ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CHEMICAL ENGINEERING

ENVIRONMENTAL ENGINEERING STREAM

Characterization of Physicochemical Parameters for Tap Water and Removal of Hardness Using Moringa Stenopetala seed as Natural Absorbent

The Case of Mekelle Town, Tigray, Ethiopia

By

Amhagiyorgis Mesfin

June, 2007 EC

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THESIS Work

ON

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The Case of Mekelle Town, Tigray Ethiopia

Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering

By

Amhagiyorgis Mesfin

Advisor: Engineer Gizachew Shiferaw

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Abbreviations

ACH	Aluminum Chlorohydrate
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CCD	Central Composite Design
CCFD	Center Composite Face Design
EC	Electrical Conductivity
EDAT	Ethylenediaminetetraacetate
EPA	Environmental Protection Agency
FMOH	Federal Ministry of Health
FMOWR	Federal Ministry of Water Resources
ETB	Ethiopian Birr
IEX	Ion Exchange
ISO	International Organization for Standardization
M. oleifera /MO	Moringa Oleifera
MOCP	Moringa Oleifera Coagulant protein
M. stenopetala/MS	Moringa Stenopetala
MSCP	Moringa Stenopetala Coagulant protein
NHMRC	National Health and Medical Research Council
NTU	Nephelometric Turbidity Unit
Nobj	Non objectionable

Obj	Objectionable
PACl	Poly Aluminum Chloride
RADWQ	Rapid Assessment of Drinking-Water Quality
RSM	Response Surface Methodology
SDWA	Safe Drinking Water Act
SG	Specific gravity
TDS	Total dissolved solid
TH	Total Hardness
TS	Total Solid
UFW	Unaccounted for water
UNICEF	United Nations Children's Fund
Uobj	Unobjectionable
WHO	World Health Organization

Abstract

The physicochemical examination of tap water used for domestic purposes in Mekelle town was carried out to ascertain their suitability for consumption. Water softening experiments were also conducted to observe the changes in total hardness, with varying dosages of a natural coagulant. The natural coagulant was extracted from Moringa stenopetala seed

A total of twenty (20) water samples were collected from various parts of the town tap water used for domestic purposes and characterized for their physicochemical parameters, arising public interest. The physicochemical implications render Mekelle's tap water unfit for human consumption, though it can be used for other purposes.

Tap water samples containing high concentration of hardness from Mekelle town, Enda Mariam and Enda Giyorgis areas were used for hardness removal mechanism part of this study. The optimum hardness removal efficiency for Mekelle tap water sample produced from ground water source was approximately 58 % (from initial total hardness of 523.25 to final hardness result of 220.3 which is within Ethiopian and WHO standard, i.e. below 300 mg/l as $CaCO_3$) which was attained at M.Stenopetala dosage of 200 mg/l. The optimum hardness removal efficiency for synthetic hard water analysis done by taking two factors, coagulant dose concentration and P^H as independent factors was approximately 49 % (from 500 to 256.6 mg/l as $CaCO_3$) which was attained at M.Stenopetala dosage of 200 mg/l and 6.5 P^H value. The mechanism for hardness removal in hard water seems to be precipitation of insoluble products of the reaction between M.Stenopetala extract and the hardness causing ions. Even at a relatively higher dosage of the M.Stenopetala coagulant compared to the chemical softening, natural coagulant is preferred for economic use, health and environmental safety.

Key words: Water Hardness, coagulant protein, Moringa Stenopetala, physicochemical parameters, Tap water

1. Introduction

1.1 Back ground

Potable water is the fundamental need of man to sustain life. Water serves as lubricant, regulates the body temperature and provides the basis for the body fluids and metabolism [1]. Drinking water should be suitable not only for human consumption but also for washing/ showering and domestic food preparation because chemical and other constituents of the water would give a rise to economic damage as well [1]. Water is a good solvent and picks up impurities easily and thus changes its taste, color and odor. It is well-known fact that when water is polluted, its normal functioning and properties are affected. Continual improvement in the quality of water for purposes of drinking, domestic consumption, personal hygiene and certain medical situations is among the top challenges of the world. A silent humanitarian crisis kills about 3900 children every day and thwarts progress towards all the Millennium Development Goals (MDGs), especially, in Africa and Asia [2]. Worldwide water borne diseases are the cause of death and suffering of millions of people, especially, children in developing countries [3]. The provision of high-quality drinking water is the most important connote for improving human health of a community by preventing the spread of water born disease . Drinking water plays an important role in taking essential minerals. Elevated level of nonessential elements can cause morphological abnormalities, reduce growth, increase mortality and mutagenic effects. Contaminants are substances that are dissolved in water and make it unfit for use. Some contaminants can be easily identified only by assessing the taste, odor and turbidity of the water because pure water remains tasteless, colorless and odorless. However, most contaminants cannot be easily detected and require testing to reveal whether or not water is contaminated. Physicochemical parameters of water are important to determine the quality of drinking water according to WHO [1]. The physical parameters that are likely to give rise to complaint from consumers are color, taste, odor and turbidity while low pH causes corrosion and high pH results in taste complaints [1, 3].

Mekelle, the Capital of Tigray region, is located within the Mekelle Geological outlier who is fully covered with sedimentary rocks of limestone, shale, shale-gypsum interaction and dolerite sills and dykes. It is surrounded by volcanic sedimentary rock of sand stone and metamorphic rocks [4]. As a result Mekelle outlier faces water salinity problems due to its spatial geological formations and rock water interaction during ground water flow and circulation. Many organizations and scholars have studied the hydrogeology of Mekelle area. All of the studies focused on groundwater potential assessment, recharge and discharge estimation and few of these dealt with hydro geochemistry but none on the solution of water quality on water hardness removal and treatment options. So, present paper tries to fill this gap and report the possible impact of water quality and propose cost effective mechanism to reduce house hold water hardness.

The common methods of water treatment process require coagulation/flocculation followed by sedimentation, filtration and disinfection. The Common coagulants are aluminum sulphate, ferric chloride, polyaluminum chlorides and synthetic polymers [5]. The dosage of coagulant depends on several parameters such as type and concentration of contaminants, pH and temperature. Chemical coagulants like Aluminum sulphate (alum), FeCl2 are used in Municipal drinking water treatment plant for purification process. This excess use of amount of chemical coagulants can affect human health e.g. Aluminum has also been indicated to be a causative agent in contaminated water as the lacks of knowledge of proper drinking water treatment also not afford to use high cost of chemical coagulants. Some drinking water treatment plant in developing countries face a myriad of problems which are large seasonal variation in raw water quality e.g. turbidity, high cost of water treatment chemicals, under dosing of chemicals leading supply of poor drinking water [6].

It is necessary to increase the use of natural coagulants for drinking water treatment to overcome chemical coagulant problems. Naturally occurring coagulants are usually presumed safe for human health. Some studies on natural coagulants have been carried out and various natural coagulants were produced or extracted from microorganisms, animals or plants. One of these alternatives is Moringa seeds. Moringa is a perfect example of a so-called “multipurpose tree”. Earlier studies have found Moringa to be non-toxic and recommended it to use as a coagulant in developing countries [7, 8]. The use of Moringa has an added advantage over the chemical treatment of water because it is biological and has been reported as edible. Hardness removal efficiency of Moringa Stenopetala was found to increase with increasing dosage. M. oleifera seed act as a natural absorbent and antimicrobial agent as their seeds contain 1% active polyelectrolyte's that neutralize the negatively charged colloid in the dirty water [9]. This protein can be therefore nontoxic natural polypeptide for sedimentation of mineral particles and organics in the purification of drinking water. These seeds also act as antimicrobial agent against variety range of bacteria and fungi [10]. The seed contain number of benzyl isothiocyanate and benzyl glucosinolate which act as antibiotic [11]. It is believed that the seed is an organic natural polymer. The active ingredients are dimeric proteins. The protein powder is stable and totally soluble in water. The coagulation mechanism of M.oleifera coagulant protein has been explained in different ways. It has been described as adsorption and charge neutralization and inter-particle bridging [10]. Flocculation by inter-particle bridging is mainly characteristic of high molecular weight polyelectrolytes. Due to the small size of the M.oleifera coagulant protein, a bridging effect may not be considered as the likely coagulation mechanism [12]. Moringa seeds possess antimicrobial properties reported that a recombinant protein in the seed is able to flocculate Gram-positive and Gram-negative bacterial cells. In this case, microorganisms can be removed by settling in the same manner as the removal of colloids in properly coagulated and flocculated water. On the other hand, the seeds may also act directly upon microorganisms and result in growth inhibition. Antimicrobial peptides are thought to act by disrupting the cell membrane or by inhibiting essential enzymes reported that Moringa seeds could inhibit the replication of bacteriophages [11].

Among all the plant materials that have been tested over the years, powder processed from the seeds of Moringa Stenopetala has been shown to be one of the most effective as a primary coagulant for water treatment and it can be compared to that of Alum, [9, 10]. It was inferred from their reports that the powder has antimicrobial properties. A general rule of thumb is that powder from one Moringa kernel to two liters of water is a good amount when water is slightly turbid, and to one liter when water is very turbid. The seeds and powder can be stored but the paste needs to be fresh for purifying the water [13].

1.2 Statement of the problem

Physical statuses as well as life threatening chemicals get to pollute the tap water system by different contributing factors such as leaching from the source, weak water treatment system and environmental interaction at different points due to poor handling and transmission. When such polluted water is sourced for human consumption, health implications can be overwhelming [1].

Mekelle town, the capital of Tigray region have water distribution systems to provide tap water and curb the acute water shortages of household drinking and cooking, bathing and showering, dishwashing and clothes washing experienced by the inhabitants. But the tap water is not comfortable for the major purposes listed here although the inhabitants are managed to use this water, which is highly concentrated with ash colored dissolved substances forming sediment at a bottom of a stand still container within hours. Thus the possibility of the local tap water system being contaminated by physicochemical interactions from the various pits cannot be overlooked. Again, health records obtained from the nearby hospital showed that the communities experience periodic outbreaks of water-related diseases like skin diseases (irritation), dull and lifeless hair etc. The following consumer problems are also easily detectable in the current tap water use of Mekelle:

- Produces soap scum most noticeable on tubs and showers.
- Produces white mineral deposits on dishes more noticeable on clear glassware.
- Reduces efficiency of devices that heat water. As hardness deposits build in thickness, they act like insulation, reducing the efficiency of heat transfer (Inhabitants told me that they collect rain water during the rainy season and handle for the use of food cooking during the dry season)

➢ It is therefore important to characterize the tap water and search treatment alternatives. Thus this thesis work, being a scientific information, and data input will help ascertain for further treatment work and improved management of the water at use.

1.3 Objectives of the study

1.3.1 General Objective

This thesis work was aimed at characterizing the tap water quality of Mekelle town related to the physicochemical parameters and investigated the possibility of hardness removal by natural coagulant/absorbent, Moringa stenopetala seeds.

1.3.2 Specific objectives

- ✓ To characterize physicochemical parameters of tap water
- ✓ To determine the total hardness of water samples before and after applications of Moringa stenopetala coagulant
- ✓ To study moringa stenopetala seed for drinking water treatment applications

1.4 Significance of the study

The purpose of physicochemical characterization of tap water is to identify the physicochemical components, their concentration, and areal distribution in the study areas, assess water suitability for public use and to introduce natural, cost effective and environmental friendly Coagulant/ absorbent for water hardness removal. A pressing need has emerged for comprehensive and accurate assessments of trends in water quality, in order to raise awareness of the urgent need to address the consequences of present and future threats of contamination and to provide a basis for action at all levels. Reliable monitoring of data is indispensable basis for such assessments due to the sensitivity of water quality parameters. Monitoring is defined by the International Organization for Standardization (ISO) as the programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives.

1.5 Scope of the study

This thesis work focused on characterization of the physicochemical parameters of tap water quality at Mekelle town. Water hardness removal using coagulant extracted from Moringa Stenopetala seed was also successfully examined. The Physicochemical parameters with special emphasis on PH, Turbidity, Conductivity, Hardness, Alkalinity and TDS were determined in well-organized water quality laboratories at Mekelle University EiT-M Civil and Chemical Engineering departments, Analytical Chemistry laboratory of Mekelle University Chemistry department and Mekelle water supply service, water testing laboratory. Total hardness of the water is calculated before and after application of the natural coagulant so as to evaluate the future potential that moringa stenopetala seed can be used as economical and eco-friendly raw material for water treatment facilities.

2. Literature Review

2.1 Introduction

2.2 Physicochemical parameters of water

It is very important to test the water before it is used for drinking, domestic, agricultural and industrial purposes. Water must be tested with different physicochemical parameters. Selection of parameters for testing water solely depends upon the purpose for what we are going to use the water and to what extent we need its quality and purity. Water contains different types of floating, dissolved, suspended and microbiological as well as bacteriological impurities. Some physical test should be performed for testing of its physical appearance such as temperature, color, odor, pH, turbidity, TDS etc, while chemical tests should be performed for its alkalinity, dissolved oxygen, hardness and other characters. For obtaining more and more quality and purity water, it should be tested for its trace metal, heavy metal contents and organic i.e. pesticide residue [14]. It is obvious that drinking water should pass these entire tests and it should contain required amounts of mineral levels. Only in the developed countries all these criteria's are strictly monitored. Due to very low concentrations of heavy metals and organic pesticide impurities present in water, it needs highly sophisticated analytical instruments and well trained manpower [2, 14]. The following different physicochemical parameters are tested regularly for monitoring quality of water.

2.2.1 Temperature

Temperature is one of the important factors in an aquatic environment for its effects on the chemistry and biological reactions in the organisms. The change in atmospheric temperature with change in season brought corresponding changes in water temperature. The difference in atmospheric temperature and groundwater temperature are under the influence of high specific heat of water [15, 16]

In former researches on the relation of drinking water supply and water quality, the focus was mostly on drinking water distribution systems. However, the domestic drinking water system also influences the water quality through high residence times, leaching of metals, hydraulic regimes, and material use [16]. Drinking water passes this domestic drinking water system before it enters the tap to be used for flushing, washing, cleaning, drinking or cooking [15 ,35].

Domestic drinking water systems exhibit several properties which can, if they interfere, create unwanted situations e.g. excessive bacterial growth. One can think of the presence of biofilms, which occurs at all surfaces in contact with water combined with high residence times and high temperatures [3]. Figure 1 below shows the relationship of the four major parameters which influence the water quality within the domestic drinking water system.

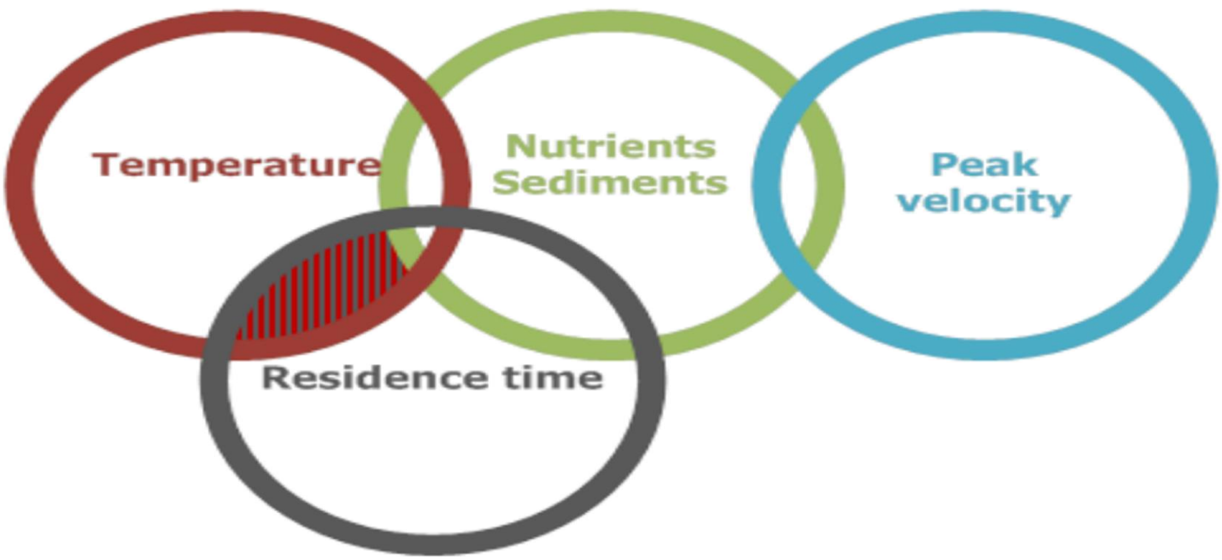


Figure 1. Relationship between four major parameters of water quality

2.2.2 p^H

The pH value of a water source is a measure of its acidity or alkalinity. The pH level is a measurement of the activity of the hydrogen atom, because the hydrogen activity is a good representation of the acidity or alkalinity of the water. The pH scale, as shown below, ranges from 0 to 14, with 7.0 being neutral. Water with a low pH is said to be acidic, and water with a high pH is basic, or alkaline. Pure water would have a pH of 7.0, but water sources and precipitation tends to be slightly acidic, due to contaminants that are in the water.

Surface water typically has a pH value between 6.5 and 8.5 and groundwater tends to have a pH between 6.0 and 8.5. The pH of a water source can vary naturally. Some types of rock and soil, such as limestone, can neutralize acid more effectively than other types of rock and soil, such as granite. Or, when there are a large number of plants growing in a lake or river, they release carbon dioxide when they die and decompose. When the carbon dioxide mixes with the water, a weak carbonic acid is formed; this can then cause the pH of the water body to decrease. Figure 2 shows the p^H values and their corresponding effects on the different environments and living components [1, 2].

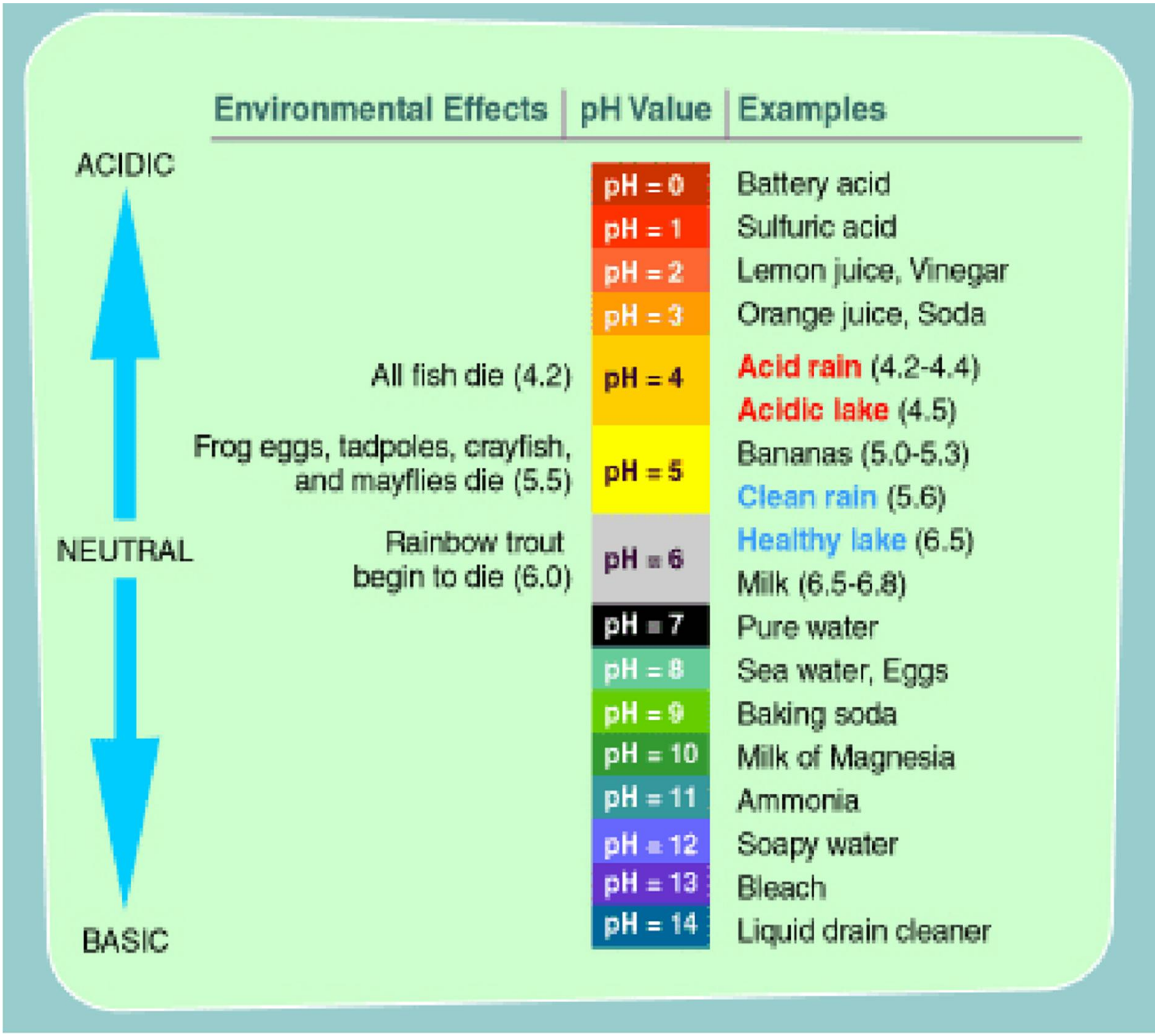


Figure 2. The PH scale

2.2.3 Turbidity

Turbidity is a principal physical characteristic of water and is an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through water sample. It is caused by suspended matter or impurities that interfere with the clarity of the water. These impurities may include clay, silt, finely divided inorganic& organic matters, soluble colored organic compounds, plankton and other microscopic organisms.

