Addis Ababa University
School of Graduate Studies
School of Chemical and Bioengineering
Environmental Engineering Stream

Organic Matter Removal to Reduce Disinfection By-products Precursors

A Case study in “Legedadi Water Treatment Plant”

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July 2014

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A Thesis Submitted to the Graduate Studies of Addis Ababa University Institute of Technology in Partial Fulfillment of the Requirement for the Degree of Master of Science in Environmental Engineering Stream

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Addis Ababa, Ethiopia

July 2014

ADDIS ABABA UNIVERSITY INSTITUTE OF TECHNOLOGY SCHOOL OF

Chemical and Bioengineering

ENVIRONMENTAL ENGINEERING STREAM

This is to certify that thesis prepared by Getahun Kebede, entitled: Organic Matter Removal to Reduce Disinfection By-products Precursors A Case study in“Legedadi Water Treatment Plant” and Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Environmental Engineering Stream Complies with the Regulations of the University and Meets the Accepted Standards with Respect to Originality and Quality.

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Acknowledgement

First and foremost, thanks to the Almighty God for granting me His limitless care, love and blessings all along the way.

I would like to express my deepest and sincere gratitude to my advisor Dr. Tassisa Kaba for his indispensable prompt help and invaluable effort in guiding and giving me invaluable ideas from the beginning to the end.

I would like to acknowledge; Addis Ababa Water and Sewerage Authority (AAWSA) especially, surface water production and water quality department for providing me the required materials, laboratory facility and information to fulfill this research work.

I would like also to extend my acknowledgements, to Addis Ababa Environmental protection Agency (EPA) for their help by providing necessary chemicals and, laboratory facility to conduct a study without which this research was not possible.

Finally, I would like to express my warm feeling of appreciation and thank to my families and friends who are contributed a lot for my success throughout my educational activities including material and moral support starting from my elementary school up to this level.

It is also my pleasure to thank all staff members of the department of chemical engineering for giving me the opportunity for the study and the privilege of conducting such a research.

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LIST OF ABBREVIATIONS

AAU	Addis Ababa University
AAWSA	Addis Ababa Water and Sewerage Authority
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
PolyDADMAC	Poly Diallyl Dimethyl Ammonium Chloride
DAP	Di-Ammonium Phosphate
DBP	Disinfection by-Product
DEM	Digital Elevation Model
FEPA	Federal Environmental Protection Authority
LWTP	Legedadi Water Treatment Plant
MACL	The Maximum Allowable Concentration Level
MAMSL	Meter Above Mean Sea Level
NOM	Natural Organic Matter
PACl	Poly-Aluminum chloride
TDS	Total Dissolved Solid
TOC	Total organic Matter
THM	Tri-halomethane
USEPA	United States Environmental Protection Agency
UNICEF	United Nation International Children Emergency fund
UN	United Nation
UNEP	United Nation Environmental Program
USEPA	United State Environmental Protection Agency
WHO	World Health Organization
UNITS	
FTU	Formazene Turbidity Unit
MCM	Million Cubic Meter
NTU	Nephalometric Turbidity Unit
UTM	Universal Transverse Mercator

Abstract

The main aim of this study was the use of enhanced coagulation method to reduce DBPs precursors from surfaces raw water source to control the formation of DBPs in drinking water. Jar test experiments were conducted to study the effectiveness of enhanced coagulation for removal of DBPs precursors from Legedadi reservoir, which is the major water supply to Addis Ababa Metropolitan the capital city of Ethiopia. In this study, for the removal of turbidity and organic matter polyelectrolyte, PACl, and alum were used. The performance of the three coagulants with varying dose level were assessed through treated water turbidity measurement and content of organic matter measured by surrogate parameters of total organic carbon value. These coagulants showed almost similar turbidity removal value. The results were indicated by TOC tested the optimum factorial combination of 1.75 optimum dose of PACl, which gave better resulting with optimum response values of 98.80 % organic matter removal efficiency, whereas Alum, and polyelectrolyte at 1.5*optimum dose showed optimum response value of 96.20, and 96.70 % organic matter removal efficiency respectively.*

The result showed that 84 % organic matter removal efficiency was obtained in conventional treatment, where as enhanced coagulation process showed an efficiency of 98.08 %. .Since organic matter is a large contributor in the formation of THMs, lower TOC values will likely indicate a lower potential for formation of disinfection by-products. *This indicated that enhanced coagulation process is an effective means for removing organic matter present in drinking water if the coagulant dose and pH condition are adjusted to optimum condition. In general, TOC removal enhanced with increasing coagulant dose. However, further increases in coagulant dose beyond the optimal value had little negative effect on DBPs precursors' removal*

Key words: Enhanced Coagulation, Organic Matter (DBPs Precursor), Total Organic Carbon, Organic Carbon Removal, Addis Ababa, Legedadi Water Treatment Plant, Ethiopia

1. Introduction

1.1. Background of the Study

Water is crucial for all aspects of life, most essential for human existence and the defining feature of our planet. Almost 97.5% of all water found in the oceans, from the remaining fresh water, only 1% is accessible for extraction and use (**UN *et al.*, 2010**). The current worldwide growth in population and affluence is putting global resources under increasing pressure. Specifically, in most developing countries like Ethiopia, there is a growing public health concern, which directly or indirectly related to contamination of water sources **(Amare Shiberu, 2008)**. Surface water sources are subject to ever-increasing withdrawals to supply a growing population, industry, and agriculture. This leads ever-increasing quantities of domestic, industrial, and agricultural wastewaters discharged directly or indirectly to water supply sources (**Bagwell *et al.*, 2001**).

Due to limited alternatives, surface water either from rivers or from rain fed ponds has become one of the main sources of water supply. Surface waters used for drinking purposes can vary markedly in their organic and inorganic content. High levels of variation occur in a range of water quality parameters such as turbidity, alkalinity, color, and natural organic matter (NOM), algae and microorganisms (**Leeuwen *et al.*, 2005**). Many communities have problems with DBPs in their water that comes from organics present in the water reacting with the disinfectant, which used to reduce the occurrence of waterborne disease (**USEPA, 2007**).The Organic substances that originate from soil, decaying of vegetable matter or contamination by domestic and industrial wastewater, are commonly present in lake or surface water. They presence not only imparts taste and color to water, but also form organohalodes like THM with chlorine (**Trussell and Umphrfs, 1978**)

Humic substances such as humic and fulvic acids comprise the major part of the organic substances. The removal of humic acid from natural surface water becomes one of great importance in water treatment process because of health, aesthetics and operational problems (**Semmens and Field, 1980; Eilen *et al.*, 1985**).

Protection of drinking water quality goes back several hundred years. Scientific and medical advances in the 1800s, along with the need to provide basic sanitation in the rapidly urbanizing cities, laid the foundation for today's drinking water field (**Edzwald, 2011**). There are various methods to make water safe and attractive to the consumer, which depends on the character and source of the raw water (surface water, groundwater). Surface water coagulation/flocculation followed by sedimentation, filtration and disinfection, often done by addition of chlorine, used worldwide in water treatment industry before distribution of the treated water to consumers. In the 1970s and 1980s, a new drinking water concern arose: the potential long-term health risks posed by trace amounts of organic compounds present in drinking water **(Baruth, 2005**).

The production of potable water from most raw water sources usually entails the use of a coagulation flocculation stage to remove turbidity in the form of suspended and colloidal material. This process plays a major role in surface water treatment by reducing turbidity, bacteria, algae, odor, color, organic compounds, and clay particles (**Vara, 2012**). However, conventional coagulation is not much effective treatment option to remove NOM in water treatment. Enhanced coagulation is currently proposed as one of the available treatment options and is implemented by applying increased doses of hydrolyzing coagulants (**Yan, 2007**)

This research focuses on the enhancement of coagulation method to remove organic matter for controlling the production of DBPs in final treated drinking water in case of Legedadi water treatment plant.

1.2. Statement of the Problem

Drinking water safety is a worldwide concern. Contaminated drinking water has the greatest impact on human health worldwide, especially in developing countries**.** Addis Ababa has been getting above 65% of its drinking water from Legedadi and Geffersa surface water supply for years. However, the existence of the major source of water quality problem in catchment area such as: a) Domestic and animal wastes from settlement villages, towns, feedlots, grazing lawns etc; b) Agricultural inputs (fertilizers and manure, herbicide and pest control chemicals) and, c)Transportation and construction related activities. These lead to a higher concentration of organic matter, and which, contributed to increase of raw water turbidity within a period of 10 years (1989-1998 G.C) on average 80-150 FTU to 260 FTU during the dry season and up to 600 FTU during rainy season. In 1986, the maximum measured turbidity in Legedadi reservoir was 300 FTU and in 1998 after few days of stormy showers, the maximum turbidity level reached 1666 FTU **(TAHAL, 2000).** Nowadays, according to AAWSA laboratory report in 2011, the average measured raw water turbidity in the summer season is 1100 FTU and after few days of stormy showers, the maximum turbidity level reached 2666.667 FTU.

In Legedadi water, treatment plant pre-chlorination applied to the raw water in order to control microorganism development in the treatment plant during water treatment processing before removing the organic matter. Thus, the existence of high organic matter significantly affect quality of drinking water including, a) Impacts of aesthetic drinking water quality by imparting color, taste and odor to the water, b) Increases the demand or dose of coagulants, oxidants and disinfectants required for drinking water treatment; c) the presence of NOM in water entering the distribution system may lead to biological re-growth in the distribution system and Some NOM fractions may promote corrosion in the distribution system, and d) organic matter that are present in water reacts with chlorine which do have negative impact on producing harmful DBPs such as THMs and HAAs, many of which are carcinogenic or mutagenic;

Despite the fact that various studies has been carried on the Legedadi reservoir and speculations forwarded regarding the key issues as well as sources of the siltation problems in the catchment, there is no detailed and objective study of the treatment technique for DBPs precursor (organic matter) removal concerning the formation of THMs and HAAs.

1.3. Objectives of the Study

1.3.1. General Objective of the Study

The general objective of this study is organic matter removal through enhanced coagulation process before pre-chlorination to reduce DBPs by comparing different coagulant for the existing Legedadi Water Treatment Plant.

1.3.2. Specific Objectives of the Study

The specific objectives of the study are:

- to evaluate the organic matter load of existing Legedadi surface raw water
- to evaluate the performance and determine the optimal dosage of the three coagulants (PolyDADMAC, Alum, and PAC) in terms of turbidity removal
- to evaluate the application of enhanced coagulation method to organic matter removal efficiency by introducing different coagulants.
- to study the major limitation of enhanced coagulation process

1.4. Significance of the Study

This study is looking forward to find efficient kind of organic matter removal method for surface water treatment plant to increase the safety of water supply. The study would attempt to enhance organic matter removal efficiency in water treatment process by using different coagulants and explain the coagulants combine to raw water to decrease DBPs, which have detrimental effect to health. The knowledge from this study can generate and help water experts and chemists to deliver effective water treatment at micro and macro level especially for Legedadi Water Treatment Plant.

The study is based on experimental approach to exploring the reasons behind the treatment of water.

This study aims to contribute to-enhanced organic matter removal efficiency for water treatment process. Generally, the results of the study will be used as information for further application of coagulants in polluted by high organic matter of raw water

.

2 Description of the Study Area

2.1 Location

The research area is located about 30 km from Addis Ababa in the east direction, which is one of the sources of drinking water for the city of Addis Ababa, and its environs. The reservoir catchment area exists in Oromia Regional State under the administration of North Shoa Zone in Aleltu Bereh District, Sendafa town Administration. Legedadi catchment area was constructed in 1970 to harvest run-off water during the rainy seasons for urban water supply. It is the principal source of water for the Addis Ababa metropolitan area. The catchment basin, which is situated between UTM coordinates 493,000 km E to 510,000 Km E and 997,000 km N to 1,018,000 Km N, covers an area of 204.9 km^2.

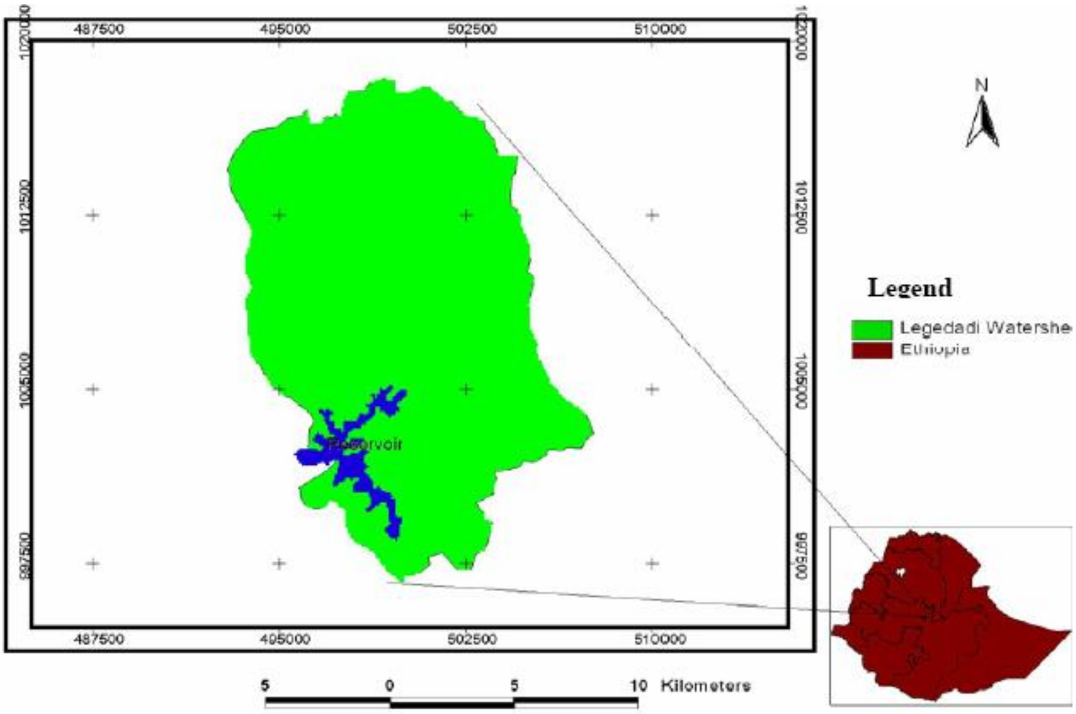


Figure 1: Location Map of Legedadi reservoir water shade

The reservoirs area capacity and Elevation-Volume curves were prepared in 1979 and 1998. A total volume at the maximum water level for the 1979 data was 45.9 MCM. For the same elevation in 1998, the volume is 43.8 MCM. This indicates a 2.1 MCM reduction occurred over a period of 19 years (**TAHEL, 1999**). As mentioned a more recent bathymetric survey conducted by SEURECA and others (2010) the survey showed a total reservoir volume at FSL (2,466 m) is 42.17 MCM. The total amounts to a volume reduction of 3.72 MCM since 1979 to 2010. It appears that in later years the rate of siltation of the Legedadi reservoir has increased. The resulting sediment yield of the catchment according to the results of the 1998 survey was 762 t/km^2/yr, but from the 2010 survey is obtained a value of 845 t/km^2/year. Based on the results of the three bathymetric surveys the average annual siltation rates are: 1979 to 1998: 110,000 m^3/year, 1979 to 2010: 120,000 m^3/year, and 1998 to 2010: 135,000 m^3/year (**Master plan AAWASA, 2011)**

Figure 2: Siltation in the Legedadi Reservoir (2012)

The major physiographic units found in the study area are mountains, dissected side slopes of mountains and hills, gullies, valleys, undulating plains and flat plains. In the north, the catchment is mountainous with dissected very steep slopes and rugged topography. Catchment area elevation ranges from 2,460 to 3,200 meter above mean sea level (MAMSL) and its slopes vary from 0 to 30.8% **(TAHAL, 1999; Omran, 2011).**

2.2. Climate

Climatic conditions of the Legedadi catchment is characterized by warm and cool tropical highlands with a mean annual temperature of 20 ^{0}C. Traditionally, the Legedadi catchment classified into the ‘Dega’, and ‘Woina-Dega’ agro-climatic zone (**Devecon and Metaferia consulting Engineers, 1994**). Average mean annual precipitation at Sendafa station, within the study area, is about 1121 mm (for the period from 1985 to 2000) were recorded (**Tahal**, **2000**). Now the mean annual rainfall range calculated for the study catchment, based on the Legedadi meteorology station is 1,000-1,250 mm/yr.

2.3. Soil Type and Its Susceptibility to Erosion

The soil type in the catchment area are classified into four based on their color. These are Black Vertisols (‘Koticha afer’), Grey (‘Dalecha afer’), Light (‘Gembore afer’) and Red (‘Key Afer’) (**Tahal & Metaferia, 2000**).

The Koticha afer (Black soil) is found on flat to almost flat areas and valley bottom and is not sensitive to erosion. It gives good yields of crops when fertilizers are applied; teff, wheat, barley, lentil, chickpea and rough pea are grown on these soils. These crops occupy 45%, 30%, 5%, 10%, 5% and 5%, respectively, of the cropped areas situated on the black vertisol soils.

The Dalecha afer (Grey soil) occupies some of the undulating plains and valley sides. According to the farmers, this soil has low fertility. Half of the area of these soils has to be left fallow every other year and the residues burned to give good crop yields. These soils are susceptible to erosion.

The Gembore afer (Light soil) and the Key afer (Red soil) occupy the hills, mountainsides and the foot slopes. They are susceptible to erosion when ploughed because of their steep slopes .Due to the fast population growth; the grasslands in the catchment area are being progressively encroached by cropped lands. New croplands fertilized with Urea and DAP (Di-Ammonium Phosphate) to give good yields. Common crops grown on the foothills and mountain slopes and hills are wheat, barley (the major crops), bean, field pea, lentil, and flax (minor crops).

2.4. Land use and Land cover

The Land use of the study area consists of intensively and moderately cultivated land, grassland, shrubs, eucalyptus wood plots, natural vegetation, water body, barren land, and built-up areas (paved road, dam, and concrete buildings in Sendafa town. Grasses covering the undulating valley and plains provide grazing land for livestock. The cultivated land, which predominates the land uses, are scattered all over the catchment area including the steep mountain slopes, undulating valley, foothills and (**TAHAL and Metaferia, 1999**).

2.5. Economics Activity

At present the catchment area of Legedadi, is the major surface water source of Addis Ababa. However, at the same time this area inhabited and mostly utilized for agricultural production including grazing of live stokes. The population density of the catchment area can be taken as indication of the intensity of present and possibly future land use. The total population in the study area (with a total number of households of 4,219) is about 20,568. The population density in the area is 100 persons /km^2. The economic activities of the catchment are comprised two major sectors; agriculture and livestock farming.

