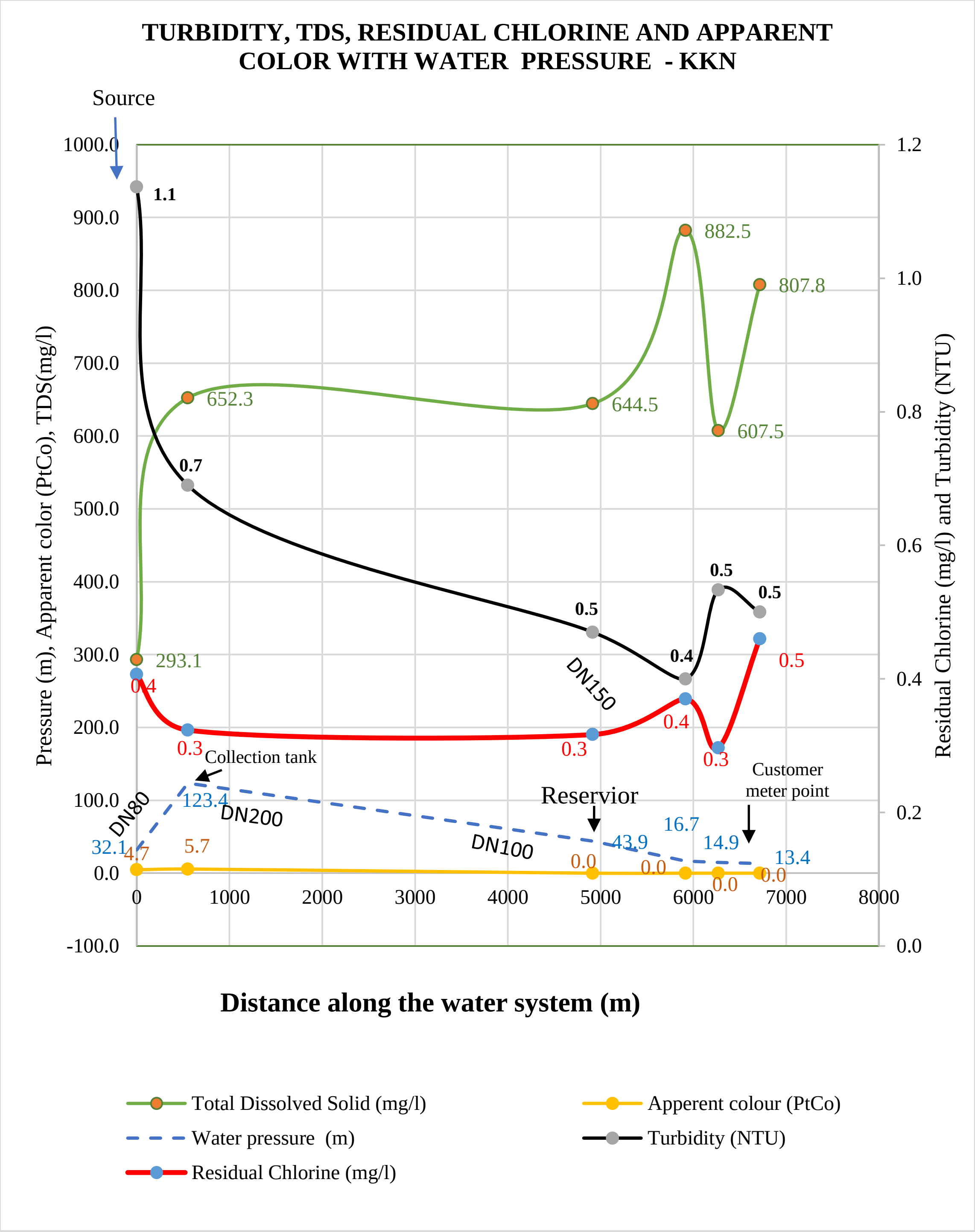

Figure 4.17: Water pressure variation with Turbidity, Residual Chlorine, Total Dissolved Solids and Apparent color along the supply chain of Kabembe-Kalagi-Naggalama small water system

From the figures 4.16 & 4.17 above, the results showed that, under Nakifuma small water system, in the distribution system, 0.6 NTU Turbidity, 102.1 mg/l TDS, 0.4 mg/l and Apparent Color of 18.3 PtCo 24.3 at the Reservoir outlet at water pressure of 4.8m. As water traveled into the supply chain, water pressure increased to 26.8m as well as TDS and Apparent color increased to 114.9 mg/l and 24.3 PtCo respectively whereas Residual Chlorine and Turbidity reduced to 0.3mg/l and 0.5 NTU respectively. As water reached the customers ‘meter, water pressure reduced to 22.5m, Turbidity and Apparent color increased to 0.6mg/ and 30.7 PtCo respectively. Whereas TDS reduced to 108.5mg/l and Residual Chlorine stagnated at 0.3 mg/l. under KKN small water system, at the outlet of the reservoir into the distribution pipe, the water pressure, TDS, Apparent color, Residual Chlorine and Turbidity recorded was 43.9m, 644.5 mg/l, 0 PtCo, 0.3 mg/l and 0.5NTU respectively. As water traveled 1km in DN150, the water pressure reduced to 16.7m, TDS and Residual Chlorine increased to 882.5 mg/l and 0.4 respectively. At the same point, Turbidity reduced to 0.4mg/l whereas Apparent Color stagnated at 0 PtCo. At DN100, 354m away from the previous point, water pressure, Turbidity and Residual Chlorine reduced to 14.9m, 607 mg/l and 0.3 mg/l respectively. Whereas Turbidity increased to 0.5 NTU and Apparent color recorded was 0 PtCo. Water reached the customer meter point in DN20 pipe at a reduced pressure of 13.4m, and increased TDS and Residual Chlorine of 807.8 mg/l and 0.5 mg/l respectively. Whereas Turbidity and Residual Chlorine stagnated at 0.5 mg/l and o PtCo respectively from the previous point.

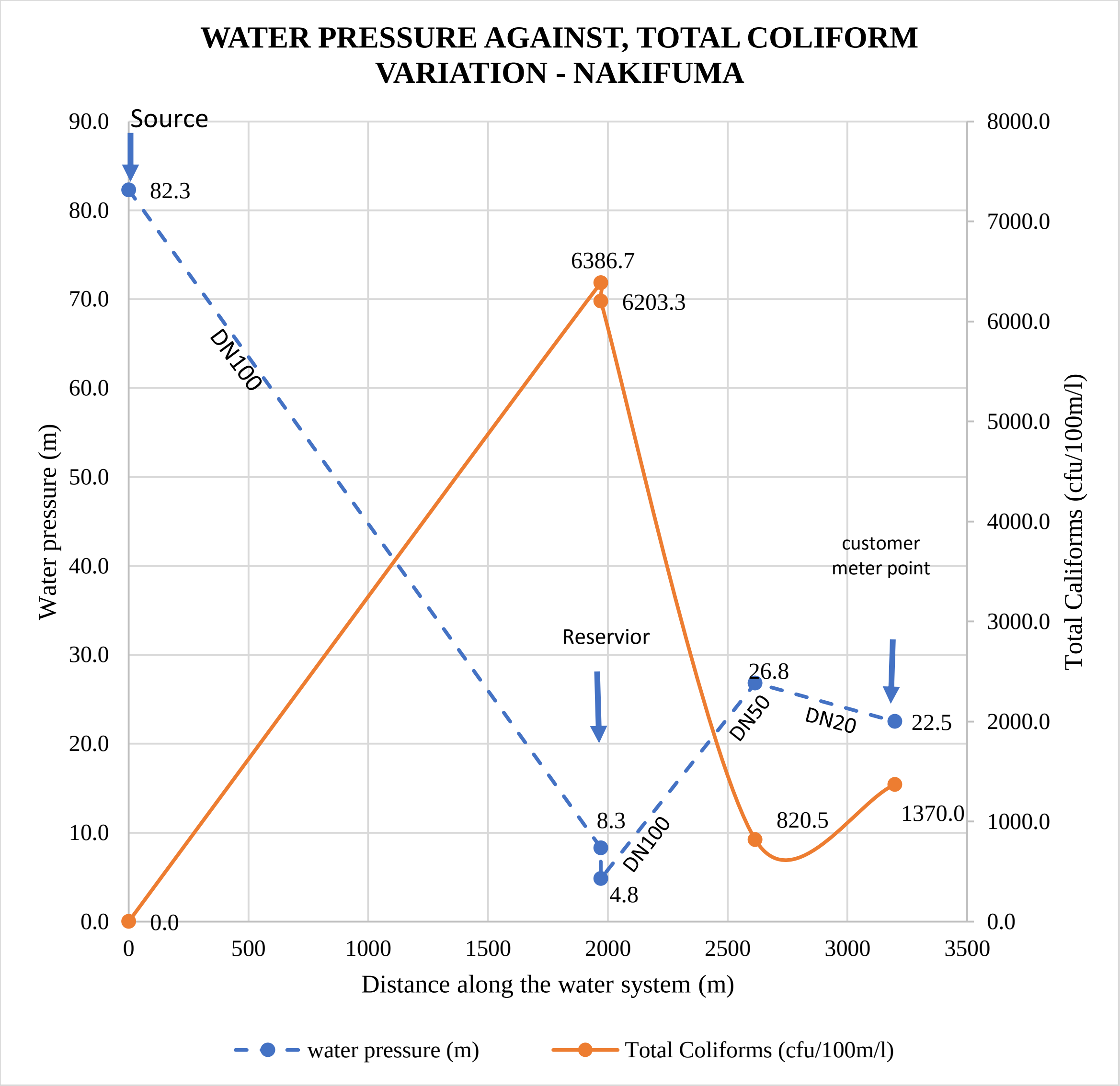

Figure 4.18: Water pressure variation with Total Coliforms along the supply chain of Nakifuma small water system

