ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ASSESSSMENT OF LEAD EXPOSURE AND MICROBIAL CONTAMINATION IN ADDIS ABABA KINDERGARTEN SCHOOLS' TAP WATER

By:

DAWIT DEBEBE TAYE

October, 2018

Addis Ababa University

School of Graduate Studies

A Thesis Submitted to

The School of Civil and Environmental Engineering

Assessment of Lead Exposure and Microbial Contamination in Addis Ababa Kindergarten Schools' Tap Water

By:

Dawit Debebe Taye

October 2018

A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of the Requirement for Degree of

Masters of Science

in

Water Supply and Environmental Engineering

Approved by Board of Examiners:

Dr. Fiseha Behulu	___________________	___________________
Advisor	Signature	Date
___________________	___________________	___________________
Internal Examiner	Signature	Date
___________________	___________________	___________________
External Examiner	Signature	Date
___________________	___________________	___________________
Chair Person	Signature	Date

Date ____________________

This is to inform that the Thesis Dissertation by candidate _________________________

on the topic entitled ____

____

is completed and ready for defense. This is therefore, to request you to take appropriate measures and arrange for the defense time.

By a copy of this letter, the candidate ____ is advised to submit three copies of his/her thesis to the school.

Thank you,

Research advisor:

Id. No. ____________________________

Stream:___________________________

Sponsor:__________________________

Phone No.__________________________

ABSTRACT

The objective of this study is to evaluate the quality of water consumed by kindergarten school children in Addis Ababa city, who are highly susceptible to issues associated with heavy metal in water. Through conducting chemical analysis, the level of Lead (Pb) using Micro Plasma Atomic Emission Spectrophotometer (MP-AES), total coliforms & *E.coli* in the water distribution system were measured at 38 schools. The study can be considered as an unprecedented piece of work as it addresses critical issues and methods to mitigate the problems caused by high concentration of Pb in water supply distribution infrastructure. The samples were taken from 3 water supply sub-systems; *Akaki*, *Legedadi* and *Gefersa*. The results revealed that the average Pb concentration in the city was 62.37µg/L which was higher than the WHO recommended threshold value of 10µg/L. The children's blood lead levels and exposure to Pb was also calculated using integrated exposure uptake bio-kinetic (IEUBK) model as per the USEPA guidelines. In average figure, the model predicted that 20.17% of the children in the city will have their blood lead levels above the WHO recommended 10µg/dL. In the microbial analysis, 7 out of 38 schools were contaminated with total coliform bacteria. However, E. coli was not detected in any of the samples, meaning that all samples were free from fecal contamination. In addition, the free chlorine level of the samples was also tested. The results indicated that 16 out of 38 (42.1%) of the water samples had a free chlorine value below the WHO recommended 0.2mg/L. It is therefore, possible to conclude that regardless of the different water sources, a water supply infrastructure determines the concentration levels of lead and residual chlorine that reaches the end users.

KEY WORDS: Lead contamination, Blood Lead Levels, E.coli, Total coliform, Free chlorine

Declaration

I, the undersigned declare that this thesis is my original work performed under the supervision of research advisor Dr. Fiseha Behulu and Co-advisor Zerihun Getaneh and has not been presented as a thesis for a degree in any other university in Ethiopia. All sources of materials used for this thesis have also been duly acknowledged.

Name: Dawit Debebe Taye

Signature: ___________________

Place: Addis Ababa institute of Technology, Addis Ababa University

Date: October 2018

ACKNOWLEDGMENTS

I, first of all, praise God for the blessings and guidance I have received in completing this study and the research paper. Next, I would like to express my deepest gratitude to my Advisor, Dr. Fiseha Behulu, who provided me deepest support and guidance from the beginning to the completion of this study. I would also like to thank my co-advisor, Mr. Zerihun Getaneh, who shared me his kindest heart and facilitated all the laboratory works for me during the study period. In addition, it's worth mentioning here, the intensive support of Johnny Girma, Henock Mekonnen and Nebiat Negussie during the laboratory studies that helped me to meet my objectives.

Furthermore, I would also like to thank Dr. Adey Feleke and the Department of Microbiology of, Addis Ababa University, for supplying essential chemicals and equipment. I convey earnest thanks to the Addis Ababa Water and Sewerage Authority (AWWSA), for allowing accessing the major water treatment plants and providing me relevant data that contributed for this research.

I would like to thank my Mother Azeb Leulseged for sharing her love, encouraging and standing by my side for the motherhood support what I needed. The last, but not the least, my father, Debebe Taye, my heartfelt gratitude for all the logistics support I needed to materialize, this study, for coaching and mentoring me to make things happen the right way.

ABBREVIATION AND ACRONYMS

AAWSA: Addis Ababa Water and Sewerage Authority

AAT: Akaki After Treatment

ABT: Akaki Before Treatment

BDL: Below Detection Limit

BLLs: Blood Lead Levels

CDC: Control for Decease Center

CFU: Colony Forming Unit

DL: Deciliter

DPD1: Diethyl-p-phenylene Diamine

E.coli: Escherichia coli

EMB: Eosine Methylene Blue

EPA: Environmental Protection Agency

GAT: Gefersa After Treatment

GBT: Gefersa Before Treatment

GPS: Global Positioning System

IEUBK: Integrated Exposure Uptake and Bio-Kinetic model for windows

IWA: International Water Association

Km: Kilometer

kW: Kilowatt

LAT:	Legedadi After Treatment
LBT:	Legedadi Before Treatment
MHz:	Mega Hertz
ml:	Milliliter
mm:	Millimeter
MP-AES:	Microwave Plasma Atomic Emission Spectroscopy
Nm:	nanometer
ORP:	Oxidation Reduction Potential
Pb:	Lead
PH:	Power of Hydrogen
PPM:	Parts Per Million
PVC:	Polyvinyl Chloride Pipes
UN:	United Nations
UNICEF:	United Nations International Children’s Emergency Fund
USEPA:	United States Environmental Protection Agency
WHO:	World Health Organization
µg:	Micro gram
µl:	Micro liter

TABLE OF CONTENTS

ABSTRACT .... **v**

ACKNOWLEDGMENTS .... **vii**

ABBREVIATION AND ACRONYMS .... **viii**

TABLE OF CONTENTS .... **x**

LIST OF FIGURES .... **xiii**

LIST OF TABLES .... **xiv**

1. INTRODUCTION **1**

1.1 Background 1

1.2 Statement of the Problem 3

1.3 Objectives of the study 5

1.3.1. General Objective 5

1.3.2. Specific Objectives 5

1.4 Research Questions 5

1.5 Significance of the Study 6

2. LITERATURE REVIEW **7**

2.1. Water Distribution Systems 7

2.1.1 Factors Contributing to Contamination of Water Distribution Systems 7

2.2 Lead Contamination 9

2.2.1. Sources of Contamination 10

2.2.2. Factors Which Affect Lead Release 11

2.2.3 Blood Lead Levels (BLLs) in Children 14

2.2.4 Relevant Studies Associated with Lead Contamination 18

2.3 Microbial Contamination 21

2.3.1 Indicator Organisms 21
2.3.2 Chlorination 24
2.4 Sanitation and Drinking Water Contamination in Addis Ababa 24
3. MATERIALS AND METHODS 28
3.1 Study Location 28
3.2 Sampling Method 29
3.3 Measuring Chlorine, PH and Temperature 31
3.3.1 Measuring Chlorine 31
3.3.2 Measuring PH and Temperature 33
3.4 Microbial Analysis for Total Coliform and E.coli 34
3.5 Measuring Lead Concentration 37
3.6 Data Entry and Analysis 41
3.7 Model Calibration 44
3.8 Limitations of the Study 44
4. RESULTS 45
4.1 PH 45
4.2 Free Chlorine 47
4.3 Microbial Analysis 48
4.5 Lead Concentration 50
4.6 Model Calibration Results 51
4.7 Blood Lead Levels (BLLs) in Children 53
4.7.1 Blood Lead Levels (BLLs) in Akaki Catchment 55
4.7.2 Blood Lead Levels (BLLs) in Legedadi Catchment 56
4.7.3 Blood Lead Levels (BLLs) in Gefersa Catchment 58
5. DISCUSSION 60

5.1 PH 60

5.2 Free Chlorine 60

5.3. Microbial Analysis 61

5.4. Lead Concentrations and Blood Lead Levels (BLLs) in children 62

6. CONCLUSION 65

7. RECCOMENDATION 67

REFERENCES 70

APPENDICES 74

Appendix A: Name of samples, Location and Collection time 74

Appendix B: GPS Coordinates of Sampling Points 77

Appendix C: Temperature and PH results 79

Appendix D: Residual Chlorine Results 81

Appendix E: Microbial Analysis Results 83

Appendix F: Lead and Blood Lead Concentrations 85

Appendix G: Contaminated samples with total coliform 87

Appendix H: Some of the Sampling Schools 88

LIST OF FIGURES

Figure 1: Biological Structure of the IEUBK Model. 17
Figure 2: Location of Addis Ababa city, Ethiopia 28
Figure 3: Water sample collection from *Gefersa* Treatment Plant (date: 19 May, 2018)30
Figure 4: All 44 samples 31
Figure 5: Reading residual chlorine on Palintest photometer 33
Figure 6: Measuring PH and temperature 34
Figure 7: Working in a bacteria free hub. 35
Figure 8: Boiled EMB media (left) and Measuring EMB media on a Scale (right) 36
Figure 9: Agilent 4200 MP-AES measuring lead concentration 38
Figure 10: Correlation coefficient line 39
Figure 11: Digesting samples with Nitric acid on a hot plate 40
Figure 12: Default soil concentration selected in the model 41
Figure 13: Default air concentration selected in the model 42
Figure 14: Dietary lead concentration selected in the model 43
Figure 15: Water lead concentration in the model 43
Figure 16: Distribution of PH in the Addis Ababa 45
Figure 17: Mean and Median PH values 46
Figure 18: Chlorine distribution (highlighted samples have residual chlorine below 0.2mg/L) 47
Figure 19: Contaminated sample with Total coliforms 49
Figure 20: Mean Lead concentration of the three catchments. 50
Figure 21: Calibration result using default values 52
Figure 22: Calibration results using zero values 53
Figure 23: Probability distribution curve of exposure in Addis Ababa city for 3-7 ages 54
Figure 24: Probability distribution curve of exposure in *Akaki* catchment for 3-7 ages.................... 56
Figure 25: Probability distribution curve in *Legedadi* catchment for 3-7 ages 57
Figure 26: Probability distribution curve of exposure in *Gefersa* catchment for 3-7 ages 59

LIST OF TABLES

Table 1: Chemical factors which affect lead release 11
Table 2: Physical factors which affect Lead release... 13
Table 3: Operating conditions for Agilent MP-AES 4200... 39
Table 4: PH levels of samples taken from the treatment plants 46
Table 5: Free chlorine levels of samples taken from the treatment plants..................... 48
Table 6: Microbial analysis of samples taken from the treatment plants 50
Table 7: Lead concentrations in samples taken from the treatment plants.................... 51
Table 8: Average Lead uptake and BLLs in Addis Ababa city....................................... 54
Table 9: Lead uptake and BLLs in *Akaki* Catchment.. 55
Table 10: Lead uptake and BLLs in Legedadi Catchment... 57
Table 11: Lead uptake and BLLs in *Gefersa* Catchment.. 58

1. INTRODUCTION

1.1 Background

A healthy and safe school environment encompasses the physical surroundings, the psychosocial, learning, and health-promoting environment of the school. Additionally, Hygienic practices, such as accessing to sanitation and providing clean water are all important contributors to children's health (Babayigit et al. 2015).

Access to adequate, clean and safe water greatly contributes to improve health and productivity (Mohammadi, 2014). Moreover, access to clean water and sanitation is declared as a human right by United Nations in 2010 (UN, 2010). It is a prerequisite for the realization of many human rights, including those relating to people's survival, education and better standard of living.

Access to safe drinking water and hygienic living conditions is a global concern and these issues are especially serious in developing countries, like Ethiopia that have suffered from a lack of safe drinking water and inadequate sanitation services (Amenu et al. 2013). Mekonnen (2015) has stated that despite the improvements in the water quality leaving water treatment facilities, contamination often occurs within the water distribution infrastructure. Common causes include: cross-connected pipelines, water backflow and low/negative pipe-pressure events.

Water is an effective medium for the transmission of toxic heavy metals and pathogens of viral, bacterial, parasitic and protozoan origins; and has been implicated for disease outbreaks in developed and developing countries (Mohammadi, 2014). According to research findings, 2.5 million annual deaths, particularly among children under age of five were attributed to risk factors including the consumption of contaminated water (WHO, 2012).

Lead is one of the toxic heavy metals which could be transmitted in water, present in tap water to some extent as a result of its dissolution from natural sources, but primarily from household plumbing systems in which the pipes solder, fittings or service connections to homes contain lead. Polyvinyl chloride pipes (PVC) also contain lead compounds that can be leached from them and result in high lead concentrations in drinking-water.

In recent years, lead poisoning has been recognized as a serious environmental health problem throughout the world, particularly, for children in developing countries (Meyer et al 2003). Lead can cause serious illness for young people, especially to brain development. It can reduce the level of IQ, cause impaired growth and harm kidneys. Severe poisoning can induce coma, or cause death (Suherni, 2010).

Another similar study also states that, lead, which can be taken into the body because of the corrosion of drinking water supply systems covered with lead, may also cause health problems in the form of learning and behavioral disorders, such as mental retardation (Babayigit et al. 2015). When exposed to high doses of lead, damage occurs in the brain, the red blood cells, and the kidney (USEPA, 2015).

Children may be more exposed to lead intoxication than adults due to their behavior, diet, and metabolic and physiologic characteristics. And, they take in more air, water, and food per unit of body weight per day than adults (Wigle et al., 2007). In addition, school-aged children may spend many hours in and around school facilities. Because of their behavior, especially their hand – to - mouth habits, children are particularly vulnerable to lead contamination. For these reasons assessing lead contamination in schools' water is very important to study the status and to take appropriate action in order to reduce the risk.

The other major water contaminants are pathogenic microorganisms. They do infiltrate into water distribution systems through broken pipe fittings and joints. Recent research carried out on water quality revealed that waterborne diseases caused by Vibrio cholerae (serotypes O_1 and O_{139}), *Salmonella typhi* and *paratyphi*, *Shigella dysenteriae* and *Escherischia coli* (serotype O_{148}, O_{157} and O_{124}) were responsible for epidemic diseases mainly in developing countries due to poor hygiene and sanitation (Bahati, 2015). Up to 80% of all the epidemic diseases in the world are caused by inadequate sanitation, polluted water and water scarcity (Battu and Reddy, 2009; Salomon et al., 2011). According to Salomon *et al*. (2011), approximately three out of five persons in developing countries do not have access to safe drinking water. The contamination of drinking water by pathogens causing diarrheal disease is the most important aspect of drinking water quality problems (Manegabe, 2015**).**

The presence of coliforms in water indicates contamination, pointing to a potential risk of the presence of pathogenic organisms. The absence of coliforms is evidence of bacteriologically safe drinking water, since coliforms are more resistant in water than the pathogenic bacteria of intestinal origin (Manegabe, 2015). Also (WHO, 2017**)** states that detection and enumeration of pathogens in water is inappropriate under most circumstances in view of the difficulties and resources required. So, *Escherichia coli* and total coliforms are used as indicators of fecal contamination. The assumption is that if the indicators are detected, pathogens, including viruses, could also be present and therefore, appropriate action is required to ensure availability of safe water for drinking. Therefore, for every drinking water tested, no total coliforms should be detected.

1.2 Statement of the Problem

The basic focus of this study is assessing lead exposure and microbial contamination of Addis Ababa Kindergarten schools tap water. Lead in drinking water may come from contamination at the source, but it can also result from the water treatment and distribution systems. However, the authority running the water delivery and administration (AAWSA) does not monitor the level of heavy metals in its drinking water. Data for water lead concentration is also unavailable at AAWSA. Unlike the industrialized countries, there are very limited researches conducted on the status of lead (Pb), and therefore, it has been a major limitation to get data for developing countries including Ethiopia (Getaneh et al. 2014). Non-occupational exposure of the general population to lead is most likely to occur in Ethiopia through the ingestion of contaminated drinking water (Getaneh et al., 2014). One study conducted in Addis Ababa showed higher concentration of lead in piped drinking water. The mean lead concentration levels observed in samples taken from *Legedadi* and *Gefersa* treatment plants were higher than 10µg/L threshold as set world health organization (WHO, 2006). Even though there are such findings, children blood lead level prediction has never been conducted. Equivalent to this, in several educational institutions, waterborne diseases have become common problems causing health complications on children and adults. This may be related to contamination of water tanks or infiltration of the microorganisms in water pipes. Therefore, the monitoring and further analysis of the quality of water originating from faucets for school children's consumption becomes important to conduct research for diagnosing the problem and to develop prevention and mitigation strategies.

According to a data from the educational statistics annual abstract (2017) taken from Addis Ababa Education Bureau, there are 164,072 students, 51.16% male and 48.84% female, attending in 1172 Kindergarten schools in Addis Ababa. All of the children are directly affected by the contamination of water they get from their school's tap water. Their families are also indirectly affected by costs of medical treatment they spend on their children, which is unaffordable to most of the poor family members.

This problem has been increasing from time to time as there is no action taken by government or users of the service to reduce the lead accumulation in the water pipes and distribution systems, and, the action taken to supply microbial free and safe water to the target children and the broader communities is still inadequate.

This problem will continue affecting health, efficiency, mental and physical capability of the target children and other social groups who have been using drinking water from same source and distributions systems, unless a practical research is conducted and appropriate recommendations are portrayed to inform decision makers take reversal action.

1.3 Objectives of the study

1.3.1. General Objective

The general objective of this study is to evaluate the quality of water consumed by kindergarten school children in the Addis Ababa city through chemical and microbial analysis

1.3.2. Specific Objectives

- To determine the concentration of lead in Addis Ababa kindergarten schools tap water.
- To determine the level of *Escherichia coli* and total coliforms in Addis Ababa kindergarten school tap water
- To determine the residual chlorine content in the schools' tap water.
- To predict the human health risk from lead contamination of tap water using Integrated Exposure Uptake Bio-kinetic (IEUBK) model
- To assess which sub system of water supply in Addis Ababa is contaminated with respect to its water supply coverage (*Akaki, Legedadi* and *Gefersa*)

1.4 Research Questions

The study addresses the following research questions.

1. Does the Addis Ababa kindergarten schools' tap water contain lead concentrations above the allowable limit?

2. Does the Addis Ababa kindergarten schools' tap water show contamination by total coliforms and *E.coli*?

3. Does the Addis Ababa kindergarten schools' tap water contain acceptable residual chlorine contents?

4. Are the contaminations subject to water sources?

1.5 Significance of the Study

This study investigated important information concerning the quality of water supply in Addis Ababa city kindergarten schools. Lead concentration and water quality parameters like, PH, residual chlorine, total coliforms and *E.coli* were tested for the three catchments in the study.

No substantial studies have been conducted and recommendations provided to inform decision makers to take appropriate action to mitigate particularly, the problem caused due to high concentration of lead in the water distributed to schools. This study fills the large gap related to shortage of data on residual chlorine and lead concentrations in Addis Ababa's water distribution system.

Therefore, findings of this research will contribute to advice researchers and AAWSA to conduct a follow up research in other geographic areas in order to reduce the risks mentioned under this study.

2. LITERATURE REVIEW

2.1. Water Distribution Systems

A water distribution system is planned and built to deliver water to people at sufficient pressure, quantity and quality. Throughout the epochs of history, several civilizations have developed pipe-networks to transport water from water sources to settlements. The Classic Mayas (200-650 AD) used water pressure systems that could control the water supply to and within urban areas (Mohammadi, 2014). The Romans and the Greeks built aqueducts for the transportation of water from fountains to build up areas. In these early civilizations, the main aim for the design of the water distribution system was to ensure the supply of water in sufficient quantities to the population. Water quality was not a major concern. For instance, the Romans covered some of the aqueduct for the purpose of protecting the water against the heat of the sun and enemies that could destroy or contaminate the distribution system (Mohammadi, 2014).

In the last century, there have been significant developments in the planning and designing water distribution systems, to ensure that treated water is conveyed through the water distribution network in sufficient quantity and quality to the consumer populations. Despite these advances, water distribution networks are still vulnerable to contamination and have been implicated in waterborne disease outbreaks (WHO, 2017). Several factors account for the vulnerability of the water distribution network to contamination; poor designing and management of the water storage, treatment and distribution systems are among the contributors. The details are elaborated hereunder:

2.1.1 Factors Contributing to Contamination of Water Distribution Systems

Water distribution systems can be contaminated due to a wide range of factors. Some of these factors are presented as follows.