The main crops cultivated are cereals (wheat, teff and barley). In addition, there are small commercial eucalyptus plantations and vegetable fields (onion, garlic and cabbage). There is modest use of agro-chemicals. According to the district agriculture office on average 100 kilogram of fertilizer per hectare is used (DAP and Urea), Pesticide is applied mainly in vegetable fields and amounts to 1 kg/ha. There is an increase in unregulated pesticide use, leading to severe pollution of water bodies. Livestock production: livestock is equally important economically in the catchment area and most farmers combine cultivation with livestock keeping. The main sources of feed resource to livestock are natural pasture, hay, and crop residue, weed and crop remnants.

2.6 Raw Water Quality of Legedadi Reservoir

Raw water for the Legedadi water treatment is supplied from Legedadi water reservoir that impounds rainwater from its catchment area. The raw water is characterized with high turbidity and color, low alkalinity and hardness. The suspended solids are very fine and of colloidal nature. The color is partly from the suspended solids. Water quality in the reservoir deteriorated through the years as result of inadequate protection of its catchment area. Raw water turbidity increased within a period of 10 years from averages of 80-150 FTU to 260 FTU during the dry season and to 600 FTU during rainy season (TAHAL, 2000). Recently, according to AAWSA lap report (July 2011), the maximum turbidity value is reached to 2666 FTU. In 1998 Bathometric survey, average concentration of the total organic matter is 102 mg/l. The high organic matter in the raw water likely consumes large quantities of chlorine and causes to the negative impact of producing high concentrations of DBPs such as Trihalomethanes (THMs). THMs are chlorinated organic, maximum allowable concentration level (MaCl) of chlorine in potable water is limited to 100 microgram/liter in developed countries. Recently, pre-chlorination was abandoned for health reasons in many treatment plants regarded that treatment process enabled it (**TAHAL, 2000**)

2.7 Legedadi Existing Surface Water Treatment Plant Processes

The Legedadi Water Treatment Plant is located next to the Legedadi dam; its primary purpose is providing clean and potable water free from pathogenic and toxic substances. Both the dam and the water treatment plant first built in 1971 and improvement and extensions in the water treatment plant carried out in 1985. The treatment plant first designed to produce 50,000 m^3 /day of potable water with the improvement and extensions it can now produce 150,000m^3/day. The raw water in the

Legedadi reservoirs fed to a treatment plant. The treated water delivered to the city by an 18 km long gravity pipeline. (**TAHEL, 2000**).

Figure 3: Legedadi Water Treatment Plant

The treatment process of Legadadi plant is consists of gravitational raw water intake, pre-chlorination, and flashes mixing of the coagulant, sedimentation, filtration, post chlorination, and treated water reservoir that are described in the next section.

2.7.1 Raw Water Intake

The raw water reservoir provides water by a gravity flow system. The intake structure has three intake valves at three different depths of the reservoir. The water from the reservoir drawn by one tee and two isolating valves distribute the raw water one leading to the Stage I plant and the other to Stage II plant by 700 mm and 900 mm diameter pipelines, which have capacities of 50,000 and 100,000 m^3/day respectively.

2.7.2 Pre-chlorination

Chlorine is added both at the beginning and at end of the process to destroy disease-causing organisms or pathogens likely to grow, the various units of the plant and the sludge blanket. It oxidizes the organic substances, which may form organo soluble complexes. For pre-chlorine 3.06 mg/l added into the pipeline between a throttling valve and coagulant feed

Chemical Dilution and Dosing: The chemical process of Legedadi water treatment plant was synthetic polyelectrolyte, such as Superfloc or Catfloc as the main coagulant. The chemical composition of Catfloc is polydimethyl-diallyl-ammonium-chloride $((((CH_3)_2)_n\text{-}CH_2)_2)\text{-}NH_4Cl)$.The solution is prepared gravitationally through small constant level vessels without use of dosing pumps.

2.7.3 Mixing/Distribution/Regulation Structures

The raw water arrives from the raw water intake structure through the previously described 900 mm dia. Pipeline and arrives at the mixing/distribution/regulation structure. The raw water first enters the “Mixing chamber” portion of the structure at which polyelectrolyte is added and the mixer (agitator) thoroughly mixes the chemicals and chlorine solution with the raw water. It then moves through a series of baffles to the “distribution chamber” portion of the structure, where the coagulant aid injected. The raw water then passes over two 90 cm feed weirs which evenly distributes it to the two clarifiers.

2.7.4 Sedimentation

Up flow solid contact clarifiers used at the Legedadi water treatment plant are pulsator type clarifier .The water once has mixed with chlorine, polyelectrolyte (cationic) and coagulant aid (an ionic) has run over the weirs into clarifier vacuum chamber. The pulasator vacuum chamber connected to distribution pipes within the pulasator clarification/Sedimentation purpose. Coagulation, Flocculation and sedimentation all performed in one single tank.

2.7.5 Filtration

Filtration is an operation process to separate water that contains very finely suspended matter such as minute particles of floc, clay and mud, which have not removed in clarification, removed. There are two types of wastewater produced in the treatment plant such as, sludge drawn off from the clarifiers and wasted filter backwash water. Treated Water reservoir is used to storing the treated water from which, the treated water is flows through pipes to the distribution system by gravity. In case of Legedadi there are two storages, each can has the capacity to hold 20,000 m^3/day treated water for the capital city of Addis Ababa.

2.7.6. Post Chlorination

In Post chlorination system, 2.8 mg/l is added to the treated water in order that the treated water leaving the treatment plant will have optimum chlorine residual through the distribution system to prevent the growth of microorganisms.

3. Literature Review

3.1.Dirinking Water Source and Pollution

The major sources of water supplies are rainwater, surface water, and groundwater. Rainwater recharges the surface water and ground water during the water cycle process. Major surface water source include rivers, streams, lakes, natural and artificial (man-made) ponds, reservoirs (**Lee, 2007**). These water sources due to natural and increasing human activities in catchment areas cause a large set of adverse effects upon the quality and ecological status of the above listed water bodies. Hence, water pollution generally caused by natural or anthropogenic factors. The natural causes of water pollution include climate change, volcanoes, storms, earthquakes and hydrological processes in which the decomposed animal and plant materials and weathering products of rocks, minerals and soil ingredients are brought into the main water resources. Anthropogenic causes of water pollution are those that are associated with human settlement, industrial, agricultural, urban and rural activities of man. The nature and extent of water pollution are also depending upon the following factors: physical, chemical and biological characteristics of different types of wastewater originating from an area. Socio-economic characteristics of the communities i.e. urban, industrial, agricultural etc. creating the waste; hygienic conditions and health situation of the communities; and in conditions where runoff is the main cause of water pollution, hydrological characteristics, and degree of weathering, vegetation and soil type are important features. Regarding pollutant sources, water pollution is originating either from point or non-point sources. Non-point source of water pollution, which arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses i.e. those of precipitation, land runoff, infiltration, drainage, seepage, hydrologic modification, or atmospheric deposition pollution **(Amare Shebru, 2008).**

3.1.1 .Water Pollution in Ethiopia

Water pollution is a serious problem in the global context today. It has been identified as the leading worldwide cause of deaths and diseases and that it accounts for the deaths of about 14,000 people daily **(Amare Shebru, 2008).** Agriculture, as a major cause of degradation of surface and groundwater resources through erosion and chemical runoff, has implications on the global water quality. The associated agro food-processing industry is also a significant source of organic pollution in most countries. Several general water quality variables must be considered, some of the common parameters are pH, Alkalinity, Hardness, Turbidity, Natural organic matter (NOM), Total Dissolved Solids (TDS), Electrical conductivity (**Edzwald, 2011**).

Ethiopia's economy is heavily dependent on rain-fed, small-scale and subsistent farming; the intense agrochemical utilization resulted in environmental degradation and pollution, which in turn affected the existence and quality of water resources. The sources of major pollutants affecting Ethiopian lakes and rivers are erosion deposits, effluent discharges and agro-chemicals. Effects of industrial pollution obviously appear in all environmental media: air, water and land. The harmful industrial waste liquids are mixtures of organic, inorganic (inert substances), heavy metals, toxic and microbiologically loaded substances etc. There is an intensive use of chemical fertilizers, insecticides and pesticides for the exploitation of the country's available agricultural land. Part of the used fertilizers usually drained into the surface and groundwater systems. The use of these sources for drinking water supply is risky due to the presence of nitrogen and phosphorus salts. These runoff fertilizers and pesticides lead to occur of eutrophication (**FEPA, 2006**).

3.2. Organic Matter in Drinking Water Sources

There are currently over 150 drinking water chemical contaminants that have been either proposed listed or finalized for regulation. Among this number, over 100 are organic compounds. Regulated contaminants have risen substantially over the past two decades and will continue to rise into the foreseeable future (**Bagwell *et al.*, 2001**).

Organic matter is found in natural water are particulate organic compound, and dissolved organic compound. Organic compounds in water derive from three major sources. These are NOM including humic substances, synthetic organic chemicals (SOCs) including pesticides, and volatile organic chemicals (VOCs) (**Lamsal, 1997**). Naturally, occurring materials are the greatest source of organic compounds in water (**Edzwald, 2011).**

Volatile Organic Contaminants in Drinking Water (VOCS) have distinctive common property, which is high volatility relative to most other organic substances. Several of these VOCs recognized as a threat to public health that in some instances must be removing the chemical from the water supply by appropriate treatment (**Bagwell *et al.*, 2001**).

Synthetic Organic Contaminants in Drinking Water (SOCs**)** are organics that originate from domestic and commercial activities, and many of those that have identified in water supplies have adverse health effects. The majority (SOCs) contaminants include pesticides, organic solvents, chemical dyes, metal degreasers, and polychlorinated as result of this factor removal of SOCs are an important part of water treatment (**Ding, 2010**).

3.2.1. Natural organic matter and its characteristics in drinking water

The NOM is present in all ground and surface water, with typical concentration ranging from 0.5 mg/l to 12 mg/l as TOC (**Ding, 2010**). Modern water treatment processes utilized in order to create an adequate and continuous supply of water that is chemically, bacteriological and aesthetically pleasing. A major challenge in water treatment is the efficient removal of NOM with typical removal efficiencies varying from 20-90%; Poor removal can lead to NOM reacting with disinfectants to form potential carcinogens DBPs such as THMs and HAAs. Therefore, one of the principal aims of drinking water treatment is the optimization of NOM removal **(Louise, 2011).**

NOM is a complex mixture of pedogenic (soil derived) and anthropogenic (water column) material derived from the contact of water with dead and living organic matter in the hydrological cycle. NOM is present in dissolved, particulate and colloidal forms, and studies in organic matter characterization have identified its main components as carbohydrates, lipids, protein polymers, humic macromolecules, nucleic acids and phenolic compounds **(Louise, 2011)**. Aquatic NOM is an intricate combination of heterogeneous organic compounds varying in size, structure, and functionality from source to source. In general, raw water contains organic matter of different characteristics depending upon geological conditions and the surrounding watershed (**Kenny, 2010**). The composition of NOM is highly dependent on formation conditions of the catchment basin; Hydrological pathways, temperature and biological predominance help determine relative compositions of NOM in surface waters. NOM transported to surface waters by surface runoff and near surface lateral flow, and can increase dissolved organic matter concentrations **(Louise, 2011).**

NOM can be divided into three main types based on the source.

1) Allochthonous NOM: This type of NOM originates from the decay of terrestrial biomass or through soil leaching in the watershed, mainly from runoff or vegetative debris. The production and characteristics of this type of NOM is therefore, related to vegetative patterns and to hydrologic and geological characteristics of the watershed.

2) Autochthonous NOM: This type of NOM originates from in-situ sources, mainly algal organic matter, macrophytes, and other phytoplankton. The production of this type of NOM is therefore, related to photosynthetic activity and decay products of algal matter.

3) Effluent NOM: Organic matter that is not removed during wastewater treatment plus soluble microbial products formed during biological treatment of wastewater. The characteristics of effluent of organic matter therefore depend on the type of drinking water source and treatment as well as the type of wastewater treatment applied **(Baghoth, 2012)**

One common approach for characterizing NOM divides the mixture into hydrophilic and hydrophobic fractions. The hydrophilic fraction includes carboxylic acids, carbohydrates, amino acids and amino sugars, and proteins, while the hydrophobic fraction includes so-called humic species, and responsible for the yellow/orange colorings of water **(Louise, 2011)**. It typically dominates the NOM on a mass basis, contributing from 50 percent to 90 percent of the dissolved organic compound (DOC). Organic in the form of humic substances are undesirable in a potential water supply for a reasons ranging from aesthetics to being the precursors of potentially carcinogenic THM waters (**Lamsal, 1997**).

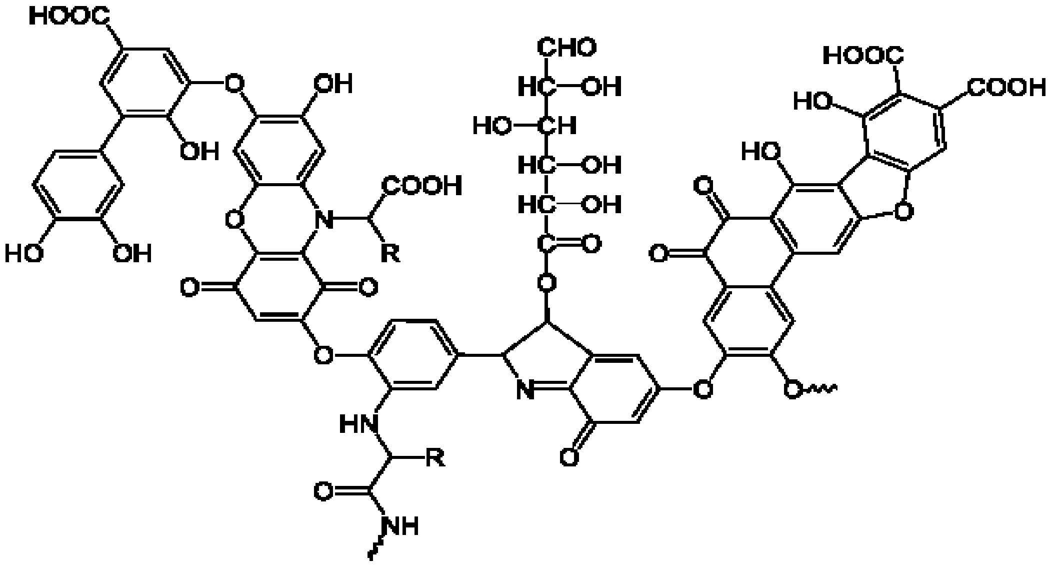


Figure 4: Humic Acids **(Kenny, 2005)**

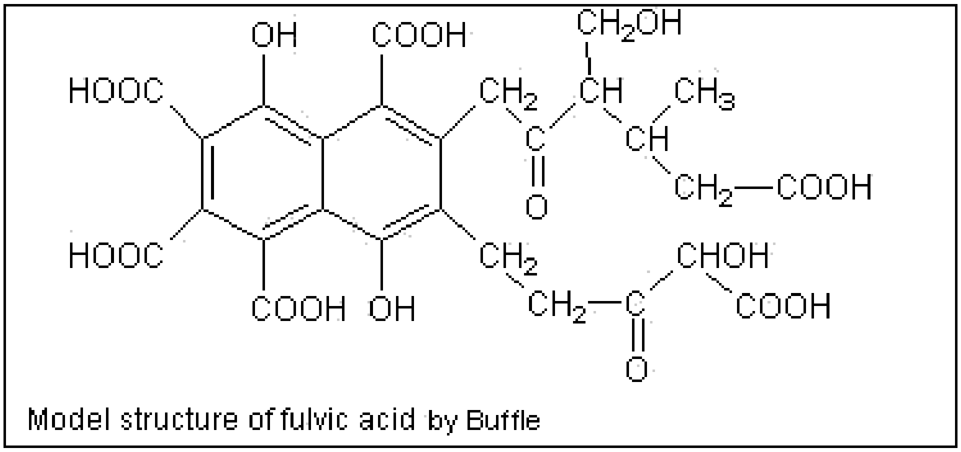


Figure 5: Suggested Structure of Fulvic Acid **(Check, 2005)**

The presence of NOM in water significantly affects quality of drinking water and the performance of water treatment process including the following:

a) Impacts of aesthetic drinking water quality by imparting color, taste and odor to the water;

b) Increases the demand or dose of coagulants, oxidants and disinfectants required for drinking water treatment;

c) It present in water reacts with chlorine (disinfectants/oxidants to produce potentially harmful DBPs, many of which are carcinogenic or mutagenic;

d) It responsible for fouling of membranes, reducing the flux, resulting in high frequency of backwashing and cleaning of membranes to restore the flux;

e) Presence of biodegradable NOM in water entering the distribution system may lead to biological re-growth, when a sufficient disinfectant residual is not maintained in the distribution system and Some NOM fractions may promote corrosion in the distribution system **(Baghoth ,2012**),

3.2.2. Disinfections By-products (DBPs) Formation

In modern water treatment, practices incomplete removal of NOM can negatively affect treated water quality (**Baghoth, 2012**). Chlorine has traditionally used to disinfect drinking water because it is very effective at inactivating microorganisms/pathogens that may be present in the water. However, it is also very reactive with natural compounds, which also be presented, both organic and inorganic. Disinfection by-products (DBPs) form when disinfectants used to treat drinking water, such as chlorine, react with organic compounds in the water which are usually naturally occurring (**USEPA, 1999**). The formation of DBPs depends primarily on water source quality characteristic and on the location in the treatment process where disinfectants added. In general, fewer DBPs can be formed if disinfectants are added later in the process. Natural organic matter (NOM) is the major component of organic precursors for disinfection by-products in chlorinated drinking waters**.** The five main chemical groups of NOM are humic substances, carboxylic acids, carbohydrates, amino acids, and proteins**.** Natural organic matter existing in raw water reacts with chlorine or other disinfectants, and then generates halogenated disinfection by-products, which have adverse health effects**.** It is thought that humic substances, which tend to be aromatic and hydrophobic, contain the bulk of DBP precursors **(Kenny, 2010)**

The Studies into THM and HAA show formation is highly affected by pH, temperature, nature and concentration of NOM, disinfectant type and dose, reaction time and bromide concentration **(Louise, 2011).** The most prominent of these DBPs are the potentially carcinogenic trihalomethanes (THMs) and halo acetic acids (HAAs). The THMs are simple, single carbon compounds that have the general formula CHX_3, where X may be any halogen atom. Include chlorine, bromine, fluorine, iodine and are all volatile, colorless, easily dissolved in water and considered possible carcinogens .Halo acetic Acids (HAAs) are colorless, have a low volatility, dissolve easily in water, and are stable. They are formed when a halogen atom takes place of hydrogen atom in acetic acid. HAAs typically form when chlorine reacts with NOM, such as humic acids, found in raw water supplies (**Montreuil, 2011, Baghoth, 2012**).

