

**ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE  
STUDIES**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**



**Effects of Pit Latrines Seepage on Groundwater Quality in Addis Ababa City**

**A Thesis submitted to the School of Graduate Studies of Addis Ababa  
University in Partial Fulfillment of the Requirement for the Master of Water  
Supply and Environmental Engineering**

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**ADDIS ABABA UNIVERSITY**  
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This is to certify that the project presented by Abraham Gido entitled Effects of Pit Latrines Seepage on Groundwater Quality in Addis Ababa City and submitted to the Water Supply and Environmental Engineering department in Partial Fulfillment of the Requirement for the Master of Water Supply and Environmental Engineering with the regulation of the university and meets the accepted standards concerning originality and quality.

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## DECLARATION

I, here by affirm that this thesis, authored by Abraham Gido Giya, is entirely my original work. Any additional materials used are duly acknowledged as references. This dissertation has not been submitted as a thesis for any other degree at another university.

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## ABSTRACT

The water supply for Addis Ababa relies on a combination of surface water and groundwater sources, with groundwater being the dominant source. As the construction of wells has increased dramatically, the quality of the groundwater has become more sensitive and vulnerable to contamination. One potential source of groundwater contamination is seepage from pit latrines due to improper construction and aging infrastructure.

This research study aimed to investigate the impact of pit latrines on groundwater quality, specifically focusing on nitrate concentration as an indicator of human waste contamination. The methodology involved creating a groundwater nitrate distribution map for Addis Ababa and then collecting and analyzing groundwater samples from three different areas: a sewerage line uncovered area, a partially covered area, and a fully covered area. The groundwater samples were analyzed using a HACH DR 5000 UV-Spectrophotometer, Hach 2100 AN Turbidimeter and Hanna Ph.ISE.EC instrument.

The results showed significant nitrate contamination in the groundwater sample from the Teklehaimanot site, which is located near an uncovered sewerage line, with a nitrate concentration of 58.876 mg/l, exceeding the WHO standard. In contrast, the nitrate concentrations at the Zenebework (7.968 mg/l) and Jemo 1 (11.5 mg/l) sites were lower, suggesting that sewerage line coverage has a positive impact on reducing groundwater contamination from human waste.

Further analysis revealed a strong correlation (R square value of 99.99%) between nitrate and chloride concentrations in the groundwater samples, indicating a common source of contamination and the nitrate with turbidity correlation shows (R square value of 99.06%) the cleanness of the well is having a relation with the nitrate concentration. Additionally, a survey of the pit latrines in the high-nitrate Teklehaimanot area showed that the calculated wastewater production exceeded the removal capacity of vacuum trucks, suggesting seepage from the pit latrines. A Spearman rank correlation and Excel analysis revealed a correlation (r value of 0.9) between pit latrine age and the efficiency of waste removal, indicating that the age of the pit latrines affects their ability to contain the waste and prevent seepage.

The study also found that improper usage of toilets, with 8 houses directly connected their toilets to the drainage system, further contributed to the groundwater pollution in the area.

Ensuring the protection of groundwater quality is crucial for sustaining water supply. The impact of improper pit latrine use and aging infrastructure cannot be overlooked.

**Keywords:** -Pit latrines, toilet, groundwater, sewerage line and Spearman rank correlation

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## ACRONYMS AND ABBREVIATIONS

AAWSA- Addis Ababa water and sewerage authority

APHA – America Public Health Association

DFID- Department for International Development

DO – Dissolved oxygen

EPA – Environmental Protection Agency

NCBI – National Center for Biotechnology Information

NTU - Nephelometric Turbidity unit

PT - Pit Latrine

VIP -Ventilated Improved Pit latrines

Unisa – University of South Africa

UV- Ultra-violent

WSUP - Water and Sanitation for the Urban Poor

## 1. INTRODUCTION

### 1.1 Background

Groundwater is the main source of water for day-to-day use in many parts of the world. Wells and boreholes provide water for domestic, irrigation, and industrial purposes, while groundwater is also used as a source of energy for heating. Over a third of the world's population is supplied with drinking water from groundwater, and as the demand for water increases, most of the unserved population will have to be supplied from groundwater in the future. Groundwater also meets over 40% of irrigation water demand and provides about a quarter of all industrial supplies (International Association of Hydro Geologists, 2020).

However, groundwater pollution is a widespread problem with significant effects on human health and environmental security. Increased urbanization and population growth have exacerbated the contamination of groundwater, mainly through the misuse of groundwater assets and the discharge of domestic and industrial sewage into the groundwater system. Human health is susceptible to exposure to even trace levels of metals and metalloids due to their persistence in the environment and acute toxicity (D. Karunanidhi et al., 2021).

Pit latrines are one of the most common human excreta disposal systems in low-income countries, and their use is on the rise as countries aim to meet the sanitation-related targets of the Millennium Development Goals. However, there is a concern that the discharge of chemical and microbial contaminants from pit latrines to groundwater may negatively affect human health (Jay et al., 2013). Pit latrines generally lack a physical barrier, such as concrete, between the stored excreta and the soil and/or groundwater, allowing for potential seepage and contamination (van Ryneveld and Fourie 1997).

This research paper focuses on the effects of pit latrine seepage on groundwater quality in Addis Ababa. The study investigates the groundwater contamination related to sewerage line coverage and uses laboratory analysis and observation questionnaires to examine the issue.

## 1.2 Statement of the Problem

Groundwater contamination is nearly always the result of human activity. In areas with high population density and intensive land use, groundwater is especially vulnerable to pollution. Any activity that releases chemicals or wastes to the environment, either intentionally or accidentally has the potential to contaminate groundwater. Once groundwater becomes polluted, it is difficult and expensive to clean up (EPA, 1993; Fetter, 2001).

In Addis Ababa, the capital city of Ethiopia, the highest groundwater pollution is measured around the Mercato Area. The high nitrate and chloride levels observed in this area correspond to the maximum population density within the city (Water Ethiopia, 2013; Abiy et al., 2019). In addition to nitrate, many springs in the city are highly contaminated and have a large number of coliforms, indicating fecal contamination (Water Ethiopia, 2013; Yirga et al., 2021).

Pit latrines, which are commonly used in developing countries like Ethiopia, are not designed specifically to reduce pathogen concentrations. Although fecal matter undergoes some degradation over time, the pit should be sited to avoid or limit contamination of underlying groundwater, especially in cases where the groundwater is pumped back to the surface for human use or is hydraulically connected to a spring or other surface water (Kevin Orner et al., 2019; Dzwaïro et al., 2006).

While previous studies have identified groundwater contamination issues in Addis Ababa. This study aims to evaluate the effect of pit latrine seepage on the groundwater quality in the Mercato Teklehaimanot Area of Addis Ababa and provide necessary solution ideas for the identified problems, addressing this research gap.

## 1.3 Objectives

### 1.3.1 General Objective

The general objective of this study is to evaluate the impact of pit latrine seepage on the groundwater quality in Addis Ababa, Ethiopia.

### 1.3.2 Specific Objective

- To assess the physicochemical characteristics of groundwater in the study areas.
- To investigate the relationship between the service life of pit latrines and groundwater contamination.
- To compare the groundwater quality between areas covered by a sewerage line system and areas without a sewerage system.

## 1.4 Research Questions

- What are the physicochemical characteristics of groundwater in the study areas?
- How does the waste water management in the pit latrines study area?
- What is the sewerage line coverage effect on groundwater quality in the study area?

## 1.5 Scope and limitation of the Study

The scope of this research was to identify the effect of pit latrine seepage on groundwater quality in Addis Ababa, Ethiopia. Given the large size of the city and the extensive number of pit latrines, it was not feasible to study all pit latrine conditions within the available time and resources. Therefore, the study focused on a representative area selected based on available groundwater quality data.

Specifically, the study concentrated on the nitrate concentration in groundwater as an indicator of the impact of human waste. The rationale for this focus was that nitrate is a common contaminant associated with pit latrine seepage and could provide insights into the extent of groundwater pollution.

The study utilized secondary data on groundwater quality in Addis Ababa to identify areas with high, medium, and low levels of nitrate contamination. Groundwater sampling was then conducted in these selected representative areas to assess the impact of pit latrine seepage.

Due to resource and time constraints, the study did not focus on the detailed transport of human waste through the soil medium. Instead, the research relied on a combination of questionnaire

distribution to pit latrine users and field observations to understand the general condition of pit latrines in the study area.

The limitations of this study are, for some pit latrines, detailed information could not be obtained because the people living there had no information, as they were new to the area. Secondary data shortage about Addis Ababa total well number and their quality.

By focusing on the nitrate concentration in groundwater and using a targeted approach to study representative areas, this research aimed to provide valuable insights into the impact of pit latrine seepage on groundwater quality in Addis Ababa. The findings were expected to help inform appropriate mitigation measures to address the identified groundwater quality issues.

### 1.6 Significance of the Study

This study on the impact of pit latrine seepage on groundwater quality in Addis Ababa, Ethiopia holds significant importance due to the lack of regulatory mechanisms for pit latrine construction in the city. The research highlights the absence of a strong controlling mechanism, where anyone can construct a pit latrine without considering the potential groundwater seepage of the waste. This study provides evidence to support the city construction office in developing and enforcing regulations and standards for pit latrine construction and maintenance.

Furthermore, the study helps the Addis Ababa Water and Sewerage Authority (AAWSA) encourage people to connect their toilets to the sewer line where the infrastructure is accessible. Currently, many people are reluctant to connect to the sewer line due to the high service fees, prioritizing the long-term use of pit latrines over environmental considerations. The findings of this research can inform policymakers to revise the connection fee structure and incentivize people to opt for sewer line connections, thereby reducing the reliance on pit latrines and their impact on groundwater quality. Additionally, the study provides valuable insights into the environmental impact associated with the widespread use of pit latrines, which can help the government review and revise existing policies and regulations related to sanitation and environmental protection.

## 2. LITERATURE REVIEW

### 2.1 Groundwater pollution by Pit Latrines

The pit latrine is one of the human waste collection systems. In this system, the groundwater is affected by its seepage because of its improper construction. From human excreta, nitrogen is the basic element of contaminating the groundwater by changing it to nitrate. When the groundwater level is shallow, the effect increases. Other research exploring pit latrine seepage in groundwater effect is studying. According to Ms Raboshaba (2019) suggests that the construction method of pit latrines has an effect by seeping the leachate from the pit latrine into the aquifer. And also, stated that pit latrine distance from the well is critical, as the radius of influence affects the groundwater quality. However, the research does not relate the pit latrines' efficiency with the service life of pit latrines. Careful siting of latrines and appropriate pit latrine design and management is especially important in areas with high water tables (Michael et al., 2015).

Because of the increasing uses of both pit latrines and groundwater resources in low-income countries, there is concern that pit latrines may cause human and ecological health impacts associated with microbiological and chemical contamination of groundwater. Pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil and/or groundwater (van Ryneveld and Fourie, 1997).

There is a need for the local government to enforce standard construction procedures to minimize pollution of water sources. Unsewered sanitation can cause groundwater contamination by chlorides, nitrates, and pathogenic microorganisms (Saria et al., 2011).

As stated by D.A. Still and S.R. Nash (2002) the water quality in protected wells is much better than that in unprotected wells. Girmay Kahssay et al., (2010), in *Low-Cost Sanitation and its Impact on Quality of Groundwater in Addis Ababa* on Unisa institutional repository, stated that their focus is on pit latrine distribution with population density and aquifer characteristics. With the distribution of pit latrines, their quality and management must be considered.

Djousse et al. (2023) in the *Assessment of the Impact of Pit Latrines on Groundwater in the Melen Slum, Cameroon* identified that groundwater was polluted by poorly designed pit latrines and solid and liquid waste disposal. Groundwater pollution also results from poor site selection

and design of groundwater supply infrastructure and excessive exploitation of groundwater due to the inability of national water companies to provide drinking water to these residents.

A standard pit generally contains a range of materials, including faeces, urine, anal cleansing material and general solid waste. On the other hand, Most South Africans are “wipers.” If toilet paper is unaffordable then newspapers, and sometimes other materials such as plastic bags or maize cobs, will be used for anal cleansing. As these materials represent different volumes and biodegradability, they can have very different impacts on filling rates (David Still & Kitty Foxon, 2012).

In this research, the impact of pit latrine seepage on groundwater quality is conducted by identifying the polluted well depending on laboratory results and ascertained through the correlation method by considering sewerage line coverage conditions. The pit latrines were taken within a 100-meter radius of the polluted well then, the pit latrines data was collected and analysis was done relating the quality and service life of the pit latrines with the water consumption of each household.

## 2.2 Demography

Addis Ababa's 2024 population is now estimated at 5,703,628. In 1950, the population of Addis Ababa was 392,000. Addis Ababa has grown by 243,037 in the last year, which represents a 4.45% annual change. World population review, (2024) indicates that these population estimates and projections come from the latest revision of the UN World Urbanization Prospects. These estimates represent the Urban agglomeration of Addis Ababa, which typically includes Addis Ababa's population in addition to adjacent suburban areas.

Addis Ababa is the capital city of Ethiopia. It is also the largest city in the country by population, with a total population of 3,384,569 according to the 2007 census. However, it is believed that this number was inaccurate when recorded and underestimated the city's population. The city has through recent years seen a robust annual growth rate, and population counts as of 2017 are growing closer to 4 million. The most recent census was scheduled for the 2018 to 2019 fiscal year, as security concerns between 2017 and 2018 delayed it. Addis Ababa is a chartered city and as such, is considered both a city and a state. It is the largest city in the world located in a landlocked country (World Population Review, 2024).

## 2.3 Geology

### 2.3.1 Groundwater Depth of Addis Ababa

As Water Supply Master Plan of Addis Ababa Stage III, Groundwater, Suereca 1993, The depth of various places to place at the center of Addis Ababa around the depth is 0 to 40 meters, the deep groundwater depth of more than 120 meters depending on the topography of the area.

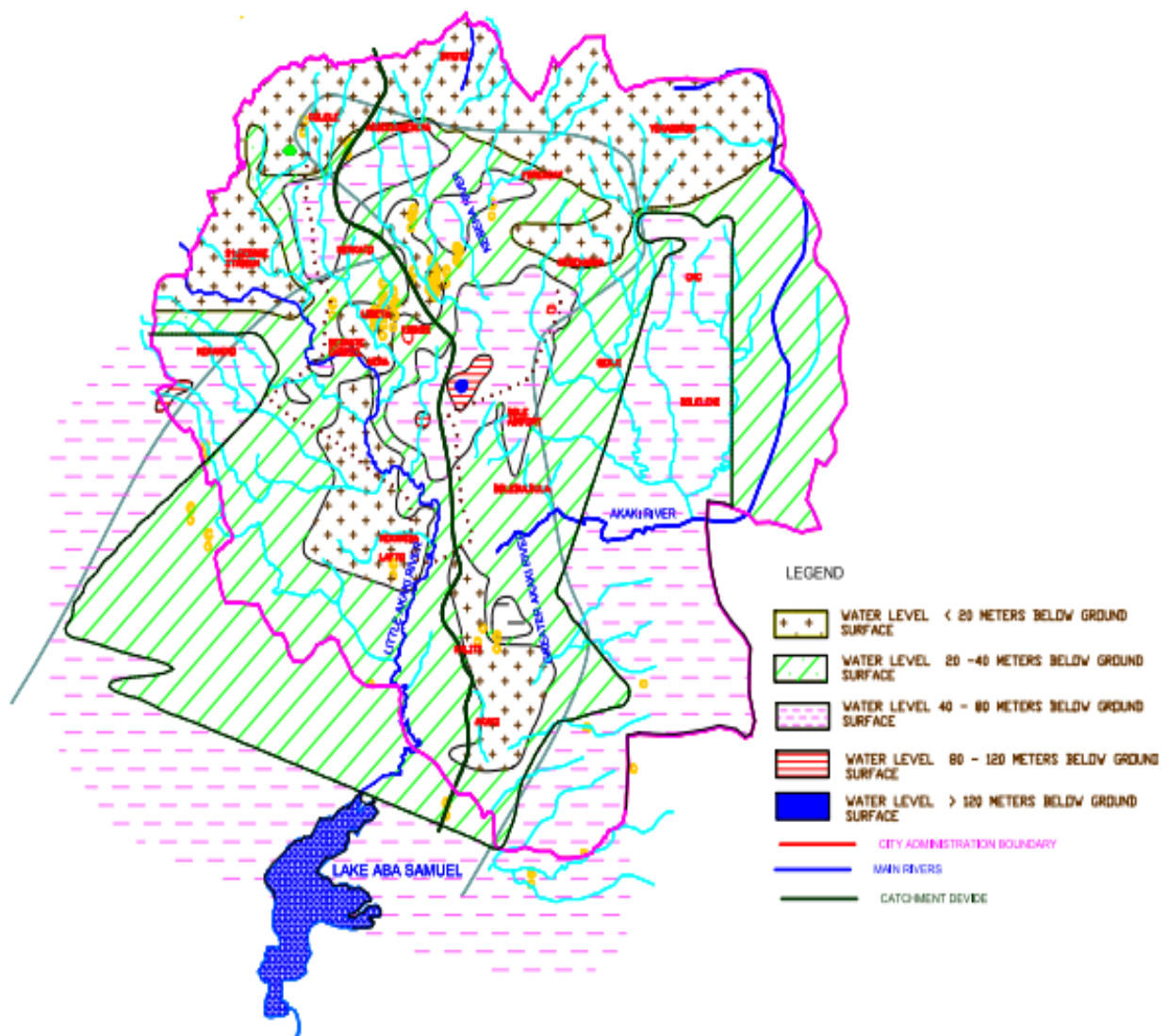


Figure 1. Groundwater depth of Addis Ababa area (Source: Engeda, 2001)

The groundwater in Addis Ababa which is unconfined and groundwater depth is less than 80 meters is considered highly vulnerable to many pollutants except those highly absorbed and or readily transformed. The main reason to consider it highly vulnerable is that the aquifers are fractured and weathered volcanic rocks, with a probability of transferring polluted water through the fractured unsaturated zones (Engida Z.A, 2001)

AAWSA- WSIDD, (2023) also says depth to groundwater level for the deep regional aquifer varies between artesian flowing conditions close to weak zones along river courses and to over 200m, at elevated parts of the area depending on the topographic setup. Depth to the groundwater for shallow aquifers is within a range of 20 to 30m.

### 2.3.2 Aquifer Characteristics

Addis Ababa city area is found at the edge of the main Ethiopian rift valley. The dominant geological formation found in the city area is volcanic rocks (ignimbrites, rhyolites, basalts, scoria, etc.). Generally, from the north-south the geological formation changes from trachytes and rhyolites at the north to basalts at the center to basaltic lava and cinder cones to the south. The aquifers of the northern and central part of Addis Ababa city and in the mountain, area are largely due to weathered and fractured volcanic rock with minor sediments deposited between different series of lava flows. The aquifers in the southern part of the city (Akaki well field) are mainly young volcanic rocks of lava flow and tectonic fractures. In general, the aquifers are complex and highly variable. The thickness of the aquifers is not yet determined (Engida Z.A, 2001).

In addition, the drilling supervision of 32 wells in the Addis Ababa condominium and pocket areas project, (2018) document describes how the main aquifer of Addis Ababa pocket areas varies from place to place. Fractured Ignimbrite is the main aquifer of boreholes drilled in north Eastern and Western parts of Addis Ababa. Whereas, the main aquifers of boreholes located in the south part of Addis Ababa are Basalt and Ignimbrite. As observed from borehole data, the yield of the wells drilled in the vicinity of dislocation related to the Ambo Filwuha fault and penetrated structurally affected basalt and ignimbrite is high. Whereas boreholes drilled in intermediate rocks such as trachyte have low yield (AAWSA- WSIDD, 2023).

The first high to moderate productive pyroclastic deposit consists of a vesicular basaltic aquifer. Which is dominantly found around the southwest central part of the study area. They have high

primary porosity and form moderately to highly productive. Moreover, they are affected by tectonic activity along the river banks. They are highly fractured so that they can form highly productive aquifers. The fault systems also improve productivity (AAWSA- WSIDD, 2023).

The second dominant aquifer in both study areas is a highly productive scoriaceous basalt which is a dark brown and reddish grey color, vesicular coarse-grained rock. They have high primary porosity and are highly productive. This aquifer can form a highly productive aquifer. The fault systems also improve productivity. Groundwater flows from northwest to southeast away from Mt. Furi towards central Addis Ababa and to the southern part towards Abasamuel River (AAWSA- WSIDD, 2023).