A. Infiltration of contaminants into the pipe-network

Infiltration of contaminants into water distribution systems is a major problem in many countries. This happens when contaminated water outside the distribution system enters the distribution system to cause contamination. For this to occur, three conditions have to be met: contaminated water around the distribution system, a low-pressure zone in the system and a path for the contamination to enter the pipes (IWA-publishing, 2003). Contaminated water around the pipes can be a leakage from sanitary facilities, storm, or combined sewers. It can then enter the distribution system when the pressure in the pipes is low. Contaminants may also enter the water distribution network through holes created by corrosion, cracks or leaking joints in the walls of the distribution system. Since Addis Ababa's water supply distribution system has fluctuating pressure due to shortage of supply, it is vulnerable to contamination by infiltration.

B. Unprotected Water Reservoirs in the distribution system

Open water storage reservoirs in the distribution system, can make the water vulnerable to contamination from the outside. For instance, bird excreta containing Salmonella can contaminate water in the reservoir if it is not properly secured Mohammadi, 2014). Also, unprotected water reservoirs can easily be contaminated by dust due to wind, dirt from construction materials etc. In addition, reservoirs facilitate the growth of toxin- forming bacteria (IWA-publishing, 2003).

C. Intermittent and continuous piped water supply

There need to be sustainable clean water supply to communities for safe and healthy life. In urban Africa, Latin America and the Caribbean one-third, and in Asia, half of the water distribution systems work intermittently (WHO, 2012). Intermittent water supply can lead to damages to the distribution system due to changes in flow that can stress the pipes and additionally weakening of pipes and joints. Likewise, the hygienic aspect is also crucial as contaminated water can enter the pipes through joints or cracks when the water supply is operating intermittently. A major reason for intermittent operations in the water supply system is power cuts that affects the pumps and hence flow (Mekonnen, 2015).

2.2 Lead Contamination

Lead is a naturally occurring heavy metal that is soft. Due to this, it provides moderate corrosion resistance, and has a relatively low melting point, its use dates back as far as the Roman Empire (Canas et al. 2013). Understanding of the toxic effects of lead also dates back to the Roman Empire (McIlwain, 2013). A significant increase in lead production began at the onset of the industrial revolution, as it began to appear in items such as tin-lead utensils, lead paints, and gasoline. (Brad 2013).

Lead is a toxic metal whose widespread use has caused extensive environmental contamination and health problems in many parts of the world (Canas et al. 2013). Lead poisoning can affect people at any age. However, young children, pregnant women and certain workers are most likely to be higher at risk than other groups (Suherni, 2010). Children are likely to be more sensitive to lead poisoning than adults because their central nervous systems are still developing (Albabal et al. 2003). Children are particularly vulnerable to the neurotoxin effects of lead and even relatively low levels of exposure can cause serious and, in some cases, irreversible neurological damage (Getaneh et al. 2014). In addition, children spend time playing on the floor, or on the ground outdoors, exposed to soil and dust which may be contaminated with lead. Children also play with toys and often put them in their mouths. The toys may contain lead (Suherni, 2010). Women who are exposed to lead also have higher risk of causing lead poisoning in their children during pregnancy and breastfeeding because lead ingested by the mother can cross the placenta and affect the unborn fetus or the baby (Suherni, 2010).

The accumulation of Pb in humans occurs through ingestion of food, drinking water and the inhalation of atmospheric Pb dust (Manegabe, 2015). The presence of Pb in the organism is unwanted as it disturbs metabolic processes (WHO, 2017). It needs to be recognized that lead is exceptional compared with other chemical hazards, in that most lead in drinking-water arises from lead service connections and plumbing in buildings, and the remedy consists principally of removing plumbing and fittings containing lead, which requires much time and money. It is therefore emphasized that all other practical measures to reduce total exposure to lead, including corrosion control, should be implemented. New sources of lead, such as lead service connections and solder, should not be introduced into any system, and low lead alloy fittings should be used in repairs and new installations (WHO, 2017).

Thus, the monitoring of Pb ions in Addis Ababa's water distribution system is of high importance. It should help to reduce the severe effects which may be associated with the exposure to compounds contaminated by this metal.

2.2.1. Sources of Contamination

Current sources of lead include the air, dust, soil, food and drinking water (McIlwain, 2013). Because of increasing human activity, such as mining and smelting, and the use of lead in petrol and a myriad of other manufactured products, the level of lead in the biosphere has risen in the past 300 years (Suherni, 2010). Lead can get into the environment and human body from various sources such as gasoline (petrol), recycling and dumping of car batteries, toys, paint, pipes, soil, some cosmetic and traditional medicine products and many other sources (WHO, 2006).

Drinking water has been recognized as a source of lead contamination since the middle of the 19th century and currently it is assumed to contribute to approximately 20% of lead exposure (McIlwain, 2013; and USEPA, 2006).

The main contributor of lead in drinking water systems is through corrosion of leaded materials in the treatment plant, distribution system, service lines, or in premise plumbing (McIlwain, 2013). Although lead may occasionally be found in source waters, it is usually at very low concentrations (USEPA, 2006). Leaded materials may include valve parts and gaskets at the treatment plant and within the distribution system.

2.2.2. Factors Which Affect Lead Release

Various factors affect the rate of lead release and the levels of lead measured at the tap. Extensive research has been conducted to determine the impacts of various water quality parameters and plumbing factors which impact lead concentrations in drinking water. The means by which these factors affect lead levels is quite complex, and depending on the nature of corrosion scales formed in a distribution system, and the qualities of the treated water, changes of a single element could potentially increase or decrease lead levels. A simple example of this would be a change of disinfectant type from free chlorine to chloramines. Chloramines are weaker oxidants, and would therefore be expected to decrease corrosion rates; however, in systems where tetravalent lead corrosion scales are present, the reduced oxidation reduction potential (ORP) of the water could cause a shift to the more soluble divalent lead species, consequently causing elevated lead levels at the tap (McIlwain, 2013).

Factors which affect lead release include: chemical factors such as PH, alkalinity and hardness. These factors are briefly explained in the Table below, along with how they may impact lead release in water distribution system.

Table 1: Chemical factors which affect lead release

Chemical Factors	Effect on lead release	Reference
PH	• Affects the solubility of corrosion by-products • Increased PH typically decreases solubility of by-products • Effects of PH related to alkalinity	(Schock et al, 1996; Dodrill et al, 1995)

Alkalinity	• Controls the ability of a water to maintain a consistent PH • Effect on lead release expected to be dependent on type of corrosion scales present	(Schock et al, 1996; Dodrill et al, 1995)
Disinfection residual	• Presence of corrosion scales affects lead release due to disinfectants • On new pipes where scales haven't developed, chlorine increases corrosion of lead due to the increased ORP • Free chlorine is a stronger oxidant than chloramines; chlorinated water therefore has a higher ORP than chloraminated water • Water disinfected with free chlorine may have persistently high ORP which then may lead to the development of lead corrosion scales which have very low solubility	(Boyd et al, 2008a; Lytle et al, 2005; Cantor et al, 2003)

Source: (McIlwain, 2013)

Table 2: Physical factors which affect Lead release

Physical factors	Effect on lead release	Reference
Flow rates	• High flow can cause increased lead release in either dissolved or particulate form by either accelerating mass transfer of lead from pipe scale or by physically destabilizing the scale • Increased velocity may increase corrosion rates by increasing the supply of oxidant to cathodic surfaces • High flow rates may cause spikes in lead particulate concentrations	(Cartier et al, 2012a; Sarver et al, 2011; Xie and Giammar, 2011)
Temperature	• The effect of temperature on lead release in drinking water is complex • Increasing temperature is likely to increase corrosion rates • Solubility of corrosion by products may either increase or decrease with changes to temperature, so the effects of temperature could vary based on scale mineralogy • A survey of US utilities found that lead levels were not significantly greater during warm water conditions when compared to the cold water conditions • Hot water has been found to significantly increase lead release from brass	(Sarver et al, 2011; Dodrill et al, 1995)

Age of pipes	● In older pipes, solubility equilibrium may take far longer than in new pipes, which may reach equilibrium in as little as 24 hours ● A study examining lead release from lead pipes of varying ages found that soluble lead levels decreased significantly with aging, but to a lesser extent than particulate lead did	(Edwards et al, 2002)

Source: (McIlwain, 2013)

2.2.3 Blood Lead Levels (BLLs) in Children

The effects of lead exposure for child health are numerous, including reduction in IQ development, hyperactivity, learning difficulty, behavior problems such as inattentiveness and aggressiveness, hearing loss and impaired growth (Meyer et al., 2003). Blood lead concentrations between 12µg/dL and 120µg/dL in children can result in lower IQ, shorter attention span, learning disabilities, hyperactivity, impaired physical growth and motor skills development, as well as affect audio-visual abilities. Levels of blood lead over 50µg/dL can cause kidney damage and anemia (Aboh et al., 2013). Overt signs of acute intoxication, including dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, abdominal cramps, hallucinations, loss of memory and encephalopathy, occur at blood lead levels of 100–120µg/dL in adults and 80–100µg/dL in children. Signs of chronic lead toxicity, including tiredness, sleeplessness, irritability, headaches, joint pain and gastrointestinal symptoms, may appear in adults at blood lead levels of 50–80µg/dL. After 1–2 years of exposure, muscle weakness, gastrointestinal symptoms, lower scores on psychometric tests, disturbances in mood and symptoms of peripheral neuropathy were observed in occupationally exposed populations at blood lead levels of 40–60µg/dL (WHO, 2012).

The USEPA has recommended integrated exposure uptake bio-kinetic (IEUBK) model as a predictor of potential long-term blood lead levels for children (USEPA, 2005). To estimate the blood Lead levels in children exposed to lead-contaminated media, the model employs four inter-related modules (exposure, uptake, bio-kinetic, and probability distribution).

The IEUBK model enables the user to estimate blood lead levels for a hypothetical child or population of children. Based on the available information about the child's or children's exposure to lead, the BLL is predicted. Accordingly, the model estimates the risk (i.e., probability) that a child or a population of children will have their BLL concentrations exceed a certain level of concern (typically 10µg/dl) (WHO, 2006).

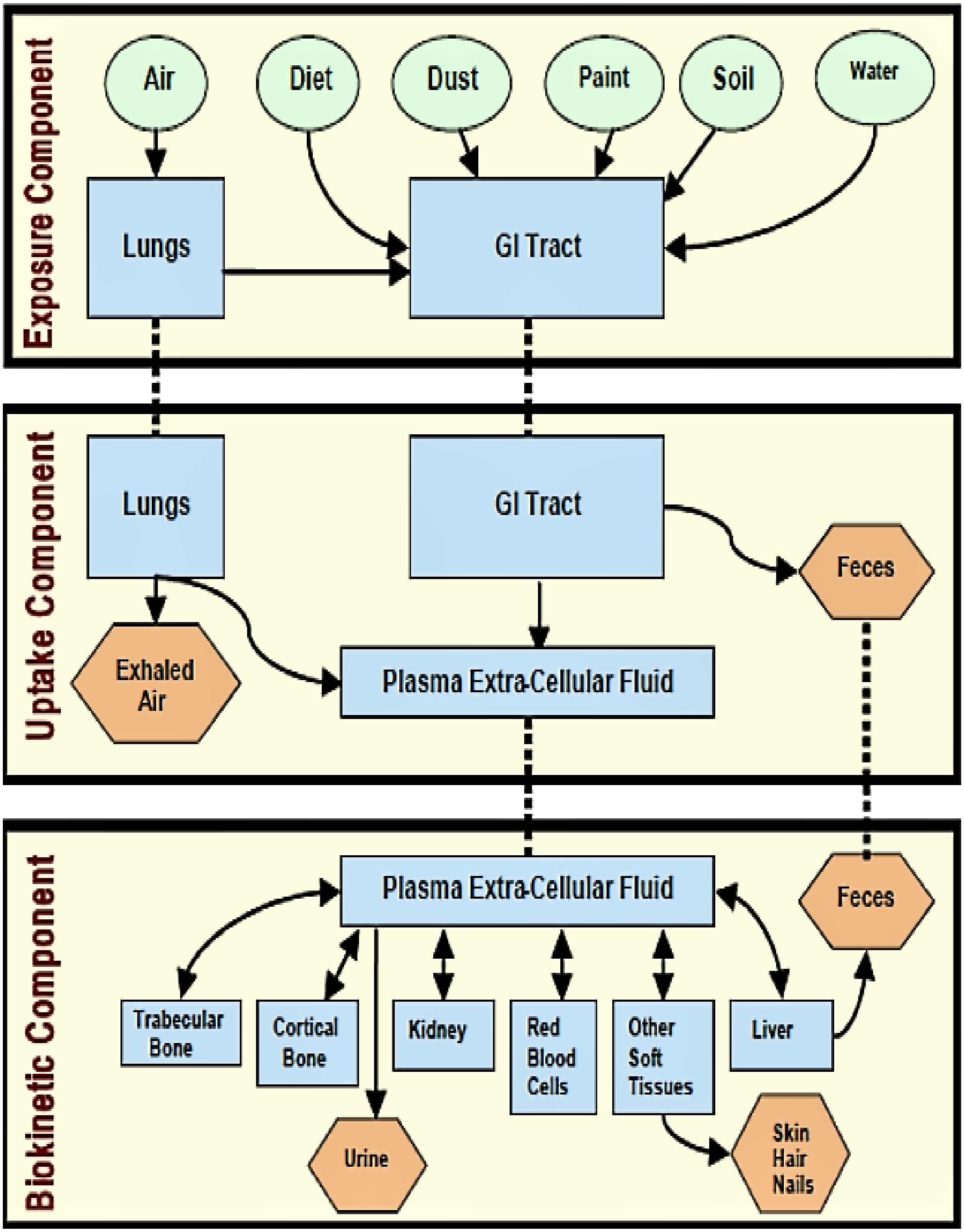
The IEUBK model combines estimates of lead intake from air, water, soil, dust, and diet with an absorption module for the uptake of lead from the lung and gastro-intestinal tract, and a bio-kinetic model of lead distribution and elimination from a child's body. This allows the IEUBK model to predict plausible distributions of blood lead levels in children six months to seven years of age. It assumes three months of consistent exposure through these pathways. Three month period of exposure is based on the premise that if a child is exposed to the same environment over time, he or she will have a steady-state BLL (USEPA, 2006).

The IEUBK model uses the following four components to calculate blood lead levels:

- **Exposure Component:** Uses lead concentrations in environmental media to calculate the amount of lead entering a child's body. The exposure component uses media-specific consumption rates and lead concentrations to estimate media-specific lead intake rates.

- **Uptake Component:** Uses lead intake into the lungs and digestive tract and considers absorption of lead to calculate the amount of lead that enters a child's bloodstream.

- **Bio-kinetic Component.** Considers the transfer of lead between bloods and other body tissues, or elimination of lead from the body in determining a blood lead concentration.
- **Probability Distribution Component.** Shows the probability of a certain outcome (*e.g.,* a blood lead concentration greater than 10μg/dL in an exposed child based on the parameters used in the model).



Source: IEUBK manual

Figure 1: Biological Structure of the IEUBK Model.

2.2.4 Relevant Studies Associated with Lead Contamination

On a study from Getaneh et al. (2014), done in Jimma, Ethiopia, 80 sampling sites were selected from four quadrants of the city. Tap water, soil and air samples were taken from the sites to measure their corresponding lead concentrations. The mean lead concentration from the water samples were 24.5±10.01μg/L. All the water samples from each quadrant had lead concentrations greater than the WHO (2006) recommended value of 10μg/L. Water samples collected relatively far from the treatment plant had higher lead concentration than the closest sites. The study also states that, there was strong positive correlation (r = 0.72, p value \0.01) between the lead concentrations of tap water and distance of the sampling points from the treatment plant. This could suggest that the longer the distance from the water treatment plant the higher lead concentration in tap water of Jimma town. This may be due to the fact that the water flowing through the pipe to a longer distance has higher contact time with the piping materials than the closer sites. The longer water remains standing in the plumbing systems, the more lead it can absorb from any lead sources accessible to it (Getaneh et al. 2014). The mean lead concentration of the soil from the four quadrants of the town was 220.08±135.95μg/g. And the average air lead concentration of quadrant 1, 2, 3 and 4 was 0.77±0.26, 0.86±0.18, 0.77±0.29 and 1.63±0.12μg/m^3 respectively. The high air lead content may be related to pollutants emitted from cars, buses, trucks etc. (Getaneh et al. 2014). In the study, the calculated risk using IEUBK showed that 7.51% of the children are expected to have blood lead levels greater than 10μg/dL.

A study by Fite (2008) was done on the title 'Assessment of Lead Toxicity Awareness among Battery Charging Garage and Workshop Workers and Levels of Lead in Piped Drinking Water of Addis Ababa'. Raw water samples were taken from Dire, *Legedadi* and *Gefersa* reservoirs. And the water lead concentrations were measured. Results revealed that the water contained 30.18±3.44, 14.98±1.55 and 21.46±1.73μg/L for *Dire*, *Legedadi* and *Gefersa* reservoirs respectively. All samples taken from the *Akaki* ground water reservoirs also contained higher values than

WHO recommended level of 10µg/L. Lead concentrations in treated water from the *Gefersa* and *Legedad* treatment plants was 13.85 ± 2.23µg/L. Samples randomly taken from households also ranged from 6.7 – 53.71µg/L. Fite (2008) suggested that the high level observation of Pb in the raw samples may be due to the natural occurrences of Pb in the vicinity or the uses of lead compounds in the agricultural activities or the leachates of Pb from cement- mortar lining of the dams.

A study from Endale et al. (2012), was done is Addis Ababa, Ethiopia on determining levels of lead in roadside soils of the city. 44 roadside soil samples were selected from 14 main roads of the city to measure the lead concentrations. But BLLs were not predicted in this study. The mean soil lead concentration was found to be 418.6±3.4µg/g. In most of the sample sites the concentration of lead observed is directly correlated with the traffic density of the roads near the sample sites. Hence, the major source of lead in road side soils is the use of lead additives in gasoline and the high concentration of lead in almost all of the sampling sites of Addis Ababa city may be attributed to the previous use of leaded fuel for automotive. Although at present the lead content of the gasoline imported and distributed by the Ethiopian Petroleum Enterprise is low (0.013 g/L), the lead from previous use has persisted in the soils and can have long term effects. Moreover, the level of lead determined in the roadside soil samples of this study was also compared with the levels determined in similar studies in the other cities around the world. It has been recognized that slightly higher quantities of lead were obtained for the soils of Addis Ababa, compared to the accumulations determined for many other cities around the world (Endale et al. 2012).

A study from Aboh et al. (2013), done in Tema, Ghana 47 surface soil samples were taken from 9 different sites. The sites included a municipal playground, school parks, residential areas, waste disposal sites, industrial use areas and lead acid battery recycling plant. The minimum and maximum soil lead concentrations were 16.7µg/g and 653,645µg/g for the municipal playground and lead acid battery recycling plant respectively. And the lead concentrations for the waste dump and light industrial areas were 715.7μg/g and 192μg/g. The IEUBK model was used to predict exposure of children to lead. And soil lead concentration was only used as an input; other parameters were set on default. The probability of exposure showed that 19.92% of children at the waste disposal site, 0.04% of children at the light industrial site and 99.4% of children at the lead acid battery recycling sites are expected to have BLLs above 10μg/dL.

On a similar study from (Gorsevski et al. 2014), Soil lead concentrations were only used in the IEUBK model. Soil samples were taken from 81 schools in Toledo, Ohio. It was found that 8.6% of sampled sites had total soil lead concentrations above the USEPA action level of 400μg/g. The model predicted that 28.4% of the samples had elevated blood lead levels.

Another study from Albalak et al. (2003), done in Jakarta, Indonesia blood samples from children between the age of 6 and 8 in 40 schools were taken. And 15 children were chose from each school. The results showed that a quarter of Jakarta school children had blood lead levels in the range 10-14.9μg/dL, which exceeds the level of less than 10μg/dL that the WHO regards as not lead-poisoned. [Recent research indicates that there are also dangers in having a blood-lead level below 10μg/dL (Suherni 2010).]. Among those children, higher blood lead levels more than 10μg/dL was found in children who live near a highway or a major intersection due to the higher air pollution. Meanwhile, children who live close to a street with lower traffic density were found to have lower blood lead levels.

A study by Hogan et al. (1998) was done on comparing blood lead data and the IEUBK models predictions. 834 children's blood lead data was collected from three states in America. This blood lead data was compared with the model prediction using measured soil, water, paint and air lead concentrations. Geometric mean observed and predicted blood lead levels were within 0.7μg/dL, and proportions of study populations expected to be above 10μg/dL were within 4% of those observed.

