



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY

INVESTIGATION OF DRINKING WATER QUALITY FROM SOURCE TO POINT OF
DISTRIBUTION :-(THE CASE OF GIMBI TOWN, IN OROMIA REGIONAL STATE OF
ETHIOPIA).

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University
in Partial Fulfillment of the Degree of Master of Science in Civil &
Environmental Engineering

(Major in Water Supply & Environmental Engineering)

By Gurmessa Oljira Erena

Advised By Dr. Ing. Geremew Sahilu

Addis Ababa

Ethiopia

June 2015



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DECLARATION

I declare that I have elaborated my M.Sc. thesis aimed at “INVESTIGATION OF DRINKING WATER QUALITY FROM SOURCE TO POINT OF DISTRIBUTION :- THE CASE OF GIMBI TOWN, IN OROMIA REGIONAL STATE OF ETHIOPIA” independently under the leadership of my supervisor, Dr. Ing. Geremew Sahilu, Assistant Professor, Addis Ababa Institute of Technology. I have used only the literature and other information sources that are cited in the work and listed in bibliography at the end of this work. As the author of the thesis, further I declare that I am related to its creation and did not infringe the copyright of the third parties.

June 2015

Signature _____

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ABSTRACT

This research focuses on the investigation of the existing main drinking water quality of Gimbi town, which is located in Western Ethiopia, from the source to points of distribution in relation to safety and acceptability for users concerning water quality parameters. Efforts were also made to identify the relationship between the residual chlorine and pressure in the gravity distribution of the water supply network systems. The town gets its water supply from a treatment plant, which is established on Gafere River. Two subsequent methods were used to achieve these objectives. The first method involved the collection of samples from different locations of the study area followed by laboratory analyses, and the other method involved the use of simulation models such as EPANET Software to identify the pressure effect on residual chlorine in the water supply gravity distribution system. The analyzed water sample parameters include physico-chemical and bacteriological parameters. For bacteriological analyses, the whole 30 representative samples were randomly selected from sensitive areas for expected pollution such as raw water, treatment plant, service reservoir, water points, ends of pipe network, and customer point of use, and 17 samples were used for physico-chemical analyses. The results were analysed and interpreted by using Microsoft excel spread sheet, Global mapper and suffer software. The results obtained show that except iron, residual chlorine and pH, the rest all parameters were within the World Health Organization (WHO) permissible limit. The results for iron concentration were found between the range of 0.6-2.5 mg/l, the majority of samples have pH values between 6.01-6.45 (only two samples have pH values of 6.5, which is the WHO minimum permissible limit), and 30% of tested samples have residual chlorine below the WHO minimum permissible limit (0.2 mg/L). All the remaining physico-chemical parameters and Biochemical Oxygen Demands were safe and within the range of acceptable drinking water quality. By contrast, all parameters were found within the range of the Ethiopia recommended values permissible limit for drinking water quality. However, regarding the aesthetic and acceptability of physical parameters like colour and turbidity were above the maximum permissible limit of both WHO and Ethiopian recommended guideline for permissible limit. Although further research is required to draw ultimate conclusions, at this point it can be considered that there is no health significance on the users concerning the physico-chemical parameters. Similarly, the result of bacteriological analyses indicated that in most of the samples low risk were observed after treatment plant except for sample-7 and sample-12 due to high turbidity, longer residence time of the water in the system, and the presence of total coliforms expressed by Too Numerous To Count (TNTC). To overcome these problems regular chlorination is recommended. The simulation results showed that the pressure has inverse relationship with the residual chlorine in the gravity distribution systems of the networks

KEY WORDS: Water quality parameters, WHO standards, Water borne diseases, Pressure, Residual chlorine, Gimbi, Oromia, Ethiopia.

ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DWR	Distribution of Water Reservoir
EC	Electrical Conductivity
EPS	Extended Period Simulation
ES ISO	Ethiopia Standard International Standard Organization
ES	Ethiopia Standard
GIP	Galvanized Iron Pipe
GIS	Geographical Information System
GPS	Global Position System
HDPE	High Density Poly Ethel yen pipe
MDG	Millennium Development Goal
MS EXCEL	Microsoft Excel
NTU	Ne photometric Turbidity Unit
pH	Power of Hydrogen ion scale
PPM	Part Per Million
PVC	Polyvinyl Chloride
RC	Reinforcement Concrete
TCU	Total Color Unit

TDS	Total Dissolved Solid
TNTC	Too Numerous To Count
UNICEF	United Nation International Children’s Emergency Fund
WHO	World Health Organization

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CHAPTER ONE

1 INTRODUCTION

1.1 Background

Water is one of the main important abiotic components of the environment. Approximately, 97% of the total water is found in oceans, which is not appropriate for drinking, and only 3% is considered as fresh water, out of which 2.97% is found as glaciers and ice caps. Only the remaining little portion, 0.03%, is obtainable as surface and ground water for human use (Muhammad et al., 2013). Harmless drinking water is a basic need for good health and it is a rudimentary right of humans (WHO, 2001). In addition, it is impossible to imagine clean and sanitary environment without water.

Water quality is the measure of how good the water is, in terms of supporting beneficial uses or meeting its environmental standards. Potable water is the water which is suitable for drinking and cooking purposes. Portability considers both the safety of water in terms of health, and its acceptability to the consumer, usually in terms of taste, odor, color, and other sensible qualities (Benignos, 2012).

Various health problems may occur due to inadequacy and poor drinking quality of water supply. Infant mortality rate is high due to unsafe water supply. Therefore, drinking water quality should be completely free from pathogenic microorganisms, physico-chemical elements in concentration that causes health impact. It should be clear and aesthetically attractive, low turbidity and color recommended by WHO guidelines and should not be saline, contain any compounds that cause offensive taste, should not cause corrosion scale formation, discoloring or staining and should not have a temperature unsuitable for consumption.

The quality of drinking water is an influential environmental determinant of health, management has been a key pillar of primary prevention for more than 150 years, and it continues to be foundation for the prevention and control of water borne diseases. Water is essential for life, but it can and does transmit disease in countries in all continents from the poorest to the wealthiest. The most predominant water borne disease, diarrhea, has an estimated annual incidence of 4.6 billion episodes and causes 2.2 million deaths every year (UNICEF/WHO, 2012). Access to safe drinking water and sanitation is a global concern.

However, developing countries like Ethiopia have suffered from a lack of access to safe drinking water quality and cause of human health problems due to waterborne diseases. Today, close to a billion people, most living in the developing world, do not have access to safe and adequate water (UNICEF/WHO, 2012). The World Health Organization (WHO) estimated that around 94% of the global diarrheal burden and 10% of the total disease burden are due to unsafe drinking water, inadequate sanitation, and poor hygienic practices (Pruss-Ustun and Covalan, 2006; Fewtrell et al., 2007; Doria, 2010).

One of the most important factors that affect drinking water quality through distribution and with sustainable use of town water supply systems is the quality of water the distribution systems deliver to the users (Brikke , 2002; Schoutern and Moriarty, 2003). If domestic water supply of any town is fail to meet acceptable drinking water quality standards (that is, physical, chemical and/or bacteriological) people may stop using the scheme and resort to unsafe sources; and will be further exposed to acute and chronic illnesses (Karn and Harada, 2002). This will bring challenge in meeting the Millennium Development Goals (MDGs) of ensuring environmental sustainability, improving health and eradicating extreme poverty of the rural & town majority living in the developing world (United Nations, 2005).

There are several variants of the fecal-oral pathway of water borne disease transmission. These include contamination of drinking water catchments (e.g. by human or animal faces), water within the distribution system (e.g. through leaky pipes or obsolete infrastructure) or of stored household water as result of unhygienic handling. Millions of people are exposed to unsafe levels of chemical contaminants in their drinking water. This may be due to a lack of proper management of urban and industrial wastewater or agricultural run-off water potentially giving rise to long-term exposure to pollutants, which can have a range of serious health implications.

Ethiopia is one of the participant countries that decided the millennium development announcement with its main impartial of poverty reduction. This resulted in prioritizing accessibility to improved drinking water quality. Therefore, to achieve these goals, drinking water quality concerns are often the most important component for measuring access to enhanced water supply sources & treatment distribution systems for the public. Acceptable water quality shows the safety of drinking water in terms of its physical, chemical, and bacteriological parameters (WHO, 2004). User communities' perceptions of quality also carry great weight in their drinking water safety (Doria, 2010).

The people of Gimbi town get their drinking water supply from Gafere River which is situated in the downstream side of the town. There could be a potential water pollution Gafare River due to expected effluents of waste water or storm water from domestic and agricultural fields. It is crucial to identify whether the water obtained from the river, along its various stages until it reaches the consumers, is safe with regard to water quality parameters. Therefore, this research attempts to assess the drinking water quality from the main existing drinking water system of Gimbi town in terms of water quality parameters such as physico-chemical, bacteriological and pollution loads at the source. The ultimate result of this study is useful to address the main cause of public health problems related to deteriorated quality of drinking water, and to point out the way to produce a safe water for the population of the town.

1.2 Statements of the problems

Water quality and the risk of water-associated diseases are serious public health concerns in many developing countries like Ethiopia. This is mainly due to lack proper research and subsequent monitoring of water quality parameters for most of the towns in Ethiopia. The populations of Gimbi town obtain their drinking water from a river source, which is located on the downstream side of the town. So far, there is no research activity conducted on the water supply system of the town that may enable one to know the quality of drinking water and the effectiveness of the water supply network systems. The health sector of the town regularly reports that water associated diseases are one of the top-ten diseases, and there are certain indicators that the population of the town is suffering from water-associated diseases, very probably due to poor drinking water quality.

Systems that have large transmission and distribution lines may have problem on changes of pressure in the distribution system. For the reason that the increase in water age is dependent on the difference between the production and consumption rates, high residence time in pipes and storage duration in water tanks some of the problems. Therefore, Gimbi Town topography very gorge that has great elevation variation from service reservoir to end of customer use, very long and complex networks of the distribution system and also the water supply distribution pipes networks does not has pressure classification zone during the designed. The Gimbi Town water supply pipes distributions networks frequently damaged. This is may be very probably due to excessive pressure in the water supply distribution networks system.

1.3 Research question

The principal research question that were attempted to be addressed are:

- 1) Do the drinking water quality parameters of Gimbi town fit the guidelines set in the WHO standard and that of the Ethiopian recommended guideline?
- 2) If the water quality of the town, expressed in terms of the water quality parameters, is in short of the WHO guidelines and the Ethiopian recommended maximum and minimum permissible limits, what will be the health significance of the water on the health of the users?
- 3) What relationship does exist between the residual chlorine concentration and pressure in the water supply gravity distribution system of the water supply network system?

1.4 Objectives

1.4.1 General objectives

The main objective of this research paper was to seek ways to improve the drinking water quality and producing safe drinking water for the Gimbi Town through investigating the quantitative and qualitative measures of water quality parameters referencing to the WHO guidelines and Ethiopian recommended values.

1.4.2 Specific objectives include

- To characterize the drinking water quality from source to point of distribution up to public fountains.
- To assess the pollution load of the drinking water supply source of the town.
- To assess the safety and acceptability of drinking water quality parameters using different characteristics unit process such as physico-chemical and bacteriological through laboratory experiment.
- To assess the prevalence of water associated diseases in the town.
- To assess the relationship of effects of pressure variation on water quality (residual chlorine concentration) in gravity distribution system at different pressure nodes of network pipes systems.

1.5 Scope of the research

This research was mainly focused on the investigation of the factor that affect the different characteristic of water quality parameters such as physic-chemical, bacteriological and to

identify the relationship of pressure at different nodes with residual chlorine concentration within the water supply distribution system by using EPANET model without including other parameters. The study area is limited to Gimbi Town's Gafere River water supply treatment plant source, customer end users, and public fountains. The lacks of enough budgets, logistics, distance of the study area from laboratory, and chemical reagents were some of the main challenges/limitations for the research work. The investigation from sources to point of distribution to the customer was specifically focused only on the major standards of water quality parameters (physic-chemical and bacteriological: total coliform & faecal coliform), without considering heavy metals due to lack of reagent. More attention has been given to identifying the major factors of water quality deterioration, pressure variation, and residual chlorine concentration of the water supply scheme.

1.6 Thesis organization

Chapter 1: The back ground of the importance drinking water quality parameters tests and health significance of water-associated diseases, statements of the problem, general objective, specific objectives, and scope and limitation of the research.

Chapter 2: it includes literature review and conceptual frame of drinking water quality assessment, main importance of drinking water quality parameters regards to physic-chemicals, and bacteriological tests analysis within maximum permissible limits regards to WHO guidelines, Ethiopia guidelines, and significance on the human health, as well as the review of the pressure effect on water quality.

Chapter 3: methods and material used description of the study area in detailed and samples location points of study area were explained.

Chapter 4: it includes the result and discussion of the research in detailed.

Chapter 5: It includes the conclusion and recommendation of the research.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 General

The health of any community fully depends on the accessibility of adequate and safe water. Hence, water is predominantly essential for life, health and for human self-respect. Therefore, in addition to community health benefits, all people have the right to safe and adequate water retrieved in equitable manner for drinking, cooking, personal, and domestic hygiene. In this case, both adequacy and safety of drinking water are equally important to reduce the incidence of water-related & water borne health problems especially diseases like diarrheal (Bharti et al, 2011).

A possible contamination source that carries threats to drinking water quality are open field defecation, animal wastes, plants, economic activities (agricultural, industrial and businesses) and even wastes from residential areas as well as flooding situation of the area. Any water sources, especially older water supply systems, hand dug wells; pumped or gravity-fed systems (including treatment plants, reservoirs, pressure break tank, pipe networks, and delivery points) are vulnerable to such contamination. Particularly systems with casings or caps that are not watertight are most vulnerable. This is particularly true if the water sources are located close to surface runoff that might be able to enter the source. Additional way by which pollution reaches and enters a water supply system is through overflow or infiltration by floodwaters and inundation of waters commonly contain high levels of contaminants (Haylamichael et al., 2012).

The fitness of community extremely depends on the availability of safe and adequate water for drinking, domestic use, and personal hygiene. If public health is to be improved and maintained through provision of safe and adequate water supply the major five key elements are vital which includes quantity, quality, cost, coverage, and continuity. Most of the time the occurrence of communicable diseases in the country is related with water supply conditions in the locality. Infectious diseases affected by changes in the water supply condition are categorized as follows (Addisie, M., 2012):

- Those spread through drinking water (water borne diseases, such as typhoid, cholera, gastroenteritis etc.)

- Those transferred through aquatic vectors (water based diseases, such as schistosomiasis)
- Those spread by insects that depend on water (water related diseases, such as malaria and yellow fever)
- Those diseases produced by the lack of adequate water for personal hygiene (water washed diseases, such as scabies and trachoma).

Based on the morbidity records, there is still a high incidence of communicable diseases which most of the time is related to water supply conditions in the country among which about 60% of the top ten diseases are relate to poor quality and scarcity of household water consumption (UNICEF, 2008).

2.2 Water quality analyses

Before determining on the sources of surface or groundwater, it is important to conduct water quality tests through representative samples. These tests ideally should be performing on site and through samples taken to the laboratory for definitive analysis (WHO Edition 4th, 2004).

2.3 Water quality parameters

Water quality parameters are classified in to three aspects such as physical, chemical, and biological characteristics of water in association to the set of standards. These parameters directly connected to the safety of the drinking water to human use. Water quality parameters deliver important information about the fitness of a water body. These limits are used to find out the quality of water for drinking purpose (D.Gupta & J. Saharan, 2009).

2.3.1 Physical aspects of drinking water quality

Physical aspects of drinking water quality mainly classified as; residual chlorine, temperature, color, odor, taste, turbidity, PH, electrical conductivity, and total dissolved solids and regards to examination of quality test categorized in to physiochemical and aesthetical parameters (De Zuane J., 1996).

2.3.1.1 Physiochemical examination

2.3.1.1.1 Residual chlorine

The fumigation of drinking-water supplies constitutes an important fence against waterborne diseases. Although numerous disinfectants may be used, chlorine in one form or another is the principal disinfecting agent employed in small communities in most countries.

Chlorine residual has a number of advantages as a disinfectant, including its comparative cheapness, effectiveness, and comfort of measurement, both in laboratories and in the field. An important extra advantage over some other disinfectants is that chlorine leaves a disinfectant residual that assists in preventing recontamination throughout distribution, transport, and household storage of water. The absence of a chlorine residual in the distribution system may in certain circumstances, indicate the possibility of post-treatment contamination (Taylor & Francis.G, 2007).

2.3.1.1.2 pH of pure water

The pH of pure water refers to states of acidity and alkalinity of solutions with respect to hydrogen and hydroxide ions can be expressed by a series of positive numbers between 0 to 14. In general, water with a pH of 7 is considered neutral while lower than this referred acidic and a pH greater than 7 known as basic. Normally, water pH ranges from 6 to 8.5. It is noticed that water with low pH tends to be toxic and with high degree of pH, it is turned into bitter taste. According to the WHO standards, pH of water should be 6.5 to 8.5 It is significant to measure pH at the similar time as chlorine residual since the effectiveness of disinfection with chlorine is extremely pH dependent: where the pH exceeds 8.0, disinfection is less effective. To check that the pH is in the optimal range for disinfection with chlorine (less than 8.0), simple tests may be conducted in the field using comparators such as that used for chlorine residual. With some chlorine comparators, it is possible to measure pH and chlorine residual simultaneously (Muhammad et al., 2013).

2.3.1.1.3 Total dissolved solids (TDS)

Water has the aptitude to dissolve an extensive variety of inorganic and some organic mineral deposits or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulfates etc. These mineral deposits formed undesirable taste and diluted color in appearance of water. There is no contract have been developed on bad or optimistic effects of water that exceeds the WHO standard of maximum permissible level is 1,000 ppm. A total dissolved solid (TDS) in drinking water originates in numerous ways from sewage and urban industrial wastewater etc. Hence, TDS test is mostly an indication to control the general quality of the water (Muhammad et al., 2013).

2.3.1.1.4 Electrical conductivity (EC)

Used to measure the ability of aqueous solution to carry an electric current such as; concentration of ions, mobility, valence and temperature

Clean water is not a good electrode of electric current rather a good heat proofing and increase in ions concentration improves the electrical conductivity of water. In general, the amount of dissolved solids in water concludes that the electrical conductivity. Electrical conductivity (EC) is really measures the ionic process of a solution that allows it to transmit current. Therefore, according to WHO standards EC value of drinking water quality should not exceeded 400 $\mu\text{S}/\text{cm}$ and the conductivity of potable waters varies generally from 50 to 1500 $\mu\text{ mhos}/\text{cm}$ (Gaur, 2008).

2.3.1.1.5 Turbidity

Turbidity is a measure of the degree of cloudiness or muddiness of water. It is an expression for an optical property that causes light to be scattered and absorbed. It is not possible to correlate turbidity with the weight concentration of suspended matter because light scattering properties of the suspended particulate matter depends upon size, shape and refractive index of the particulates. It is caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and other microscopic organisms.

Turbidity is important because it touches both the acceptability of water to consumers, and the selection and competence of treatment processes, particularly the efficiency of disinfection with chlorine since it uses a chlorine demand, defends microorganisms, and may stimulate the growth of bacteria.

In all procedures in which disinfection is used, the turbidity must always be low preferably lower than 1 NTU. It is recommended that, for water to be disinfected, the turbidity should be reliably less than 5 NTU (John C. et al, 2012) and preferably have a median value of less than 1 NTU (Nephelometric Turbidity Unity).

2.3.1.2 Aesthetic parameters of drinking water quality

Aesthetic limits are those obvious by the senses, namely turbidity, color, taste, and odor. They are important in monitoring public water supplies because they may cause the water supply to be disallowed and alternative (possibly poorer-quality) sources to be adopted, and they are simple and cheap to monitor qualitatively in the field.

2.3.1.2.1 Color

Color is due to the presence of colored substances in solution, such as vegetable matter and iron salt. It does not necessarily have detrimental effects on health. Color intensity could be

measured through visual comparison of the sample to distilled water. Colored water is not acceptable for drinking (Aesthetic as well as toxicity reasons). Therefore, Drinking water should be colorless.

Intended for the purposes of investigation of public water supplies, it is useful simply to note the presence or lack of observable color at the time of sampling. Changes in the color of water and the appearance of new colors serve as indicators that additional investigation is needed (WHO Edition^{4th}, 2004).

2.3.1.2.2 Odor and tastes

Odor: should be absent or very weak for water to be satisfactory for drinking purposes. Pure water is odorless; hence, the presence of unwanted odor in drinking water is symptomatic of the existence of contaminants.

Tastes: pure water is tasteless; hence, the presence of unwanted taste in water shows the presence of contaminants. Taste problems relating to water could be indicators of changes in the water source or in the treatment process. Inorganic compounds such as magnesium, calcium, sodium, copper, and iron are usually detected by the taste of water. Algae, decomposing organic matter, dissolved gases, and phenolic material may cause tastes (Gaur, 2008).

2.3.2 Chemical aspects of drinking water quality parameters

Chemical impurity of drinking water supply sources may be caused due to natural sources such as; certain industries and agricultural exercises. While toxic chemicals are present in drinking water, there is the risk that they may cause either acute or chronic health effects. Chronic health effects are more common than acute effects because the levels of chemicals in drinking water are rarely high enough to cause acute health effects (Benignos, 2012).

The major chemical or inorganic parameters of drinking water quality mainly classified as; hardness, calcium, magnesium, chloride, sulphate, fluoride, alkalinity, nitrate, phosphate and some toxic metals such as; copper, chromium (Cr^{+6}), Iron, Manganese, etc.

2.3.2.1 Hardness

Hardness of drinking water is due firstly to calcium and magnesium carbonates and bicarbonates (which can be removed by boiling) and calcium and magnesium sulfate and chloride (which can be removed by chemical precipitation using lime and sodium carbonate).

Hard water is mainly described with high mineral contents that are usually not dangerous for humans. It is frequently measured as calcium carbonate (CaCO_3) because it contains mainly calcium and carbonates which is the most dissolved ions in hard water. Public acceptability of the degree of hardness of water may be different considerably from one community to another. The taste threshold for the calcium ion is in the range of 100–300 mg/l and maximum permissible concentration for total hardness of 500mg/l as CaCO_3 . According to World Health Organization (WHO, 2004) and according to National drinking water quality recommended for Ethiopia total hardness permissible limit is 300mg/l (Girmay et al, 2011).