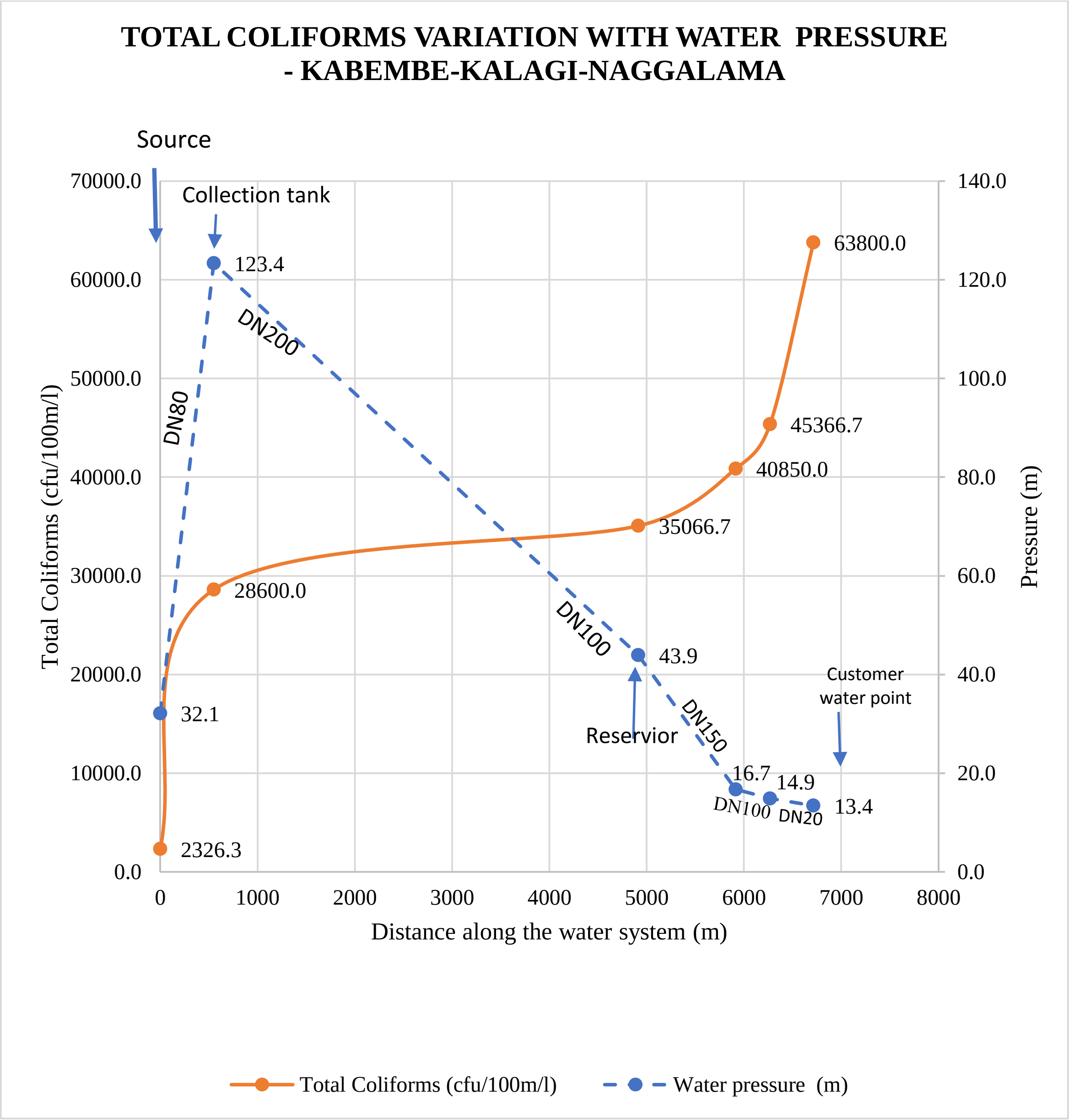

Figure 4.19: Water pressure variation with Total Coliforms along the supply chain of Kabembe-Kalagi-Naggalama small water system

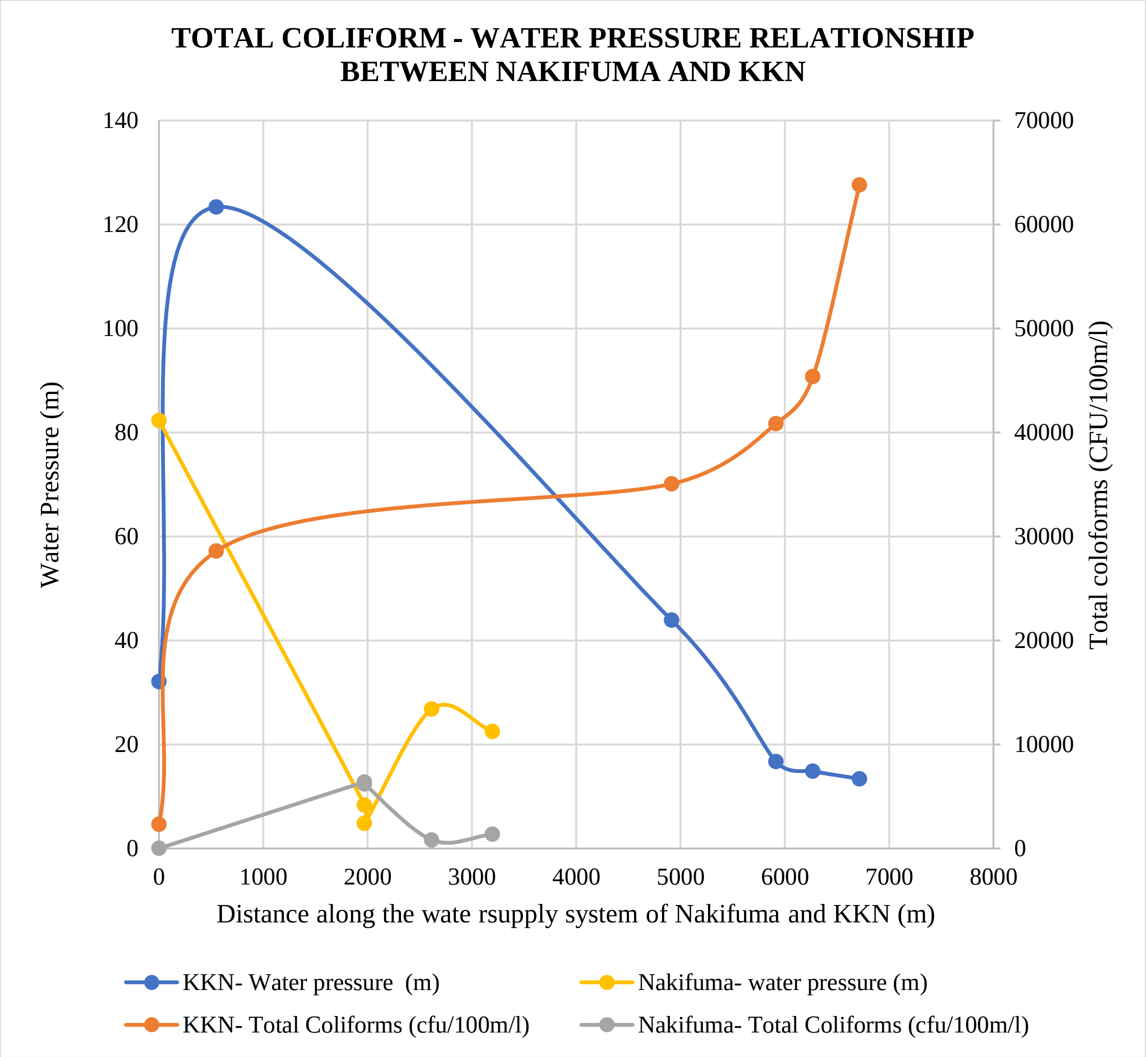

Figure 4.20: Water pressure and Total Coliforms relationship between Nakifuma and Kabembe-Kalagi-Naggalama small water system

From the figures 4.18, 4.19 & 4.20 above, shows that under Nakifuma water supply system, water leaves the reservoir into DN100 HDPE distribution main at water pressure of 4.8m, and Total Coliforms of 6203.3 Cfu/100m/l. As water travels through the network, the pipe reduces to DN50 at and water pressure increases to 26.8m whereas Total Coliforms reduces to 820.5 Cfu/100m/l. water reaches the customers Meter point in Dn20, the water pressure reduces to 22.5m, whereas Total Coliforms increases to

1370 Cfu/100/l. Under KKN, water pressure leaves the tank at water pressure of 43.9m and Total Coliforms of 35066.7 Cfu/100m/l. One thousand meters away, water pressure reduced to 16.7m and Total coliforms increases to 40850 Cfu/100m/l in DN150 UPVC pipe. At 1354m away from the reservoir, water pressure reduced to 14.9m and Total Coliforms increases to 45366.7 Cfu/100m/l in DN100 pipe. water reaches the Customers meter with 13.4m water pressure, and an increase in Total Coliforms of 63800 Cfu/100m/.

Total coliforms increases and reduces with a reduction and increase in water pressures respectively in Both the old (Nakifuma) and the new (KKN) small water system, but higher figures of total coliforms observed in the new system compared to the old system.

Quality of water supplied-(questionnaire results)

Table 4.3: Response rate from households with water connections on water quality supplied under Nakifuma and KKN small water systems. .

Response from households with water connections										
Area	**Quality of water supplied**		**Quality of water supplied**		**Quality of water supplied**		**No response**		**∑f**	**∑%**
	Good		Moderate		Bad					
	Frequency (f)	%	Frequency (f)	%	Frequency (f)	%	f	%		
Nakifuma	27	52	10	19.2	2	3.8	13	25	52	100
KKN	54	85.7	9	14.3	0	0	0	0	63	100

Source: Field Survey (July 2021)

Customers with water connections in both Nakifuma and KKN perceive the quality of water as safe. The table 4.3 above show a higher frequency of good water quality compared to moderate and bad i.e., good (52%), moderate (19.2%) and bad (3.8%) in Nakifuma, where as in KKN, good (85.7%), moderate (14.3%) and bad (0%).

Table 4.4: showing analysis of response rate from operators of the water system on water quality supplied under KKN.

Response from operators of the water										
Area	**Quality of water supplied**		**Quality of water supplied**		**Quality of water supplied**		**No response**		**∑f**	**∑%**
	Good		Moderate		Bad					
	Frequency	%	Frequency	f	%		f	%		
Nakifuma	3	60	1	20	0	0	1	20	5	100
KKN	5	71.4	1	14.3	0	0	1	14.3	7	100

Source: Field Survey (July 2021)

Operators of the water system in KKN area perceive the quality of water supplied safer i.e., 71.4% good, 14.3% moderate and 0% bad as shown in the table 4.4 above. Most operators in Nakifuma (60%) perceive the quality of water to be good while others (20%) indicated moderate and 0% bad.

Occurrence of defects/ system failure (leaks and bursts) in the water network- (Questionnaire results)

Table 4.5: Response rate from households under Nakifuma and KKN with water connections on occurrence of defects on the pipe network.

Response from households with water connections on occurrence of defects (leaks and bursts)

Occurrence of defects

Area	**Defects occur**		**Defects do not occur**		**No response**		**∑f**	**∑%**
	f	%	f	%	f	%		
Nakifuma	31	**59.6**	17	32.7	4	7.7	52	100
KKN	42	**66.7**	21	33.3	0	0	63	100

Response from households with water connections

Points Where defects occur

Area	**pipes**		**Joints**		**Meter point**		**Others**		**No response**		**∑f**	**∑%**
	f	%	f	%	f	%	f	%	f	%		
Nakifuma	13	**59.6**	10	19.2	0	0	0	0	11	21.1	52	100
KKN	47	**74.6**	13	20.6	0	0	0	0	3	4.8	63	100

Source: Field Survey (July 2021)

The highest number of respondents with water connections in both Nakifuma and KKN see occurrence of defects regularly on the water supply network i.e. 59.6% and 66.7% against 32.7% and 33.3% in Nakifuma and KKN respectively who don’t see defects occur. More defects are seen on pipes followed by joints and none at the meters points, with 59.6%, 19.2% and 0% respectively in Nakifuma, and 74.6%, 20.6% and 0% in KKN respectively, as shown in table 4.5 above.

Table 4.6: Response rate from operators of the water system on Occurrence of defects on the pipe network

Response from operators of the small water systems on occurrences of defects (leaks and bursts) in the network systems

	Occurrence of defects							
Area	**Defects occur**		**Defects do not occur**		**No response**		**∑f**	**∑%**
	f	%	f	%	f	%		
Nakifuma	2	**40**	1	**20**	2	40	5	100
KKN	5	**71.4**	1	**14.3**	1	14.3	7	100

Response from operators of the small water systems.

	Points Where defects occur											
Area	**pipes**		**Joints**		**Meter point**		**Others**		**No response**			
	f	%	f	%	f	%	f	%	f	%	**∑f**	**∑%**
Nakifuma	4	**80**	1	**20**	0	0	0	0	0	0	5	100
KKN	3	**42.8**	2	**28.6**	0	0	0	0	2	28.6	7	100

Source: Field Survey (July 2021)

The highest number of operators agree that there are occurrence of defects on the network in KKN, i.e. 71.4% of the respondents see the occurrences and 14.3% don't agree. The defects occur more at the pipes than at the joints and meter points, i.e. 42.8% at the pipes, 28.6 at the joints and 0% at the meter points as shown in table 4.6 above. In Nakifuma, the highest number of operators (80%) agree on occurrence of defects on the network and 20% don't see. The defects are seen more on the pipes as agreed upon by 80% of the operators than at joints (20%) and 0% at the meter points.

