Ingebjørg Hovland Evang and Nina Bjørnvold Bakken

Reliable Water to Rural Districts in Tanzania

Studies of water availability, quality and customer perception in the districts of Hanang, Mbulu and Mkalama

Master's thesis in Civil and Environmental Engineering
Supervisor: Sveinung Sægrov
January 2021

Master's thesis

NTNU
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Abstract

Almost half of the rural Tanzanian population is without access to an improved water source. Consequently, they are prone to diseases caused by contaminated water and they have to spend a significant amount of time to collect water. Access to an improved water source for all people is essential to ensure economic, environmental and social sustainability.

Changing precipitation patterns and rapid population growth stress an already strained water supply situation in Tanzania. As a measure to adapt to climate change reliance on groundwater is expanding. Groundwater is little affected by unstable precipitation patterns and is thus seen as a reliable water source.

The groundwater must have sufficient capacity and be of satisfactory quality to be a reliable water source. This thesis evaluates groundwater reliability in Hanang, Mbulu and Mkalama districts in Tanzania in terms of availability, management and quality.

Sufficient supply is investigated based on groundwater availability and management. By remote monitoring of the groundwater table, this thesis found that groundwater availability is reliable and further extraction can be performed.

Groundwater reliability in terms of management faces challenges in order to supply sufficient amounts year-round. Our results show that people's satisfaction with the water services is not reflected by the performance of the Community-Owned Water Supply Organizations (COWSOs) but is influenced by other factors. Community-members' level of satisfaction is strongly impacted by having a long distance to the well and having to use a local well as a non-improved water source in the dry season. Therefore, effort should focus on providing safe water to remote areas, particularly in the dry season.

As for quality, high fluoride levels threaten the groundwater reliability in Tanzania. This thesis investigates the potential of various fluoride adsorbents. H_2SO_4-treated activated alumina exhibits high fluoride adsorption but is too costly to adapt in poor rural settings. Adsorption with moringa and neem leaves was investigated as a low-cost alternative. This study found that adsorption with moringa and neem leaves is not suitable for poor, rural settings.

This thesis shows that groundwater in Hanang, Mbulu and Mkalama districts in Tanzania has reliable availability but do not exhibit sufficient supply due to management challenges. In areas with excessive fluoride levels, groundwater quality is not reliable due to lack of appropriate fluoride removal methods for poor, rural settings.

By addressing these challenges, potential opportunities to enhance progress rate towards obtaining reliable groundwater supply are revealed.

Sammendrag

Nesten halvparten av befolkningen i de rurale områdene i Tanzania er uten tilgang til sikre vannkilder. Befolkningen må bruke mye tid på å samle vann, og drikkevannsbårne sykdommer forårsaket av forurenset vann er vanlig. Tilgang til en forbedret vannkilde er essensielt for å sikre økonomisk, miljømessig og sosial bærekraft i landet.

Endringer i nedbørsmønstre og rask befolkningsvekst påvirker en allerede anstrengt vannforsyningssituasjon i Tanzania. Tidligere har regnvann vært viktig som vannkilde mange steder. På grunn av klimaendringer er det økt behov for å kunne bruke grunnvann. Grunnvann påvirkes lite av ustabile nedbørsmønstre og blir dermed sett på som en pålitelig vannkilde.

Grunnvannet må ha tilstrekkelig kapasitet og være av tilfredsstillende kvalitet for å være en pålitelig vannkilde. Denne oppgaven evaluerer grunnvannets pålitelighet i distriktene Hanang, Mbulu og Mkalama i Tanzania i form av tilgjengelighet, forvaltning og kvalitet.

Tilstrekkelig vanntilgang ble undersøkt basert på tilgjengelighet og forvaltning av grunnvann. Fjernovervåking av grunnvannsnivået viste at tilgjengeligheten av grunnvann er stabil og ytterligere utvinning kan utføres uten risiko for å redusere grunnvannsstanden.

Resultatene viser at folks tilfredshet med vanntjenestene ikke reflekteres av hvor fornøyde de er med vannforsyningsorganisasjonene (COWSO), men er påvirket av andre faktorer. Befolkningens tilfredshetsnivå påvirkes sterkt av avstanden til brønnene og av om de må bruke en lokal brønn i den tørre årstiden. Derfor bør innsatsen videre fokusere på å gi trygt vann til avsidesliggende områder, spesielt i den tørre årstiden.