2.3.2.2 Alkalinity

The presence of acid substances is indicated by pH below 7.0 and alkaline substances by pH greater than 7.0. Acidic water is corrosive to metallic pipes. Alkalinity is the presence of one or more ions in water including hydroxides, carbonates, and bicarbonates. It can be define as the capacity to neutralize acid. Moderate concentration of alkalinity is desirable in most drinking water supplies to stable the corrosive effects of acidity. However, excessive quantities may cause a number of damages. The WHO standards express the alkalinity only in terms of total dissolved solids (TDS) of 500 mg/l (Muhammad et al ,2013)

2.3.2.3 Nitrate (NO_3)

Nitrate is one of the extreme significant disease causing parameters of drinking water quality, particularly blue baby syndrome in babies and has been used as an indicator for the presence of organics. Nitrates can cause methemoglobinemia at greater than 100 mg/l where a baby cannot take breaths enough oxygen (Roberts, 2006). The sources of nitrate are nitrogen cycle, industrial waste, nitrogenous fertilizers etc. The WHO guide lines maximum permissible values of nitrate in drinking water is 50 mg/l as NO_3 for nitrate and 3mg/l as NO_2 for nitrite (Alan et al., 2000).

2.3.2.4 Phosphate

Phosphates in surface waters mostly originated from sewage effluents, which contains phosphate, based synthetic detergents, from industrial effluents, or from land runoff where inorganic fertilizers have been used in farming. Ground water usually contains insignificant concentrations of phosphates, unless they have become polluted. Phosphorous one of the crucial nutrients for algal growth and can contribute significantly to eutrophication of lakes and reservoirs (Alan et al., 2000).

2.3.2.5 Sulphate (SO₄)

Sulphate comes from several sources such as the dissolution of gypsum and other mineral deposits containing sulphates from seawater intrusion, from the oxidation of sulphides, sulphites, and thiosulphates in well-aerated surface waters and from industrial effluents where sulphates or sulphuric acids have been used in process such as tanning and pulp paper manufacturing.

High levels of sulphate in drinking water supply can impart taste and, when combined with magnesium or sodium, can have a laxative effect (e.g. Epsom salts). Sulfate concentration in natural water varieties from a few to a several hundred mg per liter but no major negative impact of sulfate on human health is reported so far. According to the WHO (2004) guideline maximum permissible value recognized 250 mg/l SO₄ based on taste and corrosion potential.

2.3.2.6 Chloride (Cl)

Sometimes special significance is given to the chloride contents of water, particularly sodium chloride and is mainly obtained from the dissolution of salts of hydrochloric acid as table salt (NaCl), NaCO₂ and sources of chlorides are mainly from road salts, wastewater, storm sewers and animal feed etc (Terence, 1979). Surface water bodies often have low concentration of Cl and are a home of main physiological processes. High chloride concentration demolition metallic pipes and structure as well as harms growing plants. Permitting to WHO guideline maximum permissible limits of the concentration of chloride should not exceed 250 mg/l.

2.3.2.7 Iron and manganese

Groundwater usually contains more of these two minerals than surface water. Iron and manganese are irritants that should be avoided if in excess of 0.3 mg/l and 0.1 mg/l correspondingly. They stain clothing and plumbing fixtures, and the growth of iron bacteria causes strainers, screens to clog, and metallic conduits to rust. The appearance of a reddish brown or black precipitate in a water sample after shaking indicates, respectively, the presence of iron or manganese (Alan et al., 2000).

2.3.2.8 Calcium

Calcium is the greatest significant and abundant in the human body and sufficient consumption is essential for normal growth and health. Around 95 percent calcium in human

body stockpiled in bones and teeth. The high deficiency of calcium in humans may cause of; rickets, poor blood clotting, bones fracture etc. The maximum daily requirement is of the order of 1 - 2 grams and come from mostly dairy products. There is certain evidence to indication that the incidence of heart disease is reduced in areas served by a public water supply with a high degree of hardness, the primary constituent of which is calcium, so that the presence of the element in a drinking water supply is advantageous to health (Environmental Protection Agency, 2001). According to WHO (1996), its permissible range in drinking water is up to 75 mg/l.

2.3.2.9 Magnesium (Mg)

Magnesium is plentiful and a major nutritional requirement for humans (0.3-0.5 g/day). It is the second major component of hardness and it generally comprises 15-20 per cent of the total hardness expressed as CaCO_3 (Environmental Protection Agency, 2001). Human body contains about 25g of magnesium (60% in bones and 40% in muscles and tissues). According to the WHO standards, the allowable range of magnesium in water should be 150 mg/l (Muhammad et al., 2013).

2.3.2.10 Toxic substances

A quantity of toxic chemical substances, if present in appreciable concentration in drinking water, may constitute a danger to health. These toxic substances include Copper, hexavalent chromium, lead etc.

2.3.2.11 Dissolved Oxygen (DO)

Oxygen is considered poorly soluble in water. The aforementioned solubility is related to pressure and temperature. In water supply technology, dissolved oxygen in raw water is considered as the necessary element to support life of fish and other aquatic organisms. It is also an indicator of water treatment process and is an important factor in corrosively. The DO content is evaluated in comparison to its maximum level of solubility for a given pressure and temperature, defined as saturation. Because saturation is obtained from the atmosphere, oxygen is only a portion of the dissolved gases; but fortunately, its content in water is approximately 38% of the dissolved gases that is twice its percentage in air. Therefore, in fresh water, dissolved oxygen reaches 14.6mg/l at 0°C and approximately 9.1, 8.3, and 7mg/l, respectively at 20°C, 25°C, and 35°C at 1atm of pressure (De Zuane, 1996).

It must be noted that the popularity and frequency of the DO testing in sanitary Engineering, and even more the BOD (Biochemical Oxygen Demand) and the COD (Chemical Oxygen Demand) are due to the necessity of evaluating particularly wastewater and industrial waste biological processes, stream aeration, and pollution load in water pollution control surveys and programs. However, less importance is given by the sanitary engineer to these tests when water supply is involved with the exception of stream analysis.

There is no WHO guidance level for DO standards were ever issued by the Health Authority, mainly due to the lack of toxicity. Moreover, the low concentration and the continuous variation in concentration (change in pressure and temperature) make the dissolved oxygen a parameter of limited importance from a health viewpoint, but its effect on corrosion has practical piping life and psychological results for consumers due to discolored water and taste problems.

2.3.3 Bacteriological aspects of drinking water quality

The type and numbers of microorganisms present in the water determine the microbiological properties of water. A diversity of microorganisms can be present even in very good quality domestic waters. Most of these microorganisms are harmless but if the water is, polluted pathogens may be present (Kasrils & MSimang, 2001)

Pathogens are disease-causing microorganisms such as those causing cholera, gastro enteritis, hepatitis, etc. (Pathogen from the Greek words pathos, meaning suffering and gen, meaning to give rise to).

It is difficult to determine the presence of all the different pathogenic organisms and therefore the presence of certain indicator organisms are used to give an indication of the possible presence of pathogens.

There are different types of indicator organisms. The most common indicator organisms used for domestic water quality assessment are total coliforms and fecal coliforms.

2.4 Sampling methods and location of sampling points

2.4.1 Location of sampling points

The main objective of investigation is to assess the quality of the water supplied by the supply agency& researcher and of that at the point of distribution of water for public use, so

that samples of both should be taken. Any significant difference between the two has important implications for remedial measures.

Samples must be taken from locations that are representative of the water source, treatment plant, storage facilities, distribution network, points at which water is delivered to the consumer, and points of use. In selecting sampling points, each locality should be considered individually; however, the following general criteria are usually applicable:

- Sampling points should be selected such that the samples taken are representative of the different sources from which water is obtained by the public or enters the system but by this research, case was considered only one source (WHO, 1997).
- These points should include those that yield samples representative of the conditions at the most unfavorable sources or places in the supply system, particularly points of possible contamination such as unprotected sources or raw water, treatment plant, loops, reservoirs, low-pressure zones, ends of the system, etc.
- Sampling points should be uniformly distributed throughout a piped distribution system, considering population distribution; the number of sampling points should be proportional to the number of links or branches.
- There should be at least one sampling point directly after the clean-water outlet from each treatment plant (WHO, 1997).

2.4.2 Sampling frequency amounts

The most important tests used in water-quality surveillance or quality control in small communities are those for microbiological quality (by the measurement of indicator bacteria) and turbidity and for free chlorine residual and pH where chlorination is used. These tests should be carried out whenever a sample is taken, regardless of how many other physical or chemical variables are to be measured. The recommended minimum frequency of critical measurements in minimum sample numbers for piped drinking water in the distribution system is shown in table 2-1 below (WHO, 1997).

Table 2-1: Minimum sample numbers for piped drinking water in the distribution systems

No	Population served	Numbers of monthly samples recommended
1	Less than 5,000	1
2	5,000-100,000	1 per 5,000 population
3	Greater than 100,000	1 per 10,000 population plus 10 additional samples

Source: *Guideline for drinking water quality 2nd edition, volume-3 surveillance & control of community supplies* by (WHO, 1997), Geneva.

2.5 Regulatory of drinking water quality limitations

Drinking water well defined as having adequate quality in relations to its physical, chemical, bacteriological parameters so that it can be safely used for drinking and cooking (Addisie, 2012). WHO describes drinking water to be safe if and only if no any significant health risks during its lifespan of the scheme and when it is consumed. This research paper is emphasis on water quality for drinking and domestic uses.

2.5.1 Institutional Assessment and analysis about water supply systems

Institutional assessment of water supply system will help to identify poor operation and maintenance situation of relevant functions like defective design, ineffective supervision, insufficient training, lack of inter-sartorial co-ordination resulting in capacity gaps and absence of clarity of roles, which consequently the water supply components fail to operate at optimum efficiency (WHO,2006).

2.5.2 Bacteriological limits of drinking water quality

The completely coliform group could be seat as the primary indicator bacteria for the presence of disease causing organisms in drinking water. It is a primary indicator of suitability of water for consumption. If large numbers of coli forms could be found in water, there is a high probability that other pathogenic bacteria or organisms exist. The WHO and Ethiopian drinking water guidelines require the absence of total coliform in public drinking water supplies. The frequency of testing for public water supplies depends on the size of the population served and the disease caused by water related microorganisms is divided into four main classes;

- Water-borne diseases: it is caused by water that to be contaminated by human, animal or chemical wastes. Examples include cholera, typhoid, meningitis, dysentery, hepatitis, and diarrhea. A host of bacterial, viral, causes diarrhea and

parasitic organisms most of which can be spread by contaminated water (WHO, 2006). Poor nutrition resulting from frequent attacks of diarrhea is the primary cause for stunted growth for millions of children in the developing world (Addisie, 2012).

- Water-related vector diseases: diseases that transmitted by vectors, such as mosquitoes that breed or live near water. Examples include malaria, yellow fever, dengue fever and filaria. Malaria causes over 1 million deaths a year alone (WHO, 2006). Stagnant and poorly managed waters provide the breeding grounds for malaria-carrying mosquitoes.
- Water-based diseases: Parasitic aquatic organisms referred to helminths cause that and to be transmitted via skin penetration or contact. Examples include Guinea worm disease, filaria, paragonimiasis, clonorchiasis, and schistosomiasis (WHO, 2006).
- Water-scarce diseases: These diseases flourish in conditions where freshwater is scarce and sanitation is poor. Examples include trachoma and tuberculosis

2.5.3 Physicochemical Quality of Drinking Water

Amount of chemical contaminants have been to cause adverse health effects in humans because of prolonged exposure through drinking water. These include, both organic and inorganic chemicals including some pesticides. Some of them are toxic to humans or affect the aesthetic quality of water. In this regard, the WHO has put forward guideline values that set limits for many of the contaminants in drinking water. Ethiopia has also ready its own drinking water quality specification in line with the international norms and values. The Quality and Standards Authority of Ethiopia have stipulated legally binding drinking water quality specifications (ES 261:2001) in 2001. The Ethiopian standard ES 261:2001 set limits for not only the physic-chemical parameters but also for Microbiological and radiological parameters (Girma, et al., 2011).

2.5.4 Standard of Drinking Water Quality guide fulfilment criteria

2.5.4.1 Physical requirements

Table 0-1: physical characteristics of drinking of water quality

Characteristics	Maximum permissible level	Test method
Odor	Unobjectionable	ES605
Taste	Unobjectionable	
Turbidity (NTU)	5	ES ISO 7027
Color (TCU)	15	ES ISO 7887

Sources: *National Drinking Water Quality monitoring and surveillance strategies, 2011*

2.5.4.2 Chemical requirements

Characteristics that affect the delicious properties of drinking water quality shall be conforming to the level specified in table 2-3.

Table 0-2: Characteristics that affect the deliciousness of drinking water

Substances or characteristics	Maximum permissible level	Test method
Total hardness (as CaCO_3) mg/l	300	ES 607
Total dissolved solids mg/l	1000	ES 609
Total iron (as Fe) mg/l	0.3	ES ISO 6332
Manganese (as Mn) mg/l	0.5	ES ISO 6333
Ammonia ($\text{NH}_3 + \text{NH}_4^+$) mg/l	1.5	ES ISO 7150-2
Residual free chlorine mg/l	0.5	ES ISO 7393
Anionic surfactants mg/l	1	ES ISO 7875-1
Magnesium (as Mg) mg/l	50	ES ISO 7980
Calcium (as Ca) mg/l	75	ES ISO 7980
Copper (as Cu) mg/l	2	ES ISO 8288
Sulfate (as SO_4) mg/l	250	ES ISO 9280
Chloride (as Cl) mg/l	250	ES ISO 9297
Total alkalinity (as CaCO_3)	200	ES ISO 9963-1
Potassium (as K) ,mg/l	1.5	ES ISO 9964-2
PH value ,units	6.5 to 8.5	ES ISO 10523

Sources: *National Drinking Water Quality monitoring and surveillance strategies, 2011*

2.5.5 Bacteriological analyses of drinking water quality

Drinking water practitioners are concerned with water supply and water purification through a treatment process. In treating water, the primary concern, of course, is producing potable water that is safe to drink (free of pathogens) and has no accompanying unpleasant characteristics, such as a foul taste or odor. To achieve this, the drinking water practitioner must possess a wide range of knowledge. In short, to correctly examine raw water for pathogenic microorganisms and to determine the type of treatment necessary to ensure that, the quality of the product potable water meets regulatory standards.

Absolutely the most serious public health risk associated with drinking water supplies is microbial contamination. Pathogens; bacteria, viruses and parasites, then can cause a wide range of health problems when consumed in drinking water, but the primary concern is infectious diarrhea disease transmitted by the faecal-oral route.

It is impractical to analyze water for every individual pathogen, some of which can cause disease at very low doses. As an alternative, since most diarrhea causing pathogens are faecal in origin, it is more practical to analyze water for indicator species that are also present in faecal matter. The most commonly used indicator species are coliform bacteria, which include a wide range of bacteria, all of which can ferment lactose and produce gas at 37°C. Many but not all coliforms are faecal in origin, so the presence of total coliforms in water is not a good indicator of poor water quality.

Coliforms that come from faecal matter can tolerate higher temperatures than most environmental coliforms, so those that ferment lactose and produce gas at 44°C are called thermo tolerant coliforms, or faecal coliforms. These are more closely associated with faecal pollution than total coliforms. The most specific indicator of faecal contamination is *Escherichia coli* (*E. coli*), which unlike some faecal coliforms never multiplies in the aquatic environment (UNICF, 2008).

When evaluating faecal contamination, it is suggested to measure turbidity along with *E. coli* (or faecal coliforms), since pathogens can adsorb onto suspended particles, and to some extent be shielded from disinfection. When water has been disinfected, it is also important to measure chlorine residual and pH. These four parameters (*E. coli*/faecal coliforms, turbidity, disinfectant residual chlorine and pH) are considered the minimum set of “essential parameters” required to assess microbiological quality of drinking water (WHO, 2006).

Therefore, bacteriological analysis mainly includes estimation of faecal coliform and total coliforms.

2.5.5.1 Total coliforms

The coliform organisms was better referred to as total coliforms to avoid confusion with others in the group, are not an index of fecal pollution or of health risk, but can provide basic information on source water quality. Total coliforms have been long utilized as a microbial measure of drinking water quality, largely because they are easy to detect and enumerate in water.

Traditionally they have been defined by reference to the method used for the group's enumeration and hence there have been many variations dependent on the method of culture. In general, definitions have been based around the following characteristics; gram-negative, non-spore forming, rod shaped bacteria capable of growth in the presence of bile salts or other surface active agents with similar growth inhibiting properties, oxidize-negative, fermenting lactose at 35-37°C with the production of acid, gas, and aldehyde within 24-48 hours according to Assessing Microbial Safety of Drinking Water (2002).

2.5.5.2 Faecal coliforms

The term 'fecal coliforms', although frequently employed, is not correct. The correct terminology for these organisms is 'thermo tolerant coliforms'. Thermo tolerant coliforms were defined as the group of total coliforms that are able to ferment lactose at 44-45°C.

The genus *Escherichia* comprise to a lesser extent, species of *Klebsiella*, *Enterobacter*, and *Citrobacter*. Of these organisms, only *E.coli* was considered to be specifically of fecal origin, being always present in the faeces of humans, other mammals, and birds in large numbers and rarely, if ever, found in water or soil in temperate climates that has not been subject to fecal pollution (Fujioka et al., 1999).

The danger of coliform presence can rest on the health or sensitivity of the user. The risk of *E. coli* presence, rather than WHO Guideline is zero count per 100ml that may be of only low or intermediate risk. According to risk classification presence or absence of thermo tolerant coliforms or *E. coli* (Michael, 2006) of rural water supplies shown below.

Table 0-3: Water quality counts per 100ml and the associated risk (Source: Michael H., 2006)

No	Water quality counts per 100ml and the associated risk count per 100ml	Risk category
1	0	In conformity with WHO guide lines
2	1-10	Low risk
3	11-100	Intermediate risk
4	101-1000	High risk
5	>1000	Very high risk

2.5.5.3 Bacteriological requirements

When tasted with the corresponding test methods, the bacteriological requirements of treated drinking water shall not exceed the levels shown in table 2-5.

Table 0-4 Maximum permissible bacteriological level

Organism	Maximum permissible level	Test method
Total viable organisms, colonies per ml	Must not detectable	ES ISO 4833
Fecal streptococci per 100ml	Must not detectable	ES ISO7899-1 ES ISO7899-2
Coliform organisms, number per 100ml	Must not detectable	ES ISO 9308-1
E.coli ,number per 100ml	Must not detectable	ES ISO 9308-1 ES ISO 9308-2

Sources: *National Drinking Water Quality monitoring and surveillance strategies may, 2011 Addis Ababa*

2.6 Effects of pressure changes on water quality in distribution system

One of the parameter that could reason to decrease water quality in distribution system is pressure change in network. Numerous researchers have been carried out about affects pressure change in the water quality in distribution systems. Changes in pressure could cause leakage in distribution systems, and that changes in pressure could lead to a problem of drinking water quality. High residence time, high pressure and low-pressure systems and distribution net- work will cause a decline in the water quality in the gravity distribution system. Declared that systems with high pressure will have problem of pipe fracture in the distribution system (Shamsaei H. et al, 2013). Even so, in large distribution networks and systems, hydraulic changes are high, there is so much pressure along the gravity distribution lines and this might cause fractures or cracks in pipes even at the dead end areas of the system.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of the study area

Gimbi Town is located in Western Oromia Regional State 441 km far from Addis Ababa, the capital city of Ethiopia at latitude of 9°10' N and longitude of 35°50'E, as shown in figure 3-1. The elevation of the town ranges from 1600m to 2140m above sea level. Elevation varies between 1820 and 2140m at mountain peak, South of Gimbi town.

The area receives an annual rainfall of 600 to 1400mm. The movement of Inter Tropical Convergence Zone (ITCZ) in the northward direction brings moisture from the South Atlantic Ocean, which result in the high rainfall. The mean daily temperature also varies between 18°C and 24°C.

The Gimbi town is located in the western part of the northwestern plateau of the Ethiopia physiographic subdivision. A rolling plateau landscape type characterizes its surroundings, which is the result of the geographical set up of the area and the action of erosion, as shwn in figure

The Town covers area of 23.39 km². Based on the CSA census result (2007), the total population of Gimbi Town about 30, 981. However, presently the total population of the town is about 43,467.

LOCATION OF GIMBI TOWN

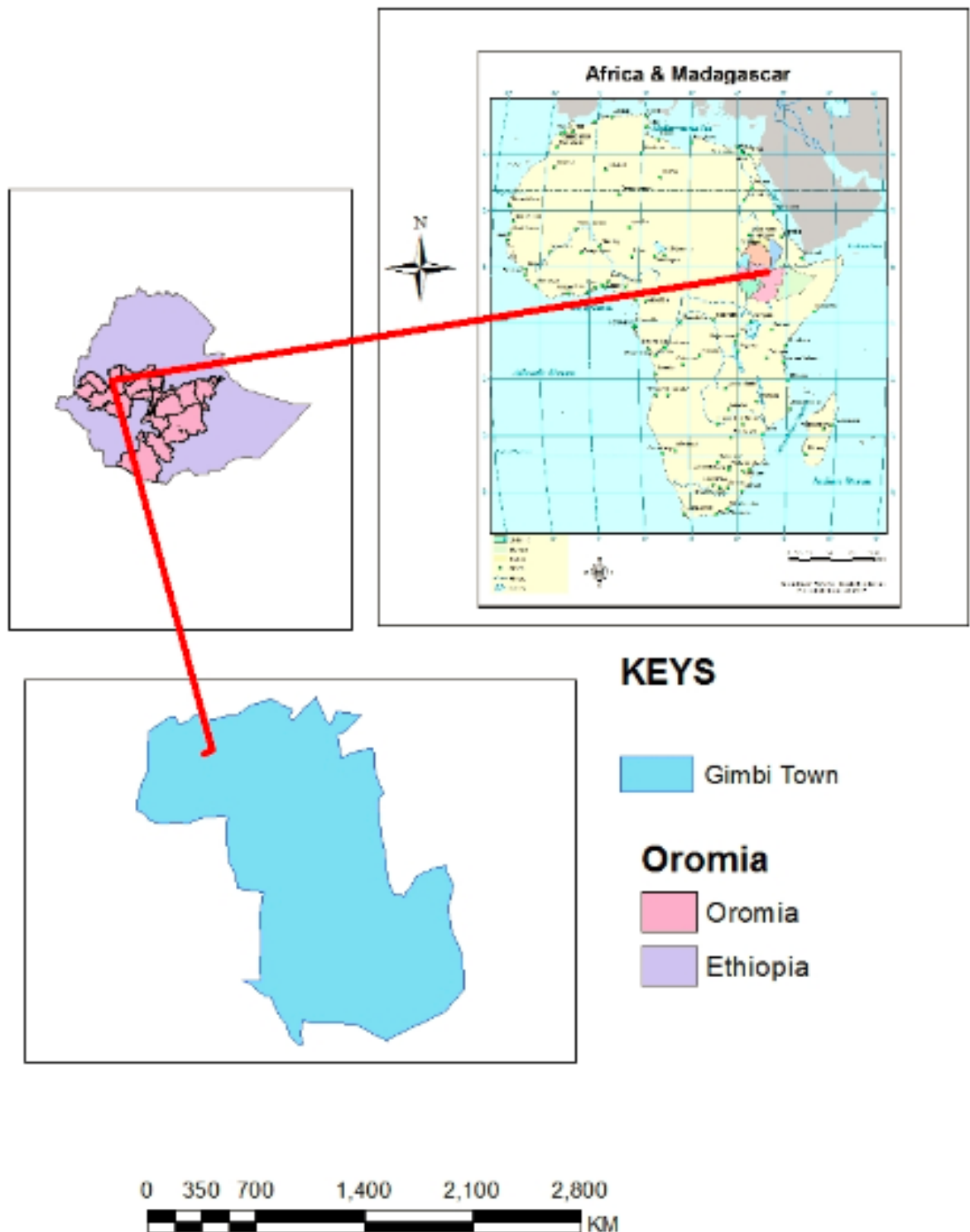


Figure 3-1: Location of Gimbi Town

3.2 Health status of Gimbi Town

In the Town, there are two hospitals, one health center, two pharmacy and nine clinics. The number and percentage of prevalence ten top diseases recorded in the year 2014/2015 G.C at the health institutions as shown in Figure 3-2.