Table 1: THMs and HAAS Compounds and Chemical Abbreviation (Motreuil, 2011)

THMs	Chemical Formula	**Haloacetic Acids**	Chemical Formula
Chloroform	$CHCl_3$	Monochloroacetic acid	CH_2ClCO_2H
Dichloro-bromomethane	$CHCl_2Br$	Dichloroacetic acid	$CHCl_2CO_2H$
Dibromochloromehane	$CHBr_2Cl$	Trichloroacetic acid	CCl_3CO_2H
Bromoform	$CHBr_3$	Monobromoacetic acid	CH_2BrCO_2H
		Dibromoacetic acid	Br_2CHCO_2H

Drinking Water Standard under the Stage 1 Disinfectants and DBPs rule, THMs and HAAs regulated with maximum contaminant levels set at 80 μg/l and 60 μg/l, respectively. Several strategies are available to reduce THMs. One strategy is to remove them after they have formed. However, instead of trying to remove the problem after being formed reducing the source is ideal. Reducing DBPS, precursors, such as NOM, will reduce DBPs formed with disinfection (**Faust and Aly, 1983).**

3.3. Methods for Analysis of Organic Substances in Water

Analyses of organics made to assess the concentration and general composition of organic matter in raw water supplies, wastewaters, treated effluents, and receiving waters. Methods for total organic carbon and chemical oxygen demand used to assess the total amount of organics present in wastewater. The organic matter fractions identified by analytically, measurement of BOD; the test measures the molecular oxygen utilized during a specified incubation period for the biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron. It also may measure the amount of oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand) unless an inhibitor prevents their oxidation.

The other method used to measure organic matter COD, the quantity of oxidant consumed is expressed in terms of its oxygen equivalence. Because of its unique chemical properties the dichromate ion $(Cr_2O_7)_2$ is the specified oxidant. In the COD test both organic and in organic components of a sample are subject to oxidation, but in most cases the organic component predominates and the greater interest (**APHA *et al.*, 1999**).

The other best method used to measure organic matter is TOC. The organic carbon in water and wastewater is composed of a variety of organic compounds in various oxidation states. The above discussed methods may be used to characterize these fractions, but (TOC) is a more convenient and direct expression of total organic content than either BOD, or COD, the TOC can be used to estimate the accompanying BOD, or COD. Unlike BOD or COD, TOC is independent of the oxidation state of the organic matter and does not measure other organically bound elements, such as nitrogen and hydrogen, and inorganic that can contribute to the oxygen demand measured by BOD and COD. Measurement of TOC is of vital importance to the operation of water treatment and waste treatment plants. TOC methods utilize high temperature, catalysts, and oxygen, or lower temperatures (<100°C) with ultraviolet radiation, chemical oxidants, or combinations of these oxidants to convert organic carbon to carbon dioxide (CO_2) (**APHA *et al.*, 1999**).

3.4. Organic Colloids and Stabilizing Effect

The colloids may include organic and inorganic particulates. Colloids are very fine particles, typically ranging from 10 nm to 10 µm. Dissolved molecules are present as individual molecules or as ion.

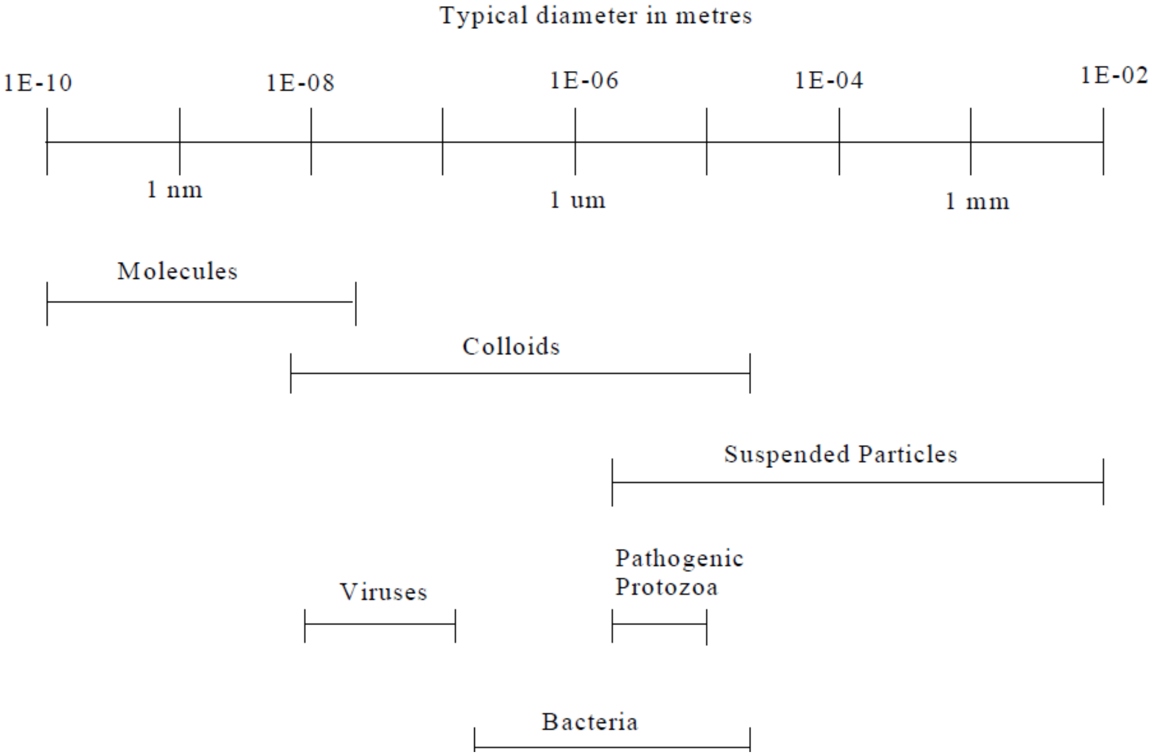


Figure 6: Size Range of Particles of Concern in Water Treatment **(Yan, 2005)**

The recent investigations showed that naturally occurring organic materials (NOM), particularly the pool of dissolved organic carbon, caused strong stabilization of inorganic particulates in water. The stability effect further increased with the increase of humic acid concentration and with the decrease of pH. It believed that this phenomenon was due to the surface hydrogen bonding of non-dissociated acidic groups by the humic acids on silicon dioxide (SiO_2).The increased stability of inorganic colloids by organic materials was due to the organic coating formed on the surface of inorganic colloids **(Asnake Birhane , 2010).**

The removal of colloid is the main objective and the most difficult aspect in conventional water treatment. When the colloids are mixed with water, they form colloidal solutions that are not easily destabilized. Since the particles have similar negative electrical charges and electrical forces to keep the individual particles separate, the colloids stay in suspension as small particles the magnitude of the zeta potential (Zp) usually used to indicate colloidal particle stability.

3.4.1. Zeta Potential

The zeta potential is the electrical potential representing the difference in voltage between the surface of the diffuse layer and the water. It is important to know the magnitude of the zeta potential, as it represents the strength of the repulsion between colloid particles and the distance, which must be overcome to bring the particles together. The primary charge on a colloid cannot measure directly. However, zeta potential can be computed from measurements of particle movement within an electrical field. Therefore, the zeta potential, ζ, is defined by the equation:

$$\zeta = 4\,\pi\delta q\,/D \quad (1)$$

Where q = charge of the particle

δ = thickness of the zone of influence of the charge on the particle

D = dielectric constant of the liquid

The magnitude of the zeta potential is an approximate measure of colloidal particle stability. Low zeta potentials indicate relatively unstable systems (particles tend to coagulate), while a high zeta potential represents strong forces of separation (via electrostatic repulsion) and a stable system (particles tend to suspend) **(Crittenden *et al.*, 2012).**The result of stabilization effect, the flocculent dosages are much increase in the case of high organic content. When the fulvic acid concentration in the clay suspension was increased by 3 mg/i (as TOC), the alum dosage needed was increased to 5.3 times to destabilize the suspension; and if the increase of fulvic acid concentration was 7 mg/L (as TOC), the alum dosages had to be 10.2 times as much to cause the stabilization **(Edzwald, 2011).**

3.5 Treatment for Control of DBPS Precursors

Different types of treatment used in the production of potable drinking water to remove the contaminants from the raw water and to deliver safe drinking water to the population, but these treatment processes also significantly affect, directly or indirectly, the formation, removal and speciation of DBPs in drinking water (**Garcia, 2005).**

Several water treatment methods have been used to remove Organic matter (DBPS Precursors) through a variety of mechanisms .Commonly used processes are Aeration or Air Stripping, Oxidation, Coagulation, Enhanced Coagulation, Adsorption, Biologically Active Carbon (BAC), Ion Exchange, and Membrane. Each method is best suited for specific organic compounds or groups of compounds **(Baghoth, 2012; Asnake, 2010; Check, 2005 and Bagwell *et al.*, 2001**)**.** Aeration used for taste and odor control, and remove excess carbon dioxide from water. Since the 1970s, it used for the removal of radon and VOCs (**Bagwell *et al.*, 2001; Baruth, 2005 and Edzwald, 2011).**

3.5.1. Conventional Technologies for Surface Water Treatment

Conventional treatment process in surface water treatment plant performed after being withdrawn from a source (lake or river).

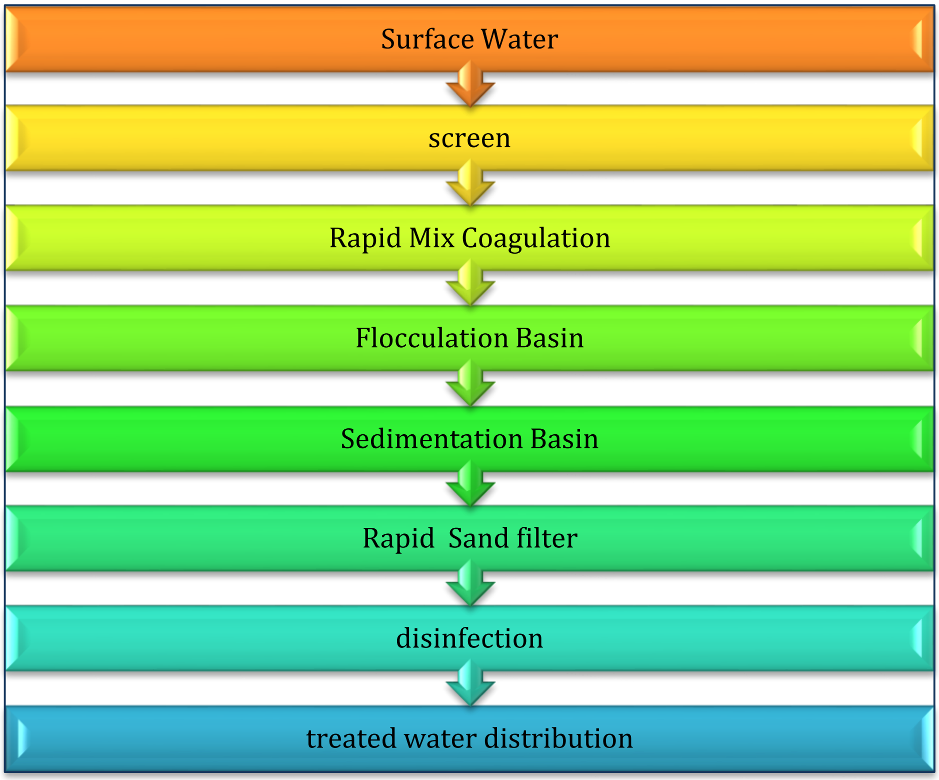


Figure 7: Flow of Conventional Potable Water Treatment Plant (**Al-Tufaily and Entesar, 2010)**

As indicated in Figure 7 the surface water is a suspension of small, stable colloidal particles whose motions governed by molecular diffusion. Screen used to remove entering of debris and large materials to treatment plant. In coagulation, these particles destabilized through the addition of a coagulant during rapid mixing. Flocculation promotes the collisions of these unstable particles to produce larger particles called flocs. In sedimentation, these flocs settle under the force of gravity. The particles that do not settle removed during rapid sand filtration. A disinfectant such as chlorine is then added, and, after a certain amount of contact time, and the treated water is distributed to consumers (**Al-Tufaily and Entesar, 2010; Tuan, 2008**). Coagulation is part of the conventional treatment used in the drinking water facilities in LWTP and it is known that the formation of DBPs is reduced when it is enhanced **(Baghoth, 2012).**

3.5.1.1. Enhanced Coagulation and organic matter removal

The removal of organic matter is a critical process in the reduction of DBPs. Coagulation and flocculation are two concepts essential to chemical treatment methods **(Yu, 1999**). From the theories of Coagulation Virtually, all natural colloids acquired negative charges on their surfaces either by ionization of surface functional groups or by adsorbing negatively charged organic molecules. The aggregation of these suspended colloidal particles takes place in two separate and distinct phases. There are two theories in coagulation; these are chemical theory and physical or double-layer theory. The first theory presumes that destabilization (coagulation) of colloids is a result of the Precipitation of insoluble complexes that are formed by chemical reactions between the colloids and the coagulants. The second theory based on the presence of physical factors, such as electrical double layers surrounding the colloidal particles in the solution (**Bagwell *et al.*, 2001**). In general, coagulation is a physiochemical process that causing stable colloids to become unstable and agglomerate into larger aggregates, which removed by sedimentation and filtration. Therefore, coagulation is an essential treatment process for removal of colloidal matter and other contaminates in water. Flocculation, on the other hand, involves the transport of these particles **(Yu, 1999)**.

Coagulation accomplished through any of four different mechanisms. These are double-layer compression, adsorption and charge neutralization, enmeshment by a precipitate (sweep-flocs coagulation), and adsorption and inter-particle bridging.

1) Double-Layer Compression: The mechanism of double-layer compression relies on compressing the diffuse layer surrounding a colloid. This accomplished by increasing the ionic strength of the solution through the addition of in different electrolyte. The added electrolyte increases the charge density in the diffuse layer. The diffuse layer compressed toward the particle surface, reducing the thickness of the layer. Therefore, the zeta potential, Zp, is significantly decreased (**Bagwell *et al.*, 2001, Jin, 2005).**

2) Adsorption and charge neutralization**:** Adding coagulants with a charge opposite to that on the colloidal particles can cause adsorption of the ions on to the colloidal

particles and neutralize surface charge **(Bagwell et al. 2001).** This leads to easier aggregation.

3) Enmeshment by a precipitate (Sweep-floc coagulation); Chemical compounds such as aluminum sulfate ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$), and lime (CaO or $Ca(OH)_2$) are frequently used as coagulants to form the precipitates of $Al(OH)_3$, $Fe(OH)_3$ and $CaCO_3$. These precipitates physically entrap the suspended colloidal particles as they settle, especially during subsequent flocculation. When the colloidal particles themselves serve as nuclei for the formation of the precipitate, the flocs formed around colloidal particles and the sweep-floc coagulation process can be enhanced. Thus, the rate of precipitation increases with increasing concentration of colloidal particles (turbidity) in the solution. When the colloidal particles themselves serve as nuclei for the formation of the precipitate, the flocs formed around colloidal particles and the sweep-floc. The speciation of metal complexes or hydroxides depends on the amount of Al (III) or Fe (III) salts added. (**Bagwell *et al.*, 2001**) with increasing alum dose, turbidities decrease to a minimum value, as complete destabilization occurs. This stage dominated by adsorption and charge neutralization mechanism. The optimum dosage often (but not always) corresponds to a Zp, which is near zero. The further addition of alum to very high doses results in the formation of a precipitate of Al $(OH)_3(S)$ because the amount of Al(III) added to the water exceeds the solubility limit of the hydroxide. This bulky precipitate enmeshes particles and settles rapidly to form the 'sweep-floc' region of coagulation (**Jin, 2005).**

4) Destabilization by Inter-particle Bridging***;*** the last process involved in coagulation is interred particle bridging. Bridging comes into effect when the surface charge of the particle nears zero. This process accomplished via medium to high molecular weight polymers and their ability to gather and hold flocs together that are already charge-neutralized. Bridges formed between two particles that repel one another. This network of bridges and coagulated particles is a floc. The formation of this floc is important for the next process for flocculation **(Yu, 2000, 2001; Julve *et al.*, 2007**).

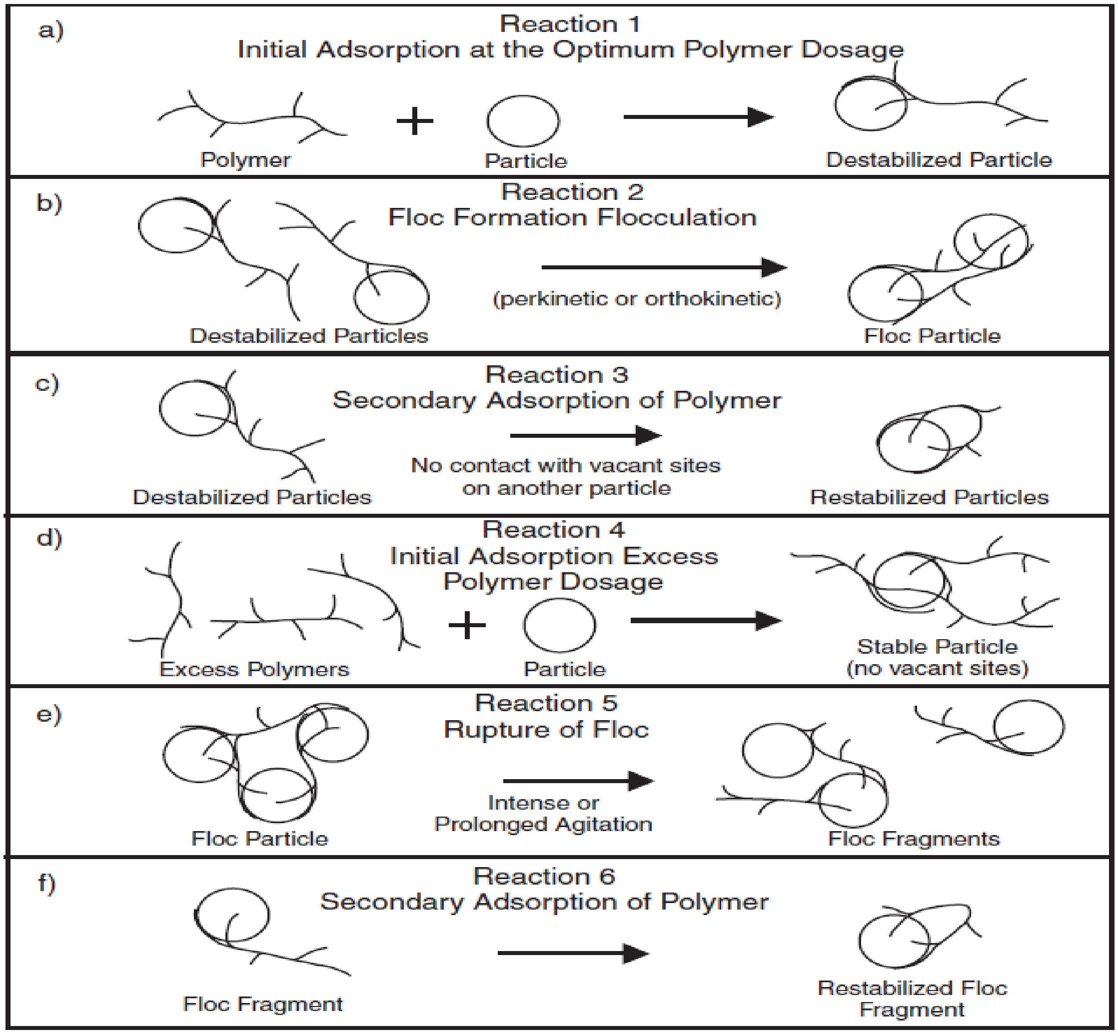


Figure 8: Schematic Representation of Bridging Model for Destabilization of Colloids by Polymers (**Bagwell et al. 2001**).