Assessment of the condition of the water supply network- (Questionnaire results)

Table 4.7: Conditions of the water supply Network, Maintenance and Effectiveness of the System of Nakifuma small water supply system (Kaama village)

Response from operators of the water system, households with water connections								
Component	**Physical condition of the pipe network**		**Physical condition of the pipe network**		**Physical condition of the pipe network**		**∑f**	**∑%**
	Good		Fair		Bad			
	Frequency	%	Frequency	%	Frequency	%		
Transmission system from plant to reservoir	3	60	2	40	0	0	5	100
Reservoir (s)	4	80	1	20	0	0	5	100
Distribution network from reservoir to final consumer	2	40	3	60	0	0	5	100

Source: Field Survey (July 2021)

Highest number of respondents (60%) perceive Nakifuma water network as good in a good Physical condition, 40% in a fair condition and none perceive it as bad as shown in the table 4.7 above. The reservoirs and the distribution network to the final consumer are highly perceived as good (80% respondents), 20% as fair and 0% bad in terms of Physical condition. While the distribution network from reservoir to final consumer is perceived fair (60%), 40% perceive as good, and 0% perceive it to be bad.

Table 4.8: Conditions of the water supply Network, Maintenance and Effectiveness of the System of Kabembe-Kalagi-Naggalama small water supply system (Kalagi village):

Response from operators of the water system, households with and without water connection										
Component	**Physical condition of the pipe network**		**Physical condition of the pipe network**		**Physical condition of the pipe network**		**No response**		**∑f**	**∑%**
	Good		Fair		Bad					
	Frequency	%	Frequency	%	Frequency	%	f	%		
Transmission system from plant to reservoir	6	85.7	1	14.3	0	0	0	0	7	100
Reservoir (s)	5	71.4	1	14.3	0	0	1	14.3	7	100
Distribution network from reservoir to final consumer	5	71.4	1	14.3	0	0	1	14.3	7	100

Source: Field Survey (July 2021)

Highest number of respondents (85.7%) perceive KKN water network as good in a good Physical condition, 14.3% in a fair condition and none perceive it as bad as shown in the table 4.8 above. The reservoirs and the distribution network to the final consumer are highly perceived as good (71.4% respondents), 14.3% as fair and 0% bad in terms of Physical condition.

Impact of defects failures on quality, quantity and water pressure – Questionnaire results)

Table 4.9: Impacts of system failure defects occurrence on the quality, quantity and pressure of water supplied to consumers in Nakifuma small water supply system (Kaama village)

Impacts of system failure defects occurrence on the quality, quantity and pressure of water supplied to consumers in Nakifuma small water supply system (Kaama village)
(0=very low, 1=Low, 2=moderate, 3=High, 4=Very high)

	Effectiveness Parameter	**Effectiveness Ratings/Frequency (f)**					**Percentage (%.)**					**No response**		**∑f**	**∑%**
S/No.	Impact Parameter	0	1	2	3	4	0	1	2	3	4	f	%		
i .	Water contamination	1	1	0	2	0	20	20	0	**40**	0	1	20	5	100
ii.	Affects the quantity of water received by the consumers	1	0	0	2	2	20	0	0	**40**	**40**	0	0	5	100
iii.	Affects the residual pressures received by the consumers	2	0	0	1	1	**40**	0	0	**20**	**20**	1	20	5	100

Source: Field Survey (July 2021),
0=very low, 1=Low, 2=moderate, 3=High, 4=Very high

From the table 4.9 above, majority of the respondents (40%) indicate that water contamination is high as a result of system failure defects, 20% indicated low or slightly, another 20% mentioned very low, and no respondent indicated very high or moderate, 20% did not respond. Regarding whether it affects the quantity of water received by consumers, a considerable number of respondents (40%) mentioned very high, another 40% high, 20% very low, no respondent indicated moderate and low or slightly.

Table 4.10: Impact of system failure defects occurrence on the quality, quantity and pressure of water supplied to consumers in Kabembe-Kalagi-Naggalama small water supply system (Kalagi village)

Impact of system failure defects occurrence on the quality, quantity and pressure of water supplied to consumers in Kabembe-Kalagi-Naggalama small water supply system (Kalagi village) (0=Bad, 1=Low, 2=moderate, 3=High, 4=very high.)															
	Effectiveness Parameter	**Effectiveness Ratings/Frequency (f)**					**Percentage (%.)**					**No response**		**∑ f**	**∑ %**
S/N	Impact Parameter	0	1	2	3	4	0	1	2	3	4	f	%		
i.	Water contamination	1	1	0	4	0	14.3	14.3	0	**57.1**	**0**	1	14.3	7	100
ii.	Affects the quantity of water received by the consumers	1	0	0	3	2	14.3	0	0	**42.8**	**28.6**	1	14.3	7	100
iii.	Affects the residual pressures received by the consumers	1	0	0	2	3	14.3	0	0	**28.6**	**42.8**	1	14.3	7	100

Source: Field Survey (July 2021)
0=Bad, 1=Low, 2=moderate, 3=High, 4=very high.

There is a high rate of water contamination, high negative effects on the quality of water supplied, and very high negative impact on residual pressure in the Kabembe-Kalagi-Naggalama small water network perceived as per the questionnaire results shown in the table 4.10 above.

Discussion of results

The analysis indicated that under Nakifuma (the older small water system) and KKN (new small water system), the pH slightly increases and decreases with change in water pressure, with negative correlation of 0.184 & 0.63, and significant levels of 0.767 and 0.255 in Nakifuma and KKN small water systems respectively (see table 7.3 and 7.4 Annex). It implied that; water residual pressure affect the pH of water in a small water system. The argument is reported from related report by Jasim, (2019). He states pressure reduce the level of pH because it my increase the mixing of CO2 with water which produce carbonic acid leading to decrease of pH (Jasim, 2019).

Dissolved oxygen in both Nakifuma and KKN small water systems slightly reduces with a reduction in water pressure. It is evident with the positive correlation values and significance levels recorded in the two systems (i.e., Nakifuma recorded 0.396 correlation & 0.51 Significance level, and 0.655 correlation & 0.23 significance levels under KKN) (see table 7.3 & 7.4 Annex). There is a change noticed in Dissolved Oxygen with change in water pressure. The results Concurs with other related studies as noted by Naffrechoux, (2015). He noted that dissolved oxygen increases as pressure increases and vise-versa (Naffrechoux, 2015). However, in Nakifuma small water system, Dissolved Oxygen is too low in accordance to WHO standards of drinking water. i.e., it should be between (6.5-8) mg/l. Where as in a new system, DO ranged with in the acceptable values.

Total Dissolved Solids changes relatively with residual pressure in both the old and new small system, though TDS is much lower in the old small water system and higher in the new system. I.e. its <300mg/l in the old system and between (300 – 900) mg/l in the new small water system. Negative correlations of 0.339 and 0.411 in Nakifuma and KKN respectively and significance levels of 0.577 & 0.492 where reported respectively (see table 7.3 & 7.4 Annex) which confirms that, water residual pressure affects the quality of water in relation to Total dissolved solids.

Electrical conductivity increases with a reduction in water pressure in both the new and old system. Electrical conductivity in both systems recorded negative correlation with water pressure i.e., -`0.327 and -0.411 in Nakifuma and KKN respectively, and at 0.592 and 0.492 significance levels respectively (see table 7.3 & 7.4 Annex). It should however be noted that, EC detected was higher in the new small water system compared to the old system, <400(µs/cm) in the old system and >400(µs/cm) in the new system. Therefore, EC is affected by the water pressure variation in small water systems.

Higher values of Total Coliforms with at lower values of residual water pressures were detected as shown in the figure 4.5 and 4.8 and Table 7.1 & 7.2 in the appendix. Table 7.3 & 7.4 shows that there was a negative correlation (i.e., of -0.327 & -0.411) between Water pressure and Total coliforms and significance levels of 0.592 & 0.492 respectively in both Nakifuma and KKN small water systems (see table 7.3& 7.4 Annex). It implied that water residual pressure is a factor in determining the number of Total Coliforms in a supply network, in small water supply systems. The results therefore confirms to the study results which revealed that, pressure has a reversed relationship with bacterial growth in water distribution system (Hossein Shamsaei, Othman Jaafar, 2013a).

Apparent color in both Nakifuma and KKN water system had positive correlation with water pressure. However, KKN registered higher correlation (i.e., 0.964) and lower significance level (i.e., 0.08) compared to Nakifuma which registered 0.402 correlation and 0.5.3 significance levels. It implied that there is a higher significance change of Apparent color with water pressure in an older small water system compared to a new smaller water supply system.

Turbidity was detected slightly dropping in the new system and distributed evenly in the old small water system with a reduction in water pressure. Nakifuma recorded a higher significance level (i.e., 0.951) and lower correlation (i.e., 0.038) whereas KKN recorded a lower Significance level (i.e., of 0.0311) and a higher correlation (see Table7.3 & 7.4). However, both systems recorded turbidity values ranging between the acceptable values according to WHO drinking water standards, i.e. <1NTU. This implies that pressure does not affect the Turbidity of water as it travels through the supply network system. In a related study entitled, impact assessment for water pressure and Turbidity occurrence by change in water flow rate in a water network, the researchers observed increased occurrence of turbidity in the water service distribution network with drastic change in water pressure (Choi, D. *et al.,* 2014). It was therefore reverse observation with small water systems during the study.

In the network system, Residual Chlorine was recorded to reduce in both old and new small water system with a reduction in Residual Pressure. However, a small positive correlation (i.e., 0.125) with water pressure was recorded in Nakifuma, where as in KKN a slightly higher negative correlation (i.e., -0.499) with low significance was recorded. This therefore confirmed that residual pressure affects the quality of water in terms of Residual Chlorine in a small water supply network system. Relevant studies done by Hossein Shamsaei, and

Othman Jaafar, (2013) noted that, water pressure has a direct relationship with residual chlorine in a small water distribution system, hence corresponding to the results got during this study on the small water system.

4.5 Proposed model to ensures safe water and adequate residual pressures

The data collected and discussed shows that pressure varies in different ways with different parameters of water quality as it’s supplied in the network for both a new and old small water systems. The results were compared with the desired standard values recommended by WHO and it proved that somewhere far above and others below the minimum (see Appendix; Table: 7.1 & 7.2).

To achieve the desired, a framework (figure 4.15 below) was developed and can be adopted in attaining Standard Equilibrium of pressure and water quality in small water sources. It is discussed as below.

> Ensure the water pressures supplied is not less than 10m to at least 160m in order to prevent occurrence of network defects which may lead to contamination.
>
> Ensure the quality (PH, DO TDS, EC, Turbidity, Apparent color, Total Coliforms, and Residual Chlorine) of water supplied meets the standards as guided by WHO 1984, for drinking water and should be maintained till the final consumer.
>
> To achieve the pressure desired in the small water supply system, the network, including the reservoirs should be well designed and laid with good pipe materials (such as HDPE, PE). Good working practices, workmanship and quick

resolution of any network defects should be employed to prevent any pressure drop and intrusion of contamination into the water system.

Points of monitoring and disinfection in the water network should be created on the network to allow disinfection of water whenever and after any maintenance works are done (for example; a point at major changes in pipe diameter of the distribution network, at points at low laying areas and at every reservoir)

Points for water pressure monitoring should be created on the pipe network system and include pressure gauges to measure, monitor and manage pressure variations in the water supply network.

Customer engagement and relations platform should be availed and maintained to receive live feedback from customers for better decision making and quick response to any occurrence to network defects in order to avoid contamination of water.