According to officials of the health institutes in Gimbi Town, the major health problems are internal parasite, thiphod, and acute fever illness. These are the most common water borne, and water related diseases linked to poor water quality supply of the town. The high prevalence of these water-associated diseases of these is an indication of the status of drinking water supply and personal hygiene.

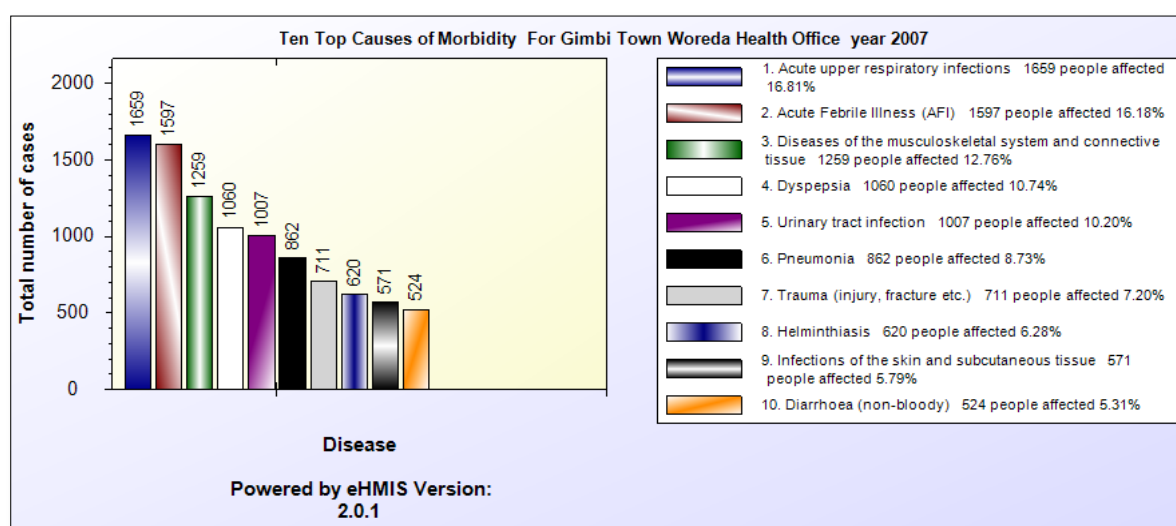


Figure 3-2: Top ten causes of disease of Gimbi Town (Sources: Gimbi Town Health Centre)

3.3 General sanitation service status of the town

The overall sanitation of the town is poor. There is no system for collecting, transporting, and dumping waste in the town.

3.3.1 Solid waste management

The majority of households have no containers for storing garbage. Facilities located few garbage collections in the community. Therefore, residents of the town dispose of domestic waste in any opens paces especially on the river courses, streets road verge and in drainage ditches.

3.3.2 Liquid waste disposal

There is no liquid waste disposal system in the town. The waste resulting from bathing and other domestic washing activities almost entirely thrown out into the streets. There is no specific site for liquid waste disposal.

3.3.3 Toilet facilities

Most of the excreta disposal facilities in Gimbi Town comprise pit latrines, which are frequently poorly constructed, offensive and over filled. According to the town's municipality, the majority of households use toilets in their own compound and the prevalence of open defecation is also significant and demands improvement according to (Oromia Water Design and Supervision Enterprise, 2009).

3.3.4 Sludge disposal method

The municipality does not own a vacuum truck for sludge disposal. Accordingly, households dig a new pit when the old one filled.

3.4 Existing Water Supply System of the town

The existing water supply source of Gimbi town is Gafare River with a weir intake structure. The scheme was studied and designed by German Water Engineering and constructed by Ethiopian Water Works Construction Enterprise. The construction work of the scheme was completed about 20 years ago in 1995. The scheme was designed as emergency water supply service to alleviate the water shortage problems.

Detail information was gathered for clear understanding of the existing water supply demand, coverage, service level, operation, and maintenance of the scheme from Water Supply and Sewerage Authority Office. Moreover, the community in the town needs additional protected water supply sources in the views of beneficiaries both from the commercial, public and domestic consumption due the scarcity of potable water of the existing scheme. This is caused due to the increased living standards of the residents. Therefore, Oromia Water Supply, Mineral and Energy Bureau proposed and designed new water supply project as long-term solution to mitigate the problems.

The system consists of different units: intake weir, raw water pumping station, slow sand filtration, chlorination system, clear water pumping, 400m³ reinforce concrete service reservoir, 100m³ reinforced concrete service reservoir, booster station, twenty functional water point, customers service connection and transmission and distribution pipe system. The

system initially designed to pump water from the 400-m³ service reservoir to 100m³ service reservoirs but now this system is not functional due to shortage of water supply.

3.4.1 Current Status of the System

The status of the water supply scheme was assessed by field observations, discussions with operators and other relevant staff. As a result, the following gaps were identified.

- Communities settled at higher elevation than present service area are not getting water.
- The water draining from the town discharge into Gafare River upstream of the scheme intake structure.
- The system design requires pressure zoning as the expansion of the town is along the main roads on narrow ridge.
- The design of the treatment plant was having pre-treatment unit of horizontal roughing filtration unit and slow sand filtration unit. However, at present the horizontal filtration unit has been changed into sedimentation unit preceded by chemical coagulation system due to frequent clogging of the roughing filter media. For chemical coagulation alum added into the raw water without any appropriate coagulation and flocculation unit as the horizontal roughing unit has not been designed to meet such conditions. Thus, it is anticipated that flocculation and coagulation is not properly carried out in this system. Besides when Alum is added to water, because of the chemical reaction the pH of the water could be low, this in turn could affect slow sand filter unit, which is biological treatment unit that depends on bacteria. The low pH could perhaps kill certain bacteria, which are important for the filtration unit. Moreover, adding of chemical could incur additional cost on the utility.



Figure 3-3: The intake weir structure of water supply source



Figure 3-4: The primary sedimentation tank at treatment plant when Aluminum Sulfate added

From the sedimentation basin the water, drain into the slow sand filter unit. The treated water from the slow sand filter lead to the clear water underground tank. After chlorination for disinfection, water pumped to service reservoir supplying consumers along its way.



Figure 3-5: Mixing systems of chlorination at clear water tank

3.4.2 Components of the existing pipe network of the distribution systems

The transmission & distribution network is branching types. The total length of transmission and distribution networks is about 29.76 km having different types of materials. The diameters of the pipe varies from 25 mm to 250mm. Out of the total length pipelines about 19.4km length (65.73%) are PVC pipes with diameters ranging from 25mm to 250mm, about 9.86 km length (33.4%) are GIP with diameter ranging from 25mm to 80mm and 0.5km length are DCI pipes with diameters of 150mm. The existing pipe networks are shown in figure 3-6.

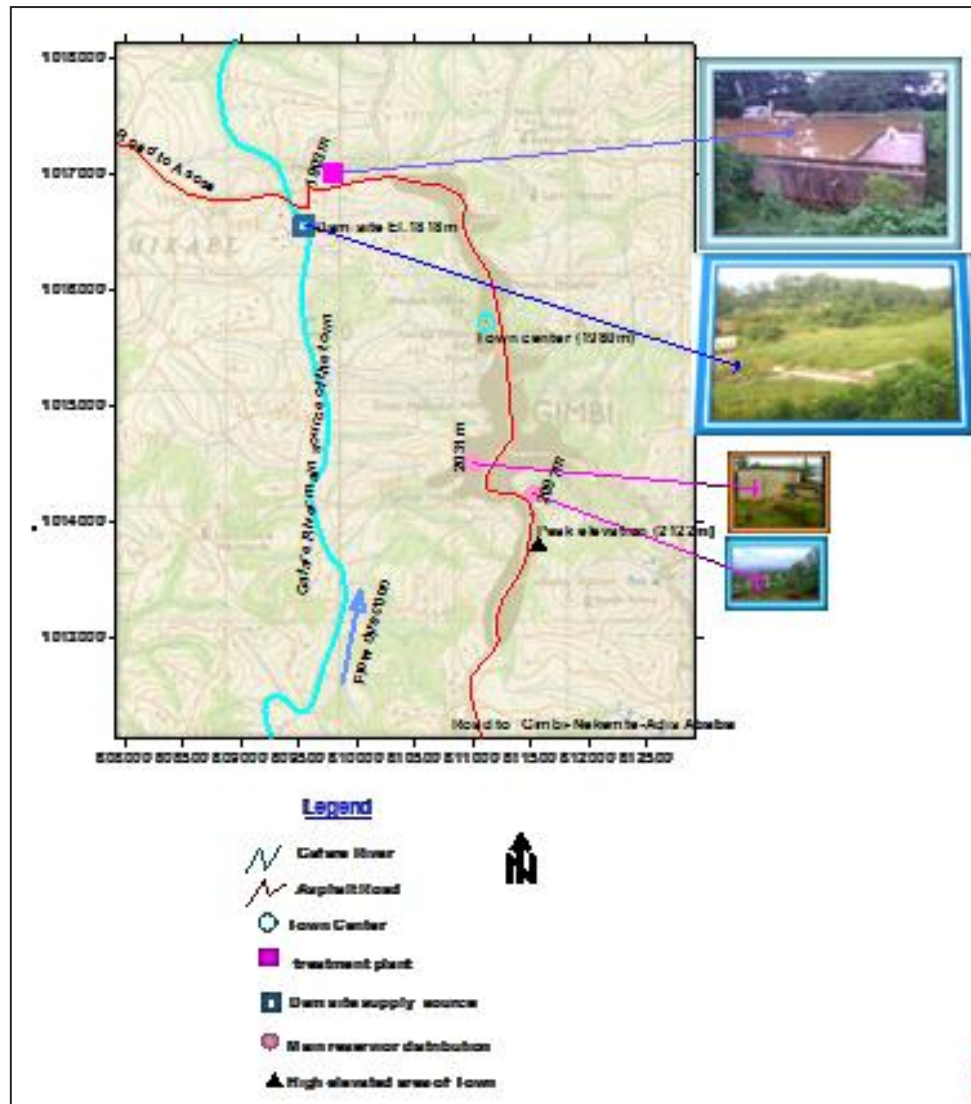


Figure 3-6: Existing Water Supply System of Gimbi Town

3.5 Water Quality parameters and instruments

3.5.1 Physiochemical Test Methods

3.5.1.1 pH, Temperature, Total Dissolved Solids and Electrical Conductivity Measurements

Water samples were collected randomly in properly washed and rinsed appropriate sampling bottles. The pH meter, Cyber scan, PC300PH, Temp., TDS and EC meter having electrodes were used immediately on spot to measure pH, Temperature, Total Dissolved Solids (TDS), and Electrical Conductivity (EC), respectively. These electrodes were immersed in the samples and then the measured parameters were displayed on the LCD screen of the instruments.

The physiochemical tests were performed using DR/2400 spectrophotometer. A powder reagent chemical was dissolved in 10ml of water sample in a cylindrical sample cell and allowed to react. Color develops with intensity proportional to the amount of the target element was measured. Each element has a unique maximum absorption wavelength at which the spectrophotometer was adjusted. Light was allowed to pass through the sample cell so that light is absorbed at the required wavelength. The results were displayed on the LCD screen in mg/l in proportion to the amount of light absorbed at that particular wavelength.

3.5.1.2 Titration

Titration is a laboratory method of quantitative analysis used to determine unknown concentration of a substance by known substance. The analysis was performed using burette-kind of laboratory glass made for exact measurement of volume of solution used by using Digital Titration.

In the total hardness test procedure, the water sample is first buffered (using an organic amine and one of its salts) to a pH of 10.1. An organic dye, calmagite, is added as the indicator for the test. The organic dye reacts with calcium and magnesium ions to give a red-colored complex.

EDTA (ethylene di-amine tetra acetic acid) is added as a titrant. The EDTA reacts with all free calcium and magnesium in the sample. At the end of the titration, when free magnesium ions are no longer available, EDTA removes magnesium ions from the indicator changes its color from red to blue.

3.5.2 Bacteriological Test Method

Water samples were collected in pre-sterilized plastic bags and were filtered on the spot using membrane filters with a pore size of 45µm. The filters were incubated in an ELE Paqualab 25 field incubator, in sterilized aluminum Petridis with a bacterial medium of m-Coli Blue24 on absorbent pad, at 37°C and 44°C for total coli forms and E-coli/fecal coli forms, respectively. The filters were examined for 24 hours to assess bacterial growth. The results were compared with WHO guidelines maximum permissible limit value.

3.5.3 Methods of assessing pollution load of water supply source

BOD and COD tests the pollution load of the source and efficiency of treatment plant. The procedure of samples assessment was made by completely filling clean and dry one litres plastic bottle and sealed. These samples were packed in the Ice box contained crushed ice

with a temperature of less than 4°C and transported a distance of about 441km for 6 hours from Gimbi to Addis Ababa (Oromia Water Mineral and Energy Bureau Water Quality Control Laboratory). In the laboratory the samples temperature were kept at room temperature. For BOD the necessary conditions such as pH and residual chlorine were checked and adjusted. Samples with free residual chlorine were neutralized and seeded. The necessary proportion of bacteria food, Phosphate buffer, Calcium Chloride, Ferric Chloride and Magnesium Sulfate were used. The initial dissolved oxygen for each of the samples was measured and equal volume for each was simultaneously measured and incubated at 20 ± 1 °C in the dark. On the fifth day, the final dissolved oxygen for each incubated sample was measured and the BOD was calculated from the difference between initial and final dissolved oxygen and seed correction for samples with residual chlorine.

For COD, 100ml of each of the sample was taken and homogenized. 2ml of each of the homogenized sample was taken and gently added to the prepared COD vessel. The blank was prepared by adding 2ml of deionized water to another COD vial. The vial contains premeasured amounts of potassium dichromate, sulfuric acid, and catalyst. Heat was provided by the digestion reactor, which kept at 150°C. Each sample was refluxed for 2hours. After the refluxing period was completed, each vial was taken from the reactor, turned up and down, and allowed to cool to room temperature. Finally, the COD was determined using the spectrophotometer.

3.5.4 Procedures for assessing the causes of water pollution and prevalence of water associated diseases

Discussions was made with appropriate stakeholders such as municipality, Health center and hospital regarding sanitation situation and occurrence of water associated diseases such as water borne and water related diseases. Secondary data concerning water borne and water related diseases recorded for the past five years (2009 to 2014) were collected from the Gimbi town health center as shown in Table 3-1. In addition, the actual sanitation situation of the area were observed during site visit.

Table 3-1: Population affected by water associated diseases (Sources: Gimbi Town Health Centre)

year	Total population in the town	infected population with water borne	% of Water borne infected population	infected of water related population	% of Water related population
2002	37359	1528	4.09	70	0.19
2003	38442	2365	6.15	12	0.03
2004	39935	1416	3.55	30	0.08
2005	41128	1464	3.56	37	0.09
2006	42286	1479	3.50	63	0.15
2007	43467	1700	3.91	70	0.16

Detail discussion have been held with Water Supply and Sewerage Authority office concerning the way to operate, carryout maintenance work and daily monitoring of water quality status before distributing to the customers.

3.5.5 Method of Sampling

Samples were taken from locations that are representative of the water source, treatment plant, storage facilities, distribution network, points at which water is delivered to the consumer, and points of use. In selecting sampling points, each locality was considered individually; however, the following general criteria are usually applicable:

Sampling points should be selected in such a way that the samples taken are representative of the different sources and points of distributions. These points should include the samples representative of the conditions at the most unfavorable sources or places in the supply system, particularly points of possible contamination such as raw water sources, treatment plant before and after coagulation process, reservoirs, low-pressure zones ends. The location of sample points selected in this study are shown in figure As depicted below the sampling

points are located enclosed delineated map of the study area as shown in figure 3-7.

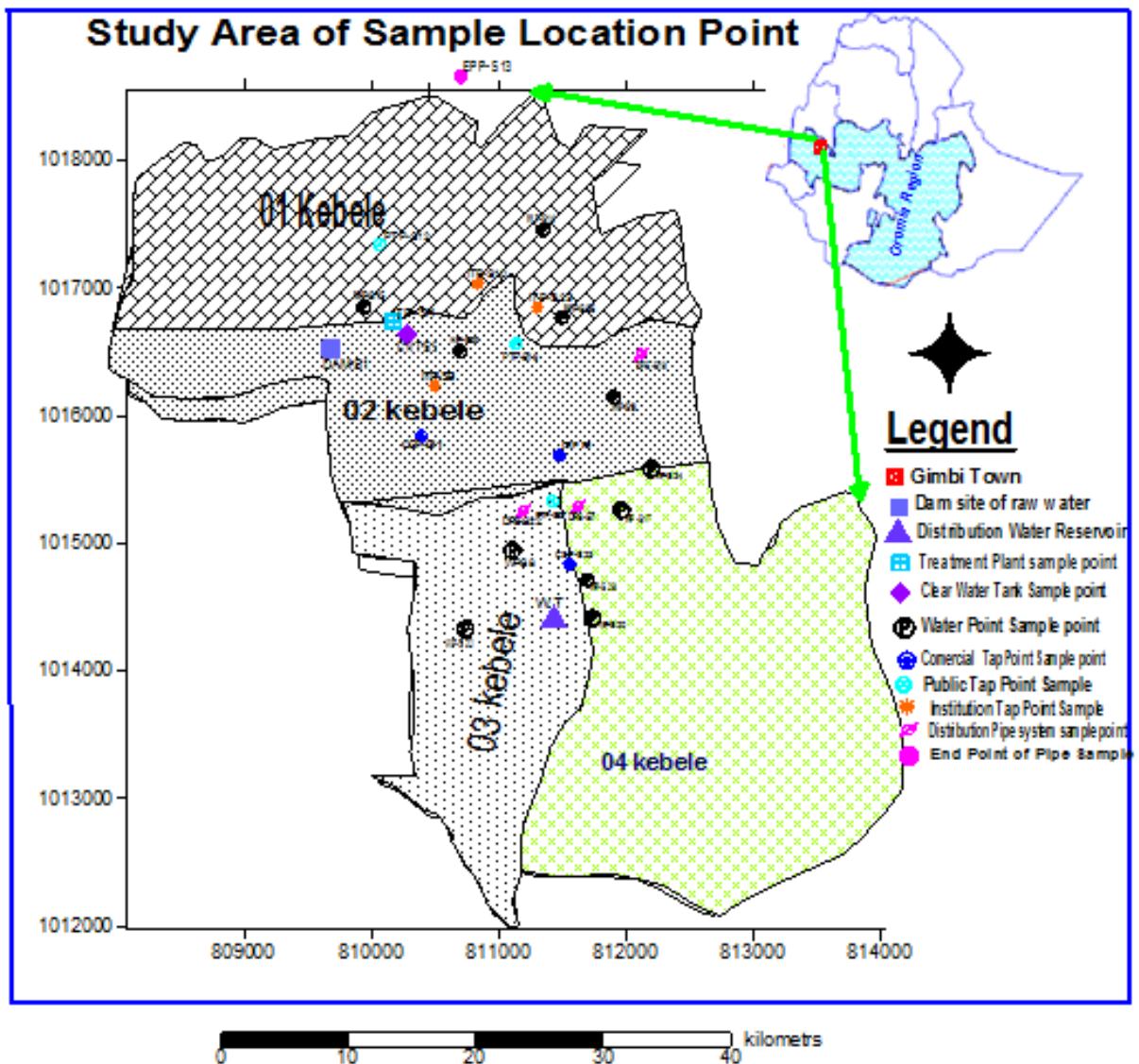


Figure 3-7: Location of the sampling points

3.6 Hydraulic Model: EPANET

3.6.1 The EPANET Model

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of residual chlorine throughout the distribution network (Rossman, 2000).

3.6.2 The EPANET Model Set Up Procedure

One typically carries out the following steps when using EPANET to model a water distribution system:

- ✓ Draw a network representation of your distribution system or import a basic description of the network placed in a text file.
- ✓ Edit the properties of the objects that make up the system
- ✓ Describe how the system is operated
- ✓ Select a set of analysis options
- ✓ Run a hydraulic/water quality analysis
- ✓ View the results of the analysis

3.6.3 EPANET Model Set Up

Water supply network presentation is clear that the ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality is very important.

Regularly system maps are drawn as combination of different system components of the water supply network system. It is mainly includes Reservoirs, Tanks, Pipes, Pumps and Valves as much as possible and the resulting sketch fairly represent the actual water network. With little difference, the real water distribution system showed as combination of nodes and links. Junctions, Reservoirs and Tanks are usually referred as nodes. Pipes, Pumps and Valves were categorized as links as shown in figure 3-8.