Når det gjelder kvalitet, gir høye fluorinnhold i grunnvann helsemessige utfordringer i Tanzania. Denne oppgaven undersøker potensialet til forskjellige fluoradsorbenter. ce H2SO4 -behandlet aktivert aluminium har høy fluoradsorpsjon, men er for kostbar. Adsorpsjon med moringa- og neemblader ble undersøkt som et billig alternativ. Denne studien fant at adsorpsjon med moringa og neemblader ikke er egnet.

Denne oppgaven viser at det er nok grunnvann i distriktene Hanang, Mbulu og Mkalama i Tanzania, men at det er problemer med forvaltningen slik at tilgjengeligheten for befolkninger er ustabil gjennom året. I områder med for høyt fluorinnhold er grunnvannskvaliteten ikke akseptabel og det er per i dag ingen billige, passende metoder for fjerning av fluor.

Ved å kartlegge utfordringene kan videre arbeid fokusere på mulige løsninger og prioriterte områder i det videre arbeidet.

Preface

This thesis is the culmination of an integrated master's degree in Civil and Environmental Engineering at the Norwegian University of Science and Technology (NTNU). Our choice of thesis subject was motivated by a desire to contribute to improving people's lives. Water is essential for human life and there are still many unsolved challenges hindering access to clean water for everyone. By writing this master's thesis we hope to change some of these challenges towards opportunities.

The research has been carried out in collaboration with the local Tanzanian organization 4 Corners Cultural Program (4CCP) and Engineers Without Borders (EWB) Norway.

First and foremost we thank our supervisor Sveinung Sægrov for his significant support and interest in this thesis from the very beginning. His knowledge has been invaluable and his enthusiasm truly inspiring.

We also express our profound gratitude to the employees of 4CCPfor making it possible to write this thesis. With Covid-19 making it impossible to travel to Tanzania to conduct fieldwork, they laid the foundation of the research by providing us with leaves for the lab experiment and conducting surveys. We also thank all the respondents, without whose cooperation we would not have been able to conduct our analysis.

We are grateful that EWB continued the collaboration from the project thesis, even when the problem statement changed substantially due to Covid-19. We are especially grateful towards EWB for providing us with our mentor, Rebecca Martinsen. She has shared valuable insight from the study area and assisted in structuring the thesis.

We had little experience with lab experiments, hence guidance related to the lab experiment was highly treasured. Trine Margrete Hårberg Ness dedicated countless hours in assisting us and her creativity and sense of responsibility are praiseworthy. We thank Thuat Trinh for professional evaluations during the experiments and Thomas Meyn for initiating the problem statement of fluoride removal by leaves.

The master's theses written by Rebecca Martinsen (2018), Ingvild Misund and Sigrid Elizabeth Stang Møller (2019), Maria Asklund (2020) and Trine Ånestad Røer (2020) paved the way for our study and by sharing their materials made it possible to compare previous findings with the current situation.

Lastly, we thank our family and friends who provided qualified feedback on the thesis. A special thank goes to Torsten Bergh Moss for providing technical assistance.

Trondheim 25$^{\text{th}}$ of January 2021
Nina Bjørnvold Bakken and Ingebjørg Hovland Evang

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Abbreviations

4CCP	The Four Corners Cultural Program
AA	Activated Alumina
AC	Activated Carbon
CBWSO	Community-Based Water Supply Organization
COWSO	Community-Owned Water Supply Organization
EWB	Engineers Without Borders
GAC	Granular Activated Carbon
GPCC	Global Precipitation Climatology Centre
GPD	Global Precipitation Dataset
IAM	Infrastructure Asset Management
IC	Ion Chromatography
NAWAPO	National Water Policy of 2002
NCA	Norwegian Church Aid
NTNU	Norwegian University of Science and Technology
PAC	Powdered Activated Carbon
PV	Photo-voltaic
RUWASA	The Rural Water Supply and Sanitation Agency
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
WTP	Willingness To Pay
UN	United Nation
WHO	World Health Organization
WASH	Water, Sanitation and Hygiene

Chapter 1

Introduction

1.1 Background and motivation

Tanzania struggles with water scarcity both in terms of quantity and quality, which limits Tanzania's growth towards sustainable development. Despite national and international funding and effort, development in the water sector has stagnated. In the rural areas almost half of the population do not have access to improved water services (UNICEF, 2019). The water resource development is challenged by population growth and climate change. During the last two decades, the Tanzanian population has expanded from 32 million people to 58 million (The World Bank, n.d.). While population growth rapidly increases demand, climate change limits sustainable water supply. Actions need to be taken to bridge the escalating gap between demand and supply.