These studies clearly show the importance of determining lead concentrations and child blood lead levels in large cities like Addis Ababa. In this study only water lead concentrations were used to determine blood lead levels. But it is seen that soil and air parameters also contribute significantly for a child's exposure to having BLLs above 10μg/dL.

2.3 Microbial Contamination

Microbial contamination is by far the most important public health challenge of drinking water supply systems. All microbial organisms of viral, bacterial, parasitic and protozoan origins can be found in the distribution network of the water supply (Mekonne, 2015). These harmful organisms can originate from a variety of sources such as industrial waste, decayed plant matter, agricultural runoff and human wastes. Some of these microbial organisms are more pathogenic than others. The hazardous pathogens in drinking water are usually associated with human or animal excreta in many circumstances, but there are also other pathogens capable of causing infection through the drinking water. The most transmissible diseases related to drinking water are those caused by pathogenic viruses, bacteria and parasites (WHO, 2017). Examples of pathogenic organisms implicated for water borne disease outbreaks include *E. coli* O157:H7, *Salmonella, Norovirus, Cryptosporidium* and *Giardia*. These pathogens are also different in characteristics, behavior and resistance. Simultaneously they affect different persons in various ways, reliant on factors as age, sex, state of health and living conditions (WHO, 2017). This study focused on indicator organisms (total coliforms and *E. coli*) in characterizing the microbial quality of the water from the distribution network.

2.3.1 Indicator Organisms

Indicator organisms are useful for various purposes since they are organism that helps us to find out if a pathogenic microorganism is in a sample or not. It can be used to discover if a microorganism is in a sample, in a filtration system, or as disinfection validation (WHO, 2011). When using indicator organisms we are not detecting the hazardous organism itself but an organism that will be present when the hazard organism is present. For example, E. coli is widely used as an indicator for fecal contamination (WHO, 2011). E. coli is commonly used because it can be complex, expensive and time consuming to detect pathogenic organisms in a water sample (WHO, 2011). The indicator organisms accounted for in this study were total coliforms and *E. coli*.

A) Total and Fecal Coliforms

The Coliform groups are different types of bacteria with various characteristics and are often correlated with fecal contamination (IWA-publishing, 2003). Coliform bacteria are found in the environment as in the soil, vegetation, intestines or feces of warm-blooded animals and humans, and are mostly not harmful (WHO, 2017). The coliform bacteria are divided into two groups, total coliforms and fecal coliforms, depending on their characteristics (WHO, 2017). Total coliforms are not helpful as fecal organism indicator, but are good in evaluating the purity and reliability of a distribution system and additionally as indicator for the presence of biofilm in the distribution network (WHO, 2017).

According to Mohammadi (2014), quantifying total coliform bacteria in water samples gives an indication of the sanitary conditions of the supply. It is one of the most basic tests for bacterial contamination and is widely used to determine if water supplies are contaminated by a fecal or environmental source.

The total coliforms multiply at 37ºC and stand for the whole group of coliforms (IWA publishing, 2003). They are generally found in soil and vegetation and if detected the main source is most likely environmental, but if the total coliform is discovered in drinking water, one have to be sure that the sample is not contaminated by pathogens form of fecal contaminants. When fecal coliforms has been detected in a water source or a water sample it means that there is a great possibility of recently contamination by fecal contaminants as feces from animals or humans, and that it can contain bacteria, viruses or protozoa which can be the cause of different disease as diarrhea Mohammadi (2014). For that reason, application of fecal coliform bacteria as indicator organism is a good way to indicate fecal contamination in water. The major fecal contaminants are discussed below:

B) Escherichia coli (*E. coli*)

E. coli is a bacterium that exists in the gut of warm-blooded animals and humans. It is a thermo tolerant bacteria, meaning that it can grow in higher temperature (44.2ºC) (IWA publishing, 2003), but it grows best in moderate temperatures from 7-10 ºC up to 50 ºC, with an ideal growing temperature at 37 ºC (Mohammadi, 2014).

Mostly, the E. coli bacterium itself is not pathogenic, however, a limited number of special sorts like E. coli O157:H7 can cause acute diarrhea (WHO, 2017). When there is *E.coli* in drinking water, then there is a high likelihood of fecal contamination in the water.

The application of E. coli as indicator for monitoring drinking water has existed for many years, and is a well-recognized indicator organism as it is an important indicator for fecal pollution and treatment efficiency. E. coli is a good indicator since, as mentioned, it exists in large number in intestines of warm-blooded animals and human beings, and are normally not harmful (Mohammadi, 2014), and are respectable in monitoring drinking water because of the high amounts in polluted waters (WHO, 2017). E. coli cannot multiply in natural waters and it is persistent in water in the same way as other pathogenic organisms. It is also found in greater numbers than the fecal pathogen and responds to treatment in the same way as fecal pathogen. Finally, it is easy to detect E. coli in samples and it is economically beneficial compared to other methods (WHO, 2017). When using fecal indicators as E. coli, the WHO guidelines says that water intended for drinking purposes should not contain any E. coli in a 100 ml water sample (WHO, 2017). It is important to note that relying only on E. coli as indicator alone can in many cases, as they may not reflect the behavior of pathogenic organisms such as viruses and protozoa (IWA-publishing 2003). For example *E. coli*, is very sensitive to chlorine (IWA-publishing 2003) while viruses and protozoa are more resistant to it.

2.3.2 Chlorination

Chlorine is a powerful oxidant and is effective as a disinfectant due to its ability to oxidize the enzymes of microbial cells and reduce their ability to survive (Mekonnen, 2015). Drinking water that is sourced from surface or groundwater is often contaminated by microbes. This water is often treated to destroy harmful microorganisms and is an essential process in the supply of safe drinking water. As a result, the World Health Organization recommend as minimum as 0.2mg/L free residual chlorine in household water to ensure that it is free of harmful microbes (WHO, 2011).

In developing countries, many domestic water supplies are treated with chlorine and maintain a certain concentration of residual chlorine to disinfect potential bacterial contamination within the supply infrastructure (Mekonnen, 2015). Monitoring residual chlorine concentrations within the distribution system can indicate if water quality degradation is occurring. Any rapid deterioration or sudden disappearance of the residual chlorine concentrations can indicate contamination of the supply. For example, a high demand of chlorine may indicate that bacteria and/or biofilms are present in the distribution system (WHO, 2017). Measuring the residual chlorine in water samples is important to ensure safe water is being delivered to consumers. The results can also indicate if the supply is contaminated by microorganisms and other contaminants (WHO, 2017).

2.4 Sanitation and Drinking Water Contamination in Addis Ababa

Addis Ababa has been declared as one of the worst cities in Ethiopia in terms of environmental sanitation conditions and hygiene practices (Mekonnen, 2015). It has been approximated that 26% of the houses and the majority of slum dwellings have no toilet facilities. Rivers, ditches and open spaces are usually used as defecation sites. A study by Abay (2010) has also previously reported that as much as 25% of the population has no access to sanitation services. Shared pit latrines may be used by up to 75% of the population in the city and only 0.6% of the population used modern flush toilets are connected to a sewer system. It was suggested that only

0.6% of the total sewage produced was reaching the wastewater treatment plant. The remainder is likely to be leaching through the soil and polluting waterways. Waste from pit latrines can directly pollute the groundwater which is used as a drinking water supply. The waste can also seep into unsecure water supply pipelines and can contaminate household water.

Mekonnen (2015) has previously stated that the city's sanitation facilities and services are among the lowest in Sub-Saharan Africa. Only 12% of households in Addis Ababa have flush toilets that discharge to sewers or septic tanks. The greatest proportion (63%) of households uses individual or shared pit latrines. The remaining 25% do not have access to sanitation facilities. The incidences of disease are greatest in the densely populated areas where water supply and sanitation services are particularly inadequate.

Cities that do not have adequate wastewater networks and management practices will have issues with supplying safe drinking water. In Addis Ababa, the majority of houses and business centers (such as hotels, garages and car washes) dispose of their grey-water into the drainage systems. However, these drainage systems are ineffective in many areas. During the wet season, solid wastes mixed with rainfall can flow into cross-connected water supply systems.

A study by Mekonnen (2015) reported the water quality analysis done in *Legedadi* catchment on 60 households. The samples were taken from *Woreda 6, woreda 8* and *Bole* Sub city. The mean residual chlorine levels measured in the household tap water samples of W-8, W-6 and the wider Bole sub-city were 0.47±0.08, 0.12±0.11, and 0.16±0.17 mg/L, respectively. As Mekonnen (2015) stated in this study, residual chlorine levels dramatically declined after the treated water left the *Legedadi* treatment plant and entered into the distribution system. The residual chlorine levels measured in the remote households of *Woreda* 6 and the wider Bole sub-city were minimal.

The other tested water quality parameter in this study was *E. coli* and total coliforms. The results revealed that no *E. coli* bacteria were found in the majority of the water samples collected from *Woreda* 8. Only two samples had *E. coli* counts of less than 2 CFU/100ml. Similarly, the majority of samples collected from *Woreda* 8 were free of coliform bacteria. Four samples (20%) had total coliform bacteria ranging from 4-40 CFU/100ml. In *Woreda* 8, all tap water samples with *E. coli* had total coliforms present.

A median concentration of 0 CFU/100ml of *E. coli* was detected in W-6 and the wider Bole sub-city. However, elevated *E. coli* concentrations ranging from 2-33 and 2-32 CFU/100ml were detected in 35% and 40% of the water samples collected from *Woreda* 6 and the wider Bole sub-city, respectively. The concentrations of total coliform bacteria ranged from 4-144 and 1-71 CFU/100ml in *Woreda* 6 and the wider Bole sub-city, respectively. The majority of *E. coli* and total coliform bacteria were detected in samples collected from W-6 and the wider Bole sub-city after supply interruption and reinstatement events. Mekonnen (2015) suggested that, the higher concentrations detected in W-6 and the wider Bole sub-city may be attributed to the aged, leaked and cross-connected water supply distribution systems which are common in these areas. Many of the samples were collected from these areas after supply interruption and reinstatement events. Leaky and cross-connected pipelines could be contaminated by the external environment due to negative pressures or suction occurring at these times.

Addis Ababa has grown very rapidly since it was founded in 1886. This growth has put enormous pressure on water supply services and the sewerage system. The water supply infrastructure in the city is more than 40 years old and is known for its low output capacity and high water losses due to degraded pipelines (Mekonnen, 2015). Similarly, Abay (2010) has also stated that the growth of Addis Ababa City has been unregulated and unstructured and the city has not had formal urban planning until recently. This has put many constraints on the water supply system. A major concern is the significant losses of water caused by leakage from the old supply infrastructure.

The national drinking water standards are identical to the World Health Organization's (WHO, 2017) guideline for the provision of safe drinking water. However, the treated water is generally delivered to households and schools in old metallic (galvanized iron and cast iron) pipelines. Some piping has been replaced by HDPE and PVC materials. Pipes are either buried underground or exposed to the environment. In many of the slum dwellings, the pipelines are very old and degraded. Approximately 30-40% of the drinking water supplied to the city does not reach consumers. The water is lost at different levels of the distribution system due to leaking pipes and aging infrastructures (Mekonnen, 2015; and Abay, 2010).

The combination of the degraded infrastructure and a cross-connected distribution system may provide a favorable environment for drinking water contamination to occur. Considering the poor environmental conditions in many districts of the city, there are many chances for drinking water contamination in cracked and leaky water supply pipes. Currently, there is no comprehensive water quality monitoring or data for drinking water quality at the household and school levels. It is therefore unclear how much contamination is occurring to the drinking water quality once it is distributed from the treatment plants, and whether the water is safe to drink once it reaches school.

3. MATERIALS AND METHODS

3.1 Study Location

The study was conducted in Addis Ababa, the capital city of Ethiopia, which is located in central part of Ethiopia. The city lies at a geographic coordinate of 9.03000°N 38.74000°E and has an area of 540 km^2. Its average altitude above sea level is 2355 meters. The city has through recent years seen a strong annual growth rate, and population counts as of 2017 are growing more than 4 million, making it the biggest city in Ethiopia.

The city's temperature generally ranges from 9.9-22.7^{0}C and has 1205.2 mm of average annual precipitation. It has three distinct seasonal periods. The seven months between March and September are a wet period. The short rain season occurs between March and May, while the main rain season occurs during the months of June to September. The dry season occurs during the months of October to February.

Figure 2: Location of Addis Ababa city, Ethiopia

The treated water distributed to the Addis Ababa residents is sourced from surface and ground water (AAWSA). Over 100 deep and shallow wells have been dug since 1995 and are operational. 413,000 cubic meters out of the city's total daily water production of

608,000 cubic meters is obtained from ground water sources, which amounts to 67.9% of the total water supply. The city has three different treatment plants; two for surface water and one for ground water source. The groundwater source is mainly for the *Akaki* treatment plant that receives its water from 77 water wells according to Addis Ababa water and sewerage Authority. The treatment plant is located at southern part of the city at GPS coordinates of 8.875029°N, 38.762627°E. The second is the *Gefersa* treatment plant with surface water source. The dam that supplies water to this plant was originally developed in 1940. It underwent a rehabilitation project in 2008, which increased its raw water holding capacity to 9.5 million cubic meters. The current water yield is 30,000 cubic meters per day. It is located about 10 Km North West of the city with coordinates 9.06421°N, 38.642887°E. The third is the *Legedadi* treatment with mixed ground and surface water sources. It was established in 1970, Underwent expansion works in 1985) and in 2015. Currently in 2018, its water yield is 195,000 cubic meters per day. It is located about 20 Km North East of the city with GPS coordinates 9.065799°N, 38.961116°E.

3.2 Sampling Method

Fifteen kindergarten schools from *Akaki* catchment, fifteen from *Legedadi*, and eight schools from *Gefersa* sub-systems were selected according to the sub system's coverage areas. Samples were randomly chosen to make the schools dispersed and representative of the catchments. The schools were selected from a school list and location guide book from Addis Ababa Education Bureau.

One water sample was taken from each school giving a total of 38 samples. However, from the sources, two water samples were taken from each treatment plant, before and after the water is treated, which means six samples have been taken from the three treatment plants. The total number of samples taken is sum up to44. Appendix-A shows the list of sampling schools and their location.

Each sample had a volume of 500-1000ml, collected using pre-labeled 500 -1000 ml sterile plastic bottles. The bottles were initially cleaned using standard detergents and distilled water. All samples were analyzed for chlorine, PH, temperature, and microbial tests within 24 hours. And water samples were transported to the Addis Ababa University Faculty of Science, Department of Chemistry laboratory, and acidified to a PH < 2 with 69 % HNO_3 immediately and stored at 4^oC in a refrigerator before analysis.

Figure 3: Water sample collection from *Gefersa* Treatment Plant (date: 19 May, 2018)

Figure 4: All 44 samples

3.3 Measuring Chlorine, PH and Temperature

3.3.1 Measuring Chlorine

The residual chlorine in the water was tested using Palintest 7100 photometer. Palintest photometer is made in England for water quality and wastewater tests. The instrument has dual light source photometer offering direct reading of pre-programmed test calibrations, absorbance and transmittance. The instrument is working with wave lengths 450nm, 500nm, 550nm, 570nm, 600nm, and 650nm ranges. The accuracy of the measurement is ±1%.

The fundamental operating technique applied to the photometer 7100 is based on the principles of optical absorbance and scattering of visible light. The optical absorbance techniques are based on the use of Palintest photometric reagent, creating visible colors with specific analyses upon action. The intensity of color produced is measured with the photometer 7100 and the stored calibration data and deliver the final result. Optical scattering techniques produced small particles to scatter the source beam, the amount of scatter providing a result for the concentration of parameter under test (www.palintest.com/en/products/photometer-7100). This photometer was selected for this research for its speed of measurement and higher accuracy.

This test was conducted in Addis Ababa University, Addis Ababa Institute of technology; Waste Water Laboratory.

A) Method

Chlorine in water reacts with diethyl-p-phenylene diamine (DPD1) and changes its color to pink. The test is carried out by adding one tablet to a sample of water.

The intensity of the color produced in the test tube is proportional to the chlorine concentration and is measured using the Palintest photometer.

B) Reagents and Equipment

- Palintest diethyl-p-phenylene diamine (DPD1) Tablets
- Palintest Automatic Wavelength selection photometer
- Round test tubes, 10ml glass (PT 595)

C) Test Instructions

1. Fill two test tubes with sample to the 10ml mark.
2. Add one DPD1 tablet in one of the test tubes, crush and mix to dissolve.
3. Wait for ten minutes to allow color development.
4. Select phot 007 on photometer to measure for free chlorine mg/l as Cl_2.
5. Insert the blank test tube first, and then insert the one with the reagent.
6. Read results.

Figure 5: Reading residual chlorine on Palintest photometer

3.3.2 Measuring PH and Temperature

PH and temperature were measured simultaneously using a hand PH meter. Each sample was measured 3 times and an average result was taken. This test was conducted in Addis Ababa University, Technology Faculty; Waste Water Laboratory.

A) Equipment

- 100ml beaker
- PH meter

B) Procedure

1. Pour 50 - 100ml of sample in the beaker
2. Immerse the tip of the PH meter in the sample.
3. Wait for a few seconds, and record the result.

Figure 6: Measuring PH and temperature

3.4 Microbial Analysis for Total Coliform and E.coli

Total coliform and *E. coli* were tested simultaneously using Eosine Methylene Blue (EMB) agar. This selective media grows only gram negative bacteria. Since both total coliforms and E. coli are groups of gram negative bacteria, it was possible to test for both using this media. If *E. coli* bacteria are present in the sample, it shows a metallic green color on the media after it's kept in an incubator for 24 hours at 37^{o}C. Other colors represent different groups of total coliform bacteria.

The samples were carefully processed in **FASTER TWO 30** hub. This hub creates a vertical laminar flow which guarantees excellent decontaminated working area and particle-free conditions. Also, to prevent any environmental contamination, the media and petri dishes were autoclaved. The researcher's hands were also sanitized with 70% denatured ethanol at all times during my work on the hub to prevent contamination.

This test was conducted in Addis Ababa University, Science Faculty; Microbiology Laboratory.

Figure 7: Working in a bacteria free hub.

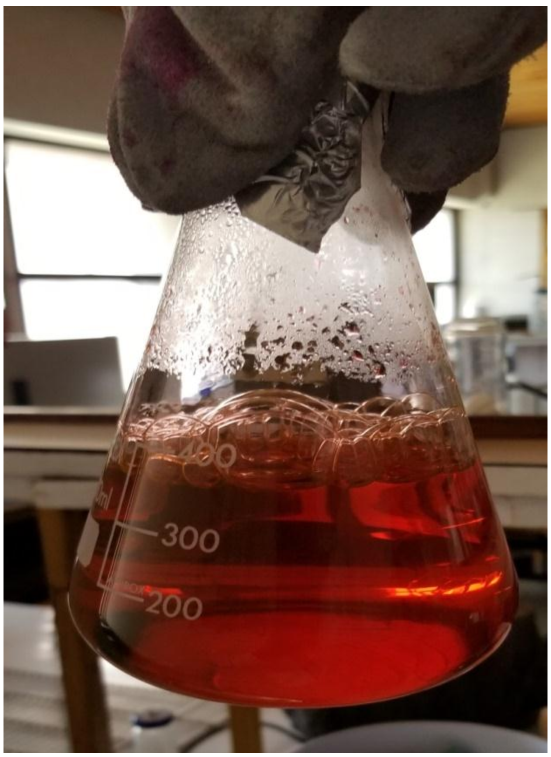
A) Equipment and Agar

Eosin Methylene Blue (EMB) agar, Gloves, Alcohol, Petri dishes, Micropipette, Spreader, Bunsen burner, Autoclave, Oven, 500ml conical flask, Hot plate, and **FASTER TWO 30** hub

B) Procedures

1. Decide on number of samples done at a time then wash and prepare petri-dishes.
2. Prepare EMB media with 37.5gm of EMB to 1000 ml distilled water ratio.
3. Mix the agar and distilled water in the 500ml conical flask and boil on a hot plate.
4. Autoclave the petri dishes and the boiled media for 15 minutes at 121^{o}c to remove any bacteria.
5. Take out the petri dishes and media out of the autoclave and immediately put in the **FASTER TWO 30** bacteria free hub.

6. Wait for about 10 minutes until the petri dishes are cool and write a label on them.
7. Gently pour the media on the petri dishes and wait till the media is dry.
8. Use the micropipette to pour 100μl of sample water on a petri dish. Then discard the micropipette tip to prevent contamination and use a new one for next sample.
9. Use spreader to evenly distribute the water sample on the petri dish.
10. Apply alcohol on the spreader and burn on the Bunsen burner to prevent contamination.
11. Repeat steps 8 -10 for remaining samples then put the petri dishes in an oven for 24 hours at 37^{o}c.