Typical sources of turbidity as Shown in figure 3 below include the following:

- ✓ Waste discharges;
- ✓ Runoff from watersheds, especially those that are disturbed or eroding;
- ✓ Algae or aquatic weeds and products of their breakdown in water reservoirs, rivers, or lakes;
- ✓ Humic acids and other organic compounds resulting from decay of plants, leaves, etc. in water sources; and
- ✓ High iron concentrations which give waters a rust-red coloration (mainly in ground water under the direct influence of surface water).
- ✓ Air bubbles and particles from the treatment process (e.g., hydroxides, lime softening)

Simply stated, turbidity is the measure of relative clarity of a liquid. Clarity is important when producing drinking water for human consumption and in many manufacturing uses. Once considered as a mostly aesthetic characteristic of drinking water, significant evidence exists that controlling turbidity is a competent safeguard against pathogens in drinking water.

Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing, and may also represent a health concern. Turbidity can provide food and shelter for pathogens. If not removed, turbidity can promote re growth of pathogens in the distribution system, leading to waterborne disease outbreaks, which have caused significant cases of gastroenteritis throughout the United States and the world. Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa [11, 12].

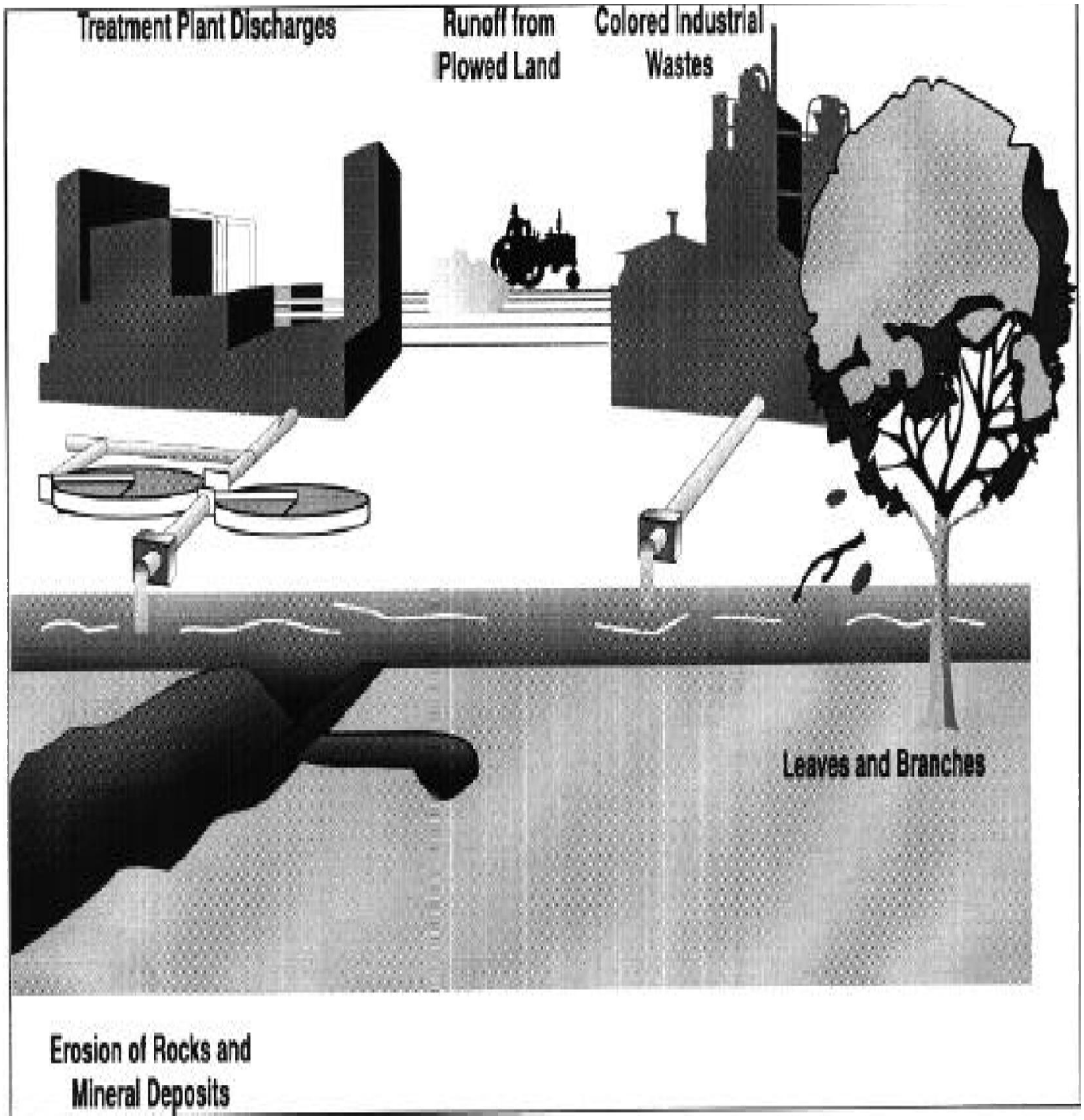


Figure 3.Typical Sources of Turbidity in Drinking Water

2.2.4 Chloride

Every water supply contains some chloride. Chloride is common in nature, generally as a salt. Most chloride found in nature is in the oceans. However, underground deposits are found in most Canadian provinces. Sodium chloride is also used in industry for making chemicals, and to melt snow and ice.

Chloride in groundwater may be due to a number of natural or human sources. This can include dissolving rock, highway salt, industry, oil wells, sewage, irrigation drainage, and leachates from garbage dumps. Chloride is dissolved in water and moves with groundwater. Therefore, sources of chloride can impact water quality in distant locations [15].

A normal adult human body contains approximately 81.7 g chloride. On the basis of a total obligatory loss of chloride of approximately 530 mg/day, a dietary intake for adults of 9 mg of chloride per kg of body weight has been recommended (equivalent to slightly more than 1g of table salt per person per day. For children up to 18 years of age, a daily dietary intake of 45 mg of chloride should be sufficient. Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride reacts with metal ions to form soluble salts [6], thus increasing levels of metals in drinking-water. In lead pipes, a protective oxide layer is built up, but chloride enhances galvanic corrosion [15]. It can also increase the rate of pitting corrosion of metal pipes [6].

2.2.5 Hardness

2.2.5.1 Source of Hardness

Water is a good solvent and picks up impurities easily. As water moves through soil and rock, it dissolves very small amounts of minerals and holds them in solution. Dissolved calcium and magnesium are the two most common minerals that make water “hard”. The degree of hardness becomes greater as the calcium and magnesium content increases. The increased hardness is caused by the natural percolation of water through the soil which is shown in figure re 4. When surface water passes through the ground it collects minerals, which results in hard water [10].

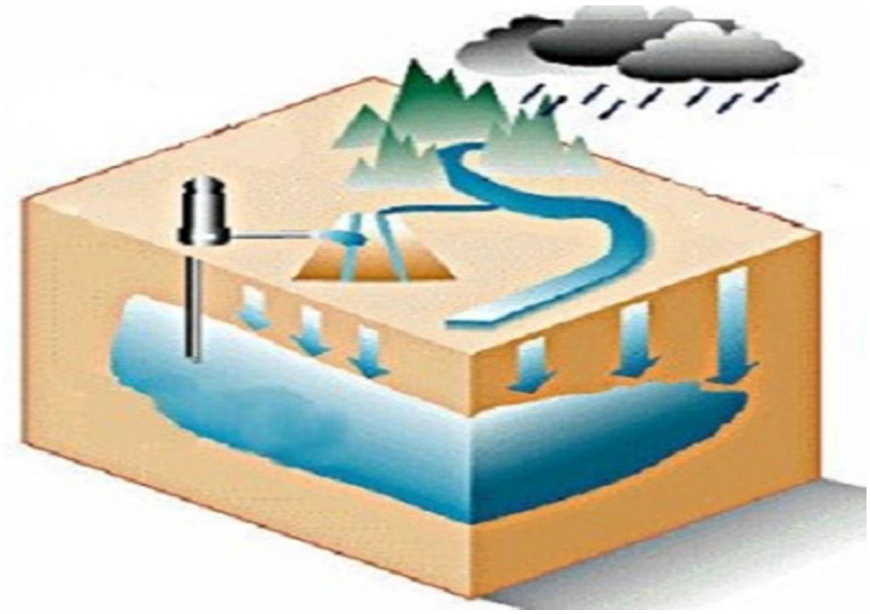


Figure 4. Natural percolation of water through the soil

Initially, water hardness was understood to be a measure of the capacity of water to precipitate soap, which is in practice the sum of concentrations of all polyvalent cations present in water (Ca, Mg, Sr, Ba, Fe, Al , Mn, etc.); nevertheless, since the other ions (apart from Ca and Mg) play a minor role in this regard, later it has been generally accepted that hardness is defined as the sum of the Ca and Mg concentrations, determined by the EDTA titrimetric method, and expressed in mmol/l or as $CaCO_3$ equivalent in mg/l, less frequently as the CaO equivalent[19]. From the technical point of view, multiple different scales of water hardness were suggested (e.g. very soft – soft – medium hard – hard – very hard). Expectedly, both extreme degrees (i.e. very soft and very hard) are considered as undesirable concordantly from the technical and health points of view. However, the optimum Ca and Mg levels are not easy to determine since the health requirements may not coincide with the technical ones [18, 19]. Calcium and magnesium presence in waters result from decomposition of calcium and magnesium aluminosilicates and, at higher concentrations, from dissolution of limestone, magnesium limestone, magnesite, gypsum and other minerals etc… [21].

Water supply professionals do not fully agree on the descriptive terminology that should be used when categorizing the concentration of hardness in water nor what lower threshold concentration justifies the investment in a water softener. Table 1 below shown below are the two common severity scales used to categorize hardness.

Table 1. Categorizing Hardness [21]

Worded Description	Sanitary Engineers (mg/L as $CaCO_3$)	Water Conditioning Industry (mg/L as $CaCO_3$)
soft water	0-75	0-50
somewhat hard water	76 to 150	51-100
hard water	151 to 300	101-150
very hard water	301 and up	151 and up

2.2.5.2 **Indications of Hard Water**

Hard water interferes with almost every cleaning task, from laundering and dishwashing to bathing and personal grooming.

The amount of hardness minerals in water affects the amount of soap and detergent necessary for cleaning. Soap used in hard water combines with the minerals to form sticky soap curd. Some synthetic detergents are less effective in hard water because the active ingredient is partially inactivated by hardness, even though it stays dissolved. Bathing with soap in hard water leaves a film of sticky soap curd on the skin. The film may prevent soil and bacteria from being removed. Soap curd interferes with the return of skin to normal, slightly acid condition and may lead to irritation. Soap curd on hair may make it dull, lifeless and difficult to manage. When doing laundry in hard water, soap curds lodge in fabric during washing to make fabric stiff and rough. Incomplete soil removal from laundry causes graying of white fabric and the loss of brightness in colors. A sour odor can develop in clothes. Continuous laundering in hard water can shorten the life of clothes. In addition, soap curds can deposit on dishes, bathtubs and showers, and all water and plumbing fixtures. Hard water also contributes to inefficient and costly operation of water-using appliances. Heated hard water forms a scale of calcium and magnesium minerals that can contribute to the inefficient operation or failure of water-using appliances. Pipes can become clogged with scale that reduces water flow and ultimately requires pipe replacement [22].

The National Research Council states that hard drinking water generally contributes a small amount toward the total calcium and magnesium needed in the human diet. The Council further states that in some instances, where dissolved calcium and magnesium are very high, water could be a major contributor of calcium and magnesium to the diet. Many researches have been done on the relationship in water hardness and cardiovascular disease mortality but no firm conclusions have been drawn. The National Research Council has recommended further studies be conducted. World Health Organization is attempting to coordinate a worldwide study on the effect of water hardness for cardiovascular disease before and after changes in water supply hardness [19].

2.2.6 EC (Electrical Conductivity)

Conductivity shows significant correlation with ten parameters such as temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids, chemical oxygen demand , chloride and iron concentration of water. The underground drinking water quality of study area can be checked effectively by controlling conductivity of water and this may also be applied to water quality management of other study areas. It is measured with the help of EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution [15].

2.2.7 Dissolved Oxygen

DO is one of the most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. [23]. In the progress of summer, dissolved oxygen decreased due to increase in temperature and also due to increased microbial activity [17]. High DO in summer is due to increase in temperature and duration of bright sunlight has influence on % of soluble gases (O_2 & CO_2). During summer the long days and intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO_2 and giving off oxygen [6]. This possibly accounts for the greater qualities of O_2 recorded during summer [17]. DO is measured titrimetrically by Winkler's method after 5 days incubation at 293 K. The difference in initial and final DO gives the amount of oxygen consumed by the bacteria during this period. This procedure needs special BOD bottles which seal the inside environment from atmospheric oxygen. [6, 17]

2.2.8 TDS (Total Dissolved Solids)

TDS represents the total concentration of dissolved substances in water. TDS is made up of inorganic salts, as well as a small amount of organic matter. Common inorganic salts that can be found in water include calcium, magnesium, potassium and sodium, which are all cations, and carbonates, nitrates, bicarbonates, chlorides and sulfates, which are all anions [7].

High concentration of dissolved solids is usually not a health hazard. In fact, many people buy mineral water, which has naturally elevated levels of dissolved solids. The United States Environmental Protection Agency (EPA), which is responsible for drinking water regulations in the United States, includes TDS as a secondary standard, meaning that it is a voluntary guideline in the United States. While the United States set legal standards for many harmful substances. TDS, along with other contaminants that cause aesthetic, cosmetic and technical effects, has only a guideline. Most people think of TDS as being an aesthetic factor. However, a very low concentration of TDS has been found to give water a flat taste, which is undesirable [7, and 8].

2.2.9 Alkalinity

The value of alkalinity in water provides an idea of natural salts present in water. The cause of alkalinity is the minerals which dissolve in water from soil. The various ionic species that contribute to alkalinity include bicarbonate, hydroxide, phosphate, borate and organic acids. These factors are characteristics of the source of water and natural processes taking place at any given time [1, 2, and 8].

2.2.10 Biochemical Oxygen Demand (BOD)

BOD is a measure of organic material contamination in water, specified in mg/L. BOD is the amount of dissolved oxygen required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials (e.g., iron, sulfites). Typically the test for BOD is conducted over a five-day period [3].

2.2.11 Chemical Oxygen Demand (COD)

COD is another measure of organic material contamination in water specified in mg/L. COD is the amount of dissolved oxygen required to cause chemical oxidation of the organic material in water. Both BOD and COD are key indicators of the environmental health of a surface water supply. They are commonly used in waste water treatment but rarely in general water treatment [4, 5].

2.3 Standards for Physicochemical parameters of tap water

Drinking water quality standards describes the quality parameters set for drinking water. Despite the truism that every human on this planet needs drinking water to survive, water may contain many harmful constituents. There are no universally recognized and accepted international standards for drinking water [1]. Even where standards do exist, and are applied, the permitted concentration of individual constituents may vary by as much as ten times from one set of standards to another [13].

2.3.1 WHO Standard

The primary aim of the WHO Guidelines for Drinking-water Quality (GDWQ) is the protection of public health. The Guidelines are intended to be used as a basis for the development of national standards that, if properly implemented, will ensure the safety of drinking water supplies through the elimination, or reduction to a minimum concentration, of constituents in drinking water that are known to be hazardous to health [1,3]. The guideline values recommended are not mandatory limits. They are intended to be used in the development of risk management strategies which may include national or regional standards in the context of local or national environmental, social, economic and cultural conditions [1].

The main reason for not promoting the adoption of international standards for drinking water quality is the advantage provided by the use of a risk-benefit approach (qualitative or quantitative) to the establishment of national standards or regulations. This approach should lead to standards and regulations that can be readily implemented and enforced and which ensure the use of available national financial, technical and institutional resources for public health benefit [10]. WHO standard limits of some physicochemical parameters are given in table 2

2.3.2 Other standards

2.3.2.1 Australian standards

Drinking water quality standards in Australia have been developed by the Australian Government National Health and Medical Research Council (NHMRC) in the form of the Australian Drinking Water Guidelines. These guidelines provide contaminant limits (pathogen, aesthetic, organic, inorganic, and radiological) as well as guidance on applying limits for the management of drinking water in Australian drinking water treatment and distribution [27].

2.3.2.2 European Union standards

The parametric standards are included in the Drinking Water Directive and are expected to be enforced by appropriate legislation in every country in the European Union. Simple parametric values are reproduced, but in many cases the original directive also provides caveats and notes about many of the values given [10].

2.3.2.3 United States standards

In the USA, the federal legislation controlling drinking water quality is the Safe Drinking Water Act (SDWA) which is implemented by the EPA, mainly through state or territorial primacy agencies. States and territories must implement rules that are at least as stringent as EPA's to retain primary enforcement authority (primacy) over drinking water. Many states also apply their own state-specific standards, which may be more rigorous or include additional parameters. Standards set by the EPA in the USA are not international standards since they apply only to a single country, however, many countries look to the USA for appropriate scientific and public health guidance and may reference or adopt USA standards [10].

2.3.2.4 Ethiopian Standard

A national standard for drinking-water, ES 261:2001 Drinking-water – specifications were established in 2001 by the Quality and Standards Authority of Ethiopia, the organization responsible for setting standards in Ethiopia. The 2001 standard supersedes the first edition of 1990 (ES 261:1990), which was limited to piped drinking-water supplies and supplies that served more than 10000 people [37]. ES 261:2001 was developed by a national technical committee of members from FMOH, FMOWR, EHNRI and the Ethiopian Environmental Protection Agency, as well as from other governmental and nongovernmental organizations. The national standards were largely based on the second edition of the WHO Guidelines for drinking-water quality (the latest guidelines at the time. The maximum permissible levels for the parameters used in the RADWQ project were consistent with the WHO guideline value. Some selected physicochemical parameters and their maximum limit of Ethiopian and WHO are shown in table 2 below.

Table 2. Selected physicochemical parameters and their maximum limit of Ethiopian and WHO

Parameters	**Ethiopian Standard**	**WHO Guide Lines**
Color	Non objectionable	Unobjectionable
Odor	Non objectionable	Unobjectionable
Taste	Non objectionable	Unobjectionable
Temperature	25oc	25^0c
PH	6.5-8.5	6.5-8.5
Turbidity	5NTU	5NTU
E C	1500µS/cm	2000µS/cm
T D S	1000ppm	1000ppm
Iron, Total	0.3mg/L	0.3 mg/L
Copper	2mg/L	1.5 mg/L
Chromium	0.05mg/L	0.05mg/L
Manganese	0.5mg/L	0.5mg/L
Alkalinity, Total	200mg/L	500mg/L
Total Hardness, mg/l as CaCO3	300mg/L	300mg/L
Fluoride, F-	1.5mg/L	1.5mg/L
Nitrate, NO3-	50mg/L	45mg/L
Nitrite, NO2-	3mg/L	3mg/L

2.4 Chemistry of water hardness removal process

Softening is undertaken as part of water treatment to remove calcium and magnesium salts, particularly carbonates and bicarbonates, which cause water hardness. Hard water can cause scale build-up on water heating elements and can cause problems with the use of soaps and detergents. Softening very hard waters can also lead to high concentrations of sodium in water while this may possibly give the water a salty taste [15].

2.5 Application of coagulants in drinking water treatment

2.5.1 Chemical Coagulants

Chemical treatment typically is applied prior to sedimentation and filtration to enhance the ability of a treatment process to remove particles. Two steps typically are employed: coagulation and flocculation. Coagulation is a process to neutralize charges and then to form a gelatinous mass to trap (or bridge) particles thus forming a mass large enough to settle or be trapped in the filter. Flocculation is gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from solution.

The primary use of coagulant and flocculant chemicals is in the removal of suspended and colloidal solids such as clays. Coagulation is particularly important in the treatment of surface waters. Removal of the solids is achieved by aggregating fine suspended matter into larger flocs. Coagulant and flocculant chemicals will also remove some natural organic matter, color and microorganisms (e.g. bacteria, viruses and algae) [38].