4.5.1 Water residual pressure and quality optimization Framework.

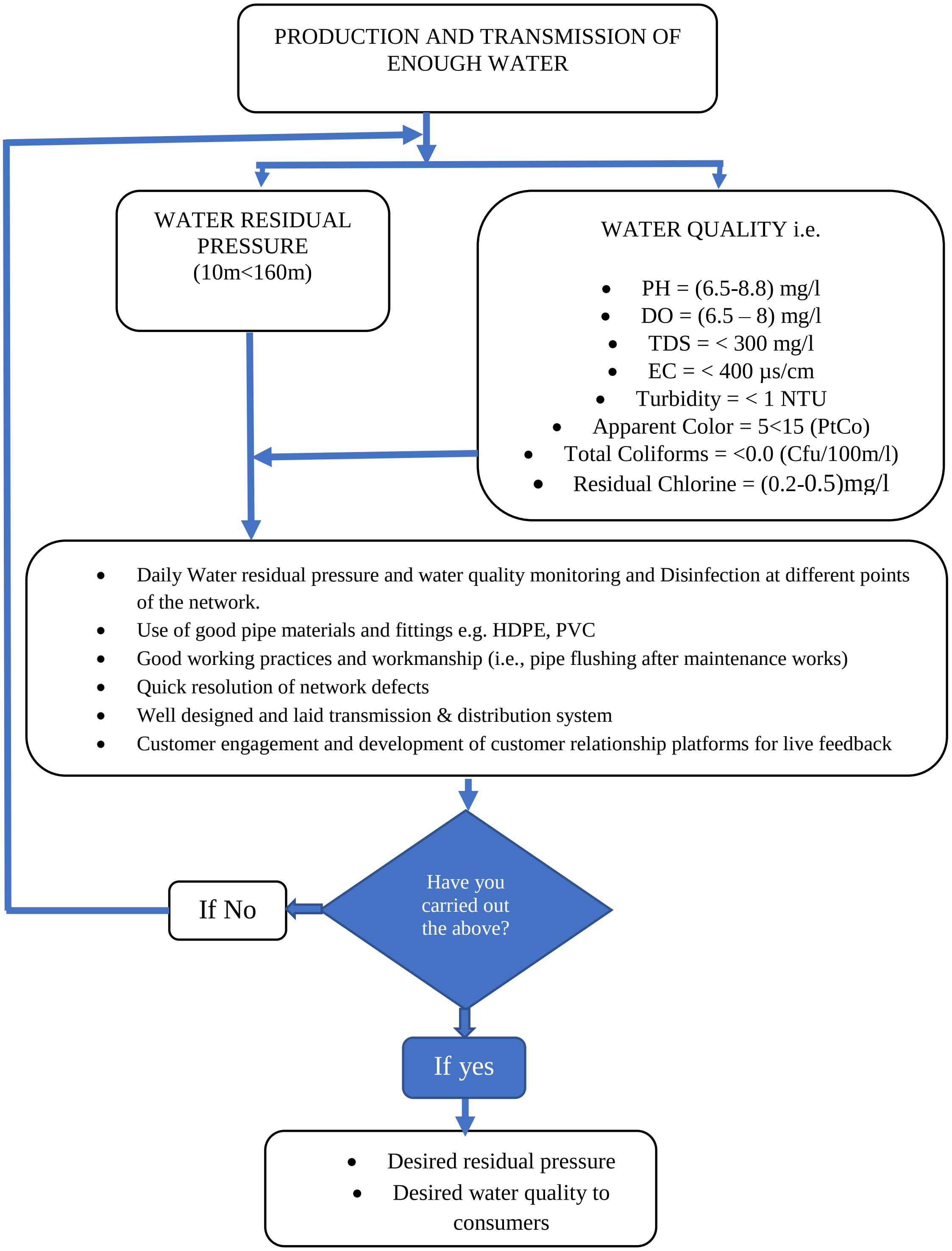

Figure 4.21: shows the proposed Framework to attain the desired residual pressure and water quality in small water system

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Pressure variations in water supply network influences the quality of water supplied to the households in the water system in addition to other factors that leads to deterioration of water quality at the household. Water residual pressure in small-scale piped water supply networks causes variation of water quality as low pressure makes the network prone to intrusion of impurities due to defects/failures (as noted from the questionnaire results, table 4.5& 4.6, and 4.9 & 4.10) in the water supply system, aided by either water pressure variation in the water network or system failure due to other internal or external factors.

However, regardless of a system's age the variation is more pronounced in networks that experience prolonged ration time where pipes stay under low/no pressure for some days. Its evidenced, for example with the higher values of total coliforms in the new system (KKN) which has a longer network & retention time, characterized with less residual pressures which reaches the final consumers compared to the older system (Nakifuma) which comprises of a smaller network hence higher values of residual pressures in the distribution system.

The available evidence indicates that adopting efficient management strategies that utilize historical data to ensure optimal residual and continuous pressure can improve performance of Small piped water systems to meet acceptable water quality standards. Decisions derived from relevant operational data of previous experiences, while embracing capacity and skills development of technical personnel through training and other technical supports, is essential for future improvements of small piped water systems. Additionally, in response to larger geographic coverage and growing demand, there might be a need to consider reorganizing and managing small piped water supply schemes as medium-sized or even large-scale supply schemes.

5.2 Recommendation

i) This study ignored the other factors which may affect water quality in small water system. I therefore recommend it for further studies to understand other factors which lead to quality variations in small water systems in the study area.

ii) I recommend a study on pressure variation with Quality in regards to the material of pipes and fittings used in small water supply system in the study area.

iii) I recommend a study on effects of water pressure on water quality in regards to the methods of tapping water connections.

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APPENDICES

7.1 Questionnaire used

Assessment of water supplied from small water systems and their effects to the community.

Field Survey Questionnaires

A. Survey Objective: This survey is an academic exercise that is aimed at assessing the performance of a small water supply system of Mukono in terms of quality, demand adequacy and pressure a view of highlighting its effects and make recommendations that could support the community and hence protect public health as well as provide a hygienic environment.

Please provide the information needed in the sections that follow as accurately as possible by marking or ticking (√) within the appropriate box.

B. **General information of the consumer:**

1. Property Address: …………………………………………………..
2. Use of Premises: a. Residential ( ) b. Business/Commercial ( )
   c. Institutional ( ) d. Others (Specify) _________
3. Which position is your property located?
   a. On a hill ( ) b. flat land ( ) c. Swamp/Valley ( )
   d. Others (Specify) _________

C. **Supply status**

1. Are you connected to the area pipe network? a. Yes ( ) b. No ( )
   If yes, answer the remaining questions in this section; if No, please move to section D
2. When was your connection made to the Pipe network in the area? ....

3. Is water available all the time?
   a. Yes ( ) b. No ( ), if “No”, how often does reach your taps in terms of days ………………………………………………………………
4. Do you have an alternative source of water alongside the piped water?
   a. Yes ( ) b. No ( ), if Yes please specify …………………….
5. Do you have a water reservoir/tank? a. Yes ( ) b. No ( ), if “Yes” which capacity is it? ……………..
6. Is it a combined system with rain water and piped water? a. Yes ( ) b. No ( ).
7. According to you, is the amount of piped water supplied to your area enough to meet your demand? a. Yes ( ) b. No ( ), if “No” please you’re your reasons what you think is causing it. ……………………………………………………………………...………………………
8. How do you perceive the quality of water that you receive at your tap? a. Good ( ) b. Moderate ( ) c. Bad ( )
9. Which color of water do you receive at your tap? ……………………………

D. **Assessment of defects/ system failure (leaks and bursts) in the network**

1. Do you notice leakages and bursts occurring from the water pipe network a. Yes ( ) b. No ( )

If “Yes”, answer the remaining questions in this section; If No, please move to Section **E**

2. Where do you see them occurring?
   a. Pipes ( ) b. Joints ( ) c. Meter point ( )
   d. Others (Specify) …………………………………………..
3. How often do you see leaks and bursts occurring?
   a. Very often ( ) b. Often ( ) c. Not Often ( ) d. Not at all ( )
   e. Others (Specify)...

4. Have you ever reported these problems to the System Operator of the water network?
   a. Yes (   )   b. No (   )

5. If Yes, State their response ………………………………………………
   b. If No, give reasons ………………………………………………......

6. How often do you report these defects?
   a. Very often (   ) b. Often (   ) c. Not Often (   ) d. Not at all (   )
   e. Others (Specify) …………………………………………………………

7. How often do you notice a team carrying out control and rectifying activities in your neighborhood by the System Operator whenever reported?
   a. Very Often (   ) b. Often (   ) c. Not Often (   ) e. Not at All (   )
   e. Others (Specify) ………………………………………………………..

8. What season of the year do the above defects occur the most?
   a. Rainy Season (   )   b. Dry Season (   )   c. Not Seasonal (   )

4 **Assessment of the condition of water supply network, maintenance and Effectiveness of the system**

Assess the Physical conditions of the following components of the pipe network and distribution system as: “Good”, “Fair” or “Bad” where:

“**Good**” means the network component does not have noticeable defects causing occurring defects like leaks, bursts, intermittent supply, pressure drop and deterioration in water quality.

“**Fair**” means the network system has noticeable defects, defects causing occurring defects like leaks, bursts, intermittent supply, pressure drop and deterioration in water quality.

“**Bad**” means the network system has deteriorated with major defects causing occurring defects like leaks, bursts, intermittent supply, pressure drop and deterioration in water quality.

S/No.	**Component**	**Good**	**Fair**	**Bad**
a	Transmission system from plant to reservoir			
b	Reservoir (s)			
c	Distribution network from reservoir to final consumer			

5 How would you rate the effectiveness of the following maintenance activities of the network on a scale of 0 to 4, where:

0 = Very Poor or Maintenance is never carried out
1 = Poor or Maintenance is only slightly carried out
2 = Fair or Maintenance is fairly carried out
3 = Good or Maintenance is adequately carried out

4 = Very Good or Maintenance is prompt and largely adequate

S/No	Maintenance Activity	0	1	2	3	4
i.	Routine Inspection of pipe network and fixtures (to check for cracks in reservoirs, leaking joints/seals, exposed pipes due to erosion that may lead to a pipe leak/burst)					
ii.	Routine flushing of pipe network to prevent blockages and deterioration of the quality of water supplied.					
iii.	Repair of works in time and to right sizes and standards including installation of require fixtures that ease distribution and transmission of water for example; Air valves, control valves and washouts					

6 How would you rate the impacts of system failure defects occurrence on the quality, quantity and pressure of water supplied to consumers in the supply area on a scale of 0 to 4, where:

0 = Very Low
1 = Low or Slightly
2 = Moderate
3 = High
4 = Very High

S/No.	Impact Parameter	0	1	2	3	4
i.	Water contamination					
ii.	Affects the quality of water received by the customer					
iii.	Affects the residual pressures received by the consumers					

7.2 Field results

Table 7.1: Extracted field results of Nakifuma small water supply system as well as the acceptable ranges as per the WHO standards of drinking water.