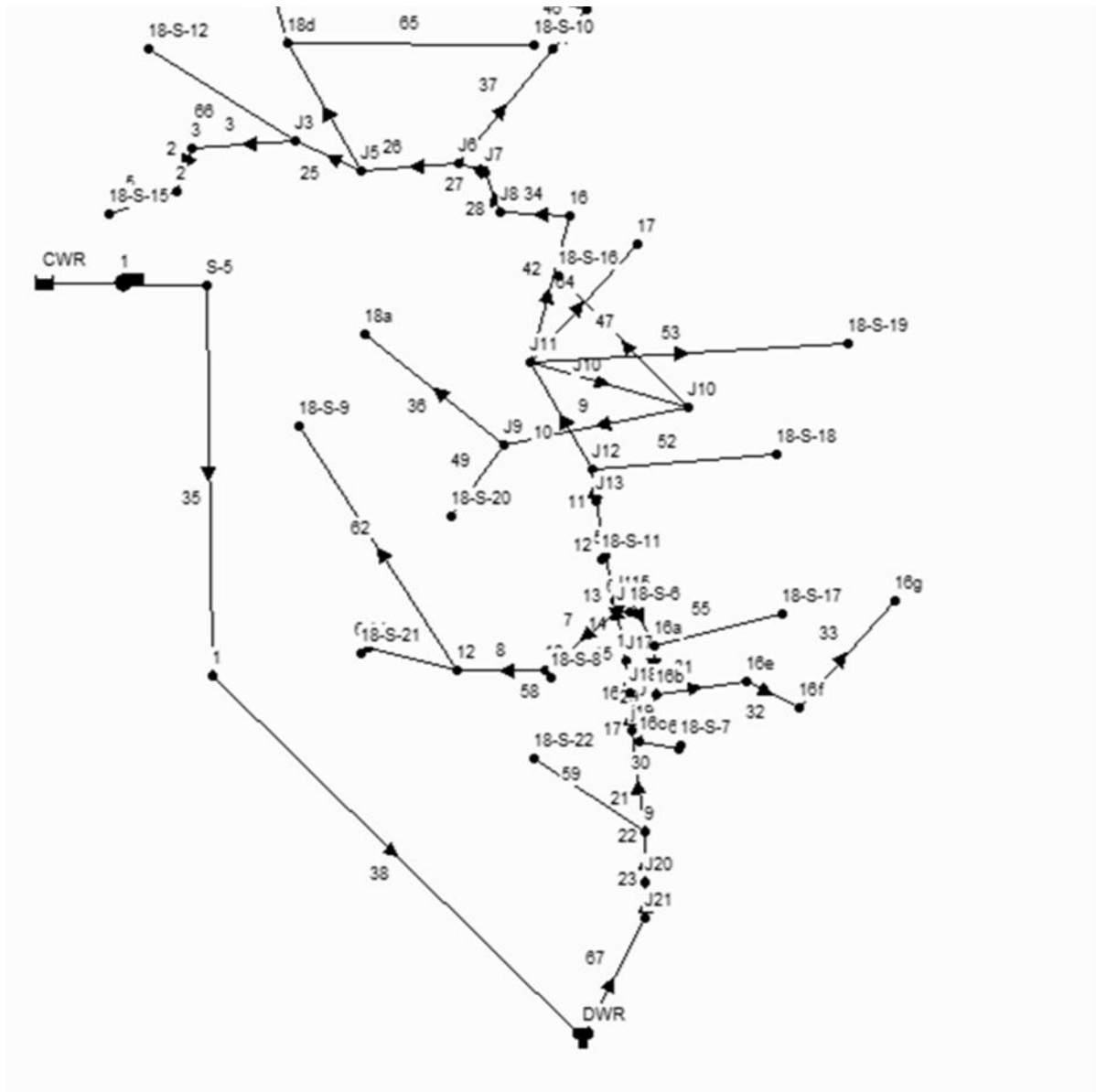


Figure 3-8: EPANET Model Set Up

3.6.4 Water Quality Modelling

Water quality modeling is a direct extension of hydraulic network modeling and can be used to perform many useful analyses. Designers of hydraulic network simulation models recognized the potential for water quality analysis and began adding water quality calculation features to their models in the mid-1980s (Thomas et al., 2003). Transport, mixing, and decay are the fundamental physical and chemical processes typically represented in water quality models. Water quality simulations also use the network hydraulic solution as part of their computations. Flow rates in pipes and the flow paths that define how water travels through the network are used to determine mixing, residence times, and other hydraulic

characteristics affecting disinfectant transport and decay. The results of an extended period hydraulic simulation can be used as a starting point in performing a water quality analysis.

In the large water supply network systems, water wants to travel a large distance with a long water residence time. The problem could affect water quality. This might be due to low pressure, big and multiple reservoir storages, inadequate disinfection in the system, leaking, fracture and work loose of joints, and so on. Even though, the problems of quantity are basic agents in the decay of water quality in distribution systems. One of the parameters that could reason to decrease water quality in distribution system is pressure change in network. Many researchers have been carried out about affects pressure change in the water quality in distribution systems (Shamsaei et al., 2013).

3.6.5 Bottle test

A bottle test allows the bulk reactions to be unglued from other processes that affect water quality, and thus the bulk reaction can be evaluated exclusively as a function of time. The parameter of bulk reaction used to express the rate of the reaction occurring within the bulk fluid is called the bulk reaction coefficients can be determined using a simple experimental procedure called a bottle test. In addition, a bottle test allows for the evaluation of the impact of transport time on water quality and for an experimental determination of the parameters necessary to model this process accurately. Determining the length of the bottle test and the frequency of sampling is the first and most critical decision (Thomas, et al., 2003).

3.6.6 Model Calibration and Validation

Once a water distribution model has been developed, it must be calibrated so that it accurately represents the actual working real-life water distribution network under a variety of conditions. This involves making minor adjustments to the input data so that the model accurately simulates both the pressure and flow rates in the system. Note that both the pressure and flow rates need to be matched together, since pressure and flow rates are dependent upon each other

Pressures are measured throughout the water distribution system using pressure gauge installed at selected location to monitor the level of service and to collect data for use in model calibration.

Therefore, matching only pressures or flow rates is not sufficient. In addition, ideally the model should be calibrated over an extended period, such as a time range for the maximum of one day.

The computed pressure and measured field pressure will not exactly match for every node contained within the network system is 85% of field test measurements should be within ± 0.5 m the computed or simulated pressure by EPANET software at that nodes.

3.6.7 The variation of pressure with residual chlorine

The analysis of the effects of pressure changes on the residual chlorine in water distribution systems are carried out by installing pressure gauge at selected sampling location such as, public fountains, customer tap point, distribution water reservoir, pump house, and other sampling points.



Figure 3-9: Pressure and residual chlorine field measurement

In order to assess the relationship between the pressure and residual chlorine concentration in the system, the measured pressures and chlorine residual collected at different locations were used for calibration and validation of EPANET water quality model.

3.7 Other tools

3.7.1 Global Mapper

Global mapper is the geographical information system (GIS) software package currently developed by Blue Marble Geographic's that runs on Microsoft windows. Global Mapper handles vector, raster, and elevation data, and provides viewing, conversion, and other general GIS features.

The Global Mapper was used for delineation of the study area and sketch the layout of the pipe networks by using GPS data of the sample point locations.

3.8 Method of data analyses

The result of the experimental data was used to analyzing by using application of software such as MS EXCEL, surfer, and GIS softwares. Finally the analysis results was compared with WHO guideline values and Ethiopia Guidelines.

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Water Quality Analysis

4.1.1 Physic-chemical analysis

The physic-chemical parameters directly related to the safety of the drinking water to human consumption. The physic-chemical water quality parameters provide important information about the health of a water body. These parameters are used to find out the quality of water for drinking purpose. During field survey the following physic-chemical parameters were also investigated using laboratorial experiment.

Seventeen samples collected at different components of existing water supply system from source to point of distribution were analyzed. The physical and chemical water quality parameters analyzed in the laboratory were pH, Turbidity, Color, Temperature($^{\circ}\text{C}$), Electrical Conductivity (EC), Total Dissolved solids (TDS), total hardness (TH), Ca^{2+} , Mg^{2+} , alkalinity, Cu, Fe, Mn, K, Ca (hardness), Mg (hardness), nitrate (NO_3^-), ($\text{NH}_4^+ + \text{NH}_3$), Phosphate, sulphate chloride and fluoride. (WHO, 2004).

4.1.1.1 Turbidity

Turbidity is the unit of measurement for quantifying the degree to which light traveling through a water column is scattered by the suspended organic (including algae) and inorganic particles. The scattering of light increases as the presence of suspended load increases and turbidity is commonly measured in Nephelometric Turbidity Units (NTU).

Turbidity may be classified as both as physical microbiological parameter. It is classified as physical parameter, because it can raise aesthetic and psychological objections by the consumer, and as a microbiological parameter, because it may harbor pathogens and obstruct the effectiveness of disinfection. Direct health effects depend on the precise composition of the turbidity-causing materials, but there is other implication. As turbidity can be caused by sewage matter in water there is a risk that pathogenic organisms could be shielded by the turbidity particles and hence escape the action of the disinfectant.

According to the WHO (2012) standard for turbidity, the maximum allowable permissible limit value must always be low, preferably lower than 1 NTU. It is recommended that for water to be disinfected, the turbidity should be reliably less than 5 NTU and preferably have a median value of less than 1 NTU.

Figure 4-1 shows the results of turbidity of Gimbi town water supply during dry and wet season scenarios. The results show that it is much greater than the maximum permissible value recommended by both WHO and Ethiopia recommended values especially during wet (rainy) season.

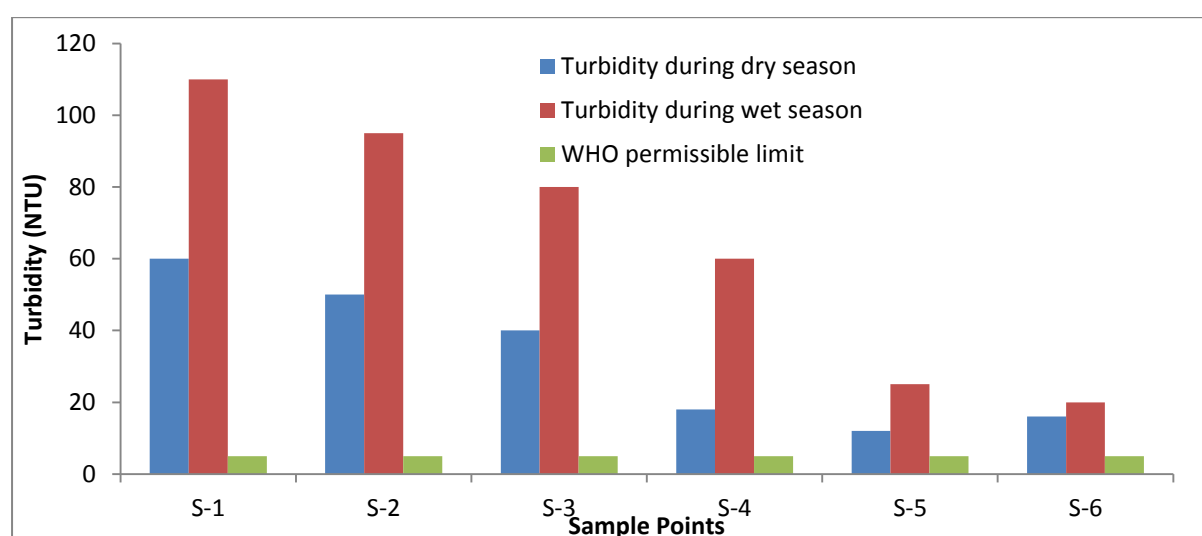


Figure 4-1: Turbidity of Water during dry and wet season as compared with the WHO Maximum Permissible Limit

4.1.1.2 Color

Generally, color can be classified into two types: true and apparent color. The most common cause of true color is decaying organic material such as dead leaves and grass. This type of color usually found in surface water. Apparent color is caused by inorganic materials, usually iron, copper or manganese.

When water has a visible tint to it, it is usually due to the presence of decaying organic material or inorganic contaminants such as iron, copper, or manganese. Limits for color in drinking water are usually set based on aesthetic considerations. According to the WHO (2012) standard guideline, it should not be more than 15TCU, which is the maximum permissible limit.

Figure 4-2 shows that the values of color during wet and dry scenarios. The result indicates that the values are greater than the WHO Maximum Permissible value. In addition, the color values are higher for wet scenarios than the dry scenarios. This is because of the liquid wastes from the town drain to the sources of water supply due lack of properly constructed sewerage system and the source location is downstream of the town.

The color in water does not pose any health risks. However, there are some exceptions. If the color is due to a metal contaminant, such as copper, mild gastro intestinal symptoms may result. We can see that the main causes of color in the study area may be due to decaying of organic material such as dead leaves, grasses and might be due to high iron concentration.

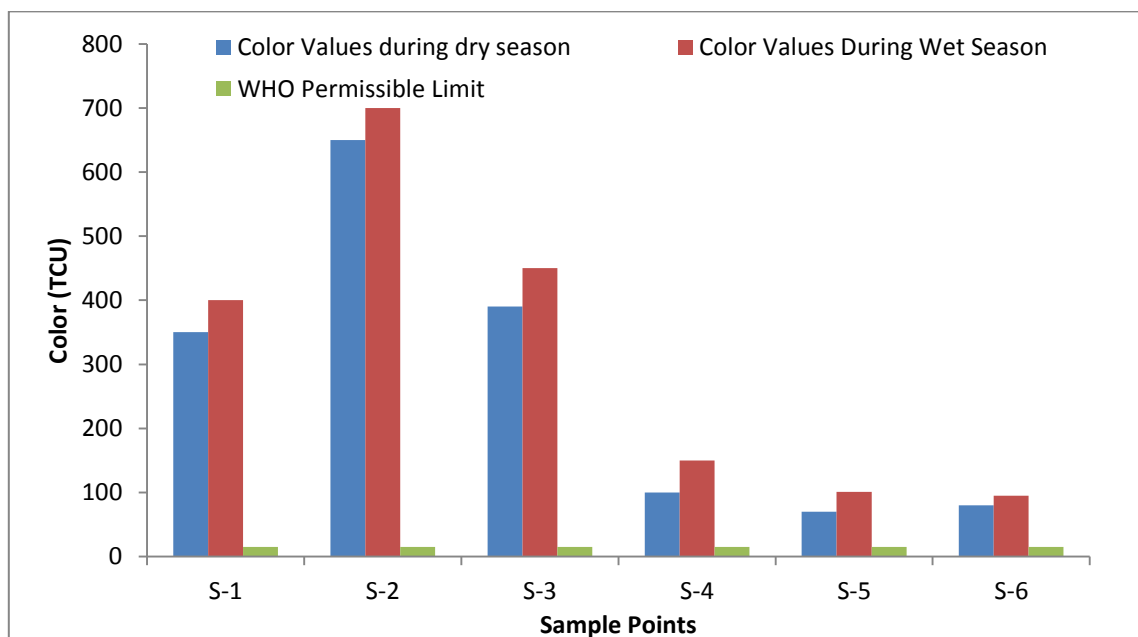


Figure 4-2: The Color Values during Wet and Dry Season as Compared to Maximum Permissible Limit

4.1.1.3 Electrical conductivity (EC)

Electrical Conductivity (EC) was an indicator of total dissolved salts (TDS). It establishes if the water is drinkable and capable of satisfying thirst. The conductivity of potable waters varies generally from 50 to 1500 $\mu\text{mhos/cm}$. The conductivity of municipal wastewater may be near to that of the potable water. However, the industrial wastewaters may have conductivities above 10000 $\mu\text{mhos/cm}$. According to WHO standards the EC value of drinking water supply should not be exceeded 400 $\mu\text{S/cm}$.

The result depicts that the EC values of Gimbi town water supply varies from 85.6 to 103.3 $\mu\text{S}/\text{cm}$, which is below the WHO maximum permissible limits as shown in figure 4-3. These results clearly indicate that the water in the systems are characterized by low ionized and has the low level of ionic concentration activity due to low concentrations of dissolved solids.

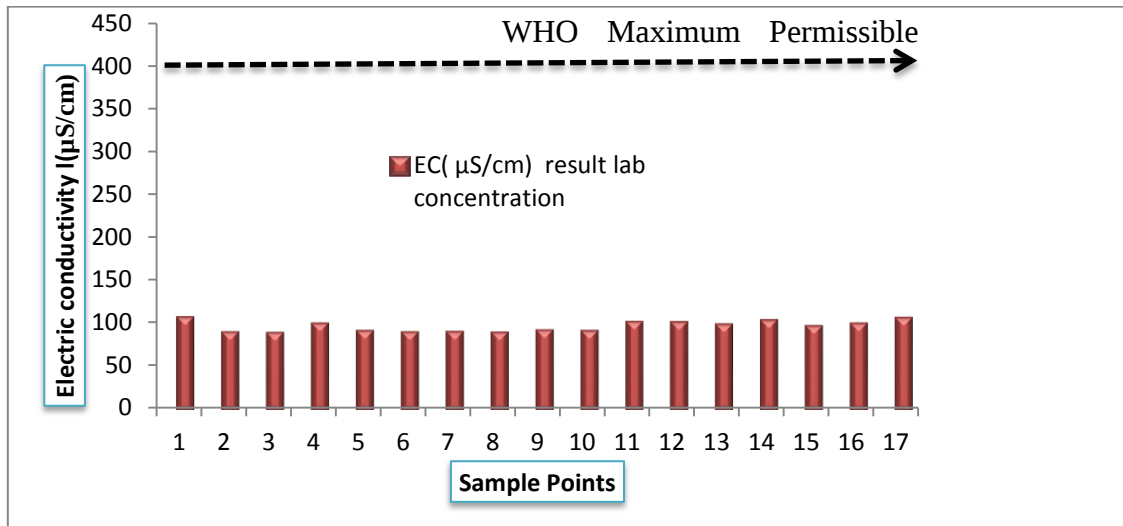


Figure 4-3: Electrical conductivity laboratory results

4.1.1.4 Total Dissolved Solids (TDS)

In drinking water, total dissolved solids are primarily made up of inorganic salts with small concentrations of organic matter. Contributory ions are mainly carbonate, bicarbonate, chloride, Sulphate, nitrate, potassium, calcium, and magnesium. Major contribution to total dissolved solids in water is due to the natural contact with rocks and soil. Minor contribution to TDS are from pollution including urban runoff. In some cases, however, considerable impact occurs from snow and ice control on roads in winter.

The TDS tests are considered to determine the general quality of water. The TDS values found in water supply systems ranges from 42.6 to 51.6 PPM. The health risks are not significant as the values of TDS is much less than 1000 PPM, which is the WHO standard maximum permissible limit.

4.1.1.5 pH of potable water

PH is an index of the amount of hydrogen ions (H^+) that are in a substance. The pH scale measured with respect to neutral substances as reference. Substances with a pH higher than 7.0 (7.1-14.0) are considered alkaline or basic. Substances with a pH less than 7.0 (0 - 6.9)

are considered acidic. According to the WHO, the minimum and maximum allowable pH ranges from 6.5 to 8.5 for portable water.

The pH of water is controlled by the equilibrium achieved by dissolved compounds in the system. In natural waters, the pH is primarily a function of the carbonate system, which consists of bicarbonate and carbonate. Acid inputs to a water system may substantially alter the pH. The main sources of acid include acid mine drainage and atmospheric acid deposition.

There are no health risks related to consuming slightly acidic or basic water. After all, we can eat lemons, drink soft drinks, and eat eggs. However, when water has a pH that is too low, it will lead to corrosion and pitting of pipes in plumbing in distribution systems. Acidic water can be corrected using one of the following two methods:

1. Neutralizing filters increase the pH by passing water through a filter bed of Calcium Carbonate (CaCO_3). This neutralizes the acid and increases the pH.
2. Soda Ash (Sodium Carbonate) solution is fed through a tube into the pumping intake and is automatically injected whenever the water pump is running.

Figure 4-4 depicts the pH values of water in the study area. The pH values range from 6.2 to 6.45 for most of the sample as shown in figure 4-4. In general, the result shows that the existing water supply of Gimbi town is slightly acidic. Therefore, Gimbi Town Water Supply Authority should adjust to recommended ranges by using one the methods above.

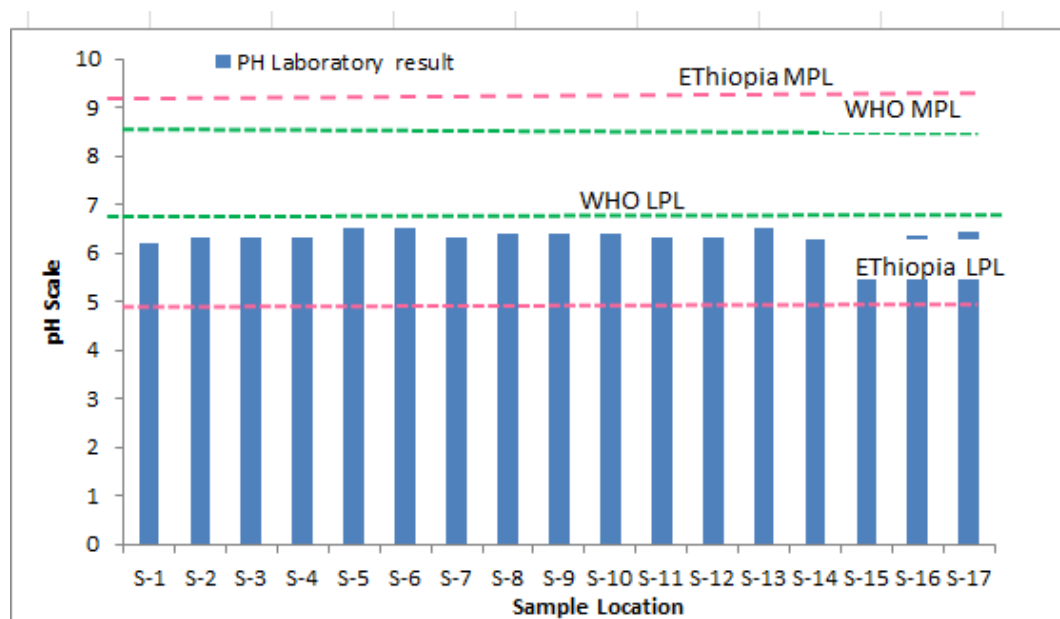


Figure 4-4: pH values compared with the WHO maximum permissible limit

4.1.1.6 Alkalinity

Alkalinity is a measure of the ability of water to absorb hydrogen ions without significant pH change. Simply stated, alkalinity is a measure of the buffering capacity of water and is thus a measure of the ability or capacity of water to neutralize acids. The major chemical constituents of alkalinity in natural water supplies are bicarbonate, carbonate, and hydroxyl ions. These compounds are mostly the carbonates and bicarbonates of magnesium, and calcium. These constituents originate from carbon dioxide (from the atmosphere) and occurring as a by-product of microbial decomposition of organic material or minerals primarily from chemical compounds dissolved from rocks and soil.

From the portability viewpoint, alkalinity is not significant parameter. The concentration of alkalinity varying from 5 to 125mg/l is expected, and extremes of these values are tolerated in water supplies. Titration with Sulphuric acid or other strong acids determine total alkalinity. According to the portability of drinking Water set by WHO standard guideline, the maximum permissible allowable limit should not be exceeded 200mg/l of CaCO_3 .

The Total alkalinity assessment of the study area shows that it varies from 12 to 132mg/l of CaCO_3 as shown in Table A-2a and Table A-2b(page 81) (Appendix). These results show that at all points of sample taken the values of total alkalinity lay below the WHO maximum permissible limit. Thus, there is no significance harm effect on human health.