### 2.3.3 Groundwater Recharge

De Vries and Simmers (2002) generally define Groundwater recharge as the amount or process of downward flow of water reaching the water table, forming an addition to the groundwater reservoir. Hartmann et al., (2015, 2017) also describe water that contributes to groundwater recharge as formed as a result of precipitation reaching the surface, precipitation infiltrating into the subsurface, or snowmelt percolating vertically through the unsaturated zone into the groundwater. There are three types of recharge the first type is direct recharge, which occurs from excess soil moisture and direct vertical infiltration through the unsaturated zone to reach the water table, the second type is indirect recharge, which occurs by infiltration and seepage, and the third type is targeted or localized recharge, which results from localized horizontal accumulations of infiltrating water near the surface, such as in fissures, depressions, sinkholes, or streams (but not riverbeds or lakes). Global estimates of direct recharge range from very low annual amounts in deserts to over 1000 mm/year in the tropics. In addition to direct recharge, targeted or localized recharge has been shown to recharge large amounts of groundwater in a very short time.

When we come to the groundwater study in Addis Ababa. In the study groundwater resource evaluation for selected sites in different pocket areas quantifying recharge of an aquifer is highly crucial for proper evaluation, development, and management of groundwater resources. The major sources of groundwater recharge for the aquifer in the area are inflow from the regional groundwater flow due to the infiltration of precipitation in the highlands and some percolation through local fractures. From different studies, it is known that sufficient recharge is available in the area (AAWSA- WSIDD, 2023).

Based on the detailed groundwater potential assessment and evaluation conducted in the area, the recharge area for the target site could be in the northern part through a volcanic plateau. The soils are silty to sandy in texture. The outcropping rocks in the area are highly fractured, jointed, and weathered. Local minor faults are densely distributed in the area which are expected to percolate water into the deeper zones. The rock and soil nature in the northern side of the study sites facilitates infiltration rather than runoff. The groundwater recharge from the annual precipitation in the area is among the highest due to these structural features that promote recharge. Therefore, recharge to the groundwater from the local precipitation within the catchment and from the plateau through fractures and fault systems is expected to be high, so the groundwater storage of the area is expected to be very high. According to estimates made by different researchers' annual recharge ranges from 80mm to 120mm for the region (WWDSE, 2008).

The major sources of groundwater recharge for the polygons in the Addis Ababa area are regional as subsurface seepage from the fracture openings of the volcanic rocks of the Abay plateau (WWDSE, 2008). As discussed previously the Addis Ababa area groundwater is part of the Ada'a-Becho plains groundwater system. According to the previous studies recharge from Abay plateau passes through Addis Ababa aquifer systems through preferential flow paths area in a north-south general direction to well fields in the south & Ada'a plain groundwater system. The annual recharge as estimated by (Ada'a-Becho Plain Groundwater Resources Evaluation, WWDSE 2008) is 88 mm/year.

#### 2.4 Groundwater Abstraction Condition in Addis Ababa

Drilling for groundwater is no longer feasible for Addis Ababa as the city's wells are drying up, warns a new study presented. The engineering experts who presented the study at a UN conference in the capital cautioned that its water supply is at risk of drying up if the pumping of groundwater goes unchecked and unregulated (The Reporter, 2024).

Along with the increasing groundwater development there is growing awareness that management is needed to ensure the sustainability of investments in groundwater development, to optimize the opportunities for groundwater recharge and reuse, and to regulate the long-term equitable use of the resource. In this context, the Ministry of Water Resources requested support from the World Bank/GWMATE in helping develop a strategic framework for managed groundwater development, with special attention for areas of intensive groundwater development, like the Addis Ababa area (Ministry of Water and Energy, 2013).

## 2.5 Wastewater Collection and Removal Practice in Addis Ababa

In Addis Ababa city most residents use some form of on-site sanitation: Half of the residents use shared pit latrines, while about 18.3 percent and 26.4 percent, respectively, use private pit latrines or flush toilets, including pour flushing. The problems of open defecation; unsafe containment; and lack of appropriate desludging services, transportation, and treatment of wastewater remain significant (World Bank, 2017).

Based on Sanitation Master Plan, average faecal sludge volumes are estimated to be 0.35 m<sup>3</sup>/cap./year for septic tanks, and 0.11 m<sup>3</sup>/person/year for VIP latrine and pit latrines. During the desludging operation, additional water amounting 1 time for the septic sludge and 3 times for the latrine's sludge is assumed to be mixed with the sludge. The highest volume of sludge generated over the city is expected for 2030 since then, more and more housing should connect to sewer networks and WwTP expansions. Therefore, the on-site wastewater treatment facilities shall decrease accordingly as well as the faecal sludge volumes coming out from these (AAWSA, 2023).

### 2.5.1 On-site Sanitation

The cost of a sewerage system (which is usually more than four times that of on-site alternatives) and its requirement of a piped water supply preclude its adoption in the many communities in developing countries that lack adequate sanitation. On-site disposal, dealing with excretion where it is deposited, can provide a hygienic and satisfactory solution for such communities (WHO, 1992).

According to the findings of the Wastewater Masterplan, most of the population in Addis Ababa will continue to use on-site sanitation. This will be either dry pit latrines or septic tanks that will require a significant effort to properly standardize and control implementation by the households and public offices (AAWSA- WSIDD, 2022).

### 2.5.2 Faecal Sludge Management

Faecal sludge management (FSM) includes the collection, treatment, and disposal of the contents of OSS (on-site sanitation systems) which includes sludge, water, and solid waste that accumulates in pits, septic tanks and soak pits over time (WSUP, 2018).

The Masterplan also revealed that the collection of sludge from the city is constrained by the following problems:

- Poor access (narrow, steep unpaved roads) for suction trucks to reach and empty sludge from septic tanks and pit latrines.
- Sludge removal is difficult especially from the dry pit latrines, as the sludge contains a lot of extraneous matter such as plastic, clothing, and other solid waste.
- The fecal sludge collection by vacuum trucks is currently performed both by the public utilities and private service providers in a ratio of 1:1 The treatment system currently used for faecal sludge treatment is a drying bed located at Kaliti and Kotebe is fully owned and operated by AAWSA (AAWSA- WSIDD, 2022).



Figure 2. AAWSA Pit latrine Sludge when removed by vacuum truck around the Teklehaimanot area

## 2.6 Sewer Line Coverage in Addis Ababa

Addis Ababa is divided into three wastewater catchments; the Akaki Catchment, the Eastern Catchment and the Kaliti Catchment. The Akaki Catchment is situated in the south west of Addis Ababa and has a limited sewer network draining to Chefe WwTP. The Kaliti Catchment is situated in the northwest of Addis Ababa and has an extensive sewer network draining to the recently constructed Kaliti WwTP. Major construction works have expanded the Kaliti sewer network in recent years. Several condominium developments in both

the Akaki Catchment and the Kaliti Catchment have internal sewer networks which drain to decentralized WwTPs (AAWSA, 2020).

AAWSA- WSIDD, (2022) stated in its inception report the population of Addis Ababa City and provision of water supply and other associated socio-economic development are increasing from time to time as is the increase in the amount of generated wastewater from domestic and other establishments. A sewer network and a Wastewater Treatment Plant currently serve some parts of the Kality catchment specifically Bole, Ledeta, Old Airport, the Central part of the city, Mekenisa, and Kera areas. The present coverage of wastewater treatment facilities in the city is very low. 51% of the population has access to faecal sludge collection services and 29% of the population has access to sewer sanitation systems.

The inception report adds the existing situation of the wastewater management facilities and the service in the city shows the prevalence of limitation of capacity as well as geographical location problems to be connected to the existing system.

AAWSA- WSIDD, (2022) also states these catchments have been subdivided into sub-catchments that correspond to the service areas. Addis Ababa currently has a rudimentary sewerage network and two major wastewater treatment plants: Kotebe and Kality Wastewater Treatment Plants. The Kality Wastewater Treatment Plant serves the Kality sewer catchment. It was commissioned in 1981 with a design capacity of 7,600m<sup>3</sup>/day. Treatment consists of inlet screens and grit chambers, two settling chambers, and two parallel pond systems, each made up of a facultative pond, a maturation pond, and two polishing ponds. Sludge lagoons and drying beds were constructed in 1999 with a treatment capacity of 110,000 m<sup>3</sup>/year of sludge. To address the basic sanitation needs of the city, the Wastewater Masterplan formulated sewerage development strategies for each sewer catchment.

Based on this development plan, the Wastewater Treatment Plant of Kality has currently undergone major rehabilitation and expansion works and when it is fully functional the plant will have a total capacity of 100,000 m<sup>3</sup>/d. The existing sewerage network consists of 42 km of trunk sewers and 320 km of secondary sewers and laterals in the Kality sewer catchment. The old sewerage system before the expansion was designed to serve an equivalent population of 200,000. AAWSA is currently undertaking a wide sewer line expansion project in the catchment. Other small decentralized biological treatment systems with limited capacity mainly serve the Condominium housing units located nearby (AAWSA- WSIDD, 2022).

A recent procurement and implementation program is underway in the eastern catchment located mainly in the eastern part of the city to have a sewerage network and new treatment plant having a capacity of more than 100,000 m<sup>3</sup>/day funded by the World Bank. It has also formulated a decentralized wastewater management strategy. That can be implemented at a variety of scales including government-constructed condominium housing sites constructed through the city government and housing projects constructed through real estate and businesses or small communities (AAWSA- WSIDD, 2022).

Those types of projects are currently being introduced at different condominium housing sites and their construction status is at different stages. In addition to the above, AAWSA has currently completed construction of 12 decentralized wastewater projects with a capacity of more than 30,000 m<sup>3</sup>/day that use MBR technology at twelve condominium housing sites. Those systems are believed to treat wastewater to levels protective of public health and water quality and work well in all environments both in suburban and urban settings. There are some ongoing efforts by AAWSA regarding the application of effluent reuse. For example, some of the treated water discharged from these units is used for public gardening and in some places, it is used for car washing by a group of Small and Medium Enterprise SMEs. AAWSA is also planning on conducting a study of the reuse of wastewater produced from all wastewater treatment plants (AAWSA- WSIDD, 2022).

The total sewer line coverage: Trunk line more than 131 km, secondary sewer line 1,474 km. when we see the customer coverage from AAWSA Nov 2023 bill data from 617,407 water customers 207,287 customers are the sewer line connected.

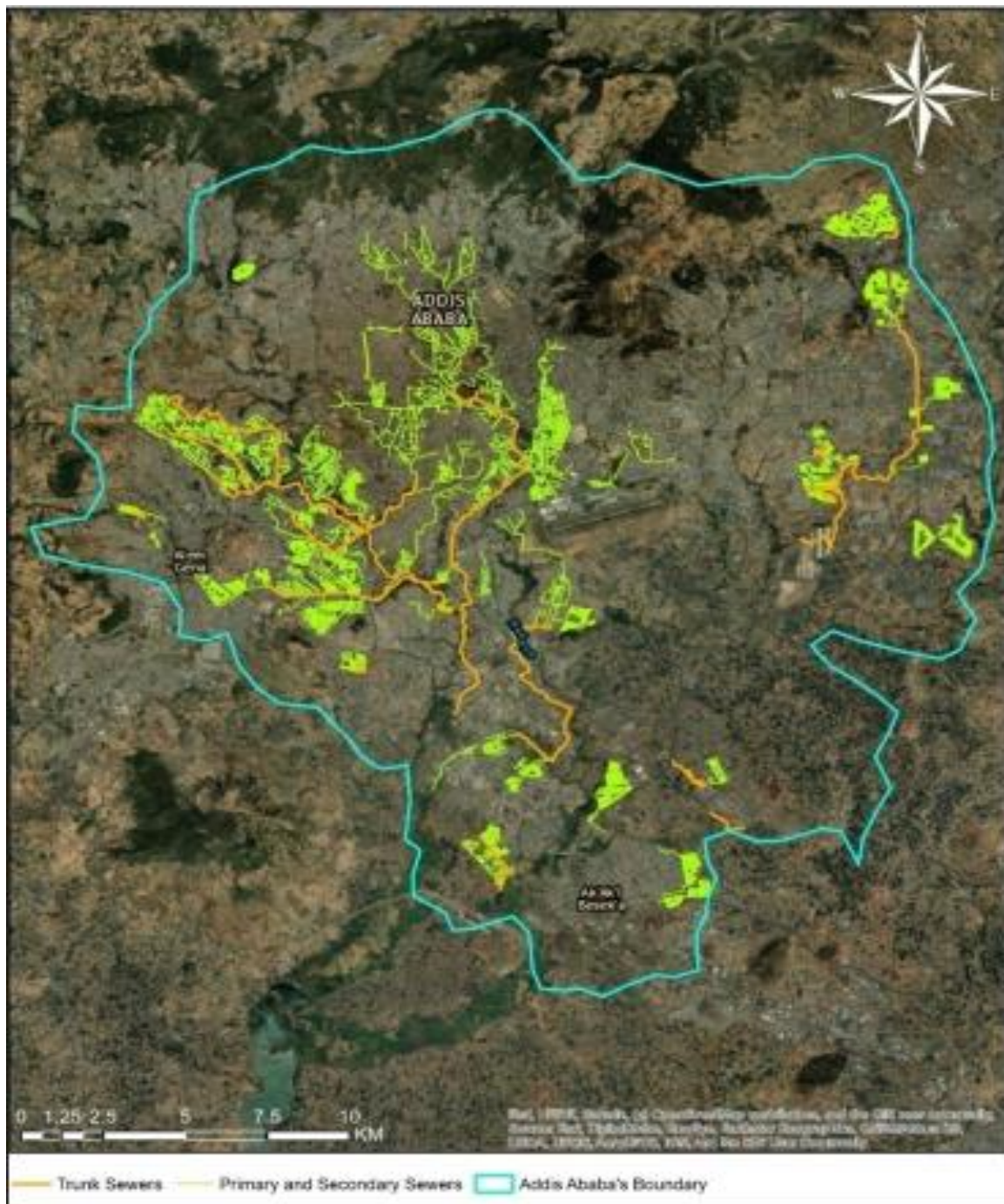


Figure 3. Addis Ababa city existing Sewerage line coverage map (Source: AAWSA, 2020)

## 2.7 Pit Latrines Practice

### 2.7.1 Statics of Pit Latrine in Addis Ababa

Average at least 252,954 pit latrines exist in the city. This spatial distribution appears to suggest a more realistic distribution. The less populated areas in the major aquifer zones show a lesser

number of pit latrines. Of these estimated pit latrines at least 236,215 are estimated to be located in the central or highly populated areas, while the remaining 16,739 are located in the periphery of the city (Girmay Kahssay et al., 2010). However, 44% of households use unimproved pit latrines and only 20-30% of the city's residents have access to safe wastewater collection and treatment, either through centralized sewerage lines or vacuum trucks (Birhane, 2017).

The Master Plan has set the following targets (Table 1) related to the population's access to sanitation services to be achieved by the planning horizons. These figures are based on: The existing situation analysis, AAWSA Long-Term Road Map (2016), and based on United Nations SDG 6.2 & 6.3 (AAWSA, 2023).

*Table 1. Addis Ababa Sanitation Master Plan Targets (Source: Sanitation master plan & feasibility study for the city of Addis Ababa)*

	2022 (Existing)	2025 (SMP)	2030 (Short-term)	2035 (Mid-term)	2040	2045 (Long-term)
<b>Off-site Sanitation (Connection Rate)</b>	18.5%	20%	25%	55%	68%	80%
<b>On-Site Sanitation (Access Rate)</b>	74.5%	75%	75%	45%	32%	20%
<b>Septic Tank</b>	7%	7%	7%	5%	5%	5%
<b>VIP Latrines</b>	30%	30%	30%	20%	12%	11%
<b>Pit Latrines</b>	38%	38%	38%	20%	15%	4%
<b>Sludge Treatment Rate</b>	35%	35%	47%	52%	75%	100%
<b>Open Defecation</b>	7%	5%	0%	0%	0%	0%

*Table 2. Estimation of Addis Ababa sludge projection (Source: Sanitation master plan & feasibility study for the city of Addis Ababa)*

		2022	2030	2035	2040	2045
<b>TOTAL SLUDGE</b>	m <sup>3</sup> /d	4,596	5,035	4,487	3,508	2,244

In 2022 VIP latrines and Pit latrines cover 68% of the city's sanitation system. This prediction is not considered improper sewerage management regarding the pit latrine quality and its management. If the pit latrines construction and management are applied properly the number of projected pit latrines may not vary but the total sludge will increase or stay there.

## 2.7.2 Types of Pit latrines

### 2.7.2.1 Simple Pit Latrine

On-site sanitation systems are more widely employed in low-income and rural areas of the world. Numerous forms have been developed ranging in both price and complexity. A number of publications exist that outline the features of different types and the consequences of employing them. This brief simply outlines the range of technologies in common use and the main advantages and disadvantages. The simplest form of pit latrine is a hand dug pit that is unlined and covered with a series of wooden logs strapped together allowing the user to defecate into the pit. This system can gradually be improved. The advantage of simple pit latrines is Construction costs are low (householders can perform a large part of the work themselves), technology is simple and understandable it allows a range of anal cleansing materials and does not require water to operate. On the contrary, it contaminates groundwater easily, it is not completely lined, it is difficult to construct in rocky unstable ground and simple pit latrines exposed to fly and smell nuisance (Boat Niall, 2008).

### 2.7.2.2 Ventilated Improved Pit (VIP) Latrine

During the 1980s the VIP latrine was developed in Zimbabwe. The main drivers for design were to eliminate two unpleasant aspects of using on-site sanitation systems, flies and smell. Furthermore, the reduction of flies can also reduce the transmission of disease. Put simply, the technology facilitates the flow of air through the system. One important aspect is that the inside of the toilet should remain dark as a means of attracting flies up a vent pipe where they will eventually die and fall back into the latrine. The advantage of ventilated improved pit latrines is, construction costs are low (householders can perform a large part of the work themselves), technology is simple and understandable, allow the use of a range of anal cleansing materials, do not require water to operate and VIP controls smells and files. The disadvantages of VIP are that if the pit is not completely lined it contaminates the groundwater, not easy to construct in rocky or unstable ground, it cannot prevent mosquitoes, the Vent pipe increases costs and can make

construction more complicated, and need to keep inside of latrine dark and increases odour at the outside (Boot Niall, 2008).

### *2.7.2.3 Pour-Flush Latrine*

Where water is more widely available, or traditionally used for anal cleansing, a pour-flush latrine may be appropriate and can bring several further benefits on top of simple or VIP latrines. A water seal is created by a plastic u-bend which prevents bad odour and flies from affecting the user (this system is less susceptible to building errors than the VIP system). The system only requires a few liters of water so should not put a strain on resources and could be provided by greywater from the kitchen. Pour-Flush Latrine effectively reduces levels of flies, mosquitoes, and odour, the system can incorporate an offset pit and so can be installed inside a household, the installations are easy to keep clean, the construction is not as complicated as a VIP latrine. On the other hand, it requires a water supply to operate the system, the water seal prevents the use of solid anal cleansing materials, the plastic pan requires increased skill to produce finally it is more expensive than simple types (Boot Niall, 2008).

### *2.7.2.4 Cistern Flush Toilet*

People use cistern flush toilets for pit latrines, septic tank systems and connected sewer systems. Open Learn Create, (2016) describes the cistern flush toilet also known as a water closet or WC, as usually made of ceramic material. The flush toilet consists of two parts: a tank (cistern) that supplies flush water for carrying away the excreta and a bowl into which the excreta are deposited. It also needs a connection to constant running water and a discharge pipe to take the wastewater away to a sewer or septic tank. WCs are rarely found in rural households but are quite common in government offices, some schools, and health facilities. The attractive feature of the flush toilet is that it has a water seal to prevent odors from coming back up through the plumbing. A skilled plumber is needed to install a flush toilet. From the users' perspective, it is a safe and comfortable toilet to use provided that it is kept clean, but the high capital cost for installation and the need for skilled personnel make it not affordable for every family, especially those living in rural areas.

## 2.8 Chemical Composition of Human Excreta

Table 3. Average composition of human faeces and urine (Source: Anicko Zseni, Research gate)

	Faeces	Urine
<b>amount</b>	150-300 g/person/day	1-1.3 l/person/day
<b>moisture content</b>	66-80%	93-96%
<b>dry matter</b>	40-81 g/person/day	50-70 g/person
<b>in the dry matter organic compounds</b>	88-97%	65-85%
<b>N</b>	5-7%	15-19%
<b>P (as P<sub>2</sub>O<sub>5</sub>)</b>	3-5.4%	2.5-5%
<b>K (as K<sub>2</sub>O)</b>	1-2.5%	3.0-4.5%
<b>C</b>	40-55%	11-17%
<b>Ca (Ca CaO)</b>	4-5%	4.5-6%

From the above table of human faeces urine average composition, the organic compound is very necessary to investigate groundwater pollution.