Chemical coagulants, usually salts of aluminum or iron given in table 3 below, are dosed to the raw water under controlled conditions to form a solid flocculent metal hydroxide. Typical coagulant doses are 2–5 mg/liter as aluminum or 4–10 mg/liter as iron [18]. The precipitated floc removes suspended and dissolved contaminants by mechanisms of charge neutralization, adsorption and entrapment. The efficiency of the coagulation process depends on raw water quality, the coagulant or coagulant aids used and operational factors, including mixing conditions, coagulation dose and pH. The floc is removed from the treated water by subsequent solid–liquid separation processes such as sedimentation or flotation and/or rapid or pressure gravity filtration [38].

Table 3: The most common Chemicals recommended as coagulant uses in the treatment of drinking water

Chemical Name	**Chemical Formula**	**Primary Coagulant**	**Coagulant Aid**
Aluminum sulfate (Alum)	$Al_2(SO_4)_3 \cdot 14\ H_2O$	**X**	
Ferrous sulfate	$FeSO_4 \cdot 7\ H_2O$	**X**	
Ferric sulfate	$Fe_2(SO_4)_3 \cdot 9\ H_2O$	**X**	
Ferric chloride	$FeCl_3 \cdot 6\ H_2O$	**X**	
Cationic polymer	Various	**X**	**X**
Calcium hydroxide (Lime)	$Ca(OH)_2$	**X***	**X**
Calcium oxide (Quicklime)	CaO	**X***	**X**
Sodium aluminate	$Na_2Al_2O_4$	**X***	**X**
Bentonite	Clay		**X**
Calcium carbonate	$CaCO_3$		**X**
Sodium silicate	Na_2SiO_3		**X**
Anionic polymer	Various		**X**
Nonionic polymer	Various		**X**

*Used as a primary coagulant only in water softening processes [34]

In general, the lower the coagulant dosage, the faster the mixing should occur because chemical reactions happen very quickly at low dosages. Rapid mixing disperses a coagulant through the raw water faster than the reaction takes place. When alum or ferric chloride are used in lower dosages (for charge destabilization; not sweep floc development), it is important to ensure that they mix very quickly with the raw water to be effective [34].

2.5.2 Natural Coagulants

Natural materials have been used in water treatment since ancient times. But lack of knowledge on the exact nature and mechanism by which they work has impeded their wide spread application and they have been unable to compete with the commonly used chemicals. In recent years there has been a resurgence of interest to use natural materials due to cost and associated health and environmental concerns of synthetic organic polymers and inorganic chemicals. A number of effective coagulants have been identified from plant origin. Some of the common ones include Moringa Oleifera, Cactus latifaira and Prosopis juliflora, tannin from valonia apricot, peach kernel and beans, and maize compared 10 natural coagulants from plant seeds [19, 24]. The study indicated that maize and rice had good coagulation effects when used as primary coagulants or coagulant aid. One of the natural coagulants from animal origin is chitosan. It is a high molecular weight polyelectrolyte derived from deacetylated chitin. Chitin is cellulose like biopolymer widely distributed in nature, especially in insects, fungi, yeasts and shells of crabs and shellfish. Chitosan possesses effective coagulation properties and it can be used in water and wastewater treatment [17, 19]. By using natural coagulants, considerable savings in chemicals and sludge handling cost may be achieved. 50-90% of alum requirement could be saved when okra was used as a primary coagulant or coagulant aid [24]. Apart from being less expensive, natural coagulants produce readily biodegradable and less voluminous sludge. For example, sludge produced from M.oleifera coagulated turbid water is only 20-30% that of alum treated counterpart [35]. There are very few reports on the use of natural coagulants for sludge conditioning. The study reported that MO had comparable conditioning effect as ferric chloride and aluminum sulphate. The biodegradable nature of MO makes it a preferred option over the others. In dual or multimedia granular filtration anthracite coal and garnet are often used. In many places these materials are not commonly available and they are expensive. Some of the locally available filter media, which have been used in a single or multimedia filtration, include: crushed coconut shells, burned rice husk and crushed apricot shell [20].

Moringa oleifera and Moringa stenopetala are the two most common species among the 13 species of the Moringa family. Both species have many characteristics in common. For both species the use as a vegetable and water purifier are similar. They share several medicinal uses and both have high contents of oil in the seeds: between 32 - 42 %. Moringa oleifera has a faster development and yields fruits and seeds quickly. Moringa stenopetala is better suited to a drier climate; yields of seeds are higher and they have a higher coagulant content [35].

2.5.2.1 Moringa Stenopetala

2.5.2.1.1 Taxonomy and Distribution

*M.*stenopetala belongs to family Moringaceae that is represented only by a single genus Moringa. The genus is represented by 14 species to which *M.* stenopetala belongs. Northeast tropical Africa is a center of endemism plus diversity to the genus [30]. The taxonomic position of the family is not clear [35]. It has some features similar to those of Brassicaceae and Capparidaceae but the seed structure does not agree with either of the above families [16, 35].

M. Stenopetala is a tree 6-10m tall; trunk: more or less 60cm in diameter at breast height; crown: strongly branched sometimes with several branches; thick at base; bark: white to pale grey.

Figure 5. M.Stenopetala tree

2.5.2.1.2 Origin and Uses

M.stenopetala is often referred to as the African Moringa tree because it is native only to southern Ethiopia and northern Kenya [30]. Though it grows in many other parts of the tropics, it is not as widely known as its close relative, Moringa oleifera but often considered generally more desirable than M.oleifera [31]. Francis K.Amaglaoh investigated the use of Moringa seeds as coagulant for water purification [16].

The best studied with regard to potential medicinal uses and the identification of compounds of potential therapeutic importance, is M.oleifera, which is native to the Indian subcontinent. Based on a review of the literature concerning M.oleifera, a project was developed to investigate the traditional uses of M. stenopetala, a species that grows widely in southern parts of Ethiopia. Its crown is strongly branched, sometimes with several trunks, and its wood is soft [25].

Figure 6: Bole of Moringa Stenopetala

The leaves are bi- or tri-pinnate, with about 5 pairs of pinnae and 3-9 elliptic to ovate leaflets per pinna. The flowers are very fragrant with cream flushed pink sepals, white, pale yellow or yellow-green petals, white filaments and yellow anthers. The ovary is ovoid and densely hairy. Pods are elongate reddish with greyish bloom having grooved valves.

Figure 7. Moringa Stenopetala Leaves

M. Stenopetala grows naturally in the Acacia tortilis-Delonix elata-Commiphora spp. vegetation-complex. This type of vegetation is often found in well-drained soils at altitudes of 900-1200 m. The species is quite drought resistant. In southern Ethiopia, it has been found in areas of mean annual rainfall ranging from 500-1400mm. Cold temperatures are limiting factor for the cultivation of the species in Ethiopia because it does not tolerate frost. [28]

The leaves and fruits are eaten as vegetables and are rich in proteins, calcium, iron, and phosphorous as well as vitamins A and C. The use of leaves and pods for animal fodder is currently of minor importance compared to their use for human consumption. Yet, due to their high protein content this is a promising potential use [31].

The people of Konso use the tree not only for food but also as a medicine and they cultivate it in large areas around their villages. There are claims that the leaves, boiled in water, can cure malaria, hypertension and stomach pain, whereas the roots, chopped and mixed with water, are also used for treating severe cases of malaria. M.stenopetala is used as a herbal medicine in areas where visceral leishmaniasis or kala-azar (caused by the Leishmania parasite) prevails. In addition, there are reported cases of M.stenopetala leaves being used to expel the retained placenta in women who have just given birth. It is a valued ornamental in its natural range. Boundary or barrier or support: It serves as a live fence in areas of its natural range [28].

The species is grown in mixed multi-storey stands with food crops. The home gardens in Ethiopia (Arba Minch area) for instance include sometimes up to 15 M.stenopetala trees per 0.1 ha. Farmers practice permanent multi-storied cultivation with M. stenopetala at the uppermost level, Carica papaya, coffee and bananas in the upper-middle level, cassava, maize and sugar cane in the lower-middle level and cotton and pepper in the lowest level. One of the most promising potential uses of M. stenopetala is to purify turbid water. The seeds of this and some other species of the Moringaceae have flocculating and anti-microbial properties [30].

2.5.2.1.3 Properties of Moringa Stenopetala seeds

Moringa seeds contain a cationic polyelectrolyte that has proved efficient in water treatment, as a substitute to aluminum sulphate and other flocculent [40]

There is a dual advantage to this property:

1. It can be used as local-produced substitute for imported flocculants, thus reducing expenditure of foreign currency reserves by third world countries;

2. Moringa flocculent, unlike aluminum sulphate, is completely biodegradable. Oil extracted from the seeds is an excellent edible vegetable oil and is also useful within the cosmetics industry. A dual usage of Moringa seeds, as a source of oil and flocculent, is possible, since the seed cake remaining after oil extraction retains the flocculating properties [17]. The seed cake is biodegradable and can also be used as a fertilizer. Compared to the imported chemicals that are usually applied in water plants Moringa thus has several advantages:

- It saves foreign exchange
- High cost of water treatment chemicals which constitute between 35% to 70% of recurrent expenditure of water treatment plants.
- In adequate supply of chemicals for water treatment. Sludge produced by chemical purifiers are voluminous and non-biodegradable after treatment and therefore poses disposal problems leading to increase cost of treatment [31]

Pumice and Moringa oleifera seeds as alternative natural materials for drinking water treatment were studied based on problems identified at the Stretta Vuadetto water treatment plant in Eritrea [29]. Results show that coagulant protein can be purified from the Moringa seeds through a simple purification method that can be scaled up and hence promote the use of Moringa seeds for large scale applications. The lab and pilot scale studies showed that the coagulant protein possessed considerable coagulation and sludge conditioning properties similar to aluminum sulphate. It also showed antimicrobial effects, some of which are antibiotic resistant [17, 29].

2.5.2.1.4 Characteristics of the coagulant component from M.Stenopetala seed

In recent years the use of the Moringa seed for water treatment applications is gaining popularity and ongoing research is attempting to characterize and purify the coagulant component. The nature and characteristics of the component, which has coagulation and antimicrobial effects has been reported differently by a number of researchers [17]. It was described as a water-soluble cationic peptide with isoelectric point (pI) above 10 and molecular mass of 6.5 kDa. The theoretical pI of the protein as estimated from the amino acid sequence is 12.6. On the other hand, a non-protein and non-polysaccharide coagulant compound, with molecular mass of 3 kDa, has been identified from a salt extract solution. In the subsequent research, the coagulant was purified using anion exchange resin. More than one coagulant peptide has been isolated from the seed and the sequence of one of them has been established. This suggests that a number of coagulant proteins are present, which may differ in one or more amino acid residues. Seeds from different sources (geographic locations) exhibit varying coagulation performance, which may have to do with differences in the protein content and development of the seed. The complete array of proteins from the seed that posse the coagulation and antimicrobial property has not been fully identified. This entails the need for extensive research to identify and characterize the whole range of proteins with their amino acid sequences and structure. The coagulation mechanism of the moringa seed coagulant protein has been explained in different ways. It has been described as adsorption and charge neutralization and inter-particle bridging. The coagulation mechanism of the non-protein organic compound was attributed to enmeshment by net-like structure. Flocculation by inter-particle bridging is mainly characteristics of high molecular weight polyelectrolytes. Due to the small size of MSCP (6.5-13 kDa) bridging effect may not be considered as the likely coagulation mechanism. The high positive charge (pI above

10) and small size may suggest that the main destabilization mechanism could be adsorption and charge neutralization [24]. MSCP can be extracted by water or salt solutions (commonly NaCl). The amount and effectiveness of the coagulant from salt and water extraction methods vary significantly. In crude form, salt extract shows better coagulation performance than the corresponding water extract. This may be explained by the presence of higher amount of soluble protein due to salting-in phenomenon. However, purification of MSCP from the crude salt extract may not be technically and economically feasible. In the case of IEX purification, for example, ionic strength of the crude extract has to be lowered to that of the equilibration buffer in order to maximize binding efficiency. This entails either handling of large sample volume (as a result of dilution) or the need for desalting prior to purification [29].

2.6 The study area water distribution

2.6.1 Location

The city of Mekelle, located in northern Ethiopia, is the capital of Tigray region. The area is geographically bounded between Latitudes 1472872 and 1512872 m North and Longitudes of 543650 and 573650 m East and covers a total land area of 1,200 square kilometres. Mekelle region is found on the north-eastern part of the central plateau west of the Rift valley, and is 783 km North of Addis Ababa. Mekelle town is geographical located at coordinates of 1491663 m North, Latitude and 551089 m East, Longitude with elevation of 2000 meter above sea level and having sub locations as shown in figure 9 below.

Water supply in Mekelle does not meet demand, and sanitation coverage needs. Many households, schools and health institutions often lack water and basic sanitation facilities, which has had drastic implications for the public health.

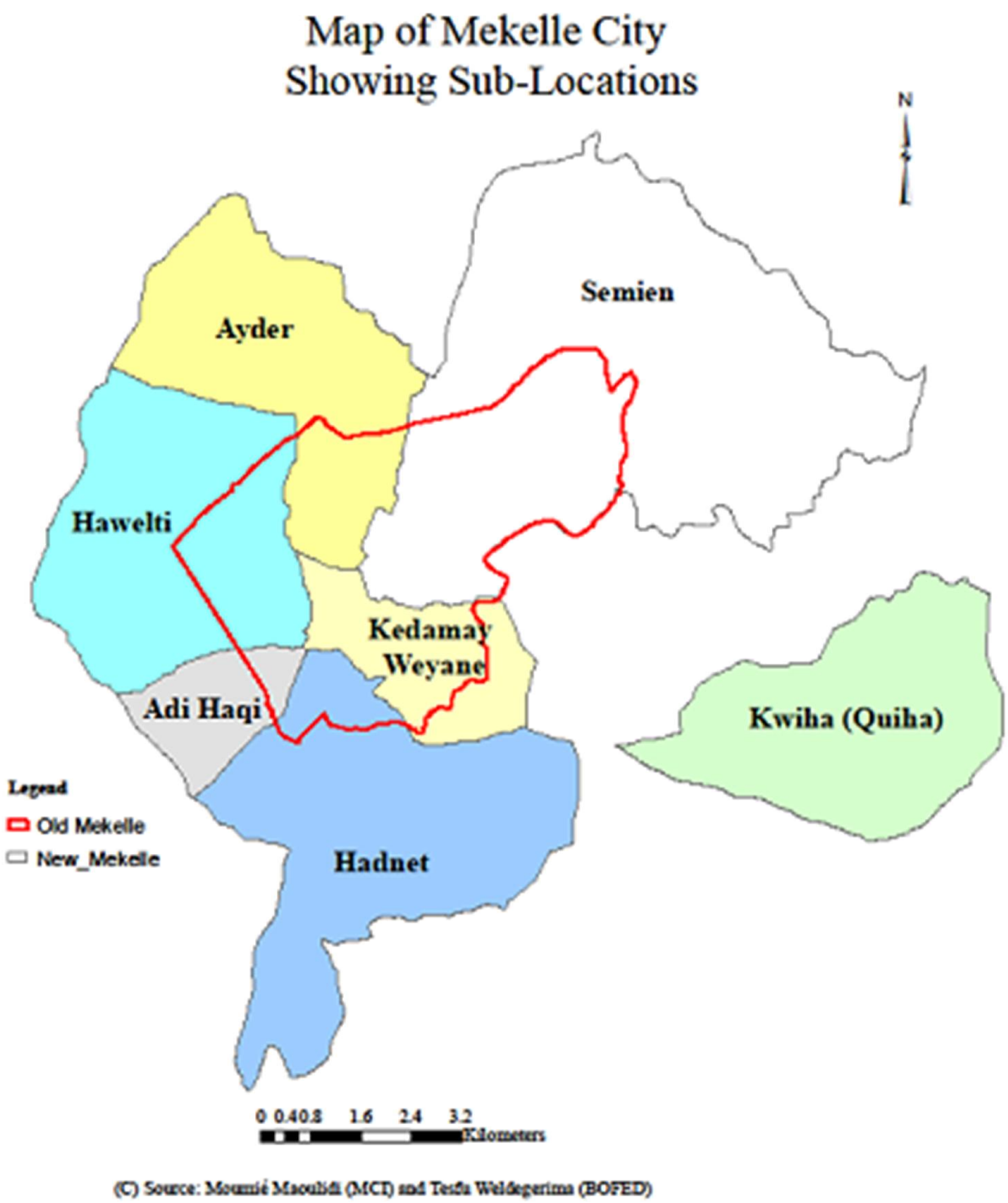


Figure 8: Mekelle Administrative Map [41]

2.6.2 Survey of current water supply system in Mekelle town

The water supply system in and the treatment practices are experiencing a number of design and operational problems. Consequently the quality and quantity of distributed water do not meet the requirements of consumers and the targets set by the authorities. Unaccounted for water (UFW) of the system amounts to 40% of the total water production. This is mainly due to leakage in the distribution system. The recent renovation work (replacing the existing pipes with PVC material) is believed to have significantly reduced the amount of UFW and improved the water quality. Water from the different sources of tap water for Mekelle town (Lachi, Enda Mariam (Quiha), Aynalem, Enda Giyorgis, Enda Gebreil reserviors) is directly distributed to the consumers after disinfection (the only treatment process being practiced).

The main source of Mekelle City's water supply is ground water from 17 boreholes that ranged from 32- 250 meters deep [41]. The distribution system depends primarily on gravity, but the network also relies on 17 pumps. Water is pumped to surface reservoirs where it is treated with chlorine. The yield of the boreholes varies from 4 to 45 liters per second. 10 of these boreholes are located in Aynalem well field, about five kilometers south of the town. [Annex 1]

Table 4. 2006 EC water distribution data

Consumptions accounts	Quantity in m^3
Water truck	86058.72
Water point	7500
Flush outs & cleaning	1000
Unread customers for d/t reasons	120780
Domestic	2446353.6
Industry &Commercial	1100367.6
Government	1021586.4
Total consumption	4783646.32
Total production	6766969
Loss	1983322.68
Loss in %	0.293088779

3. Materials and Methodology

For water analysis and assessment regarding the suitability of water for human consumption and other domestic purposes, specialized sampling and sample handling procedures were used. Sites of sampling were selected randomly by considering the population, location and source. The water samples were analyzed for various parameters in the laboratory of the institutes selected. Various physicochemical parameters like, pH, turbidity, total dissolved Solids (TDS), hardness, electrical conductivity (EC), total alkalinity, were measured. Plastic bottles of 500ml capacity were used for collecting samples. Each bottle was washed with 2% Nitric acid and rinsed three times with distilled water. The bottles were preserved in a clean place.

3.1 Coagulant preparation

Tree dried Moringa Stenopetala seeds were procured from local trees. Good quality dry seeds of Moringa stenopetala were selected from the pods. The seeds coat and wings had been removed manually before ground using mortal grinder and sieved through sieve 250 μm. The powder with< 250 μm was used. Hexane (96%) in 1:10 ratio (1gm of seed powder and 10ml hexane) was used to extract the oil from the crushed powder of Moringa Stenopetala. The Moringa cake residue stock after oil extraction was used as a crude coagulant in the treatment process of the drinking water.

On large scale, the extracted oil can be used as edible oil [35].

3.2 Sampling points

Using clean sample holding plastic bottles, tap water samples were taken from each district of Mekelle town. Prior to sampling, the bottles had been rinsed thoroughly with the water of the source from which each sample was collected and the rinsed water was discarded away. The samples were then brought to the laboratory and analyzed. Each container was clearly marked with the name and address of the sampling station, sample description and date of sampling.

General Sample collection procedures followed were:

- Turn tap on to desired flow
- Let run for 3+ minutes
- Collect samples in a sample container
- Transfer sample from container to sample cells
- Perform tests on sample as fast as possible

3.3 Sample Testing Techniques

The sample testing techniques employed here were Colorimetric, Titrimetric, and Electronic. Colorimetric methods are based on measuring the intensity of color of a colored target chemical or reaction product. The optical absorbance is measured using light of a suitable wavelength. The concentration is determined by means of a calibration curve obtained using known concentration of the determinant. In volumetric titration, chemicals are analyzed by titration with a standard titrant. The titration end point is identified by the development of color resulting from the reaction with an indicator by the change of electrical potential or by change of PH value. Typical colorimetric methods used were:

- Test strips
- color chart
- slid comparators

Typical titrimetric methods used were:

- Dropper bottle
- Direct reading titrator
- Automatic burette

Typical Electronic methods used were:

- ✓ Spectrophotometer
- ✓ Turbidity meter
- ✓ colorimetric
- ✓ Handheld meter

Table 5. Methods used for tap water analysis (Laboratory analytical methods)

S. No	Physicochemical parameters	Methods
1	Color	-
2	Odor	-
3	Taste	-
4	P^H	P^H meter
5	Turbidity	Nephelometer
5	Conductivity	Conductivity meter
6	Total dissolved solids	Evaporation
7	Ca hardness	Titration
8	Mg hardness	Titration
9	Total Hardness	Titration
10	Alkalinity	Titration

3.4 Experimental works

3.4.1 Measurement of Turbidity

There are various instruments which are used to measure turbidity of water and these are called turbidity meter.