As a response to meet the acute environmental, political and economic challenges facing the world the United Nations established the Sustainable Development Goals (SDG) in 2015, were goal number 6 aims at "ensuring availability and sustainable management of water and sanitation for all" by 2030. It is evident that SDG 6 strongly impacts all aspects of sustainability; economic, environmental and social (UN, 2018). One important aspect of sustainable water services is accessibility, which comprises the location and reachability of the water services.

The accessibility of a water source impacts economic sustainability in various ways. One way is by enabling people to spend time and energy contributing to society instead of spending time on collecting water. Another reason is that contaminated water is a common source for diseases, hence safe water improves health and results in a more productive population. Children are most prone to catch diseases related to water, sanitation and hygiene (WASH), thus improved WASH-services has shown to increase school attendance. Many places it is common that children are responsible for collecting water, thus easing children of the burden to collect water frees time for education, which is important for long term economic development. Access to safe water will also ease national economic stress in the short term, as Tanzania uses approximately 70% of their health budget to treat WASH-related diseases (UNICEF, 2019). Therefore, access to safe water is a pathway for Tanzania to move out of poverty.

Environmental sustainability and access to water is mutually reinforcing. This is due to poverty harming the environment as crucial needs, such as food, water and health, are prioritized above environmental issues. (Cobbing, 2020). Hence, alleviating poverty will naturally benefit the environment. This means that improved water supply services are an indirect measure to cope with climate challenges, which again will make the water supply challenges in the future less severe.

Social sustainability treats how systems and activities impact people and is closely related to reducing inequality. In Tanzania there is a large economic gap between rural and urban areas, and residents in rural areas are generally poorer than those living in urban cities (ibid.). Rural areas also have the lowest access to safe water sources, thus an increase in sustainable water access in rural areas will improve economic equality, and vice versa. In addition, there is an economic and educational gender gap in Tanzania (UNICEF, 2019). It is not uncommon that girls cannot attend school when they are menstruating, thus improved WASH-facilities is necessary for enabling girls to attend school also when menstruating. Another gender difference is that the task of collecting water often is assigned to women, hence a water source closer to the household will particularly influence the possibility for women to spend time on education and work (UNESCO, 2019). Thus, improved water access would improve gender equality.

These are some of the reasons why an improved water supply service is essential to ensure economic, environmental and social development in Tanzania. It shows reasons to why improved access to safe water will have an immense impact on the Tanzanian society.

1.2 Problem description

The United Republic of Tanzania recognized water as a human right in their constitution in 2013. This right includes that water should be affordable, physically accessible, sufficient and safe in terms of quality. Affordability and physical availability have been thorough examined by previous masters (Asklund, 2020; Martinsen, 2018; Misund and Møller, 2019; Røer, 2020). This thesis reviews the two latter qualities; water should be sufficient and safe.

In rural Tanzania it is common to collect rainwater during the rainy season, as it is free, relatively safe and can be collected near the house. Due to large seasonal and yearly variations in precipitation, using rainwater harvesting as a water source is highly vulnerable. It is predicted that precipitation patterns are going to be more fluctuating due to climate change. Consequently, rainwater harvesting is becoming an increasingly insecure and unstable water source. Tanzania is already experiencing changes in the climate and as global warming occurs adaptation is necessary to reduce the impacts of climate change. Groundwater is a buffer for rainwater instability as it is not as influenced by short term variations in precipitation. WHO and UNESCO (2014) reports that the reliance on groundwater is expanding due to climate change because the reliability is less impacted by changes in the precipitation pattern than surface water sources.

In order for groundwater to be reliable it has to provide sufficient quantity and satisfactory quality. Sufficient quantity can be inflicted by groundwater availability and poor resource management. Satisfactory quality in Tanzanian groundwater is challenged by high fluoride concentration in some areas. Therefore, this thesis reviews groundwater availability, water supply management and fluoride removal to evaluate reliability of groundwater supply in rural Tanzanian settings. The evaluations are done by addressing and understanding challenges. Identifying challenges reveals potential opportunities to improve groundwater reliability. Thus, this thesis seizes to both evaluate and to detect opportunities in order to enhance groundwater reliability in rural Tanzania.