### 2.8.1 Nitrogen

There are four forms of nitrogen in water and wastewater: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. If water is contaminated with sewage, most of the nitrogen is in the forms of organic and ammonia, which are transformed by microbes to form nitrites and nitrates. Nitrogen in the nitrate form is a basic nutrient to the growth of plants and can be a growth-limiting nutrient factor. A high concentration of nitrate in surface water can stimulate the rapid growth of the algae which degrades the water quality. Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants. The nitrate ions react with blood hemoglobin, thereby reducing the blood's ability to hold oxygen which leads to a disease called blue baby or methemoglobinemia (Nayla H, 2019).

Regarding nitrate contamination, pit latrines and public water points do influence nitrate concentrations in the groundwater. The effects are, however, localized and not significant from a public health point of view. Water quality in protected family wells is found to be good, while shared community wells, particularly the older unprotected wells, show signs of contamination (D.A. Still and S.R. Nash, 2002).

### 2.8.2 Potassium

Potassium content in natural bodies of water is far lower than that of sodium. Its concentration is usually only 4% to 10% of that of sodium. In some quartzite areas, the potassium content in natural water is near or exceeds sodium content but both of them are very low, only some single-digit mg/L respectively. In most freshwater with sodium concentration below 10mg/L, the potassium concentration is only 10% to 50% of the sodium concentration. In some alkaline water or hot springs, the potassium concentration multiplies by orders of magnitude. In brine, the potassium concentration is ten mg/L to hundreds of mg/L. Furthermore, potassium is a basic nutrient of plants and is absorbed by plants during the weathering process (Ministry of Environment Taiwan, 2023).

### 2.8.3 Phosphorus

Elevated Phosphorus concentrations in groundwater have been attributed to anthropogenic sources and natural processes that govern the movement of P in the subsurface. Several natural factors including temperature and pH can impact P concentrations in groundwater, but DO, which affects the ability of iron oxides to adsorb and retain P, has been identified as a primary natural control on P concentrations in water. High DO concentrations in the subsurface allow for iron oxides to remain stable, but in low oxygen environments, iron oxides can dissolve, releasing adsorbed P back into the water and increasing P concentrations. An inverse correlation between DO and P concentrations would therefore indicate a natural explanation for elevated P concentrations in groundwater (Jessica et al., 2021).

### 2.8.4 Carbon

Elemental carbon is an inert substance, insoluble in water, diluted acids and bases, as well as organic solvents. At high temperatures, it binds with oxygen to form carbon monoxide or dioxide. With hot oxidizing agents, like nitric acid and potassium nitrate, metallic acid  $C_6(CO_2H)_6$  is obtained (Lenntech, 2023).

### 2.8.5 Calcium

Calcium is largely responsible for water hardness, and may negatively influence toxicity of other compounds. Elements such as copper, lead and zinc are much more toxic in soft water. In limed soils, calcium may immobilize iron. This may cause iron shortages, even when plenty of iron is present in the soil (Lenntech, 2023).

## 2.9 Nitrate Selection as Main Pollutant

In the research, nitrate was taken as the major groundwater contaminant. Because of high concentrations of nitrogen in human excreta, its adverse impacts on human health, and its use as an indicator of fecal contamination, nitrate has been the most widely investigated chemical contaminant derived from pit latrines (Fewtrell 2004; WHO 2011).

Nitrate is a common pollutant in natural waters. Surface water is the main receiver and transmitter of pollutants into the groundwater body. Hence, the protection of surface water pollution is directly related to the protection of the groundwater system, because the two systems form a link through the geologic medium. Very high nitrogen concentrations may occur due to anthropogenic activities such as waste disposal and agricultural activities (Bouwer, 1978).

## 2.10 Health Condition Related Groundwater Quality

The use of groundwater as a source of drinking water is often preferred because of its generally good microbial quality in its natural state. Nevertheless, it is readily contaminated and outbreaks of disease from contaminated groundwater sources are reported in countries at all levels of economic development (Howard et al., 2006).

Tianshan et al. (2021) indicate that the risk for adult males, adult females, and children when exposed to oral intake and dermal contact with groundwater was analyzed through the use of a health risk assessment model parameter. Finally, they realized that the children face higher risks than females, which are higher than males. Because children have the lowest average weight and males have the highest average weight.

In an effort to capture a representative sample of confirmed groundwater-related outbreaks of enteric infection from around the world, over the past three decades, a scoping review was undertaken. The NCBI PubMed archive of biomedical and life sciences was searched using the keywords “groundwater” and “outbreak”. Overall, 98 articles dating back to 1985 were recovered, of which 94 were in English. Forty-four articles discussed either multiple or single outbreaks related to groundwater. The review identified that the following five pathogens were responsible for most outbreaks: norovirus, *Campylobacter*, *Shigella*, Hepatitis A, and *Giardia* (Murphy et al., 2017).

### 2.10.1 Health Effect Related High Nitrate Concentration Using Groundwater Source

In this research the main focused pollutant is nitrate. According to Saravan et al. (2022), Human health is affected by the frequent use of high-nitrate groundwater sources.

The impact on 6–12 months is infant methemoglobinemia which is a life-threatening disease among infants; in the 5–10 years group of people, type 1 childhood diabetes, blood pressure, and acute respiratory infection; in the 10–20 years group of people, prematurity, blood pressure, acidity, following of vasodilation, antithrombotic and immunoregulatory effects (Zeman et al. 2011; Aschebrook-Kilfoy et al. 2012; Benson et al. 2010; Ward et al. 2010); on 20–60 years group of people, pregnancy-related issues such as spontaneous abortion, fetal deaths, intrauterine growth retardation, low birth weight, congenital malformation and neonatal deaths; and on greater than 60 age groups of peoples, they can be affected by cardiovascular hypertrophy, heart attack, heart diseases, myocardial infraction and lipid peroxidation in the retina (Garcia Torres et al. 2020; Manassaram et al. 2010; Migeot et al. 2013; Abu Naser et al. 2007). In our case, the city water utility (AAWSA) distributes the water with WHO drinking water quality standards. The drinking groundwater resource of Addis Ababa is far from the polluted groundwater area. But in the future, the point sources like pit latrines and seepage pollution are not managed properly the contamination will reach another place.

### 3. MATERIALS AND METHODS

#### 3.1 Description of the Study Area

The study area is Addis Ababa. It is the capital city of Ethiopia and the seat of Africa Union headquarters. The specific pit latrines study area is differentiated by taking well water samples from three different areas of Addis Ababa depending on the sewerage coverage. The first well site is Teklehaimanot around Merkato, the second one is Zenebework around Manaharia and the third one is from Jemo 1 well.

According to the Ministry of Water and Resources (2011), the high nitrate concentration in the city observed in the Merkato area corresponds to the maximum population density. So, in this research, the pit latrine study area was selected from high nitrate concentration groundwater area. So, in this case the pit latrine study area is around Merkato Teklehaimanot well. Teklehaimanot is a highly populated and one of the oldest settlement areas in Addis Ababa, which is a 130-year-old city. The groundwater contamination in Addis Ababa shows a gradient, with the highest nitrate concentrations observed in the Teklehaimanot-Merkato region, and the levels gradually decreasing towards other parts of the city.

Notably, the high nitrate concentration area lacks a centralized sewer line infrastructure, and the population heavily relies on pit latrines for sanitation. This combination of high population density, old settlement patterns, and the absence of a comprehensive sewerage system makes the Teklehaimanot-Merkato region a critical area of focus for the study on the impact of pit latrine seepage on groundwater quality.

The selection of this pit latrines study area is strategic, as it represents a scenario where the lack of proper sanitation infrastructure and the widespread use of pit latrines have contributed to the elevated nitrate levels in the groundwater, posing potential risks to the health and well-being of the residents who rely on this water source.

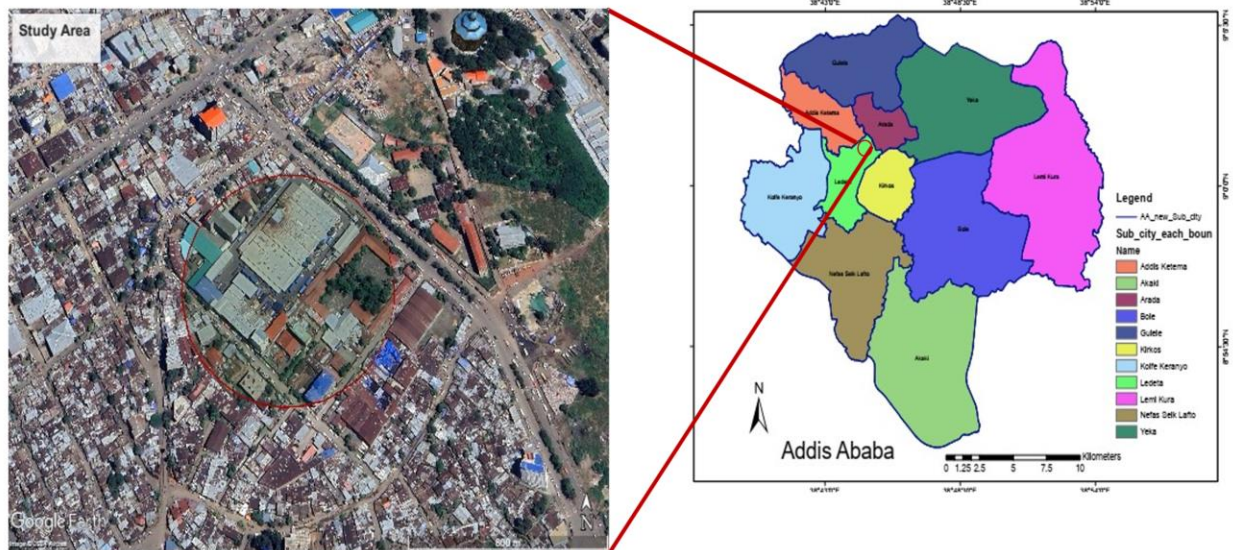


Figure 4. Teklehaimanot around Pepsi factory, pit latrines study area

### 3.2 Study Design

The study design of this research started by collecting the secondary groundwater quality of Addis Ababa city and then preparing the nitrate distribution map of groundwater. The area with high nitrate concentration is the pit latrines study area. The water sample from the well-taken to the laboratory from high, medium and low nitrate concentration areas according to the secondary data source. Pit latrine information was collected by questionnaire method. Finally, water consumption data for the selected pit latrine households and the sewer line coverage map were collected from AAWSA.

### 3.3 Data Collection

The secondary data groundwater quality physicochemical data, sewerage coverage map, water consumption, and other needed data were collected from AAWSA. Primary data groundwater well sample is taken and pit latrines condition is collected by questionnaire method.

### 3.4 Addis Ababa Well Nitrate Concentration

Addis Ababa city well nitrate concentration map is prepared by taking secondary data on the well from AAWSA. The figure below shows the red color indicates the highest concentration of nitrate more than the WHO standard. The pit latrine study area focused on the high nitrate concentration area.

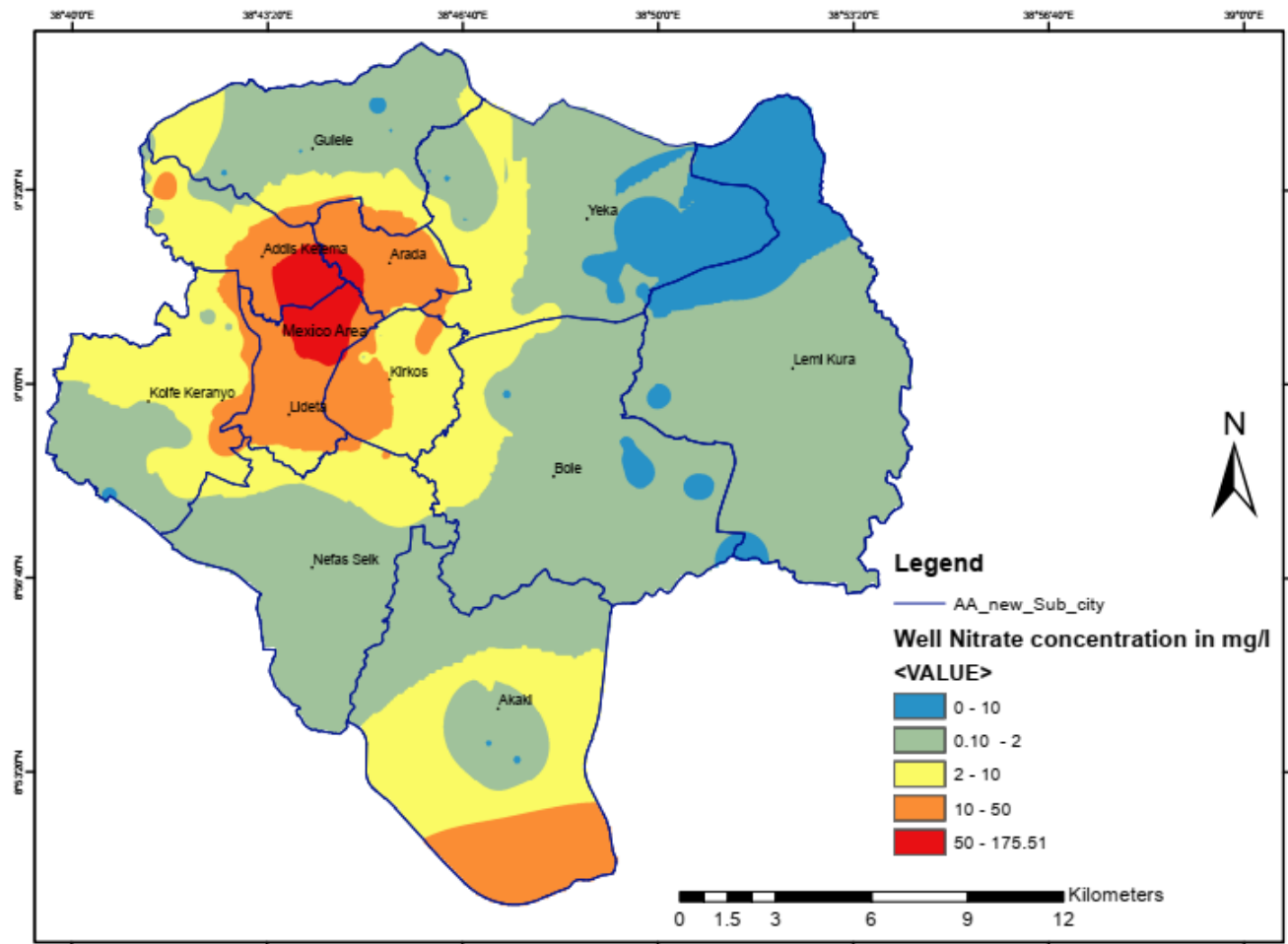


Figure 5. Addis Ababa city groundwater Nitrate concentration map (Data source: - AAWSA)

Table 4 Drinking water quality guideline/standards

S.no	Parameter	Unit	WHO standard	Ethiopia drinking water standard
1	Turbidity NTU	NTU	5	<5
2	PH		6.5-8	6.5-8.5
3	Total dissolved solid (TDS)	mg/l	600	1000
4	Electrical conductivity (EC)	$\mu\text{S/cm}$	1400	1400
5	Total Alkalinity as $\text{CaCO}_3$	mg/l	500	200
6	Total Hardness as $\text{CaCO}_3$	mg/l	300	300
7	Calcium Hardness as $\text{CaCO}_3$	mg/l	300	300
8	Magnesium Hardness as $\text{CaCO}_3$	mg/l	300	300
9	Ammonia as N	mg/l	1.5	1.5
10	Nitrite as N	mg/l	1	1
11	Nitrate as N	mg/l	11	11
12	Sulfate as $\text{SO}_4$	mg/l	250	250
13	Phosphate as $\text{PO}_4$	mg/l	0.54	–
14	Fluoride as F	mg/l	1.5	1.5
15	Total Iron as Fe	mg/l	0.3	0.3
16	Silica as $\text{SiO}_2$	mg/l	0.1	0.1
17	Chloride as Cl	mg/l	250	250
18	Bicarbonates alkalinity as $\text{HCO}_3$	mg/l	1000	–

### 3.5 Well Selection Criteria`

The purpose of selecting wells is to get primary data about the groundwater quality of the area. The sample test Wells categorized into three. Well one is Marcato around Teklehaimanot which has a high concentration of nitrate more than the WHO acceptable standard according to the secondary data map. The area has no sewer coverage. Well two is at Zenebework Manaharia the area which has a medium concentration of nitrate according to the secondary data map. In the area, the sewer collection system is partially covered. Well, there is at Jemo-1 the area which has a low concentration of nitrate according to the secondary data map and the area where all toilets are connected to the modern sewer line. Judgment sampling is the primary representative sampling approach used for groundwater assessment in the selection of monitoring wells (EPA, 1995).

The sewerage coverage is determined by AAWSA bill data registered sewerage customers and by using the sewerage line coverage map.

*Table 5. Sample collection well location*

Well code	Area name	location		Sewerage coverage
		Longitude	Latitude	
Well-1	Teklehaimanot	9.024936	38.741578	no coverage
Well-2	Zenebework	8.98195	38.706255	partially covered
Well-3	Jemo 1	8.954907	38.711161	fully covered

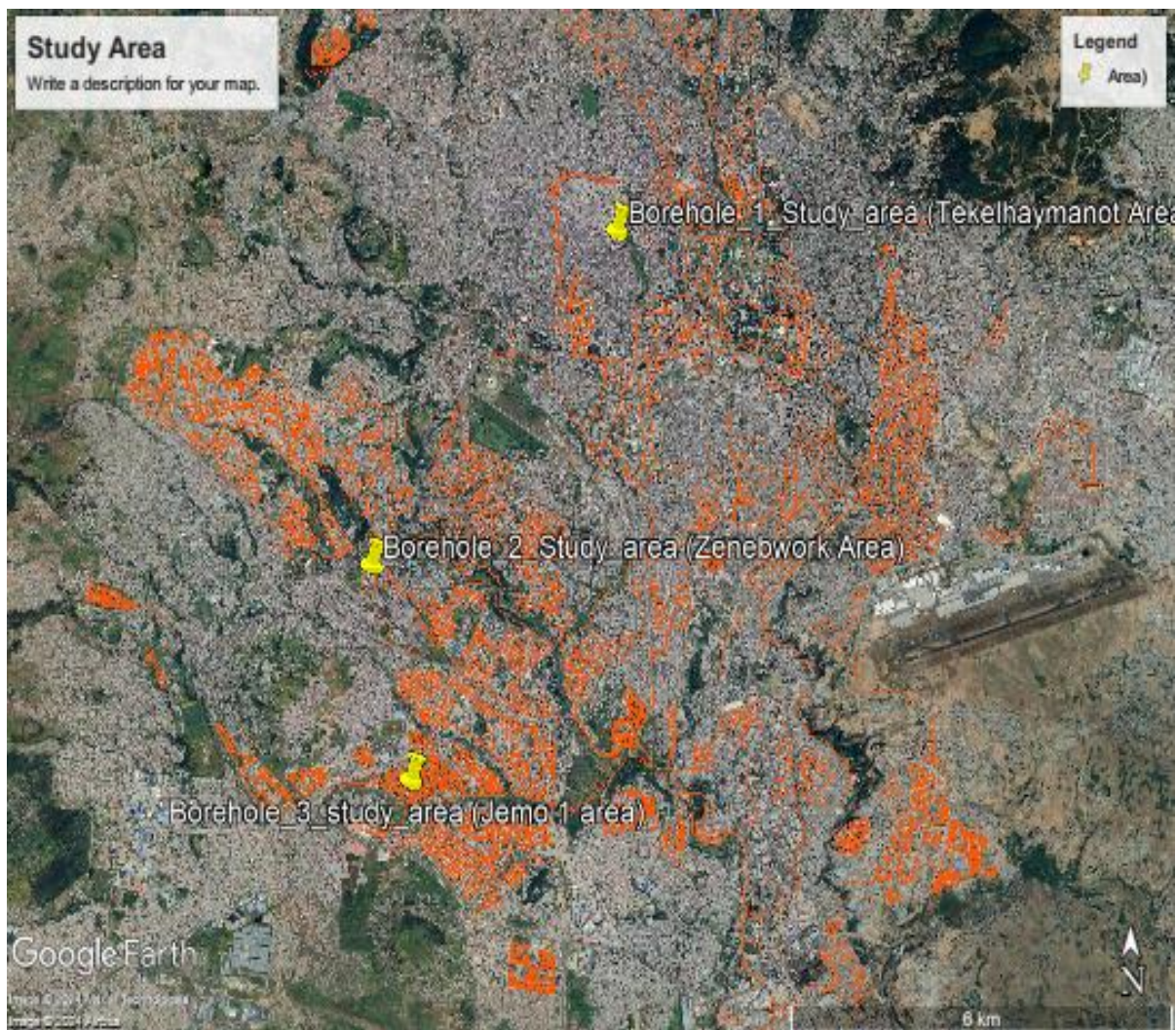


Figure 6. Groundwater sample-taking well area

### 3.6 Quality Control and Assurance

Each sample was collected within 2 Liter polyethylene clean plastic bottles by washing distilled water and rinsed by using well water and transported to the AAWSA laboratory within one hour and stored at 4<sup>0</sup>C temperature. The most common field tests for water quality purposes are temperature, pH, DO, conductivity, salinity, and CO<sub>2</sub>. Many other water quality parameters can be analyzed in the lab after the samples have been transported to the lab with or without the preservation of samples (Chunlong Z, 2007). The time elapsing between the collection of samples and processing within the laboratory (known as the holding time) should not exceed 24 hours for most microbiological testing. If samples cannot be transported to the laboratory within one hour, they should be maintained at an appropriate temperature. This helps minimize the changes that may occur in the water sample during holding time (Path West, 2021).