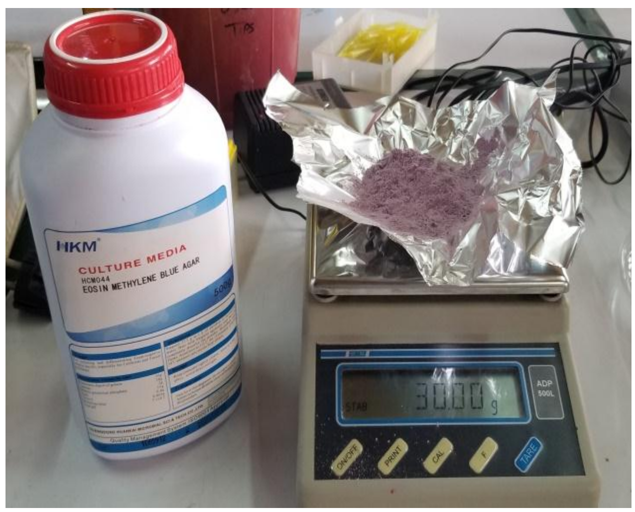


Figure 8: Boiled EMB media after autoclaved (left) and Measuring EMB media on a Scale (right)

3.5 Measuring Lead Concentration

The lead concentration in the samples was measured using Agilent 4200 MP-AES (Microwave Plasma Atomic Emission Spectroscopy). The MP-AES consists of microwave induced plasma interfaced to an atomic emission spectrophotometer (AES). It is used for simultaneous multi-analyte determination of major and minor elements. MP-AES employs microwave energy to produce a plasma discharge using nitrogen supplied from a gas cylinder or extracted from ambient air, which eliminates the need for sourcing gases in remote locations or foreign countries. Samples are typically nebulized prior to interaction with the plasma in MP-AES measurements. The atomized sample passes through the plasma and electrons are promoted to the excited state. The light emitted electrons return to the ground state light is separated into a spectrum and the intensity of each emission line measured at the detector. Most commonly determined elements can be measured with a working range of low part per million (ppm) to weight percent (wt. %). MP-AES is a technique comparable to traditional AA (Atomic Absorption) and AES but with several potential advantages including lower cost of operation and elimination of the requirement for flammable gasses. MP-AES instruments are bench top instruments. (www.agilent.com/en/products/mp-aes/mp-aes-systems/4200-mp-aes)

Figure 9: Agilent 4200 MP-AES measuring lead concentration

The MP-AES has narrow tubes in its systems which could be easily clogged. So the samples must be digested with concentrated Nitric acid (69%) to remove any solid particle. Digestion of samples was made based on the standard analytical method of the water quality (American Public Health Association 2005). This test was conducted in Addis Ababa University, Science Faculty; Analytical Chemistry Laboratory.

The Agilent 4200 MP-AES was calibration initially using four different known lead concentrations of 2.5, 5, 7.5, and 10ppms. It takes 3 readings for each concentration and takes the average. The correlation coefficient was **0.99941**. The correlation coefficient line is given in the figure below.

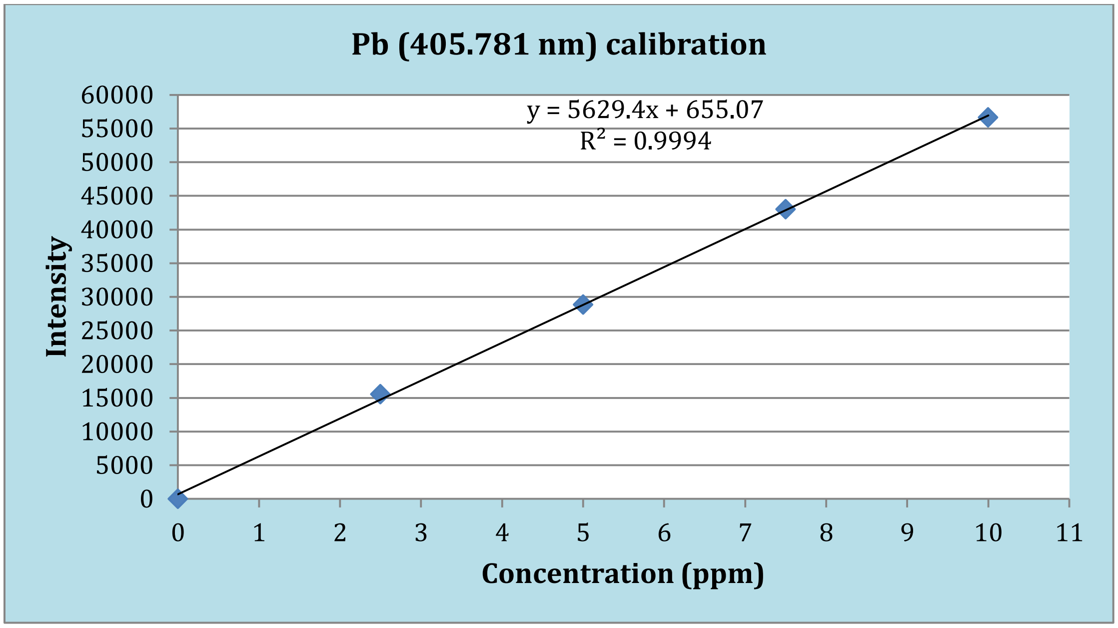


Figure 10: Correlation coefficient line

The instrument operating conditions are listed in the table below.

Table 3: Operating conditions for Agilent MP-AES 4200

Instrument Parameter	Operating condition
Microwave frequency (MHz)	2450
Microwave power (kW)	1.0
Fuel	Nitrogen
Pb wavelength (nm)	405.781
Nebulizer	Inter OneNeb
Read time (s)	5
Number of replicates	3
Stabilization time (s)	15
Sample introduction	Agilent SPS 3

A. Equipment and Chemicals

Agilent 4200 MP-AES, Concentrated Nitric acid(69%), 250ml conical flask, Filter paper, Hot plate, 50 ml volumetric flask, Agilent 4200 MP-AES test tubes

B. Test procedures

1. Pour 50 ml of sample water on 250 ml conical flask
2. Add 5 ml of concentrated Nitric acid (69%).
3. Boil on hot plate till 10 ml is left.
4. After cooling down, filter the samples and dilute with distilled water into a 50 ml flask
5. Pour the samples in the machines test tubes in their right order.
6. Run the Agilent 4200 MP-AES for 30 minutes idle.
7. Run the tests.

Figure 11: Digesting samples with Nitric acid on a hot plate

3.6 Data Entry and Analysis

Once the relevant data were collected, the next step was analyzing it using different methods. MS Excel was used to analyze the data for percentage and mean values. ARC GIS was used for delineating Addis Ababa's map and positioning samples on the map by their GPS coordinates.

IEUBK win model was used to estimate blood lead levels in children from the lead concentration results. Lead concentration in water, air, soil and dietary are the inputs for the model. But for this study, only water lead concentration was entered as µg/l and default values were selected for the other parameters.

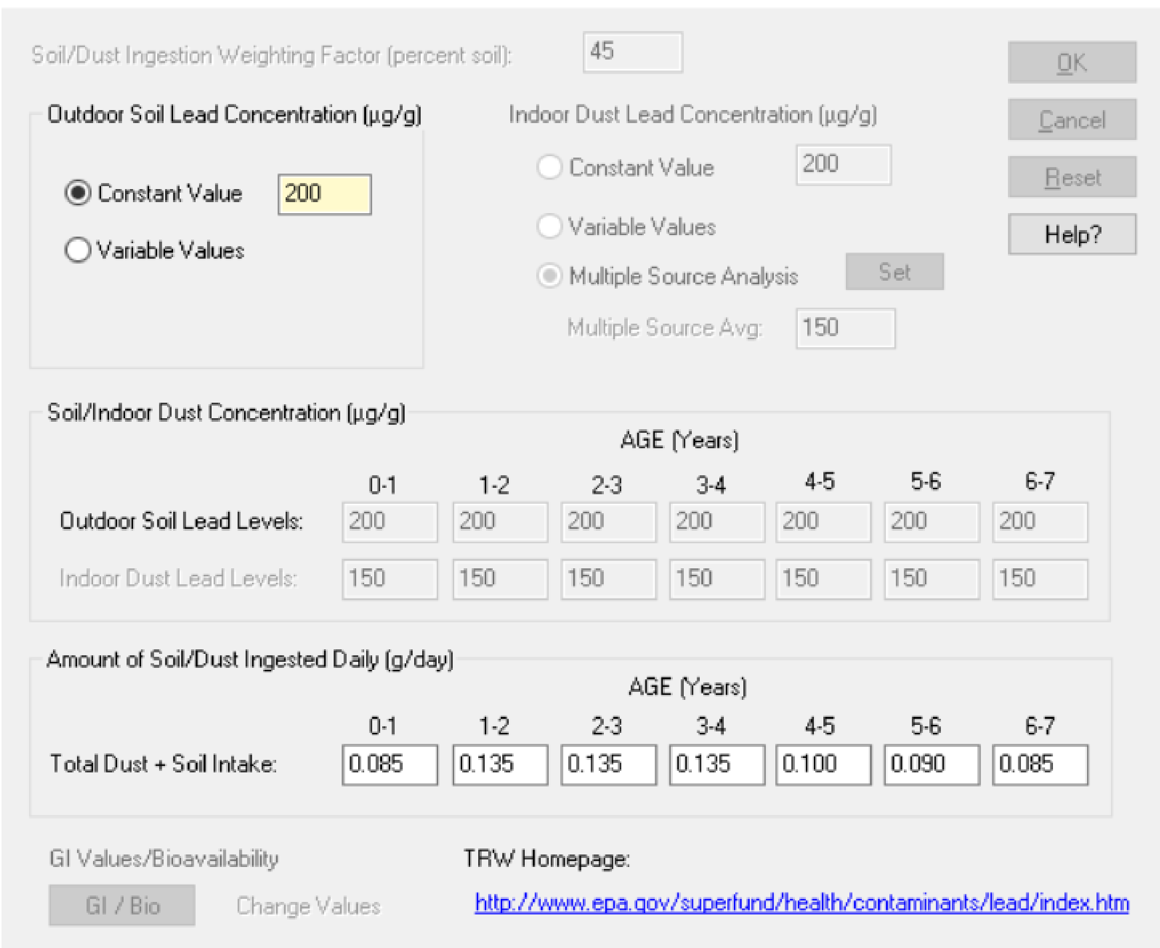


Figure 12: Default soil concentration selected in the model

The figure above shows a constant value of 200µg/g selected for soil lead concentration and the amount of soil ingested per day for different age groups. If outdoor and indoor soil lead concentrations are measured, it is possible to input those values under the 'variable values' option.

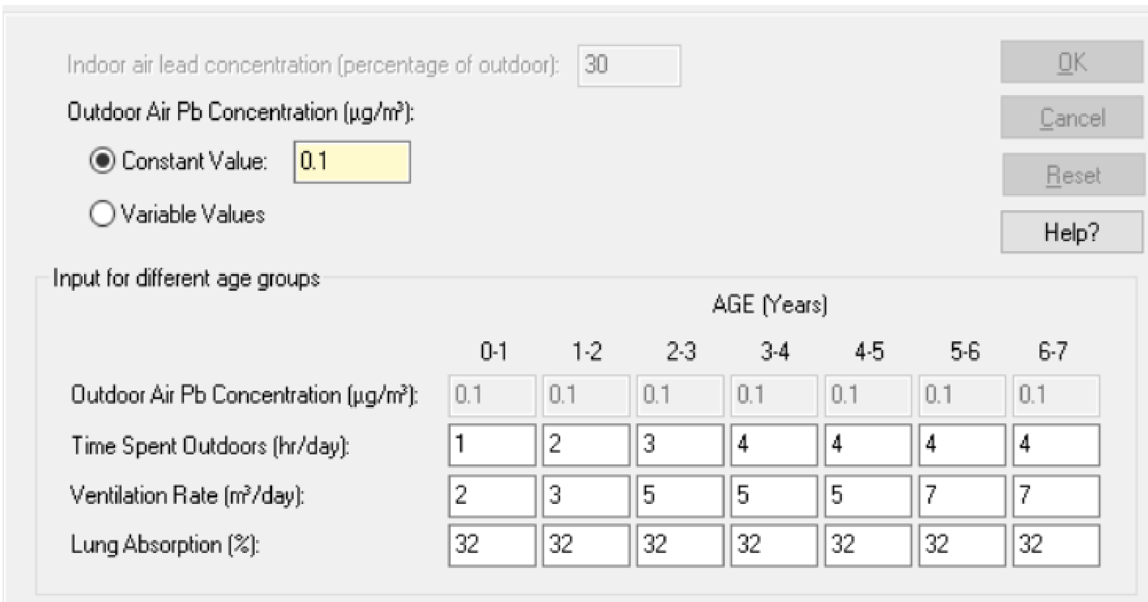


Figure 13: Default air concentration selected in the model

The figure above shows a constant value of 0.1µg/m^3 selected for air lead concentration. Time spent outdoors, ventilation rate and lung absorption parameters are also set by the model. A variable air lead concentration value can also be used under the 'variable value' option if air lead concentration is measured.

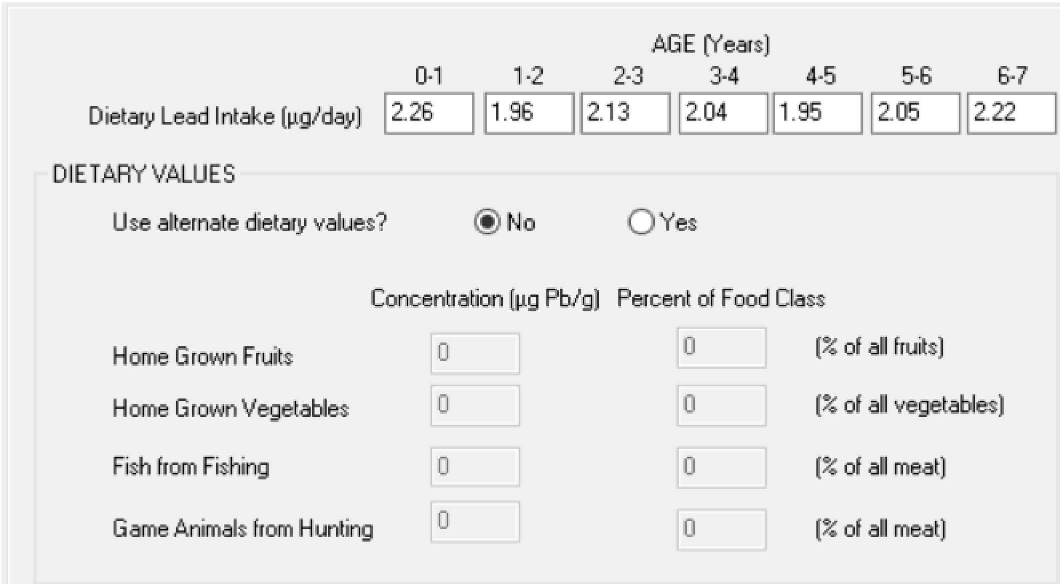


Figure 14: Dietary lead concentration selected in the model

The above figure shows dietary lead intake values selected by the model as a default. If lead concentration in the different food groups listed in the figure is measured, the alternate dietary option can be used.

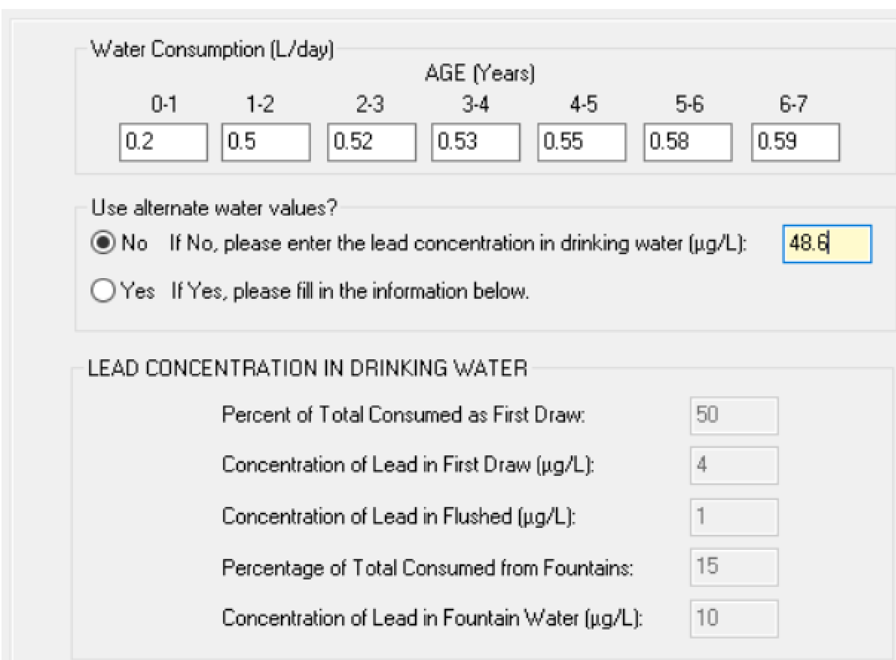


Figure 15: Water lead concentration in the model

The above figure shows the water lead concentration used for this study. On the top of the figure, it shows the daily water consumption of the different age groups. And those values are used as default. If water samples are taken from first draw, flushed and fountain water, we can use the ‘yes’ option in the model.

3.7 Model Calibration

The default values in the IEUBK model are recommended by the US EPA. These values are taken from the nation’s environmental lead concentration data and are considered to be safe and within the permissible range. The IEUBK user guide also suggests to users to take these values for unmeasured lead concentrations. In this section, default and zero values will be used to check if the model works properly. Since the default values are considered safe, the probability of exposure for having blood lead levels above 10μg/dL should be almost zero when we use these default values in the model. The default values used are, for soil 200μg/g, for air 0.1μg/g, for water 4μg/g and dietary values used in Figure 14 are used. The results are given in section 4.6.

3.8 Limitations of the Study

Initially it was proposed to take 60 samples from the 3 catchments. Unfortunately, it was very difficult to collect 60 samples since there has been a very high water supply shortage in the city which resulted most of the school water points were without water. Most of the schools visited had no running water at their taps. So it was decided to decrease the sample size to 38 according to the catchment sizes.

The other limitation is availability of R2A agar media in the market. The agar media is specifically made for studying total coliforms in potable water. Alternatively the EMB media was used for both *E. coli* and total coliforms test.

The third major limitation is availability of data regarding lead concentrations in Addis Ababa. Since this data is unavailable, default values for air, soil, and diet were used in the IEUBK model.

4. RESULTS

4.1 PH

PH and temperature results were simultaneously recorded from the hand PH meter as discussed in the methods section. The figure below shows the distribution of PH in Addis Ababa city's water distribution system at different schools.

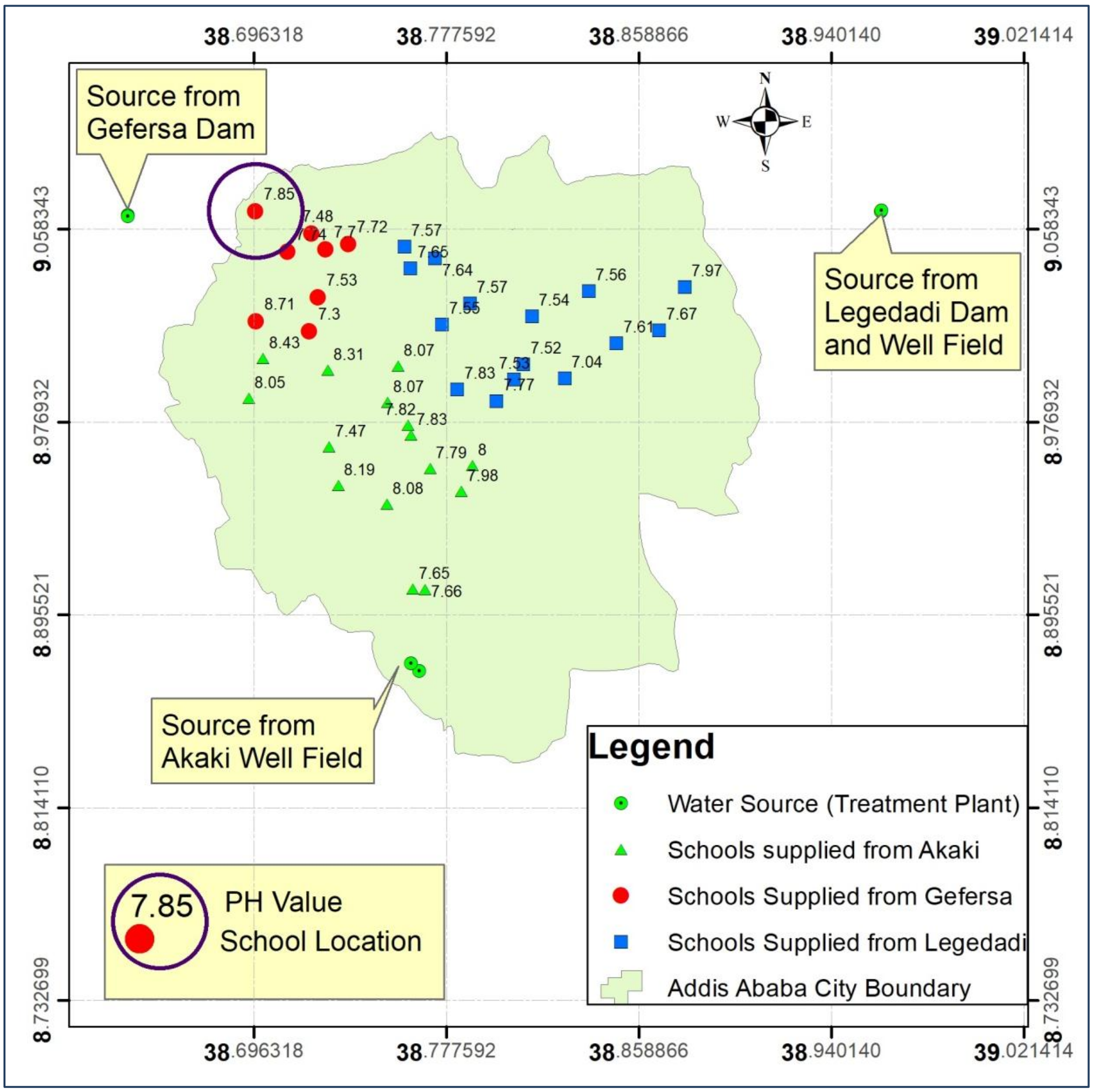


Figure 16: Distribution of PH in the Addis Ababa

Results of samples taken from the treatment plant are listed in the table below.