Generally earlier type of instrument which were used to measure turbidity of water were

- Baylis Turbidity Meter and
- Jakson Turbidity Meter

In this work an electronic instrument called Nephlometer Model 2100N/AN was used to measure turbidity of water samples and it shown in figure 9 below

Figure 9. Model 2100N/AN Laboratory Turbidity meter

3.4.2 Measurement of conductivity

Conductivity of water is a property by virtue of which the current passed through it. Conductivity is measured in terms of Micromho/cm (µmho/cm) or a bigger unit Millimhos/cm (mmho/cm) or millisimen/m (ms/m), 1ms/m=10 µmho/cm and measured by sing Model 2100N/AN Laboratory turbidity meter**.**

3.4.3 Total dissolved solids measurement

The filterable residue is the material that passes through a standard glass filter disk and remains after evaporation and drying at 180°C.

Drying until constant weigh was obtained or weight loss is less than 0.5mg.

mg/L total filtrable residue at 180°C = (A –B) x 1000 / C

Where: A = weight of dried residue + dish

B = weight of dish

C = mL of filtrate used

3.4.4 Measurement of Hardness

The tap water samples were titrated for total hardness and calcium hardness. Magnesium hardness was also noted down.

Temporary hardness, permanent hardness and total hardness of the tap water samples taken from sample sites were tried to be measured by boiling samples and applying the calculation below, however the specific divalent component causing the hardness could not be known. Hence, titrations for total hardness and Ca hardness were applied in this thesis work.

TH(mg/l as $CaCO_3$ Scale) = ml of EDTA used (unboiled sample)*10^3/ml of sample

PH (mg/l as $CaCO_3$ Scale) = ml of EDTA used (boiled sample)*10^3/ml of sample

(Where: TH = total hardness, PH = permanent hardness)

Temporary hardness = TH – PH

3.4.5 Measurement of Alkalinity

Alkalinity of water is the measure of its capacity to neutralize acids. It is due to the presence of weak salts of weak acids .Alkalinity is classified in three forms. These are:

- ✓ Hydroxide (^-OH)
- ✓ Carbonate (CO_3^{-2})
- ✓ Bicarbonate (HCO_3^-)

Among these alkalinities, bicarbonate is a major constituent. The carbonate alkalinity may be present either with hydroxide or bicarbonate alkalinity. But hydroxide alkalinity and bicarbonate alkalinity do not exist together.

Alkalinity is measured on $CaCO_3$ scale (mg/l of $CaCO_3$)

Volumetric or titration method was used in measuring alkalinity.

3.5 Experimental Works design

The physicochemical parameters characterization of tap water was analyzed using simple statistical operations. A total of 60 samples were taken from 20 sample sites and experimental results mean values were calculated to get the most representative figure of each parameters studied.

The jar test used in these experiments consisted of four paddles on a bench as shown in figure 12 below. The paddles were connected to each other by a gear mechanism, and all of these paddles were simultaneously rotated by the same motor at a controlled speed and time.

Water samples of 500 mL each, were transferred to the jars and then pH adjusted using 0.5 M HCl and 0.5 M NaOH solutions. The required dose of moringa stenopetala coagulant was added to each beaker. Directly after the addition of the coagulant, the water sample in the jar was stirred rapidly at a paddle speed of 120 rpm for 10 min then stirred slowly at a paddle speed of 30 rpm for 20 min, and finally, the treated water was allowed to settle for 30 min.

Response surface methodology (RSM), involving central composite design (CCD) matrix with two of the most important operating variables in the coagulation/flocculation process, Moringa stenopetala coagulant/absorbent dosage and pH were utilized for the study of the drinking water treatment process.

Design-expert software version 7.0.0 was used to optimize the major operating factors which were moringa stenopetala coagulant dosage and tap water pH. In this study, RSM used the common form of center composite design (CCD) which is called center composite face design (CCFD) was used. The hardness removal was selected as the dependent variable, while the coagulant dosage and water pH were selected as independent variables.

The independent variables (factors) were coagulant dosage (denoted by A) and tap water pH (denoted by B). These factors have three levels as follows: low level (−1), center level (0), and high level (+1) as shown in table 6 below. The actual values of the coded levels for these factors were selected based on preliminary experiments. Experimental design matrix is also shown in table 7 below.

Table 6. Complete experimental design matrix of CCD

Variables	Factor coding	Units	Levels		
			-1	0	1
Moringa Stenopetala coagulant dose	A	mg/l	100	150	200
P^H	B	-	6.5	7.25	8.0

- Order in which the runs were made was randomized to avoid errors which are caused by systematic.

Table 7. Experimental design matrix, Experimental variables

Run	Coded factors		Actual factors	
	A	B	MS. Coagulant dose mg/l (CD)	P^H
1	0	0	150	7.25
2	-1	-1	100	6.50
3	0	-1	150	6.50
4	1	1	200	8.00
5	0	0	150	7.25
6	-1	0	100	7.25
7	-1	1	100	8.00
8	1	-1	200	6.25
9	1	0	200	7.25
10	0	0	150	7.25
11	0	1	150	8.00
12	0	0	150	7.25
13	0	0	150	7.25

4 Results and Discussion

In this chapter, the purpose of revealing the water quality of 20 tap water samples of covering the study area is established by determining the physical and chemical characteristics as per standard methods [32]. The parameters viz., pH, total dissolved solids and Electrical conductivity know the physical characteristics of the tap water under the study area. The chemical characteristics of the tap water sourced from ground water under the study area are known by the parameters viz., total hardness, calcium hardness, magnesium hardness and alkalinity.

4.1 Physicochemical analysis of tap water

All the reagents used were of analytical grade and solutions were made of distilled water. Various water quality parameters such as alkalinity, hardness, TDS etc., were determined using standard analytical methods and procedures. The instruments used were calibrated before use for observing readings. The repeated measurements were made to ensure precision and accuracy of results

4.2 Experimental analysis results

20 samples were collected in the present study using properly rinsed plastic bottles of 500 ml and kept in refrigerator until delivered to the laboratory for analysis. The parameters like pH, electrical conductivity and temperature were measured in the field itself and the rest physicochemical parameters were measured in the Mekelle Water supply service water testing laboratory and Mekelle University chemistry and Chemical Engineering departments laboratories. Samples codes, all measured parameters and simple statistical averages are given in Annexes 10 and 11.

4.1.1 Color analysis

The method is useful in the field by comparing the color of sample with a comparator. When viewed by transmitted light through a depth of several feet, pure water exhibits a light blue color which may be altered by the presence of organic matter to greenish blue, green, greenish yellow, yellow or brown. Color is removed to make water suitable for general and industrial applications. The visual comparison method was applied to all samples of potable water.

Representative samples were collected in clean glassware. The color was determined early before biological or physical changes occurred. The analysis indicated objectionable result.

4.1.2 Odor analysis

It is assumed that odor in water is created by chemicals-particularly organic chemicals or natural process of decomposition of vegetable matter or microorganisms activity. Industrial pollution or landfill leachate may be potential sources of taste-and odor-causing substances. So it can be stated that odor stimuli are of chemical nature (distilled water has no taste or odor).

The odor taste is an organoleptic determination and, as such, has the same limitations for the taste test. The instrument used for odor testing is the nose; therefor, only a qualitative taste is available for evaluation of water. The odor threshold test is, within its limitation, a quantitative test because the scope of the analysis is to determine the minimum quantity of a chemical that produces an odor. This is accomplished using dilution water and possibly and a large number of persons to make up the panel, in consideration that olfactory capability varies not only from person to person but also in a given person from day to day, or even during the same day. Odor should be tasted immediately after collection or preparation with odor free water. Temperature should be controlled and recorded during the taste. Odor from laboratory material and equipment may influence the determination. Smoking and eating before the taste should be avoided. Unquestionably, psychological factors do influence responses. Quantitative determinations may be also influenced by the freshness of the samples, sizeable losses by evaporation, storage temperature, and improper glassware, rubber, cork or plastic stoppers. Odor threshold tests are performed at 60 ^{0}C to obtain a better evaporation (hot threshold test) but 40 ^{0}C is also used.

Water tested from the distribution system may contain chlorine residual. Of course, the chlorine odor should be noted. Odor analysis of the tap water samples showed non objectionable results.

In 1989, USEPA issued a “Secondary Maximum Contaminant Level” (SMCL) of 3 Threshold Odor Number (TON) for odor [42]. Secondary standards are parameters not related to health. When a dilution is used, a number can be devised in clarifying odor. Sometimes laboratories report such units in TON.

Threshold Odor Number = $(V_T + V_D) / V_T$

Where:

V_T = Volume tested

V_D = Volume of dilution with odor free distilled water

For $V_D = 0$, TON = 1(lowest obtainable value)

$V_D = V_T$, TON = 2

$V_D = 2V_T$, TON = 3, etc.

“Taste and odor” and “color” determination, in spite of their aesthetic and organoleptic limitations and the fact that they are seldom connected to toxicologic effects, are nevertheless important in potable health hazard, and they play an important role in the consumer’s evaluation of drinking water.

4.1.3 Taste analysis

Taste is used to determine the acceptability of drinking water from a judgment based on sensory evaluation (nerve endings in papillae located on the tongue and stimulated by chemicals). In this thesis work the major concern was with the taste rating test and not the taste threshold taste, which is used for quantitative measurement of minimum detectable taste.

The temperature of the sampled water should be around 15 ^{0}C. As this is an organoleptic test, it has not particular scientific value. Nevertheless, this parameter is important because it attempts to measure the acceptability of drinking water. Objectionable taste results were obtained from the examination of tap water samples.

4.1.4 p^H analysis

The pH of the tap water samples are neutral or close to it as they all range from 6.7 to 8.5 which are within the permissible limits 6.5- 8.5 given by WHO and Ethiopian Standards as given in the experimental result given above. One of the main objectives in controlling pH is to produce water that minimizes corrosion or incrustation. These processes, which can cause considerable damage to the water supply systems, result from complex interactions between pH and other parameters, such as dissolved solids, dissolved gases, hardness, alkalinity, and temperature. The variation of pH in the study samples is shown figure 10.

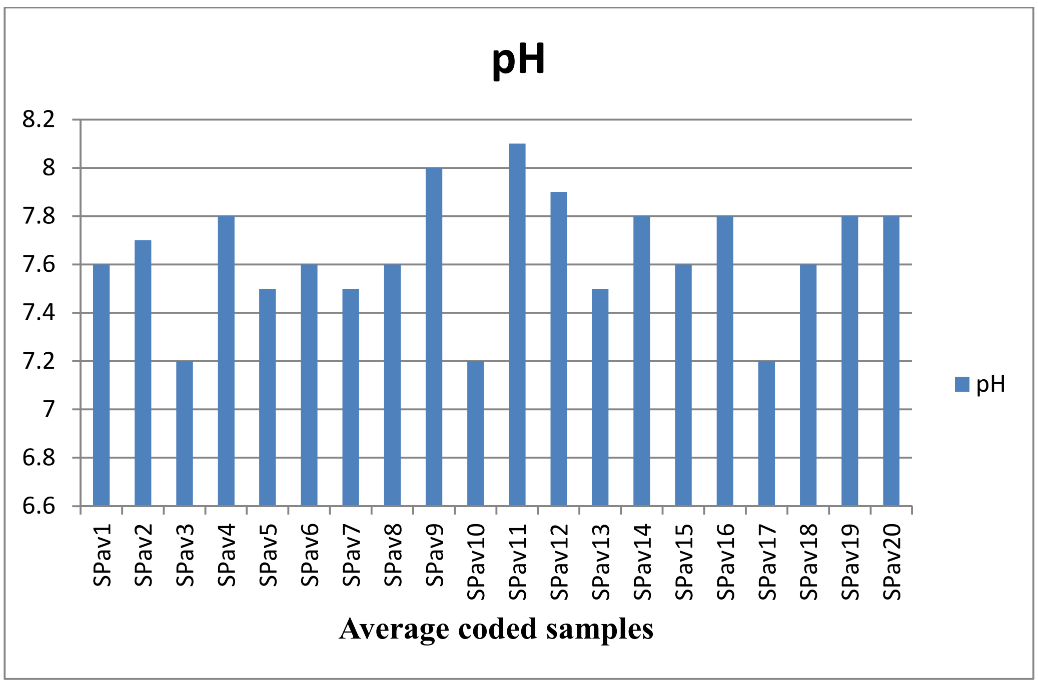


Figure 10. P^H variation of the samples examined [Annex11]

4.1.5 Turbidity analysis

The turbidity profile shown in figure 11 below varies significantly amongst the water samples throughout the study period and ranged from 8.7 to 45.0 NTU. The turbidity values obtained from the sampling points were higher than WHO and Ethiopian standard of 5 NTU. These values disqualify the tap water for direct house hold applications. High turbidity also creates difficulty to disinfect water properly.

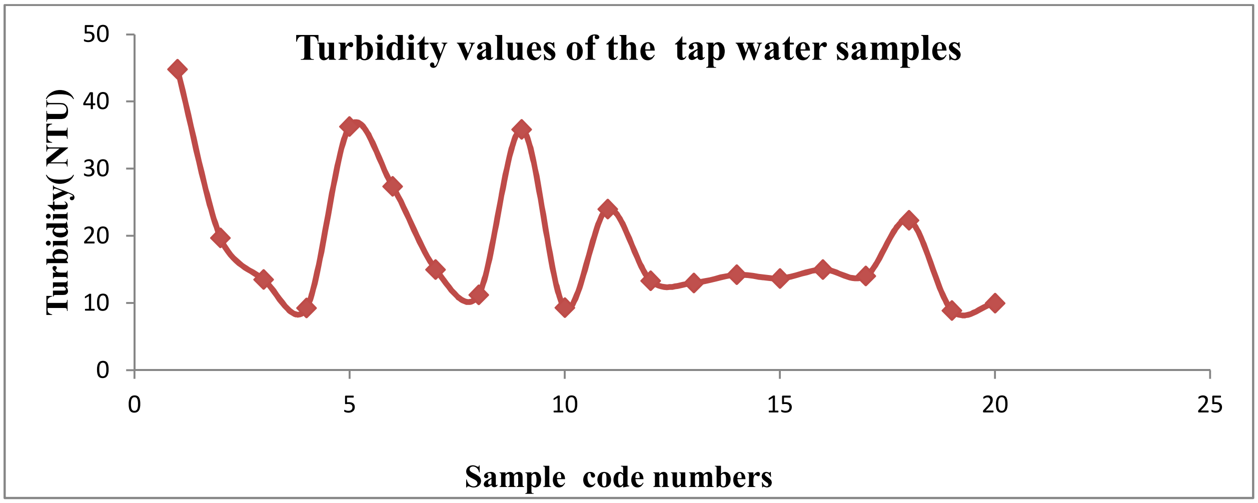


Figure 11. Turbidity Variation of the tap water samples

4.1.6 Electrical conductivity analysis

The Conductivity of the tap water in Mekelle town ranges from 585-1109µs/cm. Conductivity itself is not a human health concern, but because it is easily measured, it can serve as an indicator of other water quality problems. Water with high mineral content tends to have higher conductivity, which is a general indication of high dissolved solid concentration of the water. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. The variation of Electrical conductivity in the study period is shown in figure 15 below.

4.1.7 Total dissolved solids analysis

Total dissolved solids level in the tap water is 380-1175 ppm which exceeds the permissible limit of 500 ppm as per Indian standards and 1000 ppm as per WHO and Ethiopian Standards. The term total dissolved solids refer mainly to the inorganic substances that are dissolved in water.

The effects of TDS on drinking water quality depend on the levels of its individual components excessive hardness, taste, mineral depositions and corrosion are common properties of highly mineralized water. The variation of total dissolved solids of tap water studied is shown figure 12 below.

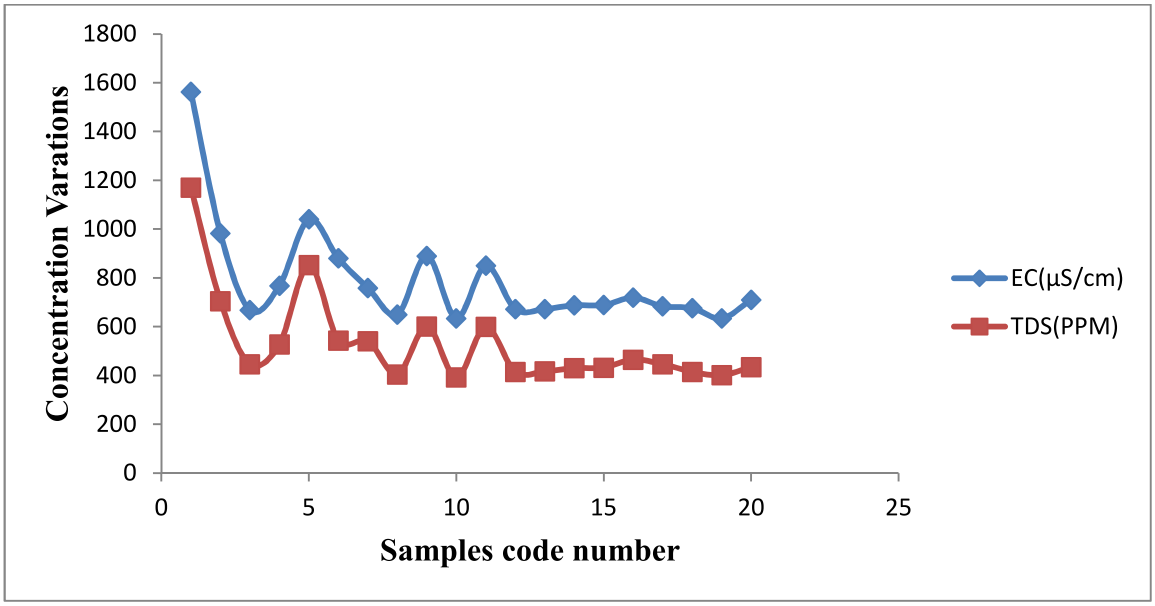


Figure 12. Conductivity and Total dissolved Solid variations of the current tap water being used at Mekelle town

4.1.8 Hardness analysis

Total Hardness of Mekelle town tap water varies from 299.9-792.34 mg/l as CaCO3 having an average value greater than 412 mg/l as CaCO3. The hardness values for the study area are found to be hard for all locations and determined to fall far from the higher edges of the desirable limit of WHO specification and Ethiopian standards. Hardness is caused by polyvalent metallic ions dissolved in water, which in natural water are principally magnesium and calcium. So the adverse effects of such hard water include Soap consumption by hard water cause economic loss. MgSO4 has laxative effects in person unaccustomed to it; precipitation by hard water adhere to the surface of tubs and sinks and may stain clothing, dishes and other items and causes periodic outbreaks of water-related diseases like skin diseases (irritation), dull and lifeless hair etc…

4.1.9 Alkalinity analysis

Alkalinity is the buffering capacity of water. It measures the ability of water to neutralize acids and bases there by maintaining a fairly stable pH. Water that is a good buffer contains compounds, such as bicarbonates, carbonates, and hydroxides, which combine with H^+ ions from the water there by raising the pH (more basic) of the water. Without this buffering capacity, any acid added to a lake would immediately change its pH.

Alkalinity of the samples is in the range of 154-295mg/L. The alkalinity levels of all the water samples are moderately high thus, resisting acidification of the groundwater, which are the sources for the tap water samples under study. The variation of total alkalinity in the study period is shown figure 13.