Figure 7. Teklehaimanot, Moha Pepsi factory sample collection

Teklehaimanot Moha Pepsi factory compound has two wells. I took the water sample from the shallow well a depth is around 160 meters.



Figure 8. Around Zenebework, Manahariya Well sample collection

Zenebework well, locate behind the Manahariya area, is an AAWSA facility with a depth of 378-meter. It supplies water to the surrounding households, with daily production capacity of  $950\text{m}^3$ .



*Figure 9. Jemo-1 Well sample collection (site-one)*

Jemo- 1 well is located on the right side of the road to Lebu's. This well, known as site-1, is owned by AAWSA and has a depth of 184-meters. It supplies water to the surrounding households, with daily production capacity of 1500m<sup>3</sup>.

### 3.7 Field Test

At the field, temperature (°C) is measured using a water-immersible thermometer road. The other physical parameters such as electrical conductivity (EC), Hydrogen ion (pH) and Total dissolved solids TDS (mg/l) are measured in the lab by Hanna Ph.ISE.EC instrument.



Figure 10. Temperature measurement at Teklehaimanot Pepsi well

### 3.8 Laboratory Analysis of Water Sample

The three water samples will be tested in the laboratory to get the chemical composition of the sample mainly the nitrate parameter is needed. In the AAWSA laboratory, the well sample water hardness was measured by using the chloride titration method in AAWSA laboratory. Turbidity is measured by an instrument called Hach 2100 AN Turbidimeter, the other parameter was measured by Hach DR 5000 UV spectrophotometer.



Figure 11. HACH DR 5000 UV- Spectrophotometer at AAWSA laboratory

The factory calibration can be adjusted slightly with the standard adjustment option so that the instrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments (Hach, 2015).

A standard method for the examination of water and wastewater APHA, 2005, 21<sup>st</sup> edition will be used. This method is adopted and used by AAWSA. AAWSA has also embraced the WHO drinking water standard. Therefore, this research physicochemical analysis done based on it.



Hach 2100 AN Turbidimeter

Hanna Ph.ISE.EC

*Figure 12. Hach 2100 AN Turbidimeter and Hanna Ph.ISE.EC instruments*

### 3.8.1 Calibration of the DR 5000 UV- Spectrophotometer

According to HACH, 2005 a calibration table is created by entering the concentration values of the standard solutions and then measuring the solutions to determine the corresponding absorbance values. The absorbance values are plotted against the concentrations of the standard solutions and the calibration curve is displayed as a graph.

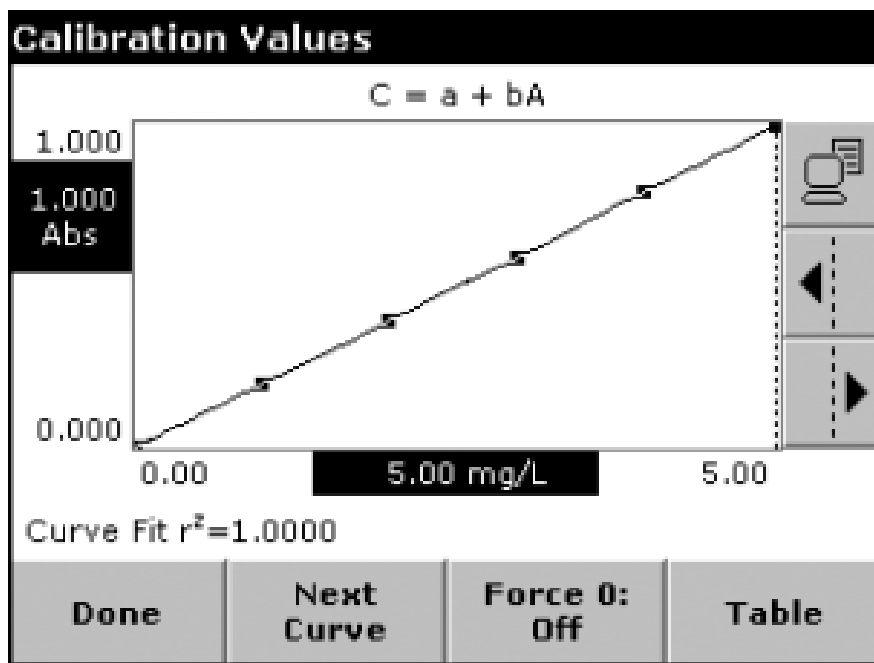


Figure 13. Calibration curve of HACH DR UV- Spectrophotometer (Source: HACH, 2015)

The factory calibration can be adjusted slightly with the standard adjustment option so that the instrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments (HACH, 2015).

### 3.9 Pit Latrines Data Collection

The pit latrines data is collected from around the selected wells in 100-meter diameter. The density of pit latrines within a 100-m radius was significantly correlated with nitrate and chloride levels but not with thermotolerant coliforms (Jim A. et al., 2012). In this research, the pit latrine area selected a 100-meter radius around the well which has a high nitrate concentration according to WHO standard after laboratory analysis of the well sample. The data collection is done by observation questionnaire.

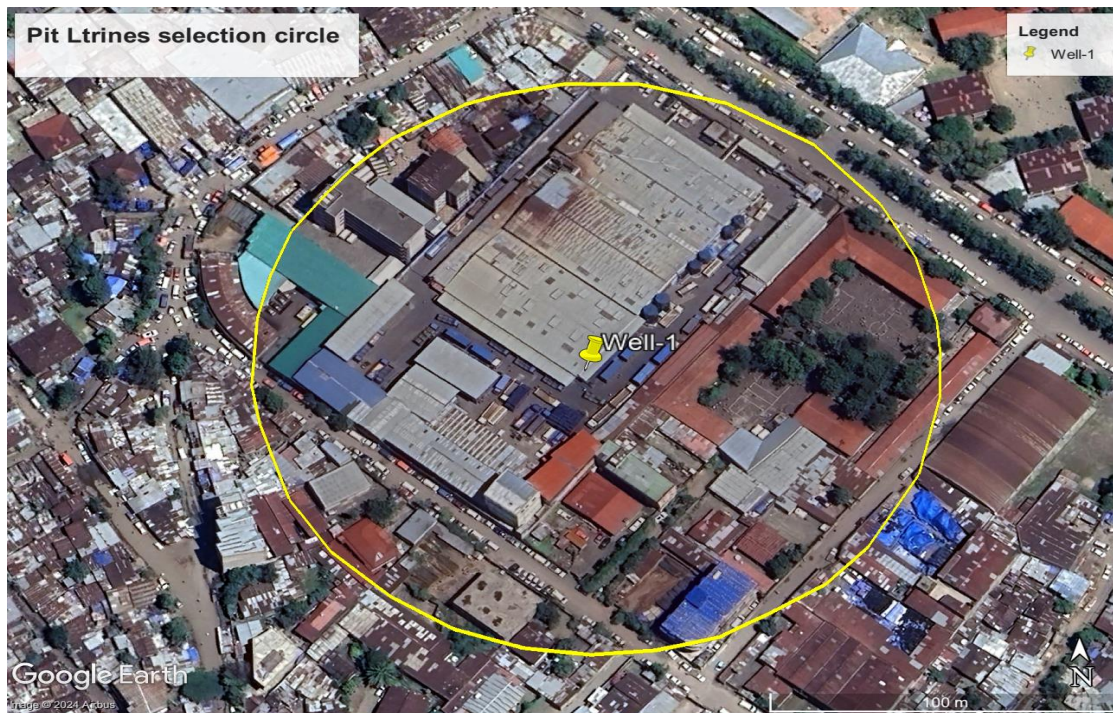


Figure 14. Around Moha- Pepsi factory pit latrines area

### 3.10 Waste Water Calculation

The water consumption determines the waste production of the household, so the water consumption data is collected from AAWSA bill data.

Mian (2020) says 75 to 80% of accounted water supplied is considered as the quantity of sewage produced.

**Waste production = 80% \* water consumption ..... 3.1**

According to the household practice at the area all 80% waste not flow to the pit latrines some amount flows to the drainage. Based on the data in the figure below, it appears that 24% of water usage is attributed to toilets.

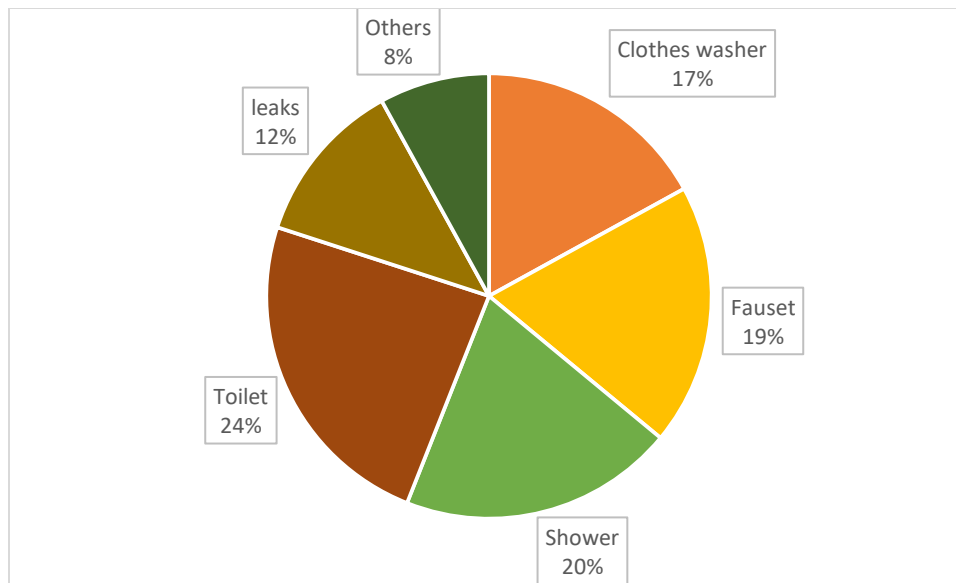


Figure 15. Household water consumptions (Source: - Water Foundation, Residential End Uses of Water, Version 2. 2016)

**Toilet water consumption (Calculated waste) = 24% \* Total water consumption ..... 3.2**

Toilet water consumption relates with waste production to fill a toilet. So, the waste production calculates by using equation 3.2.

### 3.11 Software

Arc GIS and Google Earth are the basic software to read the area map and delineate the area. The method used for correlation processes is Spearman’s rank correlation, Statgraphics XVII-X64 software for Pearson’s product-moment correlation and speared Excel sheet. I used the phone’s maps application to collect the coordinates.

#### 3.11.1 Spearman Correlation

It is a coefficient that expresses the strength and direction of the relationship between two phenomena only. The relationship will be either negative or positive on the one hand, and weak or strong on the other hand. Spearman is used for the correlation of ranks if we assume that the variable A has the rank (RA) and that the variable B has the rank (RB), and assume that (d) represents the difference between the two ranks, meaning (d = RA – RB). (Khawla A, 2011).

Table 6. The types of correlation, the direction of the relationship, and the diffusion models for each type (Source: Khawla A. 2011)

value of correlation	the meaning
----------------------	-------------

<b>coefficient</b>	
+1	Completely positive correlation
From 0.70- 0.99	Strong positive association
From 0.50- 0.69	Avarage positive correlation
From 0.01- 0.49	weak positive correlation
0	Not a positive relationship

### **Formula**

$$r_{sp} = 1 - \frac{6(\sum d^2)}{n(n^2-1)} \dots\dots\dots 3.3$$

$r_{sp}$  = Spearman's rank correlation coefficient

d = difference between the two ranks of each observation

n = number of observations

## 4. RESULTS AND DISCUSSION

### 4.1 Groundwater Quality Analysis

Table 7. Physiochemical analysis result

S.no	Parameter	Unit	Teklehaimanot	Zenebework	Jemo 1
1	Turbidity NTU	NTU	0.674	0.094	0.07
2	PH		7.28	7.18	6.88
3	Total dissolved solid (TDS)	mg/l	528	179	306
4	Electrical conductivity (EC)	μS/cm	1,058	358	612
5	Total Alkalinity as CaCO <sub>3</sub>	mg/l	240	160	244
6	Total Hardness as CaCO <sub>3</sub>	mg/l	538	210	344
7	Calcium Hardness as CaCO <sub>3</sub>	mg/l	400	154	256
8	Magnesium Hardness as CaCO <sub>3</sub>	mg/l	138	56	88
9	Ammonia as N	mg/l	0.36	ND	0.03
10	Nitrite as N	mg/l	0.01	0.008	0.008
11	Nitrate as N	mg/l	13.5	1.8	2.6
12	Sulfate as SO <sub>4</sub>	mg/l	53	2	37
13	Phosphate as PO <sub>4</sub>	mg/l	0.98	1.43	1.21
14	Fluoride as F	mg/l	0.31	0.6	0.46
15	Total Iron as Fe	mg/l	0.2	0.02	0.02
16	Silica as SiO <sub>2</sub>	mg/l	38	57	62
17	Chloride as Cl	mg/l	60	2	5
18	Bicarbonates alkalinity as HCO <sub>3</sub>	mg/l	293	195	298
19	Temperature	°C	23	24	25

#### 4.1.1 Physical Parameter

##### 4.1.1.1 Temperature

Water temperature expresses how warm or cold the water is. It is defined as the amount of average kinetic energy in water molecules and is measured in degrees Fahrenheit (F) or Celsius (C) (EPA, 2021).

The temperature results from the three wells are as follows: Teklehaimanot (23°C), Zenebework (24°C), and Jemo-1 (25°C). All values are below the WHO standard of 30°C.

#### *4.1.1.2 Electrical Conductivity (EC)*

Conductivity is a measure of the ability of water to conduct an electrical current, therefore conductivity is related to the ionic content of the water (EPA, 2014).

The Electrical Conductivity (EC) results for the three wells are as follows: Teklehaimanot well (1,058  $\mu\text{S}/\text{cm}$ ), The Zenebework well (358  $\mu\text{S}/\text{cm}$ ), Jemo-1 well (612  $\mu\text{S}/\text{cm}$ ). All results are below the WHO standard of (1400  $\mu\text{S}/\text{cm}$ ).

High conductivity is not necessarily a cause for concern due to its lack of direct health impacts. However, dissolved ionizable solids may cause frustrating water hardness or alkalinity and therefore impact consumer satisfaction (Sarah, 2020).

#### *4.1.1.3 Total Dissolved Solid (TDS)*

Total Dissolved Solids (TDS) is a measure of the sum of all inorganic and organic substances in a liquid in molecular, ionized, or micro-granular colloidal suspended form. The solids must be small enough to survive filtration through a sieve the size of two micrometers (IC Controls, 2014).

The TDS results for the three wells are as follows: Teklehaimanot well (528 mg/l), Zenebework well (179mg/l) and for Jemo-1 well (306 mg/l). All TDS results are below the WHO standard of (600 mg/l). The Teklehaimanot well has the highest TDS value among the three.

#### *4.1.1.4 Turbidity*

Turbidity refers to how clear a liquid is. High turbidity means that the liquid is not very clear; low turbidity means that the liquid is clear. Turbidity is caused by solid particles being suspended in a liquid. These particles scatter light, which can give the liquid a cloudy or murky appearance. Turbidity is often used to test water quality heuristically. Greater turbidity typically implies lower quality (AOS treatment solution, 2018).

Turbidity is measured using an instrument called the Hach 2100 AN Turbidimeter. The turbidity of the Teklehaimanot well is 0.674 NTU, which is higher than the results for the Zenebework well (0.094) NTU and the Jemo-1 well (0.07) NTU. All results are below the WHO standard limit of 5 NTU.

## 4.1.2 Chemical Parameters

### 4.1.2.1 Hydrogen Ion Concentration (pH)

The water pH is an important indicator of chemical, physical, and biological changes in a water body and plays a critical role in chemical processes in natural waters. pH values are on a scale from 0 to 14, with 7.0 considered neutral. Figure 1 shows typical pH values of common liquids. Solutions with a pH below 7.0 are considered acidic, and those with a pH above 7.0 are considered basic. The pH scale is logarithmic, meaning that every one-unit change in pH represents a ten-fold change in acidity. In other words, pH 6.0 is ten times more acidic than pH 7.0; pH 5.0 is one hundred times more acidic than pH 7.0 (EPA, 2021).

The pH values are as follows: Teklehaimanot well (7.28), Zenebework well (7.18), and Jemo-1 well (6.88). All results fall within the WHO standard range 6.5 to 8. The Teklehaimanot well is slightly acidic, the Zenebework well's pH is near neutral, and the Jemo-1 site is slightly basic.

### 4.1.2.2 Alkalinity

Alkalinity indicates how much acid a solution can absorb without changing the pH. It is the buffering capacity of a solution (water). Therefore, solutions with low alkalinity have a lower buffering capacity and change pH rather quickly when something acidic is added. On the contrary, high alkalinity water samples have a higher buffering capacity and are less affected when something acidic is added (Uruga Research, 2024).

In this lab test calcium carbonate ( $\text{CaCO}_3$ ) and bicarbonate ( $\text{HCO}_3$ ) alkalinity were tested.

#### 4.1.2.2.1 Total Alkalinity as $\text{CaCO}_3$

The laboratory results show that the Teklehaimanot well has a calcium carbonate ( $\text{CaCO}_3$ ) concentration of 240 mg/l, the Zenebework well has 160 mg/l, and the Jemo-1 well has 244 mg/l. All results are below the WHO drinking water standard of 500 mg/l. The Jemo-1 well has a higher calcium carbonate concentration than the other wells.

#### 4.1.2.2.2 Bicarbonates Alkalinity as $\text{HCO}_3$

Bicarbonate alkalinity is the most prominent form of alkalinity in water. The bicarbonate ion chemical formula is  $\text{HCO}_3$ . The structure of bicarbonate, the ion that causes bicarbonate alkalinity, is composed of a carbon atom in the center of the formation with three oxygen atoms attached to it. One of the oxygen atoms has a hydrogen atom bonded with it. Bicarbonate

alkalinity aids in neutralizing the acid in water, therefore helping to balance the pH (Corrosionpedia, 2024).

When examining the bicarbonate alkalinity ( $\text{HCO}_3$ ), the results are as follows: Teklehaimanot well (293 mg/l), Zenebework well (195 mg/l), and Jemo-1 well (298 mg/l), All results are below the WHO standard of 1000 mg/l.

#### 4.1.2.3 Water Hardness

Water described as “hard” contains high amounts of calcium and magnesium, which are naturally found in the Earth's crust. Total hardness is the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per liter (mg/L) (Vermont, 2024).

In this research, laboratory tests were conducted to measure Total Hardness (as  $\text{CaCO}_3$ ), Calcium Hardness (as  $\text{CaCO}_3$ ), and Magnesium Hardness (as  $\text{CaCO}_3$ ). These parameters are not related to pit latrine contamination of groundwater quality, as they occur naturally.

##### 4.1.2.3.1 Total Hardness as $\text{CaCO}_3$

The Laboratory results for Total Hardness (as  $\text{CaCO}_3$ ) are as follows: Teklehaimanot well (538 mg/l), Zenebework well (210 mg/l) and Jemo-1 well (344 mg/l). The WHO standard limit for Total Hardness (as  $\text{CaCO}_3$ ) is 300 mg/l; therefore, the Teklehaimanot well and Jemo-1 well exceeds this limit, while the Zenebework is below it.