4.1.1.7 Total hardness

Hardness may be considered as a physical or chemical parameter of water. It represents total concentration of Calcium and Magnesium ions. Originally, hardness was examined and evaluated in raw water sampling as an indicator of water quality in terms of precipitating soap. In this measurement, Calcium and Magnesium are the major precipitating ions. In other words, “hard” water requires more soap to produce foam or lather. The other negative aspect of hard water versus soft water is the natural capacity of hard water to produce scale in hot water pipes, boilers and heaters. Therefore, surface raw water is softer than ground water because of more rains, less contact with soil minerals. From a practical viewpoint, the degree of hardness can be interpreted as follow:

Table 4-1: Summary of hardness and softness categorize range (Source: Dezuane, 1996)

No	Range of concentration (mg/l)	Categorized of hardness
1	0-50	Soft water
2	50-150	Moderately hardness
3	150-300	Hard water
4	More than 300	Very hard water

According to WHO guide line, the maximum permissible limit of total hardness should not be exceeded 300mg/l as CaCO_3 .

The laboratory results shown in Table A-2a and Table A-2b(page 81) (See appendix) shows that the values range between 20 and 118 mg/l of CaCO_3 . Therefore, the degree of hardness of the Gimbi town water supply can be categorized as soft and moderately soft water, which is not harmful for consumers according to the WHO standards.

4.1.1.8 Iron

Iron is the fourth most abundant element in the earth's crust. Iron is a very common problem in drinking water and has a strong relationship with water hardness typically with both hardness and iron increasing at the same time. Iron can cause discoloration (laundry and plumbing), unpleasant taste, color and promotion of growth by iron bacteria. Iron can also precipitate in distribution systems and household plumbing thereby causing additional problems.

When there is no oxygen in the water then the iron is present in a reduced, dissolved form (Fe^{2+}), which is frequently present in well water. This form of iron is dissolved and has no color. When this iron is exposed to oxygen it will oxidize and this iron (Fe^{3+}) is not very soluble and instead forms small particles or colloids. These rust particles are red in color and are quite small making it a challenge to remove them. Both sedimentation and filtration are commonly used methods to remove oxidized iron.

Based on aesthetic reasons the WHO Guidelines Drinking Water Quality recommends that the iron levels should be kept below 0.3 mg/l. However, the laboratory results of the study

area were shown in figure 4-5 and the values were above the maximum permissible limit value. The concentration of iron result was increasing during rainy season than that of dry season. This implies that naturally the iron concentration of the source high concentration of iron and in very old galvanized pipes of water distribution system.

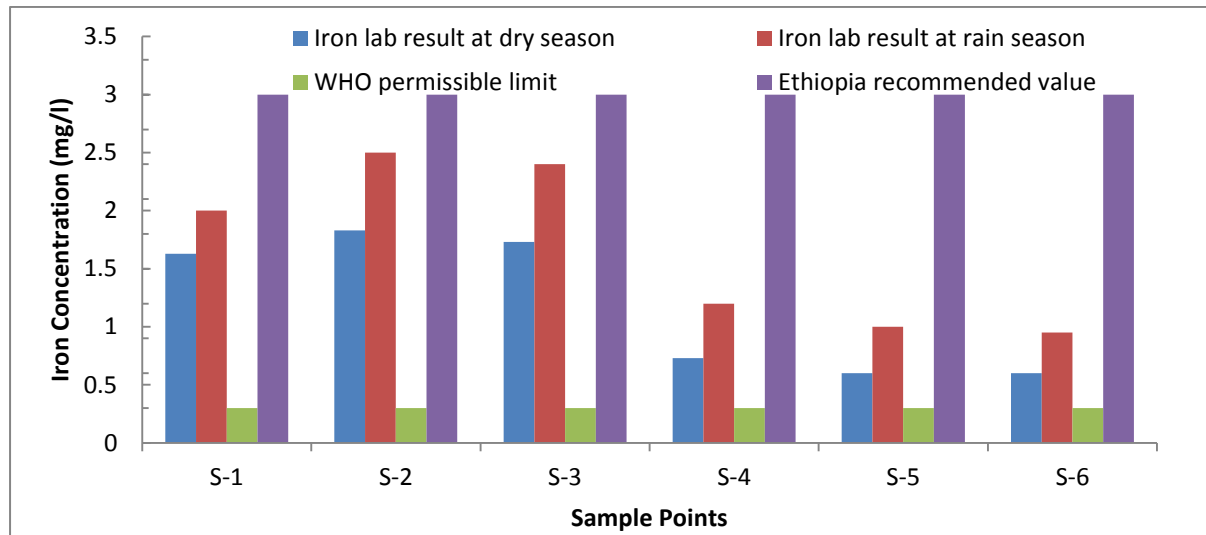


Figure 4-5: The Iron Concentration during Wet and Dry Season as Compared to Maximum Permissible Limit

Iron is an essential element for humans with food providing the majority of the iron requirements. There should be no direct health effects with iron in drinking water, but iron can be linked to excessive bacterial activity. The end-result of this action is water that is not pleasant to drink (smell and taste). Cooking with this water can also lead to a very unpleasant experience, as will using it to do laundry or wash with. Even though the Gimbi Town water Supply & Sewerage Authority Enterprise was aware of this problem and tried to minimize the concentration of the iron in the system within permissible limit by replacing galvanized pipes area into HDPE pipes, minor aeration system should also be developed at the treatment before distributing water to the customers.

4.1.1.9 Manganese

Manganese is a grayish hard white metal similar to iron. Drinking water guidelines for manganese are set for aesthetic reasons as manganese can stain plumbing and laundry as well as telling taste and odor to the water. Manganese containing water can react with coffee, tea and even alcoholic beverages producing a black sludge affecting both taste and appearance.

According to WHO guideline the maximum permissible limit of manganese concentration in drinking water quality should not exceed 0.5mg/l. The laboratory results were shown in Table A-2a and Table A-2b (page 81) (Appendix) and the values are within maximum permissible limit value in distribution system except for the sample taken from raw water and treatment plant before distribution for inhabitants of the town which was found to be between the ranges 0.2-0.7 mg/l of Mn.

4.1.1.10 Copper (Cu)

Copper is a metal that is naturally present in the environment, but the levels of contamination can be increased around agricultural land (manure spreading), near smelting facilities, and phosphate fertilizer plants. There are also significant amounts of copper released from wastewater treatment plants, which could lead to problems downstream for a community that uses this water as their source of drinking water. The World Health Organization has established a 2.0 mg/L of Cu as maximum permissible limit guidance level in drinking water supply.

The most common health effects of the excessive consumption of copper bearing water would be; nausea, vomiting, diarrhea, upset stomach, and dizziness. If extreme intake of copper occurs, kidney and liver damage is possible. Accordingly the laboratory result of the study area were shown in Table A-2a and Table A-2b (page 81) (Appendix), the maximum permissible limit guidance level i.e. less than 2mg/l at all points of sample location. Therefore, there is no health effect regards to this parameters on the customers.

4.1.1.11 Nitrate (NO₃-)

Nitrate (NO₃) is a compound of nitrogen and oxygen that is found in many everyday food items such as spinach, lettuce, beets, and carrots. There are usually low levels of nitrates that occur naturally in water but the majority run-off from, animal feedlots, wastewater and sludge, septic systems, and nitrogen fixation from the atmosphere by legumes, bacteria, and lightning. Nitrate in water is colorless, tasteless, and odorless. Therefore, it can only be detected using chemical analysis as previously explained in methodology section.

Generally, the ground water has high nitrate concentration than surface water because of the percolating sewage, industrial waste, chemical fertilizers, leaches from solid waste landfills, septic tank effluents to the ground water. Whatever may be the reason the high concentration of nitrate is harmful to human beings, particularly for infants. The low acidity in the infants

intestine permits the growth of nitrate reducing bacteria that converts the nitrate to nitrite that is then absorbed in the blood stream. The nitrite has a great affinity for hemoglobin than the oxygen and it replaces oxygen in the blood. The deficiency of oxygen causes suffocation. The color of the skin of the infants becomes blue so it is termed as blue baby disease. The medical name is ‘methemoglobinemia’. This disease is a fatal disease and it takes place when the Concentration of nitrates is more than 50 mg/l according to WHO guideline.

Figure 4-6 depicts that the Nitrate concentration during wet and dry scenarios. The results show in both scenarios the values of nitrate concentration is below the recommended WHO and Ethiopia guideline recommended values. The result also indicates that nitrate concentration during rainy season is greater than the nitrate concentration during dry scenarios. This can be due to the draining of domestic sewerage and agricultural runoff to the water supply source located at downstream of the study area.

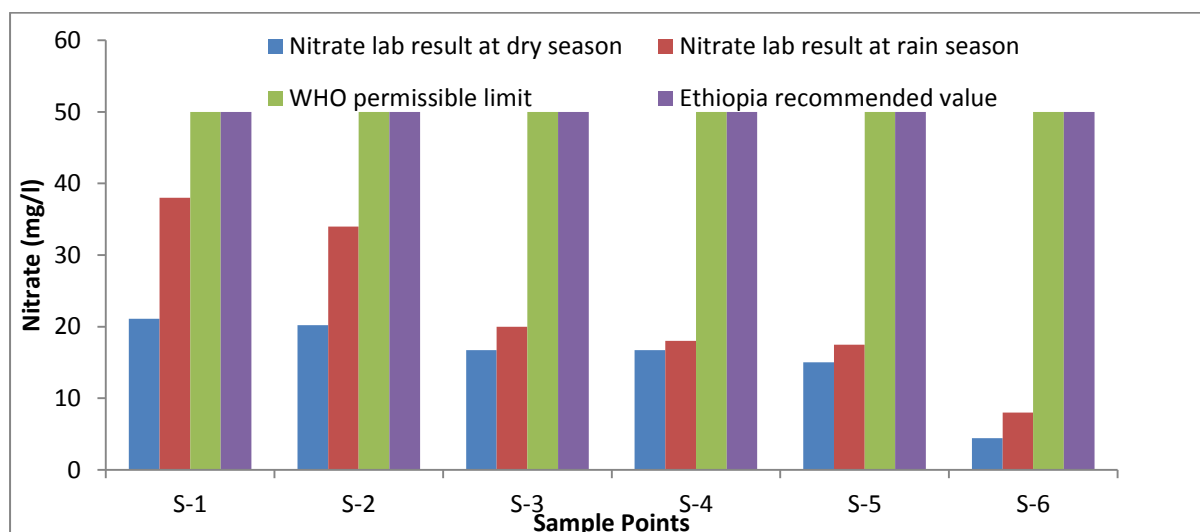


Figure 4-6 : The nitrate concentration during Wet and Dry Scenarios

4.1.1.12 Sulphate (SO_4^{2-})

Sulphur is a non-metallic element that is widely used for commercial and industrial purposes. Sulphur combines with oxygen to form the sulphate ion, SO_4 . Sulphate products are used in the manufacture of many chemicals, dyes, soaps, glass, paper, fungicides, insecticides, and several other things. They are also used in the mining, pulp, sewage treatment and leather processing industries. Aluminum sulphate (alum) is used in water treatment as a sedimentation agent, and copper sulphate has been used to control blue-green algae in raw and public water supplies.

Drinking water with excess sulphate concentrations often has a bitter taste and a strong 'rotten-egg' odor. Sulphate can also interfere with disinfection efficiency by scavenging residual chlorine in distribution systems. Sulphate salts are capable of increasing corrosion on metal pipes in the delivery system and sulphate-reducing bacteria may produce hydrogen sulphate, which can give the water an unpleasant odor and taste and may increase corrosion of metal and concrete pipes.

There are no symptoms associated with sulphate deficiency. However, most people get the majority of their dietary sulphates through food and not from the water. High sulphate levels (1000 mg/L) have been shown to have a laxative effect on humans and can cause mild gastrointestinal irritation (www.safewater.org). According to WHO (2012) guidance level the maximum permissible limit of sulphate in drinking water supply is limited to 250mg/l. Accordingly, the laboratory results of study area at all points of sample location were shown in Table A-2a and Table A-2b (page 81) (Appendix), and the values were very below the maximum permissible limit set by WHO. Therefore, the results clearly indicate that there is no significance effect on the health of the users.

4.1.1.13 Chloride

Chlorides are compounds of chlorine. They remain soluble in water, unaffected biological process, therefore, reducible by dilution. Their concentration at higher levels than adjacent waters is an indication of pollution (usually chloride concentration under 10mg/l is expected (De Zuane, 1996).

High chloride concentration damage metallic pipes and structure as well as harms growing plants. According to WHO standards, the concentration of chloride should not exceed 250 mg/l. In the study area, the chloride concentrations of the laboratory result were ranging from 0 - 12 mg/l as shown in Table A-2a and Table A-2b (page 81) (Appendix). Consequently, all the samples have lower concentration of chloride maximum permissible limit value set by WHO guidance level.

4.1.1.14 Fluoride

Fluoride is essential for human beings to fight against dental caries. The desirable concentration is 1 mg/l, if it is more than this it proves to be harmful. Fluoride concentration of more than 3mg/l is not allowed in potable water in any case. As per WHO, the fluoride

concentration should not be more than 1.5mg/l. Actually the higher concentration of fluoride leads to the discoloration of teeth known as dental fluorosis. The more dangerous is the deformation of the Skelton. In the study area, the fluoride concentration were ranging between 0.05-0.27 mg/l as shown in Table A-2a and Table A-2b(page 81) (Appendix), which is below the maximum permissible limit value set by WHO guidance level. As a result, clearly observed values from the study area there is no health effect of fluoride on the community that use the water.

4.1.1.15 Calcium (Ca^{2+})

Calcium is one of the alkaline earth elements, fifth in abundance in the earth's crust (3%), reacts with water essential constituent of bones and teeth. The most common compounds of calcium are limestone (CaCO_3), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), fluorite (CaF_2), hypochlorite [$\text{Ca}(\text{ClO})_2$], and nitrate [$\text{Ca}(\text{NO}_3)_2$].

Since there are no, or very limited, standards propagated for calcium in drinking water because of no toxicity concern. According to WHO guidance, the maximum permissible limit of calcium, in drinking water quality is limited to 75mg/l for internationally acceptable value and 200mg/l as an excessive limit.

Calcium in drinking water supply has not been associated with any specific disease, and then an upper limit as a guide may be used, such as 75mg/l in relation to hardness. The laboratory result of study area at all sample points of the location were shown in Table A-2a and Table A-2b(page 81) (Appendix). The table shows the values were below the maximum permissible limit set by WHO guide level, i.e. the result range was between 5.6-22.4 mg/l of calcium. This implies that the source of water is almost soft water and there is no any health effect on the users.

4.1.1.16 Magnesium (Mg^{2+})

Magnesium is a light, silver-white, malleable, ductile, metallic chemical element; it is the eight most abundant elements in the earth's crust, never found as a free element.

Magnesium has been considered as nontoxic to humans at the concentration expected in water or not rejected by taste. Magnesium has been used in flashlight photography, alloys, pyrotechnics, and incendiary bombs. In medicine, magnesium is known as “milk of magnesia” as an hydroxide or as “Epsom Salts” as a sulfate. In addition, it is a nutritional

element in animal and plant life. According to WHO International Standard of Drinking Water (1963), the list of the maximum acceptable level is 50mg/l and a maximum allowable level is 150 mg/l. Even though, magnesium concentration was expected in raw and finished water supply system between range 1.8-62mg/l, and 0.8-49mg/l respectively ((De Zuane, 1996). The laboratory result of the study area of Gimbi Town Water supply were found between the range of 1.44-30.16mg/l of (Mg^{+2}) and these values are below the maximum acceptable level set by WHO as shown in Table A-2a and Table A-2b (page 81) (Appendix).

4.1.1.17 Potassium (K^{+})

A soft, light, silvery-white, wax like, metallic, common chemical element of the alkali group, similar to sodium, that oxidizes rapidly when exposed to air. Potassium is the seventh most abundant element and constitutes 2.4% by weight of the earth's crust. It never exists free in nature and most potassium minerals are insoluble. In drinking water supply, tap surveys indicated values of potassium ranging from a minimum of 0.5mg/l to a maximum of 8mg/l with an expected mean concentration of 2mg/l. According to the WHO, the maximum permissible limit value for potassium is limited to 1.5mg/l. The laboratory result of potassium concentration at all sample points of the location of the study area were found between the expected range described above and below the maximum permissible limit value set by WHO as shown in Table A-2a and Table A-2b (page 81) (Appendix).

4.1.1.18 Chromium (Cr^{+6})

Natural occurrence of chromium is in ore, but chromium arises in surface waters from discharges from electroplating, tanning, textile, paint and dyeing plants.

Regarding health significance, chromium is toxic, to a degree which varies with the form in which it occurs, whether as the trivalent, Cr^{+3} , or the hexavalent, Cr^{+6} , form.

The element is an essential nutritional requirement in limited amounts and its deficiency can lead to disturbance of glucose metabolism. Certainly, it has been reported that chromium deficiency is of greater nutritional concern than overexposure. However, it is considered that the element is carcinogenic at high concentrations, though much more evidence of this is needed, and it can act as a skin irritant. Hence, it should have a limitation in domestic water supplies. The result of watering in chromium-contaminated water might be deaths of livestock. According to the WHO guidance level, the maximum permissible limit in drinking

water supply is 0.05mg/l Cr. Therefore, as the laboratory results of study area were shown in Table A-2a and Table A-2b(page 81) (Appendix), at all sample points the maximum result was 0.01mg/l Cr. This value is below the maximum permissible limit. This result indicates that there is no health significance on the users.

4.1.1.19 Phosphate (PO_4^{3-})

Drinking water supplies may contain phosphate derived from natural contact with minerals or through pollution from application of fertilizers, sewage and industrial wastes.

The significance of phosphorus is principally regard to the phenomenon of eutrophication (over-enrichment) of lakes and, to a lesser extent, rivers. Phosphorus gaining access to such water bodies, along with nitrogen as nitrate, promotes the growth of algae and other plants leading to blooms.

Phosphorous concentration in raw waters has been reported to be 50% of the samples tested, with mean concentration of 0.12mg/l and maximum of 5mg/l. But the WHO also did not issue regulations or guidelines for phosphorus, but European community (1980) issued a guide number of 0.4mg/l and a maximum of 5mg/l measured as P_2O_5 (De Zua (D.P.Gupta & J. P. Saharan, 2009)ne, 1996). The laboratory results of phosphate of the study area were shows according to (De Zuane, 1996) above the maximum acceptable limit, especially from raw water to treatment plant. This increases of concentration of phosphate result might be due to location of the source own stream of the town and lack of properly sewerage control system in the town as previously explained in the description of the study area in this paper.

Figure 4-7 depicts that the phosphate concentration during wet and dry scenarios. During the rainy season above the maximum permissible, limit. . This can be due to the draining of domestic sewerage and agricultural runoff to the water supply source located at downstream of the study area.

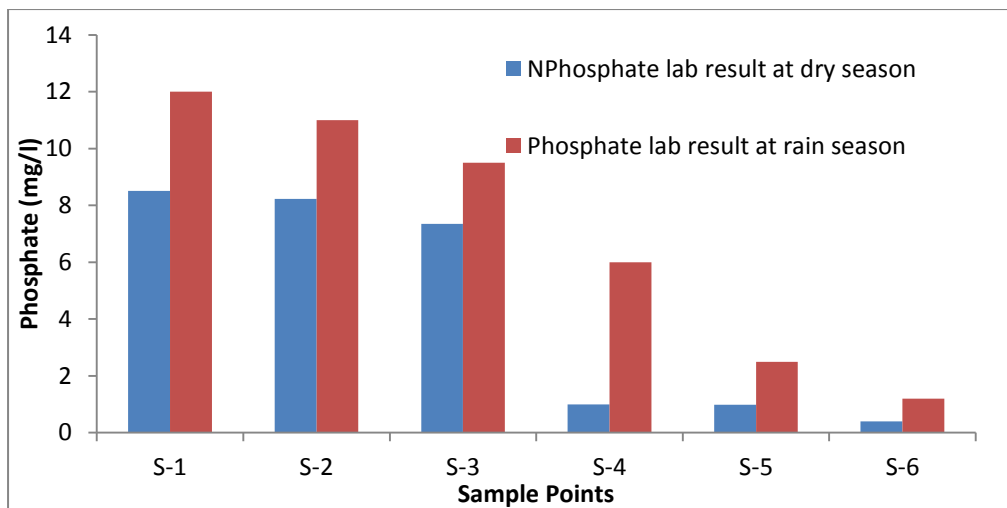


Figure 4-7: The Phosphate concentration during Wet and Dry Scenarios

4.1.1.20 Residual chlorine

Chlorine is a chemical that is used to disinfect water prior to it being discharged into the distribution system. It is used to ensure the water quality is maintained from the water source to the point of consumption. When chlorine is fed into the water, it reacts with any iron, manganese, or hydrogen sulphide that may be present. If there is any chlorine residual left, it will then react with organic materials, including bacteria. In order to ensure that water is sufficiently treated through the whole distribution system, an excess of chlorine is usually added. This amount is usually adjusted to make sure there is enough chlorine available to completely react with all organics present. The chlorine will decrease in concentration with distance from the source, until it reaches the point where the chlorine level can become ineffective as a disinfectant. Bacterial growth will occur in distribution systems when very low levels of chlorine are encountered. Therefore, it is important to make sure there is enough chlorine to efficiently disinfect even at the far ends of the distribution system. Chlorination can kill many pathogenic, disease-causing microorganisms such as E-coli, but others, like Cryptosporidium and Giardia, are very resistant to chlorine and require other measures to properly remove them.

The World Health Organization guidance level for drinking water supply recommends a minimum free Chlorine residual of 0.2mg/L and maximum residual chlorine 0.5mg/L (www.Safewater.Org) in the distribution systems of any water supply.

Studies have shown that when residual chlorine levels drop below recommendations, several water quality problems can occur. With regard to public health, bacteria and selected viruses

called bacteriophage are able to multiply in water that was not properly disinfected. Moreover, depending on the species, could potentially cause waterborne diseases. It is important to note that, although chlorination has been the most common method of disinfection for over many years. While recommendations only state minimum residual chlorine levels, it is important that a careful balance be maintained in drinking water. There needs to be enough chlorine to make sure everything is properly disinfected. However, as shown the laboratory and model simulation results of the study area were high loss of chlorine in the system.