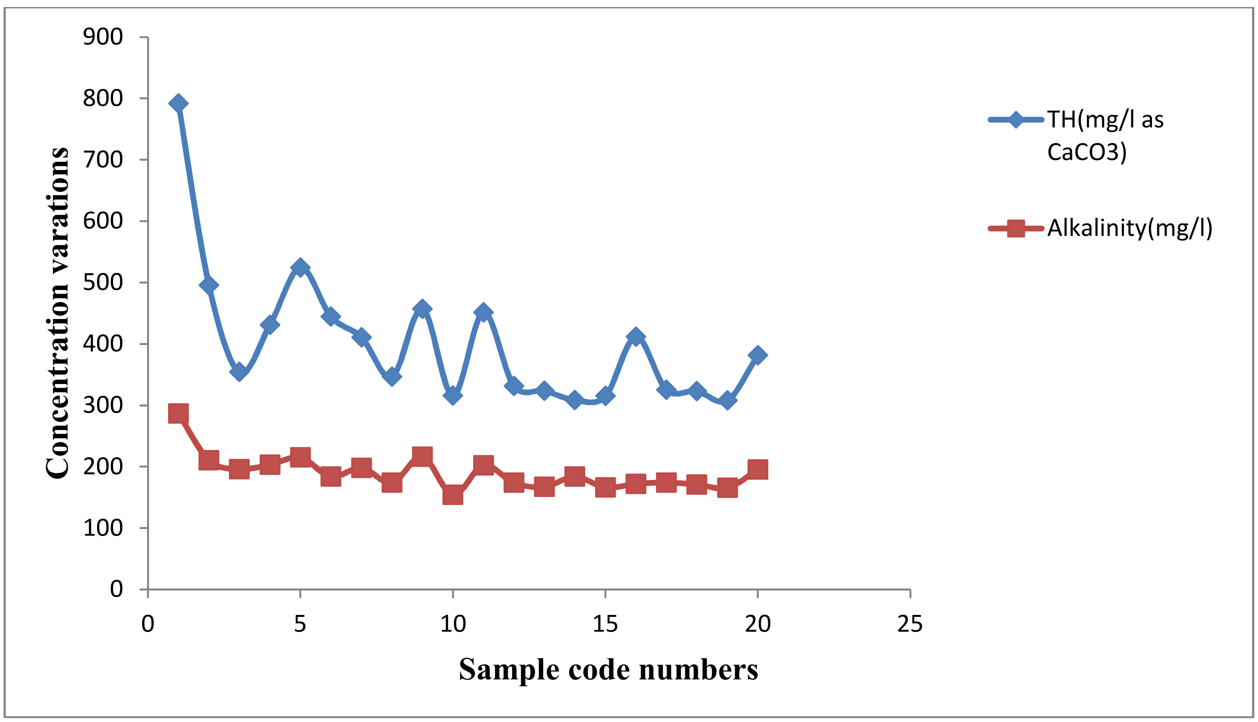


Figure 13. Total Hardness and total Alkalinity variation during the study period

4.2 productions of the natural coagulant/ absorbent

The proposed production method for natural coagulant from Moringa Stenopetala seed [Annex 8 and Figure 15] is shown in Figure 14. It represents major process operations starting from harvesting the pods to drying of the cake powder, which is the natural product in dry form.

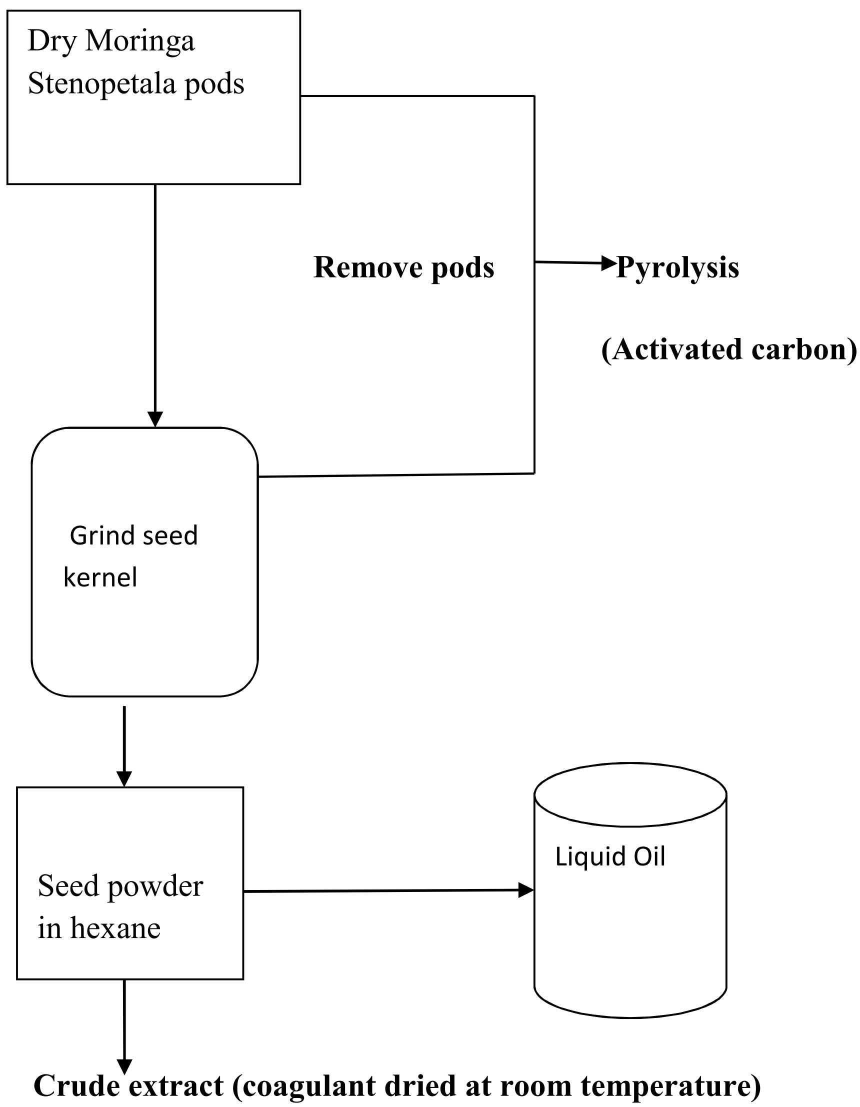


Figure 14. Extraction of the coagulant component from the seed

(The coagulant is a by- product of oil production)

4.2.1 Analysis of coagulant preparation from Moringa Stenopetala Seed

Dry stenopetala seeds shown in figure 15 were obtained from south Ethiopia, Borena rural areas and stored at room temperature. The seeds were shelled just before the extraction and the kernel was powdered using mortal grinder at MU chemical Engineering Unit operation laboratory.

Figure 15. Moringa Stenopetala seed ready for powdering

Oil was removed by mixing the powder in 96% hexane in 1:10 ratio (1gm of seed powder and 10ml hexane) for 28-32 min and the solids were separated by solid-liquid extraction laboratory equipment using 0.45µm fiberglass bed as shown below and centrifugation and dried at room temperature.

4.2.2 Characterization of the extracted coagulant/absorbent

The coagulant from the seed is believed to consist of a mixture of proteins with similar physical characteristics. The composition (peptide sequence information) of the mixtures was studied from mass spectrometry analysis of Moringa Stenopetala seed [24]. It has been reported that more than one protein family with coagulation activity is present in Moringa stenopetala and moringa oleifera seeds. M. stenopetala is not as widely known as its close relative, Moringa oleifera but often considered generally more desirable than M. oleifera [35].

4.3 Application of extracted coagulant/absorbent for water treatment

The crude extract was directly used as coagulant/absorbent. Tap water samples for study purpose were collected from Mekelle town districts. Doses of crude extract i.e. 50, 100, 150, 200,250, and 300 mg/l were selected for treatment .The coagulant was mixed with water samples having p^H value of 7.6. The jar was stirred rapidly at a paddle speed of 120 rpm for 10 min then stirred slowly at a paddle speed of 30 rpm for 20 min, and finally, the treated water was allowed to settle for 30 min. After sedimentation, supernatant of treated water was examined for its hardness. The softening results are shown in table 8 and figure 16.

Table 8. Softening Ground water using Moringa Stenopetala seed

Moringa Stenopetala dosage, mg/l	P^H	Total hardness
0	7.6	792.34
50	7.6	780.2
100	7.6	693.2
150	7.6	598.3
200	7.6	303.1
250	7.6	302
300	7.6	298

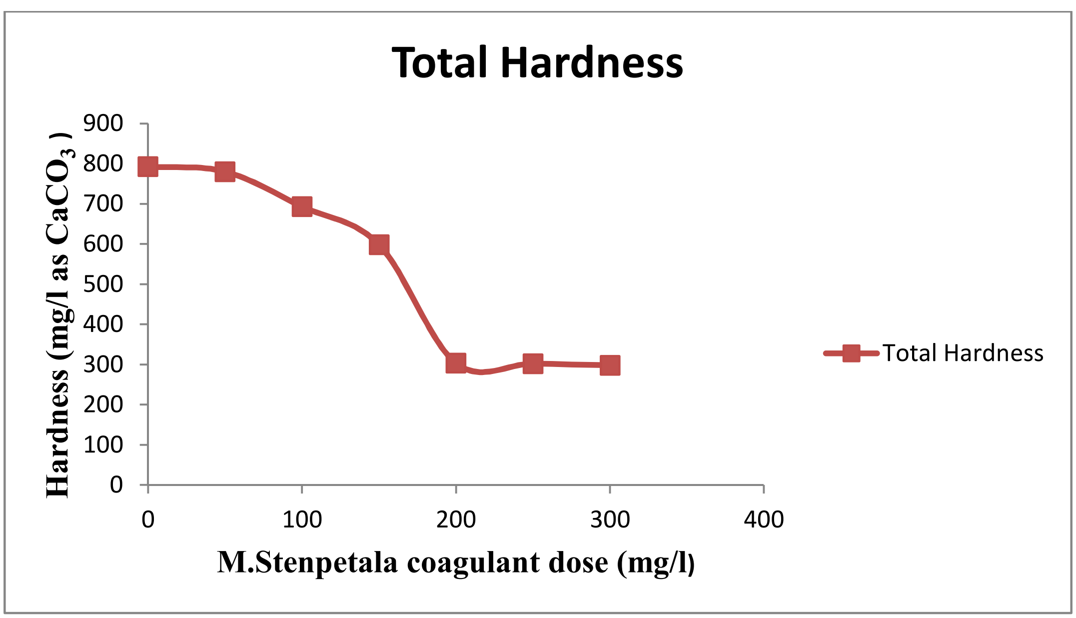


Figure 16. Ground water softening result using M.Stenopetala coagulant

Tap water samples having p^H value of 7.3 and initial hard 523.25 mg/l as $CaCO_3$ given in table 9 below were examined and the removal result is plotted as shown in figure 17.

Table 9. Softening Tap water using Moringa Stenopetala seed

Moringa Stenopetala dosage,mg/l	P^H	Total hardness
0	7.3	523.25
50	7.3	521
100	7.3	415
150	7.3	408.2
200	7.3	220.3
250	7.3	220.3
300	7.3	219.8

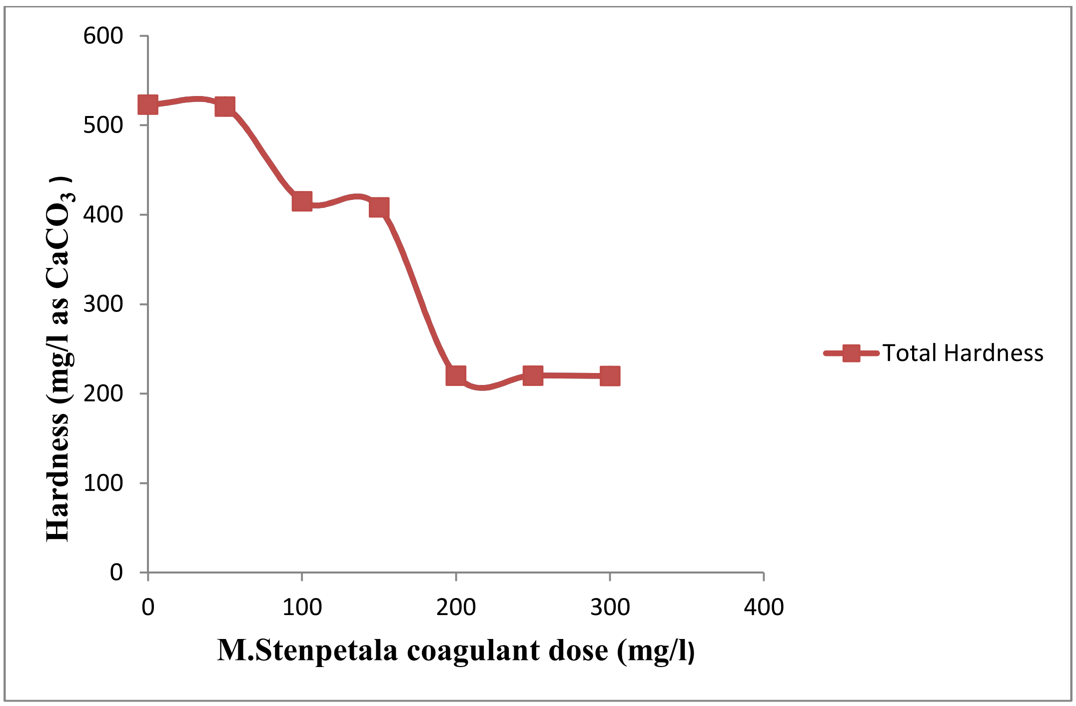


Figure 17. Tap water softening result using M.Stenopetala coagulant

4.3.1 Statistical analysis on factors affecting hardness removal process

Synthetic hard water is used for this analysis method.

The removal of hardness was calculated according to the following formula:

Removal efficiency = (initial hardness- final hardness)/initial hardness

The measured values of the water sample for the coagulation/ flocculation experiments were recorded in table 10. (Sample: Hardness 500 mg/l as $CaCO_3$, and pH 7.4)

Table 10. Experimental values of hardness removal

Run	Coded factors		Actual factors		Final hardness (Total)	hardness removal % (H removal)
	A	B	MS. Coagulant dose mg/l (CD)	P^H		
1	0	0	150	7.25	370	26
2	-1	-1	100	6.50	447.2	10.56
3	0	-1	150	6.50	368.9	26.22
4	1	1	200	8.00	265.5	46.90
5	0	0	150	7.25	371	25.80
6	-1	0	100	7.25	451	9.80
7	-1	1	100	8.00	448	10.40
8	1	-1	200	6.25	256.6	48.80
9	1	0	200	7.25	260	48.00
10	0	0	150	7.25	366.5	26.70
11	0	1	150	8.00	375	25
12	0	0	150	7.25	369	26.20
13	0	0	150	7.25	368.5	26.30

From table 11 the maximum hardness removal is obtained was 48.8% at experiment run number 8 shown above.

See ANOVA result analysis [Annex2]

Final Equation in Terms of Coded Factors:

$$\text{Hardness removal} = +26.08 + 18.82 * A - 0.55 * B - 0.43 * A * B + 3.11 * A^2 - 0.18 * B^2$$

Final Equationin Terms of Actual Factors:

$$\text{H removal} = -26.26588 + 0.087036 * CD + 5.58000 * PH - 0.011600 * CD * PH + 1.24510E\text{-}003 * CD^2 - 0.31510 * PH^2$$

As shown from the ANOVA result [Annex 2] second order polynomial equation is suggested to prove the relationship between the factors (A and B) and the investigated response (Hardness removal)

The phenomena of hardness removal is further supported by the fact that coagulant dose is the most significant variable that affects the percentage removal of hardness causing ions. Hardness removal process predicted vs. actual result is shown in figure 18 below.

The 3D graph shown in figure 19 below made this conclusion more reasonable.

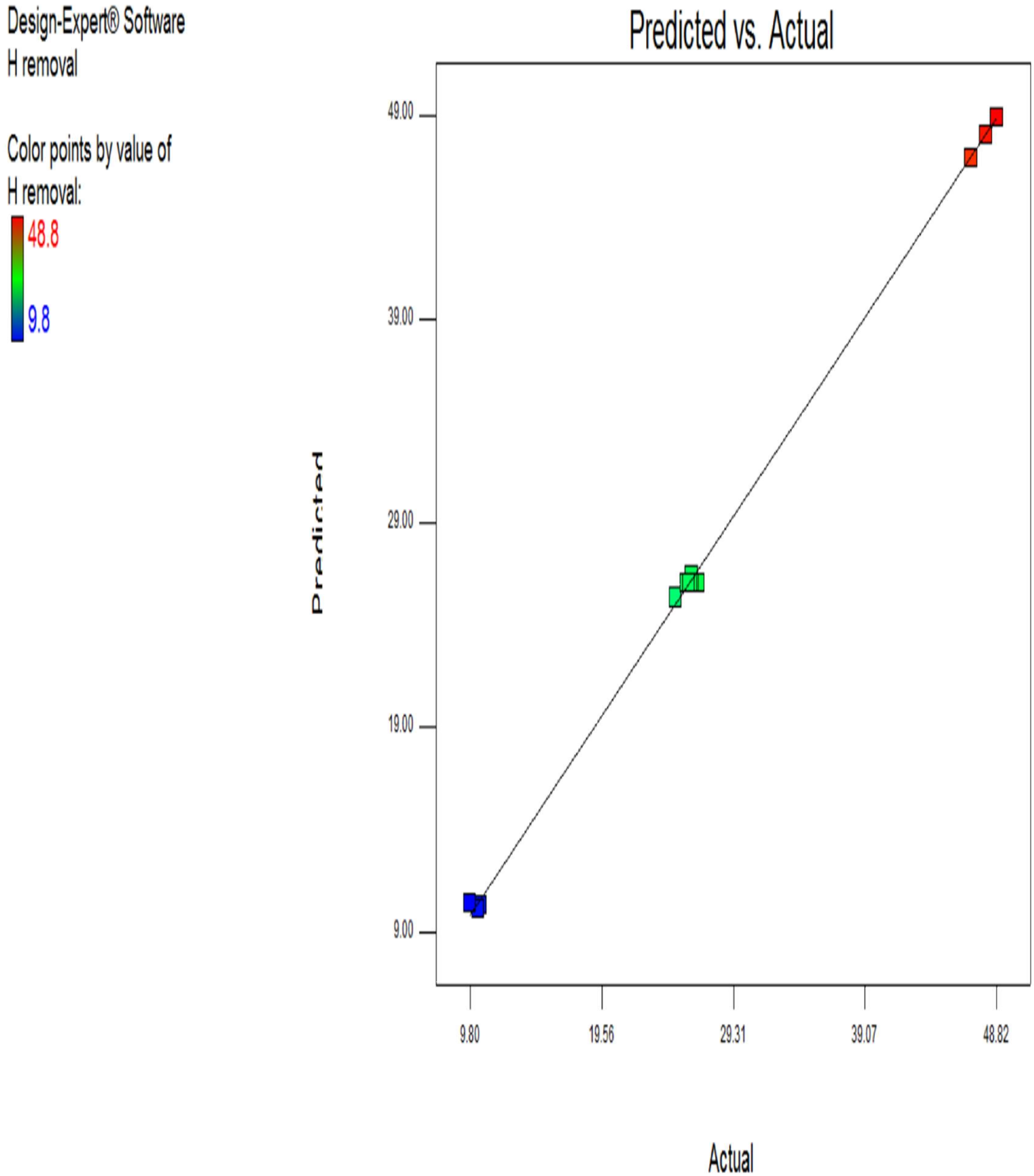


Figure 18. Predicted Vs Actual analysis of the hardness removal process

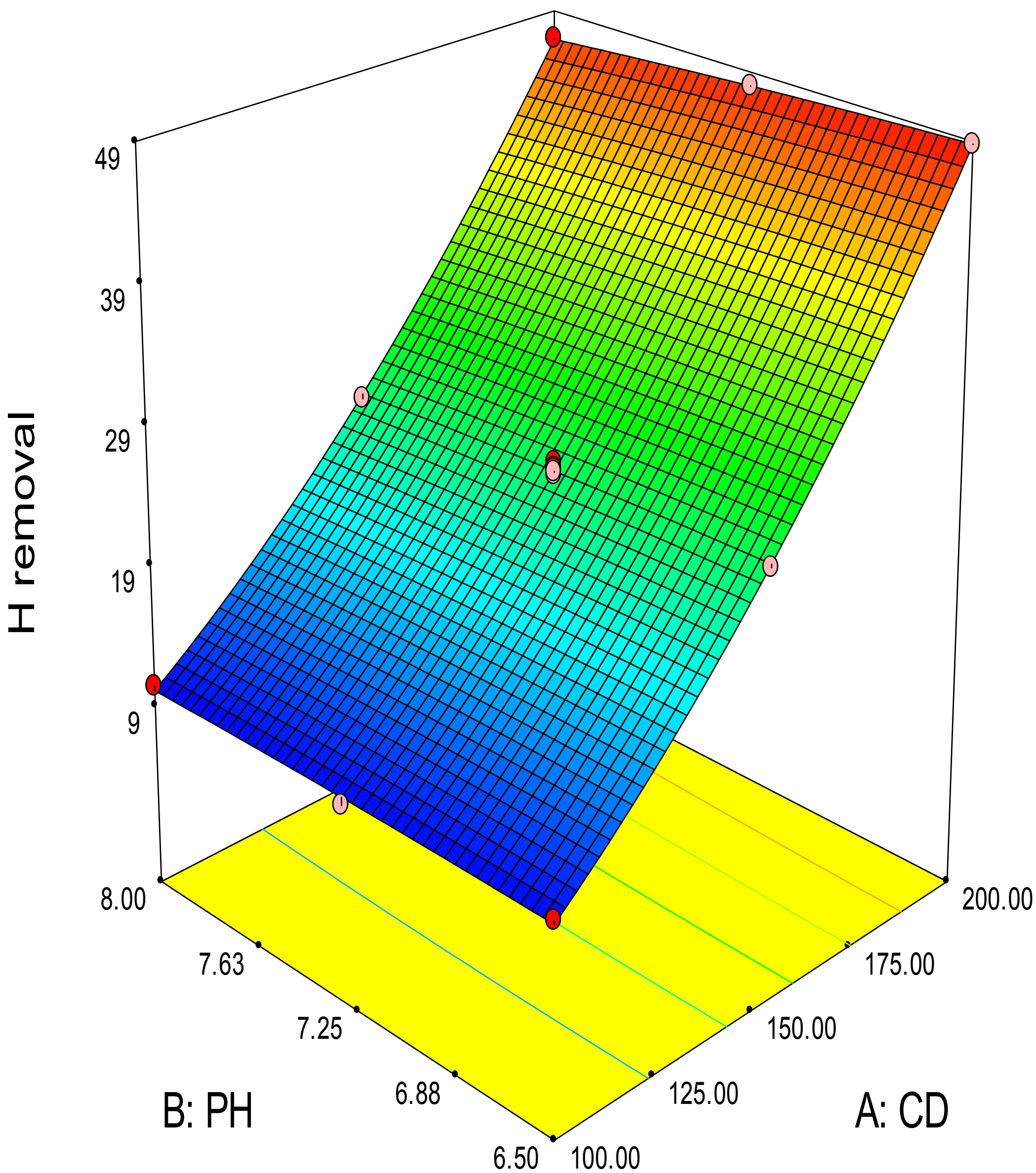


Figure 19. 3D result analysis plot for the parameters in hardness removal process