1.3 Research questions

This thesis aims to explore and evaluate opportunities to improve reliability of groundwater supply in villages in Hanang, Mbulu and Mkalama districts in rural Tanzania through the following research questions:

- What are the variations in the groundwater level during the year and how can this information be utilized?
- How is the relationship between the functionality of the Community Owned Water Supply Organisations in the past and the situation of the drinking water supply today?
- Where is the greatest potential for improvement in the water supply sector?
- What is the fluoride adsorption efficiency of various adsorbents in lab-facilities?
- What is the potential of neem and moringa leaves to remove fluoride from groundwater in poor, rural settings?

1.4 Project structure

The thesis opens with a general description of methodology, describing the five methods used to assess the research questions. The main part of this thesis is presented in three separate parts being:

- Groundwater availability
- Water management
- Fluoride removal

The part regarding groundwater availability consists of one chapter, while the parts about water management and fluoride removal consist of two related chapters each, where the latter chapter is based on findings from the first chapter. Each chapter aims to answer one research question, hence there are five research questions with five respective chapters. Each chapter opens with an introduction stating the respective research question and the structure of the chapter. Further the chapters consist of background information based on literature review, results and discussions before they end with a conclusion.

After all chapters have been presented, a general conclusion wraps up the thesis and future work is suggested.

Chapter 2

Methodology

This chapter presents the methods that were used to collect and analyze information to answer the research questions. The methods utilized in the thesis are:

- Literature review
- Survey
- Interview
- Remote monitoring
- Lab experiment

The methods are evaluated in terms of reliability and validity. Reliability is used to describe how consistent a method is. Strong reliability indicates that multiple replicated methods should get the same result. If the results do not correspond, the method is defined as unreliable. Validity describes how accurate the result represents reality and indicates how well the method measures what it claims to measure. The validity can be measured by comparing results to theories of the same concept.

Research can be divided into two main categories: quantitative and qualitative. Quantitative research is systematic empirical investigations that uses numbers and statistics to test or confirm theories and hypotheses. Qualitative research emphasizes subjectivity and involves unstructured data. It aims to gain understanding of concepts, challenges, underlying reasons, and opinions. Quantitative research often fails to identify the root challenges and underlying reasons and should be supported by qualitative research. Combining quantitative and qualitative research strengthens validity (Olsson, 2011).

This thesis is mainly based on quantitative research, as surveys, remote monitoring and lab experiments are primarily viewed as quantitative methods. The conducted survey borders to qualitative research because some questions are open-ended and aim to understand the underlying reasons for the observed tendencies. Qualitative methods, such as interviews, literature review and to some degree the survey, are used to get a deeper understanding of the concepts and to support quantitative research.

2.1 Literature review

Literature review is a systematic way of collecting previous research (Snyder, 2019). It is the literature review that lay the foundation for the research conducted in this thesis. Background information was reviewed to map existing research and detect some of the research gaps. The research questions aim to cover some of these gaps. This study builds on the project thesis by Bakken and Evang (2020) and previous master's theses discussing water supply in rural areas of Tanzania (Asklund, 2020; Martinsen, 2018; Misund and Møller, 2019; Røer, 2020). Relevant information was also found from reports from UN, WHO, the ministry of Tanzania, academic textbooks, and journal articles. The articles were found through searching on Google Scholar, Web of Science and Researchgate, and were mostly evaluated based on number of citations and year of publication. Recently published articles with a high number of citations were prioritized. Many articles were encountered through chain search, which is a non-systematic search of literature which can assist in finding the main arguments within a particular field. A relevant article is used as a starting point for a chain search, and related articles are found in the reference list or because they are citing the article.

In the chapter concerning changes in water supply services, literature review was mainly used to find background information about the water management in Tanzania and findings from earlier master's theses from the study area, particularly studying findings from Misund and Møller (2019). Literature review was used to identify and understand the main challenges within the water sector in the chapter discussing potential for improvement. The master's thesis by Asklund (2020) is used as a basis for research in the chapter regarding changes in groundwater level. For research about fluoride, literature was used to find similar lab experiments. The lab experiment in this study followed similar procedures as in previous studies, with some modifications to simulate rural Tanzanian settings. The results obtained in this thesis were compared to results from literature to detect possible errors, evaluate reliability and to increase validity.