4.1.2 Bacteriological test analyses

Table 4-2: Bacteriological laboratory analysis result

Sampling	E-coli/100ml or faecal coliform	Total coli form/100ml	Remark
S-1	Too numerous to count	Too numerous to count	High risk
S-2	Too numerous to count	Too numerous to count	High risk
S-3	30	70	Medium risk
S-4	Nil	15	"
S-5	Nil	Nil	no risk
S-7	Nil	Too numerous to count	High risk
DWR	Nil	Nil	no risk
18-S-15	Nil	6	Low risk
J20	Nil	4	Low risk
S-12	Nil	Too numerous to count	High risk

Therefore, the bacteriological test analysis of the study area were shown to be above the maximum permissible limit at some sample points when compared with the values set by the WHO as presented Table A-1a and A-1b respectively on page (78) (Appendex). Except at raw water and treatment plant at which the result shows it is too numerous to count (TNTC) total coliforms, which is very high risk in the two scenarios i.e. during dry and wet season. However, most of the system nodes have low risk number of coliform. This result indicates that additional chlorine is needed at sedimentation tank and in the distribution systems to be applied to assure a better quality of drinking water.

4.1.3 Biological pollution load of the source and prevalence of Water borne diseases analysis

Biological pollutants have a combination of inorganic and organic constituents and are characterized by being cellular in nature. For biological treatment purposes, only the organic constituents can be destroyed, and since all cellular material uses oxygen for energy, tests involve the measurement of either carbon content or oxygen demand, or an actual bacterial count.

4.1.3.1 Dissolved Oxygen (DO)

Raw water evaluated for potential use as a drinking water supply normally sampled, analyzed, and tested for biochemical oxygen demand when water turbid, polluted water is the only source available. Therefore, the Dissolved Oxygen of the study area as obtained from the laboratory result is found between the ranges of 2.23mg/l-6.03mg/l at all sample points of location (See Table A-3a and A-3b on page (82)).

4.1.3.2 Biochemical Oxygen Demand (BOD)

BOD was defined as the amount of dissolved oxygen demanded by bacterial during the stabilization action of the decomposable organic matter under aerobic conditions. This test, therefore, is a bioassay procedure to measure the oxygen consumed by living organisms utilizing the organic matter contained in the sample more likely of wastewater and the dissolved oxygen of the liquid.

The BOD test is based upon determination of dissolved oxygen. Most river waters used as water supplies have a BOD of less than 7mg/l; therefore, dilution is necessary.

According to De Zuane (1996), A BOD test is not required for monitoring water supplies. however, In this study the determination of BOD was required because of the coffee factory wastes discharge into the Gafere river.

The BOD concentration laboratory results decreases from the source to the distribution system as shown in Table A-3a and A-3b on page (82) respectively (Appendix). In addition, the concentration of BOD is higher during rainy season than during dry season at the source as shown in figure 4-8.

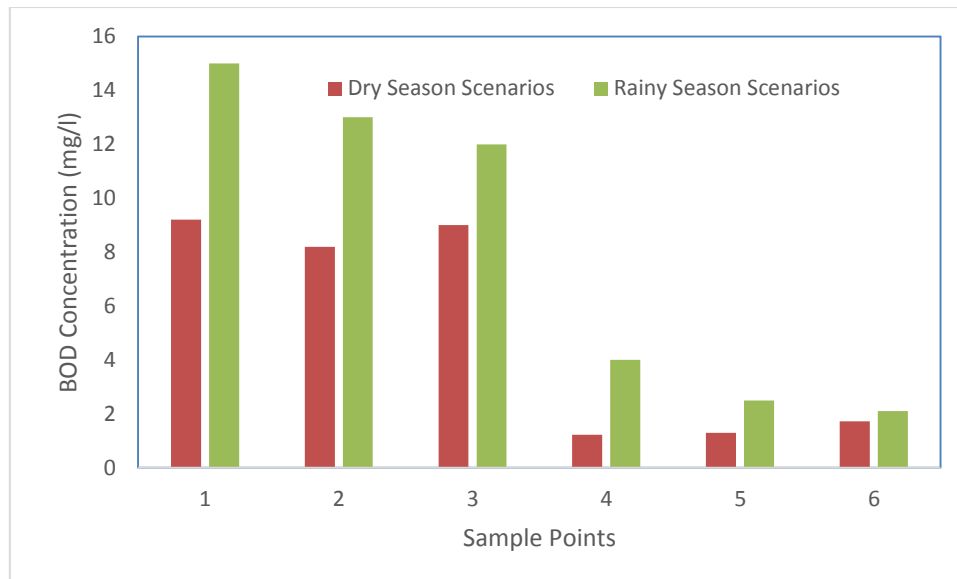


Figure 4-8: BOD concentration during Dry and Wet Season Scenarios

4.1.3.3 Chemical Oxygen Demand (COD)

This is another parameter not requested for monitoring water supplies but sometimes used for evaluation of industrial polluted raw water. Extremely useful in the determination of industrial wastes, and very practical in the determination of domestic waste and polluted waters. COD determination “provides a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by strong chemical oxidant such as potassium dichromate standard method” (De Zuane, 1996). The COD values are greater than the BOD values, but its handicap is the inability to show difference between logical oxidizable and biologically inert organic matter. Since COD can be in 2 hours versus the five day of BOD, sometimes COD for substitute the BOD test practically. As the result of the study area of COD test concentration were shown in Table A-3a and A-3b on page (82) (Appendix), the concentration from source to the distribution system was decreased and greater than concentration of BOD test.

4.1.4 Prevalence of the water associated diseases of the study area on the public health

The proverb “water is life” is found in many cultures around the world. It underlines the fact that clean water is an absolute prerequisite for healthy living. The importance of water in human well-being cannot be over-emphasized. The normal functioning of the human body depends entirely upon an adequate quantity and quality of water. However, if the water is from contaminated sources, it causes numerous water-associated diseases.

In the developed world, water-associated disease are rare, due essentially to the presence of efficient water supply and wastewater disposal systems. However, in the developing country, the majority of people are without a safe water supply and adequate sanitation. According to WHO surveillance highlighted each day, 30,000 people die and 80% of all illnesses in developing countries from water-associated diseases Collaboration with the Ethiopia Public Training Initiative ((Zeyede & Tesfaye, 2004) .

Therefore, the study area of Gimbi Town drink water supply was very poor aesthetical and acceptability regards to lack of properly sewerage system management and location of the source as previously discussed in the description of study area. So that start from these situations of the town to try surveillance water associated diseases such as water borne and water related diseases recorded from 2009-2014 in different kebeles from Gimbi Town Health Centre by developed format as shown in figure 4-9.

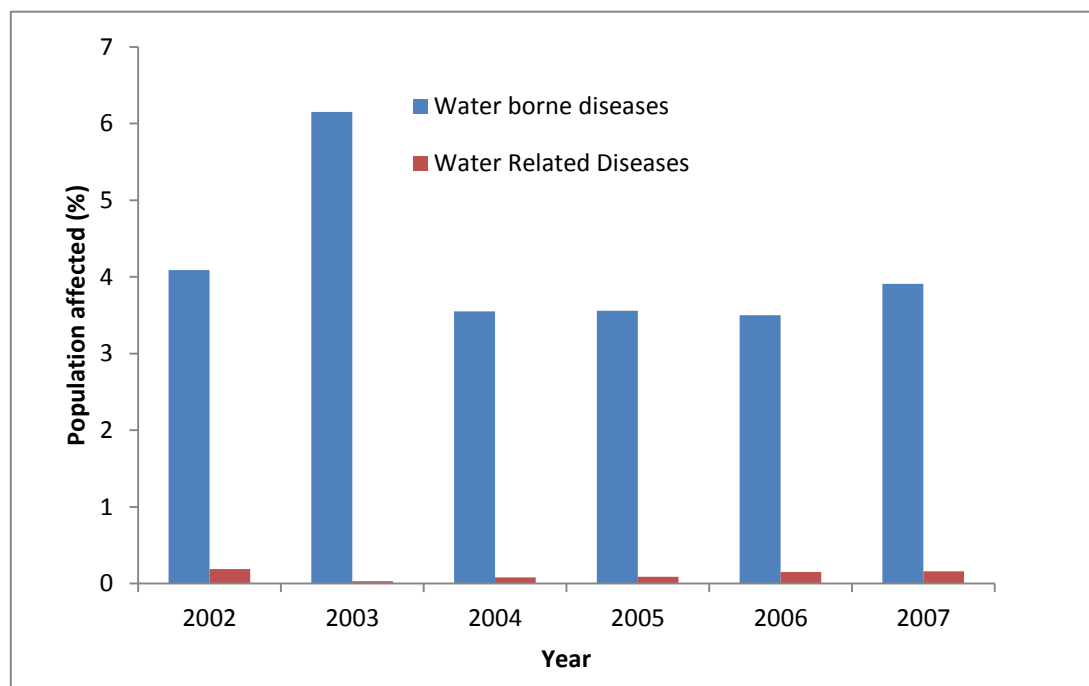


Figure: 4-9: Gimbi Town Water Associated Diseases Report Data (Source: Gimbi Health Centre)

4.2 Water Quality Modelling Results

4.2.1 Model calibration and validation

Calibration is an iterative procedure of parameter evaluation and adjustment by comparing simulated and observed values.

The EPANET Model was calibrated by adjusting sensitive parameter such as Hazen Williams's coefficient. Twenty observed pressure data were collected at public fountains, distribution reservoir, customer tap point, institution tap point, and commercial tap points, which are shown in Table A-6, A-7, A-8, A-9, A-10 and A-11 (Appendix). These pressures, tank level and flow data were taken at both peak hourly demand and minimum hourly demand (midnight).

Model validation is in reality an extension of the calibration process. It is used to assure that the calibrated model properly assesses all the variables and conditions, which can affect model results, and demonstrate the ability to predict field observations different data set.

The hydraulic model calibration parameters that are typically set and adjusted include pipe roughness factors and Control valve setting. The change in these parameters affect head losses, demands at node, pressure and residual; chlorine. The result shows that when the Hazen-Williams roughness coefficient increases the value of pressure increases and head losses decreases.

4.2.2 Model Performance Evaluation Criteria

There are many ways to judge on the performance of model calibration. The evaluation were made by calculating the squared relative difference between observed and simulated pressure for each test. The evaluation criteria used was statistical method using correlation coefficient (R^2) and Root Mean Square Error (RMS) and graphical method.

$$R^2 = \frac{(\sum(x - \bar{x})(y - \bar{y}))}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

Where R^2 = Correlation Coefficient, x and y are measured and simulated values respectively, $\bar{x}$ and $\bar{y}$ are average values of measured and simulated, respectively.

4.2.3 Pressure and flow calibration and validation

As pressure criteria calibration was 85% of the pressure field test measurements should be within $\pm 0.5\text{m}$ or $\pm 5\%$ of the maximum head loss across the system of the simulated pressure, whichever is greater according to (Thomas et al. 2003). According to Thomas (2003), for the smaller water supply system having less than or equal to 600mm diameters, the model should be accurately predict hydraulic grade line (HGL) to within 1.5–3 m depending on size of the system at calibration data points during fire flow tests and to the accuracy of the elevation and pressure data during normal demands. It should also reproduce

tank water level fluctuations to within for EPS runs and match treatment plant/pump station/ well flows to within 10–20 percent. But for master planning of larger water supply systems which has greater than or equal to 600mm diameters, the model also should be accurately predict HGL within 1.5–3 m during times of peak velocities and to the accuracy of the elevation and pressure data during normal demands. It should also reproduce tank water level fluctuations to within (1–2 m) for EPS runs and match treatment plant, and pump station flows to within 10–20 percent (Thomas et al., 2003).

4.2.4 Pressure calibration using time series along pipe networks

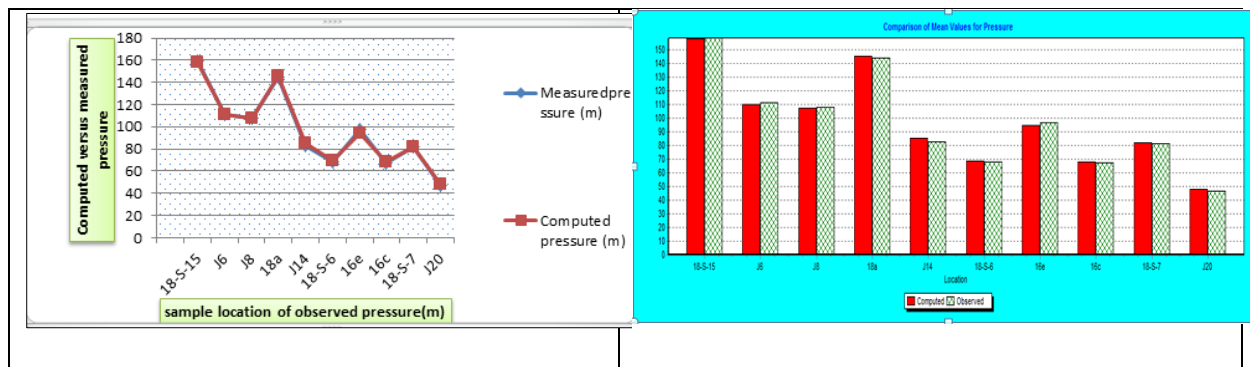


Figure 4-10: Observed versus Compute Pressure during calibration

The calibration of pressures were done both graphical and statistical method. Figure 4-10 shows the graphical representation of measured and computed pressure at different locations and time series.

Figure 4-11 shows that the statistical correlation plot of observed versus computed pressure during calibration process. The results show that R^2 value of 99.85%. This implies that the computed pressures are within the acceptable limit recommended by Thomas et al., 2003.

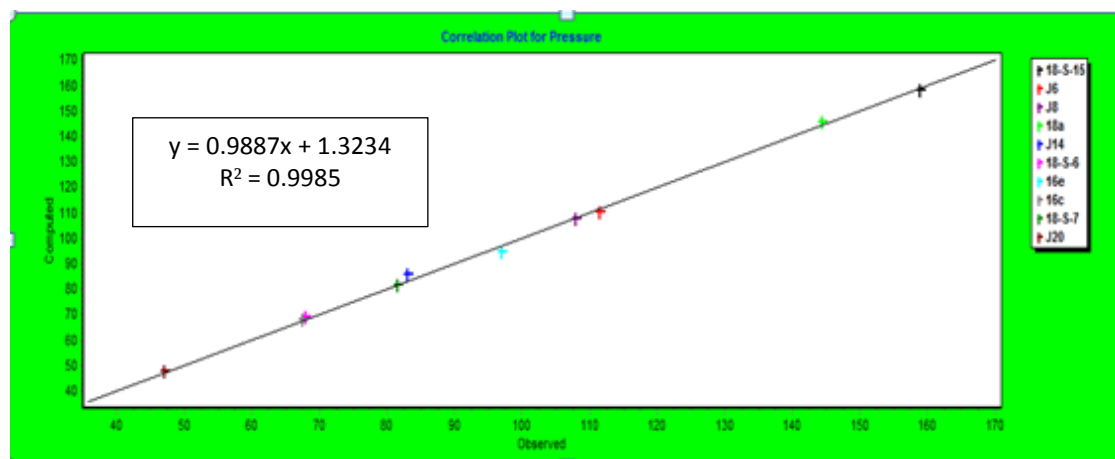


Figure 4-11: Correlated plot of computed versus observed pressure during calibration

4.2.5 Pressure validation using time series along pipe networks

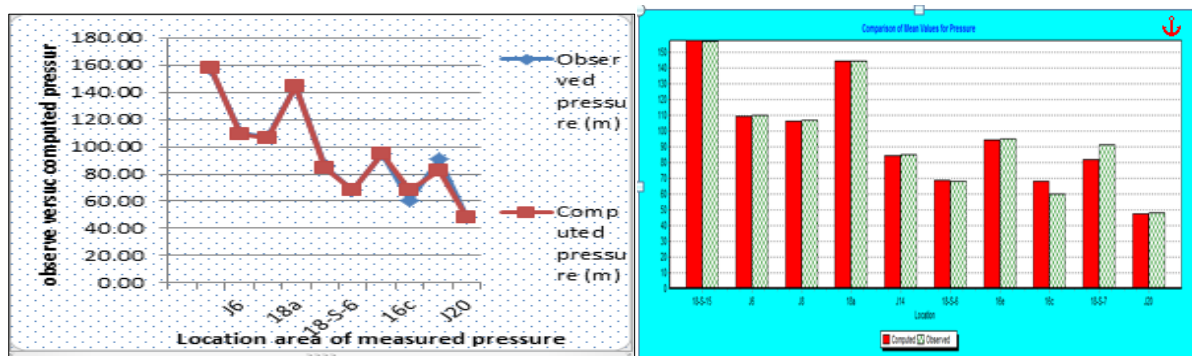


Figure 4-12: Observed and Computed Pressure during validation

The validation of pressures were done both graphical and statistical method. Figure 4-12 shows the graphical representation of measured and computed pressure at different locations and time series.

Figure 4-13 shows that the statistical correlation plot of observed versus computed pressure during calibration process. The results show that R^2 value of 98.7%. This implies that the computed pressures are within the acceptable limit recommended by Thomas et al., 2003.

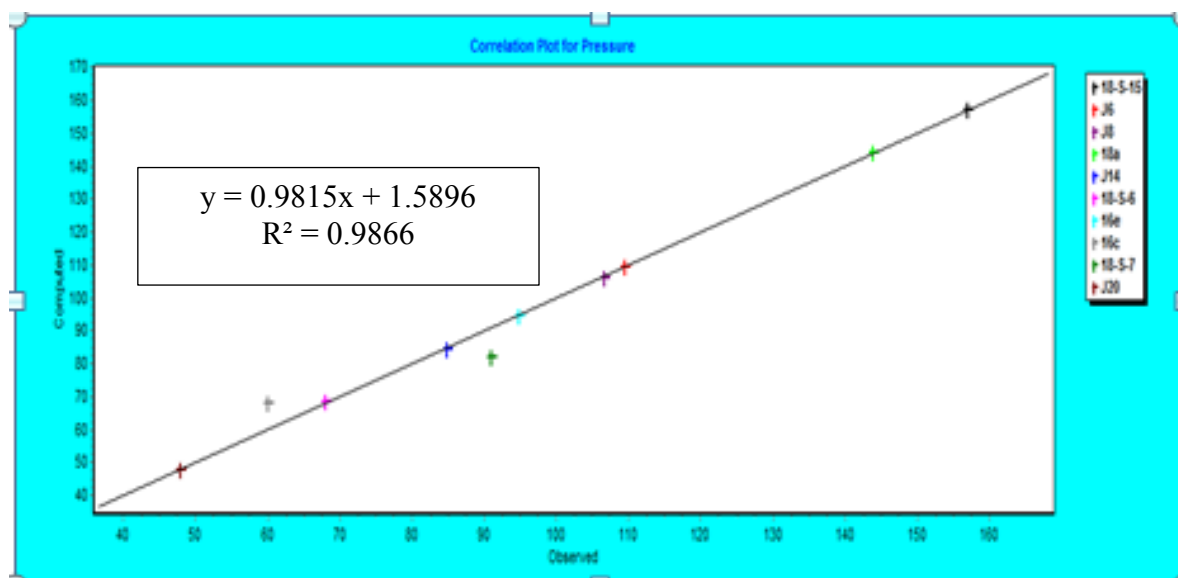


Figure 4-13: correlated plot of observed versus computed pressure during validation

4.2.6 Tank level and link flow time series calibration

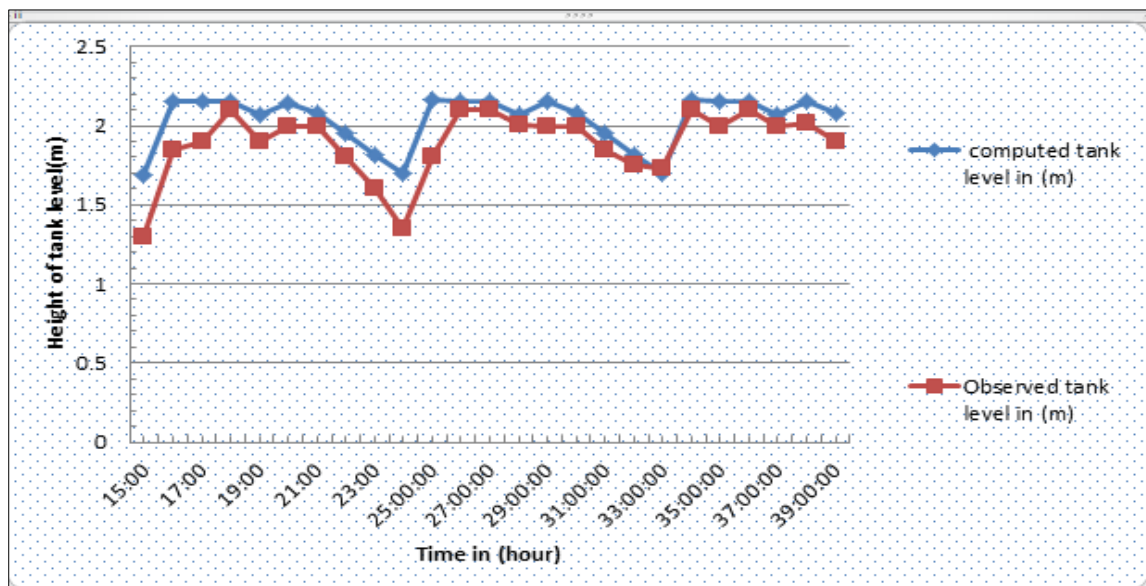


Figure 4-14: Tank level and link flow calibration

Figure 4-14 depicts graphical method of comparing observed versus simulated tank level and link flow during calibration at peak hourly demand. The result show that R^2 value of 86%.

Figure 4-15 shows that the graphical plot of observed versus computed at pipe main truck out from the tank during calibration process. The result show that R^2 value of 95.6%. This implies that the computed pressures are within the acceptable limit recommended by Thomas et al., 2003.