##### 4.1.2.3.2 Calcium Hardness as $\text{CaCO}_3$

The laboratory results for Calcium Hardness (as  $\text{CaCO}_3$ ) are as follows: Teklehaimanot well (400 mg/l), Zenebework well (154 mg/l) and Jemo-1 well (256 mg/l). WHO standard limit for Calcium Hardness (as  $\text{CaCO}_3$ ) is 300 mg/l, Therefore, Calcium Hardness of the Teklehaimanot well exceeds the WHO's standard limit by 100 mg/l.

##### 4.1.2.3.3 Magnesium Hardness as $\text{CaCO}_3$

The concentration of Magnesium Hardness (as  $\text{CaCO}_3$ ) are as follows: Teklehaimanot well (138 mg/l), Zenebework well (56 mg/l), and Jemo-1 well (88 mg/l). While the WHO and AAWSA do not specify Magnesium Hardness (as  $\text{CaCO}_3$ ), the WHO standard limit for total hardness is 300 mg/l. Therefore, all results are below these standard limits.

#### 4.1.2.4 Ammonia as N

The term ammonia includes the non-ionized ( $\text{NH}_3$ ) and ionized ( $\text{NH}_4^+$ ) species. Ammonia in the environment originates from metabolic, agricultural and industrial processes and disinfection with chloramine. Ammonia contamination can also arise from cement mortar pipe linings. Ammonia in water is an indicator of possible bacterial, sewage and animal waste pollution (WHO, 2003).

The laboratory results for Ammonia (as N) are as follows: Teklehaimanot well (0.36 mg/l) and Jemo-1 well (0.03). Both concentration below the WHO standard limit 1.5 mg/l.

#### 4.1.2.5 Nitrite as N

Nitrites are a salt or ester anion of nitrous acid, which can be naturally or artificially occurring in groundwater. Nitrites come from fertilizers through run-off water, sewage, and mineral deposits. Nitrite is used in food production for the curing of meat products due to it inhibiting the growth of bacteria. Unfortunately, it can also stimulate the growth of bacteria when introduced at high levels into a body of water (H2O distributor, 2024).

The laboratory results for Nitrite (as N) are as follows: Teklehaimanot well (0.01 mg/l), Zenebework (0.008 mg/l), and Jemo-1 well (0.008 mg/l). The nitrite concentration in all three wells are below the WHO standard limit of 1 mg/l.

#### 4.1.2.6 Nitrate as N

In this research, nitrate is put as a major human waste contaminant of the groundwater. Once the nitrate reaches these aquifers, the aquifers will remain contaminated for decades, even if there is a substantial reduction in the nitrate loading of the surface (WHO, 2016).

Nitrate conversation to Nitrate as N -----  $> 4.4268 \text{ Nitrate } (\text{NO}_3^-) = 1 \text{ Nitrate as N}$

The nitrate concentration at the Teklehaimanot site, which lacks sewerage line coverage, is 58.876 mg/l, exceeding the WHO drinking water standard of 50mg/l. This indicates polluted water that cannot be used for drinking without treatment, as it poses health risks to humans. This result is relevant for locating the Pit latrine study area and aligns with the secondary data for the same location. Additionally, another study identified high nitrate concentration in the groundwater of this area.

At the partially sewer-covered Zenebework site, the nitrate concentration is 7.968 mg/l, which is below the maximum limit of the drinking water standard, indicating it is safe for consumption. In contrast, the last result from the Jemo-1 site, which is fully connected to the sewer line, shows a nitrate concentration is 11.5 mg/l, which is also considered safe for drinking.

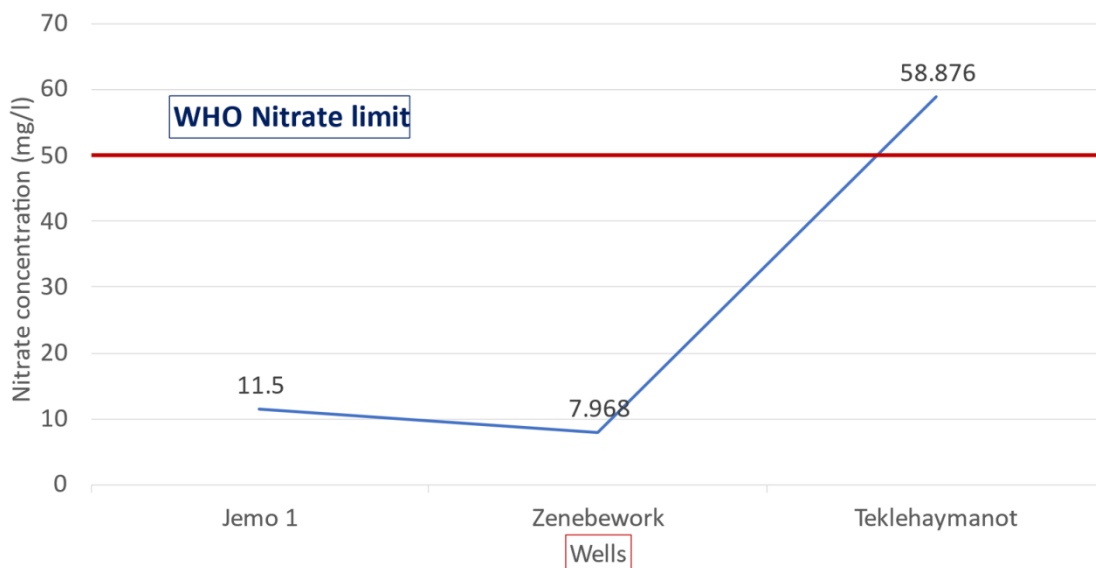


Figure 16. Wells Nitrate results relating WHO standard

AAWSA has adopted the WHO drinking water standard, which sets the nitrate concentration limit at 50 mg/l. The wells with high nitrate concentrations are not government wells or designated drinking sources; rather they are private wells. Therefore, water from these wells should be treated before use.

#### 4.1.2.7 Chloride

Chloride is a minor constituent of the earth's crust. Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff containing salt, and saline intrusion (WHO, 2011).

The chloride concentrations are as follows: Teklehaimanot well (60 mg/l), Zenebework well (2 mg/l) and Jemo well (5 mg/l). All three results are below the WHO standard limit of 250 mg/l. Chloride concentration can help correlate nitrate levels, indicating that nitrate contamination may stem from human waste. According to the Water Education Foundation (2024), nitrate contamination occurs in surface water and groundwater, leaching into the soil and subsequently into the water supply from various sources. Common culprits include irrigation water containing fertilizers, septic systems, wastewater treatment plants, dairies and natural conditions.

#### *4.1.2.8 Sulfate as SO<sub>4</sub>*

Sulfate is a substance that occurs naturally in drinking water. Health concerns regarding sulfate in drinking water have been raised because of reports that diarrhea may be associated with the ingestion of water containing high levels of sulfate. Of particular concern are groups within the general population that may be at greater risk from the laxative effects of sulfate when they experience an abrupt change from drinking water with low sulfate concentrations to drinking water with high sulfate concentrations (EPA, 2012).

The laboratory results for the three wells shows: Teklehaimanot well (53 mg/l), Zenebework well (2 mg/l), and Jemo-1 well (37 mg/l). All results are significantly lower than WHO standard limits of 250 mg/l. Furthermore, these concentrations are not related to pit latrine contamination of groundwater, as they occur naturally.

#### *4.1.2.9 Phosphate as PO<sub>4</sub>*

Fadiran et al. (2008) states that phosphates contaminate surface waters and groundwater due to natural and human-induced sources. Both surface and groundwater are naturally affected by phosphorus from atmospheric deposition, the natural breakdown of rocks and minerals, the erosion of soluble inorganic materials, the decomposition of organic matter, runoff, and sediment build-up.

The laboratory results for Phosphate (as PO<sub>4</sub>) are as follows: Teklehaimanot well (0.94 mg/l) Zenebework well (1.43 mg/l) and Jemo-1 well (1.21 mg/l). All well concentrations exceed WHO standard limit of 0.54 mg/l.

The World Health Organization (WHO), in 1980 concluded that there is no nutritional basis for the regulation of phosphorus levels in the US drinking water supplies (John D., 1990). However, to control eutrophication, USEPA makes the following recommendations: (1) total PO<sub>4</sub> – P ≤

0.05 mg/L in a stream at a point where it discharges into a lake or reservoirs, (2) total  $\text{PO}_4 - \text{P} \leq 0.1$  mg/L in streams that do not discharge directly into lakes or reservoirs, and (3) total  $\text{PO}_4 - \text{P} \leq 0.025$  mg/L for reservoirs (A.O. Fadiran et al., 1990; Mueller, 1995; Brian O., 2005).

#### *4.1.2.10 Fluoride as F*

Fluoride arises almost exclusively from fluoridation of public water supplies and industrial discharges, although it occurs naturally in quite rare instances. Past health studies have shown that the addition of fluoride to water supplies at levels above 0.6mg/l F- leads to a reduction in tooth decay in growing children and that the optimum beneficial effects were thought to occur around 1.0 mg/l. However, in light of recent international and Irish research which shows an increasing occurrence of dental fluorosis, the Forum on Fluoridation (2002) recommended the lowering of the fluoride levels in drinking water to a range of 0.6 to 0.8 mg/l, with a target of 0.7 mg/l (EPA, 2014).

The results for Fluoride (as F) are as follows: Teklehaimanot well (0.31 mg/l), Zenebework well (0.6 mg/l) and Jemo-1 well (0.46 mg/l). The concentrations of Fluoride are all below the WHO standard limit of 1.5 mg/l.

Fluoride is a common constituent of groundwater. Natural sources are connected to various types of rocks and volcanic activity. Agricultural (use of phosphatic fertilizers) and industrial activities (clays used in ceramic industries or burning of coals) also contribute to high fluoride concentrations in groundwater (R. Brunt et al., 2004). So, the source is not from pit latrine seepage.

#### *4.1.2.11 Total Iron as Fe*

Iron is an abundant metal found in the Earth's crust. It is naturally present in water but can also be present in drinking water from the use of iron coagulants or the corrosion of steel and cast-iron pipes during water distribution. Iron is an essential element in human nutrition. The WHO (WHO, 2004) states that values of up to 2 mg/l (10 times the parametric value) do not present a hazard to health. However, at levels less than 2 mg/l but above the parametric value, the color of water may turn brown, become turbid, or may deposit solids on clothes washed in the water or food cooked using water (EPA, 2014).

The laboratory results for Total Iron (as Fe) concentration in groundwater samples are as follows: Teklehaimanot well (0.2 mg/l), Zenebework well (0.02 mg/l), and Jemo-1 well (0.02 mg/l). All results exceed the WHO drinking water standard limit of 0.3 mg/l.

#### 4.1.2.12 Silica as SiO<sub>2</sub>

Silica, also known as silicon dioxide (SiO<sub>2</sub>), is an abundant, naturally occurring mineral commonly found in sand. Silica is used directly in water treatment as a filtration media, and also as an input in the manufacturing of liquid silicate solutions for corrosion control. The most common domestic use is in hydraulic fracturing well development (EPA, 2022).

The laboratory results for Silica (as SiO<sub>2</sub>) concentrations in groundwater wells are as follows: Teklehaimanot well (38 mg/l), Zenebework well (57 mg/l), and Jemo-1 well (62 mg/l).

In the United States silica is not regulated as a primary or secondary contaminant under the Safe Drinking Water Act. While often screened as part of source water characterization studies, monitoring of silica is required only for those utilities adding silicates to their water as a corrosion control strategy, as part of compliance with the Lead and Copper Rule. No other regulatory or monitoring requirements relating to silica in drinking water could be found, including the World Health Organization, the United Kingdom Drinking Water Inspectorate, the European Drinking Water Directive, or the Guidelines for Canadian Drinking Water Quality (Stephen et al., 2014).

The results indicate that silica concentration is below the WHO drinking water standard limit of 0.1 mg/l. Additionally, Silica concentration is not related to pit latrine seepage contaminants.

## 4.2 Nitrate Relation with Other Parameters

The concentration of Nitrate is related to parameters that have a direct or indirect relation with human wastewater pollution to groundwater. Ph, Turbidity, Total dissolved solids (TDS), Nitrite and Chloride have a relation with human waste. The other tested parameters are related to fertilizer, earth crest minerals and rocks.

Chloride is a useful diagnostic tool that we use in fingerprinting nitrate sources (Dennis, 2006). To determine whether contamination could be ascribed to human waste the relationship between the chloride and nitrate concentrations was determined using Pearson's product-moment correlation coefficient ( $r$ ) (Girmay Kahssay et al., 2010).

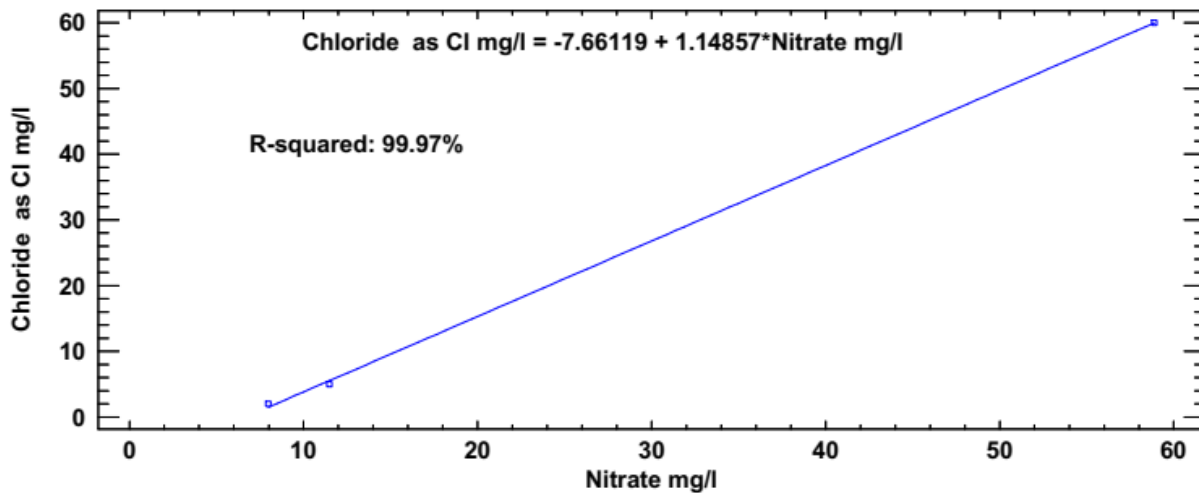


Figure 17. Nitrate and Chloride as Cl correlation

The nitrate and chloride laboratory results show when nitrate increases chloride also increases. using Pearson's product-moment correlation, the analysis is done. From the graph, the r value becomes 0.99 indicating they have a very strong correlation. We can conclude that the nitrate concentration is because of human waste.

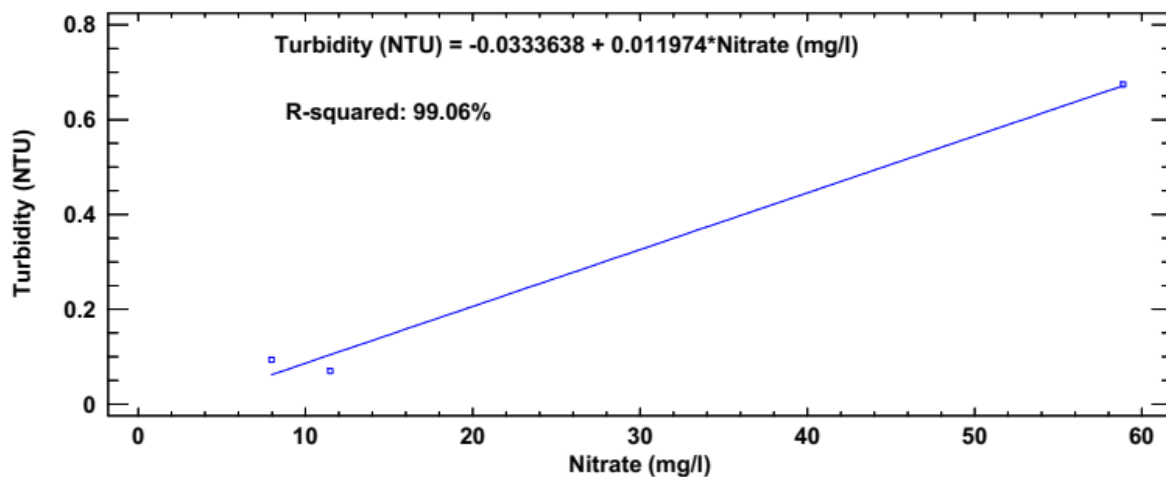


Figure 18. Nitrate and Turbidity correlation

The correlation of nitrate correlation is done for comparison purposes. It is helpful to know the clearness of the sample water.

Correlation between Nitrate and Turbidity shows a Positive value observed with  $R^2 = 99.06$  with a 99% mean prediction interval. The turbidity of the well water relates to the nitrate concentration. According to the turbidity definition, the water is not clean in high nitrate concentration occurs.

