

ASSESSMENT OF FLUORIDE REMOVAL IN A BATCH ELECTRO- COAGULATION PROCESS

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**A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of
Master's Degree in Environmental Science and Engineering of the
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ABSTRACT

A presence of excessive amounts of fluoride than the prescribed standards has been reported in sources of domestic water supply around mount Meru slopes and other parts in Tanzania while efforts to remove the excessive fluoride was carried out using various technologies and materials. This study was performed to understand the fluoride removal efficiency of the electrocoagulation technique. It has been reported that in the electrocoagulation process, ions removal efficiency depends on the electrolysis time, voltage, pH and initial ions concentration applied. In this electrocoagulation process, experiments were carried out to examine its efficiency on removal of fluoride ions. The fluoride concentration tested ranged from 1.37 to 48 mg/L in both synthetic and natural waters. The voltage applied for the electrocoagulation process ranged from 0 to 50 V while maintaining an optimal pH of 4 to 9. Experimental results showed the removal efficiency of 90% with an optimal time of 30 minutes, at an applied voltage of 20 V and a pH of 6 at initial concentration of 29.5 mg/L at 300 ml. The method showed efficient removal of fluoride in water to achieve the allowable limits by the World Health Organization and Tanzania Bureau of Standards (1.5 mg/L). At this voltage (30 V), the process could be inferred to have the capability of treating the water and hence rendering such water safe for use as reported previously.

DECLARATION

I, Risala Mureth do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and has neither been submitted nor being concurrently submitted for degree award in any other institution.

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CERTIFICATION

The undersigned supervisors, certify that they have read the dissertation titled “Assessment of Fluoride Removal in a Batch, Electrocoagulation process” and recommend for examination in requirements for the degree of Master’s Degree in Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology.



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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
Ca ²⁺	Calcium
Cl ⁻	Chloride
ClO	Chlorate
ClO ₄	Chlorite
COD	Chemical Oxygen Demand
Conc	Concentration
Cond	Conductivity
DBPs	Disinfection By-Products
DO	Dissolved Oxygen
EC	Electrocoagulation
F ⁻	Fluoride
Fe	Iron
FruVaSe	Fruits And Vegetables for all Seasons
HOCl ⁻	Hypochlorous Acid
K	Potassium
Mg ²⁺	Magnesium
Min	Minutes
Na ⁺	Sodium
NM-AIST	Nelson Mandela African Institution of Science and Technology
NO ₃ ⁻	Nitrate
OCl ⁻	Hypochlorite
Pb ⁺	Lead
PO ₄	Phosphate
Rest	Resistivity
SO ₄ ²⁻	Sulphate
SuMeWa	Sun Meets Water
TBS	Tanzania Bureau of Standards
TDS	Total Dissolved Oxygen
Temp	Temperature
URT	United Republic of Tanzania

UV	Ultraviolet
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

It is a fundamental human right and key to health to have accessible and available safe drinking water. As the human population grows the safe and clean water is becoming scarcer and the quality of water used is also deteriorating as it is getting more polluted (Kihupi *et al.*, 2016). The pollutants presence in water such as arsenic, fluoride, pesticides, heavy metals, phosphorus, mercury and coliforms is a growing problem caused by both natural and anthropogenic processes (Dhadge *et al.*, 2018; Khatri & Tyagi, 2015; Kihupi *et al.*, 2016).

Estimated 1.5 billion people worldwide depend on groundwater as the primary source of daily potable water, and it has proved to be the most dependable and reliable resource for meeting water demand especially in sub-Saharan Africa (Kihupi *et al.*, 2016; Tomar *et al.*, 2015). According to Jica (2002), more than 25% of water consumption is groundwater which means the remaining 75% is surface water. However, contamination has been a significant challenge due to the natural and anthropogenic pollutants presence (Dhadge *et al.*, 2018). All of these are of environmental issues and actions must be managed for the deteriorating conditions. Fluoride is reported to be the biogenic contaminants and causing health effects to several people in various areas worldwide .

In many countries globally, fluoride contamination has become a source of some health issues when consumed in either very low or high concentration. Either natural or anthropogenic ecological factors, groundwater is getting polluted due to deep percolations from disposal of hazardous wastes, surface impoundments, liquid and solid wastes from industries, intensively cultivated farms, sewage disposal, etc. Fluoride presence is by nature and this is by weathering of volcanic rocks which results in mineral sedimentations, evaporation which occurs in rift valley system and geothermal solutions as well as dissolution from saline rocks associated with fluoride which pollutes underground water (Kitalika *et al.*, 2018).

However, the concentration of 1.5 mg/L is the recommended amount by Tanzania Bureau of Standards (TBS, 2010) and World Health Organization (WHO, 2011). Less or greater than the allowable standards has harmful effects such as dental fluorosis, retarded growth of a child and skeletal defects when consumed (Ghosh *et al.*, 2008). In Tanzania, Lake Momella have the

highest fluoride level about 690 mg/L while in drinking water sources it has been reported to have a fluoride contain a fluoride concentration of 20 mg/L and beyond (Grich, 2019). Therefore, defluoridation is very important in drinking water for human health.

In Tanzania, massive number of people cannot access safe and clean drinking water from pathogens and fluoride. To ensure safe drinking water, boiling is recommended but usually requires the use of firewood. Filtration and ultraviolet (UV) radiation alone cannot assure safe water conditions for water distribution as none of these disinfection methods protects the water against recontamination after the disinfection process. Bone char and Nanofiltration method have been very effective in fluoride removal but expensive, microbial pathogens and social-cultural objections have become a significant hindrance to its implementation.

Different methods such as capacitive deionization, chemical sedimentation, coagulation and flocculation, ion exchange, electrodialysis, adsorption, reverse osmosis, Nanofiltration and electrocoagulation (EC) have been under investigation for removing fluoride from water (Grich *et al.*, 2019; Dubey *et al.*, 2018; Maheshwari, 2006; Waghmare & Arfin, 2015). Chemical coagulation method requires a massive chemical amounts and produces large volumes of sludge which makes it of the high cost. Other membrane filtration technologies such as reverse osmosis techniques, electrodialysis and Nanofiltration requires energy, requires maintenance cost which is high and it produces concentrated sludge (Alimohammadi *et al.*, 2019; Palahouane *et al.*, 2015; Waghmare & Arfin, 2015). The EC has been observed to deliver highly efficient removal of fluoride when iron/aluminium electrodes are used (Aoudj *et al.*, 2017; Apshankar & Goel, 2018). However, most of these techniques are not used in local communities due to their sustainability, cost and environmental factors. Therefore, this study intends to investigate the performance of the EC process for the removal of fluoride in water supply and consequent inferring its ability to disinfect the water.

1.2 Statement of the problem

In Tanzania, the defluoridation from drinking water by applying bone char household filter has been adopted for treating of fluorotic water at the point of use and has been applied in many areas (Kaseva, 2006). However, this technology has faced some challenges on its use and therefore, alternative technologies and materials for removal of fluoride are needed. Bone char filtration method targets fluoride and does not deal with other contaminants in water such as organics and microbial contaminants. Multiple contaminant removal techniques have been

developed including the Nanofiltration, which is being tested in the field. The adaption rate of using all the reported tested techniques to address the fluoride contamination issue in Tanzania is still low due to the cost of operation, environmental concerns and sustainability (Dahi, 2016; Malago *et al.*, 2017). This study evaluated the EC process performance in batch mode which provides the baseline for field set up with different water sources and conditions.

1.3 Rationale of the study

Most of sub-Saharan countries lack safe and clean water and many water related diseases are reported, treatment of water becomes crucial in every society (Dahi, 2016; Malago *et al.*, 2017). Due to urban sprawl and high rate of population growth there is unplanned expansion of the distribution network which lead to poorly performance of the system and lack of clean water in many Tanzanian communities (Chirisa, 2008). However, many technologies have been developed for fluoride removal but still remains a challenge in many communities due to non sustainable, social – cultural issues and environmental challenges.

Hence this study is focusing on establishing a new technology, that will be sustainable and environmental friendly since it uses the less energy to form coagulant which will eliminate the excess fluoride in water. This will help in reducing health issues that are related with consuming excess fluoride and provision of clean and safe water in many communities.

1.4 Objectives of the study

1.4.1 General objective

Assessment of the performance of the electrocoagulation process for fluoride removal.

1.4.2 Specific objectives

- (i) To evaluate the defluoridation capacity of EC system at various operating conditions.
- (ii) To establish the operating conditions for the system at field conditions.

1.5 Research questions

This study answered the following research questions:

- (i) How does the defluoridation capacity vary with operating conditions?
- (ii) What are the best conditions for the electrocoagulation process for field application?

1.6 Significance of the study

The study was to establish the efficiency and performance parameters of the EC system under the batch system. It will get this suitable decentralised drinking water disinfectant system from the laboratory batch experiment to field scale. Results of this research will also contribute to Tanzania's realisation of Goal Six of the UN's Sustainable Development Goals i.e. Increase accessibility to sanitation services and clean water by 2030 (Sachs, 2012). Currently, in Tanzania, only 58.7 % of the population can have access safe and clean water (United Republic of Tanzania [URT], 2013) which constitutes about 40% with no access to drinking water which is safe in the world (especially rural population) (Hoekstra *et al.*, 2017). The researched system has the potential to provide affordable, accessible-to-use and self-sustainable water solutions to local communities.

1.7 Dealination of the study

The main focus of this project was the design of an efficient water treatment which will remove fluoride. The system will be using EC technology by application of electrodes and direct current as an energy device. The electrodes will dissolve (Al^{3+}) ions in water which will form $\text{Al}(\text{OH})_3$ coagulant. The proposed system is limited only in removing fluoride and has low energy consumption. The project can be used in all communities with water sorces that exceeds the WHO limit of 1.5 mg/L. Some calculations, assumptions and selections were made as a consideration of a proper and realistic design.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

According to the Pauling scale, fluorine is the most electronegative element. It has the electronegativity value of 3.98 and its reactivity is high. Therefore, it cannot occur in elemental form (Malago, 2017). Of all chemical elements, fluorine is one of the most reactive and the lightest halogen (Kaminsky *et al.*, 1990). In water, fluorine occurs as a negatively charged ion, either in trace amounts or as a significant ion with high concentrations. In the environment, fluorine exists in different forms of mineral salts rather than in its pure form. The main fluorine-containing minerals are fluorapatite ($[\text{Ca}_5(\text{OH},\text{F})(\text{PO}_4)_3]$), fluorite (CaF_2) and cryolite (Na_3AlF_6) (Guo *et al.*, 2019; Malago, 2017). Fluorite is usually associated with barite, dolomite, calcite, or quartz and another number of other silicates, such as sodium fluoride or carbonates, villiaumite oxides, phosphates, sulfates, sellaite (MgF_2) and topaz ($\text{Al}_2\text{SiO}_4(\text{OH}, \text{F})_2$), contain minor amounts of inorganic fluoride (Malago, 2017; Yadav *et al.*, 2018).

The fluoride occurrence in water has also resulted from water-rock interaction through circulation processes of water in rocks and soils and weathering of fluoride-rich rocks (Malago, 2017). These fluorine-rich rocks are highly present in the East African Rift Valley and their high-level weathering represents the primary source of fluoride in surface waters (Kitalika *et al.*, 2018). The paucity of fluoride adsorbents in soils further rationalises the higher level of fluoride in groundwater. Even though the solubility might be low, the extended contact time and the thickness of the soil may enable quantitative leaching. Therefore, fluorides enter surface water by surface runoff and leaching from products like fertilisers with phosphates, effluents and industrial emissions (Ghaderpoori *et al.*, 2018; Khatibikamal *et al.*, 2007). Even though fluoride has benefits on human health, its consumption above the optimal levels is dangerous. Crippling skeletal fluorosis has been shown to occur due to excessive fluoride consumption which leads to the reaction of fluoride and calcium in the bones.