2.2 Survey

The questions in the survey were constructed by the authors of this thesis with the aim to address challenges concerning the water supply services in the Hanang, Mbulu and Mkalama districts in Tanzania. The questions were developed based on hypotheses about potential challenges for water supply services in rural sub-Saharan Africa rooted in literature review. Most of the questions were asked with stated preferences. Stated preference is time efficient but may influence the correspondents. This weakens the liability as the answer is limited to the alternatives presented and may fail to represent the correspondents' reality, one might lose nuances. To compensate for this, at least partly, the possibility of commenting in free text was present if none of the answer alternatives were considered suitable by the correspondent.

Three surveys were constructed: one for the community, one for the COWSO and one for technicians and RUWASA. Five representatives from 4CCP conducted the questionnaires in the field on behalf of NTNU. A draft of the survey was sent to NCA, 4CCP and authors of the previous master's theses from the study area for receiving feedback on the questions before it was finalized. KoBoToolBox was used as a shared online platform to convey the survey to 4CCP. The survey was written in English. Prior to the fieldwork the representatives from 4CCP translated all the questions to Swahili together and had a common interpretation of the questions. 4CCP contacted village leaders through Whatsapp and arranged meetings with the villages. Figure 2.1 shows 4CCP during the fieldwork. The participants are members of the village council, which have been selected by the villagers to represent the village. The village council members represent different social groups and give an authentic representation of the village population. The village leader was interviewed, but if the village leader was not available other representatives from the village council were sent instead. A translator was used if a community member did not speak English or Swahili. 4CCP reported some obstacles related to language and comprehension by some of the participants. If the respondent did not understand the question the interviewer read the question over again but did not try to explain the question. This was done to prevent that the explanation done by the interviewer influenced the answers. In some cases, this led to respondents answering a different question to the one that was asked. Every day after the interviewers had been in the field, they met in the office of 4CCP and discussed the answers. Altogether, 283 respondents from communities, 22 respondents from COWSOs and 3 respondents from RUWASA participated in the surveys. 22 different villages were included in the survey. There were 98 female and 185 male participating in the community survey. KoBoToolBox synchronized responses immediately after they were collected. The relatively low number of females reduces the representability of the study.

The data obtained from the survey were analyzed quantitatively, using the qualitative data to get a broader understanding of the survey and to address challenges the quantitative data failed to identify. The data was analyzed using excel. For written responses, the data were analyzed manually by grouping them. A filter was used to see responses of specific groups and enabling visual presentation in pie charts, making it easier to compare general and group-specific responses.

The survey was used to estimate the people's opinion of COWSOs and to determine the magnitude of challenges in the area in terms of severity of a challenge and number of people it affects. It was further used to evaluate the potential of a novel fluoride method in the study area in rural Tanzania.

Figure 2.1: 4CCP conducting surveys in Haydom area in Tanzania

2.3 Interview

An interview was conducted with Eliminata Awet, Ahadi Mollel and James Mmbando who are part of 4CCP and who were some of those who conducted the survey. The interview mainly served to get a better understanding of challenges in the water sector in the study area.

It also served at getting a description of the method used for conducting the survey and collecting and preparing leaves for the lab experiment. In the interview challenges related to the execution of the survey was identified, observations were discussed, and possible errors and misunderstandings were detected. Some of the questions from the survey were discussed in detail to get a common comprehension of the answers. They shared their thoughts on which challenges the survey address well and what the survey failed to identify. There has been close contact with 4CCP via email and WhatsApp throughout the entire period of working with the master's thesis.

2.4 Remote monitoring system

To assess water, use and groundwater level changes remote monitoring sensors were implemented at the pumping stations in Mewadani, Basonyagwe and Endagaw Chini in January 2020. The sensors were developed by a Norwegian company called El-Watch.

Asklund (2020) performed extensive research on remote monitoring in the study area in her master's thesis that was delivered in June 2020. It is valuable to continue her studies as there are seasonal variations in the weather, hence this study aims to continue her work.