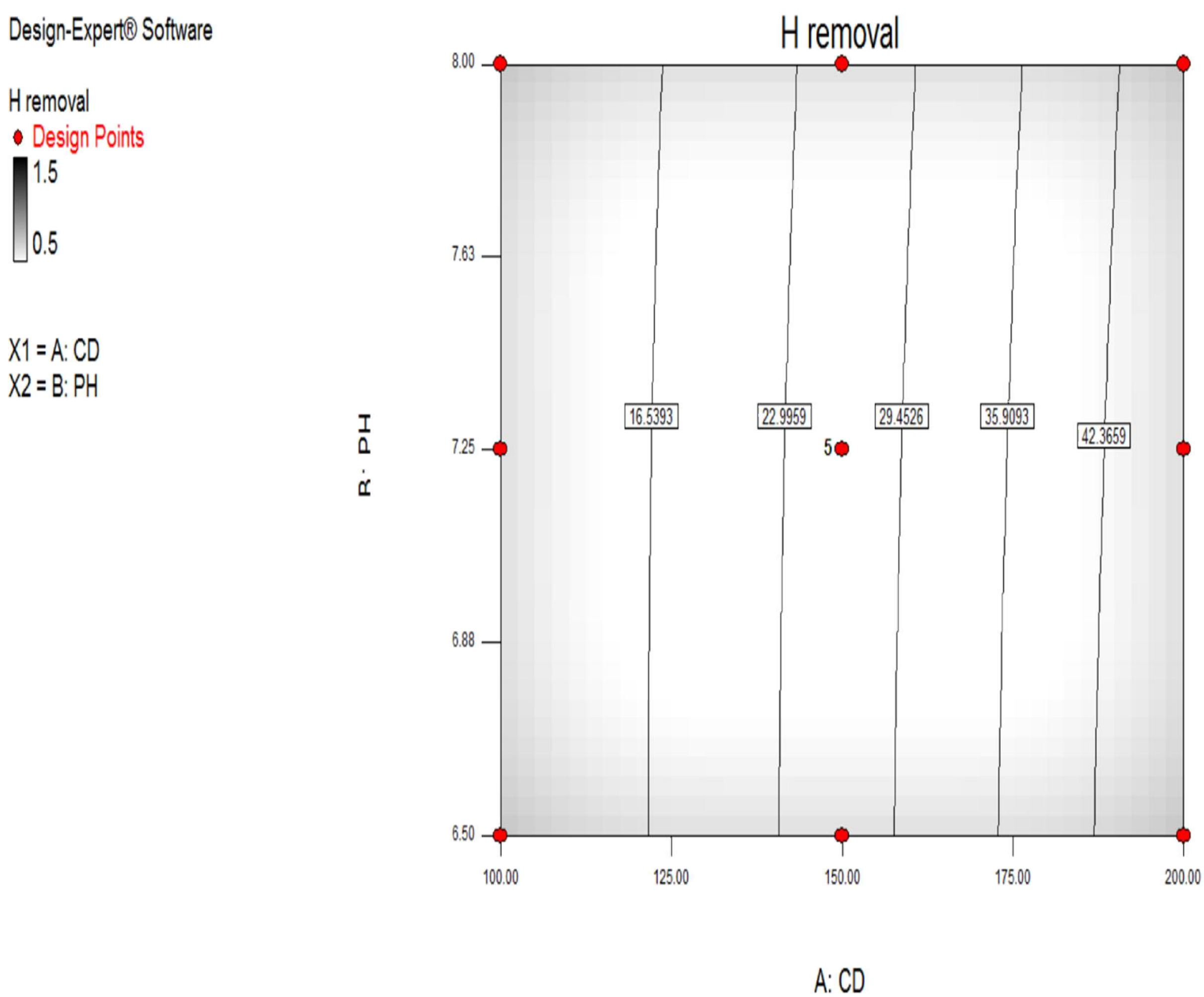


Figure 20. Model graphs of the hardness analysis result

4.3.1 Effect of P^H on the hardness removal of water

With slight decrease in pH of all water samples the precipitation of insoluble products of the reaction between the Moringa Stenopetala and the hardness causing ions seems to be better. However, the various concentrations of Moringa extract did not significantly affect the pH-value. This may be due to the natural buffering capacity of Moringa Stenopetala seed extract. The precipitates (solids / flocks) were light and did not settle easily so that the next process is better to be filtration. The chemical constituent of the precipitate is not known.

4.3.2 Effect of coagulant dose concentration on hardness removal

It was observed that for varying levels of initial hardness, increasing dosage of Moringa Stenopetala coagulant from 50 to 300 mg/ increased hardness reduction, until at a dosage of 200 mg/l. This observation served as the basis for the choice of the starting dosage of Moringa stenopetala in the softening studies from the source of tap water samples. The total hardness was almost the same at Moringa stenopetala dosages of 200 mg/l and above.

4.4 Comparative analysis of drinking water treatment

Conventional drinking water treatment includes, but is not limited to: coagulation, flocculation, sedimentation, filtration and disinfection. Coagulation and filtration are the most critical unit processes (other than disinfection) determining success or failure of the whole system and they are the bottlenecks for upgrading treatment plants.

At its simplest level, drinking water treatment seeks to remove turbidity (solids) and pathogens. Additional treatment may be applied to deal with specific problems, e.g. hardness and chemical contamination. The description of drinking water treatment discussed here addresses alternative input in the coagulation/flocculation step of the treatment process.

4.4.1Chemical coagulation in drinking water treatment

Coagulants are chemicals that are used to assist the removal of color and turbidity present in untreated, raw water. They do this by forming settle able particles in the form of flocs, which are then removed in downstream clarification or filtration treatment processes.

Coagulants may be classified as being inorganic or organic. Inorganic coagulants include those commonly used chemicals that rely on aluminum or iron. Organic coagulants include the so-called poly DADMAC (poly diallyldimethyl ammonium chloride) range of cationic polymers. These are special and expensive chemicals that are sometimes used in direct filtration plants when the low doses required make their use economical. However, they can sometimes be used in combination with inorganic types, often with spectacular and money-saving results. Alum is the first coagulant of choice because of its lower cost and its widespread availability.

Depending on the pH after the coagulant is added, two possible reactions are generally possible: With aluminum-based coagulants, the metal ion is hydrolyzed to form aluminum hydroxide floc as well as hydrogen ions. The hydrogen ions will react with the alkalinity of the water and in the process, decrease the pH of the water as can be seen from Equation (1) for alum

$Al_2\,(SO_4)_3.18H_2O \rightarrow 2Al^{3+} + 3SO_4^{2-} + 18H_2O \rightarrow 2Al\,(OH)_3 + 6H^+ + 3SO4^{2-} + 12H_2O$---- (1)

Similarly for ACH, which is described as being a pre-hydrolyzed coagulant, the following reaction takes place:

$Al_2\,(OH)_5Cl \rightarrow Al_2(OH)_5^+ + Cl^- + H_2O \rightarrow 2Al(OH)_3 + H^+ + Cl^-$ --------- (2)

Less H^+s are produced with ACH, reflecting the hydroxylated nature of this compound. PACl also shows similar hydrolysis as represented by Equation (3). In this reaction, three moles of H^+ are formed.

$Al_2\,(OH)_3Cl_3 \rightarrow Al_2(OH)_3^{\ 3+} + 3Cl^{2-} + 3H_2O \rightarrow 2Al(OH)_3^+ + 3H^+ + 3Cl^-$ -----------(3)

The above hydrolysis reactions typically take place at a dosed water pH in the range 5.8 to 7.5, depending on the particular coagulant. Color and colloidal matter is removed by adsorption onto/within the metal hydroxide hydrolysis products that are formed, and is sometimes referred to as sweep-floc coagulation. The coagulation is shown in figure 21 below.

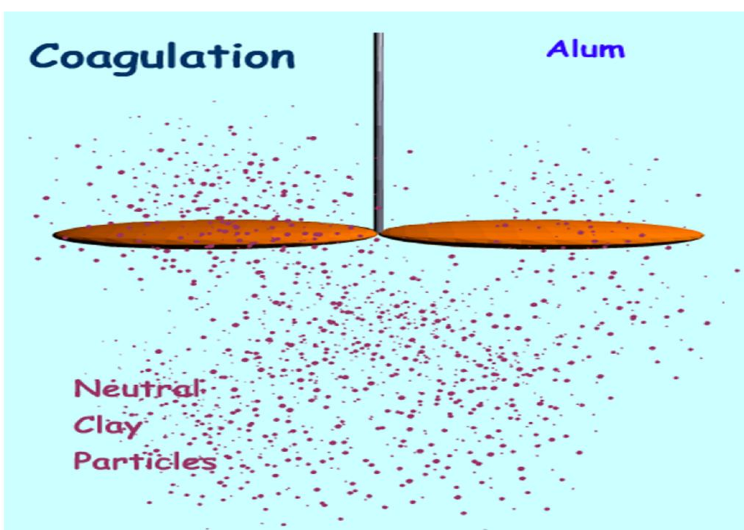


Figure 21. Cogulation process using Alum

If an excess of alum is added so that the dosed water pH is less than 5.0, then the metal ions (Al^{3+}) will directly neutralize the negatively charged organic compounds and colloids in the raw water. This allows the organic molecules to contribute to floc formation and is often referred to as enhanced coagulation and is often done to boost the removal of disinfection by-product precursors.

4.4.2 Analysis of the hardness removal Mechanism

4.4.2.1 Classic mechanisms

Polymeric coagulants can be cationic, anionic or nonionic. The former two are collectively termed as polyelectrolytes. Many studies concerning natural coagulants referred them as 'polyelectrolytes', even though many of these studies did not actually conduct in-depth chemical characterization to determine their ionic activity [30]. As such, this term should be used carefully, and be applied only after ionic activity is determined to be present in the coagulant. Natural coagulants are mostly either polysaccharides or proteins. In many cases, even though polymers labeled as non-ionic are not necessarily absent of charged interactions, as there may be interactions between the polymer and a solvent within a solution environment as the polymer may contain partially charged groups including –OH along its chain. It is imperative to fully grasp the underlying coagulation mechanisms associated with these natural coagulants so that complete understanding of their usage can be realized. Aggregation of Particulates in a solution can occur via four classic coagulation mechanisms: (a) double layer compression; (b) sweep flocculation; (c) adsorption and charge neutralization; and (d) adsorption and inter particle bridging. The presence of salts [or suitable coagulants] can cause compression of the double layer which destabilizes the particulates. Sweep flocculation occurs when coagulants encapsulate suspended particulates in a soft colloidal floc. Adsorption and charge neutralization refer to the sorption of two particulates with oppositely charged ions while inter particle bridging occurs when a coagulant provides a polymeric chain which sorbs particulates. Polymeric coagulants are generally associated with mechanisms (c) and (d) as their long-chained structures (especially polymers with high molecular weights) greatly increase the number of unoccupied adsorption sites. It appears that these two mechanisms provide underlying principles to the inner workings of plant based coagulants [38].

4.4.2.2 Precipitation reaction in hardness removal analysis

The decrease in hardness of all water samples may be due to precipitation of insoluble products of the reaction between the Moringa Stenopetala and the hardness-causing ions similar to precipitation softening using lime/soda ash. The Moringa Stenopetala seed extract appears to have natural buffering capacity. The precipitates (flocs) were light and did not settle easily. The chemical constituent of the precipitate is however not known.

4.4.3 The precipitation role analysis of Moringa stenopetala coagulant

The chemistry of coagulation/flocculation consists of three processes - flash mix, coagulation, and flocculation as shown in figure 22.

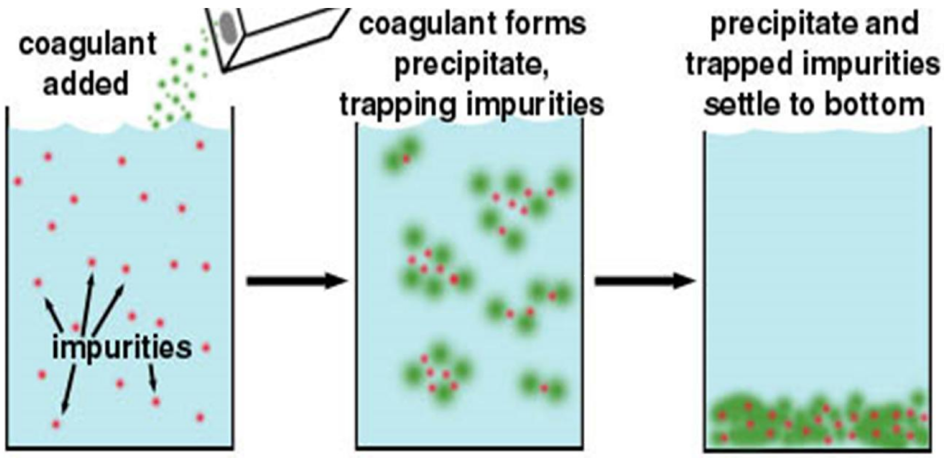


Figure 22. Chemistry of coagulation/flocculation

In the flash mixer, crude coagulant Moringa stenopetala extract powder is added to the water and the water is mixed quickly and violently. The purpose of this step is to evenly distribute the coagulant through the water. Flash mixing typically lasts 10 minute or less. If the water is mixed for less than thirty seconds, then the coagulant will not be properly mixed into the water. However, if the water is mixed for more than 10 minutes, then the mixer blades will shear the newly forming floc back into small particles.

After flash mixing, coagulation occurs. During coagulation, the coagulant neutralizes the electrical charges of the fine particles in the water, allowing the particles to come closer together and form large clumps precipitates.

The final step is flocculation. During flocculation, a process of gentle mixing brings the fine particles formed by coagulation into contact with each other. Flocculation typically lasts for about thirty to forty-five minutes. The flocculation basin often has a number of compartments with decreasing mixing speeds as the water advances through the basin. This compartmentalized chamber allows increasingly large floc to form without being broken apart by the mixing blades.

4.5 Optimum dose calculations of chemical and natural coagulant/absorbent

When calculating coagulant doses, or any other chemical for that matter, it is important to first state on what basis the dose is to be expressed. The most commonly used unit in water treatment is “mg/L”, which is a weight per volume unit. This is also the same as parts per million (ppm), but only when quoted as ppm on a weight/weight basis. To calculate the dose of a coagulant and other chemicals used for softening, we need to know the basic governing principles and chemical interactions of components in water softening. The total tap water produced at Mekelle town in 2006 EC (table 4) is given for calculation of cost and dose estimations of coagulants.

The total production of tap water for Mekelle in 2006 EC was 6766969000 L. (table 4)

And considering that alum required in particular season of most frequently designs given below

Monsoon =50 mg/l

Winter = 20 mg/l

Summer = 5 mg/l [31]

Taking 30 mg/l which is nearly equal to the average dose of alum as an assumption

Average annual alum required = $30mg/l*10^{-3}g/mg*10^{-3}kg/g*6766969m^3*1000l/m^3$

= 2030090.7kg alum is required at minimum

The coagulation/filtration process has traditionally been used to remove turbidity from drinking water supplies. However, the process is not restricted to the removal of particles. Coagulants render some dissolved species (e.g., NOM, inorganics, and hydrophobic SOCs) insoluble, and the metal hydroxide particles produced by the addition of metal salt coagulants can adsorb other dissolved species. Humic substances react with most coagulants [3]. Major components of a basic coagulation/filtration facility, as shown in Figure 23, include chemical feed systems; mixing equipment; basins for rapid mix, flocculation, settling, and filtration; filter media; sludge handling equipment; and filter backwash facilities. The process schematic shown in Figure 23 is typical of conventional coagulation/filtration facilities.

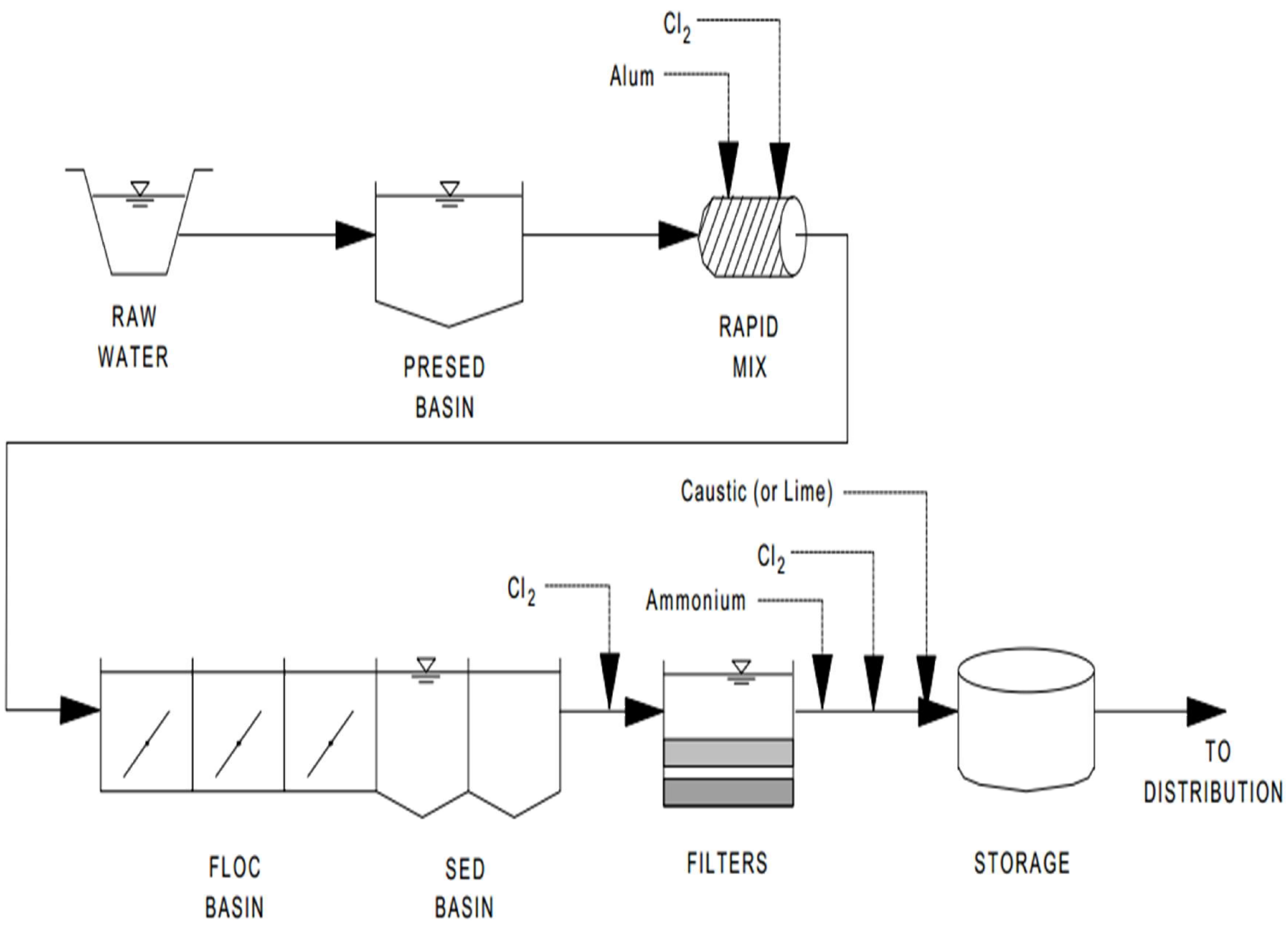


Figure 23.process flow schematic for a conventional water treatment plant

Lime, caustic and/or soda ash dosages are dependent on several raw water quality parameters including hardness, alkalinity, pH, temperature, and total dissolved solids.