2.2 Distribution of fluoride in Tanzania

Understanding fluoride variations in different water sources are significant in Tanzania since the domestic water supplies are rivers and springs. Above 30% of water sources in Tanzania are reported to have concentration of fluoride which exceeds 1.5 mg/L (Kitalika *et al.*, 2018).

In Tanzania, there are severely areas affected by fluoride in the regions of Moshi, Arusha, Shinyanga and Singida located on the foothills of Mounts Meru and Kilimanjaro. Since fluoride is present in nature as mineral sedimentations, in Tanzania, the regions that are associated with volcanic activities on rift valley zones of Mount Kilimanjaro and Meru tend to have excess fluoride concentration in water sources (Malago, 2017).

The primary fluoride contamination source in Tanzania is geogenic (Goswami & Kumar, 2017; Kitalika *et al.*, 2018), while in other parts of the world, natural fluoride content is strongly affected by various anthropogenic sources including the application of pesticides and fertilizers, industrial emissions (e.g. aluminium smelting, ceramic and brick manufacturing, burning of coal, clay production, chemical production, enamel and glass manufacturing, steel production), deposition of industrial airborne pollutants, sludge and thermal power plants and wastes from sewage (Ghaderpoori *et al.*, 2018; Khatibikamal *et al.*, 2016). Several studies have reported on the levels of fluoride in Tanzania.

In Tanzania, most of the places have an excess fluoride concentration in water sources as shown in Fig. 1. While the large number reported being wells and boreholes (Gumbo & Mkongo, 1995). Leading region is Arusha (13.57– 64.16 mg/L), followed by Manyara with (7.98–15.73 mg/L), then Kilimanjaro (7.44–13.28 mg/L), while Dar es Salaam having the lowest fluoride concentration (0.12–0.11 mg/L) (Ndé-Tchoupé *et al.*, 2019). According to Kitalika *et al.* (2018), the variations of fluoride for some sources in Arusha have been reported that are rivers (Maji ya chai 12–13 mg/L and Engare Nanyuki 21–26 mg/L), pond water 61–65 mg/L and Lake Momella which contains 690 mg/L. Statistically, this shows how fluoride in water sources is still a big challenge in Tanzania and should be reduced to avoid human health effects.

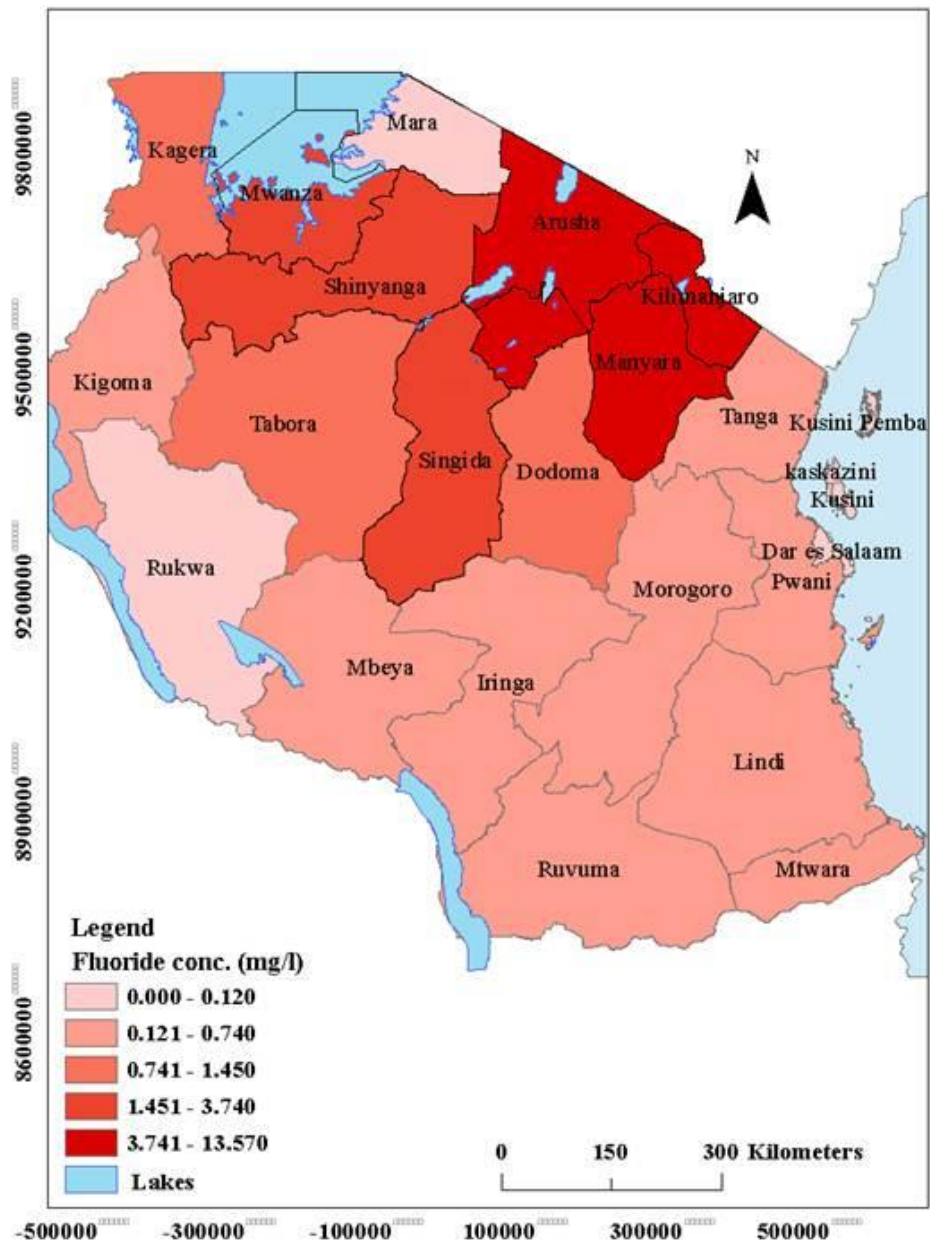


Figure 1: The map showing the distribution of fluoride in Tanzania (Ndé-Tchoupé *et al.*, 2019)

2.3 Impacts of fluoride on human health

Naturally, fluoride is found in foods, water and soil. It is also synthetically produced for use in toothpaste, drinking water and some chemical products. In recent years, low and high levels of fluoride have been termed as a significant public health issue in drinking waters (Ghaderpoori *et al.*, 2018). Fluoride can get to the human body via cosmetics, water, drugs, foodstuffs and among these, drinking water has been the main route of daily intake (Ghaderpoori *et al.*, 2018) which include dermal absorption, inhalation and oral intake.

On growing teeth, fluorosis has the most significant impact, particularly vulnerable to children less than seven years old (Sudarshan, 2017). On human health, the advantages of ingesting fluoride are limited about 1.0 mg/l fluoride levels in potable water. Drinking water which contains such fluoride level is reported to prevent the growth of harmful oral bacteria, improve rebuild weakened tooth enamel, skeletal and dental health and slows down tooth enamel mineral lost (Ghaderpoori *et al.*, 2018; Gumbo & Mkongo, 1995). It can prevent dental caries due to the formation of fluorapatite compared to hydroxyapatite since it is resistant to acid attack (Malago, 2017).

Fluoride has benefits on human health at the lowest level of less than 1.5 mg/L. In teeth enamel, hydroxyapatite is made up of phosphate, calcium, and magnesium compounds and is liable to decay inferred by bacteria producing acid. The interaction between fluoride and hydroxyapatite forms fluorapatite, which is less liable to erosion by oral bacteria producing acid. About 50% of the fluoride ingested is absorbed in the teeth and bones while the remaining is excreted in urine (Ghernaout *et al.*, 2019). Drinking/ ingesting water with fluoride concentration above 1.5 mg/l levels can lead to negative impacts on human health (Kitalika *et al.*, 2018; Malago, 2017; Waghmare & Arfin, 2015). For instance, in drinking water, fluoride level ranging between 1.5 and 3.0 mg/l is likely to cause browning and mottling of teeth which is known as dental fluorosis. Dental fluorosis results to the very hard and brittle teeth over time and it can affect structure of a bone and lead to the ligaments calcification. The hardness is due to the formation of calcium decafluoride (Waghmare & Arfin, 2015).

The fluoride level between 4 to 8 mg/l are contingent on resulting in skeletal fluorosis whereas greater than 10 mg/L fluoride levels can lead to crippling fluorosis which occurs when fluoride is consumed for an extended period. This can also lead to damage and pain to joints and bones. The bones can become less elastic and hard, increasing fractures risk and if the bone tissue accumulates and bones thicken it can lead to impaired joint mobility. In some few cases, excessive fluoride levels can damage the parathyroid gland. The result of it is hyperparathyroidism, which is due to uncontrolled parathyroid hormones secretion. There are others effects on human health which are due to elevated levels of fluoride which include neurological manifestations excessive thirst, skin rashes, muscle fibre degeneration, red blood cell deformities, abdominal pains, gastrointestinal problems, headache, low haemoglobin levels, tingling sensation in toes and fingers, depression, urinary tract malfunction and nausea reduced immunity.

Table 1 shows the different levels of fluoride and their effects on human health. The higher the level of fluoride concentration level, the critical the effect, thus maintaining a lower fluoride concentration is fundamental to human health. As part of all the approaches to defeat the fluoride contamination effect in communities, health education and the regular monitoring schedule should be provided in these regions/ areas where drinking water sources have been contaminated with high fluoride levels; this will assist in avoiding the water with higher concentrations. This problem can be overcome by combining three approaches, avoiding further anthropogenic contamination, harvest and treat (fluoride-free) rainwater and develop affordable technologies to reduce the fluoride levels (defluoridation) to the allowable levels. This study intended on developing affordable technology to reduce the fluoride concentration to legal standards.

Table 1: Different levels of fluoride with their effects on human health

Fluoride levels (mg/L)	Potential health effects
< 0.1	High levels of dental decay
0.1 – 1.5	Prevents dental caries
1.5 – 3	Dental fluorosis
3 – 6	Skeletal and dental and fluorosis
> 10	Crippling fluorosis

(Kitalika *et al.*, 2018)

2.4 Electrocoagulation process for defluoridation

One of the chemical wastewater treatments without chemicals is EC. In EC, injecting chemicals may be avoided, it forms less sludge thus reducing the cost of sludge disposal, it consumes low energy, and its cost of operation is low therefore making it an eco-friendly technique. Electrocoagulation method is operationally simple with short reactive retention time and compact reactor design (Gheraout *et al.*, 2019). Electrocoagulation method has been an effective method of processing industrial waste where the anode metal ions form is released (usually iron or aluminium) into the solution which is the active coagulant, whereas at the cathode the hydrogen gas is released by an electrolysis reaction (Taqwa & Wijarnako, 2019). Despite other techniques, coagulation is an essential process in treating water to remove pollutants/contaminants (Shirasaki *et al.*, 2016) and EC has shown its efficiency in removing other

contaminants such as Chemical oxygen demand (COD), lead (Pb), iron (Fe), phosphate (PO₄), Biochemical oxygen demand (BOD) and Total dissolved oxygen (TDS) at 87.96%, 85%, 62.5%, 35.37%, 52.98%, 50%, 88.96% respectively (Boudjema *et al.*, 2016).