Point	Station Name	Coordinates (X,Y), 36N	Elevation (m)	water pressure (m)	Safe Water pressure (m)	PH	Safe PH	Disolved Oxygen (mg/l)	Safe DO (mg/l)	Total Disolved Solid (mg/l)	Safe TDS (mgl)	Electrical Conductivity (µs/cm)	Safe EC (µs/cm)	Turbidity (NTU)	Safe Turbidity (NTU)	Apperent colour (PtCo)	Safe Apperent colour (PtCo)	Total Coliforms (cfu/100m/l)	Safe Total Coliforms (cfu/100m/l)	Residual Chlorine (Mg/l)	Safe Residual Chlorine (Mg/l)
1	Transmission line at the source (production well)	0477548, 006	1113	82.3	10 - 160	6.2	6.5-8.5	2.7	6.5-8	77.8	<300	155.6	<400	0.6	<1	25.7	5<15	0.0	0.0	0.36	0.2-0.5
2	Transmission line at reservior inlet	0476451, 006	1176	8.3	10 - 160	6.3	6.5-8.5	2.6	6.5-8	73.9	<300	150.0	<400	0.6	<1	21.7	5<15	6386.7	0.0	0.40	0.2-0.5
3	Distribution line(DN 100) at the tank outlet	0476451, 006	1176	4.8	10 - 160	6.2	6.5-8.5	2.7	6.5-8	102.1	<300	204.4	<400	0.6	<1	18.3	5<15	6203.3	0.0	0.36	0.2-0.5
4	Distribution line DN50	0477011, 005	1139	26.8	10 - 160	6.1	6.5-8.5	2.7	6.5-8	114.9	<300	243.6	<400	0.5	<1	24.3	5<15	820.5	0.0	0.31	0.2-0.5
5	Customer meter poin	0477411, 005	1142	22.5	10 - 160	6.6	6.5-8.5	2.6	6.5-8	108.5	<300	217.1	<400	0.6	<1	30.7	5<15	1370.0	0.0	0.32	0.2-0.5

Table 7.2: Extracted field results of Kabembe-Kalagi-Naggalama small water supply system as well as the acceptable ranges as per the WHO standards of drinking water

Point	Station Name	Coordinates (X,Y), 36N	Elevation (m)	water pressure readings (m)	Safe Water pressure (m)	PH	Safe PH	Dissolved Oxygen (mg/l)	Safe DO (mg/l)	Total Dissolved Solid (mg/l)	Safe TDS (mgl)	Electrical Conductivity (µs/cm)	Safe EC (µs/cm)	Turbidity (NTU)	Safe Turbidity (NTU)	Apperent colour (PtCo)	Safe Apperent colour (PtCo)	Total Coliforms (cfu/100m/l)	Tota Coliforms (cfu/100 m/l)	Residual Chlorine (mg/l)	Safe Residual Chlorine (Mg/l)
1	Batte production well (water source)	0475910, 0050604	1132	32.1	10 - 160	6.7	6.5-8.5	10.1	6.5-8	293.1	<300	586.1	<400	1.1	<1	4.7	5<15	2326.3	0.0	0.4	0.2-0.5
2	Zion production well (water source")	0475992, 0050138	1096	11.4	10 - 160	20.3	6.5-8.5	27.6	6.5-8	1160.4	<300	5435.3	<400	1.6	<1	0.0	5<15	12019.0	0.0	0.9	0.2-0.5
3	Kabembe transmision line (at the collection tank)	0475992, 0050138	1096	89.4	10 - 160	6.7	6.5-8.5	8.9	6.5-8	620.1	<300	1073.1	<400	0.8	<1	3.7	5<15	21033.3	0.0	0.3	0.2-0.5
4	Nkonge transmission line (at the collection tank)	0475992, 0050139	1096	123.4	10 - 160	6.6	6.5-8.5	8.8	6.5-8	652.3	<300	1304.6	<400	0.7	<1	5.7	5<15	28600.0	0.0	0.3	0.2-0.5
5	Inlet to nkonge main reservior (transmission line)	0472362, 0053413	1200	43.9	10 - 160	6.6	6.5-8.5	8.7	6.5-8	644.5	<300	1288.9	<400	0.5	<1	0.0	5<15	35066.7	0.0	0.3	0.2-0.5
6	Meter point, Kalagi water office (from DN150 Distribution line)	0472285, 0054687	1183	16.7	10 - 160	7.0	6.5-8.5	8.3	6.5-8	882.5	<300	1765.0	<400	0.4	<1	0.0	5<15	40850.0	0.0	0.4	0.2-0.5
7	Nkonge Distribution main after the Tank to Kalagi area (DN 100)	0472281, 0055092	1177	14.9	10 - 160	7.0	6.5-8.5	8.4	6.5-8	607.5	<300	1214.9	<400	0.5	<1	0.0	5<15	45366.7	0.0	0.3	0.2-0.5
8	customer meter point	0471943, 0055438	1183	13.4	10 - 160	6.7	6.5-8.5	8.7	6.5-8	807.8	<300	1615.0	<400	0.5	<1	0.0	5<15	63800.0	0.0	0.5	0.2-0.5

Table 7.3: Pearson correlation between the water pressure and water quality at Nakifuma small water supply system.

Correlations for NAKIFUMA Small Water Supply System

		Pipe size	Length	Water Pressure	pH	DO	Total Disolved Solids	EC	Turbidity	Apparent colour	TC	Residua Chlorine
Pipesize	Pearson Correlation	1	-0.257	**.977***	0.267	0.000	0.757	0.779	-0.577	0.826	**-.997****	**-1.000****
	Sig. (2-tailed)		0.743	0.023	0.733	1.000	0.243	0.221	0.423	0.174	0.003	0.000
	N	4	4	4	4	4	4	4	4	4	4	4
Length	Pearson Correlation	-0.257	1	-0.455	0.178	-0.723	-0.374	-0.321	-0.003	-0.059	0.448	0.029
	Sig. (2-tailed)	0.743		0.441	0.774	0.168	0.535	0.598	0.996	0.925	0.449	0.963
	N	4	5	5	5	5	5	5	5	5	5	5
Water Pressure	Pearson Correlation	**.977***	-0.455	1	-0.184	0.396	-0.339	-0.327	0.038	0.402	-0.757	0.125
	Sig. (2-tailed)	0.023	0.441		0.767	0.510	0.577	0.592	0.951	0.503	0.138	0.841
	N	4	5	5	5	5	5	5	5	5	5	5
pH	Pearson Correlation	0.267	0.178	-0.184	1	-0.807	0.079	-0.006	0.523	0.664	-0.033	-0.332
	Sig. (2-tailed)	0.733	0.774	0.767		0.099	0.900	0.993	0.366	0.221	0.958	0.585
	N	4	5	5	5	5	5	5	5	5	5	5
DO	Pearson Correlation	0.000	-0.723	0.396	-0.807	1	0.209	0.240	-0.408	-0.407	-0.273	0.167
	Sig. (2-tailed)	1.000	0.168	0.510	0.099		0.736	0.698	0.495	0.497	0.657	0.789
	N	4	5	5	5	5	5	5	5	5	5	5
Disolved Solids	Pearson Correlation	0.757	-0.374	-0.339	0.079	0.209	1	**.992****	-0.588	0.219	-0.273	-0.802
	Sig. (2-tailed)	0.243	0.535	0.577	0.900	0.736		0.001	0.297	0.723	0.657	0.102
	N	4	5	5	5	5	5	5	5	5	5	5
Electrical Conductivity	Pearson Correlation	0.779	-0.321	-0.327	-0.006	0.240	.992**	1	-0.685	0.196	-0.293	-0.819
	Sig. (2-tailed)	0.221	0.598	0.592	0.993	0.698	0.001		0.202	0.752	0.632	0.090
	N	4	5	5	5	5	5	5	5	5	5	5
Turbidity	Pearson Correlation	-0.577	-0.003	0.038	0.523	-0.408	-0.588	-0.685	1	-0.019	0.387	0.612
	Sig. (2-tailed)	0.423	0.996	0.951	0.366	0.495	0.297	0.202		0.975	0.520	0.272
	N	4	5	5	5	5	5	5	5	5	5	5
Apparent colour	Pearson Correlation	0.826	-0.059	0.402	0.664	-0.407	0.219	0.196	-0.019	1	-0.747	-0.663
	Sig. (2-tailed)	0.174	0.925	0.503	0.221	0.497	0.723	0.752	0.975		0.146	0.222
	N	4	5	5	5	5	5	5	5	5	5	5
TC	Pearson Correlation	-.997**	0.448	-0.757	-0.033	-0.273	-0.273	-0.293	0.387	-0.747	1	0.550
	Sig. (2-tailed)	0.003	0.449	0.138	0.958	0.657	0.657	0.632	0.520	0.146		0.337
	N	4	5	5	5	5	5	5	5	5	5	5
Residual chlorine	Pearson Correlation	-1.000**	0.029	0.125	-0.332	0.167	-0.802	-0.819	0.612	-0.663	0.550	1
	Sig. (2-tailed)	0.000	0.963	0.841	0.585	0.789	0.102	0.090	0.272	0.222	0.337	
	N	4	5	5	5	5	5	5	5	5	5	5

****. Correlation is significant at the 0.01 level (2-tailed).**

***. Correlation is significant at the 0.05 level (2-tailed).**

*Table 7.4**:** Pearson correlation between the water pressure and water quality in Kabembe-Kalagi-Naggalama Small Water Supply System.*

Correlations for Kabembe-Kalagi- Naggalama Small Water Supply System

		Pipe Size	Length	Water Pressure	pH	DO	Total Disolved Solids	EC	Turbidity	Apparent colour	TC	Residual Chlorine
pipesize	Pearson Correlation	1	-0.306	-0.510	0.431	-0.489	**.990****	**.990****	-0.645	-0.395	0.483	0.791
	Sig. (2-tailed)		0.617	0.380	0.468	0.403	0.001	0.001	0.239	0.510	0.410	0.111
	N	5	5	5	5	5	5	5	5	5	5	5
length	Pearson Correlation	-0.306	1	0.009	-0.451	0.249	-0.256	-0.256	-0.158	-0.259	-0.355	-0.353
	Sig. (2-tailed)	0.617		0.989	0.446	0.687	0.678	0.678	0.799	0.674	0.557	0.560
	N	5	5	5	5	5	5	5	5	5	5	5
Water Pressure	Pearson Correlation	-0.510	0.009	1	-0.630	0.655	-0.411	-0.411	**.912***	**.964****	-0.714	-0.499
	Sig. (2-tailed)	0.380	0.989		0.255	0.230	0.492	0.492	0.031	0.008	0.175	0.392
	N	5	5	5	5	5	5	5	5	5	5	5
pH	Pearson Correlation	0.431	-0.451	-0.630	1	**-.968****	0.304	0.304	-0.646	-0.491	0.220	0.082
	Sig. (2-tailed)	0.468	0.446	0.255		0.007	0.619	0.619	0.239	0.401	0.723	0.896
	N	5	5	5	5	5	5	5	5	5	5	5
DO	Pearson Correlation	-0.489	0.249	0.655	-.968**	1	-0.373	-0.374	0.758	0.567	-0.125	-0.052
	Sig. (2-tailed)	0.403	0.687	0.230	0.007		0.536	0.535	0.138	0.319	0.841	0.934
	N	5	5	5	5	5	5	5	5	5	5	5
Total Disolved solids	Pearson Correlation	.990**	-0.256	-0.411	0.304	-0.373	1	**1.000****	-0.567	-0.312	0.436	0.799
	Sig. (2-tailed)	0.001	0.678	0.492	0.619	0.536		0.000	0.319	0.609	0.463	0.105
	N	5	5	5	5	5	5	5	5	5	5	5
EC	Pearson Correlation	.990**	-0.256	-0.411	0.304	-0.374	1.000**	1	-0.567	-0.312	0.436	0.798
	Sig. (2-tailed)	0.001	0.678	0.492	0.619	0.535	0.000		0.319	0.610	0.463	0.105
	N	5	5	5	5	5	5	5	5	5	5	5
Turbidity	Pearson Correlation	-0.645	-0.158	.912*	-0.646	0.758	-0.567	-0.567	1	**.919***	-0.451	-0.408
	Sig. (2-tailed)	0.239	0.799	0.031	0.239	0.138	0.319	0.319		0.028	0.446	0.495
	N	5	5	5	5	5	5	5	5	5	5	5
Apparent Colour	Pearson Correlation	-0.395	-0.259	.964**	-0.491	0.567	-0.312	-0.312	.919*	1	-0.592	-0.375
	Sig. (2-tailed)	0.510	0.674	0.008	0.401	0.319	0.609	0.610	0.028		0.293	0.534
	N	5	5	5	5	5	5	5	5	5	5	5
TC	Pearson Correlation	0.483	-0.355	-0.714	0.220	-0.125	0.436	0.436	-0.451	-0.592	1	0.843
	Sig. (2-tailed)	0.410	0.557	0.175	0.723	0.841	0.463	0.463	0.446	0.293		0.073
	N	5	5	5	5	5	5	5	5	5	5	5
Residual Chlorine	Pearson Correlation	0.791	-0.353	-0.499	0.082	-0.052	0.799	0.798	-0.408	-0.375	0.843	1
	Sig. (2-tailed)	0.111	0.560	0.392	0.896	0.934	0.105	0.105	0.495	0.534	0.073	
	N	5	5	5	5	5	5	5	5	5	5	5

****. Correlation is significant at the 0.01 level (2-tailed).**

***. Correlation is significant at the 0.05 level (2-tailed).**

Relationship between pressure and Quality Variations in Nakifuma and Kabembe-Kalagi-Naggalama small water system supply Network.