Softening with lime is used particularly for water with high initial hardness (> 500mg/l) and suitable for water containing turbidity. Lime-soda softening cannot, however, reduce the hardness to values less than 40 mg/l

Design criteria for Lime-Soda process

It should be possible to remove 30 mg carbonate hardness and 200 mg/l total hardness by this process and from stoichiometry we can calculate chemical requirements as follows

Lime and soda required

Lime required for alkalinity

Molecular weight of:

$CaCO_3$ = 40+12+48 = 100

CaO = 40 +16 =56

100 mg/l of $CaCO_3$ alkalinity requirement = 56 mg/l of CaO

110 mg/l of $CaCO_3$ requires (56/100)/110 = 61.6 mg/l of CaO

Lime required for Magnesium

24 mg/l of magnesium requires 56 mg/l of CaO

1 mg/l of magnesium requires 56/24 mg/l of CaO

3.5 mg/l of magnesium requires (56/24)*3.5 = 8.2mg/l of CaO

Hence, the total pure lime required = 61.6 + 8.2 =69.8 mg/l

Also 56 kg of pure lime (CaO) is equivalent to74 Kg of hydrated lime

Hence, hydrated lime required = (69.8 *74)/56 = 92.23 mg/l

Soda (Na_2CO_3):

Soda is required for non- Carbonate hardness, as follows

100 mg/l of NCH requires 106 mg/l of Na_2CO_3

161.6 mg/l of NCH requires = (106/100)*161.6=65.59 mg/l of Na_2CO_3

Total quantity of lime required = 92.23 mg/l * 10^{-3} g/mg* 10^{-3} kg/g * 6766969m^3*1000l/m^3

= 624,117,550.9 * 10^{-3}kg = 624117.551 kg

Total quantity of soda required = 65.59 mg/l * 10^{-3} g/mg* 10^{-3} kg/g * 6766969m^3*1000l/m^3

= 443845496.7 * 10^{-3} kg

Precipitative softening processes are employed to remove hardness from raw drinking water sources. In most waters, hardness is primarily due to the presence of calcium and magnesium. Lime, caustic and/or soda ash dosages are dependent on several raw water quality parameters including hardness, alkalinity, pH, temperature, and total dissolved solids. Typical softening plant components are illustrated schematically in Figure 24 below.

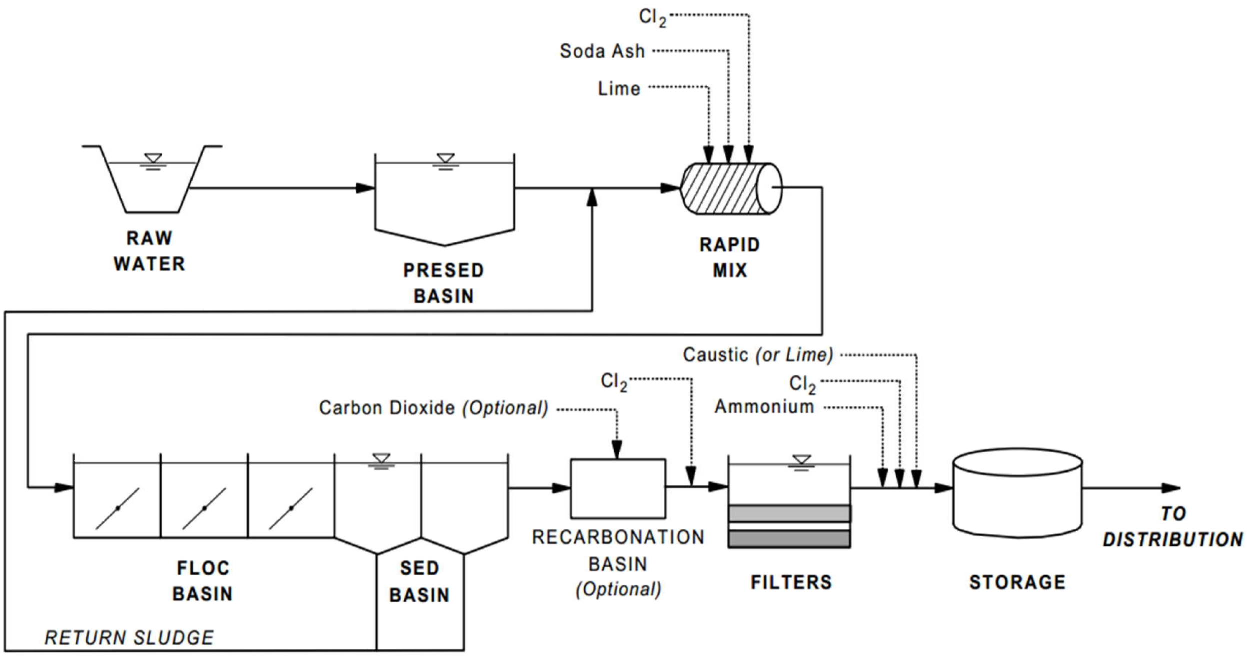


Figure 24.Process flow schematic for a lime softening water treatment plant

The coagulant amount required if the chemical softening is to be replaced by natural Moringa stenopetala seed extract is applied:

Having the optimum dose found above = 200mg/l

Total extract required = 200 mg/l *6766969 m^3 * 1000l/m^3 *10^{-3} kg/g = 1,353,393,800 kg

Having in mind that the natural coagulant is the bi-product of oil processing from Moringa stenopetala seed, the coagulant extracted from moringa stenopetala seed has an added advantage of removing turbidity [Annex 4]. Hence the coagulant obtained from this natural seed can serve not only for hardness removal but also as a best substitute for chemical coagulants used for turbidity removal.

The amount calculated for annual consumption of nearly 350,000 people is to be supported. Most commonly used coagulants are given [Annex 3].

4.5.2 Advantage of the natural coagulant over the Chemical requirement

Aluminum and iron salts are commonly used as chemical coagulants. Utilization of alum has raised a public health concern because of the large amount of sludge produced during the treatment and the high level of aluminum that remains in the treated water. The intake of large quantity of alum salt may cause Alzheimer disease. For these reasons, and also due to others advantages of natural coagulants/flocculants over chemicals, water treatment plans should adopted the use of natural polymers for the treatment of drinking water. Natural polyelectrolytes have been used as auxiliary of flocculation and coagulation in wastewater treatment and water cleaning process.

4.5.3 Mechanisms for large scale application of natural coagulants and possible drawbacks

The main drawback in using crude Moringa seed extract for large-scale water treatment application is the release of organic matter and nutrients (nitrate and phosphate) to the water[. Most of the coagulation and antimicrobial studies of moringa seeds are based on lab scale experiments and household level applications. There are very few reports where the crude extract has been used in pilot and full-scale water treatment studies [29]. The presence of organic matter in water significantly influences performance of unit processes (oxidation, coagulation and adsorption), consumes disinfectant chemicals, and becomes a substrate for biological re-growth (affecting biological stability). It plays a role in the transport and concentration of inorganic and organic pollutants and imparts color, taste and odor [17, 35]. Removal of NOM from drinking water sources can be realized by enhanced coagulation, carbon adsorption, IEX and membrane filtration, which are often expensive. The organic and nutrient release from the seed can be avoided either by purifying the coagulant component or by removing the released substances from the water. In the prior option the substances of concern are removed before any complications are inflicted to the water treatment system (prevention is better than cure).The latter option is not preferred since the removal of organic matter and nutrients from the water complicates the treatment process and increases costs. The methods employed to purify MSCP so far are cumbersome and involve a number of steps [26]. Scale-up of the methods would be capital intensive and require complex facilities. Despite the multiple purposes of M.Stenopetala and its availability, expensive purification of the coagulant hinders its use in large-scale water treatment plants. Large volume production of the coagulant protein remains a big challenge.

5. Economic Evaluations

5.1 Cost comparison of alternative coagulants for Ethiopia

An economic analysis in Ethiopian context revealed that the Moringa stenopetala cake may be obtained at zero cost as a by-product of oil extraction.

Table 11. Cost comparison

Alternative Coagulants	COST(ETB)
Alum and soda ash	6,012
Flocculant polyelectrolyte	1284
Anikem polyelectrolyte	1272
Moringa seed purchased from small holder farmers	300
Moringa plantations operated by water utilities	0

- Costs expressed as Ethiopian Birr (ETB) per 1000m3 of water treated
- The cost given is a rough estimation based on the Ethiopian translation of a research made in Malawi in 1994.

Sources indicate that import/export process of chemicals in Ethiopia is cumbersome, due to complex and require legal and government procedures, even causing withdrawal of foreign companies. As a landlocked country transport costs and transaction costs at borders are relatively high.

Moringa provides:

- leaves - either fresh or dried and powdered - are used as vegetable in meals. Locally (Konso) leaves are consumed with cereal balls as staple food. Locally fresh leaves are marketed.
- Seed oil: locally oil is used for lighting.
- Seed cake used for water purification. At local level it is reported that seed cake is used as coagulant purifier [35], but no indication that seeds are traded for this purpose.

Currently in Ethiopia there seems to be no market for the seed cake that can be used as water purifier. No information was found that shows that water purification plants in Ethiopia already use Moringa instead of chemicals.

The seeds of M. stenopetala contain edible oil that can be used for cooking and as salad dressing. Oil extracted from M. stenopetala seeds does not deteriorate under a standard procedure used during extraction and has acceptable organoleptic quality [31]. M. stenopetala seed oil showed higher stability to oxidative rancidity compared to M. oleifera seed oil. Reports indicated that M. oleifera seed oil could be used for cooking, in salad dressings, and in the manufacture of perfumes and cosmetics [35]. Thus, it can be expected that M. stenopetala seed could have its own unique properties and possibly be used for similar purposes. To date, no study has been done on the oil production potential, characteristics, or applications of M. stenopetala seed oil in Ethiopia. Thus, this is one potential area of future research. The Value chain map below explains the multipurpose of Moringa stenopetala tree is given in figure 25 below

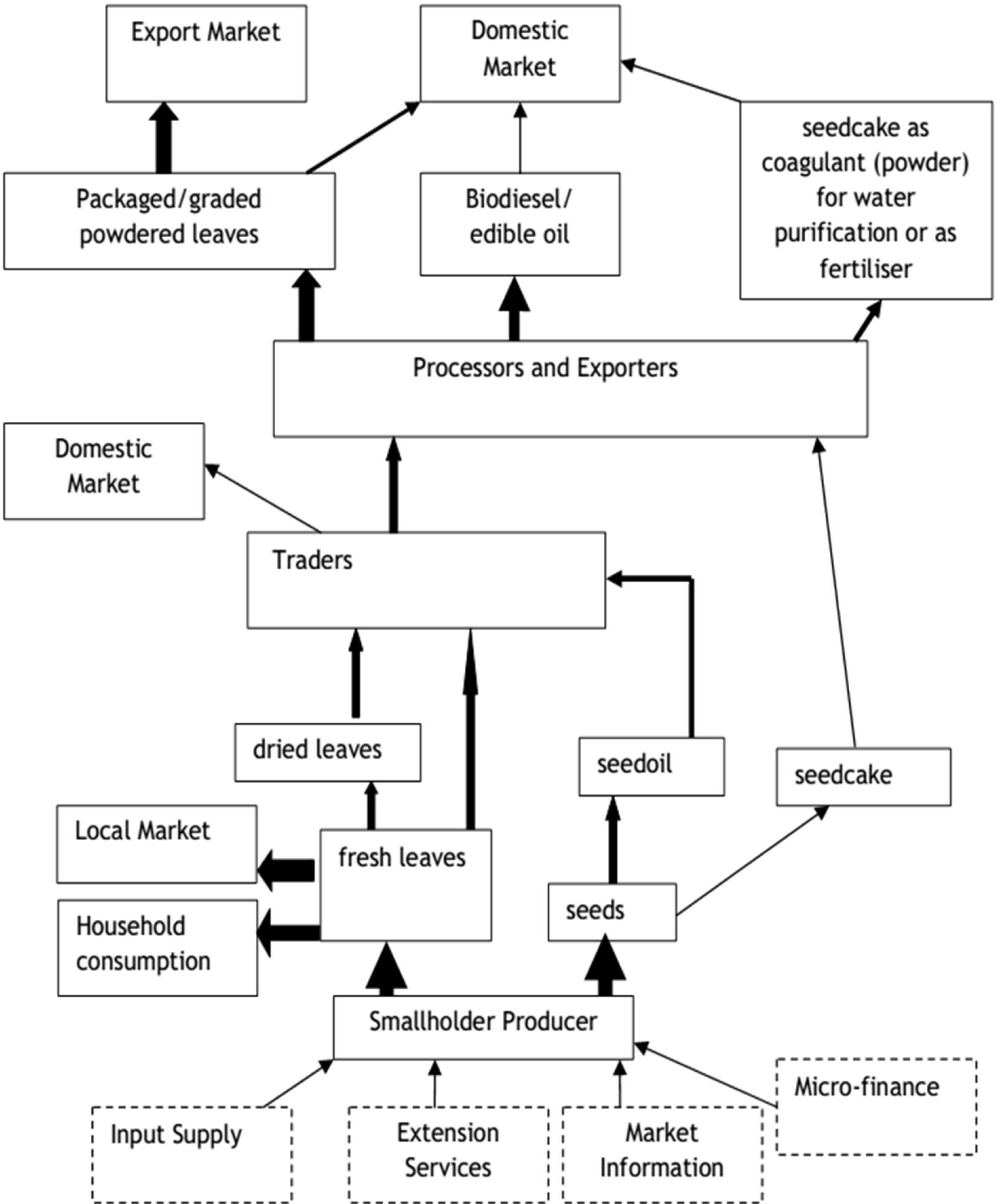


Figure 25. Potential Moringa value chain map in Ethiopia

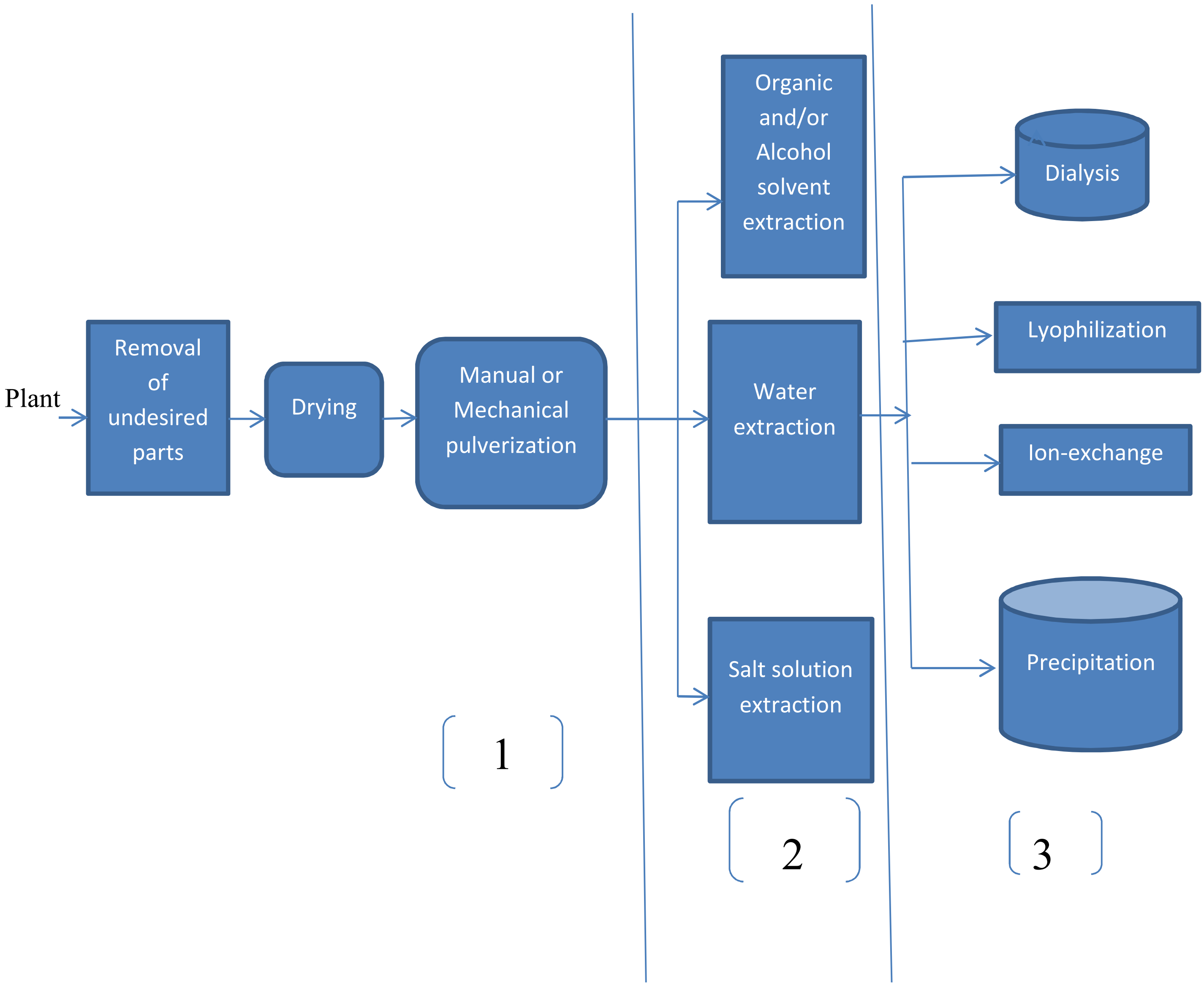
5.1 Process description and technology selection for coagulant protein extraction from moringa stenopetala for large scale application

The proposed production method for natural coagulant from Moringa oleifera seed is shown in Figure 28. It represent process details starting from harvesting the pods, grinding, sieving of the seeds, oil extraction using hexane, salt extraction with 1 M NaCl, microfiltration using the filter size of 0.2 μ m, and freeze drying of the permeate, which is the natural product in dry form.

Oil Extraction

Oil extraction from Moringa Stenopetala seed was carried out to remove the oil from the seed. Oil extraction was done by adding hexane to the seed powder. GUNT solid liquid separating apparatus was used. The extraction of oil from the seeds was done until the hexane became colorless. The Moringa stenopetala cake was dried and weighed. The oil content was 25% of the seed weight. The Moringa stenopetala cake residue stock after oil extraction was used in this research work. The tertiary purification process shown in the figure below is recommendable for large scale application and so that the most pure coagulant component can be commercialized [26, 28].

The coagulant is obtained from the byproduct of oil extraction. After coagulant extraction, the residue can be used as a fertilizer or processed for animal fodder. The multiple uses of the plant indicate significant potential of MS for commercial applications and it is becoming an important income generator. Technically speaking the part that is used for water treatment is a waste product and it can be acquired at a very low cost. The general processing step for these economic uses are presented in figure 26below



Primary processing [1] Secondary Processing (Extraction) [2] Tertiary Processing (Purification) [3]

Figure 26. General processing steps in preparation of moringa coagulants

5.2 Moringa Stenopetala and its basic properties for future economic use in Ethiopia

M. stenopetala seeds are triangular, have three wings, and are covered with a spongy, thick yellowish seed coat. The kernel has a whitish-grey color and oval shape, and its thickness decreases from the center towards either end along the length of the seed. It was reported that a single 4 to 13-year-old M.stenopetala tree can produce up to 4,500-10,000 seeds that weigh 2.3 5kg from about 500-1,000 pods [30,31]. The same report indicated that 1kg of M. stenopetala seed contains about 1,795-2,078 seeds [35]. [Annex 5]

M.stenopetala seeds are reported to be larger than the seeds of M.oleifera [35]. The average weight of under hulled seeds of M. stenopetala was found to be 73.6 g/100 seeds. This is much higher than that reported (29.9 to 30.2 g/100 seeds) for Moringa oleifera seeds [24]. The average weight of the kernel (59.6 g/100 seeds) of M. stenopetala seeds is more than double the values reported (21.2-22.5 g/100 seeds) for M. oleifera seeds. The kernel-to- hull ratio and the average weight per seed of M. stenopetala are 0.6 g and 79.7: 20.3, respectively [Annex 5].

The average fat content (41.4± 1.59 g/100 g) of M. stenopetala seeds is higher than 33.6 g/100 g and 27.5g/100g fat reported for the common oilseeds viz., flax seed, and safflower seed, respectively [35].

Moringa Stenopetala is known to be a natural cationic polyelectrolyte and flocculant, with a chemical composition of basic polypeptides with molecular weights ranging from 6000 to 16,000 daltons, containing up to six amino acids of mainly glutamic acid, methionine and arginine [35, 40]. As a polyelectrolyte it may therefore be postulated that Moringa Stenopetala removes hardness in water through absorption and inter-particle bridging Hence Moringa Stenopetala plant for sale to water supply companies would provide new job opportunities for the local population.

5.3 Analysis of commercialization for Moringa stenopetala seeds

It has been explained in previous sections that usage of plant based coagulants provides environmental benefits and numerous lab-scale studies have proven that they are technically feasible for small-scale utilization. Nevertheless, in terms of commercialization, the bottom line is that it will always be based primarily on whether the scale-up system can sustain similar treatment performance at comparable (or reduced) cost with the natural coagulants when compared with established chemical coagulants [31]. There are a few anecdotal reports that provide the costs of raw materials of the coagulants but direct comparisons in terms of coagulant types, Processing stages and prices in different geographical regions are a very complicated task given the different exchange rates, inflation factor and varying accuracies of the costing values. Thus, the costs stated in table 14 above should be treated as an indication rather than absolute values. A comprehensive survey conducted reveals that costing analysis of Moringa seeds has been given priority over other natural coagulants and this is unsurprising given the well-publicized advantages of the plant.