The EC technique has several advantages, such as use of simple equipment, smooth operation and short reaction time that does not require the use of chemicals other than locally available salt to overcome defluoridation by applying electric current to produce oxidation and reduction series reactions. Electrodes decomposition of the metallic ions produced is subjected to fast hydrolysis which can neutralize the charge of the suspended particles driving them to fast coagulation and sedimentation (Baciu *et al.*, 2015). Several factors such as presence of competing ions, applied voltage, initial contaminant concentration, reactor configuration, pH and the electrolysis time were found to influence fluoride removal efficiency (Apshankar & Goel, 2018).

The basic principles of EC are oxidation and reduction (redox) reactions. In an EC cell, an oxidation event takes place at the electrode (+), which is anode, while the reduction reaction takes place at the electrode (−) known as cathode. Electro- coagulation is capable of removing various types of pollutants/ contaminants in water such as; heavy metals, suspended particles, colours on colouring agents, and other harmful substances. In the EC process, when aluminium electrodes are applied, the aluminium dissolves at the anode (Eq. 1) and hydrogen gas is released at the cathode (Eq. 2). During the dissolution of Al at the anodes, some aluminium aqueous species can be produced, depending on the chemistry of the solution. The coagulant species formed tend to aggregate the particles suspended or precipitate and adsorb dissolved contaminants by forming various fluoro complex. Small bubbles of oxygen and hydrogen that are formed during electrolysis process, water collide with air bubbles which compel the pollutant particles to float. The selection of electrode material depends on some criterias such as low-oxidation potential, low-cost and inertness towards the system.

Aluminium has been reported to be very successful and effective in removal of pollutants at favourable operating conditions. Electro- coagulation defluoridation method works by of creating metallic hydroxide flocks within the water by electro dissolution of soluble anodes, which are constituted by aluminium or iron (Essadki *et al.*, 2010). The key features for fluoride removal are adsorption which attaches the molecules to the surface and co-precipitation. The reaction that occurs in the aluminium electrode is:

The oxidation reaction at the anode,



The reduction reaction at the cathode,



The hydrolysis reaction,



Aluminium ions react with water to form the solid aluminium hydroxides. The precipitates results to flocks that combine water contaminants with coagulant species and metal hydroxides formed by hydrolysis (Emamjomeh & Sivakumar, 2006). These coagulants aggregate and destabilise suspended particles and adsorb fluoride to form the aluminium complexes. $\text{Al}(\text{OH})_3$ flock is believed to adsorb F strongly as shown by equation (4).



Despite its high efficiency in defluoridation, coagulation in some parts of the world (India) it has been banned due to its severe limitation of high residue aluminium in treated water and increases water hardness with the large volume of sludge (Dubey *et al.*, 2018; Essadki *et al.*, 2010). Most of the reviewed studies of EC are a bench-scale and there are no full-scale tests for drinking water treatment used for both defluoridation and disinfection (Essadki *et al.*, 2010). A limitation of EC is that it requires proper maintenance of the aluminium anodes to ensure effective removal of the fluoride. Moreover, in treated water aluminum residue can be high due to the uncontrolled parameters resulting in toxicity. This study aimed to assess the performance of the EC process in batch scale and apply the optimum conditions for the drinking water treatment using real water sources characterized by different characteristics for fluoride removal and disinfection.

2.5 Disinfection by electrocoagulation

Pathogen contamination in drinking water is a source of various water-borne diseases such as diarrhea and typhoid common to many developing countries including Tanzania (Baciu *et al.*, 2015). Improper waste handling and disposal, and unhygienic behaviours are the leading cause (Kihupi *et al.*, 2016). In November 2016, more than 23 258 cases of an epidemic caused by

Vibrio cholerae in Tanzania were reported and most of the cases were influenced by short-term climate variability especially when there is an increase in heavy rainfall (Guo *et al.*, 2019). These could be attributed to the inadequate piping systems; an indication that safe drinking water is still a challenge; hence more studies are required.

Particularly, pathogenic microbes like bacteria, viruses, algae and fungi are largely observed in all water sources (Gheraout *et al.*, 2019a). Epidemics occur every year in Tanzania, indicating poor water safety (Gheraout *et al.*, 2019a; Giordani *et al.*, 2018). Piped water is widely available, but its quality has never been investigated (McCrickard *et al.*, 2017). An epidemic occurred in Tanzania in 2015–2016, caused by *Vibrio cholerae* and by November 2016, more than 23 258 cases were reported (Hounmanou *et al.*, 2019; McCrickard *et al.*, 2017). Short-term climate variability has also shown an increase in waterborne diseases example increase in *E. coli*/total coliform levels were firmly related to increases in recent heavy rainfall (Guo *et al.*, 2019). Therefore, the killing of pathogenic microorganisms in aquatic media are more than vital for both humans, animals and plants.

In disinfection, chlorination is the conventional method applied worldwide, other methods such as ozonation, ultraviolet (UV) radiation are applied but still more expensive or less convenient than chlorination (Gheraout & Gheraout, 2010; Gheraout *et al.*, 2019). Chlorination is the most applied and universal method for microorganisms killing. Chlorinating water addition of chlorine and chlorine chemical products which demolish the harmful bacteria in water. In terms of cost and efficiency, it is the most preferred disinfectant for most toxic bacteria. Regardless of several benefits, chlorine–killing microorganisms’ method shows many negative sides. If chlorine products are introduced into the water at high degrees, pathogens enter spontaneously in assemblages avoiding their demolition (Gheraout *et al.*, 2019). Therefore, they begin to be reluctant to Cl_2 in the course of disinfection. Moreover, the emergence of poisonous disinfection by-products (DBPs) such as ClO_2 , ClO and ClO_4 is the dangerous inconvenient. Chlorinating water as well as forms unpleasant odour and taste in potable water.

This study tries to narrate EC on disinfection at different conditions as an alternative method. Electrocoagulation is the more uncomplicated technique that does not require the use of chemicals other than locally available salt, chloride-containing electrolytes generate active chlorine species (like Cl_2 , HOCl and OCl^-) which are significant oxidants responsible for demobilizing pathogenic cell wall structures (Gheraout, 2019; Gheraout *et al.*, 2019). The chlorine level can be adjusted depending on requirements and maximum energy requirement

is not high, less sludge is formed; hence it becomes a cost-effective and eco-friendly process. Treatment with direct current (DC) has been shown to inactivate a large variety of microorganisms including viruses, bacteria, algae, coliforms, faecal streptococci and relatively abundant species such as *Euglena* (Ghernaout & Ghernaout, 2010).

Electrocoagulation method employing Fe/Al anodes disinfects water by entrapping pathogens in flocs, destabilising negatively charged microbes through sweep flocculation and demobilizing bacteria cell envelopes upon electrochemically formed reactive oxygen species or direct impact of the electric field (Ghernaout *et al.*, 2019). According to Boudjema *et al.* (2016) it shows that EC using aluminium electrodes has been effective in disinfection with a significant removal efficiency of 98% with an increase in time at an applied voltage of 100–200 mA. The *E. coli* eliminating performance of 99.8% was also observed at a residence time of 2 minutes at an applied voltage of 4 V (Ghernaout, 2017). Moreover, EC has shown efficiency in COD and turbidity removal (Boudjema *et al.*, 2016; Bruguera-Casamada *et al.*, 2018; Ghernaout, 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Synthetic and natural water

The batch experiments with varying parameters such as electrodes set up, current and the composition of the solution were carried out. The concentration of fluoride removed and residue aluminium in the water was determined. The current, voltage and time were also monitored during each experiment parallel with the determination of the conductivity and change of pH.

The purpose of the field study was to treat water from different sources with excessive amount of 1.5 mg/L of fluoride to make it safe and suitable for consuming. Therefore five water samples from different sources that have a higher concentration of fluoride were collected. In the experiment water with different fluoride concentrations ranging from 1.37–48 mg/L was used. Synthetic fluoride solutions were prepared by dissolving 3, 7 and 10 mg/L of sodium fluoride to make different solutions using distilled water. Tap water with 1.37 mg/L was also used. Other water samples were collected from four sources with a high concentration of fluoride. Water samples from Bulebule spring, Bulem spring, River Ngarenanyuki and River Uluwile with 7.05 mg/L, 8.05 mg/L, 29.5 mg/L and 48 mg/L consecutively were collected and parameters such as pH, fluoride concentration, and conductivity were analysed. The properties of different water samples used in the study are provided in Table 2.

3.2 Experimental setup

The experiment was performed in a double-walled (beaker) with 300 mL of water as indicated in Fig. 2. Two electrodes of aluminium 95% pure alloy $1 \times 5 \text{ cm}^2$ were immersed in the solution having a 2 cm gap provided with direct current (DC) power supply in the range of 0–80 V and 0–5 A was used to conduct EC. Before each run of EC, electrodes were rinsed with deionized water. The EC set-up was in stirring mode which was constant using a magnetic stirrer. This was to ensure that solution was homogenized and to facilitate adsorption of fluoride. After the treatment, by using a membrane filter with 0.45– μm pores, the solution was filtered through to remove the formed flocks. The temperature, conductivity, and pH were continuously monitored. The mass weight of the aluminium electrode was recorded at the beginning and end of the experiment. Furthermore, the cell voltage was recorded at 10 minutes intervals.



Figure 2: Laboratory batch experiment set up with two aluminium electrodes immersed in fluoride contaminated water

3.3 Analytical techniques

After each experiment, about 10 mL of the solution at intervals was filtered from aluminium (III) hydroxide. Fluoride ions presence was analyzed by the ion-selective electrode method according to the procedures, American Public Health Association (APHA). The interference from other ions in fluoride detection was prevented by total ionic strength adjustment buffer (TISAB), solution containing acetic acid, 1, 2–cyclohexylene diamine tetraacetic acid, sodium hydroxide and sodium chloride. This was added to each solution within the ratio volume of 1:1. Aluminium concentration was analyzed by an aluminium method according to APHA (2012). Water physical parameters such as pH, temperature and dissolved oxygen (DO), conductivity and total dissolved solids (TDS) were assayed by using the multiparameter meter (Hanna HI 9829). Calcium and magnesium concentrations from natural water were determined by titration according to standard methods, potassium and sodium were measured using flame spectrometry, while sulfate ions were measured by gravimetry and by titration using the Mohr method for chloride species analysis. Each experiment was performed three times, and the

average of the results was used. The fluoride removal efficiency (%) by the EC was determined by using Equation:

$$E = \frac{(C_0 - C_f)}{C_0} \times 100\%$$

Where; C_0 is the initial concentration of fluoride and C_f the concentration of fluoride at time t .

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characterization of water sources

In this study, the chemical and physical composition of selected water sources for domestic water supply was analyzed. Additionally, selected rivers that are not directly used for domestic water supply but instead for livestock and irrigation purposes were sampled for comparison of fluoride removal efficiencies as they had been reported to have a very high amount of fluoride. Physical parameters such as pH, conductivity (Cond), temperature (Temp), total dissolved solids (TDS), dissolved oxygen (DO), resistivity (Rest) as indicated in Table 2 were measured, while the chemical composition such as potassium (K), Magnesium (Mg^{2+}), sodium (Na^+), chlorine (Cl^-), calcium (Ca^{2+}), Sulphate (SO_4^{2-}) and nitrate (NO_3^-) were measured.