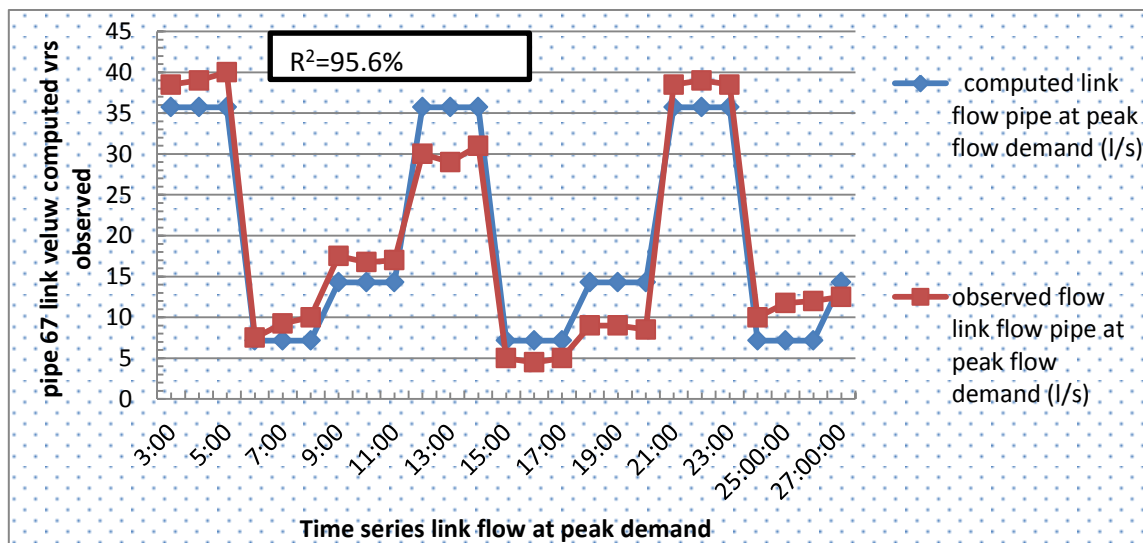


Figure 4-15 Pipe main track no-67 link flow calibration at peak hour demand

4.2.7 Tank level and link flow time series Validation

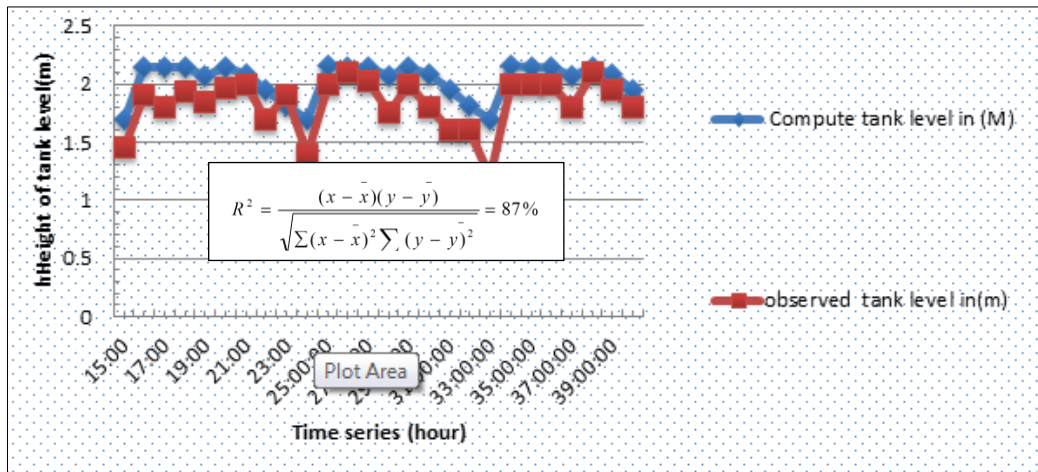


Figure 4-16 Tank level and link flow time series validation

Figure 4-16 depicts graphical method of comparing observed versus simulated tank level and link flow during validation at low hour demand. The result show that R^2 value of 87%.

Figure 4-17 shows that the graphical plot of observed versus computed at pipe main truck out flow from the tank during validation. The result show that R^2 value of 99.4%. This implies that the computed pressures are within the acceptable limit recommended by Thomas et al., 2003.

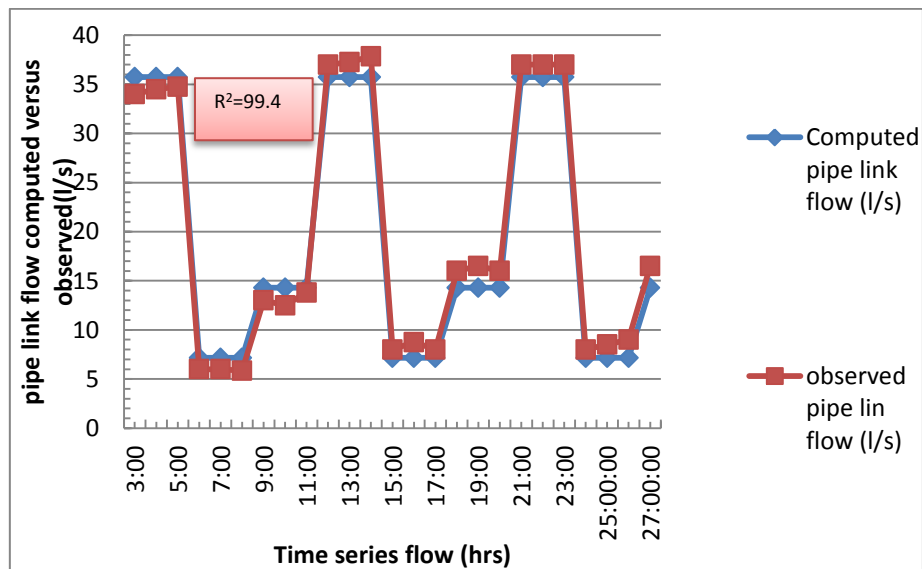


Figure 4-17: Pipe main track at no-67 link flow validation at low flow demand

4.2.8 Bottle Test

Laboratorial tests for bulk coefficient determinations were done in three test periods. Fundamentally, three test periods were favored in order to avoid possible error and make sure that the result of each test is almost the same. Three test samples were collected for each test period and measurements were taken starting from collection time. However, samples were brought to laboratory and stored in complete darkness with temperature held constant that is by keeping the sample in the dark room being protected from direct sun light. The samples were dragged at designated times and measured which provides the experimental result for all tested samples. The result for samples collected from same locations. For hydraulic analysis, simulation time step was with 1-minute intervals over a 24-hour period. Beside with hydraulic analysis, water age and thus retention time was determined by setting initial estimates of water age in reservoirs and tanks. The considered water age was used to fix maximum hour to run bottle test for the determination of bulk reaction coefficient in water quality laboratory. After all measurements have been taken and the experiment is over, the data will describe the constituent concentration for each of the samples as a function of time. The data can then be graphed. The constituent concentrations are charted along the y-axis (the dependent variable), and the time is charted along the x-axis (the dependent variable). At the finished of the lab test, the natural logarithms of the ratio of measured chlorine to initial chlorine (C_t/C_o) value were plotted against time. The rate constant was the slope of the straight line as shown in the following figures 4-18.

Based on the test result presented in the figures 4-18, were plotted using the ratio of concentration at any time (C_t) to initial concentration (C_o) as ordinate and time as abscissa. The best fitted line draw through charted result where the slope of line is the bulk reaction coefficient. Hence, for first bottle test, second bottle test and 3rd bottle test of the slope of line is - 0.0248, -0.0241, and -0.0259, respectively.

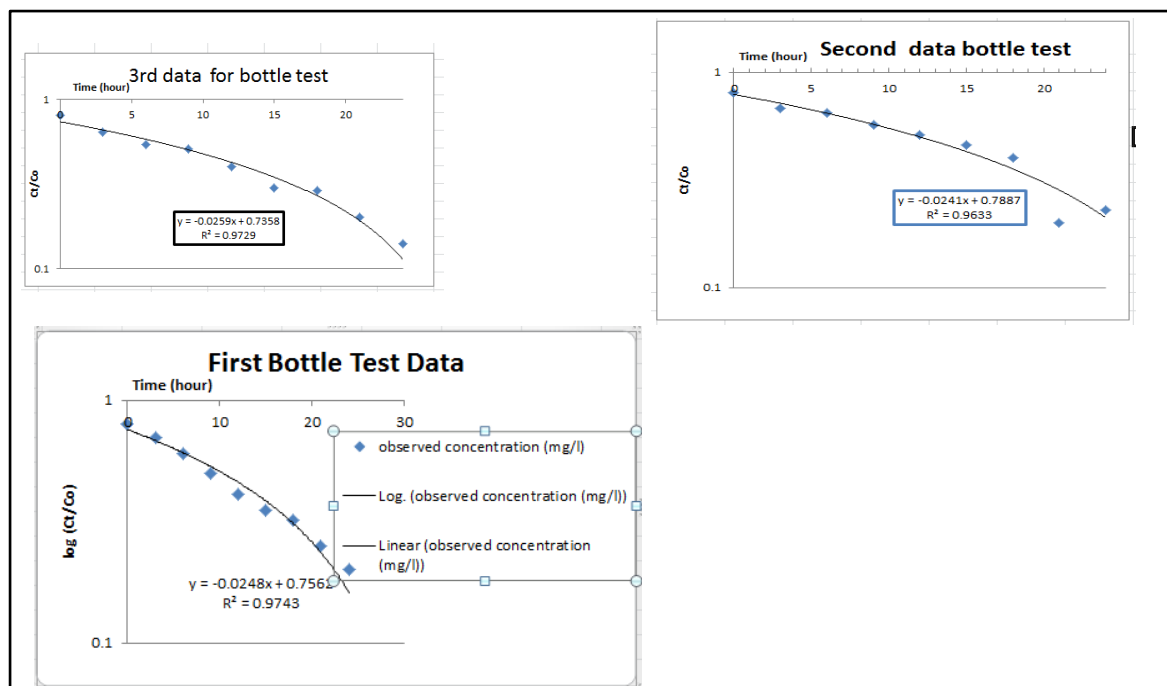


Figure 4-18: Bottle Test analysis results

4.2.9 Water quality calibration

The sampling results were used to provide an understanding of chlorine decay first order kinetics reaction of the Gimbi Town water supply system from the bottle test data discussed previously and to develop a calibrated chlorine model of the system by using 10 samples from thirty samples were observed. Therefore, water quality models that may possibly require certain degree of calibration use the following boundaries:

- **Initial Conditions:** Describes the water quality parameter (residual chlorine concentration) at all locations in the distribution system at the start of the simulation.
- **Bulk reaction Coefficients:** Describes how water quality may differ over time due to chemical,
- **Source Quality:** Describes the water quality characteristics of the water source over the period being simulated.

4.2.9.1 Residual Chlorine Calibration and Validation

Chlorine disinfectant models, the model should reproduce the pattern of observed disinfectant concentrations over the time when the samples were taken to an average error of roughly 0.1 to 0.2mg/l (Thomas et al, 2003).

4.2.10 Residual chlorine calibration and validation

Consequential to hydraulic model calibration and validation, water quality model calibration has to be performed independently. To this effort data sets were collected from diverse part of water supply distribution networks. Table 4-3 and Table 4-4 depict an attempt to water quality model calibration as guide line recommends to have an average error of roughly 0.1 to 0.2 mg/l (Thomas et al., 2003).

The residual chlorine was calibrated by adjusting Hazen Williams's roughness coefficient. Initially the value of Hazen Williams's roughness coefficient in the system were 140 for PVC, 100 for galvanized iron pipe, and 110 for DCI pipe. The corresponding value of residual chlorine decreases in the pipe networks from distribution reservoir to point of use. This implies that the wall reactions materials of pipe increases.

During calibration Hazen Williams's roughness coefficient were adjusted to 150 for PVC pipes, 120 for GIP, and 130 for DCI. These results in slightly increase in the residual chlorine in the system. This implies that the wall material reaction decreases.

Table 4-3: Summary of first data arrangement for residual chlorine calibration

Calibration statistics for residual chlorine						Location of samples points		
S.no	Time (hour)	Nodes ID	Observe residual chlorine (mg/l)	Computed residual chlorine (mg/l)	Difference	x(m)	y(m)	elevation(m)
1	6:00	18-S-15	0.12	0	-0.12	809944	1016859	1883
2	6:30	J6	0.25	0.27	0.02	810974	1017008	1931
3	7:00	J11	0.3	0.27	-0.03	811183	1016423	1937
4	7:30	18a	0.1	0	-0.1	810697	1016505	1896
5	8:00	J14	0.5	0.32	-0.18	811406	1015852	1956
6	8:30	18-S-6	0.02	0	-0.02	811476	1015688	1972
7	9:00	16e	0.4	0.21	-0.19	811816	1015485	1945
8	9:30	18-S-7	0.16	0	-0.16	811622	1015293	1958
9	10:00	18-S-19	0.4	0.27	-0.13	812115	1016479	1861
10	10:30	J20	0.5	0.6	0.1	811520	1014893	1994
11	11:00	DWR	0.55	0.64	0.09	911338	1014431	2040
				RMS	0.117			

Table 4-4: Summary of second data arrangement for residual validation

					Location of samples points			
S.no	Time (hour)	Nodes ID	Observe residual chlorine (mg/l)	Computed residual chlorine (mg/l)	Difference	x(m)	y(m)	elevation(m)
1	18:30	18-S-15	0.1	0	-0.1	809944	1016859	1883
2	18:30	J6	0.15	0.27	0.12	8109975	1017008	1931
3	19:30	J11	0.4	0.27	-0.13	811183	1016423	1937
4	20:30	18a	0.35	0	-0.35	810697	1016505	1896
5	21:30	J14	0.4	0.4	0	811406	1015852	1956
6	22:30	18-S-6	0	0	0	811476	1015688	1972
7	23:30	16e	0.22	0.21	-0.01	811816	1015485	1945
8	24:00	18-S-7	0.17	0	-0.17	811622	1015293	1958
9	24:30	18-S-19	0.48	0.27	-0.21	812115	1016479	1861
10	25:00	J20	0.7	0.6	-0.1	811520	1014893	1994
11	26:00	DWR	0.8	0.75	-0.05	911338	1014431	2040
				RMS	0.113			

Table 4-4 and Table 4-5 show that the calibration and validation values of residual chlorine in the truck mains are respectively an average RMS error of 0.117 mg/l and 0.113mg/l.

4.3 Variation of pressure with residual chlorine in system

The residual chlorine concentration in the distribution system decreases from the distribution reservoir to dead end of the pipe network. This can be due to high residence time, turbidity of water, and increase in the pressure especially at lowest elevation in the study area.

The increase in pressure in pipe networks indirectly affect the residual chlorine by increasing the turbidity of water as shown in figure 4-19.and Table -3 (in Appendix)

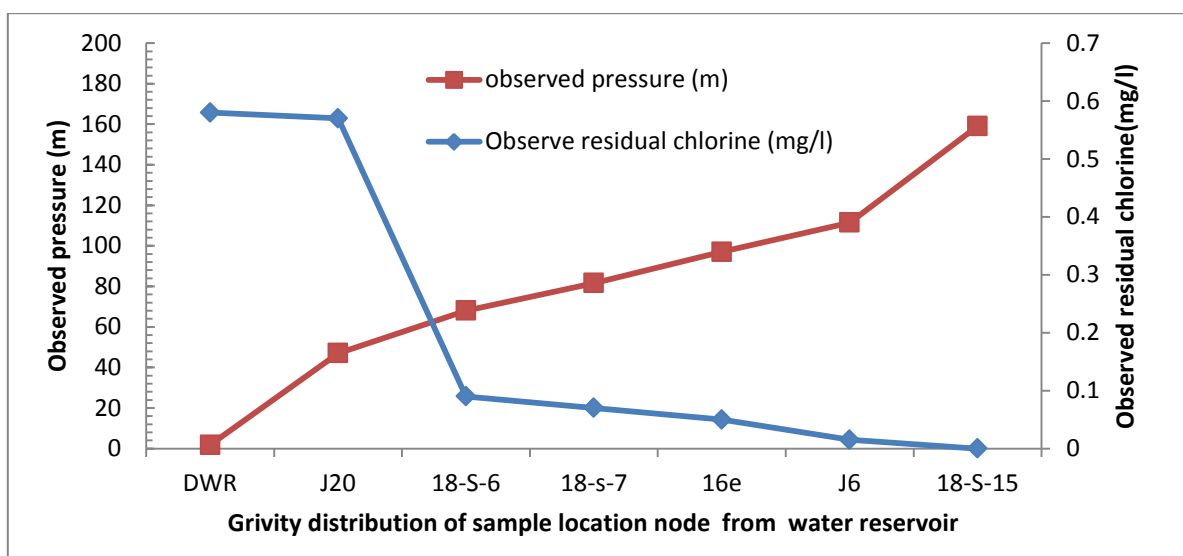


Figure 4-19 Relationship between pressure changes with residual chlorine in the distribution network system

Figure 4-20 shows the map distribution of the pressure and the residual chlorine in the gravity networks of the water supply distribution system the same elevation indicated using point C. Point C shows the location of service reservoir. In Figure 4-20 red and yellow color respectively indicates the below and above the permissible limit for both residual chlorine and pressure.

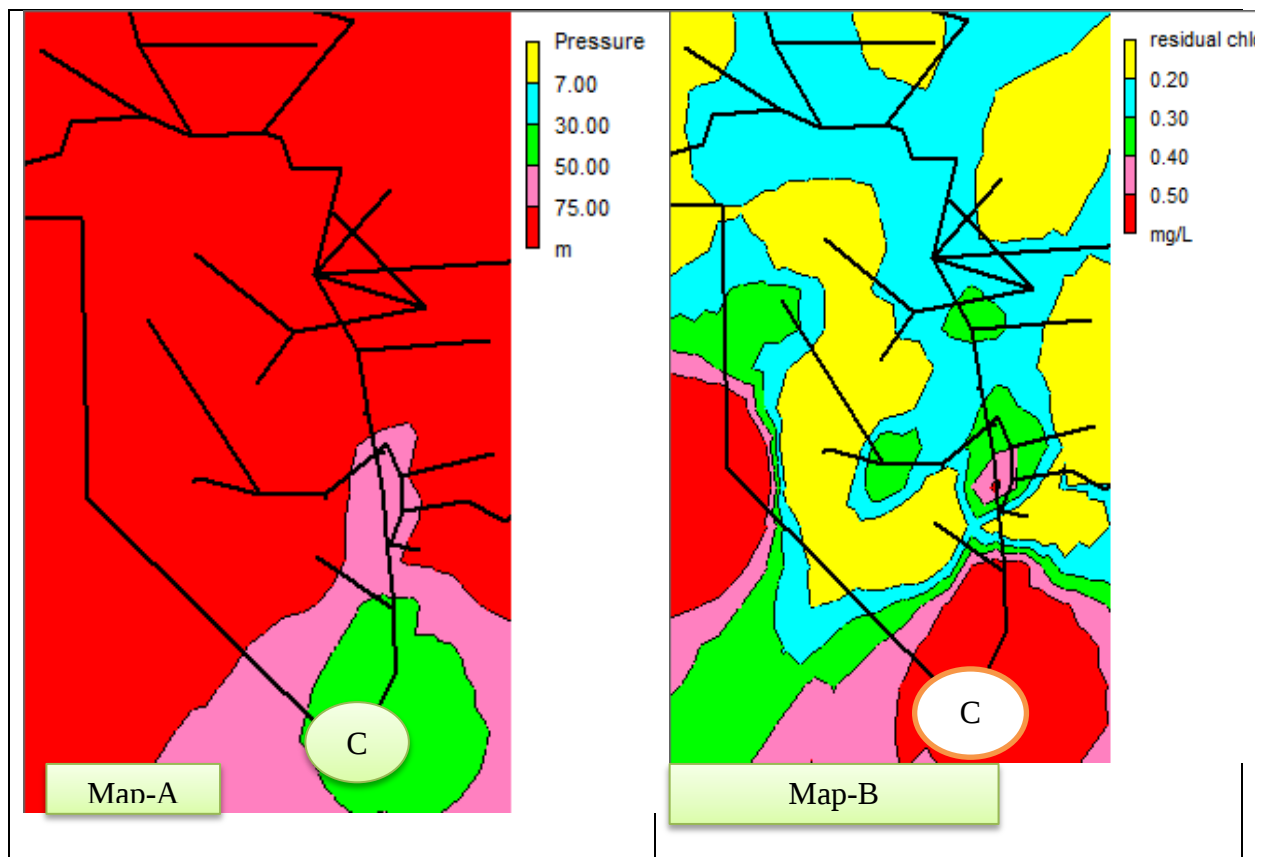


Figure 4-20: Map distribution of pressure and residual chlorine in the network systems at peak hourly demand

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The drinking water quality parameters and the effects of pressure in directly on residual chlorine in the water supply systems of Gimbi Town from source to points of distribution were investigated through laboratory experiments and simulation models using EPANET Software. Characterization and analyses of drinking water quality parameters were done using a total of 30 randomly selected representative samples of water from different locations of the water supply system of the Town. Comparison of the water quality parameters with the permissible limit of the WHO guidelines (2012) and with that of the Ethiopian recommended values (Girma et al,2011) were made regarding with safe and acceptable level of drinking water for customers.

The main physico-chemical parameters considered for investigation include color, turbidity, pH, electrical conductivity, total dissolved solids, total hardness, total alkalinity, calcium, potassium, magnesium, copper, iron, manganese, chromium (hexavalent), chloride, fluoride, nitrate, phosphate, residual chlorine, dissolved oxygen and Biochemical Oxygen Demand. Bacteriological tests such as faecal coliforms and total coliforms were analyzed in relation to the health prevalence of water-associated diseases. The laboratory results have shown that except for iron concentration, phosphate, residual chlorine and pH, among the physico-chemical parameters, the remaining all parameters were found within the permissible limit of WHO guidelines and Ethiopian recommended values concerning the safety and acceptability level (Grma et al,2011)l for the end users. Some parameters were checked through laboratory test by two scenarios, during dry and wet season, because of seasonal dependent parameters such as (iron, nitrate, phosphate, Total Dissolved Solid, Electrical Conductivity, Biochemical Oxygen Demand, residual chlorine, Color, Turbidity, pH, fecal coliform, and total coliforms) as the result show in appendix. Then the result of those all parameters were higher in concentration during dry season than during the wet season. This result clearly indicates that the source of water supply was contaminated. Out of these parameters namely iron (ranging from 0.6 to 2.5 mg/l), nitrate (ranging from 2.2 to 38), and pH. (ranging from 6.01 to 6.45), phosphate (ranging(0.4-12mg/l), BOD (ranging from(1.17-15mg/l),residual chlorine (ranging (0-0.5mg/l) and Do (ranging from(6.03-3mg/l), color (ranging from 70-700 TCU), and

Turbidity (ranging from 12-110NTU) were found beyond the WHO guidelines, but within the Ethiopia recommended values. Generally, concerning the physico-chemical parameters, the water seems to be safe and there is no significant effect on the health of the users. However, further researches that involve a wide-scale and an intensive data collection and sophisticated laboratory analyses are necessary to arrive at precise and ultimate conclusions. Only physical water quality parameters like color and turbidity were not aesthetically acceptable because at most points of sample locations their values were found above the maximum permissible limit of the WHO guidelines as well as that of Ethiopian recommended values. Although these values (Table A-2 in the Appendix) might not have a significant effect on the health of the users, it is not acceptable from psychological perception viewpoints.

The results of bacteriological analyses have shown that most of the sample points are at low risk except locations such as the raw water, the treatment plants, and at sample point-7 and 12 after treatment plants. At these locations, the result indicated “Too Numerous To Count” (TNTC), mainly due to the poor treatment efficiency of the system and poor operation of the chlorine disinfection systems which is operated manually that is not effective in homogeneously mixing. At the majority of the nodes, chlorine residual was found below the minimum permissible limits of the WHO guidelines when checked both through laboratory test and simulation models. This is mainly due to the high turbidity and the lack of appropriate design of the system components and due to the water supply system is very old and phased out of the design period.