Table 4: PH levels of samples taken from the treatment plants

Sources	PH	
	Before Treatment	After Treatment
Akaki treatment	8.33	8.2
Legedadi treatment	7.9	7.7
Gefersa treatment	7.3	7.72

Akaki catchment having a ground water source has the largest mean and median PH values of 7.96 and 8 respectively. The results were taken from the 15 schools (A1-A15) listed in Appendix C. The next is the *Gefersa* catchment with mean and median PH values of 7.75 and 7.71 respectively, representing schools from G1 to G8. The *Legedadi* catchment has the lowest mean and median PH values of 7.6 and 7.57 for schools L1-L15.

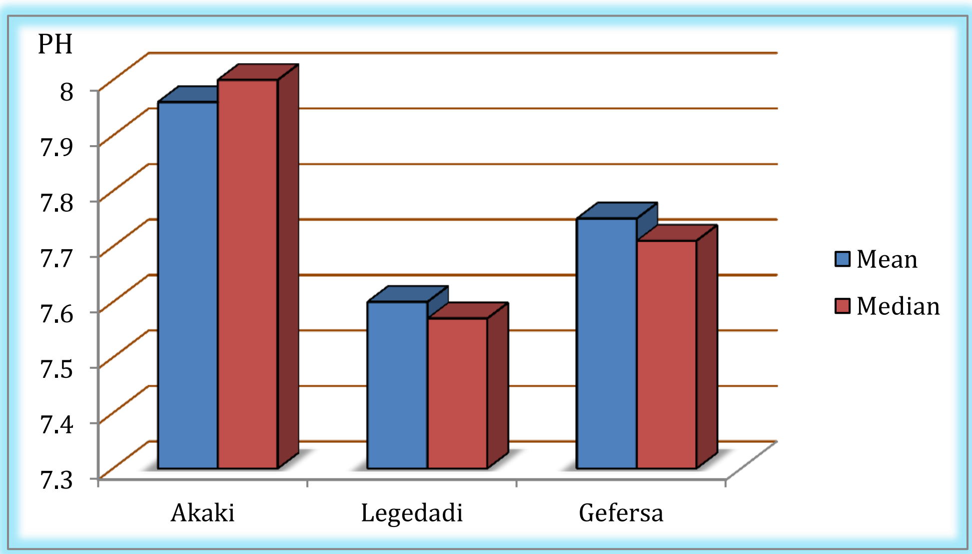


Figure 17: Mean and Median PH values

4.2 Free Chlorine

The free chlorine content of the water samples was tested using the Palintest 7100 photometer. The minimum recommended WHO value for free chlorine residue in treated drinking water is 0.2 mg/L. In this study, 16 out of 38 (42.1%) of the water samples had a free chlorine value below 0.2mg/L.

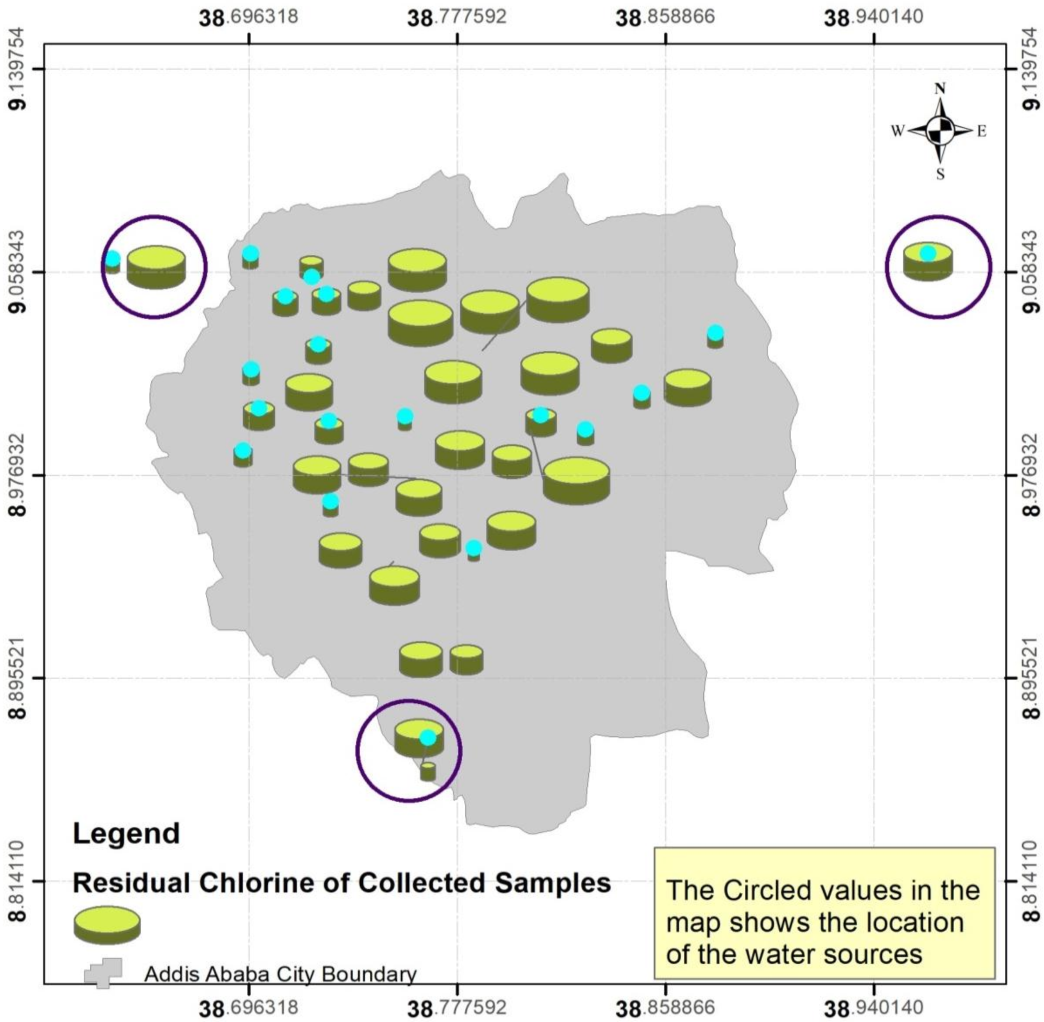


Figure 18: Free chlorine distribution (highlighted samples have residual chlorine below 0.2mg/L)

In the *Akaki* catchment, 40% (6 out of 15) of the samples have residual chlorine values below the recommended 0.2mg/L. For *Legedadi*, 26.67% (4 out of 15) and for *Gefersa* 75% (6 out of 8) of the samples have values below 0.2mg/L.

The free chlorine levels of the samples from the treatment plants are listed in the table below.

Table 5: Free chlorine levels of samples taken from the treatment plants

Sources	**Free Chlorine (mg/l)**	
	Before Treatment	After Treatment
Akaki treatment	0.04	0.45
Legedadi treatment	0	0.45
Gefersa treatment	0.63	0.04

4.3 Microbial Analysis

Bacteriological analysis of the samples revealed that there was total coliform bacteria contamination in the three catchments. Accordingly, 3 out of 15 samples from *Akaki*, 2 out of 15 from *Legedadi* and 2 out of 8 samples from *Gefersa* catchment were contaminated.

However, all of the samples did not show any sign of *E. coli* contamination. This means the water is safe from fecal contamination, since *E. coli* is an indicator of fecal contamination.

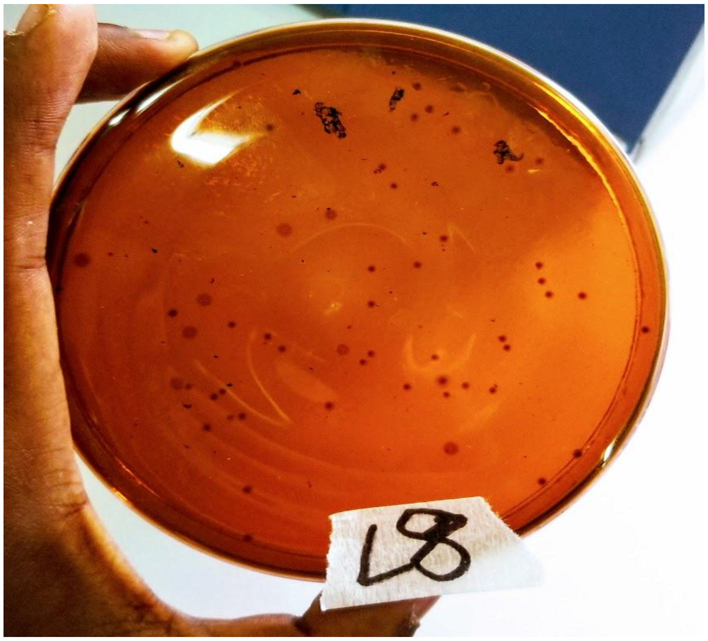


Figure 19: Contaminated sample with Total coliforms

Even though all catchments show contamination, the degree of contamination is different. Sample A13, G3 and G6 had bacterial count of 1 CFU/100ml and sample A7, L8 and L9 had bacterial count of 120, 65 and 20 CFU/100ml respectively. The figure below shows the bacterial count of the contaminated samples in CFU/100mL.

The samples from the treatment plants were also analyzed and no E.coli contamination was seen. The table below shows total results of the analysis.

Table 6: Microbial analysis of samples taken from the treatment plants

Sources		Microbial analysis	
		E. coli	Total coliforms
Akaki	Before treatment	Absent	Present
	After treatment	Absent	Absent
Legedadi	Before treatment	Absent	Present
	After treatment	Absent	Absent
Gefersa	Before treatment	Absent	Absent
	After treatment	Absent	Absent

4.5 Lead Concentration

The lead concentration of the water samples was measured using the Agilent 4200 MP-AES. The detailed results are attached in Appendix F. Generally; the findings revealed that, all water samples taken from the three catchments had lead concentrations above the WHO recommended value of 10µg/L. Mean lead concentration of all 38 schools is 62.37µg/L. And mean values of the three catchments are: for *Akaki* 48.6µg/L, for *Legedadi* 80µg/L, and for *Gefersa* 55µg/L.

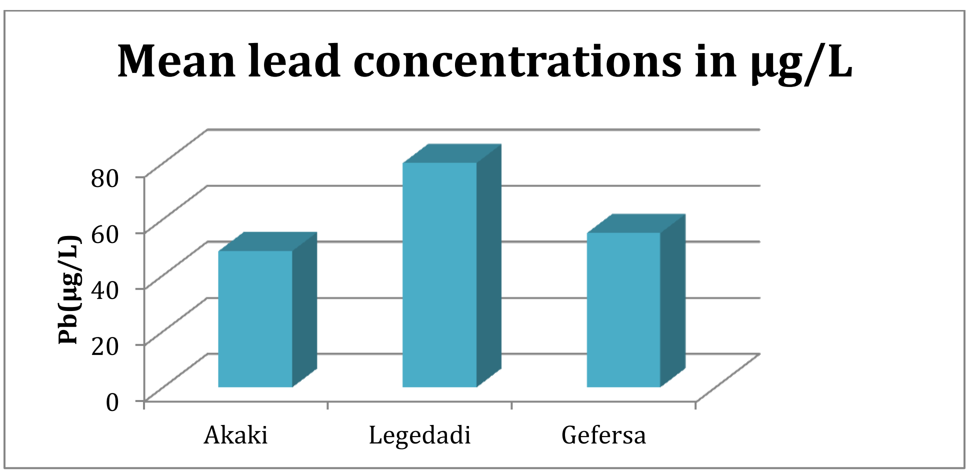


Figure 20: Mean Lead concentration of the three catchments.

In the *Akaki* catchment, 13 out of 15 samples had a lead concentration value of 50μg/L and 2 out of 15 samples read a value of 40μg/L. For the *Legedadi* catchment, values range from 30-170μg/L; 12 out of 15 samples had a value ranging from 30-90μg/L and the other 3 samples had values of 170μg/L, 110μg/L, and 110μg/L. Lastly for *Gefersa*, values ranged from 50-70μg/L. The lead concentrations from the samples taken from the three treatment plants are listed in the table below.

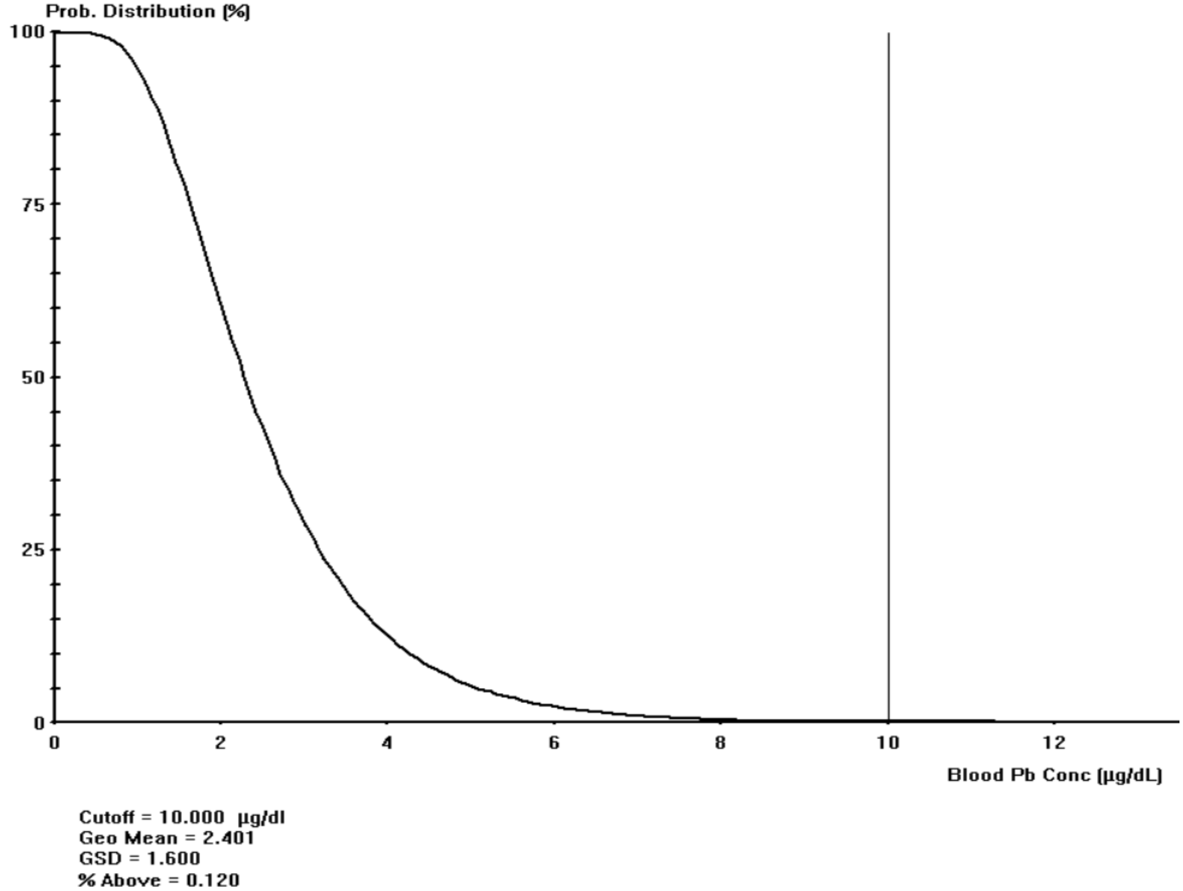
Table 7: Lead concentrations in samples taken from the treatment plants

Sources	**Lead (μg/L)**	
	Before Treatment	After Treatment
Akaki treatment	50	40
Legedadi treatment	40	30
Gefersa treatment	<0.003(BDL)	30

4.6 Model Calibration Results

Default values and zero values were used in this section. The expected outcome is to have the probability of exposure exceeding blood lead levels above 10μg/dL near to zero.

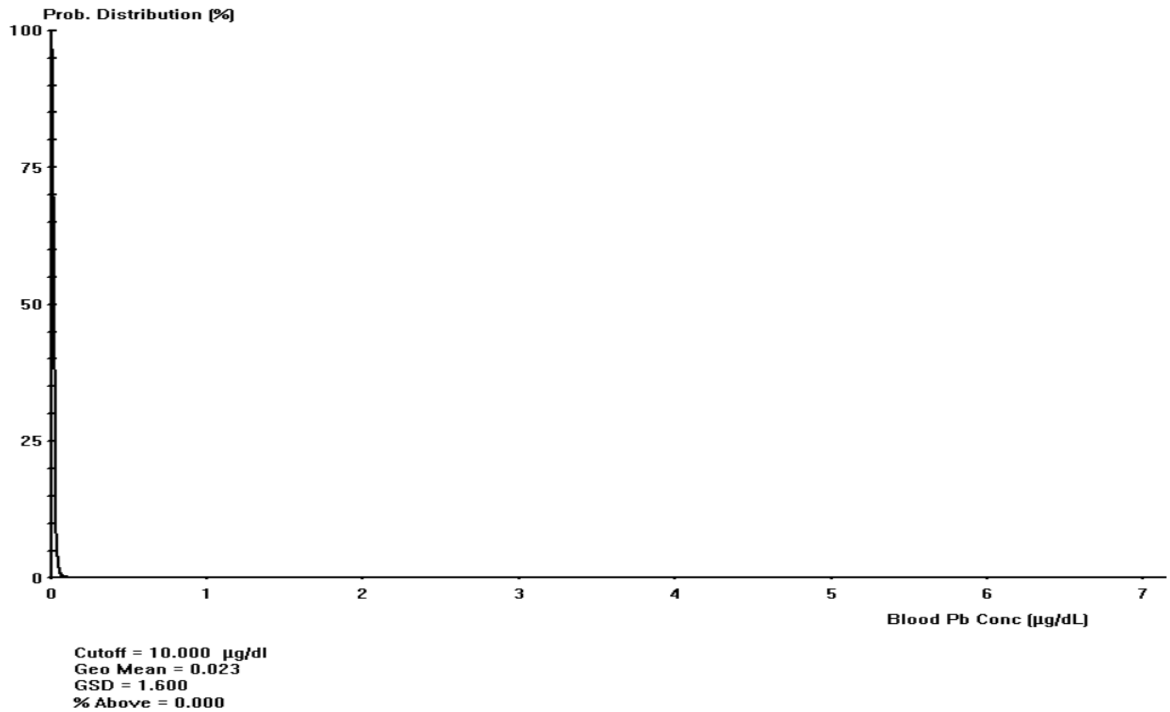
Using default values, for soil 200μg/g, for air 0.1μg/g, for dietary values used in Figure 14 and for water 4μg/g, the probability of exposure graph is given below. We can see in the graph that 0.1% of the children are expected to have their BLLs above 10μg/dL.



Source: IEUBK model output

Figure 21: Calibration result using default values

Next, we use zero values instead of the default values used in the model. We can see that the probability of exposure is 0% for the zero values used in the model. Therefore we can see that the model works properly.