Table 2: Physical characteristics of the water sources

Parameters	Coordinates		pH	TDS (mg/L)	Cond (μ S/cm)	Temp (C)	DO (mg/L)	Rest (Ω)
	South	East						
Synthetic water			5.8	1.2	2.2	25	0.24	19.2
Local tap water	3 ⁰ 25' 1"	36 ⁰ 49' 7"	6.82	1.63	846	26.6	2.46	232.2
Bulebule spring	3 ⁰ 11' 38"	36 ⁰ 51' 19"	7.2	738.8	731.3	19.4	4.33	678.8
Belem spring	3 ⁰ 11' 37"	36 ⁰ 51' 26"	7.09	1.082	1.077	21.8	2.27	462.5
River Ngarenanyuki	3 ⁰ 52' 39"	36 ⁰ 51' 26"	8.8	1.777	761.6	20.4	6.72	284.4
River Uluwile	3 ⁰ 12' 39"	36 ⁰ 51' 52"	6.67	2.151	213.3	20.7	3.46	232

Table 2 shows the physical characteristics such as TDS, pH, Temperature and Conductivities. These parameters are vital, especially for the fluoride ions existence in that water. The presence of high TDS, for instance, might hinder the removal of fluoride while changes in pH might affect the state of existence of fluoride.

The chemical composition is shown in Table 3 and these have significant effects on the fluoride removal efficiency. For instance, the various water sources show variation in the amount of fluoride and also other ions. The local water tap, Bulebule and Belem springs are the three water sources whereby domestic water supplies are drawn and contain less than 10 mg/L of fluoride. The two rivers Ngarenanyuki and Uluwile are being used for irrigation and livestock water sources, which indirectly may affect human beings.

Table 3: Composition of ions in water sources in mg/L

Water Samples	F ⁻	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K	NO ₃ ⁻
Local tap water	1.37	0.02	8	18.4	6.8	19.8	10.7	0.6
Bulebule spring	7.05	0.02	16	10.2	3.9	42.4	22.3	0.3
Belem spring	8.45	0.01	29	17.8	4.7	54.7	31	0.1
River Ngarenanyuki	29.5	0.03	57	6.09	1.89	68.7	45.6	0.1
River Uluwile	48	0.03	88	5.81	1.62	96.4	53.2	0.1

To understand the removal efficiency, the experimental set up was done to examine the influence of initial fluoride concentration in the water supply, the voltage applied, pH and residence time of the water. The following sections therefore, provide detailed information on such parameters on the removal efficiency.

4.2 Effect of pH

The pH is a very crucial parameter in EC since it results in different hydroxides formation (Changmai *et al.*, 2018). Figure 3 indicates the trend of pH and how it behaved on the water with high fluoride concentration. The fluoride removal efficiency by electrocoagulation was

shown to be dependent highly on initial pH. The pH of the solution mostly favored the stability of aluminum hydroxide (Al(OH)_3) the coagulant forming the complex. Nevertheless, the defluoridation process was observed to be active in a pH range of 5 –7. Figure 3 shows that at an optimal pH of 6, removal of fluoride was effective in all water types due to the formation of Al(OH)_3 which is polymerized to $\text{Al}_n(\text{OH})_{3n}$ and has much low solubility which results into dense flocks with a large surface area that aid the fluoride removal (Gheraout *et al.*, 2008). Above the pH 9, the removal of fluoride was observed to decrease due to the production of Al(OH)_4^- and AlO_2^- which are useless in the fluoride removal process (Alimohammadi *et al.*, 2019).

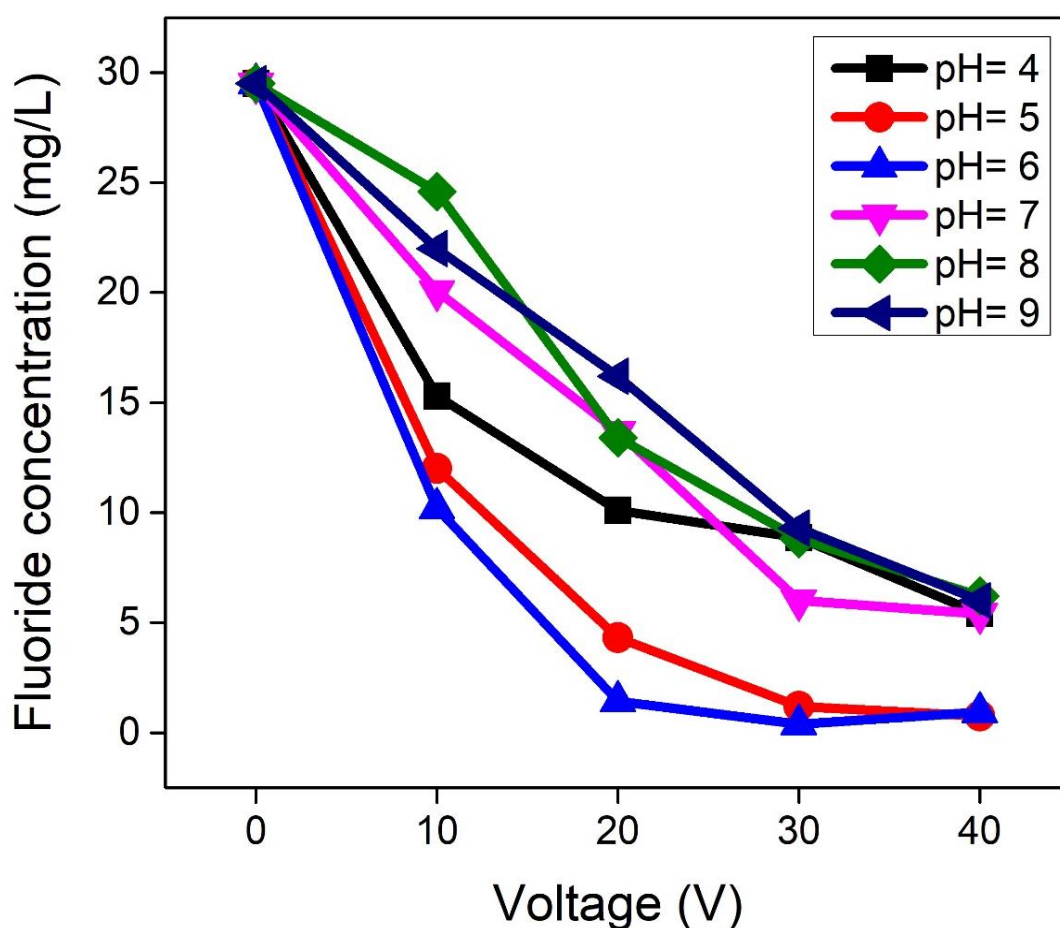


Figure 3: Effect of pH on fluoride removal efficiency for initial fluoride concentration of 29.7 mg/L over 30 minutes

Figure 4 describes the effect of pH on lower fluoride concentration. In Bulem spring water with 7.05 mg/L, the same optimum pH of 6 showed the highest removal of fluoride. In lower fluoride concentration, the removal was not active on pH of 5 and 7 compared to that of higher fluoride concentration. The study, thus showed that the highest fluoride removal efficiency is ranging from 6 due to the formation of stable aluminium hydroxides as earlier reported by Palahouane

et al. (2015). According to Changmai *et al.* (2018), under acidic pH, co-precipitation, sweep coagulation and adsorption are responsible for the defluoridation at fundamental pH values

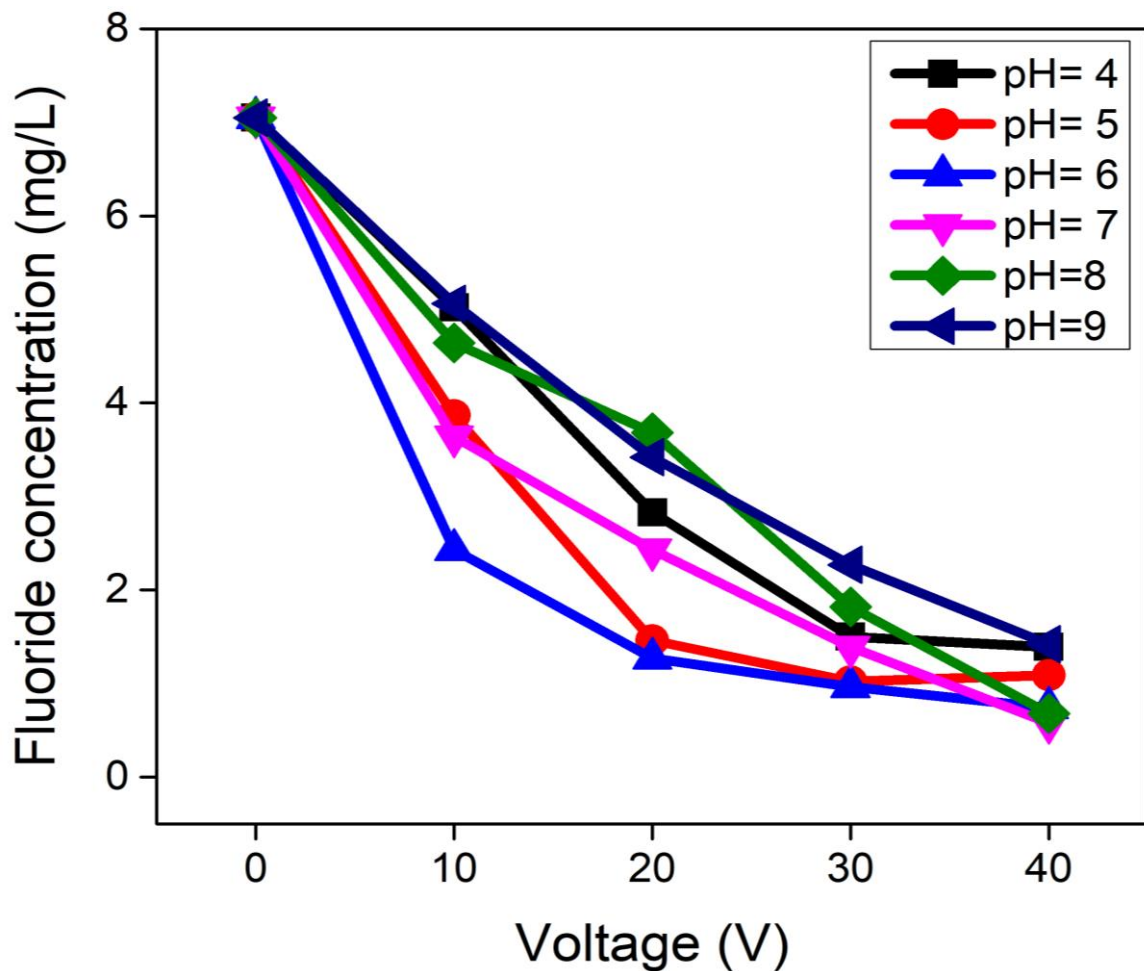


Figure 4: Effect of pH on fluoride removal efficiency for initial fluoride concentration of 7.05 mg/L over 30 minutes

4.3 Effect of initial fluoride concentration

The initial concentration of fluoride had been reported to have a significant influence on defluoridation efficiency. This study determined the effect of such initial concentrations of fluoride present in the various sources and the removal efficiencies. The water samples used had fluoride concentrations ranging from 1.37 the lowest and 48 mg/L the highest. Figure 5 indicates fluoride removal efficiency over residence time and it was based on their initial concentrations at the fixed voltage of 30 V and pH of 6. On fluoride initial concentration, it was shown that the solution with fluoride higher concentration requires more Al^{3+} to be dissolved compared with others having lower fluoride concentration. For instance, tap water containing fluoride initial concentration of 1.37 mg/L attained an 85% fluoride removal with

0.6 mg/L of Al^{3+} while water from river Ngarenanyuki with fluoride initial concentration of 29.5 mg/L obtained the same efficiency of fluoride removal at 7.2 mg/L of Al^{3+} at resident time of 30 minutes. Similarly, Bulebule spring water with an fluoride initial concentration of 7.05 mg/L attained the same removal efficiency of 85% at 4.3 mg/L of Al^{3+} concentration. The highest fluoride concentrations showed an effective removal compared to the lowest concentrations, and this is because in more dilute solutions there's a slower reaction rate due to the formation of the diffusion layer at the vicinity of the electrode while in concentrated solutions there's no migration of metal ions to the surface of electrode or effect on the rate of diffusion diffusion layer (Battula *et al.*, 2014).