6. Conclusion and Recommendation

6.1 Conclusion

The careful analysis, interpretation and discussions of the physicochemical parameters of tap water of Mekelle town revealed that the current water quality problem is beyond the limit and needs serious treatment. Examination results the total 20 samples were not in agreement with both Ethiopian standard and WHO guideline on the basis of, like, color, taste, TDS, turbidity and hardness. The quality of drinking water available in the town in turn reflects the extent that the concerned authorities should strictly monitor the quality of drinking water being supplied to the consumers.

Moringa Stenopetal seeds were suggested as alternative natural materials in coagulation process of drinking water. In a lab scale hardness removal study, Moringa Stenopetala is obtained to have potential to be used in the treatment of hard waters for domestic use. Hardness removal efficiency of Moringa Stenopetala was found to increase with increasing dosage. Moringa Stenopetal is biodegradable, eco-friendly and has not been found toxic.

6.2 Recommendation

Developing sound water resource management programs will be crucial for poverty reduction, economic growth, food security and maintenance of natural systems. The need for greater community participation in water management of Mekelle town should not be ignored and the water quality problems are recommendable to be alleviated as soon as possible.

Despite its actual and potential roles, M. stenopetala has been given little attention. Unlike M.oleifera, little scientific research has been conducted on the potential uses of M. stenopetala. The limited research carried out so far has focused mainly on survey works conducted on the field to assess the traditional uses of M. stenopetala based on information obtained from Moringa growers.

Since M. stenopetala grows in the Gamo Gofa, Sidamo, and Kaffa administrative regions of southern Ethiopia, more in-depth investigation needs to be undertaken in areas where it is domesticated and used in order to assess the various uses of this important tree in different communities and search wide spread cultivation Mechanism.

The following recommendations are also made:

1. More surveys of water quality analysis should be carried out in the municipality as well as other towns.

2. A fitting water purification method for purifying water from the tap water source needs to be developed for the area of study as soon as possible.

3. Household treatment such as boiling should be encouraged before the tap water is used for drinking purposes until well developed treatment mechanism is applied.

4. In-depth study would be required to identify the active coagulation site in the protein. If it is desired to synthesize the peptide, identification of the minimum number of residues required for its activity is important to reduce the cost and simplify the procedure.

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List of Annexes

Annex 1. Mekelle town drinking water production of 2003 EC (Source: Mekelle Water supply service office)

production I 2003 e.c

S.No	Well	Hamle	Nehasse	Meskerem	Tikmity	Hid	Tahi	Tiri	Yeka	mega	myazia	gin	sen	SUM
1	FPW9	68035	48467	57991	63895	67194	64446	61694	49344	72450	62935	64839	63887	745,177
2	PW10	9849	5609	1995	14308	12199	15327	17843	14299	15180	17654	17909	17781.5	159,954
3	PW3	5008	4289	9753	9322	13209	12650	13530	12776	13800	12872	11091	11981.5	130,282
4	TW5	19644	13640	7377	18432	20751	20809	20507	18601	20010	20386	20212	20299	220,668
5	Gomata New	20942	23705	24876	26124	27311	24598	24724	23983	28980	27957	27973	27965	309,138
6	FPW1	36430	36953	37342	34872	15020	13734	14353	13653	24150	12699	12107	12403	263,716
7	Dandera	38401	14718	63870	51216	52318	50797	20481	32093	41400	33183	47504	40343.5	486,325
8	TW1	51163	51107	56215	57868	57580	55009	59281	61490	60720	57219	27745	42482	637,879
9	TW2	4283	6865	16258	15356	12902	9843	8051	15216	15180	14789	15499	15144	149,386
10	PW2	23419	22203	23001	34426	33600	32536	33100	24277	28980	28201	28414	28307.5	340,465
11	TW4	0	0	0	0	0	0	0	0	0	0	0	0	0
12	PW8	13042	13264	0	0	0	0	0	0	16422	24210	27537	25873.5	120,349
13	PW7	31103	36852	42190	37593	36071	32868	33582	33626	35880	29128	26883	28005.5	403,782
14	Lachi	4274	4303	5828	5240	8425	5240	6304	8467	8280	1385	1385	1385	60,516
15	PW4	6342	5652	5824	8911	9071	8866	8465	9390	8280	9483	9585	9534	99,403
16	Gomata Old	0	0	0	1433	482	3347	3512	3871	13800	0	0	0	26,445
17	Sewhi Nigus	3188	759	1020	4611	4482	4535	2624	5241	12356	3181	3061	3121	48,179
18	FPW-5	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Feleg daero	0	0	0	0	0	0	0	0		1398	3352	2375	7,125
18	Chinferes-1								136800	136800	35957	29520	32738.5	371,816
19	Chinferes-2	0	0	0	0	0	0	0	0	30424	46117	50100	48108.5	174,750
	Monthly Sum	335,123	288,386	353,540	383,607	370,615	354,605	328,051	463,127	583,092	438,754	424,716	431,735	4,755,351

Annex 2. ANOVA result analysis

Response 1 Hardness removal Transform: None

Sequential Model Sum of Squares [Type I]

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Mean vs Total	9786.20	1	9786.20		
Linear vs Mean	2127.70	2	1063.85	332.35	< 0.0001
2FI vs Linear	0.76	1	0.76	0.22	0.6517
Quadratic vs 2FI30.05	2	15.02	87.21	< 0.0001	Suggested
Cubic vs Quadratic	0.24	2	0.12	0.63	0.5717
Residual 0.96	5	0.19			
Total 11945.91	13	918.92			

Response 1 Hardness removal

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	2158.50	5	431.70	2506.10	< 0.0001
A-CD	*2125.91*	*1*	*2125.91*	*12341.25*	*< 0.0001*
B-PH	*1.79*	*1*	*1.79*	*10.41*	*0.0145*
AB	*0.76*	*1*	*0.76*	*4.39*	*0.0743*
A^2	*26.76*	*1*	*26.76*	*155.35*	*< 0.0001sgnt*
B^2	*0.087*	*1*	*0.087*	*0.50*	*0.5008*
Residual	1.21	7	0.17		
Lack of Fit	*0.75*	*3*	*0.252.16*	*0.2352 non significant*	
Pure Error	*0.46*	*4*	*0.11*		
Cor Total	2159.71	12			

Std. Dev.	0.42	R-Squared	0.9994
Mean	27.44	Adj R-Squared	0.9990
C.V. %	1.51	Pred R-Squared	0.9970
PRESS	6.57	Adeq Precision	137.393

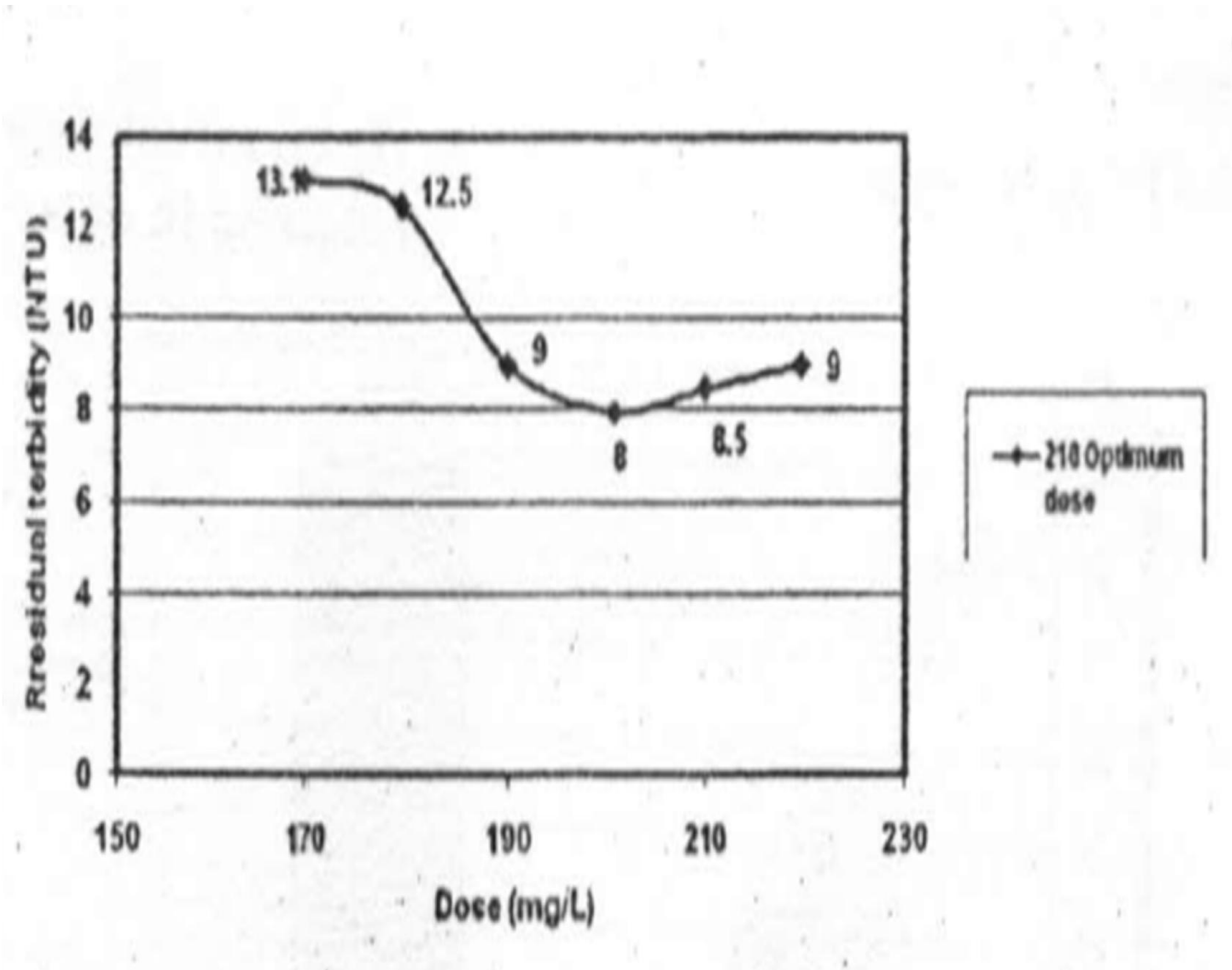
Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	26.08	1	0.17	25.67	26.49	
A-CD	18.82	1	0.17	18.42	19. 22	1.00
B-PH	-0.55	1	0.17	-0.95	-0.15	1.00
AB	-0.43	1	0.21	-0.93	0.056	1.00
A^2	3.11	1	0.25	2.52	3.70	1.17
B^2	-0.18	1	0.25	-0.77	0.41	1.17

Annex 3. Some of the commonly Available Coagulants and Details with their corresponding costs of 2006

COMMON COAGULANT NAME[1]	TYPICAL MANUFACTURERS	CHEMICAL NAME & FORMULA	TYPICAL ANALYSIS	NOTES	INDICATIVE COST, $/tonne (as 100%)[2]
Alum	Aluminates Omega Chemicals	Aluminium sulphate $Al_2(SO_4)_3.18H_2O$	* 7.5-8% Al_2O_3 or 49-52% w/w $Al_2(SO_4)_3.18H_2O$ * SG 1.3 *** 635 g/L**	Most common coagulant used in water treatment. Relatively cheap.	450
PAC 23 *MEGAPAC 23* *ALCHLOR AC* *PROFLOC A23*	Aluminates Omega Chemicals Hardman Chemicals Orica/ Spectrum	Aluminium chlorohydrate (ACH) $Al_2(OH)_5Cl$	* 23-24% Al_2O_3 or 40-41% w/w ACH * SG 1.33 * 83-84% basicity * 8.5% w/w Cl *** 535 g/L**	Used in lieu of alum where raw water has low pH & alkalinity. Has little impact on pH.	2100
PAC-10 LB *MEGAPAC 10*	Aluminates Omega Chemicals	Polyaluminium chloride (PACl) $Al_2(OH)_3Cl_3$	* 10-11% Al_2O_3 or 20-23% w/w PACl * SG 1.18 * 50% basicity * 10.5% w/w Cl *** 245 g/L**	Used in lieu of alum where raw water has low pH & alkalinity. Has greater impact on pH than ACH.	2500
PAC-10 HB	Aluminates	Aluminium chlorohydrate (ACH)	* Diluted ACH. * 10% Al_2O_3 * 80% basicity	See ACH. Sometimes used in small WTP's.	2800
PACS	Aluminates	Polyaluminium chlorosulphate $Al_3(OH)_{4.95}Cl_{3.55}(SO_4)_{0.25}$	* 10% Al_2O_3 or 5.3% w/w Al * SG 1.19 * 50% basicity * 10% w/w Cl * 2% w/w SO_4	Aluminium-based coagulant. Not commonly used; at some NSW WTP's.	2800

NB: **Brand names for coagulant products are shown in italics**

Annex 4. The optimum dose of Moringa Stenopetala seed for initial turbidity of 50 NTU



Annex 5. Physical properties of seeds of Moringa stenopetala

Variables	Range[a]	Mean[b] ± SD
Average number of seeds/pod	9-10	-
Number of seeds/tree	4500-10000	-
Weight of seeds (kg)/tree	2.3-5	-
Average weight (g)/100 seeds (kernel + hull)	48.12-55.71	73.6 ± 2.28
Average weight (g/seed)	0.5	0.6 ± 0.02
Average weight of kernel (g/100 seeds)	-	59.6 ± 2.28
Kernel fraction (% of entire seed)	-	79.7 ± 0.95
Hull fraction (% of entire seed)	-	20.3 ± 0.95
Moisture of whole seed (%)	-	6.1 ± 0.24

[a]EIAR (2003); [b]Seifu (2012)

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Annex 6. On farm trees and the stone terraces in Konso area

Annex 7. Photo of the oil extracted from Moringa seed (bi product for the coagulant production)

Annex 8. Moringa stenopetala collected seed under observation

Annex 9: 2006 EC total water production and distribution of Mekelle Town in m^3 (Mekelle water supply office)

	Branch 1			Branch 2			Branch 3			Branch 4		
	Domestic	IND & COM	GOV	Domestic	IND & COM	GOV	Domestic	IND & COM	GOV	Domestic	IND & CO	GOV
July	48896	18945	40793	30710	21697	43679	49441	15071	7376	10632	1889	1227
August	72967	59161	39502	31977	19815	27422	55614	16277	6363	17566	10865	1526
September	72854	31987	35614	37716	27561	39540	79673	23421	8713	17768	7807	2153
October	117110	43680	26808	37945	20126	42262	72954	21580	7733	10193	5566	1659
November	82208	36556	30457	36349	27133	40325	78062	23913	10216	12962	24087	1864
December	80833	32903	34937	40213	27147	45685	74545	22263	9405	98064	10264	2418
January	84840	36254	32260	39259	25162	42862	67270	19859	9730	10987	6912	2473
February	80592	43216	19514	40981	23725	38299	65312	21499	10088	10690	8017	1278
March	102429	41828	67690	37188	25038	35369	74865	24620	7164	9817	4757	1651
April	22502	42288	28597	32941	21763	39495	81434	19120	6153	10269	3201	1022
May	76523.1	38681.8	35617.2	36527.9	23916.7	39493.8	69917	20762.3	8294.1	20894.8	8336.5	1727.1
June	76523.1	38681.8	35617.2	36527.9	23916.7	39493.8	69917	20762.3	8294.1	20894.8	8336.5	1727.1
Total	918277.2	464181.6	427406	438334.8	287000.4	473925.6	839004	249147.6	99529.2	250737.6	100038	20725.2

Annex10. Physicochemical parameters test results

S.No	Sample codes	Sub Samples	Color	Odor	Taste	PH	Turbidity NTU	EC µs/cm	TDS Ppm
1	SP1	**SPav1**	**Obj**	***Nobj***	**Obj**	**7.6**	**44.80**	**1562**	**1170**
2	SP2	**SPav2**	**Obj**	***Nobj***	**Obj**	**7.7**	**19.703**	**983**	**705**
3	SP3	**SPav3**	**Obj**	***Nobj***	**Obj**	**7.2**	**13.53**	**688**	**446**
4	SP4	**SPav4**	**Obj**	***Nobj***	**Obj**	**7.8**	**9.26**	**768**	**527**
5	SP5	**SPav5**	**Obj**	***Nobj***	**Obj**	**7.5**	**36.30**	**1040**	**853**
6	SP6	**SPav6**	**Obj**	***Nobj***	**Obj**	**7.6**	**27.37**	**880**	**543**
7	SP7	**SPav7**	**Obj**	***Nobj***	**Obj**	**7.5**	**15.00**	**758.7**	**541**
8	SP8	**SPav8**	**Obj**	***Nobj***	**Obj**	**7.6**	**11.23**	**650**	**404**
9	SP9	**SPav9**	**Obj**	***Nobj***	**Obj**	**8.0**	**35.85**	**890**	**601**
10	SP10	**SPav10**	**Obj**	***Nobj***	**Obj**	**7.2**	**9.30**	**634.3**	**392**
11	SP11	**SPav11**	**Obj**	***Nobj***	**Obj**	**8.1**	**24.00**	**850**	**599**
12	SP12	**SPav12**	**Obj**	***Nobj***	**Obj**	**7.9**	**13.30**	**672**	**415**
13	SP13	**SPav13**	**Obj**	***Nobj***	**Obj**	**7.5**	**13.00**	**672.3**	**417**
14	SP14	**SPav14**	**Obj**	***Nobj***	**Obj**	**7.8**	**14.20**	**687.7**	**430**
15	SP15	**SPav15**	**Obj**	***Nobj***	**Obj**	**7.6**	**13.66**	**688.3**	**432**
16	SP16	**SPav16**	**Obj**	***Nobj***	**Obj**	**7.8**	**15.00**	**719**	**465**
17	SP17	**SPav17**	**Obj**	***Nobj***	**Obj**	**7.2**	14.02	683.3	446
18	SP18	**SPav18**	**Obj**	***Nobj***	**Obj**	**7.6**	**22.34**	**676**	**415**
19	SP19	**SPav19**	**Obj**	***Nobj***	**Obj**	**7.8**	**8.9**	**633.7**	**401**
20	SP20	**SPav20**	**Obj**	***Nobj***	**Obj**	**7.8**	**10.00**	**710**	**434**
	Overall Average	**SPave**	Obj	Nobj	Obj		**18.538**	**787.3**	**531.8**
Standards	Ethiopian	**St. values**	Nobj	Nobj	Nobj	6.5-8.5	5	1500	1000
	WHO	**St. values**	Uobj	Uobj	Uobj	6.5-8.5	5	2000	1000

Annex 11. Physicochemical parameters test results (cont…)

S.No	Sample codes	Average of Sub Samples	Calcium hardness mg/l	Magnesium hardness mg/l	Total hardness mg/l as $CaCO_3$	Total Alkalinity mg/l
1	SP1	**SPav1**	**252.00**	**39.40**	**791.47**	**286.3**
2	SP2	**SPav2**	**161.33**	**22.50**	**495.54**	**210.6**
3	SP3	**SPav3**	**118.67**	**14.00**	**354.05**	**196**
4	SP4	**SPav4**	**161.47**	**6.64**	**430.89**	**203.3**
5	SP5	**SPav5**	**174.80**	**21.30**	**524.30**	**215**
6	SP6	**SPav6**	**167.38**	**6.36**	**444.52**	**184**
7	SP7	**SPav7**	**150.83**	**8.23**	**410.80**	**198**
8	SP8	**SPav8**	**110.97**	**16.82**	**346.39**	**174**
9	SP9	**SPav9**	**150.00**	**20.00**	**456.97**	**216**
10	SP10	**SPav10**	**102.88**	**14.33**	**315.93**	**154**
11	SP11	**SPav11**	**164.2**	**9.93**	**451.20**	**202.3**
12	SP12	**SPav12**	**106.36**	**16**	**331.47**	**173.7**
13	SP13	**SPav13**	**104.00**	**15.50**	**323.53**	**167.3**
14	SP14	**SPav14**	**109.00**	**8.80**	**308.57**	**183.6**
15	SP15	**SPav15**	**112.00**	**8.53**	**314.96**	**166.3**
16	SP16	**SPav16**	**148.33**	**9.97**	**411.69**	**172**
17	SP17	**SPav17**	**114.33**	**9.63**	**325.29**	**174**
18	SP18	**SPav18**	**101.43**	**17**	**323.25**	**171**
19	SP19	**SPav19**	**98.23**	**15.20**	**307.87**	**165.7**
20	SP20	**SPav20**	**132.25**	12.**42**	**381.53**	**195.3**
	Overall Average	**SPave**			**412.28**	**181.82**
Standards	Ethiopian	St. value	-	-	300	200
	WHO	St. value	-	-	300	500

- SPave = average value of the sample parameter