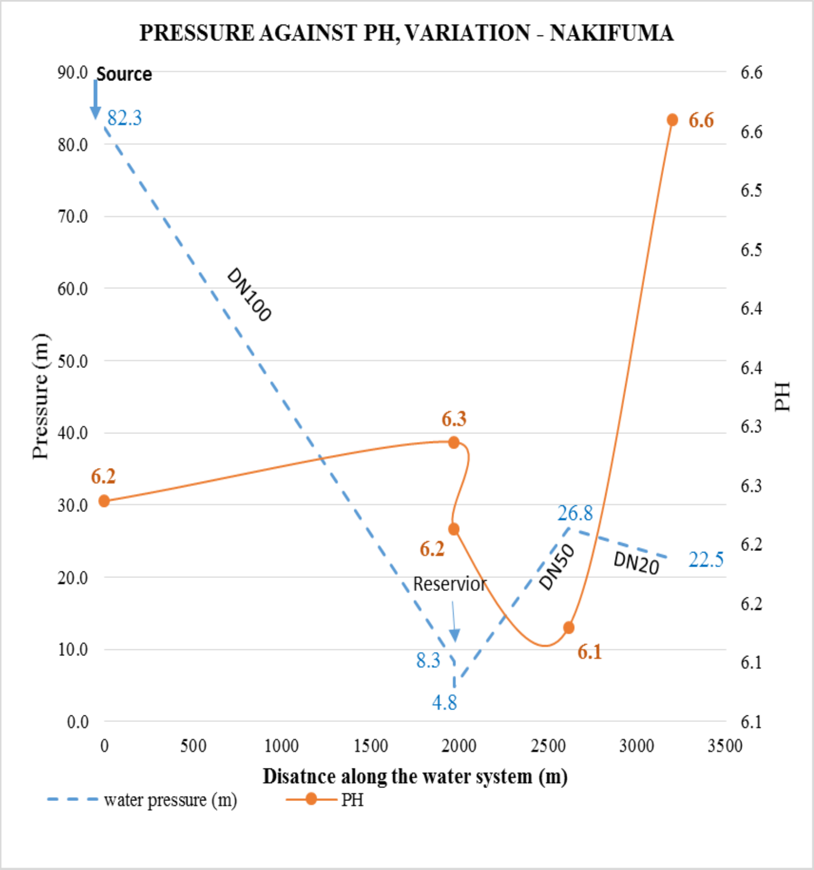


Figure 7.1: Water pressure variation with PH, along the supply chain of Nakifuma small water system

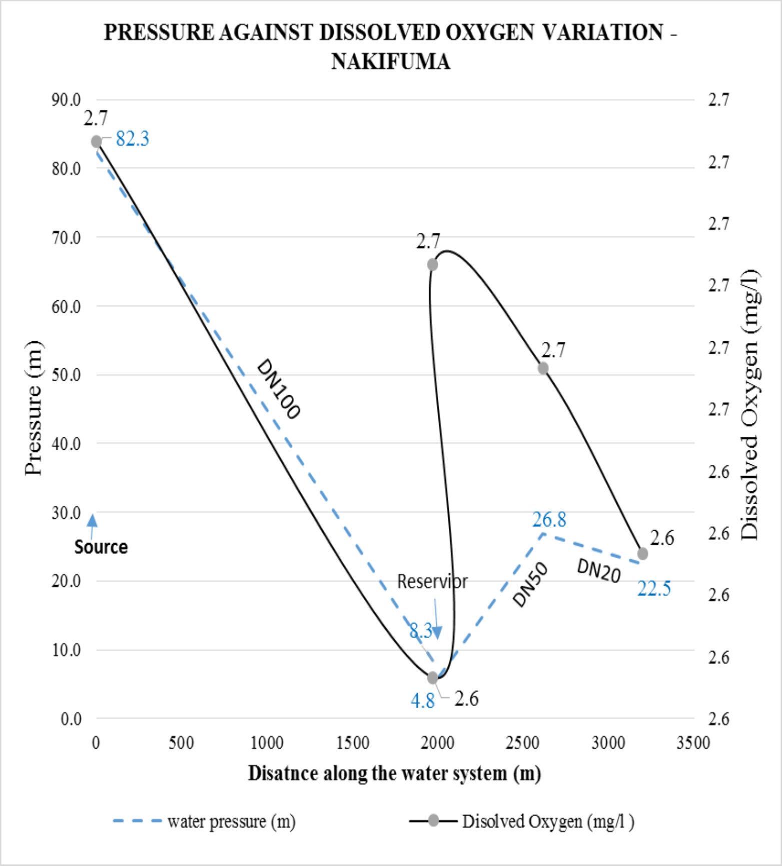


Figure 7.2: Water pressure variation with Dissolved Oxygen, along the supply chain of Nakifuma small water

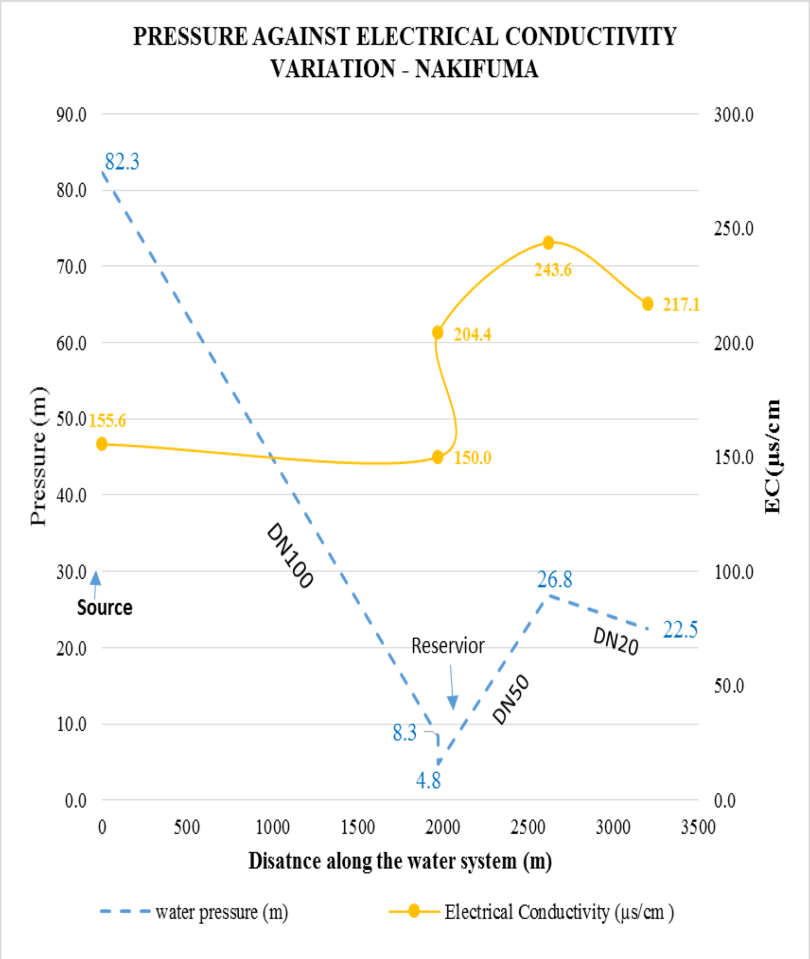


Figure 7.3: Water pressure variation with Electrical Conductivity along the supply chain of Nakifuma small

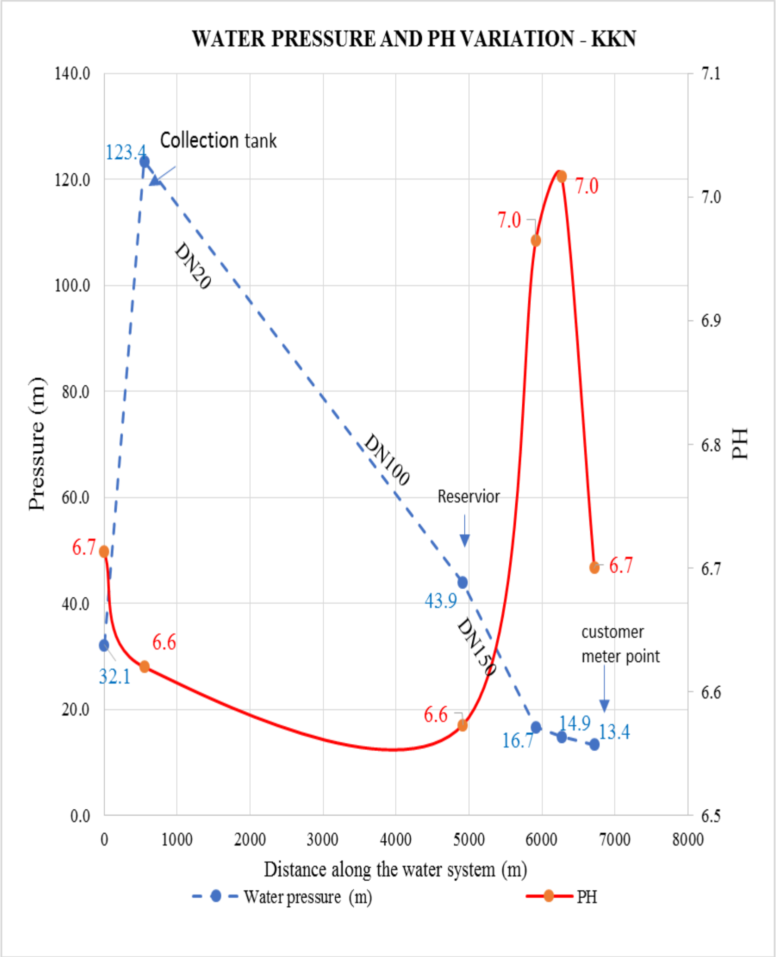


Figure 7.4: Water pressure variation with PH along the supply chain of Kabembe-Kalagi-Naggalama small