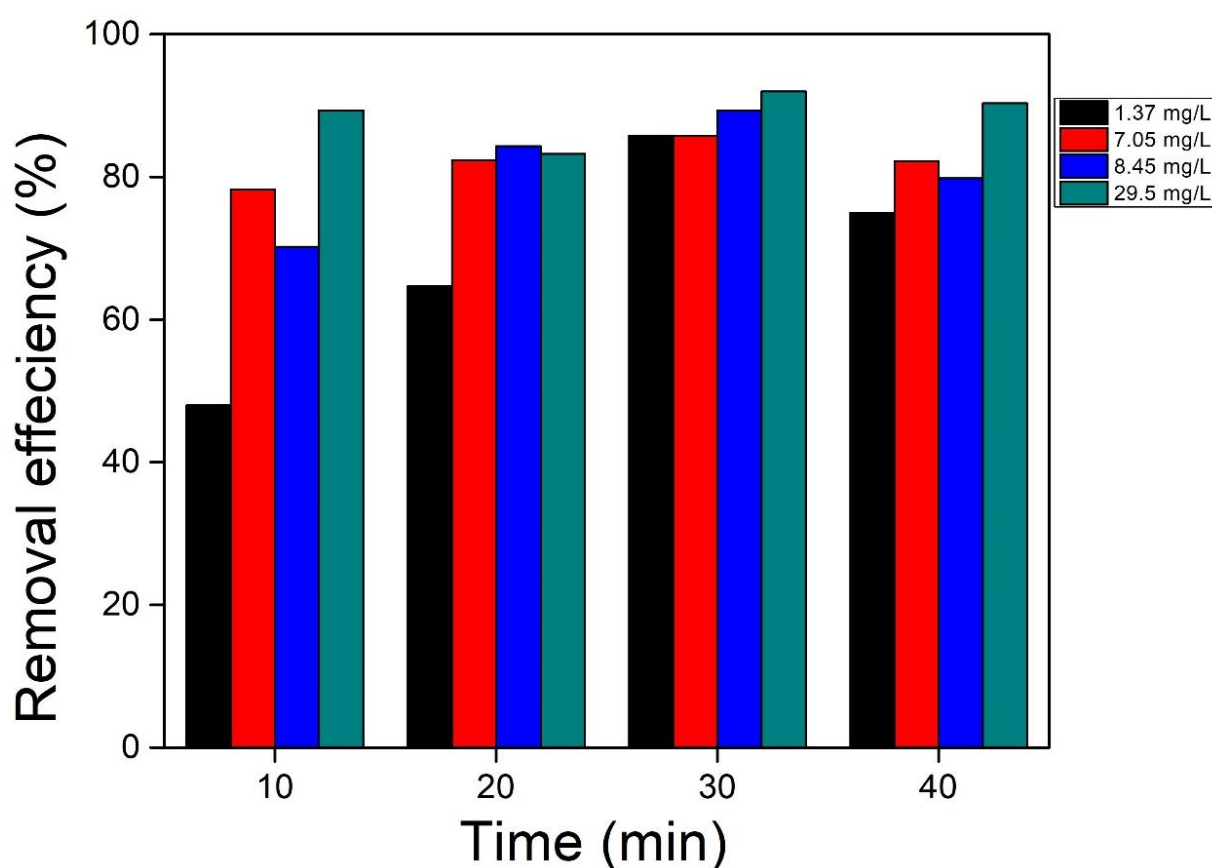


Figure 5: Removal efficiency (%) with different fluoride concentrations over time (minutes) at an applied voltage of 30 V

Furthermore, water with hydrogen carbonate ions showed efficiency over aluminium ions compared to synthetic water with the lowest amount of hydrogen carbonate ions. Figure 6 indicates how synthetic and natural water behaves on generating aluminium ions in water. The water with hydrogen carbonates generates much aluminium compared to synthetic water which reduces the efficiency on fluoride removal. It was observed that the EC process could decrease

both concentrations to accepted standards (1.5 mg/L) of fluoride (WHO, 2011). These describe that water with more ions conduct more electricity hence high Al dissolves in water compared to one with fewer ions.

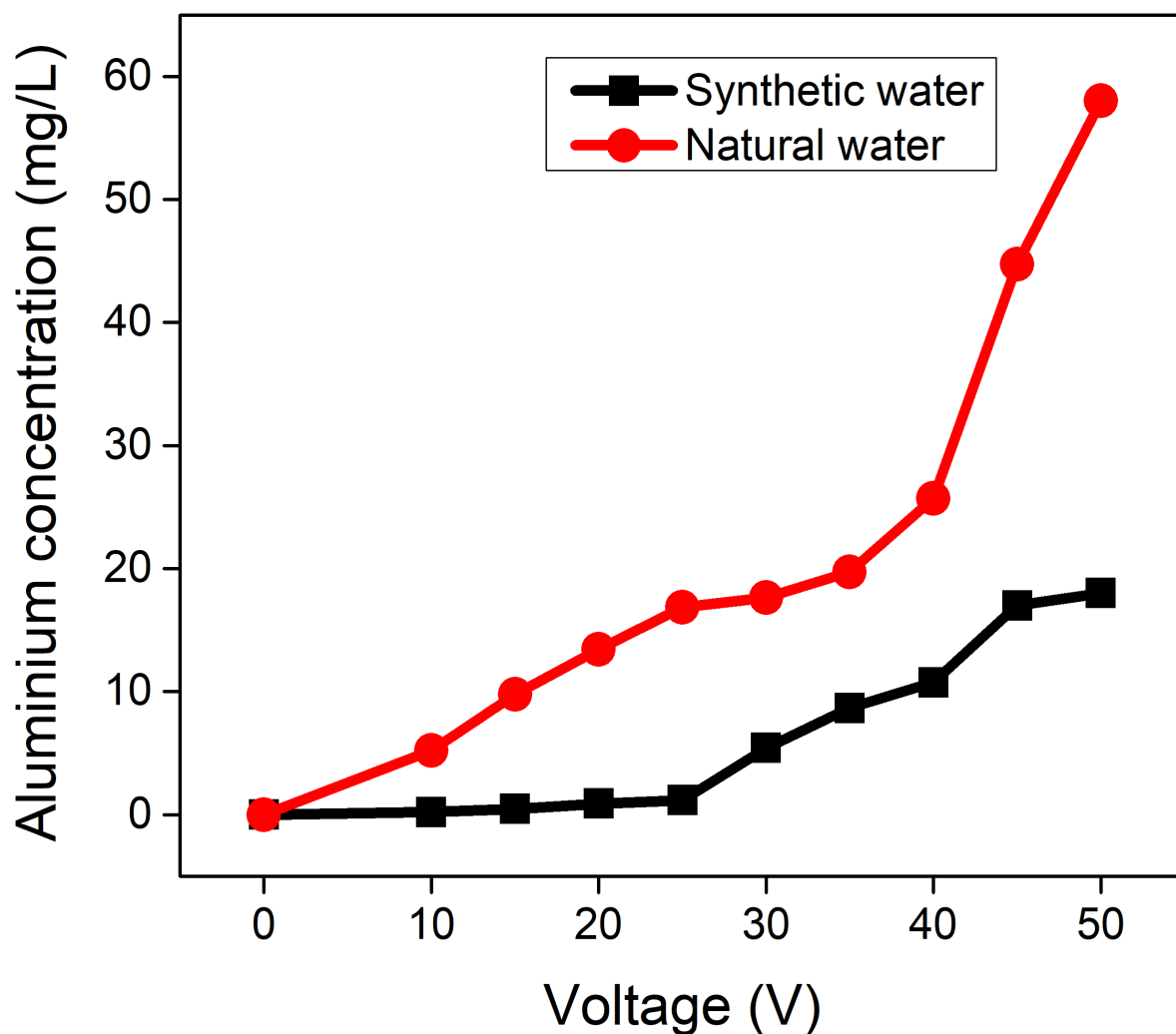


Figure 6: Aluminum concentration produced over the voltage at 30 minutes electrolysis

Various studies have reported different removal efficiencies at different initial fluoride concentrations. Table 4 compares the various studies that have been done using the EC process for the present study. It shows the voltage, electrode gap and electrolysis time and how this study was relating with others that have been done on EC with the same aluminium electrodes.

Table 4: Effect of initial fluoride concentration and associated removal efficiency

Reference	Fluoride concentration (mg/L)	Voltage (V)	Electrode gap (mm)	Electrolysis time (min)	Removal efficiency (%)
Alimohammadi <i>et al.</i> (2019)	4.93	10.47	20	40	95
Battula <i>et al.</i> (2014)	7.89	40		20	87
Changmai <i>et al.</i> (2018)	10	30	5	20	97
Grich <i>et al.</i> (2019)	10	30	5	90	97
This study	1.37	30	20	30	82
This study	7.05	30	20	30	82
This study	8.45	30	20	30	85
This study	29.5	30	20	30	90

As seen from the the study carried by Alimohammadi *et al.* (2019), Grich *et al.* (2019) and Changmai *et al.* (2018) showed the highest removal at lower voltage of 30 V compared to other studies and this is due to wide range of residence time (40–90 minutes) which lead to production of massive amounts of aluminium hydroxide at a pH (4–8.5) which have a very high affinity for the fluoride ions. Electrode gap is another factor which influences a lot on fluoride removal. As it can be observed from different studies, the electrode gaps influences the removal efficiency. The lower the electrode gap the removal efficiency is higher. Consider the highest removal efficiency in Grich *et al.* (2019) study which was conducted in lower electrode gap compared to other studies, which also was influenced by monitoring of conductivity by adding sodium chloride which can affect the EC process. According to Battula *et al.* (2014), the removal of fluoride efficiency was similar to this study since factors such as pH (5 – 7), voltage (40 V) and initial fluoride concentration (10 mg/L) applied were similarly related to parameters applied in this study too. However, in this study beyond 35 V observed

to accumulate many aluminium residues in water which is toxic and can affect the human health.

4.4 Effect of residence time

Residence time is an essential parameter in EC since it determines how long water should be in a treatment system to reach the allowed standards. Figure 7 indicates that the increase in electrolysis period, the concentration of ions and their hydroxide flocks increases and hence more removal efficiency. This is because the rate of production of Al^{3+} ions from aluminium electrodes dissolved from the anode which results in the amorphous aluminium hydroxide precipitation is determined by the reaction time (Grich *et al.*, 2019). It is indicated in Fig. 7 as time increased to 40 minutes, the aluminium produced was beyond the allowable limits of 0.7 mg/L which is not supposed to exceed the standards for human consumption. However, as time increases along with aluminium residues in water the fluoride removal efficient improves as well. The experiments showed that water standards of fluoride concentrations below the WHO and TBS recommendations were achieved within an optimum residence time of 30 minutes. As it increases above 30 minutes the increase of aluminium residues was above the WHO limits of 0.7 mg/L which in drinking water can cause toxicity (Krewski *et al.*, 2007, 2009; Shirasaki *et al.*, 2016).