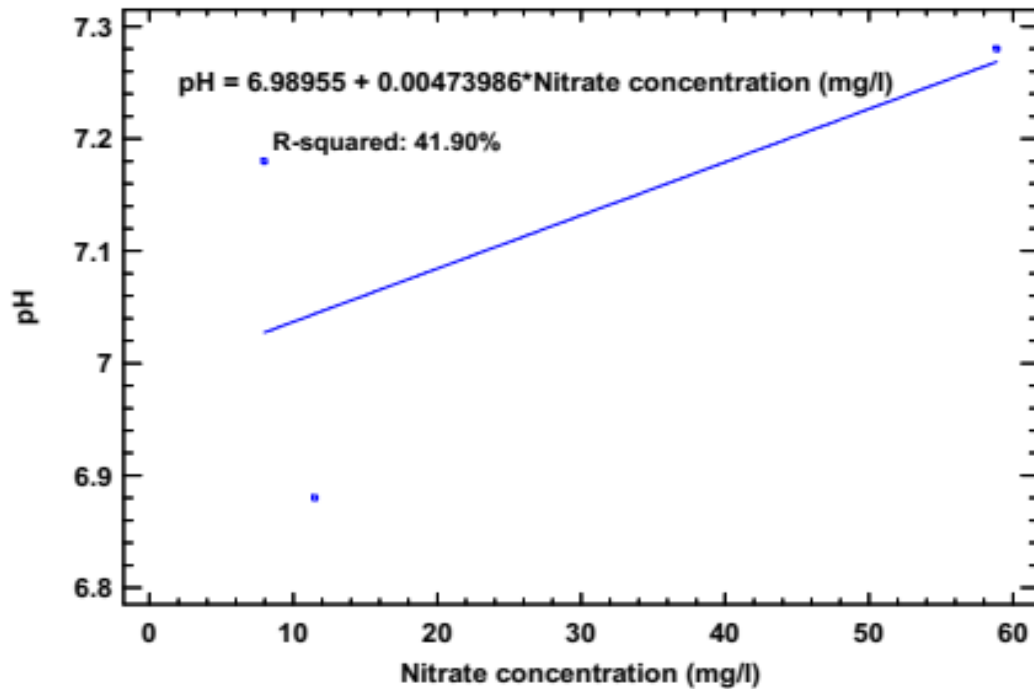


Figure 19. Nitrate and pH of the three wells

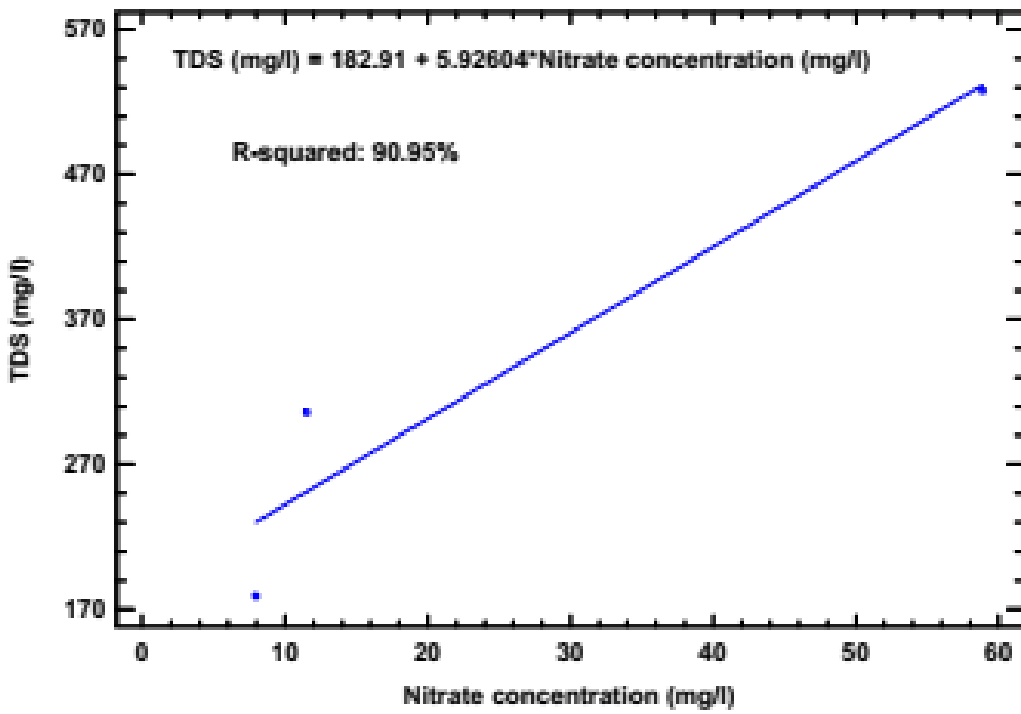


Figure 20. Nitrate and TDS correlation of three wells

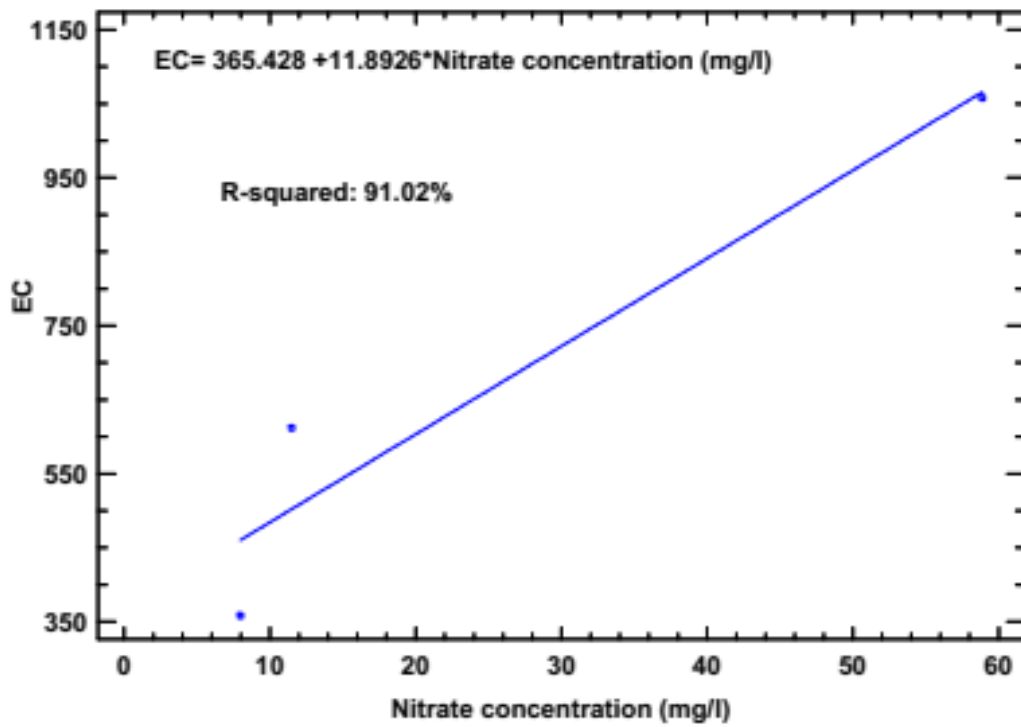


Figure 21. Nitrate and Electrical conductivity (EC) correlation of the three wells

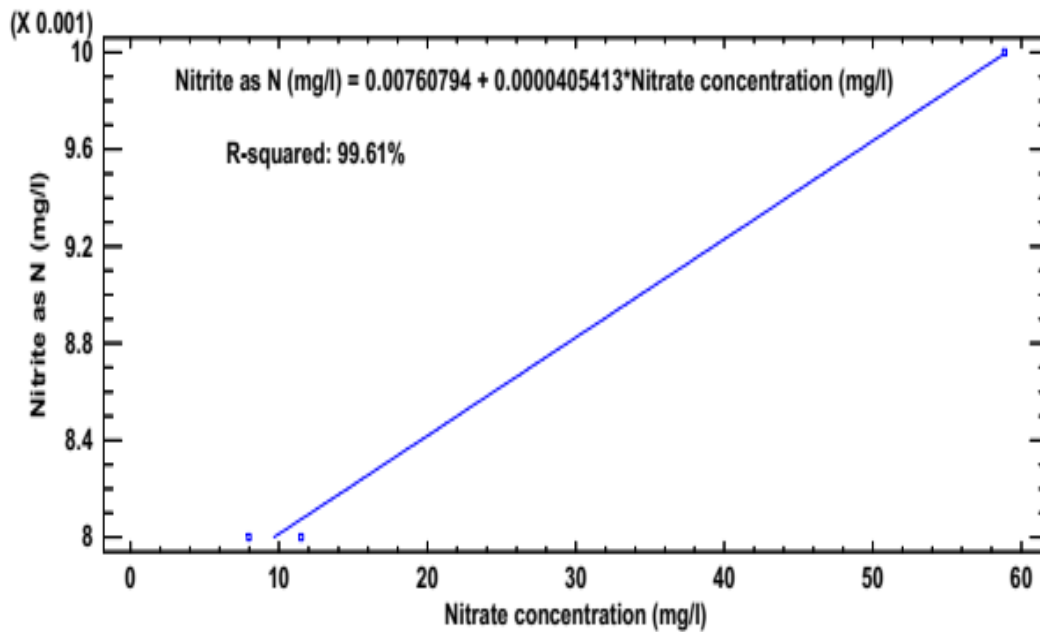


Figure 22. Nitrate and Nitrite correlation of three wells

The correlation result of the other parameter has meaning for the relation of nitrate concentration. The correlation R-squared result for pH and nitrate became (41.09%) low correlation, for TDS and Nitrate (90.95%) strong correlation, for Electrical conductivity (EC) (91.02%) strong correlation and for Nitrite and Nitrate (99.61% high strong correlation indicates.

#### 4.3 Sewerage Coverage Relation to Groundwater Quality

The laboratory result shows that the three areas are classified as having no sewerage coverage, partially covered, and fully covered areas.

Table 8. Sewerage coverage with groundwater quality

Area name	Sewerage coverage status	Nitrate concentration (mg/l)	Chloride as Cl concentration (mg/l)
<b>Teklehaimanot</b>	no coverage	58.876	60
<b>Zenebework</b>	partially covered	7.968	2
<b>Jemo 1</b>	fully covered	11.5	5

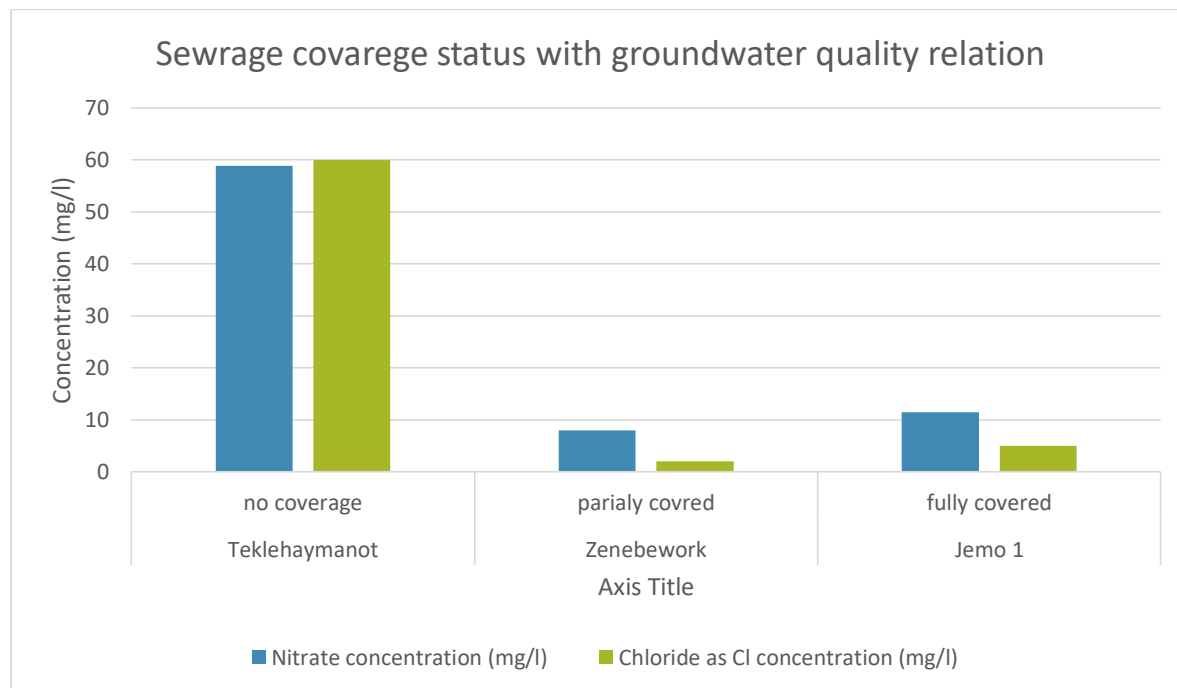


Figure 23. Relationship of sewerage coverage and groundwater quality

The groundwater quality results for the Teklehaimanot area show a high nitrate concentration, indicating the impact of sewerage coverage on groundwater quality. In the other two areas, the concentrations are below WHO standard.

when we comparing the partially covered area with the fully covered area, the results indicate that nitrate and chloride concentrations are higher in the fully covered area. This may be related to the year the settlement at Zenebework around Manahariya is not older, Additionally, there is a river near 100-meter distance from Jemo-1 well, in case the river seepage effect has on it. Further studies are needed to investigate these results.

## 4.4 Pit Latrines

### 4.4.1 Pit Latrines Distribution

The data on pit latrines was collected through observation and questionnaire method in April. Eighteen people participated in the questionnaire, including 10 men and 8 women. The age distribution participants were as follows: 7 individuals aged 18- 35 years old, 7 individuals aged 36- 60 years, and 3 individuals over 60 years old. The area is densely populated, with most households in the kebele using communal toilets. There are several institutions nearby including a Woreda office, a School, a garage, a store and an under-construction building. All but one participant were willing to complete questionnaire.

Since the study area is older, some residents are new to the place and could not provide detailed information. The population size is population size is estimated to be over 295 people, excluding institutional residents. There are 18 toilets around the well, of which 3 are communal and the others are private pit latrines. Eight of them have only toilet seats and do not have a proper pit latrine or septic tank; instead, they are connected to a drainage system that flows to a river 200 meters away.

Table 9. Pit latrine location and condition

Pit latrines code	Location		Type of block	House hold size (Person )	Water customer contract number	category of toilet	service type of the toilet	Types of pit latrines	Constr uction year	Last clean day	Interval of cleand day	other explanation
	Latitude	Longitude										
PT1	9.02582	38.74155	Residential	91	316599, 32387, 327040, 130730, 136951	Pit latrine	Communal shared	Vantelated Pit latrine	2013	Nov 2023	6 month	
PT2	9.0257	38.74133	Residential	8	137042	Pit latrine	Private	Ordinary Pit latrine	2001	Sep 2022	2 year	
PT3	9.02513	38.74089	Commercial		51502	Pit latrine	Private	Vantelated Pit latrine	2011	Dec 2020	4 year	
PT4	9.02468	38.74072	Residential	125	325282, 322752, 329120, 311417, 129259, 130451, 327314.	Pit latrine	Communal shared	Vantelated Pit latrine	1995	Jan 2024	1 year	
PT5	9.02447	38.74108	Institution	3	42996	Only sit	Private					Connected to drainage line
PT6	9.02405	38.74135	Residential	8	306334	Only sit	Private					Connected to drainage line
PT7	9.02409	38.74154	Residential	7	30410	Only sit	Private					Connected to drainage line
PT8	9.02505	38.74264	Institution (school)	-	76103	Pit latrine	Communal shared	Vantelated Pit latrine	1948	Mar 2024	2 year	
PT9	9.0245	38.74224	Institution	-	128246	Pit latrine	Private	Vantelated Pit latrine	2001	Not known		
PT10	9.02429	38.74207	Residential	5	39588	Only sit						Connected to drainage line
PT11	9.02423	38.74176	Commercial	5	39456	Only sit						Connected to drainage line
PT12	9.02443	38.7416	Residential	14	67728	Pit latrine	Private	Vantelated Pit latrine	1995	Dec 2023	not known	
PT13	9.0246	38.74184	Residential	5	46423							no information giving person
PT14	9.02458	38.74183	Residential	9	121279	Only sit						Connected to drainage line
PT15	9.02541	38.74122	Institution (Ledeta wreda 5 office)	-	139961	Pit latrine	Communal shared	Vantelated Pit latrine	2001	Dec 2023	not known	
PT16	9.02548	38.74085	Institution (Green light automotive)	-	322243	Pit latrine	Private	Vantelated Pit latrine	2008	no removed		No detail information
PT17	9.02415	38.74185	Commercial	-	34779	Only sit	Private					Connected to drainage line
PT18	9.02449	38.74192	Residential	15	136674	Only sit	Private					Connected to drainage line

Pit latrines code PT-3, PT-5, PT-6, PT-7, PT-9, PT-10, PT-14, PT-16 and PT-18 are water flush. PT-1, PT-2, PT-4, PT-8, PT-11, PT-12, PT-15 and PT-17 uses pour flush. Pit latrine PT-13 compound no one eager to give information.

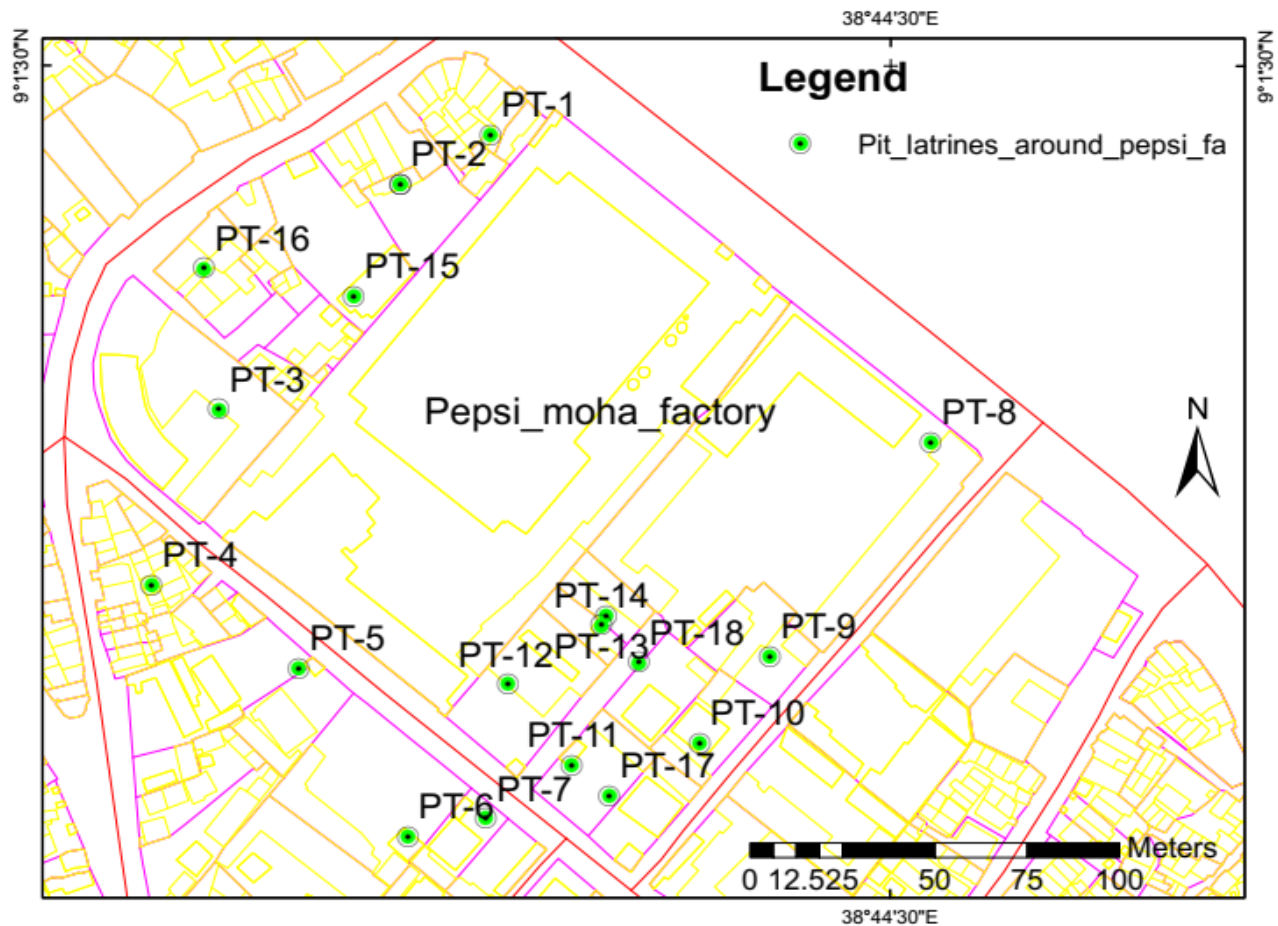


Figure 24. Pit Latrines location map

Pit latrines were selected within a 100-meter radius of the Teklehaimanot Pepsi factory well. There are no pit latrines on the northeast side of the well due to the presence of a road. Most pit latrines are located on the south side, with 8 pit latrines attached to the Pepsi factory fence. The closest pit latrine has a higher radius of influence than the other. The nearest distance from the pit latrines to the Teklehaimanot Pepsi well is 32 meters.

#### 4.4.2 Communal Shared Pit Latrines

##### 4.4.2.1 PT-1 Communal Pit Latrine

The pit latrines around the Teklehaimanot Pepsi factory include two communal shared pit latrines, excluding the toilets at the school and the Woreda office. These communal toilets serve the surrounding community. The first communal shared pit latrine is designated as PT-1. It is a ventilated improved pit latrine with a wooden slab cover, serving 12 households. On average, each household contains about 8 people, resulting in a total population of 91 people in this densely populated area. The community has five water meters.

The pit latrine was reconstructed at 2013 EC with the assistance of the Moha Pepsi factory, as the previous pit latrine was old and inadequate, negatively impacting the Pepsi factory compound according to local residents. This suggests that the older latrine may have experienced significant seepage.



Figure 25. Communal toilet, PT1

##### 4.4.2.2 PT-4 Communal Pit Latrine

The second pit latrine is a simple ventilated improved pit latrine and functions as poor flush toilet, serving 25 households. On average, each household consists of 5 people, resulting in a total population of 125 people, which is denser than the PT-1 pit latrine area. The community has 10 water meters.

This pit latrine is older, having been constructed in 1995 EC. It features 4 seats partitioned by a metal sheet, and the seats are distributed in such a way that they can be locked with a key.



Figure 26. Communal toilet, PT-4

Table 10. Communal shared Pit Latrines, water meter contract number and condition

Pit latrines code	Location		Type of block	House hold size (Person)	Water customer Contract Number	Category of toilet	Toilet service for	Types of pit latrines	Constructed year (EC)	Constructed material type	size of Pit latrine (meter)			Duration of cleaning day	last cleand day
	Latitude	Longitude									Residential	depth	Width		
PT1	9.02582	38.74155	Residential	91	316599, 32387, 327040, 130730, 136951	Pit latrine	Communal shared	Vantelated Pit latrine	2013	concreat/wodden cover	3	3	3.5	6 month	Nov 2023
PT4	9.02468	38.74072	Residential	125	325282, 322752, 329120, 311417, 129259, 130451, 327314, 324159, 320738, 136674	Pit latrine	Communal shared	Vantelated Pit latrine	1995	concreat	3	1.5	3.5	1 year	Jan 2024

#### 4.4.3 Drainage Connected Toilet Sit

In the study area, some houses have toilets connected directly to the drainage system. They use concrete drainage lines to remove waste, which flows into a river located 200 meters from the pit

latrines. However, drainage lines are not effective for transporting human waste because concrete pipes are prone to corrosion to sewage, leading to waste seepage into the ground. This issue is exacerbated by the lack of effective oversight from the environmental protection office.