The inter particle bridging process was summarized by (Bagwell et al. 2001) as above. Figure 8a shows the simplest form of bridging, a polymer molecule will attach to a colloidal particle at one or more sites. Colloidal attachment caused by columbic attraction, if the charges are of opposite charge or from ion exchange, hydrogen bonding, or van der Waal's forces. Figure 8b shows the second reaction, in which the remaining length of the polymer molecule from the colloidal particle in the first reaction extends out into the solution. Attachment can occur to form a bridge if a second particle having some vacant adsorption sites contacts the extended polymer molecule. Thus, the polymer serves as the bridge. However, if the extended polymer molecule does not contact another particle, it can fold back on itself and adsorb on the surface of itself, as shown in Figure 8c. The original particle is restabilized. If the quantity of polymer is over dosed polymer segment may saturate the colloidal surfaces, thus no sites on the surfaces are available for inter particle bridging. This reaction figure 8d causes restabilization of the particles. Intense agitation in solution can cause restabilization because polymer-surface bonds or bridges destroyed. These reactions are shown in figure 8e and 8f.

The term-enhanced coagulation refers to the process of improving the removal of DBPs precursors in a conventional water treatment plant by the addition of coagulant dosage. The dosage required for effective NOM removal is typically greater than that needed for particle (turbidity) removal. For enhanced coagulation experiments, goals desired include significant TOC reduction without the addition of unreasonable amounts of coagulant, and regulatory criteria, which can be easily enforce with minimal state transactional costs. In order to, achieve more efficient TOC removal by enhanced coagulation are use the following method. Lower raw water pH with acids to enhance DBP precursor removal with the existing coagulant, increase the dose of the existing coagulant to consume alkalinity and lower pH, change to a coagulant that is more effective in DBP precursor removal under different conditions, such as lower pH or temperature. And use of polymers or filter aids to enhanced DBP precursor removal, modify rapid mix or flocculation process to optimize coagulant efficiency, and change other pretreatment chemicals, such as the addition of ozone, to modify dissolved DBP precursor characteristics for improved removal through coagulation (**Kenny, 2010**).

3.5.1.2. Flocculation

Flocculation, or the transport of particles, is important in bringing destabilized particles together and causing collisions to occur. Flocculation is the agglomeration of destabilized particles into micro floc and then into bulky floccules which can be further formation in to macro floc. Flocculation is the transport step that causes the necessary collisions between the destabilized particles and subsequent floc aggregations .It is often accomplished via slow and gentle mixing, versus the rapid mixing necessary for coagulation so particles can be kept in suspension with enough time for collisions to occur **(Yu, 2000).**

There are three major mechanisms of flocculation transport described below **(Geng, 2005).**

1) Per kinetic flocculation is the aggregation of particles caused by random thermal motion (Brownian diffusion). The driving force for particle movement is the thermal energy of the fluid. It most likely occurs when at least one of the particles is quite small, which is less than approximately 1 μm in diameter, so it is normally not a major factor in the transport associated with flocculation in water treatment (**Bagwell et al. 2001**).

2) Ortho-kinetic flocculation is the aggregation of particles caused by induced energy in the fluid. The destabilized particles follow the streamlines and eventually result in inter particle contacts. Ortho-kinetic flocculation most likely occurs when both particles are greater than approximately 1μm in diameter and similar in size. The fluid flow varies with different intensity of mechanical mixing.

3) Differential settling is caused by different settling velocities of particles, Because the settling velocity of particles which have similar densities is proportional to the particle size, the sedimentation of differential particles in heterogeneous suspension provides an additional transport for promoting flocculation. It most likely occurs when at least one of the particles is larger than 10 μm in diameter and the other is significantly different in size **(Jin, 2005)**. Therefore, flocculation is the physical process of promoting particle contact to facilitate the agglomeration to larger floc, which can then settle by gravity. An illustration of coagulation, flocculation and settling can be seen in Figure 9

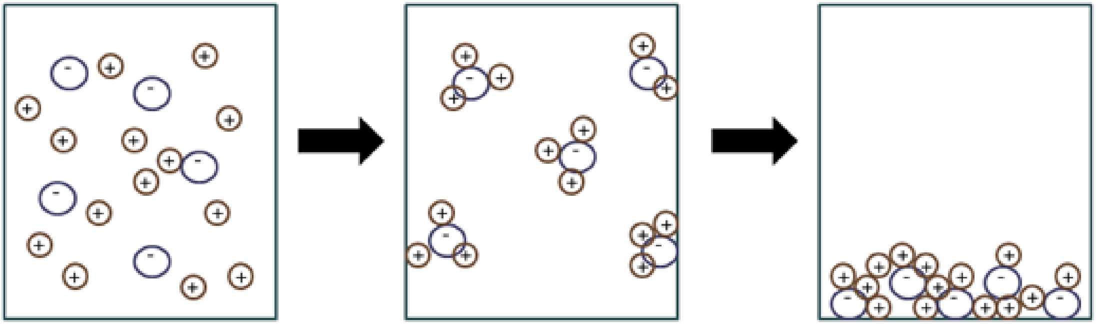


Figure 9: Coagulation, Flocculation, and Settling **(Kenny, 2010)**

3.5.2. Factors that Influence the Coagulation/Flocculation Process

Several factors influence the coagulation/flocculation process such as, raw water quality (turbidity, pH, alkanity, and temperature), coagulant dosage, and type of coagulant used, mixing/distribution geometry and mixing time. Turbidity caused by suspended colloidal clay particles, such as silt, clay, microscopic organism, soluble colored organic compounds; the higher amount of particles generally requires higher dosage of coagulant**.** The effectiveness of colloidal destabilization is directly proportional to the amount of coagulant added **(Geng, 2005**).

Alkalinity in raw water can limit the pH reduction observed after metal coagulant addition, for precursor removal (pH 4-5 for iron, pH 5-6 for alum). On the average, each mg/L of alum ($Al_2(SO4)_3.14\ H_2O$) and ferric chloride ($FeCl_3$) addition consume 0.5 mg/l and 0.62 mg/l of alkalinity respectively. Temperature affects reaction rates, viscosity, and structural characteristics in the floc formed. Lower temperatures have been found to cause lower turbidity removal. Floc settling velocity also decreased at lower temperatures due Aluminum sulfate and aluminum hydroxide precipitates provide additional adsorption sites for the removal of NOM, both coagulant dose and alkalinity as $CaCO_3$ (**Check, 2005**). Higher, colored water containing higher amounts of NOM generally requires higher dosages of coagulant **(Geng, 2005**).

3.6. Chemical Coagulants and Coagulant Aids

Chemicals used in coagulation/flocculation referred as either as primary coagulants or as coagulant aids. Primary coagulants used to cause the particles to become destabilized and begin to clump together. The purpose of coagulant aids may be to condition the water for the primary coagulant used, to add density to slow-settling flocs. The coagulants classified into three types, which are inorganic coagulants, synthetic organic polymer and natural coagulants. The commonly used metal coagulants fall into two general categories: those based on aluminum and those based on iron. The aluminum coagulants include aluminum sulfate, aluminum chloride, polyaluminum chloride and sodium aluminate. The iron coagulants include ferric sulfate, ferrous sulfate, ferric chloride, polyferric sulfate and ferric salts with organic polymers. Other metals used as coagulants include hydrated lime and magnesium carbonate. **(Bratby, 2006)**

3.6.1. Coagulation Using Al (III) and Fe (III)

Al (III) and Fe (III) are the salts used most frequently to coagulate colloidal material in water treatment. When ferric or aluminum ions are added to water, a number of parallel and sequential reactions occur. Initially, when a salt of Al (III) and Fe (III) added to water, it will dissociate to yield trivalent Al^{3+} and Fe^{3+} ions, as shown below:

$$Al_2\,(SO4)_3 \longrightarrow 2Al^{3+} + 3SO_4^{2-}$$

$$FeCl_3 \longrightarrow Fe^{3+} + 3Cl^-$$

The trivalent ions of Al^{3+} and Fe^{3+} then hydrate to form the aquometal complexes $Al(H_2O)6^{3+}$ and $Fe(H_2O)6^{3+}$,the metal ion (aluminum in this case) has a coordination number of 6 and six water molecules orient themselves around the metal ion**(Crittenden *et al.*, 2012).**

$$\begin{bmatrix} H_2O & & OH_2 \\ H_2O - Al - OH_2 \\ H_2O & & OH_2 \end{bmatrix}^{3+} \leftrightarrow \begin{bmatrix} H_2O & & OH_2 \\ H_2O - Al - OH_2 \\ H_2O & & OH_2 \end{bmatrix}^{2+} + H^+$$

The equation predicts that each mg/l of alum would consume 0.50 mg/l (as $CaCO_3$) of alkalinity. If the alkalinity is not sufficient to react with the alum and buffer the pH, then it is necessary to add alkalinity to the water in the form of lime, sodium bicarbonate, soda ash, or some other similar chemical. The reaction used to estimated the amount of sludge produced.

$$Al_2\,(SO4).14H_2O+3Ca\,(HCO_3)_2 \longrightarrow 2Al\,(OH)_3(S)\downarrow+3CaSO_4\,(s)\downarrow+6CO_2+14H_2O$$

If natural Alkalinity is insufficient, then lime or caustic soda can be added.

$$Al_2\,(SO4).14H_2O+3Ca\,(OH)_2 \longrightarrow 2Al(OH)_3(S)\downarrow+3CaSO_4(s)\downarrow+14H_2O$$

For the PACl compounds used the general formula (Aln(OH)mCl(3n-m))x and have a polymeric structure totally soluble in water mostly highly polymerized coagulants include PACl, n=2 and m=3**(Gebbie,2001)**

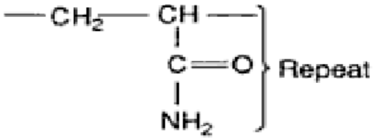
3.6.2 .Polymers

Organic polymers used as coagulant and coagulant aids in water treatment. Polymers may be anionic, cationic or neutral in charge. The most commonly used polymers are cationic polyelectrolyte that able to increase the quality of floc when used in conjunction with metal salts **(Check, 2005).** These polymers are long-chain molecules of repeating chemical units. They may contain one single monomer or may be composed of different types of sub units (**Auckland, 1999**).

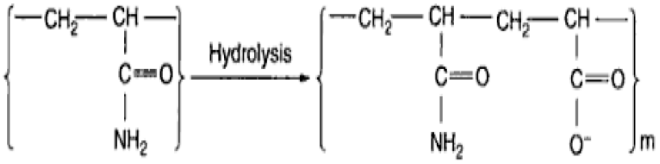
The monomers having a positive charge upon ionization are cationic; polymers and negatively charged polyelectrolyte are anionic polymers. Finally, polymers that do not contain ionizable groups are nonionic polymers. Cationic polymers can be effective in coagulating negatively charged clay particles. It has been hypothesized that electrostatic forces or ion exchange is the process by which the polymers become attached to the clay particles, which is then followed by bridging. Cationic polymers do not require a large molecular weight to be effective in destabilization. PolyDADMAC and EPI-DMA polymer known to be the most widely used polymers worldwide, and reports suggest that they form 80% of polymers sold to the drinking water industry in the USA **(Faust, 2010)**

Anionic particles generally are in effective coagulants for negatively charged particles, and there is strong evidence that the presence of divalent metal ions (such as Mg^{2+}) is necessary for anionic polymers to flocculate negative colloids. However, anionic polymers of large molecular weight or size are able to bridge the energy barrier between two negatively charged particles, thereby effectively enhancing the coagulation efficiency. When anionic polymers are used in conjunction with an electrolyte such as NaCl or $CaCl_2$ or another coagulant such as alum, their coagulation efficiency is increased. The use of alum or ferric chloride can result in copious volumes of sludge that must be handled, whereas the additional sludge quantity is negligible when a polymer is used. Overdosing or under dosing from optimum polymer dosage will result in restabilization of the colloids. The control method for polymer feed systems must be precise and reliable to give satisfactory performance**. (Faust, 2010)**

Because polymers do not affect the pH of water, their use offers a clear advantage for treating low-alkalinity waters. This is particularly true of the low-alkalinity waters that are high in turbidity. Such waters would require considerable qualities of alum, which would require the addition of soda ash or lime to replenish the buffering capacity of the water and maintain desirable pH.

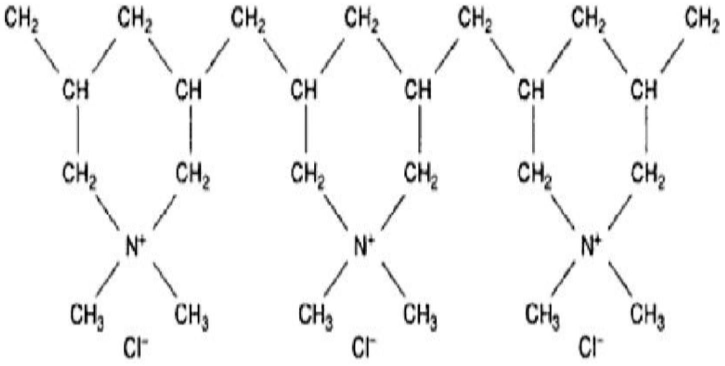


The structure of nonionic Polyacrylamide.(Bratby, 2006)



The structure of anionic hydrolyzed polyacrylamide

Common cationic quaternary ammonium compound is polydiallyldimethyl ammonium chloride (PDADMAC).



The structure of the poly DADMAC polymers

The poly DADMAC polymers are the most widely used polymers for potable water purification. They are well known to be the most chlorine resistant and operate over a wide pH range **(Bratby 2006).**

4. Materials and Methods

4.1. General

The main objective of the experimental investigation was to obtain optimum coagulant dose for maximum removal of total organic substances present in raw water by enhanced coagulation and flocculation processes. The treatment studies were conducted on Legedadi raw water to quantify the removal of turbidity and organic matter by measuring the reduction of both turbidity and TOC .The experiments were conducted under various operating conditions, such as testing of different types and dosages of coagulant by using the highest TOC value present in Legedadi reservoir 1n the month of May.

4.2. Chemicals and Apparatus

The major reagents (chemicals) used during the experiment were in analytical grade. The three type of coagulants (Aluminum sulfate. Poly-aluminum chloride, and Polyelectrolyte) were used in the enhanced coagulation and Lime was used in the softening experiments. On the other side Jar testing machines, turbidity meter, titration flask, pH meter, and TOC analyzer were the main instruments during the experiments.

4.3.Raw Water Sample Collection, and Transportation

The sample water for this study was collected from inlet of Legedadi water treatment plant as soon as enters from the reservoirs. The water samples were collected from April – May 2013 G.C. The selection of sampling season was based on the maximum total organic carbon concentration present in raw water since the concentration of organic matter increases as the reservoir water level decreases

Legedadi raw water is more turbid and brown-yellowish in color. The challenge while attempting to generate the data was the variability in turbidity characteristics of the water source. To overcome this problem the experiments were done by keeping uniformity of the raw water sampling depth, and sampling season throughout the study period. The raw water was collected using bottle containers prior to immediate experimentation. Fresh water samples were collected in order to avoid ageing effects. Some water quality parameters like pH, turbidity were analyzed in AAWSA head office laboratory, while immediately the treated water samples for TOC test were transported to the EPA, kept in bottle for analysis

4.4. Study Variables

The total organic matter was selected as a study variable. Two factors taken into consideration when investigating their effect on the response variable were coagulant types and coagulant dose.

4.5. Experimental Procedures

The study parameters were determined based on American standard methods for examination of water and wastewater treatment (**APHA *et al.*, 1999**).The description are presented in section 4.5.1 and 4.5.2.

4.5.1. Jar Test Procedure

The Jar test used to simulate full-scale plant operations and model typical treatment plant conditions. It is a widely used method to evaluate coagulation- flocculation processes **(Kawamura, 1991)**. The jar tests were conducted by placing 1L of the raw water to be tested into each of 6 beakers and labeling them 1 to 6. Then the beakers placed in Phipps & Bird jar test apparatus and six paddle stirrer jar test apparatus in ascending numerical order. Then amount of coagulant solution carefully pipetted into 50 mL beakers in the amounts shown in appendixes. Each beaker filled with 1 liter of raw water from the treatment facility and dosed with concentrations of coagulant and lime with identical turbidity level, and agitated at a rapid mixing speed of 120 rpm. A different volume of the selected coagulant added in to the 5 beakers. After 2 minutes, the stirring rate was lowered to 40 rpm and this rate kept for 20 minutes. This followed by different sedimentation time for the different coagulants used. For PDADMAC 10 minute of sedimentation time was used and for Alum and PACl 30 minute sedimentation time was used. After the sedimentation phase, samples for turbidity measurement, and TOC analysis were collected from the supernatant using a standard pipette. For each coagulant and turbidity level, two identical jar tests were carried out in order to obtain statistically reliable results. If the optimal dosage was not found in the jar test, a new jar test with new dosage was carried out until the optimum was found. In each jar test experiment, one of the six jars received no treatment which serving as a control for comparison of the TOC and turbidity reduction for all other jars.