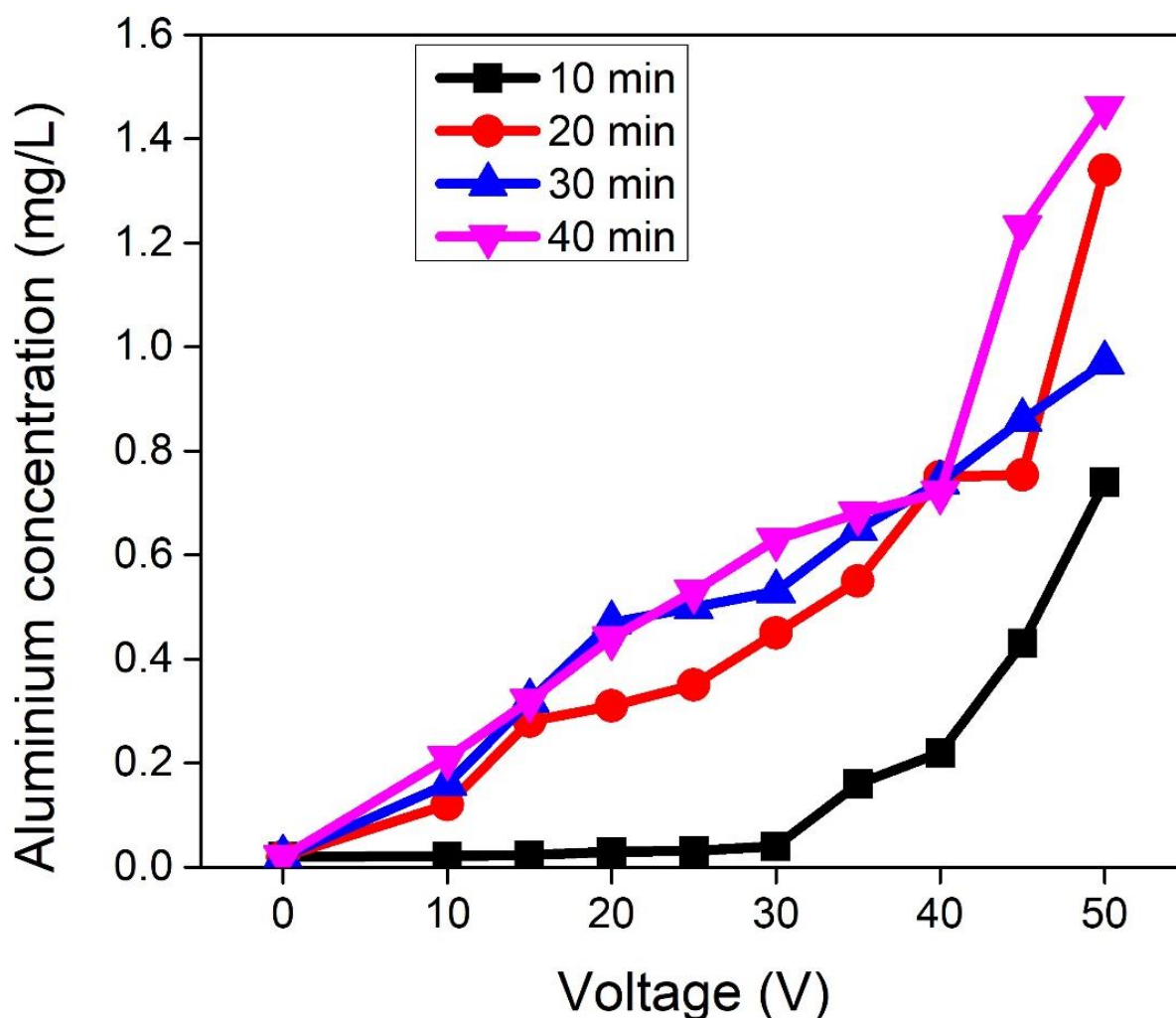


Figure 7: Aluminum residue concentration as a function of electrolysis time

4.5 Effect of an applied voltage

Figure 8 and 9 show how applied voltage affects fluoride removal. As you increase the voltage, the less time can be applied for efficient removal. In the EC process, the applied cell potential contributes to the amount of the coagulant and hence affects the growth of flocks with bubble size (Grich *et al.*, 2019; Drouiche *et al.*, 2009). To examine the effect of applied potential on the removal of fluoride efficiency, the EC experiments were carried out using different voltages (10 – 50 V). In Fig. 8 it indicates the fluoride removal in different voltages at highly fluoride concentrated water (29.5 mg/L). Under lower voltage and long residence time, the removal of fluoride was efficient. The fluoride was efficiently removed under the voltage of 30 V since it required less time to reach the allowable standards hence no aluminium residues in water. It was also observed under the voltage of 10 V but it required long electrolysis time to reach the allowable standards which directly was leading to accumulation of aluminium residues in treated water. Similarly, more electrolysis time and higher voltage resulted in more

yield of Al(OH)_3 which subsequently increase defluoridation. Therefore, the optimum applied voltage of 30 V with residence time 30 minutes should be applied for a better EC process in water treatment.

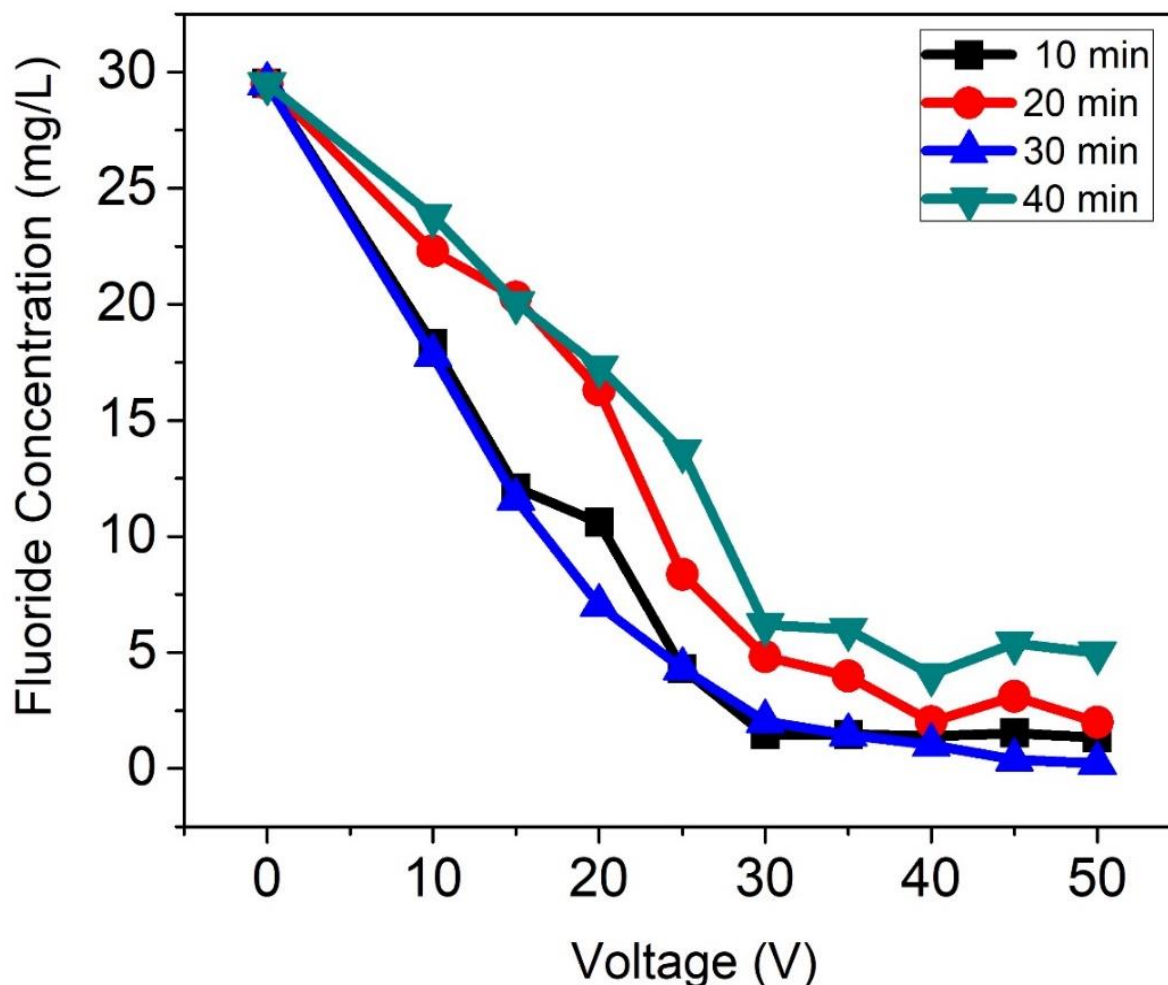


Figure 8: Effect of applied voltage over time on higher fluoride concentration at a pH of 6

The fluoride removal in water with higher fluoride concentrations is different from the water containing lower fluoride concentration. Figure 9 indicates the fluoride removal at different voltages. In water with lower concentrations of fluoride, the removal was not favoured at low voltage despite the longer electrolysis time. As the voltage increased from 20 – 30 V the removal also improved. The high voltage of 40 V did not show the efficient removal of fluoride and accumulation of aluminium residues was very high since the produced aluminium ions did not form a complex for the fluoride removal.

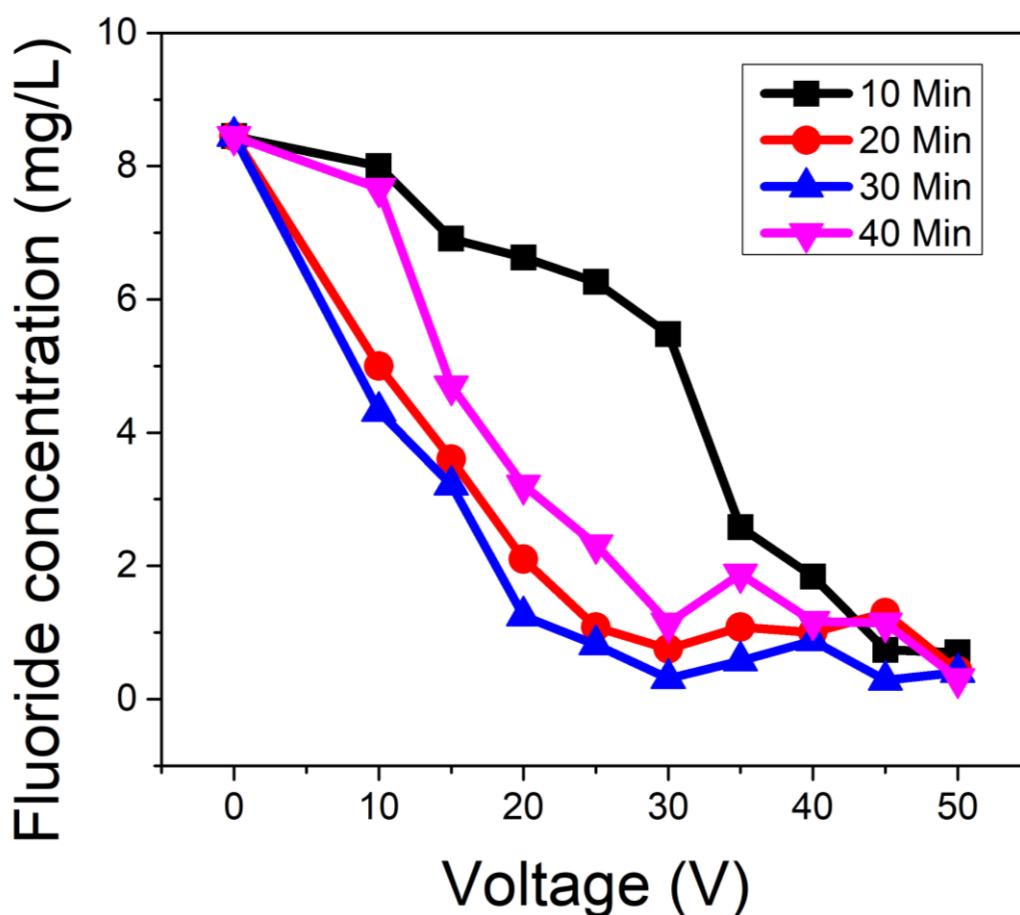


Figure 9: Effect of applied voltage over time on lower fluoride concentration of 8.05 mg/L at pH of 6