In Addis Ababa, this practice is prevalent, as evidenced by the water quality of the city's rivers. Tamiru Alemayehu (2002) indicates that the rivers in the city are severely polluted due to the discharging of solid and liquid wastes from industries, residential areas, and commercial institutions.



Water Flush toilet

Manhole connection to the drainage

Figure 27. The toilet is connected to the drainage and connection manhole

Table 11. Toilet connected to drainage line

Pit latrines code	Location		Type of block	Water customer contract number	Discription
	Latitude	Longitude			
PT5	9.024472	38.741083	Institution	42996	Connected to drainage line
PT6	9.024046	38.741352	Residential	306334	Connected to drainage line
PT7	9.024092	38.741544	Residential	30410	Connected to drainage line
PT10	9.024285	38.74207	Residential	39588	Connected to drainage line
PT11	9.024227	38.741755	Commercial	39456	Connected to drainage line
PT14	9.024582	38.741829	Residential	121279	Connected to drainage line
PT17	9.024151	38.741848	Commercial	34779	Connected to drainage line
PT18	9.024488	38.74192	Residential	136674	Connected to drainage line



Figure 28. Toilet-connected drainage interring to the river

#### 4.4.4 Pit Latrines Analysis

The analysis of pit latrines focuses on correlating their age with the presence of unremoved waste (seepage). Data was collected through a questionnaire and billing records. The age of the pit latrines can be obtained directly, but determining the amount of unremoved waste requires knowledge of the waste removal frequently.

To ascertain the waste removal duration, the dates of the last and the previous removals are necessary. Participants in the questionnaire can provide the date of the last removal and the frequency of waste removal. To calculate the date of the previous removal, simply add the duration of the last removal period to the date of the last removal.

**The previous removed day = Last removal day + Waste water removal duration .....4.1**

After getting the previous removed day we can calculate the water consumption of each household according to the water meter reading from the bill data.

**Water consumption = Last removal day reading - Previous removed day reading.....4.2**

According to the 3.1 equation the wastewater flow can be calculated by taking 80% of the water consumption.

The pit latrines were cleaned when they became full. So, it depends on the volume of the pit latrines. The volume of the pit latrines is calculated by getting the width length and depth of the pit latrines. Finally, we can get the not-removed wastewater by subtracting the volume of the pit latrines from the calculated wastewater.

**Not removed waste water = Calculated waste – Volume of pit latrines .....4.3**

Not removed wastewater is considered seepage because the pit latrines should fill as its volume.

The 5-pit latrines PL1, PL2, PL3, PL4, and PL8 were selected because they have full information about the duration of waste removal time.

*Table 12. Water consumption and waste water calculation*

Pit latrines code	Construction year	Age of pit latrine	Waste removal by vacume truck duration	Water consumption interval	Total consumption (m <sup>3</sup> )	Toilet water consumption (Calculated waste) (m <sup>3</sup> )	Pit Latrine volume (m <sup>3</sup> )	Not removed waste (seepage) m <sup>3</sup>
					A	A*24% = B		
PT1	2013	3	6 month	Jan/2023-Nov/2023	237	57	32	25
PT2	2001	15	2 year	sep/2020-sep/2022	249	60	18	42
PT3	2011	5	4 year	Dec2017-Dec/2020	333	80	24	56
PT4	1995	21	1 year	Jan/2023- Jan/2024	525	126	16	110
PT8	1948	68	2 year	Mar/2022-Mar/2024	1745	419	72	347

In this result not removed waste (seepage) for PT-1 (25 m<sup>3</sup>), PT-2 (42 m<sup>3</sup>), PT-3 (56 m<sup>3</sup>), PT-4 (110 m<sup>3</sup>) and PT- 8 (347 m<sup>3</sup>).

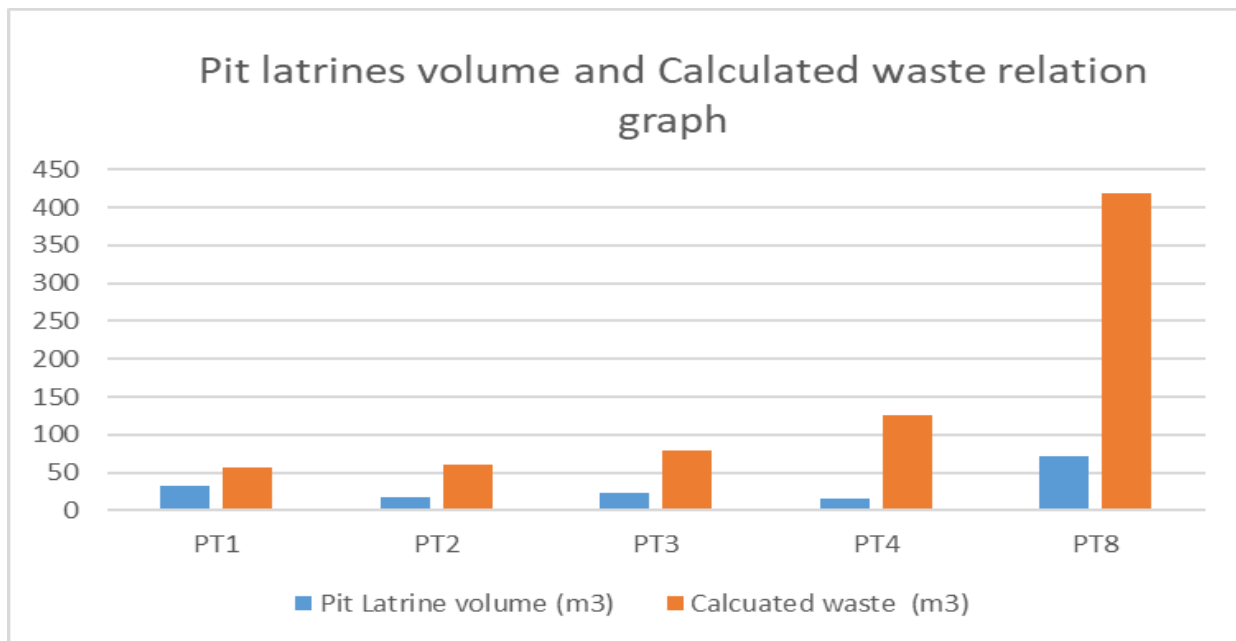


Figure 29. Pit latrines volume and Calculated waste graph

The pit latrine volume indicates that waste was removed by a vacuum truck. Various factors, such as the practice of pouring water into the toilet and the type of toilet (water flush or dry pit latrine), do not significantly affect the result, as the volume remains consistently high.

#### 4.4.5 Pit Latrines Correlation

The correlation is done with the data of pit latrine age and waste not removed (seepage) by using Spearman's rank correlation method. The calculation is done by giving a rank for pit latrines age (x) and for waste not removed (seepage) (y) then subtracting waste not removed (seepage) (Rx) from the rank of pit latrines age (Ry) to get  $d^2$  value. Finally, we can calculate by using Spearman's rank correlation formula.

Table 13. Spearman's rank correlation of pit latrines age and waste not removed (seepage)

No.	Pit latrines code	Pit latrine age year (X)	Wast not removed m <sup>3</sup> (Y)	Rx	Ry	d=Rx-Ry	d <sup>2</sup>
1	PT1	3	25	1	1	0	0
2	PT2	15	42	3	2	1	1
3	PT3	5	56	2	3	-1	1
4	PT4	21	110	4	4	0	0
5	PT8	68	347	5	5	0	0
						<b>Total</b>	<b>2</b>

$$r_{sp} = 1 - \frac{6(\sum d^2)}{n(n^2-1)} \dots\dots\dots \text{Spearman's rank correlation formula}$$

$$r_{sp} = 1 - \frac{6(2)}{5(5-1)}$$

$$= 0.9$$

Correlation was observed between the age of the pit latrines and the amount of unremoved waste (seepage), with a correlation coefficient of 0.9, indicating a strong positive correlation. As the age of the pit latrine increases, the amount of seepage also increases, suggesting that the quality of the pit latrine degrades over time.

To accurately determine the lifespan of pits within a municipality, both social factors (such as demographics and user behaviors related to pit latrines) and geophysical and biological factors (such as the interaction between pit design, water table, and soil) must be considered (David Still & Kitty Foxon, 2012).

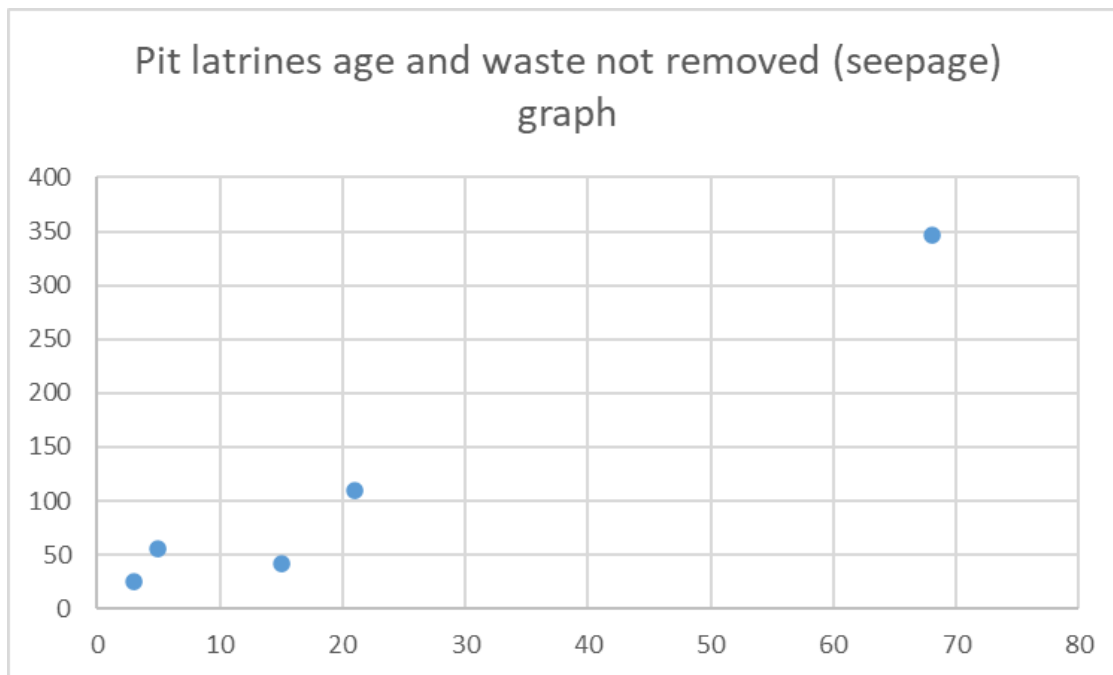
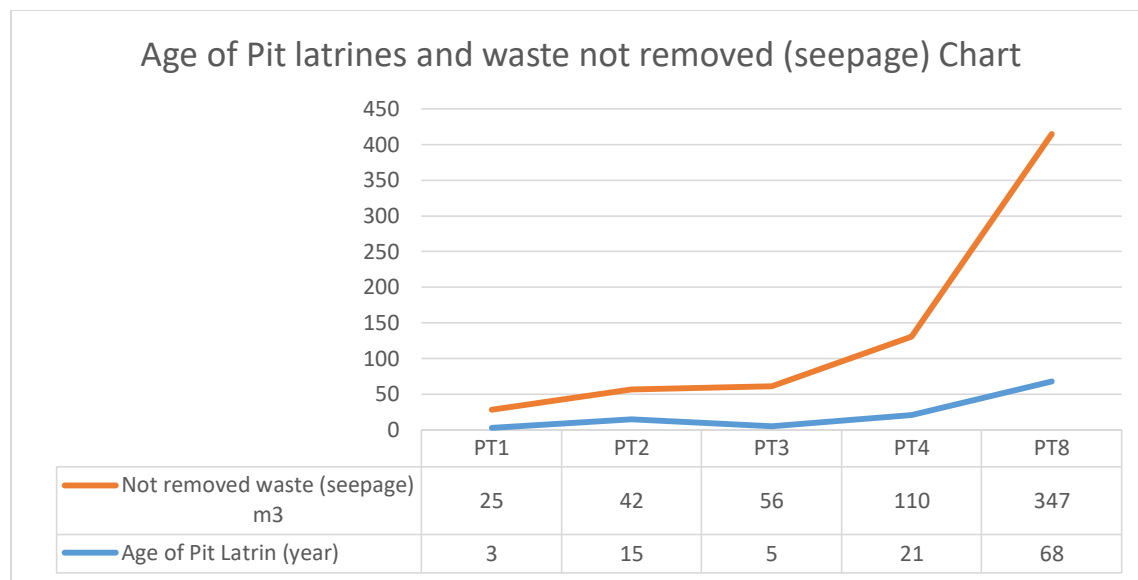


Figure 30. Spearman correlation graph: Pit latrines and waste not removed (seepage)

As shown in the table result and the graph, positive



*Figure 31. Age of Pit latrines and waste not removed (seepage) relation*

The lifetime of pit latrines is directly related to the amount of unremoved waste (seepage). For instance, pit latrine PT-8 shows that as its age increases, the seepage also rises significantly, indicating an urgent need for reconstruction or maintenance. Other pit latrines in the area also require maintenance. According to the questionnaire results old pit latrines are still being used in the area. yet little attention is given to their seepage issues.

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

The groundwater quality analysis indicates that the nitrate concentration at the well in the uncovered sewer line area around Teklehaimanot is high, measuring 58.876 mg/l, which exceeds the WHO standard by 8.876 mg/l. In the partially sewer line-covered area, the nitrate concentration is 7.968 mg/l, while in the fully covered area, it is 11.5 mg/l. Both concentrations are within acceptable limits.

Interestingly, the nitrate concentration in the fully sewer area is higher than in the partially covered area. This difference may be influenced by the age of the settlement and variations in groundwater depth. Overall, there is a noticeable effect related to sewerage coverage.

The correlation between Nitrate and Chloride is 99.97%, indicating a very strong relationship and suggesting that source of nitrate concentration source is human waste. Additionally, the correlation between nitrate and turbidity shows an R-squared value of 99.06%, indicating that water cleanness is closely related to nitrate concentration.

In areas with nitrate-polluted groundwater, the municipality water authority lacks a suitable water source because nitrate concentration exceeds WHO drinking water quality standards, instead, the existing wells in these areas are private, the residents must treat the water before use.

The pit latrine around the Moha Pepsi factory have a significant impact on groundwater pollution, as indicated by the correlation between the age of pit latrines and unremoved waste (seepage), with an R value of 0.9, indicating a strong positive correlation. As the age of the pit latrines increases, their performance decreases. Additionally, the drainage connected to the toilets contributes to groundwater pollution, particularly in the pipe section and sewer that discharge in to the river.

This situation highlights a lack of effective control mechanism for pit latrines in the city, from construction to service, as the drainage line are not regularly inspected. Furthermore, there are certain areas where it is not feasible to install sewer lines due to the topography, and other areas where a decentralized sewer system is not viable option. This result serves as a warning that areas may also face groundwater pollution over time.

## 5.2 Recommendations

Monitoring by the design and construction permission office is essential throughout the entire process of pit latrine construction. Some individuals construct their pit latrines carelessly, leading to seeping into the ground. The service life of pit latrines must be managed in relation to water consumption.

In areas with accessible sewer lines, many residents are reluctant to connect their toilets to the system due to high connection fees (minimum around 16,000 ETB) and difficulty of obtaining service, particularly for low-income households. To address groundwater pollution, the AAWSA and the City government should encourage residents to connect their toilets to the sewer system by providing financial assistance and possibly waiving fees for low-income households. Additionally, private well owners could support low-income households by covering sewer connection fees on an annual bases, contributing to environmental protection efforts.

More than half of Addis Ababa's drinking water supply comes from groundwater. Therefore, to protect this resource from contamination, the AAWSA should expand sewer line coverage. Furthermore, the city's wastewater connection to drainage systems and rivers require robust oversight from environmental protection authorities.

When constructing Pit latrines, it is crucial to consider measures to prevent waste seepage. New initiatives, such as using waterproof or non-permeable materials to prevent contamination, should be implemented. This will require creativity and collaboration of technology developers and designers.

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## APPENDIX

### APPENDIX A: Analytical Result

*Table 14. Teklehaimanot well laboratory result*

**ADDIS ABABA WATER & SEWERAGE AUTHORITY  
WATER QUALITY CONTROL SERVICE  
P.O.BOX 1505, TEL.0116-621496/622919  
WATER QUALITY ANALYSIS REPORT**

Analysis requested by: - **Abraham Gido**  
Source of sample: **Well**  
Sampling site: **Teklehaimanot, Addis Ababa**

Date of sampling: **12/04/2024**  
Date of analysis: **15/04/2024**  
Sampled by: **Abraham Gido**

S.No	Parameters	Unit	Sample	WHO
1	Turbidity	NTU	0.674	<5
2	Odor	Non obj.	Non obj.	Non obj.
3	Taste	Non obj.	Non obj.	Non obj.
4	PH	-	7.28	6.5 - 8
5	Total Dissolved Solid(TDS)	mg/l	528	600
6	Electrical conductivity(EC)	μS/cm	1,058	-
7	Total Alkalinity as CaCO <sub>3</sub>	mg/l	240	-
8	Total Hardness as CaCO <sub>3</sub>	mg/l	538	-
9	Calcium Hardness as CaCO <sub>3</sub>	mg/l	400	-
10	Magnesium Hardness as CaCO <sub>3</sub>	mg/l	138	-
11	Ammonia as N	mg/l	0.36	1.5
12	Nitrite as N	mg/l	0.01	1
13	Nitrate as N	mg/l	13.5	11
14	Sulfate as SO <sub>4</sub>	mg/l	53	250
15	Phosphate as PO <sub>4</sub>	mg/l	0.98	-
16	Fluoride as F	mg/l	0.31	1.5
17	Total iron as Fe	mg/l	0.2	0.3
18	Manganese as Mn	mg/l	-	0.1
19	Silica as SiO <sub>2</sub>	mg/l	38	-
20	Chloride as Cl	mg/l	60	250
21	Bicarbonate alkalinity as HCO <sub>3</sub>	mg/l	293	-
22	Carbonate Alkalinity as CaCO <sub>3</sub>	mg/l	Nil	-
23	Hydroxide Alkalinity as CaCO <sub>3</sub>	mg/l	Nil	-

Analysed by: \_\_\_\_\_

Chemist

Approved by: \_\_\_\_\_


**Zelege Teferi**  
Catchment Management and  
Water Quality Control Sub  
Process Leader


Table 15. Zenebework well laboratory analysis result

**ADDIS ABABA WATER & SEWERAGE AUTHORITY**  
**WATER QUALITY CONTROL SERVICE**  
 P.O.BOX 1505, TEL.0116-621496/622919  
**WATER QUALITY ANALYSIS REPORT**

Analysis requested by: - **Abraham Gido** Date of sampling: **12/04/2024**  
 Source of sample: **Well** Date of analysis: **15/04/2024**  
 Sampling site: **Zenebework, Addis Ababa** Sampled by: **Abraham Gido**

S.No	Parameters	Unit	Sample	WHO
1	Turbidity	NTU	0.094	<5
2	Odor	Non obj.	Non obj.	Non obj.
3	Taste	Non obj.	Non obj.	Non obj.
4	PH	-	7.18	6.5 - 8
5	Total Dissolved Solid(TDS)	mg/l	179	600
6	Electrical conductivity(EC)	μS/cm	358	-
7	Total Alkalinity as CaCO <sub>3</sub>	mg/l	160	-
8	Total Hardness as CaCO <sub>3</sub>	mg/l	210	-
9	Calcium Hardness as CaCO <sub>3</sub>	mg/l	154	-
10	Magnesium Hardness as CaCO <sub>3</sub>	mg/l	56	-
11	Ammonia as N	mg/l	ND	1.5
12	Nitrite as N	mg/l	0.008	1
13	Nitrate as N	mg/l	1.8	11
14	Sulfate as SO <sub>4</sub>	mg/l	2	250
15	Phosphate as PO <sub>4</sub>	mg/l	1.43	-
16	Fluoride as F	mg/l	0.6	1.5
17	Total iron as Fe	mg/l	0.02	0.3
18	Manganese as Mn	mg/l	-	0.1
19	Silica as SiO <sub>2</sub>	mg/l	57	-
20	Chloride as Cl	mg/l	2	250
21	Bicarbonate alkalinity as HCO <sub>3</sub>	mg/l	195	-
22	Carbonate Alkalinity as CaCO <sub>3</sub>	mg/l	Nil	-
23	Hydroxide Alkalinity as CaCO <sub>3</sub>	mg/l	Nil	-