Source: IEUBK model output

Figure 22: Calibration results using zero values

4.7 Blood Lead Levels (BLLs) in Children

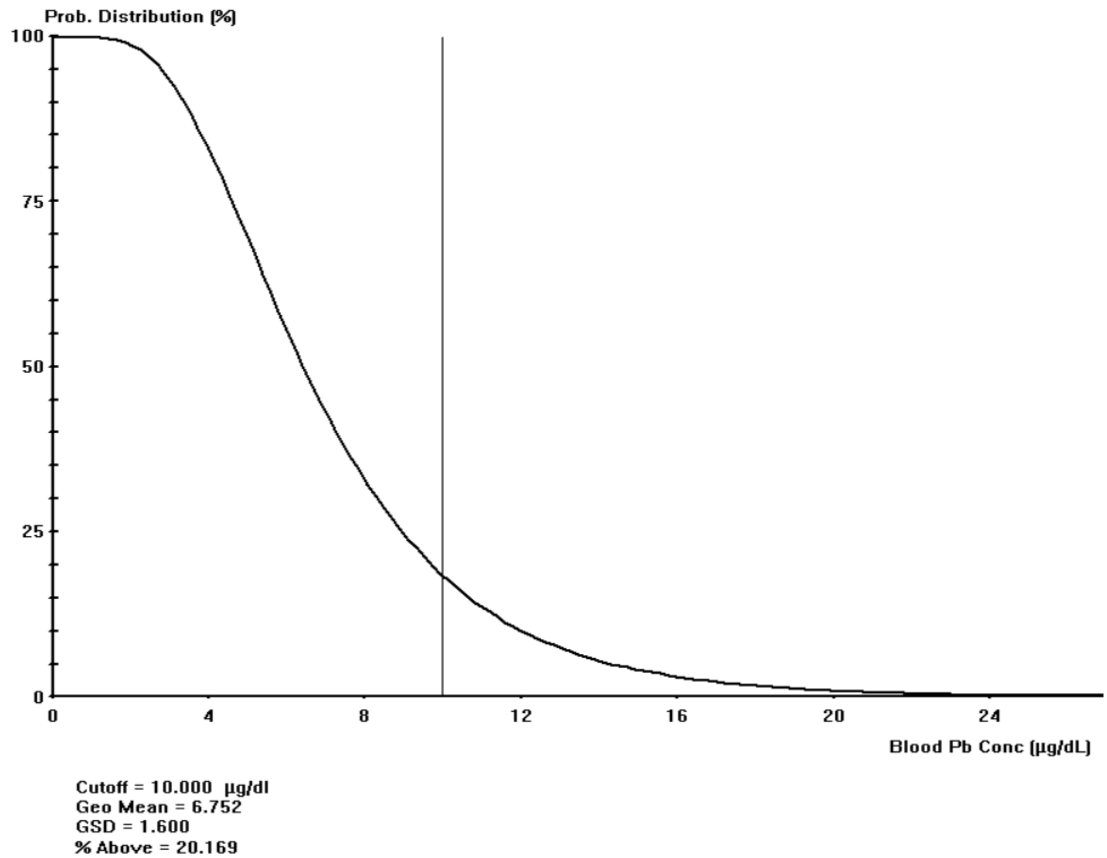
The blood lead levels in children between the ages of 3-7 were estimated using the IEUBK model. Water lead concentration of the samples was put as an input. For the other input parameters like air, soil and food default values suggested by the model were selected.

Among the 38 water samples taken from the schools, 3 samples had estimated blood lead levels above the WHO recommended 10µg/dL. All of the 3 samples are found in *Legedadi* catchment (L1, L2 and L13). The results are 13.2µg/dL, 10µg/dL, and 10µg/dL. The detail results of all the samples are attached in Appendix-F.

Taking the average lead concentration of the 38 schools (62.37µg/L), the blood lead levels and probability of exposure to lead were calculated. The average BLLs for age groups of 3-7 was 6.75µg/dL and the daily uptake of lead was 21.38µg/dL. These average results are taken from the table below.

Table 8: Average Lead uptake and BLLs in Addis Ababa city

Year	Air (µg/day)	Diet (µg/day)	Water (µg/day)	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	0.021	1.002	5.531	3.901	10.454	5.6
1-2	0.034	0.821	13.065	5.854	19.774	7.8
2-3	0.062	0.910	13.854	5.969	20.794	7.7
3-4	0.067	0.888	14.395	6.085	21.435	7.4
4-5	0.067	0.869	15.282	4.611	20.828	6.9
5-6	0.093	0.923	16.279	4.192	21.486	6.5
6-7	0.093	1.007	16.684	3.989	21.773	6.1



Source: IEUBK model output

Figure 23: Probability distribution curve of exposure in Addis Ababa city for 3-7 ages

The above probability distribution graph shows that the average BLLs for 3-7 age groups is 6.75µg/dL. And 20.17% of the children are expected to have blood lead levels above 10µg/dL.

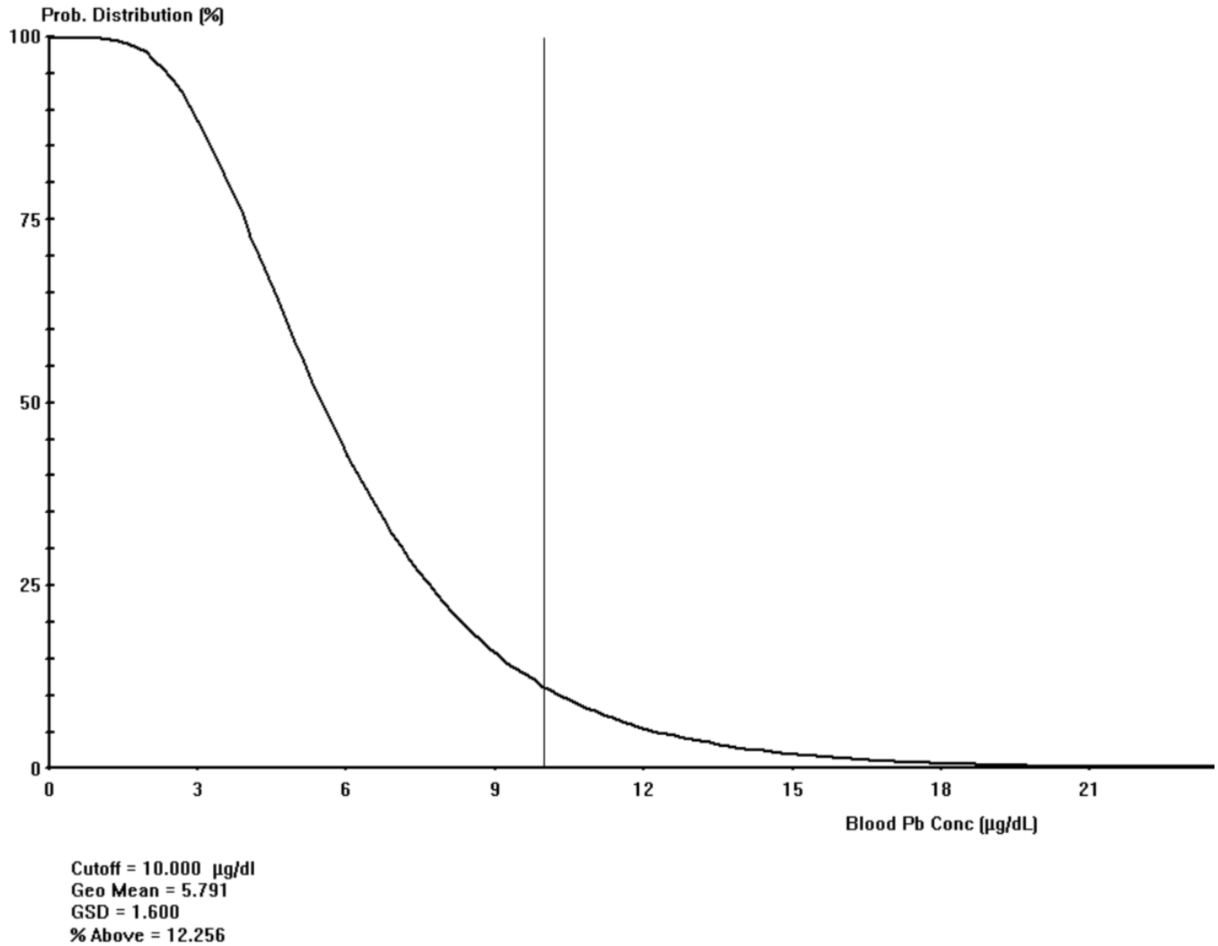
The next sections show BLLs and probability of exposures in the 3 catchments based on the average water lead concentrations.

4.7.1 Blood Lead Levels (BLLs) in Akaki Catchment

For *Akaki* catchment, an average lead concentration of 48.6µg/L was used to predict the daily uptake, BLLs and probability of exposure to lead. The average BLLs for age groups of 3-7 is 5.7µg/dL and the daily uptake of lead is 18.23µg/day. These average results are taken from the table below.

Table 9: Lead uptake and BLLs in *Akaki* Catchment

Year	Air (µg/day)	Diet (µg/day)	Water (µg/day)	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
0.5-1	0.021	1.015	4.366	3.951	9.353	5
1-2	0.034	0.84	10.417	3.951	17.281	6.9
2-3	0.062	0.929	11.024	6.095	18.109	6.7
3-4	0.067	0.905	11.429	6.2	18.601	6.4
4-5	0.067	0.884	12.117	4.692	17.76	6
5-6	0.093	0.938	12.896	4.262	18.189	5.6
6-7	0.093	1.022	13.206	4.052	18.373	5.2



Source: IEUBK model output

Figure 24: Probability distribution curve of exposure in *Akaki* catchment for 3-7 ages

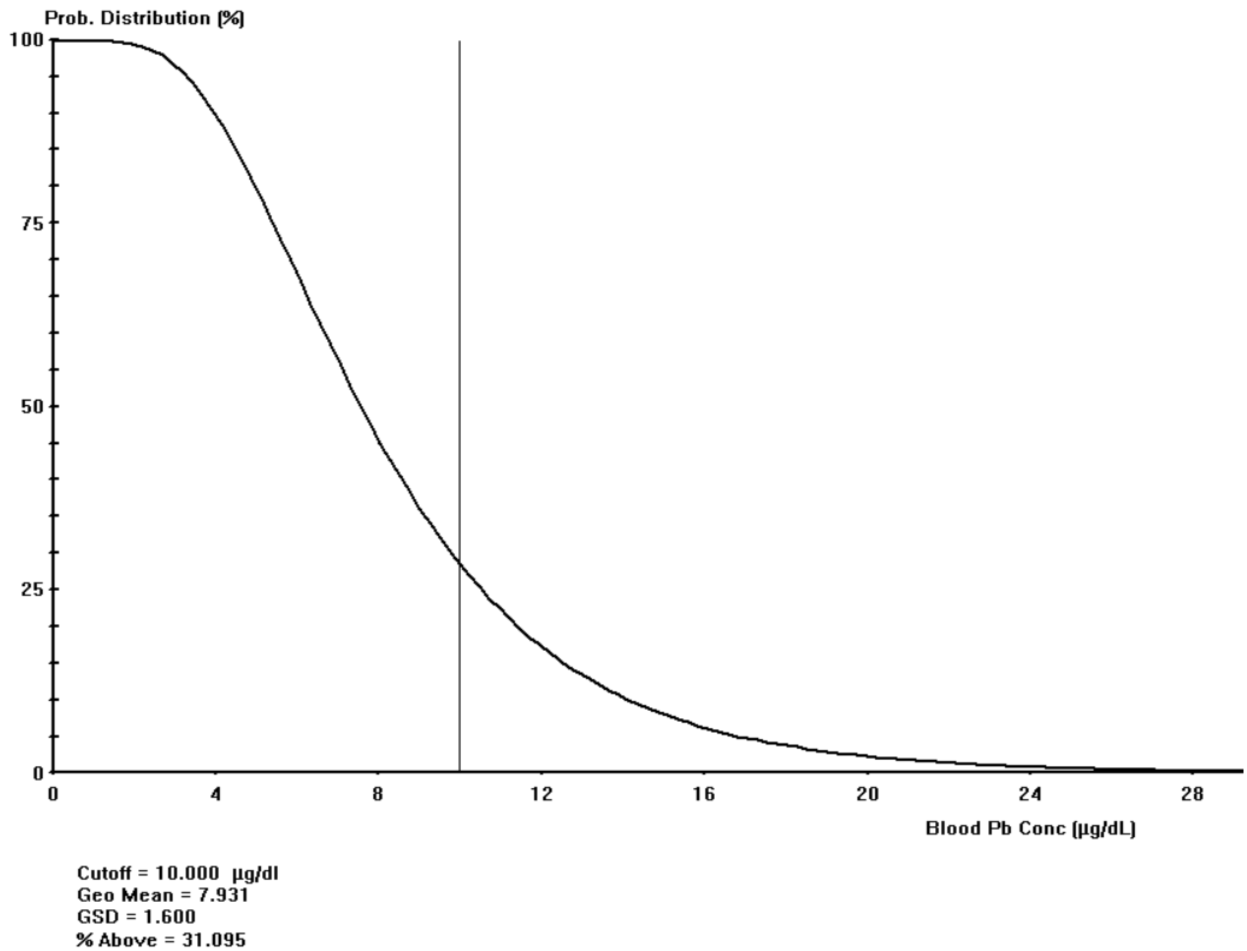
The above probability distribution graph shows the average BLLs for 3-7 age groups is 5.7µg/dL and 12.256% of the children are expected to have blood lead levels above 10µg/dL.

4.7.2 Blood Lead Levels (BLLs) in Legedadi Catchment

For *Legedadi* catchment, an average lead concentration of 80µg/L was used to predict the daily uptake, BLLs and probability of exposure to lead. The average BLLs for age groups of 3-7 is 7.93µg/dL and the daily uptake of lead is 25.26µg/day. These average results are taken from the table below.

Table 10: Lead uptake and BLLs in Legedadi Catchment

Year	Air (µg/day)	Diet (µg/day)	Water (µg/day)	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	0.021	0.986	6.98	3.838	11.825	6.3
1-2	0.034	0.798	16.292	5.691	22.815	9
2-3	0.062	0.887	17.318	5.817	24.083	8.8
3-4	0.067	0.868	18.04	5.945	24.92	8.6
4-5	0.067	0.85	19.183	4.512	24.612	8.1
5-6	0.093	0.904	20.455	4.106	25.559	7.7
6-7	0.093	0.987	20.988	3.912	25.981	7.3



Source: IEUBK model output

Figure 25: Probability distribution curve of exposure in *Legedadi* catchment for 3-7 ages

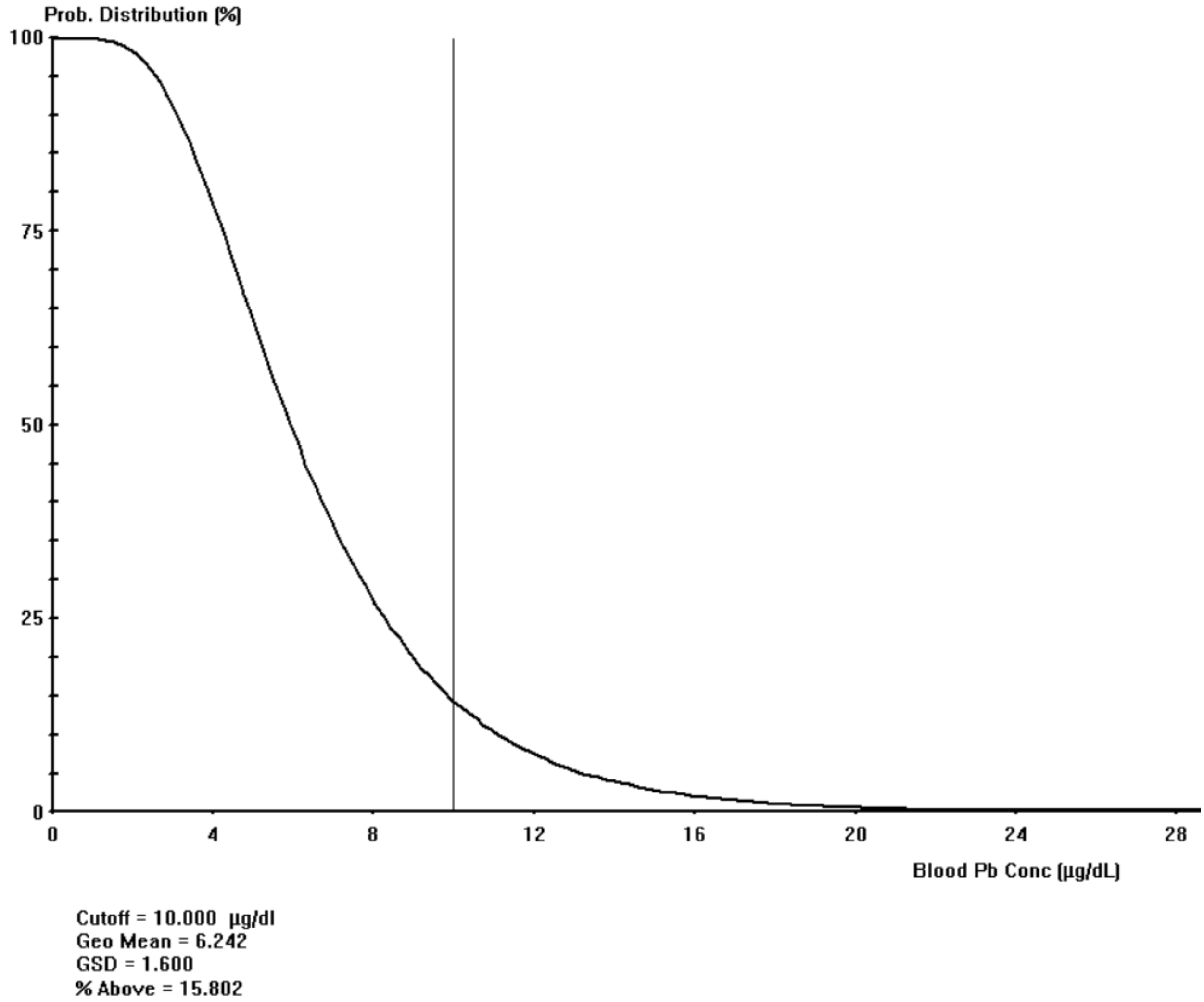
The above *Legedadi* catchment probability distribution graph shows the average BLLs for the specified age group is 7.93µg/dL and 31.095% of the children are expected to have blood lead levels above 10µg/dL.

4.7.3 Blood Lead Levels (BLLs) in Gefersa Catchment

For *Gefersa* catchment, an average lead concentration of 55µg/L was used to predict the daily uptake, BLLs and probability of exposure to lead. Average BLLs for age groups of 3-7 is 6.24µg/dL and the daily uptake of lead is 19.71µg/day. These average results are taken from the table below.

Table 11: Lead uptake and BLLs in *Gefersa* Catchment

Year	Air (µg/day)	Diet (µg/day)	Water (µg/day)	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dl)
.5-1	0.021	1.009	4.911	3.928	9.868	5.3
l 1-2	0.034	0.831	11.662	5.925	18.453	7.3
2-3	0.062	0.92	12.353	6.035	19.371	7.1
3-4	0.067	0.897	12.821	6.146	19.931	6.9
4-5	0.067	0.877	13.601	4.654	19.199	6.4
5-6	0.093	0.931	14.482	4.229	19.735	6
6-7	0.093	1.015	14.836	4.022	19.966	5.6



Source: IEUBK model output

Figure 26: Probability distribution curve of exposure in *Gefersa* catchment for 3-7 ages

The above probability distribution graph shows that the average BLLs for 3-7 age groups is 6.24µg/dL and 15.8% of the children are expected to have blood lead levels above 10µg/dL.

5. DISCUSSION

5.1 PH

The PH levels measured from the schools' tap water were generally lower than the source for all sub-systems. Both median and mean values of the samples from the schools were also smaller than the source water (AAT, LAT and GAT). The slight reduction in the PH values measured in the water samples may be attributed to the corrosion of aged and cross-connected metallic pipeline materials used in the water supply distribution system. This decrease in PH is consistent with the study by Mekonnen (2015) who reported that the PH in drinking water decreases as a result of corrosion taking place in distribution systems.

5.2 Free Chlorine

Free chlorine distribution in all three catchments varies substantially. From the analysis, sixteen out of thirty eight (42.1%) of the samples taken from the schools had values below the WHO recommended threshold (0.2mg/l).

There are 2 major problems diagnosed concerning free chlorine: The first is poor management in the treatment plants and the other is the old distribution systems.