4.6 Aluminium residues

Aluminium used as a coagulant in water treatment may lead to massive amounts of aluminium in the drinking water. The dissolution of aluminium salts is controlled by pH since the aluminium (III) cation has a strong affinity for the hydroxide ion, which leads to the formation of precipitates (Krewski *et al.*, 2007). Like magnesium (Mg^{2+}), calcium (Ca^{2+}) and aluminium (Al^{3+}) ions in most cases forms complexing agents with oxygen–atom donor sites. These are such as phosphate and carboxylate groups, including in biological systems (Krewski *et al.*, 2007). Most of aluminium adsorbents in water such as poly aluminium hydroxyl Sulphate, poly aluminium chloride, alum sludge (aluminium hydroxides), alumina impregnated and activated alumina with oxides (manganese, ferric hydroxides magnesium, etc.) are suitable for fluoride removal since their affinity between fluorine and aluminium is high and their surface active sites are in massive numbers (George *et al.*, 2010).

In this study, there were several observations on aluminium residues. As conductivity (electricity conducted) was high, more aluminium was produced from anode for adsorption

depending on residence time and voltage and this was depending with types of water, while the one with more ions concentration, more aluminium ions were produced. The dissolution of aluminium hydroxide precipitate produces positively charged, products such as $\text{Al}(\text{OH})_3$ and the aqua-metal ion (Al^{3+}) at low pH. While at high pH, the aluminate ion $\text{Al}(\text{OH})_4$ is formed which is the negatively charged. The pH of minimum solubility of the precipitate aluminium hydroxide occurs between pH of 6 and 7 in a system without aluminium complexing ligands, depending on the system temperature.

Table 5 indicates the initial concentration of aluminium in each water type, the amount of aluminium after the experiment which indicates that much aluminium was produced especially in water with the highest concentration of fluoride ions. Also, it shows the concentration of aluminium residue that left in the water after the full treatment which was below WHO standards (0.7 mg/L). To reduce the amount of aluminium residue which mainly occur as monomeric aluminum, it is crucial to maintain the pH of treated water which is close to the pH of minimum $\text{Al}(\text{OH})_3$ solubility (6.5–7.0), taking in consideration that this value varies with temperature.

Table 5: Aluminum concentration in water before and after experiment under 40 minutes

Water source	Conductivity (μcm)	Original conc of Al^{3+} (mg/L)	Conc of Al^{3+} after experiment (mg/L)	Conc of Al^{3+} after the filtration (mg/L)
Local tap water	358	0.319	2.34	
Local tap water	358	0.319	2.34	0.18
Bulebule spring	1228	0.437	15.21	0.32
Belem spring	1366	0.489	19.02	0.23
River Ngarenanyuki	1923	0.216	17.65	0.53
River Uluwile	1927	0.186	22.63	0.62

Figure 10 shows how the aluminium concentration increases with both electrolysis time and voltage. At high voltage (50 V) and electrolysis time of 40 minutes the amount of aluminium was observed to be more than 80 mg/L, moreover, it shows how both electrolysis time and voltage has a significant effect on treatment. The turbidity of the water in the distribution system can be increased due to high concentrations of aluminium. Aluminium hydroxide flocks may interfere with the disinfection process by protecting and enmeshing microorganisms (Krewski *et al.*, 2007). Aluminium hydroxide may also be settled on the pipes walls, decreasing carrying capacity. On the other hand, aluminium on pipes may form a protective film which reduces the corrosion (Driscoll & Letterman, 1995).

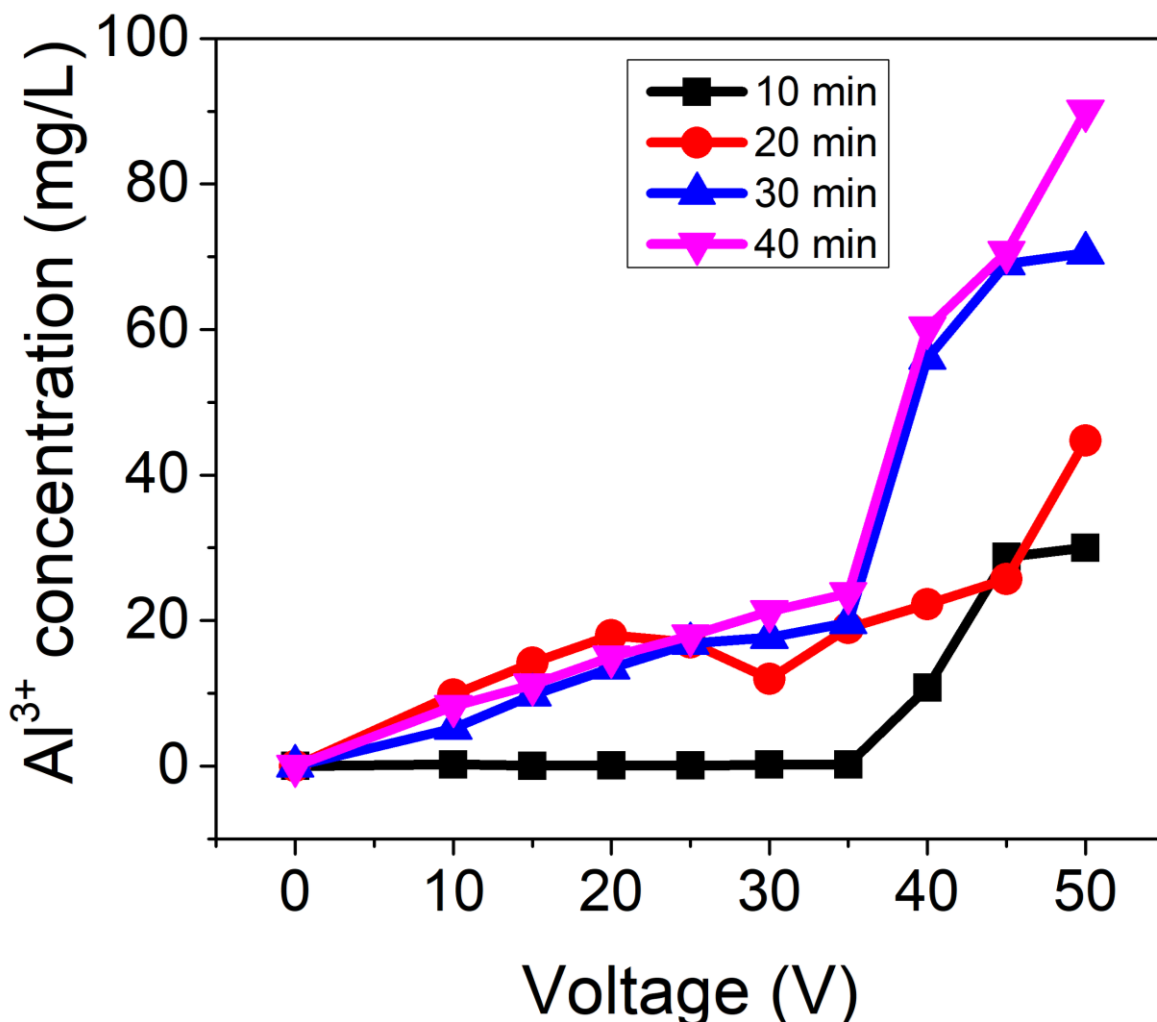


Figure 10: The Aluminum (Al^{3+}) concentration generated over time before filtration of precipitates

In the EC system, a suitable filtration membrane is required to make sure there is no excess of Aluminum residues in drinking water above the allowed standard, as illustrated in Fig. 11. Significant amount of aluminium residues in water may also have human health problems. The literature review suggests that high residues of aluminium appear to occur in either of the two forms, particulate aluminium or dissolved aluminium (Driscoll & Letterman, 1995). Oral aluminium bioavailability is higher from water than that consumed indirectly like in foods. Therefore, the optimum voltage and residence time must be used to avoid the excess aluminium residues in drinking water above the allowed standards which is toxic to human health. Moreover, the use of optimum conditions (applied voltage and residence time) reduces the chance of having an excess of aluminium residues in drinking water. The applied voltage should not exceed 35 V with the residence time of 30 – 40 minutes to ensure an effective fluoride removal with Aluminum residues below 0.7 mg/L as legal standards by World Health Organization (WHO).