It can be concluded that the selection of the location of the source site was not appropriate because of its situation at the down stream of the town that can be easily contaminated by chemical effluents from domestic sewages and agricultural activities and the subsequent biological factors that deteriorate the quality of water. The condition will be more severe if different industries are planted in the Town. From the existing water supply system design, it can simply be observed that there was no serious consideration of the factors that affect water quality.

The simulation results from EPANET Software have indicated that the effect of pressure on residual chlorine concentration in the water supply networks systems is inversely related with the gravity distribution system of the networks.

5.2 Recommendations

To improve the current state problems of the Gimbi Town Water Supply system, another option of water supply source will be needed. It is encouraging that the Oromia Water Mineral Energy Bureau is initiating the use of an alternative source which is located at the upstream side of the town. This location is very appropriate place to get ride off the current problems listed so far. In addition, the new source may solve the prominent problems associated with the design and operational systems of the existing source which was constructed twenty years ago.

As an immediate solution for the existing problems, until the new project is completed and start its full operation for the town's drinking water supply, the responsible authority and the beneficiaries should effectively use the following appropriate recommendations in order to maintain the existing quality of water:

- ✚ To use proper disinfections with higher doses of chlorine at the treatment plant mainly during the rainy season. Pressure breaker is required at high pressure zones in order to regulate pressure within the permissible limit to avoid over mixing of residual chlorine in the system. These subsequent measures may improve the efficiency to kill different pathogens at different point use of the community throughout the water supply system.
- ✚ To ensure minimum residual chlorine concentration regularly at the customers that are located at the furthest place from the treatment plant or distribution of service reservoir.
- ✚ To use additional dosage of coagulant (alum) and through filtration process during the summer season to reduce the turbidity and colour within the permissible limit.
- ✚ protection of water points through natural vegetation barriers, regular chlorination of water points, preventing water stagnation around water points and fencing, and preventing bathing and washing clothes around to prevent contamination of surface water will help maintain and improve water quality. Besides, disinfection of water at household level using uwa agar or aqua tap can be an added advantage.
- ✚ As much as possible the oldest galvanized pipe iron should be replaced by either PVC pipes or HDPE pipes. This is helpful to avoid the rusting problems in the system as well as to some extent solve the colour and turbidity problems of the source supply.

✚ To use different methods like pressure reduce valves and pressure breaker made of local materials such as masonry to solve the pressure problems (above the maximum permissible limit) in the water supply distribution system. This is important to reduce operational and frequent maintenance costs currently occurring in the system.

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APPENDICES

TABLE A- 1a and A-1b: Bacteriological Tests at rain season in the march and May, 2015

S. No.	Sample	Coordinate						Remark
	ID	X(m)	Y (m)	Z(m)	Date, time	E- coli/100ml	Total coliform	
1	S-1	809683	1016526	1824	5/5/2015			
					6:00:00 AM	TNTC	TNTC	High risk
2	S-2	810150	1016978	1907	5/5/2015	TNTC	TNTC	High risk
					6:30:00 AM			
3	S-3	810137	1016986	1904	5/5/2015	30	70	Low risk
					7:00:00 AM			
4	S-4	810110	1016961	1903	5/5/2015	Nil	15	„
					7:30:00 AM			
5	S-5	810152	1016948	1901	5/5/2015	Nil	Nil	„
					8:00 AM			
6	S-6	811476	10156881	1972	5/5/2015	Nil	8	„
					8:30:00 AM			
7	S-7	811622	1015293	1958	5/5/2015	Nil	TNTC	High risk
					9:00:00 AM			
8	S-8	811241	1015496	1957	5/5/2015	Nil	10	Low risk
					9:30:00 AM			
9	S-9	810500	1016232	1890	5/5/2015	Nil		„
					10:00:00			
10	S-10	811191	1017357	1910	5/15/2015	Nil	3	„
					10:30:00			
11	S-11 at J11	811394	1015844	1963	5/5/2015	Nil	2	„
					11:00:00			
12	S-12	810062	1017345	1903	5/5/2015 AM	Nil	TNTC	High risk
					11:30:00			
12	S-13	810456	1018560	1886	5/5/2015	Nil	7	Low risk
					12:00:00 PM			
14	S-14	811348	1017459	1894	5/5/2015	Nil	2	„
					1:00:00 PM			

	S-15	809944	016859	883	5/5/2015	Nil	3	„
16	S-16	811109	1016559	1942	5/5/2015 2:00:00 PM	Nil	8	„
17	S-17	811923	1015683	1904	5/5/2015 2:30:00 PM	Nil	5	„
18	S-18	811905	1016153	1894	5/5/2015 3:00:00 PM	Nil	8	„
	S-19 -	812115	1016479	1861	5/5/2015	Nil	9	„
20	18a	810951	1015971	1882	5/5/2015 4:00:00:00	Nil	3	„
21	18-S-15	810695	1015566	1901	5/5/2015 4:30:00 PM	Nil	6	
22	18-519	811196	1015258	1958	5/5/2015 5:00:00 PM	Nil	9	
23	J14	811567	1014844	1983	5/5/2015 5:00:00PM	Nil	5	
24	J20	811423	105332	1983	5/5/2015 6:00:00 PM	Nil	4	
25	DWR	81338	015531	2040	5/5/2015 6:30:00 PM	NIL	Nil	

TABLE A- 2a and Table A-2b: Physico-chemical Water Quality Laboratory Results during dry and wet season

Table A- 3a and A-3b: BOD, COD, and Do Laboratory Results during dry and wet season

Table-3 Observed of the residual chlorine and pressure relationship data

S.no	Time (hour)	Sample point node	Observe residual chlorine (mg/l)	observed pressure (m)	Computed pressure(m)	GPS sample location		
						x(m)	y(m)	elevation(m)
1	6:00	DWR	0.58	1.81	1.83	911338	1014431	2040
2	6:30	J20	0.57	47	47.77	811520	1014893	1994
3	7:00	18-S-6	0.09	68	69.37	811476	1015688	1972
4	7:30	18-s-7	0.07	81.6	83.22	811622	1015293	1958
5	8:00	16e	0.05	97	96.12	811816	1015485	1945
6	8:30	J6	0.015	111.5	110.33	8109975	1017008	1931
7	9:00	18-S-15	0	159	158.32	809944	1016859	1883

Table A- 4: Test Method and Laboratory instruments

S/N	Parameter Tested	Method used to measure the parameter	Remark
1	Temperature	CyberscanPC300PH/Conductivity/TDS Temperature meter	
2	PH	CyberscanPC300 PH/Conductivity/TDS/Temperature meter	
3	Total Dissolved Solids(TDS)	CyberscanPC300 PH/Conductivity/TDS/Temperature meter	
4	Electrical conductivity(EC)	CyberscanPC300 PH/Conductivity/TDS/Temperature meter	
5	Total hardness asCaCO ₃	EDTA, Titration	
6	Calcium hardness as CaCO ₃	EDTA, Titration	
7	Turbidity	Palintest, 8000	
8	Color	Palintest,8000	
9	Sulfate	8051, SulfaVer 4	
10	Iron, Total	8008,FerroVer	
11	Chloride	Mercuric Nitrate titration	
12	Chlorine, Free	8021,DPD method	
13	Chromium, Hexavalent	8023, 1,5-Diphenylcabohydazide(ChromaVer 3)	
14	Copper	8143,Porphyrin method	
15	Fluoride	8029,SPADNS method	
16	Manganese	8034,Periodate Oxidation	
17	Nitrate	8039,Cadmium Reduction	
18	Nitrite	8507,Diazotization method	
19	Nitrogen, Ammonia	8038, Nessler method	
20	Chemical Oxygen Demand	8000,Reactor Digestion method	
21	Phosphorus, reactive	8048,PhosVer 3 (Ascorbic acid) method	
22	Potassium	8049, Tetraphenylborate method	
23	Zinc	8009,Zincon method	
24	Bacteria colony	Membrane Filtration method	

	determination		
25	Dissolved Oxygen/DO	Thiosulfate Titration method	
26	Biochemical Oxygen Demand	Thiosulfate Titration method	
27	Total Alkalinity	Titration	

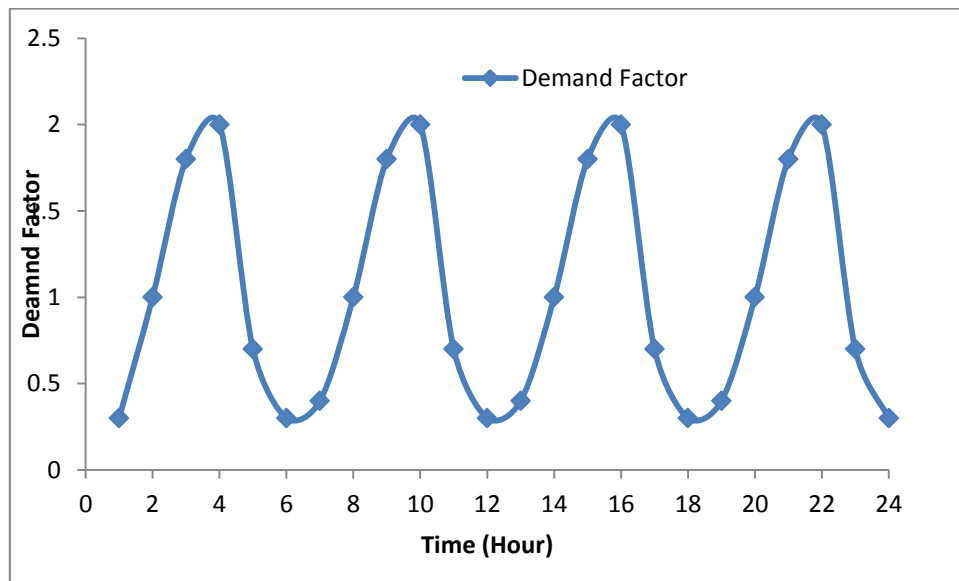


Figure A- 1: Demand Pattern Distribution of The Town (Source: from design document report of the Town)

Table A- 5: Bottle tests of data arrangement for determination of Bulk coefficient determination

	First bottle test data set	
Date	may 10,2015	
Time	Sample	Observed chlorine(mg/l) residual
6:00 AM	Clear Water Tank	0.80
6:30 AM	18-S-15	0.20
7:00 AM	J6	0.70
7:30 AM	J11	0.20
8:30 AM	18a	0.25
9:30 AM	18-5-6	0.41
10:30 AM	16e	0.40

11:30 AM	J14	0.35
12:30 PM	18-S-7	0.32
1:30 PM	DWR	0.6
2nd bottle test data set		
Date	may 11,2015	Observed chlorine(mg/l) residual
1:00 PM	Clear Water Tank	0.8
2:00 PM	18-S-15	0.2
3:00 PM	J6	0.68
4:00 PM	J11	0.23
5:00 PM	18a	0.46
6:00 PM	18-5-6	0.51
7:00 PM	16e	0.21
8:00 PM	J14	0.57
9:00 PM	18-S-7	0.02
10:00 PM	DWR	0.65
12:00 AM	3rd Bottle test data set	
Date	May12,2015	observed chlorine(mg/l) residual
8:00 AM	Clear Water Tank	0.8
9:00 AM	18-S-15	0.3
10:00 AM	J6	0.64
11:00 AM	J11	0.29
12:00 PM	18a	0.14
1:00 PM	18-5-6	0.4
2:00 PM	16e	0.3
3:00 PM	J14	0.51
4:00 PM	18-S-7	0.05
5:00 PM	DWR	0.54

Table A- 6: First data arrangement for pressure calibration and time series with pressure networks

S. N	Sample location point	Measured pressure (m)	Computed pressure (m)	Measure d time	Sample location		
					x (m)	Y(m)	Elevation (m)
1	18-S-15	159	158.32	6:00	809944	1016859	1883
2	J6	111.5	110.54	6:30	810974.8	1017007.8 1	1931
3	J8	108	107.75	7:00	811093	1016863	1934
4	18a	144.4	145.68	7:30	810697	1016505	1896
5	J14	83	85.65	8:00	811406	1015852	1956
6	18-S-6	68	69.07	8:30	811476	1015688	1972
7	16e	97	94.59	9:00	811816	1015485	1945

8	16c	67.5	67.89	9:30	811503	1015308	1972
9	18-S-7	81.6	81.89	10:00	811622	1015293	1958
10	J20	47	47.88	10:30	1014893	1014893	1994

Table A- 7: second data arrangement for pressure validation and time series with pressure networks

S.no	Sample point location	Observed pressure (m)	Computed pressure (m)	minimum range (m)- 0.5 from computed	Maximum range in (m) +0.5 on computed	Observed time (hour)	GPS Location coordination		
							x(m)	y(m)	Elevation(m)
1	18-S-15	157.00	157.31	156.81	157.81	18:00	809944	1016859	1883
2	J6	109.60	109.31	108.81	109.81	18:15	810974.8	1017007.8	1931
3	J8	106.75	106.3	105.8	106.8	18:30	811093	1016863	1934
4	J11	143.90	144.27	143.77	144.77	18:45	810697	1016505	1896
5	18a	84.80	84.37	83.87	84.87	19:00	811406	1015852	1956
6	J14	68.00	68.41	67.91	68.91	19:15	811476	1015688	1972
7	18-S-6	94.85	94.54	94.04	95.04	19:30	811816	1015485	1945
8	16e	60.00	67.91	67.41	68.41	19:45	811503	1015308	1972
9	18-S-7	91.00	81.93	81.43	82.43	20:00	811622	1015293	1958
10	J20	48.00	47.65	47.15	48.15	20:15	1014893	1014893	1994

Table A- 8: Time Series Table Link tank level first data arrangement calibration at peak flow hourly demand

Time in (hours)	computed tank level in (m)	Observed tank level in (m)	difference (m)
15:00	1.69	1.3	0.39
16:00	2.15	1.85	0.3
17:00	2.15	1.9	0.25
18:00	2.15	2.1	0.05
19:00	2.07	1.9	0.17
20:00	2.14	2	0.14
21:00	2.08	2	0.08
22:00	1.95	1.8	0.15
23:00	1.82	1.6	0.22
24:00:00	1.7	1.35	0.35
25:00:00	2.16	1.8	0.36
26:00:00	2.15	2.1	0.05
27:00:00	2.15	2.1	0.05
28:00:00	2.07	2.01	0.06
29:00:00	2.15	2	0.15
30:00:00	2.08	2	0.08
31:00:00	1.95	1.85	0.1

32:00:00	1.82	1.75	0.07
33:00:00	1.7	1.73	-0.03
34:00:00	2.16	2.1	0.06
35:00:00	2.15	2	0.15
36:00:00	2.15	2.1	0.05
37:00:00	2.07	2	0.07
38:00:00	2.15	2.02	0.13
39:00:00	2.08	1.9	0.18

$$R^2 = \frac{(\bar{x} - \bar{x})(\bar{y} - \bar{y})}{\sqrt{\sum(\bar{x} - \bar{x})^2 \sum(\bar{y} - \bar{y})^2}} = 86\%$$

Where $\bar{x}$ = X and Y sample means of average array1 and array2 respectively and R^2 correlation mean square percent

Table A- 9: Time Series Table Link tank level second data arrangement validation at low flow hour demand

Time in (hour	Compute tank level in (m)	observed tank level in(m)	Difference in(m)
15:00	1.69	1.45	0.24
16:00	2.15	1.9	0.25
17:00	2.15	1.8	0.35
18:00	2.15	1.93	0.22
19:00	2.07	1.85	0.22
20:00	2.14	1.97	0.17
21:00	2.08	2	0.08
22:00	1.95	1.7	0.25
23:00	1.82	1.9	-0.08
24:00:00	1.7	1.4	0.3
25:00:00	2.16	2	0.16
26:00:00	2.15	2.1	0.05
27:00:00	2.15	2.03	0.12
28:00:00	2.07	1.76	0.31
29:00:00	2.15	2	0.15
30:00:00	2.08	1.8	0.28
31:00:00	1.95	1.6	0.35
32:00:00	1.82	1.6	0.22
33:00:00	1.7	1.2	0.5
34:00:00	2.16	2	0.16
35:00:00	2.15	2	0.15
36:00:00	2.15	2	0.15
37:00:00	2.07	1.8	0.27
38:00:00	2.15	2.1	0.05

39:00:00	2.08	1.95	0.13
40:00:00	1.95	1.8	0.15

$$R^2 = \frac{(\bar{x} - \bar{x})(\bar{y} - \bar{y})}{\sqrt{\sum(\bar{x} - \bar{x})^2 \sum(\bar{y} - \bar{y})^2}} = 87\%$$

Where: x and y sample means of average array1 and array2 respectively and R² correlation mean square in percent.

Table A- 10: Pipe link flow at no-67 calibration arrangement first data

Time Series Table - Link 67			
Time (hours)	computed link flow pipe at peak demand (l/s)	observed flow link flow pipe at peak demand (l/s)	Difference
3:00	35.73	38.50	-2.77
4:00	35.73	39.00	-3.27
5:00	35.73	40.00	-4.27
6:00	7.15	7.50	-0.35
7:00	7.15	9.25	-2.1
8:00	7.15	10.00	-2.85
9:00	14.29	17.50	-3.21
10:00	14.29	16.75	-2.46
11:00	14.29	17.00	-2.71
12:00	35.73	30.00	5.73
13:00	35.73	29.00	6.73
14:00	35.73	31.00	4.73
15:00	7.15	5.00	2.15
16:00	7.15	4.50	2.65
17:00	7.15	5.00	2.15
18:00	14.29	9.00	5.29
19:00	14.29	9.00	5.29
20:00	14.29	8.50	5.79
21:00	35.73	38.50	-2.77
22:00	35.73	39.00	-3.27
23:00	35.73	38.50	-2.77
24:00:00	7.15	10.00	10
25:00:00	7.15	11.75	-4.6
26:00:00	7.15	12.00	-4.85
27:00:00	14.29	12.50	1.79

$$R^2 = \frac{(\bar{x} - \bar{x})(\bar{y} - \bar{y})}{\sqrt{\sum(\bar{x} - \bar{x})^2 \sum(\bar{y} - \bar{y})^2}} = 95.6\%$$

Where x is represented pipe link flow demand (l/s)

Y is represented pipe link flow demand (l/s)

R^2 is correlation mean square in present

$\bar{x}$ & $\bar{y}$ Is sample of means average array 1 and array2 respectively

Table A- 11: Second data arrangement the pipe link flow for validation at low hourly demand

Time Series Table - Link 67			
Time series (hour)	Computed pipe link flow (l/s)	observed pipe lin flow (l/s)	diferenced
3:00	35.73	34	1.73
4:00	35.73	34.5	1.23
5:00	35.73	34.75	0.98
6:00	7.15	6	1.15
7:00	7.15	6	1.15
8:00	7.15	5.85	1.3
9:00	14.29	13	1.29
10:00	14.29	12.5	1.79
11:00	14.29	13.8	0.49
12:00	35.73	37	-1.27
13:00	35.73	37.25	-1.52
14:00	35.73	37.85	-2.12
15:00	7.15	8	-0.85
16:00	7.15	8.75	-1.6
17:00	7.15	8	-0.85
18:00	14.29	16	-1.71
19:00	14.29	16.5	-2.21
20:00	14.29	16	-1.71
21:00	35.73	37	-1.27
22:00	35.73	37	-1.27
23:00	35.73	37	-1.27
24:00:00	7.15	8	-0.85
25:00:00	7.15	8.5	-1.35
26:00:00	7.15	9	-1.85
27:00:00	14.29	16.5	-2.21

$$R^2 = \frac{(\bar{x} - \bar{x})(\bar{y} - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} = 99.4\%$$

Network Table - Nodes at 6:00 Hrs

Node ID	Head (m)	Pressure (m)	residual chlorine (mg/L)
Junc 2	2041.32	149.32	0.27
Junc 3	2041.32	145.32	0.27
Junc J3	2041.32	141.32	0.27
Junc J5	2041.32	134.32	0.27
Junc J6	2041.33	110.33	0.27
Junc J7	2041.33	110.33	0.27
Junc J8	2041.33	107.33	0.27
Junc J9	2041.34	103.34	0.27
Junc J10	2041.34	103.34	0.27
Junc J11	2041.34	104.34	0.27
Junc J12	2041.35	98.35	0.32
Junc J13	2041.36	88.36	0.32
Junc J14	2041.36	85.36	0.32
Junc J15	2041.37	75.37	0.40
Junc J16	2041.37	69.37	0.40
Junc J17	2041.40	64.40	0.40
Junc J18	2041.63	60.63	0.54
Junc j19	2041.65	59.65	0.54
Junc J20	2041.77	47.77	0.60
Junc J21	2041.80	44.80	0.60
Junc 9	2041.74	44.74	0.60
Junc 12	2040.41	118.41	0.40
Junc 13	2040.88	82.88	0.40
Junc 14	2040.41	148.41	0.00
Junc 15	2041.33	73.33	0.40
Junc 16a	2041.27	75.27	0.40
Junc 16b	2041.22	72.22	0.40

Junc 16c	2041.22	69.22	0.00
Junc 16d	2041.22	78.22	0.00
Junc 16e	2041.12	96.12	0.21
Junc 16f	2041.10	101.10	0.21
Junc 16g	2041.10	137.10	0.21
Junc 16	2041.33	84.33	0.27
Junc 17	2041.34	121.34	0.00
Junc 18a	2041.33	145.33	0.00
Junc S-14	2040.88	143.88	0.27
Junc 18c	2041.10	135.10	0.27
Junc 18d	2041.24	144.24	0.27
Junc 18-S-6	2041.37	69.37	0.00
Junc 18-S-7	2041.22	83.22	0.00
Junc 18-S-8	2040.88	83.88	0.00
Junc 18-S-9	2040.40	150.40	0.32
Junc 18-S-10	2041.24	131.24	0.00
Junc 18-S-11	2041.36	78.36	0.00
Junc 18-S-12	2041.32	138.32	0.00
Junc 18-S-13	2041.10	155.10	0.00
Junc 18-S-14	2040.49	146.49	0.27
Junc 18-S-15	2041.32	158.32	0.00
Junc 18-S-16	2041.34	99.34	0.27
Junc 18-S-17	2041.27	137.27	0.00
Junc 18-S-18	2041.35	147.35	0.00
Junc 18-S-19	2041.28	180.28	0.27
Junc 18-S-20	2041.34	159.34	0.00
Junc 18-S-21	2040.41	139.41	0.00
Junc 18-S-22	2041.74	83.74	0.00
Junc 1	2045.69	84.69	0.80
Junc S-5	2049.54	148.54	0.80
Resvr CWR	1892.00	0.00	0.80
Tank DWR	2041.83	1.83	0.57

Tributaries and Catchments Of Gafare River