4.5.2. Total Organic Carbon (TOC) Test

The organic carbon in water and wastewater is composed of a variety of organic compounds in various oxidation states. TOC is a more convenient and direct expression of total organic matter content than BOD, or COD (**APHA *et al.*, 1999**). A total carbon analyzer Shimadzu TOC-VCSH used to analyze organic carbon in raw and treated water by combustion at103-105 °C. TOC Analyzer where by organics are oxidized into carbon dioxide (CO_2) and are measured as total organic carbon.

4.6 .Analytical Procedures

The Samples of supernatant were analyzed for basic water parameter. The supernatant samples were first collected 35 mL in small beaker, then the samples were analyzed for turbidity using a HACH 2100A turbidimeter with the data reported in the standard unit for turbidity measurement the Nephalometric Turbidity Unit (NTU). The turbidity meter cuvette was washed once with distilled water before recording the turbidity in order to eliminate any differences in turbidity due to different sedimentation times. Then the samples were transferred to a clean, empty bottle for analyzing total organic carbon. In each jar test experiments, one of the six jars received no treatment which serves as a control for comparison of the total organic matter reduction for all other jars. The Percent removal of the organic matter load (% TOC Reduction) was calculated based on the next equation **(Kenny, 2010)**

$$\% \text{ TOC Removal} = \frac{(\text{Raw Water TOC (mg/l)}) - \text{Treated water TOC (mg/l)}}{\text{Raw Water TOC mg/l}} * 100 \ldots\ldots (2)$$

More ever the supernatant from each beaker was taken at the same time; pH and Temperature were measured with a Horiba pH meter made in Japan. The sensor was held in the sample until the pH-value was stabilized within a one decimal range. Between every reading, the sensor was cleaned with distilled water. Conductivity and TDS were measured with HACH CO150 conductivity meter. Alkalinity was determined by means of buret titration method. Three drops of bromcresol green-methyl red indicator was added to 50 ml of sample. Then a 0.020 N sulfuric acid standard solution was added to the sample using 725-dosimat digital titration equipment from HACH. The added volume of acid was noted at the color changes from blue to light pink.

4.7. Experimental Design

The experimental design implemented is general factorial (two factors coagulant type and coagulant dose).The factorial design was used to investigate the effect of two factors on the final response of percentage TOC removal from the raw water. The coagulant dose have five levels including that obtained optimal dose for conventional coagulation and two replication of each level where as the coagulant type have three levels and two replication of each level which give total number of thirty runs.

Constant factor**:** Sampling season, raw water depth,

4.8. Statistical Analysis

The data was analyzed 95% confidence interval. The results of TOC removal as a function of the different tested parameters were analyzed by a multi-factorial analysis of variance (ANOVA) using the program design expert version 7.0. Analyses of variance (ANOVA) performed to determine which of the parameters evaluated or which combination of parameters have a significant effect on TOC removal. The hypotheses compares whether the means of the different treatment and level of the parameters are the same or at least one of them is different. The rejection of the null hypothesis indicates that the evidence favored the alternative hypothesis; it means that there is statistically significant difference between the means for the different levels evaluated **(Montgomery, 2001)**

$$H0: mean_1 = mean_2 = \ldots = mean_5$$

$$H1: mean_1 \neq mean_2 \neq \ldots \neq mean_5$$

F test in equation below is a statistic used in the hypothesis test that there is no difference between the means. F is the ratio of $MS_{\text{Treatments}}$ (Mean Square Between, which is based on the variance of the sample means) to MS_E (Mean Square Error, which is based on the Variance within samples:

$$F = MS\ Treatments/MSE$$

If the null hypothesis is true, then the F ratio should be approximately equal to one, since the $MS_{\text{Treatments}}$ and MS_E should be about the same. If the ratio is much greater than one, the null hypothesis, Ho is rejected. The F test in ANOVA allows significant parameters for the removal of TOC identified. Each individual effect was tested for significance using the F statistic at the 95% confidence level for decision-making. If the p-value (Probability>F) is less than 0.05, the parameters evaluated are significant in the removal of TOC value.

5. Results and Discussion

The following chapter provides the results of laboratory analysis made for raw water characterization; study of effects of parameters such as coagulant type and coagulant dose under the influence of enhanced coagulation on the removal of TOC are discussed. A series of jar tests were performed with three different Coagulants (alum, polyelectrolyte, and PACl), pH adjustment and control were necessary for effective coagulation and flocculation of soluble TOC, lime was used to adjust pH while, Poly-aluminum chloride and alum decrease the pH during the jar test.

5.1.Basic Raw Water Characteristics

The raw water samples were taken from inlet of Legedadi water treatment plant that enters from the reservoir from the month of April to May 2013 G.C. The values of basic water quality parameters such as pH, Turbidity, TOC, Conductivity, Total Dissolved Solid and Alkalinity were determined and described in Table (2). These parameters were measured just before each jar tests

Table 2: Raw Water Characteristics

S. No	Basic Raw water parameters	Average	Values
1	Turbidity (NTU)	294	290 -298
2	Total organic carbon (mg/l)	108	106-110
3	pH	7.42	7.26-7.58
4	Conductivity (µS/cm)	141.5	140.5-142.8
5	Alkanity (mg/l as $CaCo_3$)	58.1	56.6-59.6
6	TDS(mg/l)	64.5	61-68
7	Temperature	22.6	22.4-22.8

The raw water can be characterized as high turbidity because the turbidity is higher than 250 NTU **(Miller, 2008)** and has medium alkalinity.

According to the total organic carbon test, average concentration of the total organic matter load was 108mg/l value, which is not found in the range of 1-40 mg/l that is the typical interval for surface raw water **(García, 2005)**. From the result of Table 2, high values of both turbidity and TOC sources exist in the watershed and there is a high erosion problem at the watershed.

5.2. Optimal Dose Result for Turbidity Removal in Conventional Legedadi Water Treatment Plant

The experimental test was conducted on Legedadi raw water to find the three optimal coagulant dosages. Firstly, the effectiveness of coagulation process was evaluated in terms of turbidity and removal efficiency because at the entrance of treated water distribution system the turbidity never exceeds five NTU **(WHO, 2008).** The experimental run (Jar testing) took place by varying coagulant type and dosage to obtain the baseline data for each optimal coagulant dosage based on finished water turbidity residual and maintaining the pH at the optimal level for alum and PACl but not for polyelectrolyte since it does not depended on pH value.

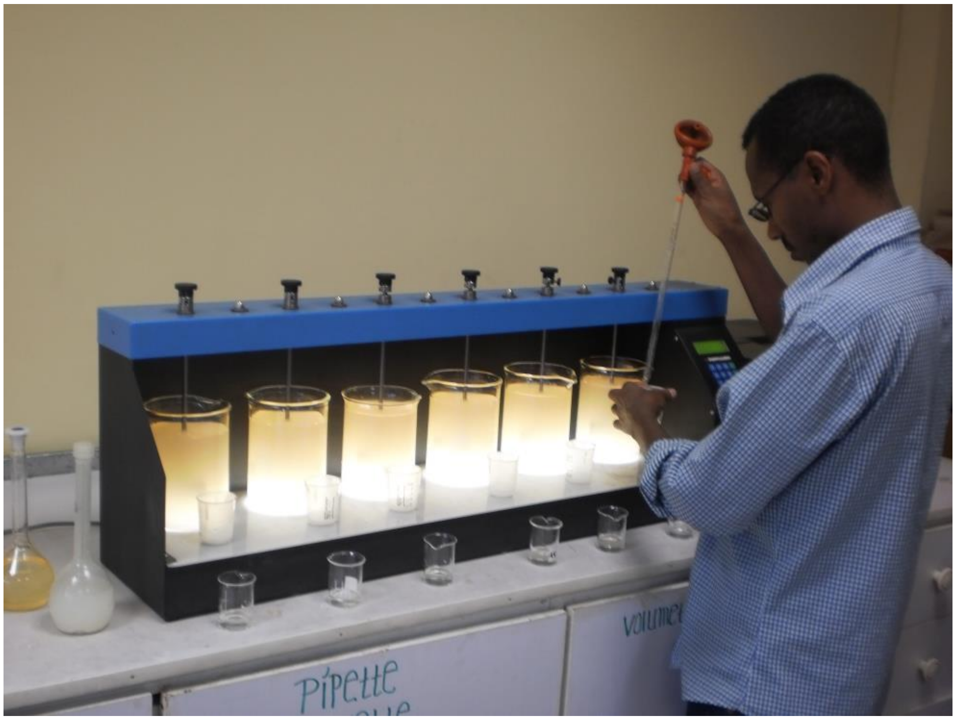


Figure 10: Jar Test for Optimal Coagulant Dose Arrangement

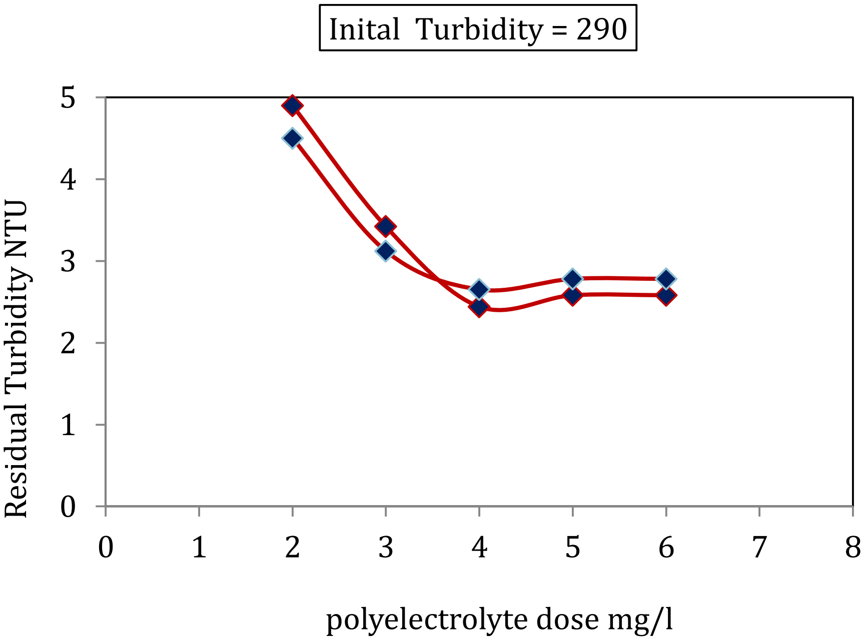


Figure 11: Effect of Polyelectrolyte, Dose on Turbidity Removal of High Turbid Water

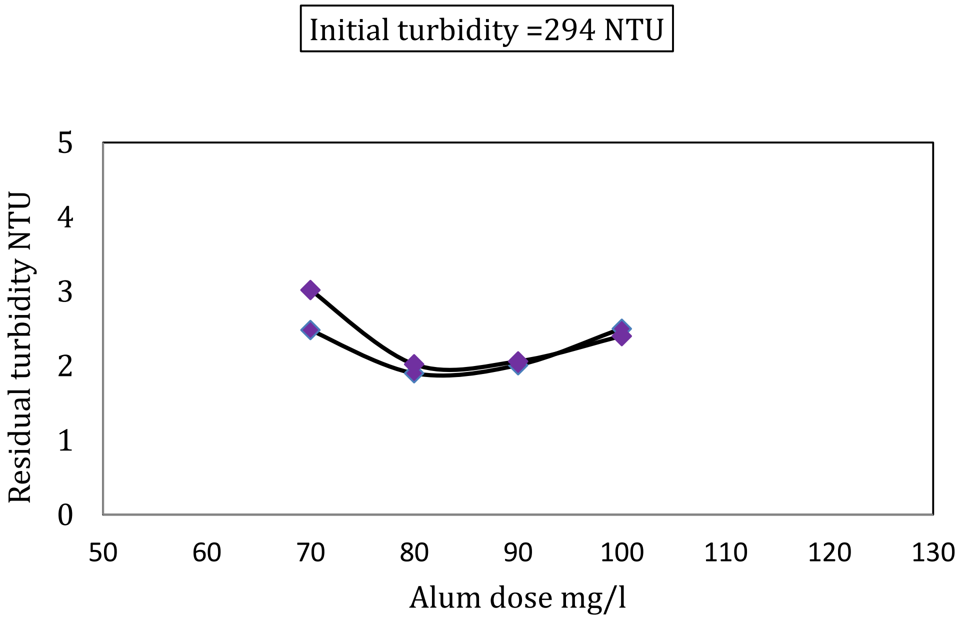


Figure 12: Effect of, Alum Dose on Turbidity Removal of High Turbid Water

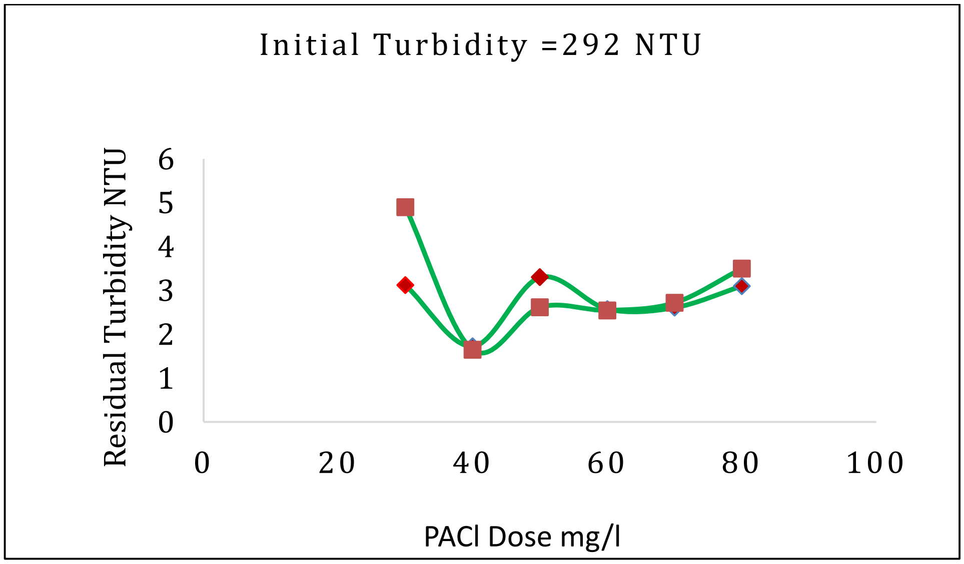


Figure 13: Effect of PACL Dose on Turbidity Removal of High Turbid Water

Thus have seen on Figure (11-13), the result indicated that the three type of coagulants are potential use to remove turbidity from the Legedadi raw water. However, the three coagulant dose increase in order to achieve the best turbidity removals efficiency. Thus the higher dosage needed indicated that in Legedadi raw water contain much colloid and particulate matter that cause for higher turbidity value. For the three coagulant type, the best turbidity removal efficiency assessed where passed through with smaller dosage of coagulant shown in appendixes(1) and then the optimal dosage was in every case shown in figure(11-13) took based on result where the dosage was the lowest possible while results for residual of turbidity lowered with the corresponding dosage. Once favorable conditions were identified for each coagulant type, additional jar tests were conducted to ensure coagulant dosage conditions.

From the above figure (11-13), the minimum turbidity attainable with the PACl was approximately 1.69 NTU whereas with alum, turbidities below 1.96 NTU and with polyelectrolyte 2.54 NTU were obtained. These residual turbidity values in treated water were below five NTU, thus indicated that performances of three coagulants are acceptable as compared to WHO, 2008 standard. The better result of PACl and alum likely due to ability of adsorption on to metal hydroxide flocs and formation of insoluble complexes. Since Poly-aluminum chlorides are synthetic polymers dissolved in water, they react to form insoluble aluminum poly hydroxides, which precipitate in big volumetric flocs. The floc absorb suspended pollutants in the water, which are precipitated with the PACl and can together be easily removed. However, for all three coagulant beyond optimum or higher dosages resulted in reestablished due to charge reversal. Here in the optimal coagulants dosage were obtained for conventional coagulation presented in Table (3)

Table 3: Optimal Coagulant Dose Value for Conventional LWTP

Coagulant Type	Optimal Dose (mg/l)	Average Residual Turbidity(NTU)	pH
Polyelectrolyte	4	2.54	7.6
Aluminium Sulphate	80	1.96	7.3
Poly Aluminium Chloride	40	1.69	7.72

5.3. Adjusted optimal dose for enhanced coagulation

Conventional coagulation of the raw water is a process mainly used to remove turbidity. Since the treatment process, first being optimized based on turbidity removals associated with these favorable optimum conditions not directly used for organic matter removal. However, many treatment plant operators would find a dosage that provides adequate treatment for turbidity. It is important to note that low turbidity values do not necessarily mean decreased organics; (TOC) can still be present in the treated water. With the concern of risks associated with DBPs, it was necessary to develop new techniques to remove natural organic matter present in the raw water

Recent change in regulation requiring the control of organic compounds in the water changed the primary treatment indicator from turbidity to total organic carbon (TOC). In order to control DBPs a process referred to as Enhanced Coagulation is most commonly used **(USEPA. 1999).** Based on this and other literature agreement the determination of reasonable coagulant dose for each coagulant type was determined by conducting as similar to previous jar tests. Each coagulant dose was arranged by introducing common coagulant dosage multiplier for the varied initial optimal or baseline coagulant dose use for conventional LWTP that has been chosen in the first jar test as shown in Table (3). The lime dose also introduced to maintain variation of pH levels for effective coagulation and flocculation process to enhance TOC removal for the Legedadi raw water sample. The values of adjusted incremental coagulant dose for all coagulant types to enhance coagulation are presented in Table (4) and the result obtained are discussed in the next section.

Table 4: Arranged Incremental Coagulant Dose for Enhancement Coagulation Process

Optimal-Dosage multiplier	polyelectrolyte Dosage(mg/l)	Aluminum-Sulfate Dosage(mg/l)	Poly-Aluminium Chloride
1*O.D	4	80	40
1.25*O.D	5	100	50
1.5*O.D	6	120	60
1.75*O.D	7	140	70
2*O.D	8	160	80

1, 1.25, 1.5, 1.75 and 2 are the common multiplier for the optimal baseline coagulants dose i.e.4 mg/l (Polyelectrolyte), 80 mg/l (Alum), and 40 mg/l (PACl) use for conventional Legedadi Water Treatment Plant.