Analysed by:  Chemist

Approved by:  Zetake Teferi  
 Catchment Management and  
 Water Quality Control Sub  
 Process Leader


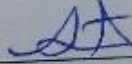


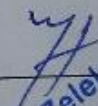
Table 16. Jemo-1 well laboratory analysis result

**ADDIS ABABA WATER & SEWERAGE AUTHORITY**  
**WATER QUALITY CONTROL SERVICE**  
**P.O.BOX 1505, TEL.0116-621496/622919**  
**WATER QUALITY ANALYSIS REPORT**

Analysis requested by: - **Abraham Gido**      Date of sampling: **12/04/2024**  
Source of sample: **Well**      Date of analysis: **15/04/2024**  
Sampling site: **Jemo, Addis Ababa**      Sampled by: **Abraham Gido**

S.No	Parameters	Unit	Sample	WHO
1	Turbidity	NTU	0.07	<5
2	Odor	Non obj.	Non obj.	Non obj.
3	Taste	Non obj.	Non obj.	Non obj.
4	PH	-	6.88	6.5 - 8
5	Total Dissolved Solid(TDS)	mg/l	306	600
6	Electrical conductivity(EC)	μS/cm	612	-
7	Total Alkalinity as CaCO <sub>3</sub>	mg/l	244	-
8	Total Hardness as CaCO <sub>3</sub>	mg/l	344	-
9	Calcium Hardness as CaCO <sub>3</sub>	mg/l	256	-
10	Magnesium Hardness as CaCO <sub>3</sub>	mg/l	88	-
11	Ammonia as N	mg/l	0.03	1.5
12	Nitrite as N	mg/l	0.008	1
13	Nitrate as N	mg/l	2.6	11
14	Sulfate as SO <sub>4</sub>	mg/l	37	250
15	Phosphate as PO <sub>4</sub>	mg/l	1.21	-
16	Fluoride as F	mg/l	0.46	1.5
17	Total iron as Fe	mg/l	0.02	0.3
18	Manganese as Mn	mg/l	-	0.1
19	Silica as SiO <sub>2</sub>	mg/l	62	-
20	Chloride as Cl	mg/l	5	250
21	Bicarbonate alkalinity as HCO <sub>3</sub>	mg/l	298	-
22	Carbonate Alkalinity as CaCO <sub>3</sub>	mg/l	Nil	-
23	Hydroxide Alkalinity as CaCO <sub>3</sub>	mg/l	Nil	-

Analysed by:  Chemist

Approved by:  **Zeleke Teferi**  
Catchment Management and  
Water Quality Control Sub  
Process Leader



## APPENDIX B: Secondary data

Table 17. Addis Ababa wells nitrate and phosphate concentration (Source: - AAWSA)

No	Well ID	X	Y	Nitrate	Phosphate
1	W1	475068	1001254	0.01	0.23
2	W2	475945	1000580	1.26	0.34
3	W3	475638	999991	0.01	0.17
4	W4	474518	1001467	0.06	0.23
5	W5	470504	1002135	0.06	0.34
6	W6	470218	1001886	0.12	0.28
7	W7	472608	1002066	0.42	0.23
8	W8	471026	1002023	0.96	0.17
9	W9	481681	994296	0.01	0.28
10	W10	482109	993423	0.44	0.33
11	W11	482719	990450	0.33	0.26
12	W12	482897	991485	0.03	0.28
13	W13	480604	992935	0.01	0.34
14	W14	481061	992052	0.01	0.42
15	W15	480760	992453	0.01	0.51
16	W16	480029	998401	0.03	0.38
17	W17	465998	1000153	0.66	0.33
18	W18	477715	997474	0.48	0.21
19	W19	481400	999700	0.06	0.15
20	W20	480999	999648	0.02	0.26
21	W21	484190	998500	0.03	0.34
22	W22	469500	989600	0.48	0.19
23	W23	470070	991000	1.25	0.22
24	W24	471125	989636	0.33	0.19
25	W25	466308	989421	0.32	0.37
26	W26	466050	993650	0.58	0.31

27	W27	484065	989378	0.03	0.46
28	W28	467135	989840	1.365	0.38
29	W29	468261	990357	1.115	0.41
30	W30	470277	989578	0.26	0.27
31	W31	465741	989188	0.48	0.24
32	W32	468512	989680	0.75	0.38
33	W33	471500	990500	1.25	0.32
34	W34	469458	990594	1.225	0.15
35	W35	468196	990422	0.8	0.23
36	W36	470790	990330	0.74	0.29
37	W37	465591	989872	0.7	0.18
38	W38	465295	990132	0.48	0.23
39	W39	463985	991540	0.61	0.34
40	W40	471400	988250	0.72	0.32
41	W41	470950	995225	21.5	0.44
42	W42	466842	993128	0.93	0.4
43	W43	463850	993100	0.61	0.36
44	W44	469150	1001150	1.86	0.32
45	W45	467660	996912	0.24	0.26
46	W46	468268	996584	0.36	0.21
47	W47	468380	996211	2.1	0.33
48	W48	468505	995156	2.4	0.29
49	W49	465500	1002150	0.01	0.42
50	W50	465717	1001230	0.01	0.48
51	W51	472900	1003550	0.01	0.35
52	W52	477252	982872	0.01	0.42
53	W53	476692	982390	1.1	0.31
54	W54	481828	981943	3	0.43
55	W55	472456	995639	0.01	0.44

56	W56	476370	983392	0.06	0.16
57	W57	481462	998906	0.01	0.14
58	W58	472585	982237	0.63	0.31
59	W59	480045	992855	0.9	0.16
60	W60	475182	989526	0.23	0.24
61	W61	476933	994457	0.01	0.36
62	W62	479550	998479	0.03	0.13
63	W63	473314	1002774	0.088	0.17
64	W64	472792	989152	1.6	0.32
65	W65	480363	997593	0.01	0.18
66	W66	468110	1001429	0.01	0.32
67	W67	466200	1001008	22	0.26
68	W68	467200	1001017	0.1	0.19
69	W69	471400	997400	176	0.14
70	W70	470000	996400	50.68	0.22
71	W71	469900	996000	40.5	0.28
72	W72	478450	995600	0.4	0.34
73	W73	474500	996200	23.8	0.16
74	W74	473800	996600	3.5	0.31
75	W75	473100	996400	3.5	0.27
76	W76	473300	996300	2.6	0.35
77	W77	473400	995800	2.2	0.24
78	W78	473000	996300	1.32	0.16
79	W79	472700	996300	13.2	0.13
80	W80	472500	996300	25.1	0.42
81	W81	471600	995800	74.4	0.47
82	W82	471300	995800	75.3	0.39
83	W83	472000	995100	19.8	0.21
84	W84	471700	995100	25.1	0.32

85	W85	471700	996300	75	0.28
86	W86	468100	993100	16.2	0.44
87	W87	473000	992700	26.4	0.32
88	W88	473100	992600	13.2	0.41
89	W89	477500	979300	45.7	0.29
90	W90	475200	999200	2.64	0.33
91	W91	474100	998500	41.8	0.28
92	W92	471400	995900	97.5	0.31
93	W93	473000	992700	2	0.25
94	W94	478463	977506	14.2	0.18
95	W95	468800	996600	15.1	0.14
96	W96	472700	999800	11.6	0.26
97	W97	469750	993850	14.96	0.33
98	W98	464538	991302	0	0.28
99	W99	481040	997714	0.04	0.16
100	W100	480879	997714	0.2	0.41
101	W101	481823	997680	0.1	0.29
102	W102	474777	996040	2.1	0.32
103	W103	478105	996912	3.7	0.47
104	W104	475764	996308	2.4	0.38
105	W105	479750	995452	0.4	0.32
106	W106	484102	995204	0.49	0.27
107	W107	470000	996400	50.68	0.36
108	W108	478640	995726	1.2	0.19

Table 18 In the questionnaire participated water customer bill data (Source: - AAWSA Bill-Data)

sn	CUST_KEY	LATITUDE	LONGITUDE	NAME	METER_KEY	CONTRACT_NUMBER	CHARGE_GROUP	questionary_code
1	7247227	9.0259739	38.7414244	LIDETA K.K.K N/A	A&M-0904069816	316599	DOM	1
2	C-000001192738	9.0201967	38.7405017	LIDETA K.K. N/A	APA-34017825	323879	DOM	1
3	C-000002135326	9.0258766	38.7413191	LIDETA K/K N/A	LIA 12586552	327040	DOM	1
4	7222904	9.0258649	38.7349631	WEREDA 5 QEB 22 N/A	LIA-722840053	130730	DOM	1
5	7228400	9.025837	38.741516	LEDETA.K.K KEB 10 N/A	MET-3465796	136951	DOM	1
6	7238922	9.024166	38.74156	ATO ABDRI HAMANABDIWAHD	SIN-62099630	306334	NON-DOM	2
7	7209068	9.0250719	38.7408126	ATO SAED AHMMEDGEHUMI	LIA-614641	51502	NON-DOM	3
8	C-000001599531	9.02471	38.740674	LIDETA K/K N/A	BAY-10737414	325282	DOM	4
9	C-000000649551	9.024775	38.740778	LIDETA K.K. NA	APA-34151089	322752	DOM	4
10	C-000002472540	9.02465	38.740715	LIDETA K/K N/A	SIN 6185718	329120	DOM	4
11	7243496	9.024764	38.74088	LIDETA KKK N/A	A&M-0904093256	311417	DOM	4
12	7221619	9.024764	38.740901	WOREDA 3 QEB 30 N/A	BAY-10789974	129259	DOM	4
13	7222648	9.0248548	38.7407534	WEREDA 3 QEB 30 N/A	LIA-702920016	130451	DOM	4
14	C-000002219030	9.0247988	38.7406724	LIDETA K/K N/A	LIA 12587709	327314	DOM	4
15	C-000001288092	9.0247875	38.740869	LIDETA K/K N/A	APR-34069246	324159	DOM	4
16	7441864	9.024868	38.740762	LIDETA K.K.K N/A	BAY-17117200	320738	DOM	4
17	7228128	9.024785	38.740823	WEREDA 3 KEBELE 30 N/A	MET-346679	136674	DOM	4
18	7207385	9.024336	38.741345	TEWFIK OMMER	MET-5180522	42996	NON-DOM	5
19	7238922	9.0241665	38.7415598	ATO ABDRI HAMANABDIWAHD	SIN-62099630	306334	NON-DOM	6
20	7204841	9.024163	38.741541	ABDULWAHID SHARIF	MET-5178944	30410	DOM	7
21	7213053	9.0251592	38.7427013	ALEMAYA P SCHOOL N/A	BAY-10791372	76103	NON-DOM	8
22	7220681	9.0245323	38.7422336	MOHAMMED AHMEDABIDLISHKUN	PRE-14717511	128246	NON-DOM	9
23	7206744	9.024413	38.7421378	AHMMED OUBEDSHAKUR	MET-1252635	39588	DOM	10
24	7206764	9.0242422	38.7417252	HAJI MILION HAILIE	SIN-6202752	39456	NON-DOM	11
25	7277504	9.0479744	38.7127857	ATO ABRHAM DAGMAWE	SIN-6225975_20409	67728	DOM	12
26	7208217	9.024692	38.741861	ATO SAIDU TABOTO	A&M-0903003662	46423	DOM	13
27	7215412	9.0245915	38.7418517	DINKU GOALE	BAY-10725564	121279	DOM	14
28	7231134	9.0258268	38.7410063	LIDETA K.K.K N/A	LIA-5188678	139961	NON-DOM	15
29	C-000000581169	9.0254172	38.7408678	FINANCE AND ECONOMY DEVELO	APA-34163667	322243	NON-DOM	16
30	7205836	9.024067	38.7418846	AHMMED BEKERI	BAY-10713694	34779	NON-DOM	17
31	7206745	9.024476	38.741856	AHMMED GIRU	BAY-10725563	39587	NON-DOM	18



Figure 32. Teklehaimanot well Temperature measurement



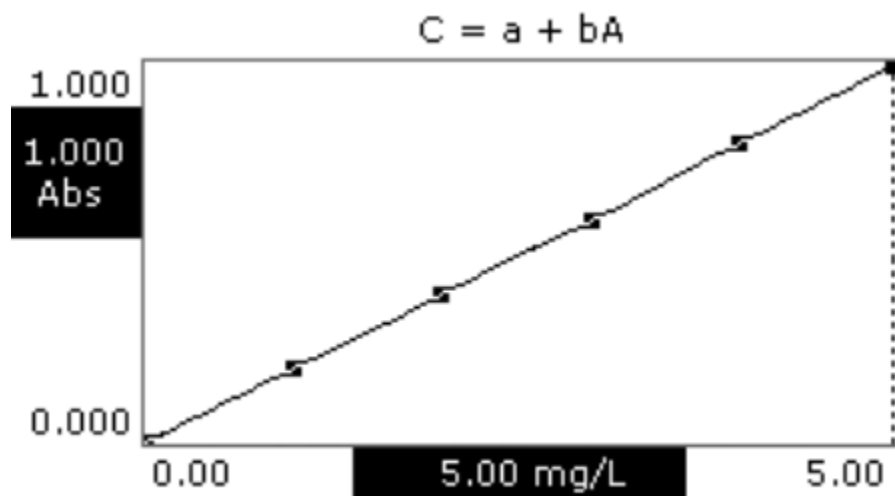
Figure 33. Questionnaire data collection-PT-10



*Figure 34. Questionary data collection-PT-16*

Table 19. Standard solution methods of DR HACH 5000 UV Spectrophotometer

Calibration Values			
mg/L	Abs		
0.0000	0.000	✕	
1.0000	0.200		
2.0000	0.400	▲	
3.0000	0.600		
4.0000	0.800	▼	
5.0000	1.000		
		+	
Exit	mg/L	Abs	Graph



Curve Fit  $r^2=1.0000$

Figure 35. Calibration Curve using standare solution method of DR HACH 5000 UV Spectrophotometer

**ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

I am a Water Supply and Environmental Engineering postgraduate student at Addis Ababa University. The purpose of this questionnaire is to collect data for the study entitled **“Effects of Pit Latrines Seepage on Ground-Water Quality in Addis Ababa City”**.

Dear respondents, your valuable information has great role on the accomplishment of the research. Therefore, I kindly request you to give a response honestly and I want to assure you that the information you provide would be used purely for academic purposes.

1. Code of the questionnaire: - .....

2. Location: -

2.1. Location Name: - .....

2.2. Coordinate: -

X: - .....

Y: - .....

3. Gender

Male

Female

4. Age group

Up to 12 years

13- 17

18- 35

36- 60

Above 61

5. Type of block?

Residential (House hold): -

Institution

Commercial

Other type, Describe it: - .....

5.1. For residential

a. What is the size of your house hold? .....

b. What is your Income? .....

5.1 If it is institution, what types of institution? .....

6. What is the water source? -

Government water line       another source

6.1. If it is a government source,

what is the water customer contract number? .....

6.2. If it is from another source what is the source? .....

7. What is the category of the toilet?

Pit latrine       Septic tank       other type

7.1. If other type, describe? .....

8. What is the service type of the toilet?

Private       Communal       public

9. What kind of toilet is that?

Ordinary       Ventilated       other type

9.1 If other type, describe? .....

10. When was the toilet constructed? .....

11. By what type of material was constructed? .....

12. What is the size of the toilet? (In meter)

a. Depth: -..... b. Width: - ..... c. Length: - ..... d. Radius (for circular): -.....

13. Is the toilet cleaned?       Yes       No

13.1 How often is the toilet cleaned? .....

13.1. What is the last cleaned day? - .....

14. Is the toilet maintained?       Yes       No

14.1. If it was maintained, when was it maintained? .....

15. Is there any problem with the toilet?       Yes       No

15.1 If there is a problem what is that? .....

16. If other things about the toilet? - .....

.....

**Thank you for your corporation**

**የአዲስ አበባ ዩንቨርሲቲ የድህረ ምረቃ ትምህርት ቤት የአዲስ አበባ ኢንስቲትዩት አፍ ቴክኖሎጂ የሲቪልና ኢንቫይሮንመንታል ኢንጅነሪንግ ትምህርት ክፍል**

እኔ በአዲስ አበባ ዩንቨርሲቲ የውሃ አቅርቦት እና አካባቢ ምህንድስና የሁለተኛ ዲግሪ ተመራ ስሆን፤ የዚህ መጠይቅ ዓላማ “የመገዳገሚያ ቤት ጉድጓድ ስርገት በአዲስ አበባ ከተማ የከርሰ ምድር ውሃ ላይ ያለው ተፅዕኖ” በሚል ርዕስ የመመረቅ ዕውቀት እና የግፍፍ ስለሆነ ለዚህ የመሆን መረጃ ለመስጠት ብቻ ነው።

ውድ የዚህ ጥናት ተሳታፊ የእርስዎ ቀና ምላሽ ለጥናቱ አላማ መሳካት ትልቅ አስተዋፅዖ ስላለው መጠይቆቹን በታማኝነት እንድትሞሉልኝ በአክብሮት እየጠየቅሁ የምትሰጡኝ ምላሽ ለትምህርታዊ ጉዳይ ብቻ እንደሚጠቅም ላረጋግጥ እወዳለሁ።

1. የቃለ መጠይቁ መላያ ቁጥር \_\_\_\_\_

2. አድራሻ

2.1 የአካባቢ ስም- \_\_\_\_\_

2.2 ኮርድኔት

X: - .....

Y: - .....

3. ፆታ

ወንድ

ሴት

4. የእድሜክልል

እስከ 12 ዓመት  12- 17

18-35  36- 60

ከ 61 በላይ

5. የቤቱ አይነት

የመኖሪያ

ተቋም (ድርጅት)

የንግድ ቤት

ሌላ አይነት አይነት ቤት ለፅ:- \_\_\_\_\_

5.1. ለመኖሪያ ቤት

ሀ. የቤተሰብ ቁጥር ስንት ነው? \_\_\_\_\_

ለ.. የገቢ ሁኔታ:- \_\_\_\_\_

5.2. ተጃምከሆነ የተጃመደህ ደንት፡- \_\_\_\_\_

6. ውሃ ከየት ነው የምታገኙት?

ከመንግስት የውሃ መከተር  ከሌላ ቦታ

6.1 ከመንግስት የውሃ መከተር ከሆነ የውሃ ደንበኛ ውልቁ ጥርስንት ነው?

6.2. ከሌላ ቦታ ከሆነ ከየት ነው ውሃው የምታገኙት? \_\_\_\_\_

7. የየትኛው መደብ ዓይነት የመጣ ዳጃ ነው ያለዎት?

ፒት ላተራል  ሴፕቲክ ታንክ  ሌላ አይነት

7.1. ሌላ አይነት መጣ ዳጃ ከሆነ ዓይነቱ ምን አይነት ነው?

8. የመጣ ዳጃ ቤቱ አገልግሎት ምን አይነት ነው?  
 የግል  የጋራ  የህዝብ

9. ምን አይነት መጣ ዳጃ ቤት ነው ያለዎት?

ተራ መጣ ዳጃ ቤት  አየር መከተር ወጫ ለው (Vent)  ሌላ ዓይነት

9.1 ሌላ አይነት ከሆነ አይነቱን ግለፅ? \_\_\_\_\_

10. መቼ ነው መጣ ዳጃ ቤቱ የተሰራው? \_\_\_\_\_

11. በምን አይነት ግብአት ነው መጣ ዳጃ ቤቱ የተሰራው? \_\_\_\_\_

12. መጣ ዳጃ ቤቱ ማከን ምን ያህል ነው? (በሜትር)

ሀ. ጥልቀት፡- \_\_\_\_\_ ለ. ወርድ፡- \_\_\_\_\_ ሐ. ስፋት፡- \_\_\_\_\_

መራድዩስ (ለክብ)፡- \_\_\_\_\_

13. እስከሁን ፍሳሹ ተወግዶአል?  አዎ  አልተወገደም

13.1 በምን ያህል ጊዜ ፍሳሹ ይወገዳል? \_\_\_\_\_

13.2 ለመጨረሻ ጊዜ ፍሳሹ የተወገደበት ቀን መቼ ነው?  
\_\_\_\_\_

14. መጣ ዳጃ ቤቱ ተጠግኖ ያወቃል?  አዎ  አያወቅም

14.1 ተጠግኖ የመቼ ወቅት ከሆነ መቼ?  
\_\_\_\_\_

15. መፀዳጃ ቤቱ ችግር አለበት?

አዎ

የለበትም

15.1 ችግር ካለበት ምን ዓይነት?

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16. ሌላ ተጨማሪ ነገር ካለ:-

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**ስለ ትብብር ዎ አመክግና ለሁ!**