For the treatment plant assessment, chlorine residue was tested based on the data collected on the 18th of May 2018. The test result revealed that the treated water leaving the *Akaki* treatment plant had free residual chlorine of 0.45 mg/l. But treated water leaving the other two treatment plants, *Legedadi* and *Gefersa*, had no residual chlorine. Since this was not logical, that water leaving a treatment plant must have residual chlorine, another sample was collected on the 19^{th} of May 2018 in order to clarify such issues. A discussion was also made with the treatment plant operators. For instance, the situation was explained to the *Legedadi* treatment plant operators and their response was that they didn't add chlorine until 12pm on the 18^{th} of May. This means, the samples collected before noon on the mentioned day were not chlorinated, and non-chlorinated water was distributed to the city's consumers. Samples were also taken from *Gefersa* treatment plant on the 19th of May 2018. These samples from the two treatment plants were tested for free chlorine and results revealed that the treated water sample from *Legedadi* sub-system had residual chlorine of 0.45 mg/l. But the sample from *Gefersa* had a value of 0.04mg/l which was less than the WHO recommended 0.2mg/l. This clearly shows the poor management and quality control works in the treatment plants.

For the assessment of distribution systems' performance in terms of residual chlorine, it is expected that the concentration degrades when the treated water enters into the distribution system. A possible reason for this rapid drop in concentration could be due to the breakdown of residual chlorine by microbes attached to biofilms, corrosion in pipes and water aging in distribution system. Another possible reason could be the intermittent supply of water that can lead to negative pipe-pressure and intrusion of contaminants. These contaminants could further reduce the residual chlorine in the distribution system. The distance of the schools to the treatment plants and increasing time spent in water storage reservoirs and pipes could also deplete the residual chlorine before it reaches the schools taps. These assumptions are similar to study findings by Mekonnen (2015) who reported that rapid deterioration of residual chlorine occurred in the water distribution network of *Legedadi* sub-system. This was a result of, the distance from the treatment plant, the intermittent supply leading to contaminant intrusion, and growth of bacteria in pipes due to the depletion free residual chlorine. In addition, a study by Kumpel and Nelson (2013) compared the microbial water quality in an intermittent and continuous piped water supply. It was reported that a significantly higher proportion of samples collected from a continuous supply met the minimum standard for residual chlorine concentrations when compared to samples from intermittent water supplies.

5.3. Microbial Analysis

No E. coli and total coliform bacteria were found in the samples collected from the treated water leaving the three treatment plants (AAT, LAT and GAT) and *E .coli* was found in all samples from the schools, meaning that the water is safe from fecal contamination. But on the contrary to the presented findings, a study by Mekonnen (2015) showed *E .coli* contamination in *Legedadi* sub-system. This may be because; the samples on that study were taken from July to September on the rainy seasons. Therefore, contaminants can easily enter the distribution system in these wet seasons.

Total coliform contamination was found in all catchments and all contaminations are directly related with the free chlorine. The seven contaminated samples had residual chlorine below 0.12mg/l which is below the WHO recommended value 0.2mg/l. Similarly, studies by Kumpel and Nelson (2013) in Hubli-Dharwad, India and Mekonnen (2015) in Addis Ababa, Ethiopia have also reported frequent and elevated bacterial contamination in tap water samples with residual chlorine concentrations below the recommended guideline values. Zero bacteria counts are reported in water samples retaining good residual chlorine concentrations in both studies. The results reported in this study are similar.

The microbial water quality results measured in this study strongly agree with a study conducted by Kumpel & Nelson, (2013). It was reported that bacterial contamination is more frequent in intermittent water supply networks when compared to those continuously supplied. The study reported by Mekonnen (2015) also suggests that bacterial contamination in an intermittent water supply could be caused to the intrusion of contaminants from the environment when the water supply to pipelines is turned off. This causes negative pipe-pressure events and causes problems when combined with cross-connection pipelines. These issues are common in Addis Ababa and are the main problems within the study areas.

5.4. Lead Concentrations and Blood Lead Levels (BLLs) in children

The findings revealed that, all water samples taken from the three catchments had lead concentrations above the WHO recommended value of 10µg/L. The guideline value is designated as provisional on the basis of treatment performance and analytical achievability. As this is no longer a health based guideline value, concentrations should be maintained as low as reasonably practical (WHO, 2017).

The mean lead concentration from all catchments is 62.37μg/L and from samples in *Akaki, Legedadi* and *Gefersa* catchments were found to be 48.6μg/L, 80μg/L and 55μg/L respectively. The study from Getaneh et al. (2014) also shows all the water samples in Jimma town had lead concentrations above 10μg/L with an average value of 24.5μg/L.

The lead concentrations of treated and raw water samples taken from the treatment plants were also higher (ABT, AAT LBT, LAT and GAT). This result agrees with the study conducted by Fite (2008). In that study all raw water samples taken from *Akaki, Legedadi* and *Gefersa* had values above the WHO recommended 10μg/L. The reason for the elevated lead levels could be because; samples were taken from old pipelines at the treatment plants. Fite (2008) suggests that the high level observation of Pb in the raw samples may be due to the natural occurrences of Pb in the vicinity or the uses of lead compounds in the agricultural activities or the leachates of Pb from cement- mortar lining of the dams. WHO (2017) also states; It needs to be recognized that lead is exceptional compared with other chemical hazards, in that most lead in drinking-water arises from lead service connections and plumbings.

The IEUBK model predicted the percentage of children BLLs exceeding 10μg/dL. Results revealed that 12.25%, 31.09% and 15.8% of the children are expected to have BLLs exceeding 10μg/dL in *Akaki, Legedadi* and *Gefersa* sub-systems respectively. The average total exposure to lead in the city was 20.17%. Similarly on a study from Gorsevski et al. (2014), using only soil lead concentration in the model, 28.4% exposure was predicted from 81 schools in Toledo, Ohio.

For this study, if soil and air lead concentrations were measured; more children would have BLLs above 10μg/dL. On a study from (Getaneh et al. 2014), done in Jimma, Ethiopia, The mean lead concentration of the soil from the four quadrants of the town was 220.08±135.95μg/g and the average air lead concentration was 1.01 ± 0.41. The high air lead content may be related to pollutants emitted from cars, buses, trucks etc. (Getaneh et al. 2014). Since Addis Ababa is densely populated and heavy traffic is present, air lead concentrations would be greater than or equal to that of Jimma town.

Similarly a study from Endale et al. (2012), was done is Addis Ababa, Ethiopia on determining levels of lead in roadside soils of the city. Results showed that the mean soil lead concentration was 418.6±3.4μg/g. In most of the sample sites, the concentration of lead observed is directly correlated with the traffic density of the roads (Endale et al. 2012). These two studies clearly show that air and soil samples would also be higher than the default selected values in the model and more children would be exposed to lead contamination in Addis Ababa.

In general, the content of mean lead in water is above the acceptable level set by WHO; 10μg/L. Children could also be affected by exposure to lead (Pb); many different organs and physiological functions (neurological, hematological, cardiovascular, renal, immune, and other functions) are affected even at very low exposure levels of lead (USEPA 2006). According to different studies carried on dose–response association between blood lead levels and intelligence quotient revealed that IQ failure is stronger at blood lead levels lower than 10μg/dL (Getaneh et al. 2014). The American Control for Disease Center (CDC) also sets a lead poisoning reference of 5μg/dL. If we take this value as a benchmark, the exposure would be even higher than the results in this study.

6. CONCLUSION

Access to clean and safe drinking water is a fundamental human requirement. However, contaminated water mostly serves as a source of water borne diseases and cause acute and chronic human health problems. Many technologies have been developed to treat, disinfect and supply safe drinking water. Despite these advancements, water supply distribution systems adversely affect the drinking water quality before it is delivered to consumers. These issues are worst in developing countries like Ethiopia where water is supplied through old and degraded pipelines that often pass through unhygienic environments.

The primary aim of this research was to investigate lead exposure and microbial contamination in Addis Ababa kindergarten schools. Water samples were collected from schools and the three treatment plants supplying for the city. The samples were then tested for PH, residual chlorine, lead (Pb) content, *E. coli* and total coliforms. The data collected was used to determine if water samples complied with national drinking water quality standards (WHO standards). The following conclusions have been determined from the data collected and analyzed.

- The PH levels measured in the schools were generally lower than the treatment plants.
- 42.1% of the samples from the schools had residual chlorine levels below the WHO recommended 0.2mg/l.
- No *E. coli* contamination was indicated in any of the samples.
- A total of 7 samples from the three catchments were contaminated with total coliform bacteria and the samples had residual chlorine below 0.12mg/l.
- All 38 water samples from the schools had lead concentration above he WHO recommended 10μg/L with an average value of 62.37μg/L
- Water samples from the treatment plants (ABT, ABT. LBT, LAT and GAT) also had lead concentrations above 10μg/L.

- The average BLLs of children from the age 3-7 in Addis Ababa city is 6.75μg/dL and their exposure to having their BLLs above 10μg/dL is 20.17μg/dL.
- The exposure of children having BLLs above 10μg/dL in *Akaki, Legedadi* and *Gefersa* catchments were; 12.05%, 31.09% and 15.8% respectively.

Based on the results from this study, the main cause of water quality degradation in the distribution system is likely due to the water supply disruption intermittent supply and age of pipes. This results in the intrusion of external contaminants and introduction of lead in the pipelines of the distribution system. This may ultimately result in non-compliance with the Ethiopian (WHO) drinking water standards. It is therefore, possible to conclude that regardless of the different water sources, a water supply infrastructure determines the concentration levels of lead and residual chlorine that reaches the end users.

7. RECCOMENDATION

There are many interconnected factors that affect the drinking water quality in Addis Ababa. It is highly recommended that lead concentrations should be maintained as low as reasonably practical. New sources of lead, such as service connections and lead solder, should not be introduced into any system, and low lead alloy fittings should be used in repairs and new installations (WHO, 2017).

From the study conducted, significant concentration of Pb was observed in the schools' tap water, raw water and treated water samples from the treatment plants. So, conducting researches to identify the exact sources of Pb in the piped drinking water of Addis Ababa is crucial. Therefore monitoring, evaluation and periodic review of lead levels in drinking water, soils, and air (environment) at regular intervals and maintaining data base either by Regional or Federal EPA of Ethiopia is mandatory. Also, monitoring of lead composed insecticides, rodenticides, herbicides, etc., in agricultural sectors is necessary since it could be the source of lead in the raw water samples.

There are many management options that can be recommended to minimize the deterioration of the water quality within the distribution system. Managing these issues individually can be both financially and technically not feasible. The following management options are suggested to reduce the degradation of water quality in the distribution systems.

A. Providing enough water: Ethiopia and Addis Ababa are gifted with a substantial quantity of surface and groundwater resources. Despite these substantial water resources, the main driving force for the deterioration of drinking water is the lack of supply. This study indicates that even though there are significant problems with the distribution system, a continuous supply would reduce the probability of contaminant intrusion caused by the drop in pipeline-pressure. Therefore, the entity for domestic water supply (AAWSA) should increase the capacity of their operations to supply enough drinking water to the residents of Addis Ababa.

The supply of water to industries puts significant pressure on the water supply in Addis Ababa. This results in a scarcity of water to household users. As there is plentiful groundwater available within the shallow aquifers in the Addis Ababa area, allowing industries and construction works to develop and use their own private wells may assist in reducing the demand for surface water.

B. **Improving Water Supply Distribution Systems:** In this study, it was observed that the condition of the pipes and intermittent water supply adversely affects the quality of drinking water in the schools. There is strong evidence for water quality deterioration and non-compliance with the drinking water standards. This is a result of the supply disruption and intrusion of contaminants.

Investment in the water supply infrastructure is required to avoid supply disruption events. This is a major cause of water quality degradation in Addis Ababa. The replacement of degraded water supply infrastructure and redesign of the distribution systems to avoid old pipelines would assist in improving water quality. Proper maintenance of the infrastructure would also assist in providing safe water to customers.

C. Additional supplementary chlorination points: Nearly half of the samples tested in this study had residual chlorines below the WHO recommendation values. Chlorination is very important in removing any pathogenic microorganisms which could be found in the distribution system. And since the city has intermittent water supply, the chlorination should be monitored regularly at the treatment plants. Chlorination at the treatment plants and reservoirs is not also enough for the complicated and vast water distribution system. So, supplementary chlorination points at remote places should be added to compensate for the intermittent flows and shortage of water supply which contribute to the intrusion of contaminants in the water distribution system.

D. Integrated water quality monitoring program: The AAWSA should take samples from the end pipes like schools and household level and do a verification test check if the consumers are getting safe and clean water to the WHOs standards. And an integrated water quality monitoring program and a robust water quality monitoring database is needed in the Addis Ababa Water and Sewerage Authority (AAWSA). Monitoring data could be recorded to allow for the identification of trends in water quality. This data could be used to design remedial actions that may be required.

REFERENCES

AAWSA website (www.aawsa.gov.et/?lang=en) (accessed Apr, 10 2018)

Abay, G. K. (2010). The impact of low cost sanitation on groundwater contamination in the city of Addis Ababa. University of South Africa

Aboh, I., Caravanos, J., Mensah, H., Ofosu, F. and Sampson, M. (2013) Assessing levels of lLead Contamination in soil an d predicting pediatric Blood Lead Levels in Tema, Ghana Journal of Health & Pollution Vol. 3, No. 5

Albalak, Rachel; Noonan, Gary; Buchanan, Sharunda; Flanders, W. Dana; Gotway Crawford, Carol; Kim, Dennis; Jones, Robert L.; Sulaiman, Rini; Blumenthal, Wendy; Tan, Regina; Curtis, Gerald; McGeehin, Michael A (2003) Blood lead levels and risk factors for lead poisoning among children in Jakarta, Indonesia, The Science of The Total Environment, Volume 301, Pages 75- 85, http://dx.doi.org/10.1016/S0048-9697(02)00297-8 (accessed Apr 20- 2018)

Amenu, D., Menkir, S., Gobena, T., Bacteriological quality of drinking water sources in rural communities of dire dawa administrative council Int. J. Res. Dev. Pharm. L. Sci., 2013, pp. 775-780.

American Public Health Association, American Water Works Association, Water Environment Federation 2005

Arbuckle, T., Liu, S., Wade, M., Walker M. Wingle, T., (2007) Environmental hazards: evidence for effects on child health. J Toxicol Env Heal B.; 10:3-39.

Babayigit, M., Bakir, B., Kilic, A., Ogur, R., Tekbas, O., and Ulus, S. (2015). Assessment of drinking water quality in public primary schools in a metropolitan area in Anakara, Turkey. https://www.researchgate.net/publication/275044476 (accessed Jan 11- 2018)

Battu P.R. and Reddy M.S (2009), Bacteriological examination of drinking water with reference to coliforms in Jeedimeth. African Journal of Biotechnology, 8, 5495-5496

Canas AI, Cervantes-Amat M., Esteban M. et al. (2013) Blood lead levels in a representative sample of the Spanish adult population: The Bioambient. Es Project. Int J Hyg Environ Health. doi:10.1016/j.ijheh.2013.09.001 (accessed Jul 10- 2018)

Cartier, C., Arnold, R.B., Triantafyllidou, S., Prevost, M. & Edwards, M. 2012a. Effect of Flow Rate and Lead/Copper Pipe Sequence on Lead Release from Service Lines. *Water Res.*, 46:13:4142.

City Government of Addis Ababa Education Bureau, 2017 Educational statistics annual abstract

Dodrill, D.M. & Edwards, M., (1995). Corrosion Control on the Basis of Utility Experience. *Jour. AWWA*, 87:7:74.

Edwards, M. & McNeill, L. 2002. Effect of Phosphate Inhibitors on Lead Release From Pipes. *Jour. AWWA*, 94:1:79.

Endale, T., Chandravanshi, B. S., Megersa, N. and Zewge, F. (2012). Determination of the levels of lead in the roadside soils of Addis Ababa, Ethiopia. Available from: https://www.researchgate.net/publication/274077245_Determination_of_the_levels_of_lead_in_the_roadside_soils_of_Addis_Ababa_Ethiopia [accessed Sept 16 2018].

Fite, T., (2008) Assessment of Lead Toxicity Awareness among Battery Charging Garage and Workshop Workers and Levels of Lead in Piped Drinking Water of Addis Ababa, Ethiopia. Addis Ababa University. AAU Institutional repository. Available from:

http://etd.aau.edu.et/bitstream/handle/123456789/7348/Tamene%20Fite.pdf?sequence=1&isAllowed=y (accessed April, 16 2018)

Getaneh, Z., Mekonen. S. and Ambelu, A. (2014) Exposure and health risk assessment of lead in communities of Jimma town, southwestern Ethiopia Bull Environ contam toxicol doi10.1007/s00128-014-1293-7

Gorsevski, Jeffery, G., John, R., Lauren, R., Pece, V., (2014) Spatial prediction of blood lead levels in Toledo, OH using fuzzy sets and the site-specific IEUBK model https://doi.org/10.1016/j.apgeochem.2014.03.012 (accessed Sept- 2018)

Hogan K., Marcus A., Smith R. and White P. (1998) Integrated exposure uptake biokinetic model for lead in children: empirical comparisons with epidemiological data, Environmental Health Perspectives. Vol 106

IWA-publishing. (2003). Assesing Microbial Safety of Drinking Water. pp291

Kumpel, E., & Nelson, K. L. (2013). Comparing microbial water quality in an intermittent and continuous piped water supply. *Water research, 47*(14), 5176-5188.

Manegabe, B. (2015) Assessment of pathogenic bacteria and heavy metal pollution in sediment and water of Kahwa river, Bukavu, Democratic Republic of the Congo, journal of water gate reaserch

McIlwain, B. (2013) Investigating Sources of Elevated Lead in Drinking Water (MSc. Thesis Dalhousie University Halifax, Nova Scotia)

Mekonnen, D. (2015) The Effect Of Distribution Systems On Household Drinking Water Quality In Addis Ababa, Ethiopia, and Christchurch, New Zealand, University of Canterbury

Meyer, Pamela A.; McGeehin, Michael A.; and Falk, Henry (2003). A global approach to childhood lead poisoning prevention, International Journal Hygiene Environmental Health 206, 363-369, http://www.ncbi.nlm.nih.gov/pubmed/12971691 (accessed Jul- 2018)

Palintest website (www.palintest.com/en/products/photometer-7100) (accessed May 14, 2018)

Salomon A, Ahmed Z, Biruktawit K, Amare D, Ali S and Endalew Z 2011: Bacteriological analysis of drinking water sources. Journal of Microbial Research, 5, 2638-2641

Sarver, E. and Edwards, M.,(2011). Effects of Flow, Brass Location, Tube Materials and Temperature on Corrosion of Brass Plumbing Devices. *Corros.Sci.*, 53:5:1813.

Suherni B. (2010) Lead poisoning in Indonesia, www.lead.org.au/

UN (2010) resolution A/RES/64/292. General Comment No. 15. The right to water 3pp.

USEPA (2002) User's Guide for the Integrated Exposure Biokinetic Model for Lead in Children (IEUBK), Windows(R) Version. Washington, EPA 9285.7–42

USEPA (2006) 3Ts for Reducing Lead in Drinking Water in Schools Revised Technical Guidance, EPA 816-B-05-008, Washington

USEPA (2015) Parameters of Water Quality. Interpretation and Standards. Wexford, Ireland https://www.epa.ie/pubs/advice/ water/quality/ Water_Quality.pdf.

WHO (2012). Water Quality and Health Strategy 2013-2020. 17 pp.

WHO (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

www.agilent.com/en/products/mp-aes/mp-aes-systems/4200-mp-aes Agilent website (accessed May 15, 2018)

Xie, Y. & Giammar, D.E., 2011. Effects of Flow and Water Chemistry on Lead Release Rates From Pipe Scales. *Water Res.*, 45:19:6525.