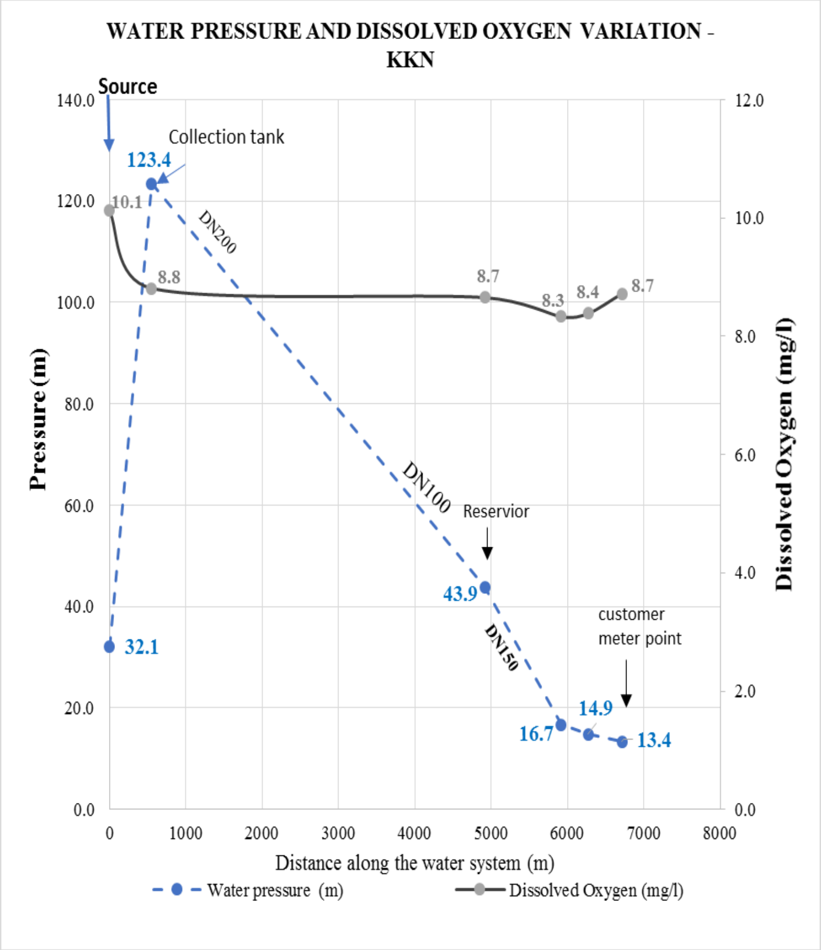


Figure 7.5: Water pressure variation with Dissolved Oxygen along the supply chain of Kabembe-Kalagi-Naggalama small water system

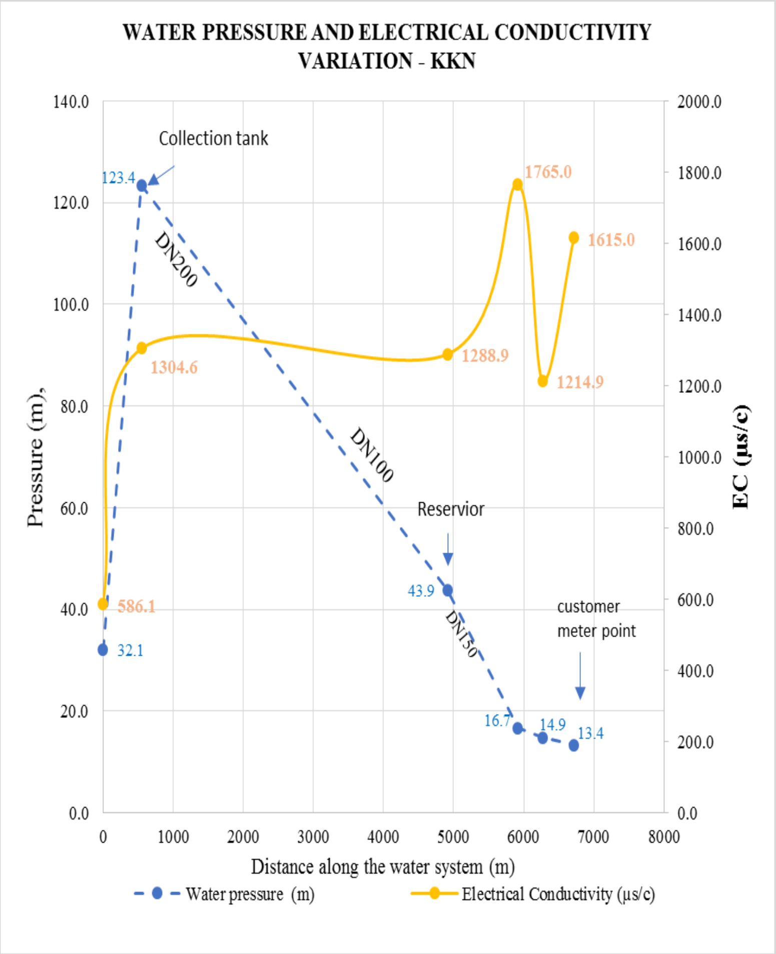


Figure 7.6: Water pressure variation with EC along the supply chain of Kabembe-Kalagi-Naggalama small water system

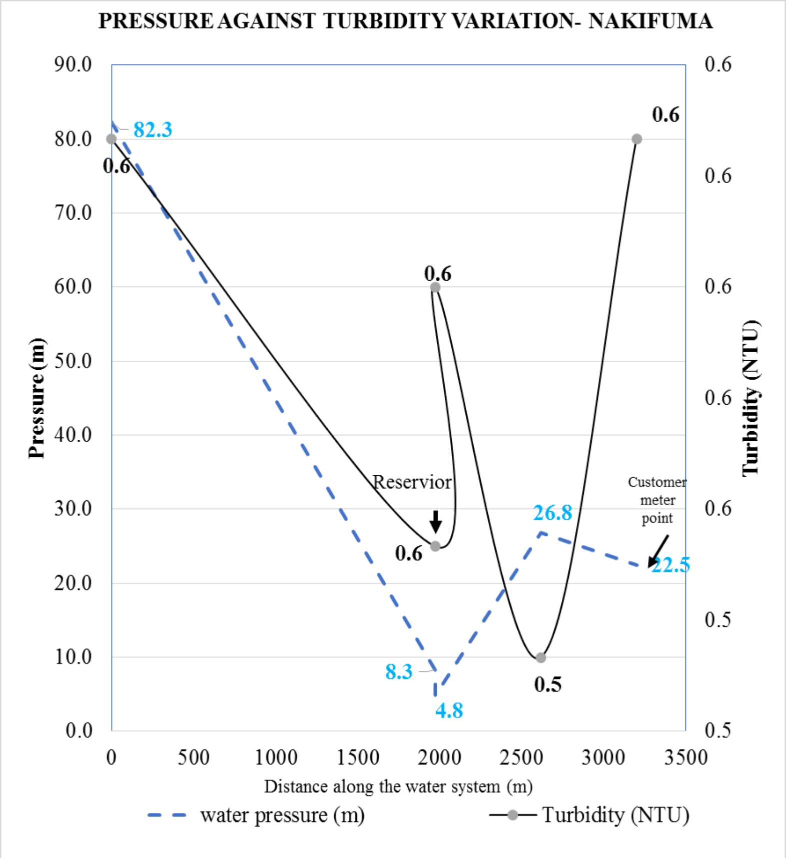


Figure 7.7: Water pressure variation with Turbidity along the supply chain of Nakifuma small water system

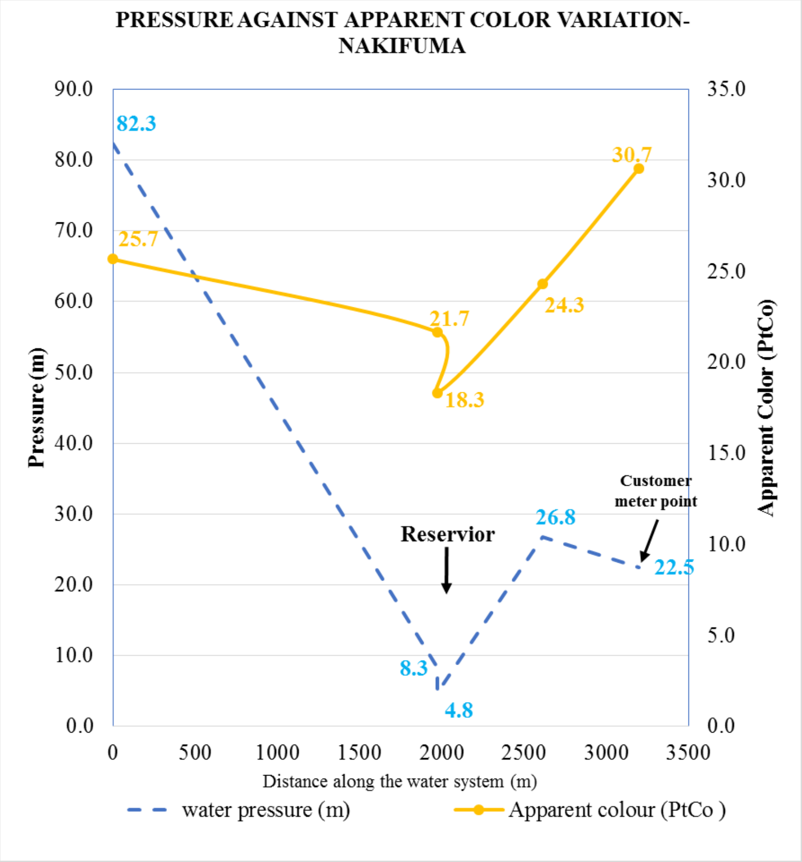


Figure 7.8: Water pressure variation with Residual Chlorine along the supply chain of Nakifuma small water

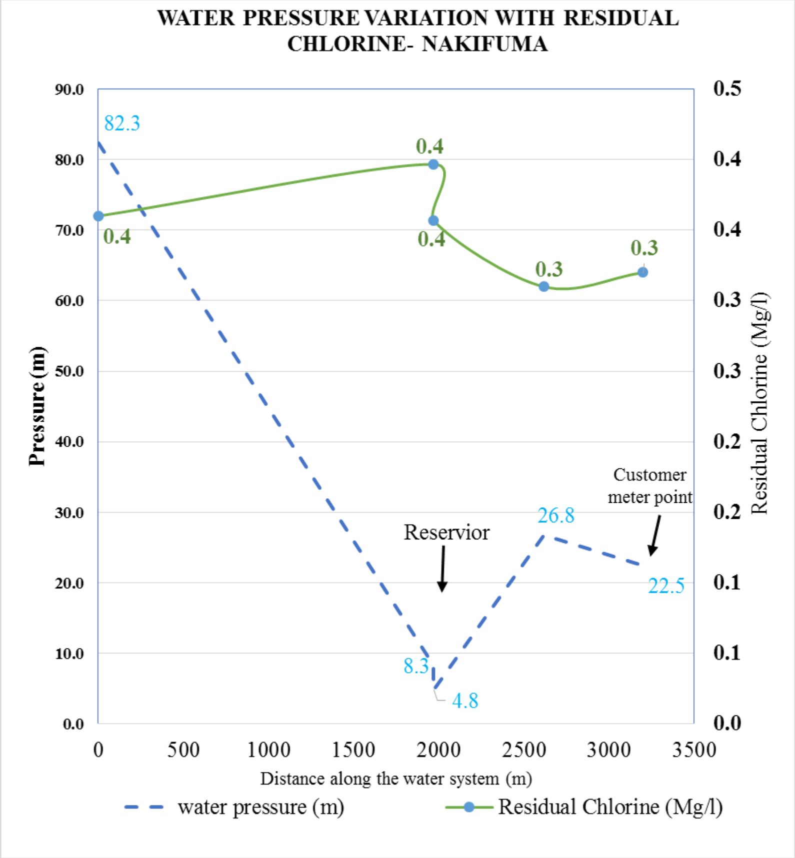


Figure 7.9: Water pressure variation with Residual Chlorine along the supply chain of Nakifuma small water system