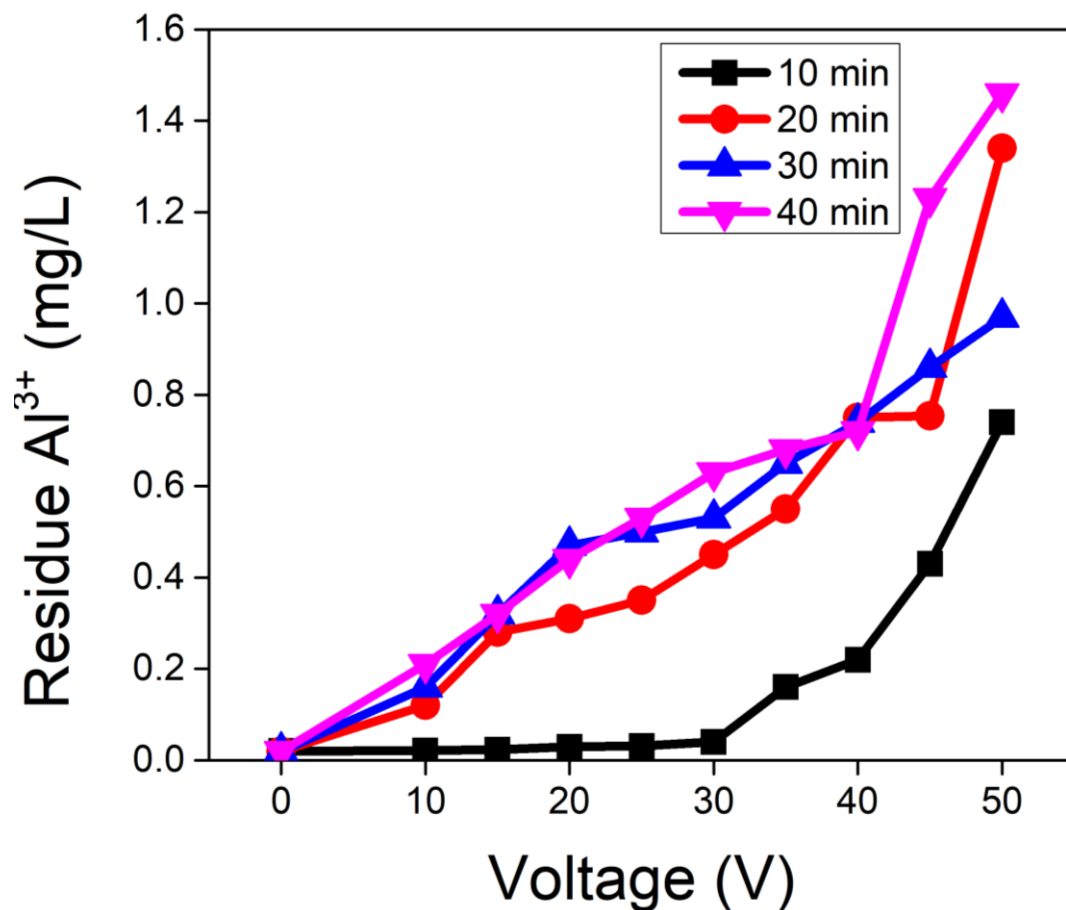


Figure 11: The residue aluminum (Al³⁺) concentration generated over time

4.7 Aluminium concentration over fluoride concentration

In the electrochemical cell, water passes on plates of aluminium connected to a direct power supply. The aluminium dissolves from the anodes and hydrogen gas is developed at the cathodes. The mixing between dissolved aluminium and water results in coagulation and flocculation. The hydrogen gas formation can lead to a pH increase and formation of the sludge which can float (Vik & Carlson, 1984). The concentration of aluminium increases as fluoride concentration decreases. In Fig. 12 it shows how the aluminium concentration behaved with fluoride decrease at the minimal time of 10 minutes. At minimal voltage, the increase of aluminium ions was slightly increasing but as the voltage increased, the concentration increased rapidly allowing more fluoride removal. At a voltage of 35 V and above the removal of fluoride was decreasing slightly leading more aluminium residues in water. Thus optimal voltage of 30 V should be maintained to avoid the effect of aluminium in drinking water.

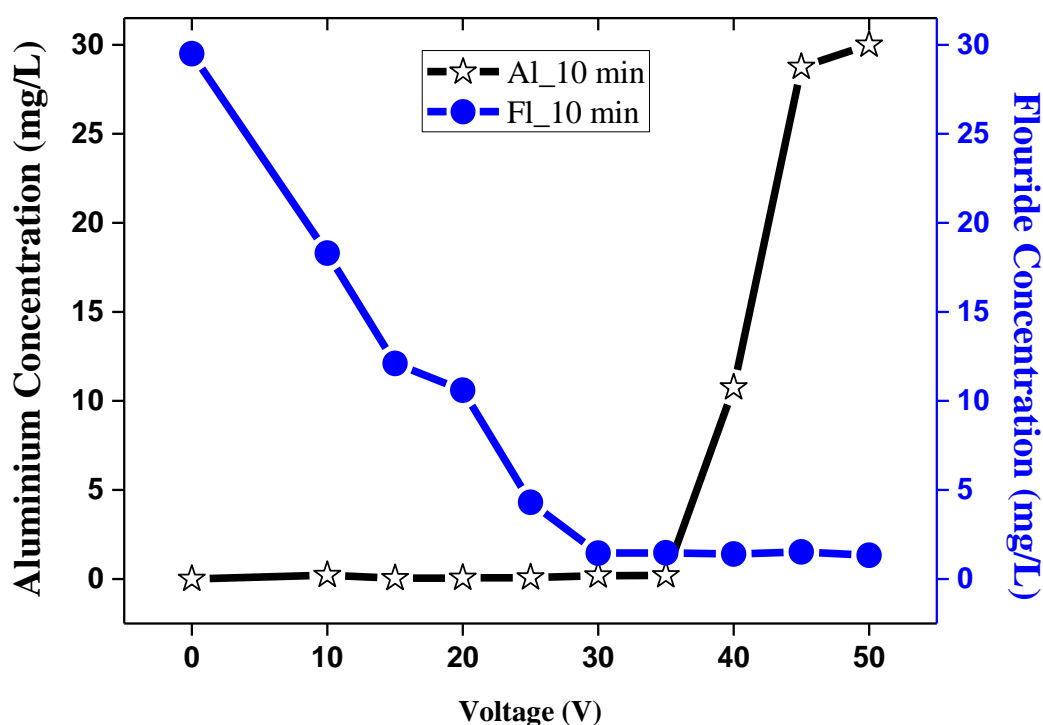


Figure 12: Aluminum concentration (Al^{3+}) versus the fluoride concentration (F^-) under 10 minutes at a pH of 6

Figure 13 shows the how the fluoride concentration behaved with aluminium concentration at the highest voltage of 40 V. At the voltage of 25 V to 30 V the aluminium ions production decreased and the removal of fluoride did not reach the allowable standards of WHO. Above the 35 V, the aluminium concentration increased rapidly. The electro dissolved aluminium as it increases linearly with the electrical charge the more fluoride removed from the water.

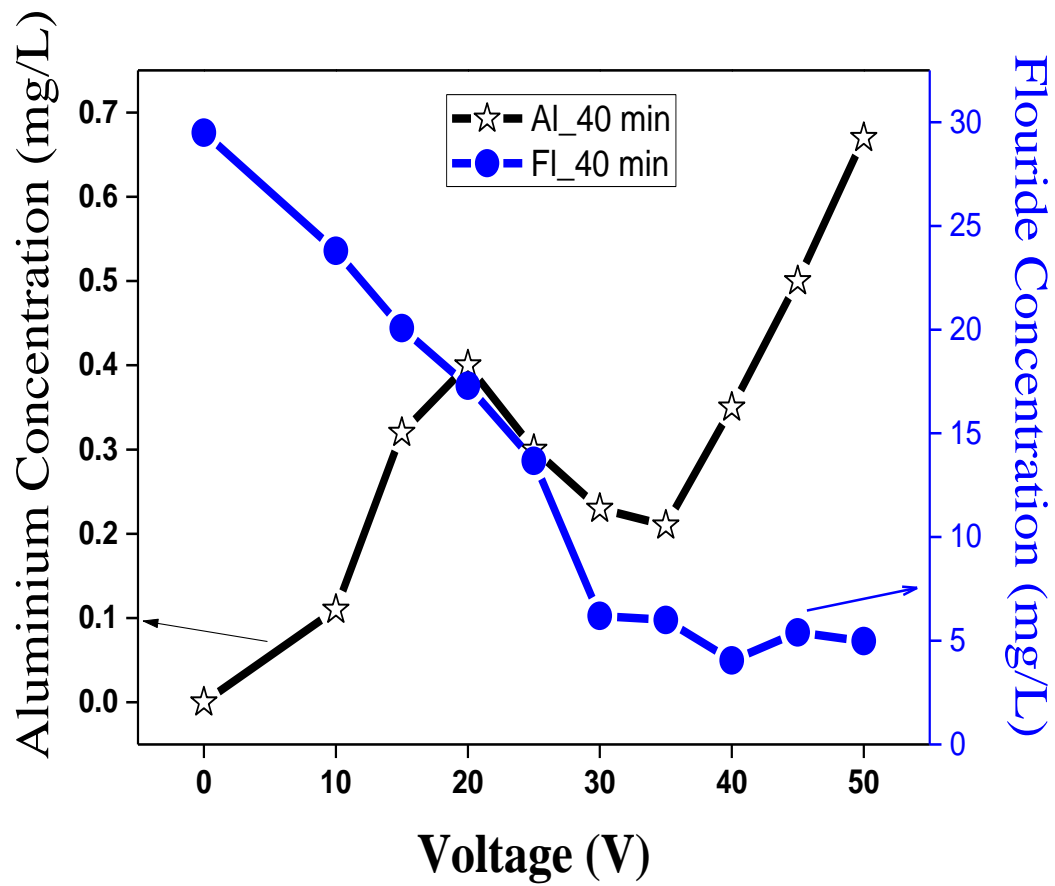


Figure 13: Aluminum concentration (Al^{3+}) versus fluoride concentration (F^-) under 40 minutes at a pH of 6

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The EC method showed positive results under a pH of 6, an electrode gap of 2 cm and a voltage range of 30 – 35 V, therefore, making it suitable for drinking water treatment. The study results reveals that the EC process depends on the coagulant (Al(OH)_3) produced in water which depends on electrolysis time and applied voltage. Other parameters such as initial concentration of solution and pH are crucial and their effect was well determined in this study. The fluoride concentration 1.5 mg/L set by both WHO and TBS guideline for drinking water was reached at high removal efficiency of 90%. From the experiments, it showed that only 30 minutes is enough to treat water to reach the standard limits for fluoride in Tanzania.

5.2 Recommendations

Further studies are required to examine and design the system which should be used to save water in large communities. The optimum conditions and operating environment should be well addressed in order to invest in saving the large community using the batch scale as a reference. The removal of pathogens should be studied too in order to establish a system that can disinfect and remove fluoride simultaneously for clean and safe water.

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RESEARCH OUTPUTS

Publication paper

Mureth, R., Machunda, R., Njau, K. N., & Dodoo-Arhin, D. (2021). Assessment of fluoride removal in a batch electrocoagulation process: A case study in the Mount Meru Enclave. *Scientific African*, 12 (2012), e00737.

Poster presentation

Assessment of fluoride removal in a batch electro-coagulation process

Poster presentation



ASSESSMENT OF FLUORIDE REMOVAL IN A BATCH ELECTRO-COAGULATION PROCESS

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INTRODUCTION

- In Tanzania, drinking water sources have been reported to have a fluoride concentration of 4 mg/L and beyond (Grich, 2019).
- In Tanzania, the defluoridation from drinking water by applying bone char household filter has been adopted for treating of fluorotic water at the point of use and has been applied in many areas (Kaseva, 2006).
- However, this technology has faced some challenges on its use and therefore, alternative technologies and materials for removal of fluoride are needed.
- This present study aimed at focusing on establishing a new technology (electrocoagulation), that will be sustainable and environmental friendly since it uses the less energy to form coagulant which will eliminate the excess fluoride in water.

Research objectives

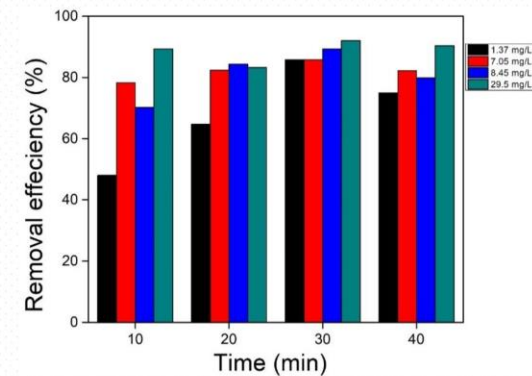
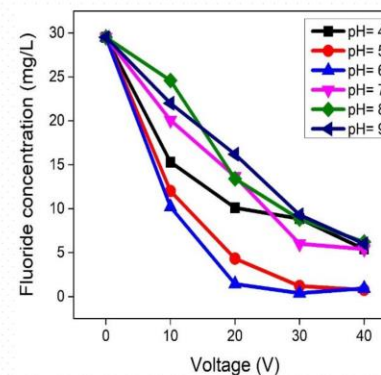
General Objective: Assessment of the performance of the electrocoagulation process for fluoride removal.



Specific Objectives:

- To evaluate the defluoridation capacity of EC system at various operating conditions.
- To establish the operating conditions for the system at field conditions.

Results and Discussion



Fluoride removal efficiency from different water sources to less fluoride concentration of 1.5 mg/L