APPENDICES

Appendix A: Name of samples, Location and Collection time

Label	Name of School	Owner	Catchment	Sub City	Woreda	Date of Collection (2018)	Time of collection
A1	Bole Bulbula School	Government	Akaki	Bole	12	11-May	7:05 AM
A2	Auxilium Catholic School	Church	Akaki	Bole	12	11-May	7:17 AM
A3	Kaliti primary school	Government	Akaki	Akaki Kality	7	11-May	7:55 AM
A4	Fury primary School	Government	Akaki	Akaki Kality	7	11-May	8:16 AM
A5	Leadership Acadamy	Private	Akaki	Nifas Silk	11	11-May	8:57 AM
A6	Neway Challenge	Private	Akaki	Nifas Silk	1	14-May	7:48 AM
A7	Great Ethiopian Transformers	Private	Akaki	Nifas Silk	2	14-May	8:30 AM
A8	Agazian No 2 School	Government	Akaki	Nifas Silk	8	11-May	9:39 AM
A9	New English School	Private	Akaki	Nifas Silk	7	14-May	10:20 AM
A10	Destiny Future Acadamy	Private	Akaki	Nifas Silk	6	14-May	11:36 AM
A11	Falcon School	Private	Akaki	Nifas Silk	9	10-May	8:22 AM
A12	Sibste Negasi School	Government	Akaki	Nifas Silk	8	10-May	8:54 AM
A13	Tibeb Gebeya School	Government	Akaki	Kirkos	4	10-May	9:19 AM
A14	Merit Acadamy	Private	Akaki	Kolfe Keranyo	4	14-May	8:54 AM
A15	Olive Acadamy	Private	Akaki	Kolfe Keranyo	5	14-May	9:19 AM
L1	BBS Acadamy	Private	Legedadi	Bole	10	15-May	9:07 AM

L2	Miraf Acadamy	Government	Legedadi	Yeka	13	15-May	9:32 AM
L3	March 8 Primary School	Government	Legedadi	Bole	2	11-May	10:15 AM
L4	Adis Global Acadamy	Private	Legedadi	Bole	2	11-May	10:34 AM
L5	Sophists Acadamy	Private	Legedadi	Bole	13	11-May	10:53 AM
L6	Hdase Primary School	Government	Legedadi	Bole	14	10-May	10:15 AM
L7	Yekatit 12 School	Government	Legedadi	Gullele	2	10-May	11:04
L8	Goro Primary School	Government	Legedadi	Bole	9	11-May	11:15 AM
L9	Vision Acadamy	Private	Legedadi	Bole	8	11-May	11:38 AM
L10	School of Tomorrow	Private	Legedadi	Yeka	8	11-May	12:15 PM
L11	Adis Birhan School	Government	Legedadi	Yeka	4	11-May	12:36 PM
L12	Genet Primary School	Government	Legedadi	Arada	6	11-May	1:00 PM
L13	Masol Acadamy	Private	Legedadi	Yeka	11	15-May	9:58 AM
L14	Hill Side School	Private	Legedadi	Yeka	9	15-May	10:22 AM
L15	Vies Nouvelles School	Private	Legedadi	Kirkos	8	15-May	10:53 AM
G1	Hilina Acadamy	Private	Gefersa	Kolfe Keranyo	8	16-May	10:19 AM
G2	Family Kindergarten	Private	Gefersa	Kolfe Keranyo	9	16-May	10:40 AM
G3	Biruh Tesfa Kindergarten	Government	Gefersa	Adis Ketema	4	16-May	11:02 AM
G4	Almaz Ashene School	Government	Gefersa	Gullele	10	16-May	11:46 AM
G5	Asco Progress Acadamy	Private	Gefersa	Kolfe Keranyo	14	16-May	12:09 PM
G6	Amigonian School	Private	Gefersa	Arada	4	17-May	10:20 AM

G7	**Ethio parents' School**	**Private**	**Gefersa**	**Gullele**	**9**	**17-May**	**11:09 AM**
G8	**Al Afia Kindergarten**	**Private**	**Gefersa**	**Kolfe Keranyo**	**13**	**17-May**	**11:39 AM**
ABT	**Akaki Before Treatment**					**18-May**	**12:37 PM**
AAT	**Akaki After Treatment**					**18-May**	**12:50 PM**
LBT	**Legedadi Before Treatment**					**19-May**	**9:23 AM**
LAT	**Legedadi After Treatment**					**19-May**	**9:29 AM**
GBT	**Gefersa Before treatment**					**19-May**	**11:49 AM**
GAT	**Gefersa After Treatment**					**19-May**	**11:53 AM**

Appendix B: GPS Coordinates of Sampling Points

Label	Name of School	GPS Coordinates (N)	GPS Coordinates (E)
A1	Bole Bulbula School	8.95843	38.788398
A2	Auxilium Catholic School	8.947756	38.7839
A3	Kaliti primary school	8.906107	38.768525
A4	Fury primary School	8.906449	38.763309
A5	Leadership Acadamy	8.942184	38.752407
A6	Neway Challenge	8.950149	38.731912
A7	Great Ethiopian Transformers	8.966408	38.727977
A8	Agazian No 2 School	8.97568	38.761221
A9	New English School	8.998788	38.727424
A10	Destiny Future Acadamy	8.985236	38.752634
A11	Falcon School	8.957398	38.770691
A12	Sibste Negasi School	8.971405	38.762466
A13	Tibeb Gebeya School	9.000558	38.757024
A14	Merit Acadamy	8.986941	38.693987
A15	Olive Acadamy	9.003821	38.700072
L1	BBS Acadamy	9.015506	38.867362
L2	Miraf Acadamy	9.034031	38.878111
L3	March 8 Primary School	8.990683	38.78211
L4	Adis Global Acadamy	8.985816	38.798738
L5	Sophists Acadamy	8.994834	38.806109
L6	Hdase Primary School	9.001171	38.810067
L7	Yekatit 12 School	9.050844	38.759817
L8	Goro Primary School	8.99528	38.827472
L9	Vision Acadamy	9.01008	38.849417
L10	School of Tomorrow	9.027038	38.787421
L11	Adis Birhan School	9.0461	38.772761
L12	Genet Primary School	9.041889	38.762342

L13	**Masol Acadamy**	**9.032247**	**38.837662**
L14	**Hill Side School**	**9.021647**	**38.813656**
L15	**Vies Nouvelles School**	**9.018095**	**38.775783**
G1	**Hilina Acadamy**	**9.019376**	**38.697023**
G2	**Family Kindergarten**	**9.015083**	**38.719652**
G3	**Biruh Tesfa Kindergarten**	**9.029428**	**38.723275**
G4	**Almaz Ashene School**	**9.056382**	**38.720666**
G5	**Asco Progress Acadamy**	**9.065793**	**38.696832**
G6	**Amigonian School**	**9.051985**	**38.736056**
G7	**Ethio parents' School**	**9.049624**	**38.726368**
G8	**Al Afia Kindergarten**	**9.048616**	**38.71036**
ABT	**Akaki Before Treatment**	**8.871706**	**38.766033**
AAT	**Akaki After Treatment**	**8.875029**	**38.762627**
LBT	**Legedadi Before Treatment**	**9.065799**	**38.961116**
LAT	**Legedadi After Treatment**	**9.066241**	**38.961162**
GBT	**Gefersa Before treatment**	**9.06421**	**38.642887**
GAT	**Gefersa After Treatment**	**9.063885**	**38.642846**

Appendix C: Temperature and PH results

Label	Name of School	Temprature (oC)	PH
A1	Bole Bulbula School	26.8	8
A2	Auxilium Catholic School	27	7.98
A3	Kaliti primary school	27.6	7.66
A4	Fury primary School	27.4	7.65
A5	Leadership Acadamy	25.6	8.08
A6	Neway Challenge	28.1	8.19
A7	Great Ethiopian Transformers	26.8	7.47
A8	Agazian No 2 School	25.7	7.82
A9	New English School	27.1	8.31
A10	Destiny Future Acadamy	28.1	8.07
A11	Falcon School	27.1	7.79
A12	Sibste Negasi School	27.5	7.83
A13	Tibeb Gebeya School	27.2	8.07
A14	Merit Acadamy	26.2	8.05
A15	Olive Acadamy	25.1	8.43
L1	BBS Acadamy	26.1	7.67
L2	Miraf Acadamy	26.4	7.97
L3	March 8 Primary School	24.1	7.83
L4	Adis Global Acadamy	24.2	7.77
L5	Sophists Acadamy	23.6	7.53
L6	Hdase Primary School	26.2	7.52
L7	Yekatit 12 School	26.4	7.57
L8	Goro Primary School	23.6	7.04
L9	Vision Acadamy	23.7	7.61
L10	School of Tomorrow	23	7.57
L11	Adis Birhan School	22.6	7.64
L12	Genet Primary School	22.4	7.65
L13	Masol Acadamy	26.4	7.56
L14	Hill Side School	25.4	7.54
L15	Vies Nouvelles School	25.7	7.55
G1	Hilina Acadamy	23.4	8.71
G2	Family Kindergarten	23.3	7.3
G3	Biruh Tesfa Kindergarten	24.4	7.53

G4	**Almaz Ashene School**	**23.7**	**7.48**
G5	**Asco Progress Acadamy**	**23.1**	**7.85**
G6	**Amigonian School**	**25.6**	**7.72**
G7	**Ethio parents' School**	**25.3**	**7.7**
G8	**Al Afia Kindergarten**	**25**	**7.74**
ABT	**Akaki Before Treatment**	**26.6**	**8.33**
AAT	**Akaki After Treatment**	**26.1**	**8.2**
LBT	**Legedadi Before Treatment**	**27.7**	**7.9**
LAT	**Legedadi After Treatment**	**27.7**	**7.7**
GBT	**Gefersa Before treatment**	**22.9**	**7.3**
GAT	**Gefersa After Treatment**	**23.6**	**7.72**

Appendix D: Residual Chlorine Results

Label	Name of School	Chlorine content(mg/l)
A1	Bole Bulbula School	0.45
A2	Auxilium Catholic School	0.02
A3	Kaliti primary school	0.2
A4	Fury primary School	0.35
A5	Leadership Acadamy	0.47
A6	Neway Challenge	0.34
A7	Great Ethiopian Transformers	0.04
A8	Agazian No 2 School	0.43
A9	New English School	0.15
A10	Destiny Future Acadamy	0.3
A11	Falcon School	0.32
A12	Sibste Negasi School	0.39
A13	Tibeb Gebeya School	0.03
A14	Merit Acadamy	0.06
A15	Olive Acadamy	0.18
L1	BBS Acadamy	0.41
L2	Miraf Acadamy	0.04
L3	March 8 Primary School	0.46
L4	Adis Global Acadamy	0.29
L5	Sophists Acadamy	0.83
L6	Hdase Primary School	0.17
L7	Yekatit 12 School	0.63
L8	Goro Primary School	0.05
L9	Vision Acadamy	0.05
L10	School of Tomorrow	0.73
L11	Adis Birhan School	0.65
L12	Genet Primary School	0.79

L13	Masol Acadamy	0.31
L14	Hill Side School	0.63
L15	Vies Nouvelles School	0.61
G1	Hilina Acadamy	0.05
G2	Family Kindergarten	0.42
G3	Biruh Tesfa Kindergarten	0.12
G4	Almaz Ashene School	0.1
G5	Asco Progress Acadamy	0.04
G6	Amigonian School	0.2
G7	Ethio parents' School	0.15
G8	Al Afia Kindergarten	0.12
ABT	Akaki Before Treatment	0.04
AAT	Akaki After Treatment	0.45
LBT	Legedadi Before Treatment	0
LAT	Legedadi After Treatment	0.45
GBT	Gefersa Before treatment	0.63
GAT	Gefersa After Treatment	0.04

Appendix E: Microbial Analysis Results

Label	Name of School	Total coliforms	Escherichera coli
A1	Bole Bulbula School	Absent	Absent
A2	Auxilium Catholic School	Present	Absent
A3	Kaliti primary school	Absent	Absent
A4	Fury primary School	Absent	Absent
A5	Leadership Acadamy	Absent	Absent
A6	Neway Challenge	Absent	Absent
A7	Great Ethiopian Transformers	Present	Absent
A8	Agazian No 2 School	Absent	Absent
A9	New English School	Absent	Absent
A10	Destiny Future Acadamy	Absent	Absent
A11	Falcon School	Absent	Absent
A12	Sibste Negasi School	Absent	Absent
A13	Tibeb Gebeya School	Present	Absent
A14	Merit Acadamy	Absent	Absent
A15	Olive Acadamy	Absent	Absent
L1	BBS Acadamy	Absent	Absent
L2	Miraf Acadamy	Absent	Absent
L3	March 8 Primary School	Absent	Absent
L4	Adis Global Acadamy	Absent	Absent
L5	Sophists Acadamy	Absent	Absent
L6	Hdase Primary School	Absent	Absent
L7	Yekatit 12 School	Absent	Absent
L8	Goro Primary School	Present	Absent
L9	Vision Acadamy	Present	Absent
L10	School of Tomorrow	Absent	Absent
L11	Adis Birhan School	Absent	Absent

L12	**Genet Primary School**	**Absent**	**Absent**
L13	**Masol Acadamy**	**Absent**	**Absent**
L14	**Hill Side School**	**Absent**	**Absent**
L15	**Vies Nouvelles School**	**Absent**	**Absent**
G1	**Hilina Acadamy**	**Absent**	**Absent**
G2	**Family Kindergarten**	**Absent**	**Absent**
G3	**Biruh Tesfa Kindergarten**	**Present**	**Absent**
G4	**Almaz Ashene School**	**Absent**	**Absent**
G5	**Asco Progress Acadamy**	**Absent**	**Absent**
G6	**Amigonian School**	**Present**	**Absent**
G7	**Ethio parents' School**	**Absent**	**Absent**
G8	**Al Afia Kindergarten**	**Absent**	**Absent**
ABT	**Akaki Before Treatment**	**Present**	**Absent**
AAT	**Akaki After Treatment**	**Absent**	**Absent**
LBT	**Legedadi Before Treatment**	**Present**	**Absent**
LAT	**Legedadi After Treatment**	**Absent**	**Absent**
GBT	**Gefersa Before treatment**	**Absent**	**Absent**
GAT	**Gefersa After Treatment**	**Absent**	**Absent**

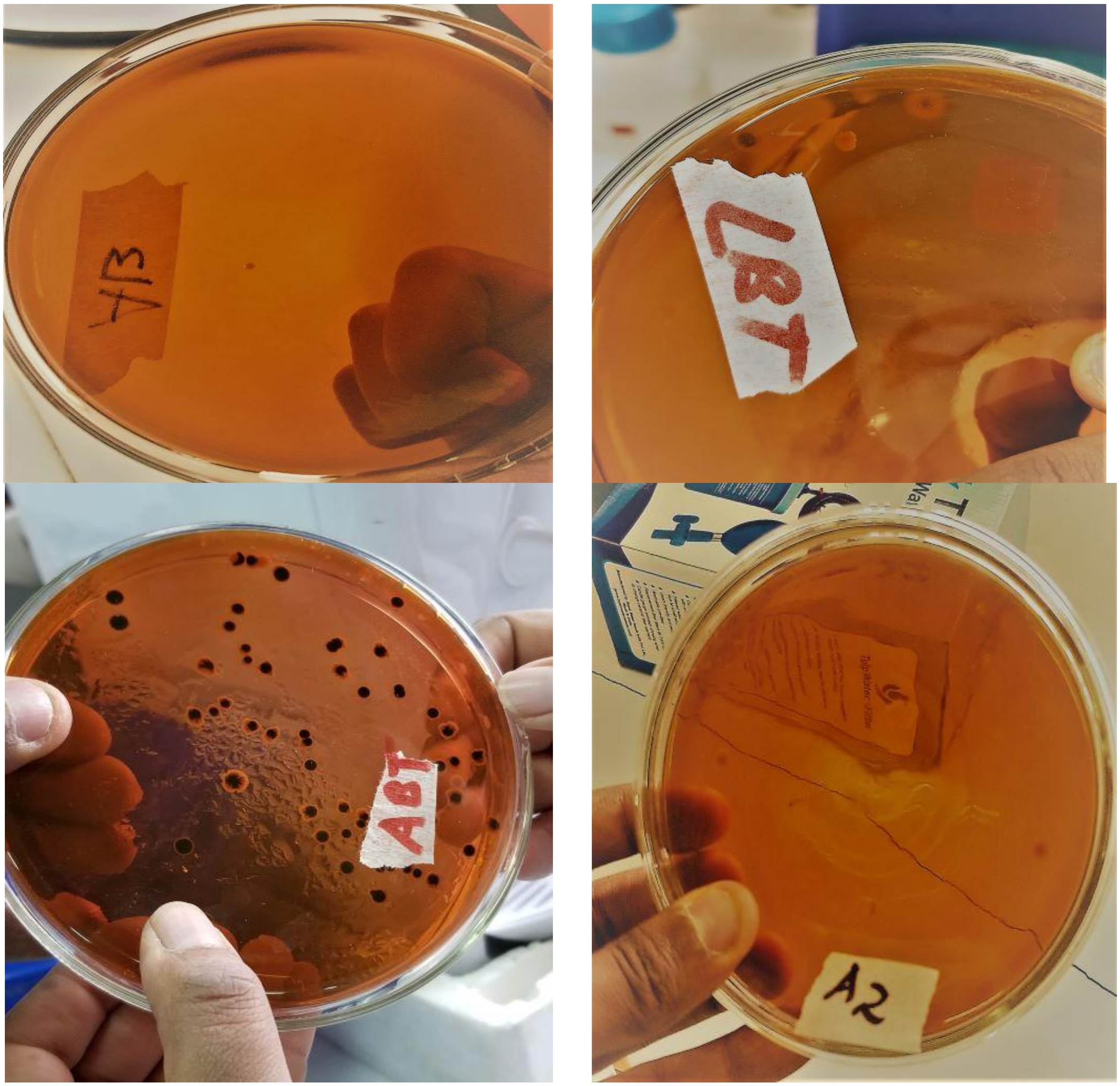
Appendix F: Lead and Blood Lead Concentrations

Label	Name of School	Lead content(mg/l)	BLL(μg/dL)
A1	Bole Bulbula School	0.05	5.9
A2	Auxilium Catholic School	0.05	5.9
A3	Kaliti primary school	0.05	5.9
A4	Fury primary School	0.05	5.9
A5	Leadership Acadamy	0.05	5.9
A6	Neway Challenge	0.05	5.9
A7	Great Ethiopian Transformers	0.05	5.9
A8	Agazian No 2 School	0.05	5.9
A9	New English School	0.05	5.9
A10	Destiny Future Acadamy	0.05	59
A11	Falcon School	0.05	5.9
A12	Sibste Negasi School	0.05	5.9
A13	Tibeb Gebeya School	0.05	5.9
A14	Merit Acadamy	0.04	5.15
A15	Olive Acadamy	0.04	5.15
L1	BBS Acadamy	0.17	13.2
L2	Miraf Acadamy	0.11	10
L3	March 8 Primary School	0.09	8.57
L4	Adis Global Acadamy	0.08	7.92
L5	Sophists Acadamy	0.08	7.92
L6	Hdase Primary School	0.07	7.25
L7	Yekatit 12 School	0.07	7.25
L8	Goro Primary School	0.06	6.6
L9	Vision Acadamy	0.07	7.25
L10	School of Tomorrow	0.06	6.6
L11	Adis Birhan School	0.06	6.6

L12	**Genet Primary School**	**0.08**	**7.92**
L13	**Masol Acadamy**	**0.11**	**10**
L14	**Hill Side School**	**0.06**	**6.6**
L15	**Vies Nouvelles School**	**0.03**	**4.45**
G1	**Hilina Acadamy**	**0.07**	**7.25**
G2	**Family Kindergarten**	**0.06**	**6.6**
G3	**Biruh Tesfa Kindergarten**	**0.06**	**6.6**
G4	**Almaz Ashene School**	**0.05**	**5.9**
G5	**Asco Progress Acadamy**	**0.05**	**5.9**
G6	**Amigonian School**	**0.05**	**5.9**
G7	**Ethio parents' School**	**0.05**	**5.9**
G8	**Al Afia Kindergarten**	**0.05**	**5.9**
ABT	**Akaki Before Treatment**	**0.05**	**5.9**
AAT	**Akaki After Treatment**	**0.04**	**5.15**
LBT	**Legedadi Before Treatment**	**0.04**	**5.9**
LAT	**Legedadi After Treatment**	**0.03**	**5.15**
GBT	**Gefersa Before treatment**	**<0.003**	**5.9**
GAT	**Gefersa After Treatment**	**0.03**	**5.15**

.

Appendix G: Contaminated samples with total coliform



Appendix H: Some of the Sampling Schools


ነዋይ ቻሌንጅ አካዳሚ


በአዲስ አበባ ከተማ አስተዳደር በአራዳ ክ/ከ/ት/ጽ/ቤት
የገነት አፀደ ህፃናት ት/ቤት
GENET K.G SCHOOL
Tel.0111-23 23 57


Vision Academ
Summit Campus
(KG-Grade 8)
15
Tel:-+251-11-647-74-17 / Mob:-+251-966-269234 Fax:-+251-11-647-74-18
P.O.Box:- 27177Addis Ababa E-mail:visionacademyethiopia@gmail.co


በቦሌ ክ/ከ ወረዳ 9 አስተዳደር
የቦሌ አዲስ የመጀመሪያ ደረጃ ት/ቤት
IN BOLE SUB CITY WEREDA 9 ADMINISTRATION
BOLE ADDIS PRIMARY SCHOOL
0116 478262
0116 479772
0116 460667
46881


ADDIS GLOBAL ACADEMY


ማርች 8
MARCH 8


ቪ. ኑቬል ት/ቤት
Vies Nouvelles School
KG
Tel: 0933 70 27 47