5.4. Residual Organic Matter after Enhanced Coagulation

Once the jar tests were complete based on Table 4 incremental coagulants dosages, then the final residual total organic carbon and some of the basic water parameters value were measured These results of residual TOC in treated water are presented in Table 5 and Figure(15-17). The Chemical type and dose as well as the combinations, which do have significant effect on TOC removal, were discussed in statistics part

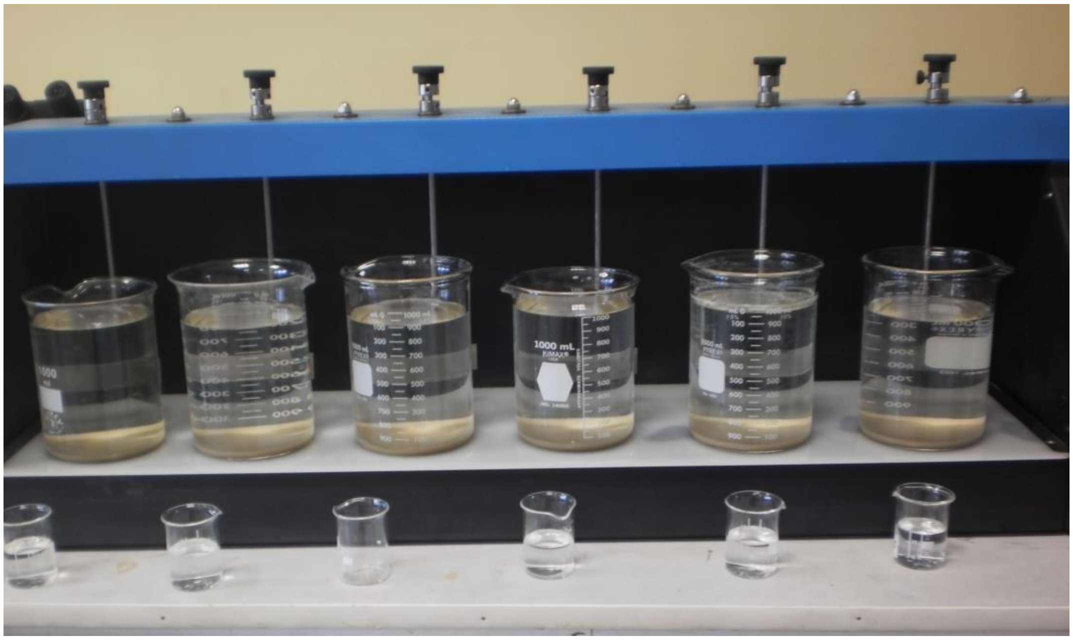


Figure 14: Legedadi treated water ready for TOC test

Table 5: Final Legedadi Treated Water Residual TOC Result after Enhanced Coagulation Experiments

Optimal Dosage factor	Polyelectrolyte Dosage(mg/l)	Aluminum Sulfate Dosage(mg/l)	Poly-Aluminium Chloride Dosage(mg/l)
1*O.D	17.5 17.1	3.9 4.2	6.8 7.1
1.25*O.D	4.9 4.5	3.7 3.8	2.4 2.6
1.5*O.D	4.3 4.1	3.6 3.3	2.1 2.2
1.75*O.D	7.2 7	4 4.2	1.4 1.2
2*O.D	9.4 9.2	6 8	4 4.2

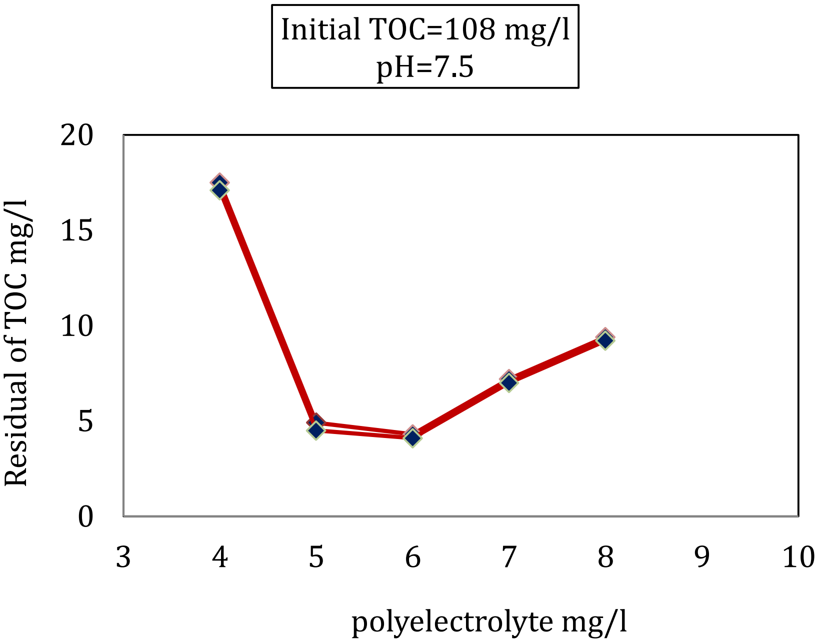


Figure 15: Effect of polyelectrolyte Dose on TOC Removal of High load of Organic Matter

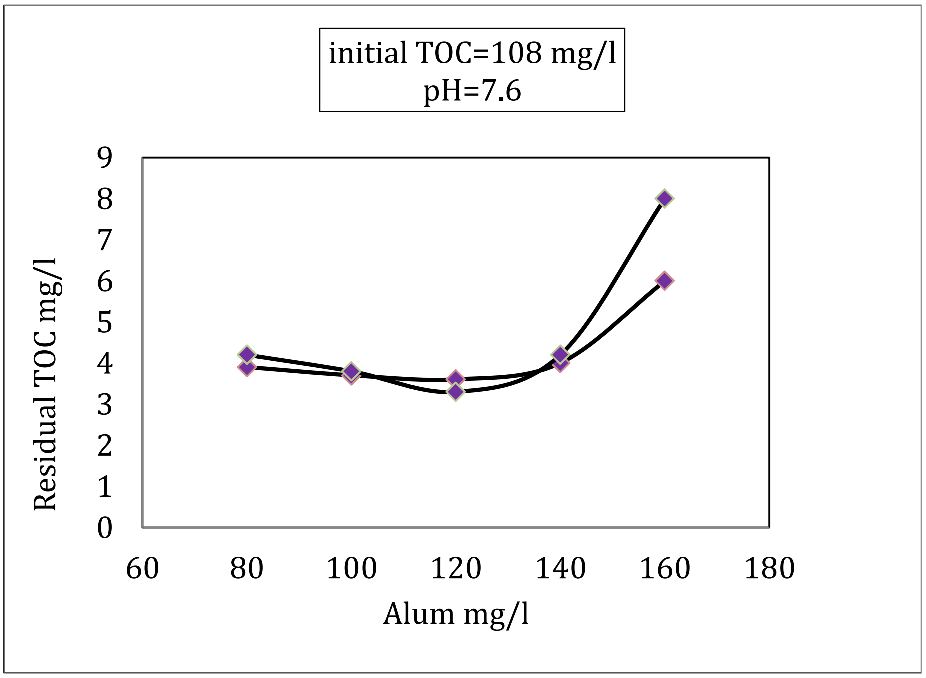


Figure 16: Effect of Alum Dose on TOC Removal of High load of Organic Matter

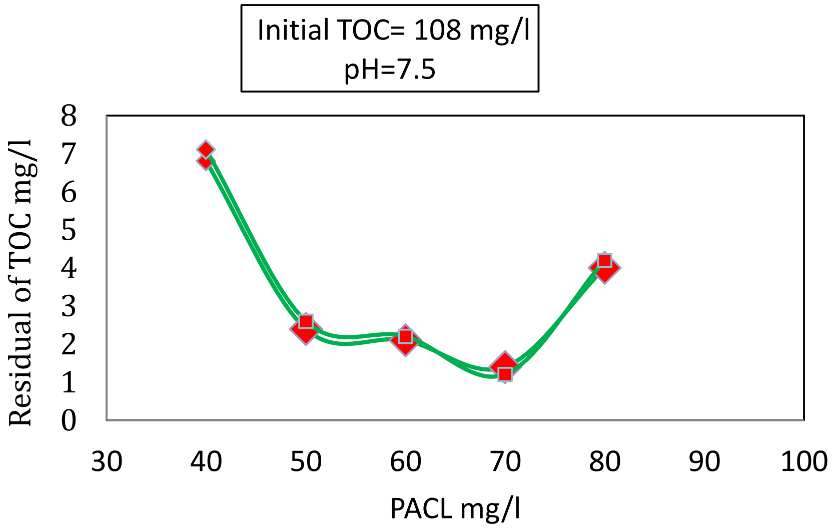


Figure 17: Effect of PACl Dose on TOC Removal of High load of Organic Matter

5.5 Enhanced Coagulation Efficiency Based on TOC Removal

The percent removal efficiency for total organic matter was determined by the difference between the amount of total organic matter that presented in raw water and the final residual TOC presented in treated water divided by the initial raw water TOC times 100%.

$$\%\ \text{TOC Removal} = \frac{(\text{Raw Water TOC (mg/l)}) - \text{Treated water TOC (mg/l)}}{\text{Raw Water TOC mg/l}} * 100 \quad \ldots\ldots\ (3)$$

The zero chemical jars provided the 108 mg/l initial total organic carbon use to be compared with the treated water to determine the performance of effectiveness and functionality of the coagulant type and dose. This TOC removal efficiency was studied by varying the two main factors such as coagulation types, and coagulant dose applied to treat Legedadi raw water means that the result of the comparison tests were conducted over the optimum dose(arranged for turbidity removal) by varied 100% range using the common multiplier (1,1.25,1.5,1.75,and 2). Based on the above formula the results were presented in Table 6.

Table 6: Combination Test Result of Total Organic Carbon Removal Efficiency

Std	Coagulant Type	Coag Dose	% R.TOC
1	polyelectrolyte	1*O.D	83.8
2	polyelectrolyte	1*O.D	84.2
3	Alum	1*O.D	96.4
4	Alum	1*O.D	96.1
5	PACl	1*O.D	93.7
6	PACl	1*O.D	93.4
7	polyelectrolyte	1.25*O.D	95.5
8	polyelectrolyte	1.25*O.D	95.8
9	Alum	1.25*O.D	96.6
10	Alum	1.25*O.D	96.8
11	PACl	1.25*O.D	97.8
12	PACl	1.25*O.D	97.6
13	polyelectrolyte	1.5*O.D	96.
14	polyelectrolyte	1.5*O.D	96.2
15	Alum	1.5*O.D	96.7
16	Alum	1.5*O.D	96.9
17	PACl	1.5*O.D	98.1
18	PACl	1.5*O.D	98
19	polyelectrolyte	1.75*O.D	93.3
20	polyelectrolyte	1.75*O.D	93.5
21	Alum	1.75*O.D	96.3
22	Alum	1.75*O.D	96.1
23	PACl	1.75*O.D	98.7
24	PACl	1.75*O.D	98.9
25	polyelectrolyte	2*O.D	91.5
26	polyelectrolyte	2*O.D	91.3
27	Alum	2*O.D	94.4
28	Alum	2+*O.D	92.6
29	PACl	2*O.D	96.3
30	PACl	2*O.D	96.11

5.6. Effect of Coagulant Dose on TOC Removal

5.6.1 Effect of Alum Dose on TOC Removal

The main goal of these tests were to determine which of the metal salts and polymers could achieve the best TOC removal efficiency, while also maintaining the turbidity value below five NTU and the pH value between 6.5 and 8.5 based on (**WHO, .2008**). It was apparent from the results that indicated in Figure (18) since the concentration of coagulants required for coagulation were proportional to the concentration of organic matter present in raw water, the coagulant should be added in sufficient amount to destabilize the organic matters

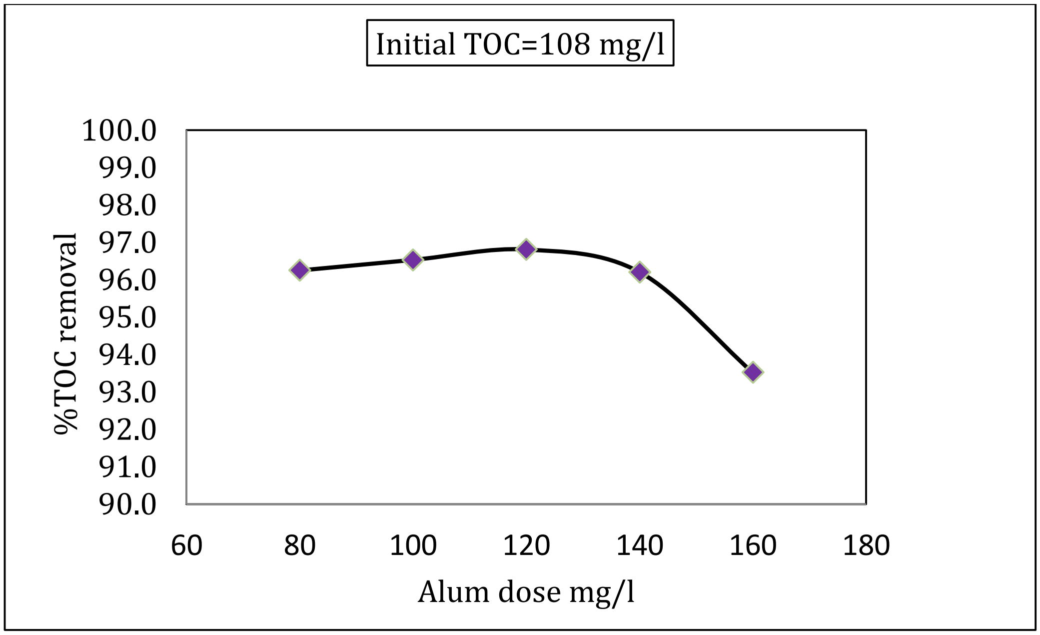


Figure 18: Effect of Alum Dose on percent reduction TOC for enhanced coagulation

As observed from Figure (18) with increase in alum dose from 80 to 120 mg/L the organic matter removal efficiency was slightly increased from 96 % to 97.7%. Further increase in alum dose to 160 mg/L caused a decrease in organic removal to 93%. Thus, maximum removal of 97.7%t of organic matter was achieved at 1.5*optimum dose with 120 mg/l, at 7.5 pH and the corresponding average turbidity residual was 2.6 NTU as presented in Appendix (2). At optimal dose of alum for turbidity removal has a good removal efficiency for organic matter as compared to polyelectrolyte and PACl as discussed below. The reason for this removal of organic substances, when salts of aluminum used as coagulants, are mainly because of direct precipitation of organic substances by co-precipitation with aluminum hydroxide and adsorption of organic substances on solid aluminum hydroxide

5.6.1 Effect of polyelectrolyte Dose on TOC Removal

Polyelectrolyte was tested also with the same procedure that followed the alum dose and PACl for legedadi raw water sample contains 108 mg/l TOC. The polyelectrolyte dose was varied started from 4 mg/l up to 8 mg/l.

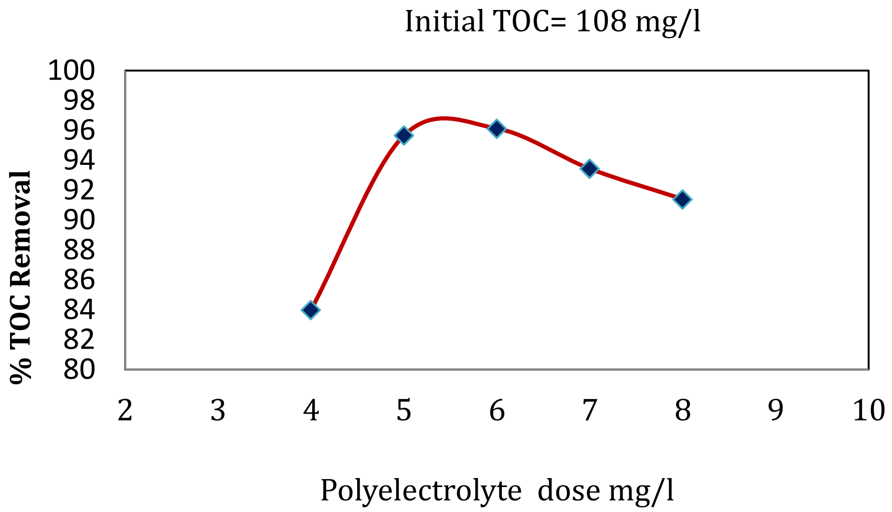


Figure 19: Effect of Polyelectrolyte Dose on percent reduction TOC for enhanced coagulation

The expected percentage of the TOC removal value was much different from the first optimal or initial dose value of 4 mg/l polyelectrolyte as compared to the initial dose of 40 mg/l, PACl, and 80 mg/l alum. The observed result from Figure 19 showed that TOC removals increased for higher dose. The polyelectrolyte with a dose of 1.25* optimum dose (5 mg/l), was compared with alum and PACL at the similar stage, yielded 95.6 % TOC removal efficiency. However, as further increase of in dose of polyelectrolyte did not bring much change in efficiency rather slightly increased and further more increase in dose of polyelectrolyte lead decrease TOC removal to 91.5 %.

5.6.3 Effect of poly-Aluminum chloride Dose on TOC Removal

The third and the new coagulant type that did not apply yet on the legedadi water treatment is PACL. The initial dose or the optimum dose of the PACL was 40 mg/l. This dose was less than the optimum dose of alum and greater than optimum polyelectrolyte. The alum and PACL were also good for the removal of turbidity and TOC at optimum dose as compared to polyelectrolyte.