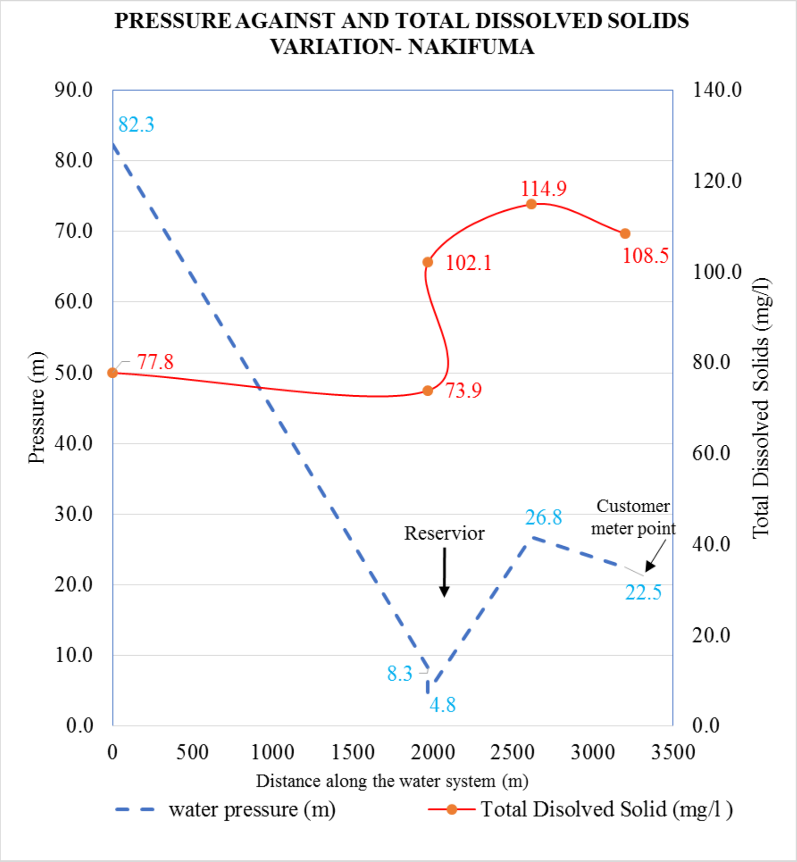
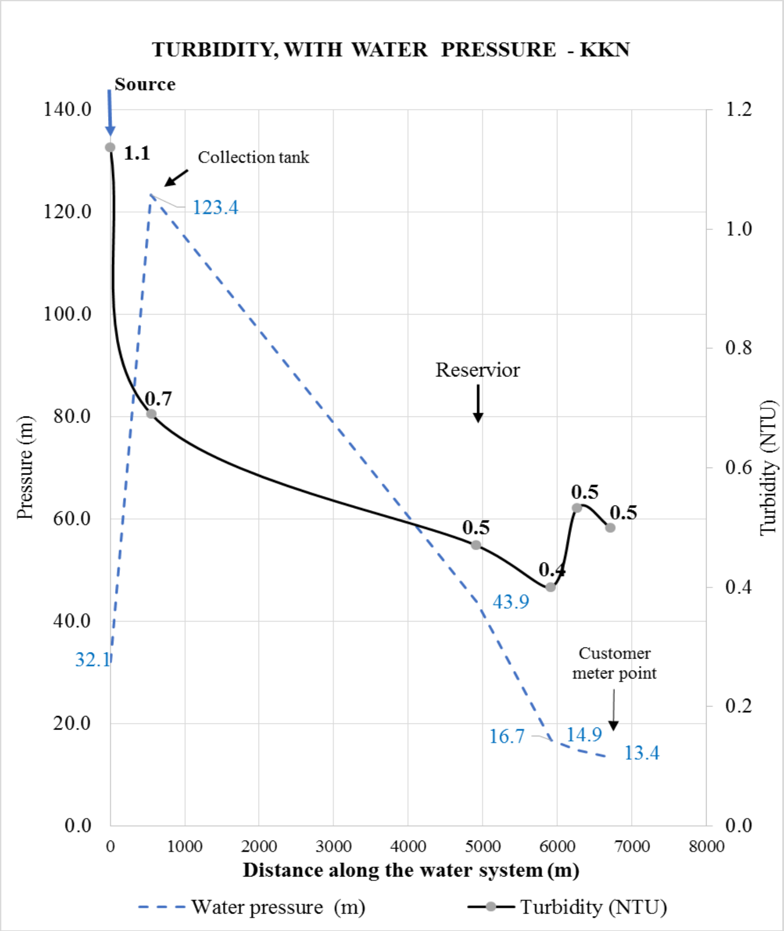


Figure 7.10: Water pressure variation with Total Dissolved Solids along the supply chain of Nakifuma small water system



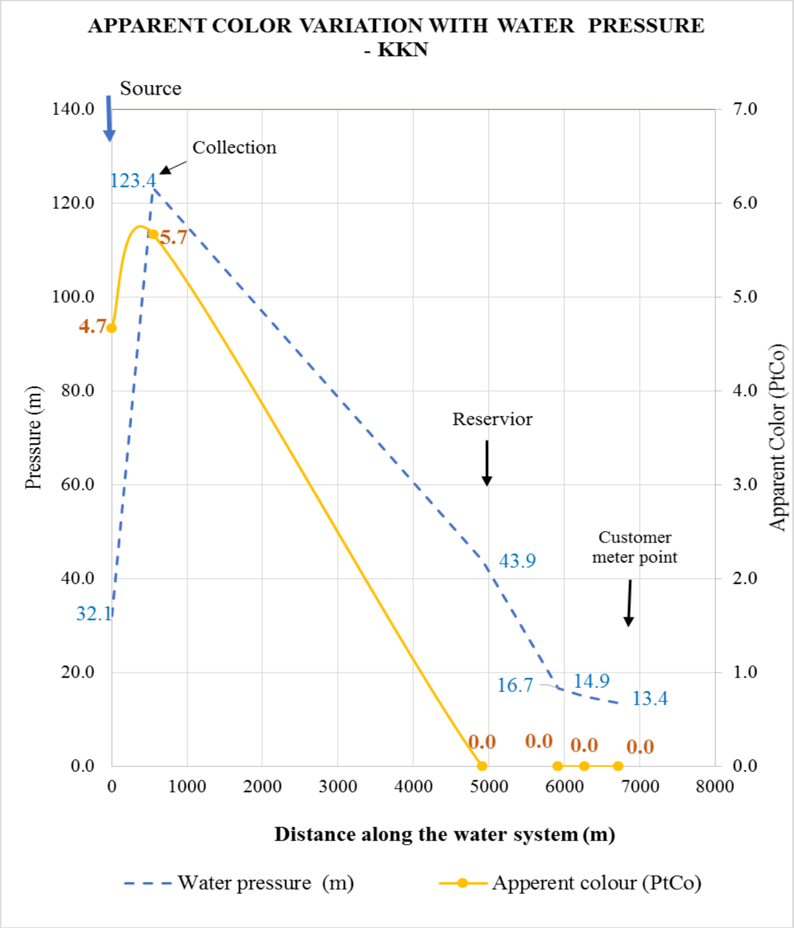


Figure 7.11: Water pressure variation with Turbidity along the supply chain of Kabembe-Kalagi-Naggalama small water system

Figure 7.12: Water pressure variation with Apparent Color along the supply chain of Kabembe-Kalagi-Naggalama small water system

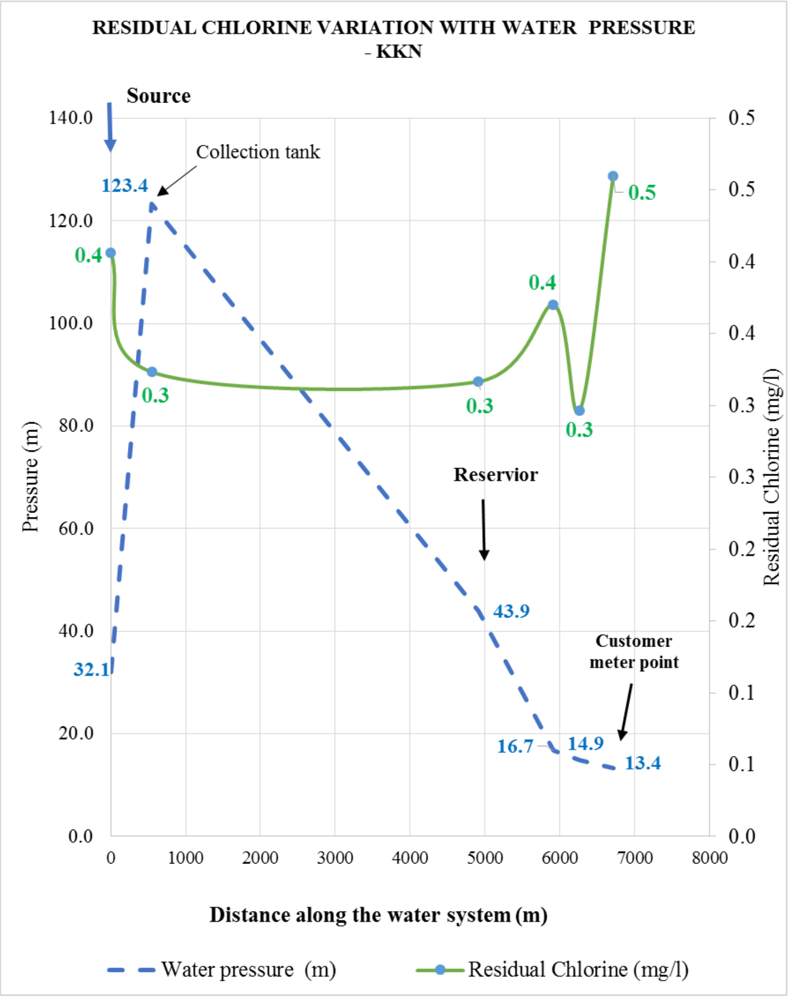


Figure 7.13: Water pressure variation with Residual Chlorine, along the supply chain of Kabembe-Kalagi-Naggalama small water system

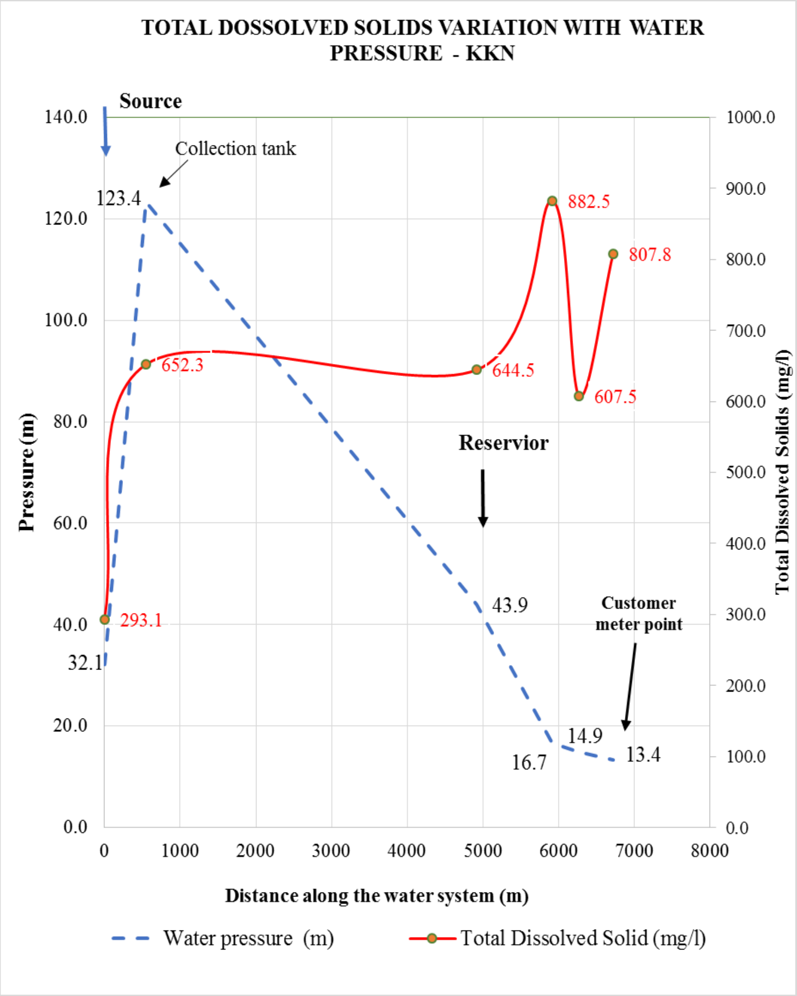


Figure 7.14: Water pressure variation with Total Dissolved Solids along the supply chain of Kabembe-Kalagi-Naggalama small water system