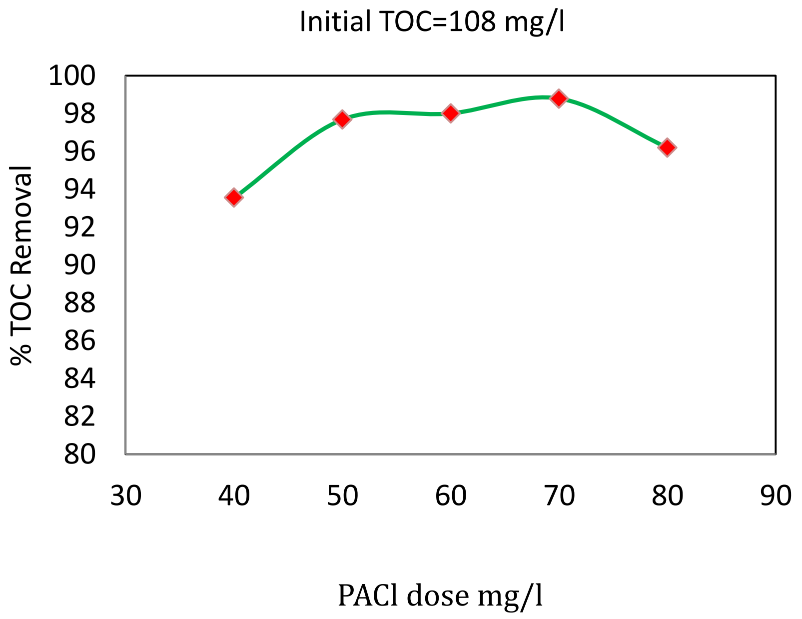
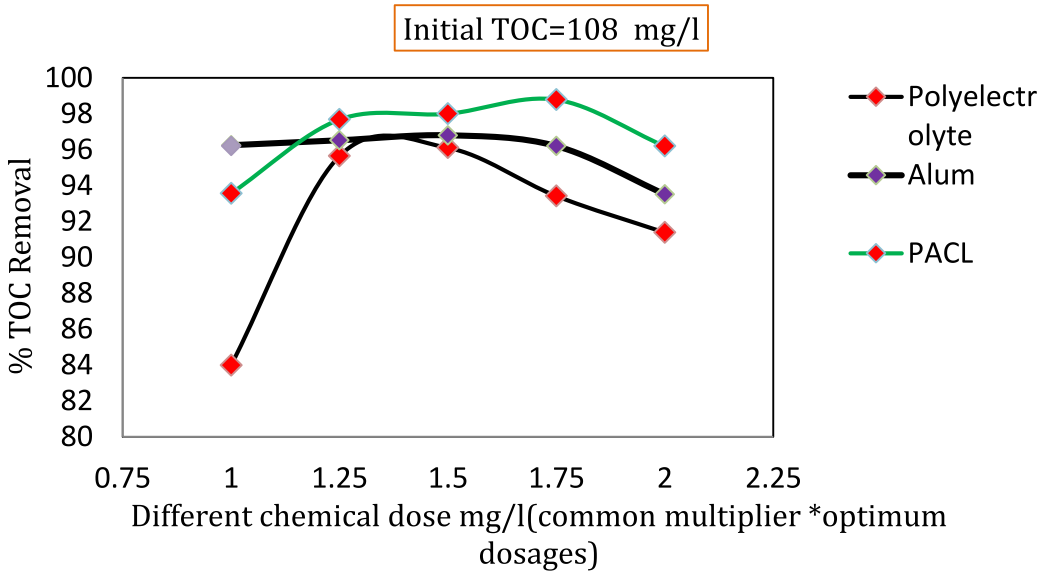


Figure 20: Effect of Poly-Aluminum chloride Dose on percent reduction TOC for enhanced coagulation

The results in Table 6 and Figure 20 showed that as the dose increase from 40 mg/l to 60 mg/l the corresponding TOC removal efficiency increased from 93.5% to 97.7 %. PACl dose was continued starting from optimum dose up to 80 mg/l, order to further increasing the TOC removal efficiency up to 100%. However, the addition of PACl above 70 mg/l did not improve TOC removals beyond 98.8 %. Therefore, the optimal chemical combination was found to be at rate 1.75 times the optimal dose,i.e 70 mg/L of PACl, and corresponding residual turbidity of 1.73 NTU and 7.2 pH was recorded Appendixes (2). The three optimum coagulants (polyelectrolyte, alum, and PACL) dosed on the Legedadi raw water that use in conventional coagulation for turbidity removal were achieved 84%, 96% and, 93.5% TOC removal respectively



1, 1.25, 1.75 and 2 are the common multiplier for the optimal coagulant dosage

Figure 21: Effect of Three Coagulants Dose on percent reduction TOC for enhanced coagulation

Enhanced coagulation result from Figure21 of the three coagulant types were compared based on removal or reduction TOC. Alum and PACl are more effective than Polyelectrolyte, which is currently being used At Legedadi Water Treatment Plant. These results indicated that enhanced coagulation, efficiency of PACl reached up to 98.9 % whereas Alum and Poly DADMAC was 96.8 and 95.8 respectively.

Reduction of TOC Figure (18-21) is important indicator for reduction of DBP precursors. TOC reduction indicates the organic matter reduced by the treatment techniques. Since organic matter is a large contributor in the formation of THMs, lower TOC values will likely indicate a lower potential for formation of disinfection by-products. Means that organic carbon reduction is an indicator of how much organic matter is reduced in the water and, therefore decreases reactions with chlorine to form DBPs.

5.7 ANOVA for the Variation of Two Parameters

The F-ratios for the parameters evaluated in enhanced coagulation method were high, indicating that each parameter has an influence on the removal of organic matter. The statistical analysis i.e. Analysis of Variance results was presented in Table (7)**.**The ANOVA result supports this idea giving rise to p-values of <.0001

Table 7: Analysis of Variance (ANOVA) Results

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F
Model	369.79	14	26.41	433.34	< 0.0001
A-Coagulant type	123.36	2	61.68	1011.88	< 0.0001
B-Coagulant Dose	143.51	4	35.88	588.61	< 0.0001
AB	102.92	8	12.87	211.06	< 0.0001
Pure Error	0.91	15	0.061		
Cor Total	370.70	29			

The analysis of variance result shown in Table (7) displayed through parameter estimate and effect test demonstrates that coagulant type affects the process. Therefore, the variation of the TOC removal efficiency was different for each coagulant type. The effect of the coagulant dose was the second factors that affect TOC removal Therefore, the effect of the coagulant type and dose showed that the variation of the TOC removal efficiency was different for each coagulant type and dose. As a result, the basic assumption of the null hypothesis is rejected i.e there was a significant TOC removal differences with applied the varying of the coagulant dose and type. This shows also that the interactive effect of two of the factors at a time is significant with p-value of <0.0001.

5.8. Limitation of Enhanced Coagulation

In order to achieve optimal organic matter removal efficiency the application of PACl and Alum rather than the currently in use polyelectrolyte have shown, relatively a better performance in Conventional Coagulation and Enhanced Coagulation method. Most systems should be able to implement enhanced coagulation or enhanced softening with minimal secondary effects **(USEPA, 1999).** However, the implementation of enhanced coagulation, and adjustment of pH for softening might have secondary effects. In this study the limitation of enhanced coagulation was mainly the production of larger sludge quantities and increased of chemical cost implication were observed, which are presented in section 5.8.1 and 5.8.2.

5.8.1. Impact of Increased Quantity of Sludge

During the analysis of enhanced coagulation, adjustment of pH has resulted increased residuals of the process. The increased quantity of solids resulted from both the increased coagulant dose and the increased of TSS in the sludge production .This main impact on the treatment process is on the sedimentation units by increasing the sludge accumulation, which can require a design modification in sludge removal units. Mostly, in the water treatment, Turbidity values used as an indicator of total suspended solids, however, there is no absolute correlation between the turbidity values (NTU) and the total suspended solids (TSS). A ratio of TSS to NTU normally varies from 0.5 to 2.0 **(Asnake Birhane, 2010).** However, based on the AAWSA laboratory and TAHH (2000) report indicates that the ratio of TSS (mg/l) to NTU is 0.74 .The total amount of sludge generation estimated based on daily raw water in flow 172, 800 m^3/d and the following procedure.

Table 8: Optimal Coagulant Dose Test Result Used in Conventional Coagulation

S. No	Chemical Type	Optimal Dose (mg/l)
1	Alum +Lime	80 + 40
2	PACl+ Lime	40+14
3	Polyelectrolyte	4

Table 9: Optimal Coagulant Dose Test Result Used for Enhanced Coagulation

S. No	Chemical Type	Optimum Dose (mg/l)
1	Alum + Lime	120 +60
2	PACl +Lime	70 +24
3	Polyelectrolyte	6 +0

Table 10: Turbidity Removed by Conventional Coagulation

S. No	Coagulant Type	(initial turbidity –residual turbidity)NTU at optimum dosages for Conventional Coagulation
1	Alum	292
2	PACl	289.4
3	Polyelectrolyte	287.4

Table 11: Turbidity Removed by Enhanced Coagulation

S.NO	Coagulant type	(initial turbidity –residual turbidity)NTU at optimum dosages for Enhanced Coagulation
1	Alum	293
2	PACl	296
3	Polyelectrolyte	294

The chemical coagulation reaction used to estimate sludge production is indicated by the next equation.

$$\begin{array}{ccccc} Al_2(SO4)_3.14H_2O+3\,Ca(HCO_3)_2 & \longrightarrow & 2Al(OH)_3(S)\downarrow & +3CaSO_4+6CO_2 & +14H_2O \\ 594 \qquad\qquad 3*162.1 & & 2*78 & 3*136.08+6*44 & 14*18 \end{array}$$

0.26 kg sludge is produced per 1 kg of aluminum sulfate if natural Alkalinity is insufficient, then lime or caustic soda will be added.

$Al_2(SO4)_3.14H_2O+3Ca(OH)_2 \longrightarrow 2Al(OH)_3(S)\downarrow+3CaSO_4+14H_2O$

594 3*74.08 2*78 3*(136.08) 14*18

0.70 kg sludge is produced per 1 kg of lime use

Poly Aluminum Chloride (PACl)

$(Al_n(OH)_m.Cl_{(3n-m)})_x$ at the value of n=2 and m=3 ,and x=2

$Al_4(OH)_6Cl_6+3Ca(HCO_3)_2 \longrightarrow 4Al(OH)_3(S)+3CaCl_2+6CO_2$

422.7 486.3 312 332.94……. 264

0.74 Kg sludge estimated per 1Kg PACl coagulant. For polyelectrolyte, the sludge quantity generated estimated using the equation S= Flow* Polyelectrolyte Dose (mg/l) **(USEPA, 1999)** .The sludge quantity generated estimated as constant result for turbidity removal (NTU), coagulants and lime presented in Table (12).

Table 12: Used Constant Value for Estimating Sludge Quantity

S.NO	Coagulant type	Constant value
1	Alum	0.26 kg per kg of Alum
2	PACl	0.74 Kg per Kg PACl
3	Polyelectrolyte	1kg per kg Polyele.
4	Lime	0.7 kg per Lime

* 0.74 NTU corresponding to 1 mg/l of TSS in case of legedadi raw water

Table 13: For Conventional Coagulation Sludge Quantity Estimation due to coagulant dose and Total suspended solid (TSS)

S.NO	Coagulant Type	Turbidity(kg/d) =(172,800m^3/d*0.74(X NTU kg/d)) /1000	Coagulant and lime Dose (kg/d) = (Const*dose kg/m^3 *172,800 m^3/d)/1000	Total sludge production(kg/d)
1	Alum + lime	37466.50	8432.60	45899.10
2	PAC+ lime	37006.20	6808.30	43814.50
3	Polyelectro.	36750.40	691.30	37441.60

Table 14: For Enhanced Coagulation Sludge Quantity Estimation due to coagulant dose and Total suspended solid (TSS)

S.N	Coagulant Type	Turbidity(kg/d) =172,800m^3/d*0.74(X-NTU kg/d)) /1000	Coagulant and lime dose (kg/d) = (Const*dose kg/m^3 *172,800 m^3/d)/1000	Total Sludge production (kg/d)
1	Alum + lime	38980.80	12026.90	51629.70
2	PAC + lime	39384.60	11854.10	51238.70
3	Polyelectro.	39118.50	1036.80	40155.30

Table 15: Comparison of Sludge Production between Conventional Coagulation (CC) and Enhanced Coagulation (EC) Methods

S. No	Coagulant Type	CC	EC	Percent of Incremental
1	Alum + lime	45899.10	51629.70	12.50 %
2	PAC+ lime	43814.50	51238.70	16.70%
3	Polyelectrolyte	37441.60	40155.30	7.24 %

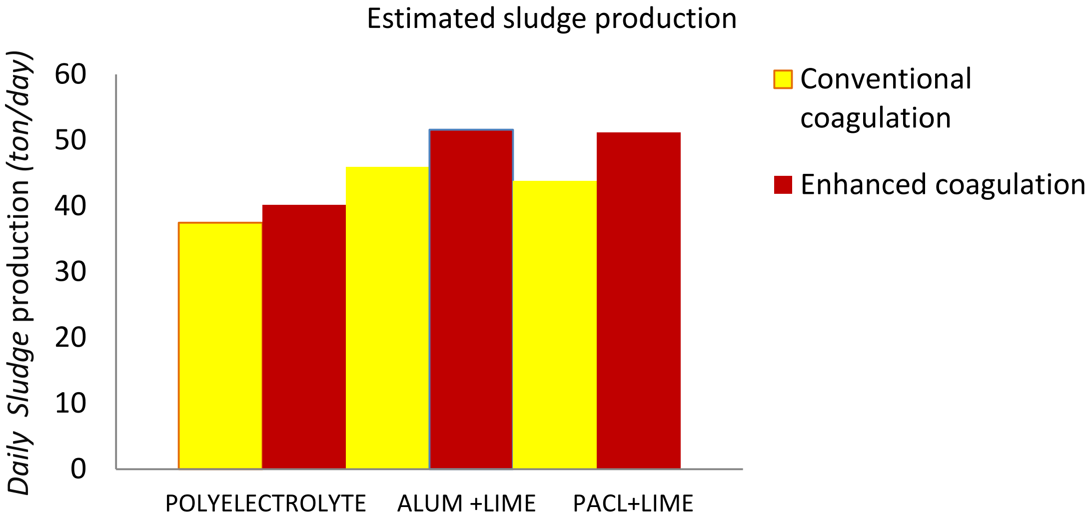


Figure 22: Comparison of Sludge Production between the Two Methods

The sludge production result shown in the Table (15) and Figure 22 indicated that alum and PACl in case of conventional coagulation and enhanced coagulation produced large sludge quantity as compared to polyelectrolyte coagulant.

5.8.2. Impact on Cost of Coagulant

Generally, the Cost can be incurred for the following changes: additional chemical use, more costly chemicals, or new chemical facilities. In this study, the cost of coagulants according to AAWSA purchase department report polyelectrolyte and chlorine for Legedadi raw water treatment are 37.07, and 35.066 birr/kg respectively. While PACl, Alum, and lime that are not in use currently in the treatment plant 12.6, 9.60, and 5 birr/kg respectively. The estimated cost of different coagulants in both conventional and enhanced coagulation as well as the cost of chlorine dosage for pre-chlorination and post chlorination are presented in Table (16) and Table (17)

Table 16: Estimated Cost of Different Coagulants to purify Legedadi raw water for Conventional Coagulation

S. No	Chemical Type	Unit	Quantity	Unit Price (Birr/Kg)	Amount(Birr/ m^3 of Raw Water)	Total(Birr/m^3 of Raw Water)
1	Polyelectrolyte	kg/m^3	0.004	37.07	0.15	0.15
2	PACl	kg/m^3	0.04	12.60	0.48	0.55
	Lime	kg/m^3	0.014	5.00	0.07	
3	Alum	kg/m^3	0.08	9.60	0.77	0.97
	Lime	kg/m^3	0.04	5.00	0.20	
4	Pre-chlorination	kg/m^3	0.0031	35.06	0.11	0.11
5	Post-chlorination	kg/m^3	0.0028	35.07	0.10	0.10

Table 17: Estimated Cost of Different Coagulants to purify Legedadi raw water for Enhanced Coagulation

S. No	Chemical Type	Unit	Quantity	Unit Price (Birr/Kg)	Amount(Birr/m^3 of Raw Water)	Total(Birr/m^3 of Raw Water)
1	Polyelectrolyte	kg/m^3	0.006	37.07	0.22	0.22
2	PACl	kg/m^3	0.07	12.60	0.88	1.00
	Lime	kg/m^3	0.024	5.00	0.12	
3	Alum	kg/m^3	0.12	9.60	1.15	1.45
	Lime	kg/m^3	0.060	5.00	0.30	
4	Post chlorination	kg/m^3	0.0028	35.07	0.10	0.10

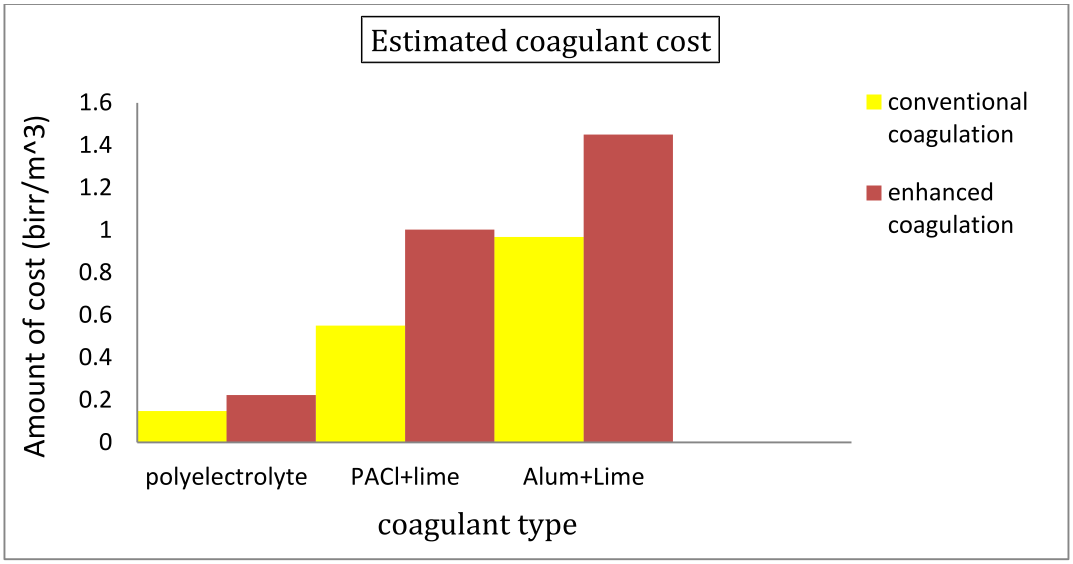


Figure 23: Comparison of coagulant cost between the Two Methods

In the above, the cost for different dosages with year 2013 G.C treated water amount is calculated .The optimal dosages for Legedadi conventional raw water treatment plant are 4mg/l for polyelectrolyte, 40mg/l for PACl, and 80 mg/l alum. This treatment plant uses average of 3.06 mg/l, and 2.78 mg/l for pre –chlorination, and post-chlorination respectively. When comparing for the optimal enhanced coagulant dosage of 6 mg/l polyelectrolyte, 70 mg/l PACl, and 120 mg/l alum found in this study increase additional cost are 0.07, 0.45, and 0.48 birr/m^3 respectively .However, enhanced coagulation and adjustment of pH was reducing the demand for chlorine by reducing organic matter, (**USEPA, 1999**). Therefore, the main aim of this study was the removal of DBPs precursors before pre chlorination by applied enhanced coagulation, in addition to this laterally provides the minimization pre-chlorination system and use post chlorination, have benefit for reducing the above estimated cost of coagulants in additional to the health concern.

6. Conclusion and Recommendation

6.1. Conclusion

- The results of the three coagulant types showed that the optimum factorial combination of 1.75* optimum dose of PACl ,and the rest of the two coagulants Alum, and polyelectrolyte at 1.5*optimum dose gave better results in optimum response values of 98.80 % ,96, 20 % and 96.70 % total organic carbon removal efficiency respectively.
- The Comparison between the water treated by conventional and enhanced coagulation shows that enhanced coagulation process is an effective means of removing organic matter present in drinking water if the coagulant dose and pH adjusted into optimum condition.
- The enhanced coagulation approach better mostly utilized during the season where organic matter load of the surfaces raw water is higher i.e. during end of dry season when depth of water in the dam is minimum and summer season. Therefore, the enhanced coagulation method has considerably further reduced TOC concentration that cannot be removed by conventional coagulation.
- The result obtained in enhanced coagulation can easily be adapted to other part of the country where the water quality due to DBPs precursor claimed to affect the health of the community.
- The Implementation of enhanced coagulation has resulted in an increase for residuals sludge produced during enhanced coagulation. The increased quantity of sludge observed from 10-15 % as result of both the increased coagulant dose and the increased of TSS in the sludge production. In addition, when comparing for the optimal enhanced coagulant estimated cost of polyelectrolyte, PAC, and alum showed additional cost of 0.074, 0.45, and 0.48 birr/m^3 respectively.

- The secondary effects observed with enhanced coagulation applications are not as such significant in comparison to its positive impact. i.e., the removal of DBPs precursors ahead of pre chlorination by applying enhanced coagulation, have benefit for cost minimization of disinfectants in addition to the health concern.

6.2. Recommendation

- The existing Legedadi conventional surface water treatment plant use pre-chlorination as disinfection during the study before the organic matter removal. In developing countries, it is not possible absolutely to avoid the use of chlorine for disinfection purpose but it should be used after conventional and enhanced coagulation to minimized formation of DBPs due to organic matter and chlorine reaction
- Legedadi conventional water treatment plant evaluate the treated water quality based on turbidity removal efficiency and there is no laboratory facility to analyzing organic matter. Therefore, it is strongly recommended that there is a need for full laboratory facility and training on uses TOC analyzer in water clarification.

Further research is suggested on the following:

- A study should be carried out to identify the type of organic matter dominated in the raw water and directly contribute to formation of THMs and HAAs.
- In this study, the removal of DBPs by considering the two factors coagulant type and dose in conventional and enhanced coagulation, formation of THMS may not depend on only organic matter and chlorine dose.
- The study of sludge dewatering characteristics should be done to evaluate the influence of organic substances in natural water.

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APPENDICES

Appendices 1: Coagulant type and dose for conventional coagulation

Coagulant Type Polyelectrolyte (PolyDADMAC)

Raw water from Legedadi water reservoir

S.No	28/08/05	Treated Water					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume PDADMAC (ml)	2.0	3.0	4.0	5.0	6.0	0
3	Concentration of PDADMAC (mg/l)	2.0	3.0	4.0	5.0	6.0	0
4	Turbidity (NTU)	4.9	3.42	2.44	2.58	2.58	290
5	Total organic carbon (mg/l)						
6	Temperature (^{0}c)	22.7	23	23.3	23.3	23.3	22.6
7	PH	7.61	7.59	7.36	7.5	7.5	7.34
8	Conductivity (µS/cm)	138.6	139.4	139.3	139.0	139.0	140.5
9	TDS (mg/l)	61	60	61	60	60	61
10	Alkalinity (mg/L as $CaCO_3$)	54.2	54.8	54.4	55.8	53.6	56.6
11	SVI (mg/l)	14.09	16.01	17.50	18.90	19.00	-

S.No	28/08/05	Treated Water					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume PDADMAC (ml)	2.0	3.0	4.0	5.0	6.0	0
3	Concentration of PDADMAC (mg/l)	2.0	3.0	4.0	5.0	6.0	0
4	Turbidity (NTU)	4.5	3.12	2.65	2.78	2.78	290
5	Total organic carbon (mg/l)	-	-	-	-	-	-
6	Temperature (^{0}c)	-	-	22.8	-	-	-
7	PH	-	-	7.44	-	-	-
8	Conductivity (µS/cm)	-	-	139.6	-	-	-
9	TDS (mg/l)	-	-	62	-	-	-
10	Alkalinity (mg/L as $CaCO_3$)	-	-	55.8	-	-	-
11	SVI (mg/l)	-	-	17.9	-	-	-

Poly Aluminum Chloride +Lime

Raw water from Legedadi water reservoir

S.No	05/09/05	Treated Water					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume PAC (ml)	4	5	6	7	8	0
3	Concentration of PAC (mg/l)	40	50	60	70	80	0
4	Added Volume lime (ml)	1.4	1.7	2.0	2.4	2.7	0
5	Concentration of lime (mg/l)	14	17	20	24	27	0
6	Turbidity (NTU)	1.73	3.3	2.58	2.61	3.10	292
7	Total organic carbon (mg/l)						
8	Temperature (^{0}c)	23.2	23.1	22.7	22.7	22.4	22.6
9	PH	7.6	7.38	6.9	7.12	6.73	7.26
10	Conductivity (µS/cm)	184.1	186.8	191.0	193.6	198.0	141.5
11	TDS (mg/l)	86	86	91.0	92	95	63
12	Alkalinity (mg/L as CaCO3)	60.8	60.2	52.2	52.8	48	59.4
13	SVI (mg/l)	27	27.5	29.0	29.8	30	-

S.No	05/09/05	Treated Water					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume PAC (ml)	2	3	4	5	6	0
3	Concentration of PAC (mg/l)	20	30	40	50	60	0
4	Added Volume lime (ml)	0.7	10	1.4	1.7	2.0	0
5	Concentration of lime (mg/l)	7	10	14	17	20	0
6	Turbidity (NTU)	7.41	3.20	1.65	2.62	2.55	292
7	Total organic carbon (mg/l)	-	-	-	-	-	-
8	Temperature (^{0}c)	-	-	22.7	-	-	-
9	PH	-	-	7.84	-	-	-
10	Conductivity (µS/cm)	-	-	178.8	-	-	-
11	TDS (mg/l)	-	-	80	-	-	-
12	Alkalinity (mg/L as CaCO3)	-	-	64	-	-	-
13	SVI (mg/l)	-	-	28.5	-	-	-

Aluminum Sulfate +Lime

Raw water from Legedadi water reservoir

S.No	07/09/05	**Treated Water**					Raw water
1	Jar number	1	2	3	4	5	**6**
2	Added Volume alum (ml)	7	8	9	10	11	0
3	Concentration of alum (mg/l)	70	80	90	100	110	0
4	Added Volume lime (ml)	3.5	4.0	4.5	5.0	5.5	0
5	Concentration of lime (mg/l)	35	40	45	50	55	0
6	Turbidity (NTU)	2.48	1.90	2.01	2.5	3.34	294
7	Total organic carbon (mg/l)						
8	Temperature (^{0}c)	22.9	22.9	23.4	23.2	22.9	22.4
9	PH	7.5	7.35	7.05	6.98	7.77	7.28
10	Conductivity (μS/cm)	205	214	214	219	226	142.5
11	TDS (mg/l)	97	102	100	104	107	67
12	Alkalinity (mg/L as CaCO3)	53.8	52	46	46.2	46.4	58.6
13	SVI (mg/l)	24	26	28	28.9	29	-

S.No	07/09/05	**Treated Water**					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume alum (ml)	7	8	9	10	11	0
3	Concentration of alum (mg/l)	70	80	90	100	110	0
4	Added Volume lime (ml)	3.5	4.0	4.5	5.0	5.5	0
5	Concentration of lime (mg/l)	35	40	45	50	55	0
6	Turbidity (NTU)	3.02	2.02	2.06	2.4	3.24	294
7	Total organic carbon (mg/l)	-	-	-	-	-	-
8	Temperature (^{0}c)	-	22.8	-	-	-	-
9	PH	-	7.12	-	-	-	-
10	Conductivity (μS/cm)	-	211	-	-	-	-
11	TDS (mg/l)	-	98	-	-	-	-
12	Alkalinity (mg/L as CaCO3)	-	2.68	-	-	-	-
13	SVI (mg/l)	-	27	-	-	-	-

Appendices 2: Coagulant type and dose for enhanced coagulation

Polyelectrolyte (Poly DADMAC), Raw water from Legedadi water reservoir

S.No	09/09/05	**Treated Water**					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume PDADMAC (ml)	4.0	5.0	6.0	7.0	8.0	0
3	Concentration of PDADMAC (mg/l)	4.0	5.0	6.0	7.0	8.0	0
4	Turbidity (NTU)	2.61	2.64	2.97	3.05	3.80	297
5	Total organic carbon (mg/l)	17.5	4.9	4.3	7.2	9.4	108
6	Temperature (^{0}c)	23.3	23.3	23.9	23.4	23.4	22.4
7	PH	7.62	7.56	7.6	7.7	7.65	7.56
8	Conductivity (µS/cm)	138.0	140.3	140.4	140.2	141.7	142.5
9	TDS (mg/l)	65.0	66.0	66.0	66.0	67.0	61
10	Alkalinity (mg/L as CaCO3)	57.0	57.0	57.2	56.4	56.4	59.6
11	SVI (mg/l)	17.5	17.8	18.6	19.2	20.2	-

S.No	**09/09/05**	**Treated Water**					**Raw water**
1	Jar number	1	2	3	4	5	**6**
2	Added Volume PDADMAC (ml)	4.0	5.0	6.0	7.0	8.0	0
3	Concentration of PDADMAC (mg/l)	4.0	5.0	6.0	7.0	8.0	0
4	Turbidity (NTU)	2.62	2.66	2.76	2.84	2.88	297
5	Total organic carbon (mg/l)	17.1	4.5	4.1	7	9.2	108
6	Temperature (^{0}c)	23.2	23.1	23.4	23.6	23.2	22.4
7	PH	7.68	7.65	7.53	7.34	7.54	7.56
8	Conductivity (µS/cm)	137.1	137.8	137.8	137.6	136.2	142.5
9	TDS (mg/l)	65.0	66.0	66.0	66.0	67.0	61
10	Alkalinity (mg/L as CaCO3)	54.2	54.6	54.8	54.6	54.6	59.6
11	SVI (mg/l)	16.2	17.4	17.8	18.8	19.7	-

Poly-Aluminum Chloride +Lime

Raw water from Legedadi water reservoir

S.No	12/09/05	**Treated Water**					Raw water
1	Jar number	1	2	3	4	5	**6**
2	Added Volume PAC (ml)	4	5	6	7	8	0
3	Concentration of PAC (mg/l)	40	50	60	70	80	0
4	Added Volume lime (ml)	1.4	1.7	2.0	2.4	3.0	0
5	Concentration of lime (mg/l)	14	17	20	24	30	0
6	Turbidity (NTU)	1.23	1.45	1.70	1.73	1.81	297.6
7	Total organic carbon (mg/l)	6.8	2.4	2.1	1.4	4.0	108
8	Temperature (^{0}c)	21.1	21.6	21.2	21.8	21.3	21.4
9	PH	7.68	7.3	7.68	7.84	6.69	7.48
10	Conductivity (µS/cm)	183.9	189.3	205	209	208	142.5
11	TDS (mg/l)	87	90	97	96	98	66
12	Alkalinity (mg/L as CaCO3)	56.6	55.4	49.6	49	42	59.6
13	SVI (mg/l)	26	27	28.5	29	31	-

S.No	12/09/05	**Treated Water**					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume PAC (ml)	4	5	6	7	8	0
3	Concentration of PAC (mg/l)	40	50	60	70	80	0
4	Added Volume lime (ml)	1.4	1.7	2.0	2.4	3.0	0
5	Concentration of lime (mg/l)	14	17	20	24	30	0
6	Turbidity (NTU)	1.34	1.41	1.54	1.63	1.74	297.6
7	Total organic carbon (mg/l)	7.1	2.6	2.2	1.2	4.2	108
8	Temperature (^{0}c)	22.2	22.4	22.4	22.3	22.2	21.4
9	PH	8.31	8.23	7.7	7.21	7.17	7.48
10	Conductivity (µS/cm)	174.2	183.2	194.8	206	212	142.5
11	TDS (mg/l)	82	87	92	99	102	66
12	Alkalinity (mg/L as CaCO3)	55.8	55.2	53.6	52.4	48.8	59.6
13	SVI (mg/l)	25.6	26.8	27.9	29.5	31.8	-

Aluminum Sulfate +Lime

Raw water from Legedadi water reservoir

S.No	13/09/05	Treated Water					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume alum (ml)	8	10	12	14	16	0
3	Concentration of alum (mg/l)	80	100	120	140	160	0
4	Added Volume lime (ml)	4	5	6	7	8	0
5	Concentration of lime (mg/l)	40	50	60	70	80	0
6	Turbidity (NTU)	2.21	2.35	2.89	2.26	4.08	295.6
7	Total organic carbon (mg/l)	3.9	3.7	3.6	4.1	6	108
8	Temperature (^{0}c)	22.4	21.5	21.5	22.9	22.9	21.4
9	PH	8.3	8.12	8.04	6.08	6.07	7.58
10	Conductivity (µS/cm)	215	235	236	238	242	142.8
11	TDS (mg/l)	101	104	111	116	119	68
12	Alkalinity (mg/L as CaCO3)	67.8	66.8	66.4	58.6	40.8	59.6
13	SVI (mg/l)	27.5	28.9	30.5	31.8	32.5	-

S.No	13/09/05	**Treated Water**					Raw water
1	Jar number	1	2	3	4	5	6
2	Added Volume alum (ml)	8	10	12	14	16	0
3	Concentration of alum (mg/l)	80	100	120	140	160	0
4	Added Volume lime (ml)	4	5	6	7	8	0
5	Concentration of lime (mg/l)	40	50	60	70	80	0
6	Turbidity (NTU)	1.41	2.5	2.38	2.44	3.04	295.6
7	Total organic carbon (mg/l)	4.2	3.8	3.3	4.2	8	108
8	Temperature (^{0}c)	22.9	23.4	22.9	22.2	22.6	21.4
9	PH	7.98	7.92	7.04	6.04	6.03	7.58
10	Conductivity (µS/cm)	212	233	237	240	244	142.8
11	TDS (mg/l)	102	106	109	112	114	68
12	Alkalinity (mg/L as CaCO3)	66.6	64.4	65.2	59.2	46.4	59.6
13	SVI (mg/l)	28	29.5	30.4	31.4	32.5	-

Appendices 3: Sample volume selection for expected concentration

Range (mg/L as CaCO3)	**Sample Volume (mL)**	**Sulfuric Acid**	**Multiplier**
0-500	50	20353	20
400-1000	25	20353	40
100-2500	10	20353	100
2000-5000	5	20353	200

Appendices 4: Legedadi treatment plant unit operation

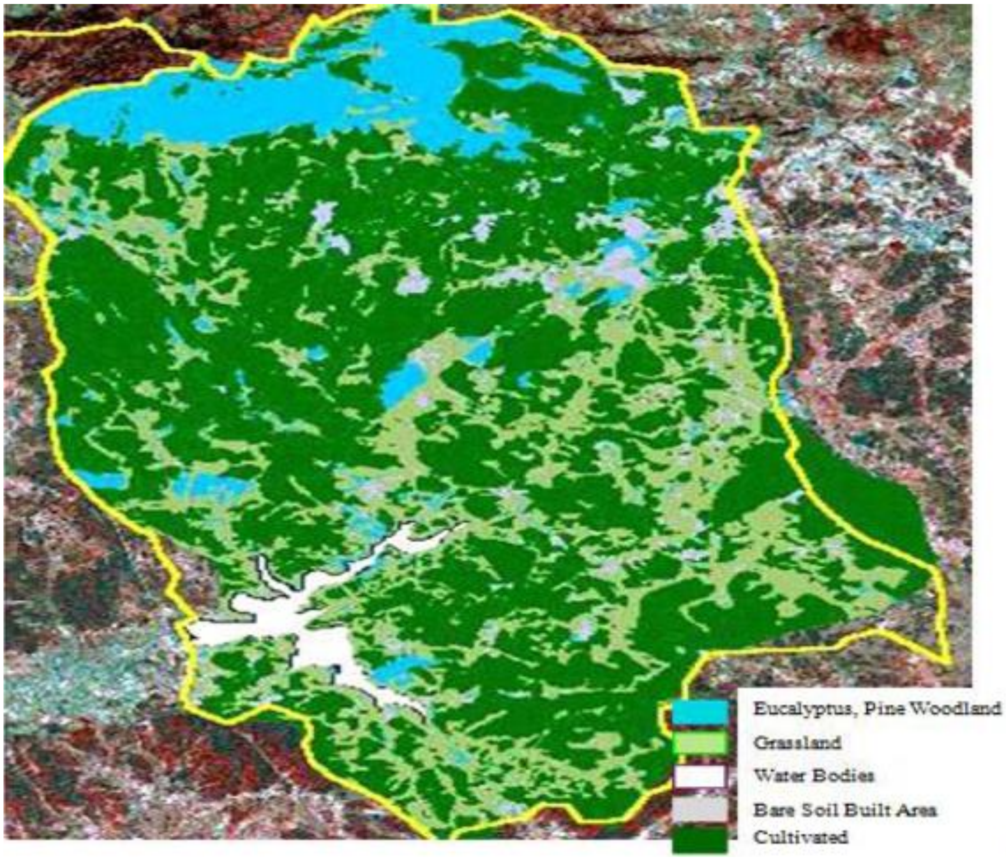
Chemical dilution and dosing

Mixing /distribution/ regulation structures

Stage one and stage two-pulsator type Clarifier

Stage one and stage two rapid sand filter bed

Appendices 5: Legedadi catchment land use and land cover



type	Area (ha)	% of catchment area
Bare land	2497.1	12.1%
Cultivated land	13582.42	65.9%
Plantation Forest	1591.96	7.7%
Settlement	1681.9	8.2%
Water body(Dam)	374.42	1.8%
Open grassland	691.1	3.4%
Woodlot	84.73	0.4%
Bush shrub land	96.4	0.5%
Total	20600	100%

Appendices 6 : Design Summary

Table 11: Design Summary

Study Type	Factorial
Initial Design	Full Factorial
Center Points	0
Design Model	2FI
Runs	30

Factor Name	Units	Type		
A.Coagulant	Type	Categoric	Levels:	3
B.Coagulant Dose	mg/l	Categoric	Levels:	5

Response	Name	Units	Obs	Analysis	Minimum	Maximu
Y =	TOC	%	30	Factorial	83.80	98.90

Mean	Std. Dev.	Ratio	Trans	Model	
94.94	3.49		1.18	None	2FI