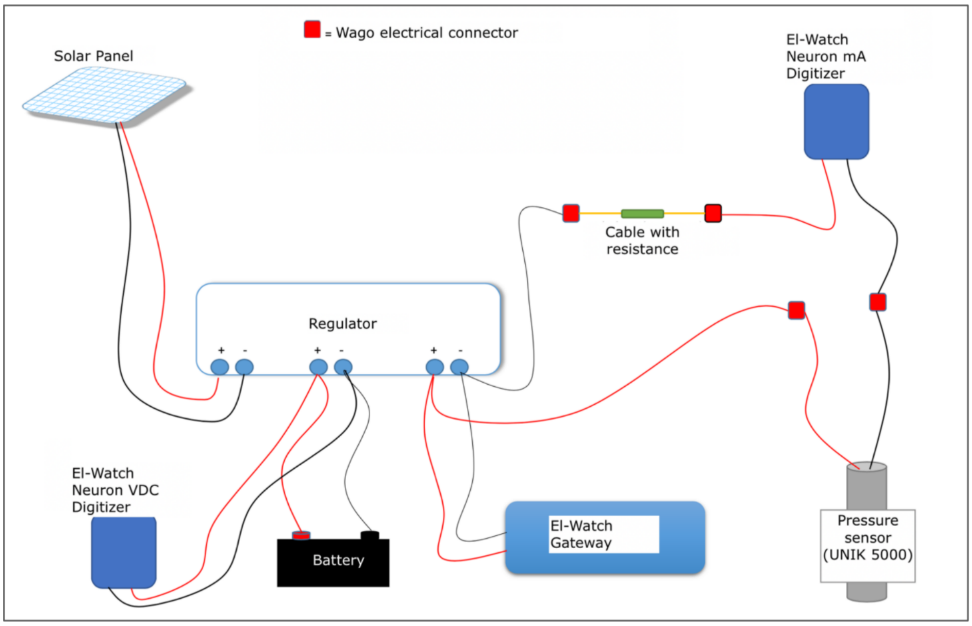

Figure 2.2: Remote monitoring system configuration

As seen in figure 2.2 the system provided by El-Watch consists of different units that are connected through a regulator. Most of the components are connected in parallel to the regulator. The different sensors register data which are sent to the gateway which uses the mobile network to send the data for "cloud storage". Then the data can be downloaded from a password protected website named *neuronsensors.app*. The data are registered and sent approximately every tenth minute. The regulator makes sure the battery is not overcharged by the solar panel in daytime and that power is not transmitted from the battery to the solar panel in night-time.

The UNIK 5000 sensors were installed on the 31st of January 2020 in both Basonyagwe and Mewadani. The pressure sensor UNIK 5000 was installed inside the borehole, submerged in water. It registers the pressure in the well in milliampere and the value is converted to meters to know the groundwater level. The solar panel provides electricity to the system which is stored in a battery. The Neuron mA Digitizer converts the analogue data from milliampere to a digital signal that the gateway can receive. The Neuron VDC Digitizer measures the voltage of the circuit.

Another pressure sensor measures the pressure in the water tanks, hence the water level in the tanks can be deduced. This is not included in the sketch, as it is wireless and has its own battery that is going to last 15 years sending data to the gateway. The components are placed in a wooden box for protection, as wood does not disturb the signals to the gateway. Asklund (ibid.) found that it is difficult to make use of the data from these sensors, hence these data are not used in this thesis.

The pumps in Mewadani and Basonyagwe are submersible multistage centrifugal pump provided by Davis and Shirtliff, DSP 3-16 and DSP 5-16 respectively. Dayliff recommends that the pump is submerged at least 3 meters below the dynamic water level and that there is at least 3 m to the bottom of the borehole to prevent silting damage (Davis and Shirtliff, 2014). It can be seen in table 3.1 that both the pump intakes are more than 3 m from the borehole bottom. In the boreholes there are sensors that stop the pump if the water level falls below the pump intake to prevent it from running dry.

The pumping stations have 10 Dayliff PV panels from Davis and Shirtliff that delivers a peak power of 0.195 kW each. The maximum solar input power of the Sunverter is the limiting factor deciding the number of solar panels. The Dayliff Sunverters from Davis and Shirtliff in the study area are of the types SV2/1.5M or SV2/2.2M, which have a maximum input power of 2.2 and 3.3 kW, respectively (Sunverter, n.d.).

2.5 Fluoride adsorption experiments

In this thesis the lab experiments were used to determine adsorption efficiency in terms of adsorbent dosage and time, while experiences with performing the lab experiments were used to evaluate the potential of neem and moringa leaves as potential fluoride adsorbents in rural Tanzanian settings.

Adsorbent experiments with commercially available adsorbents, Granular Activated Carbon (GAC), Powdered Activated Carbon (PAC) and Activated Alumina (AA), were conducted prior to the experiments with neem and moringa leaves in order to get to know the methods, get a deeper understanding about adsorption and to compare results.

2.5.1 Practical approach

Fluoride adsorption experiments with variable adsorbents have been conducted using batch operation process. The various adsorbents tested in this study are GAC, PAC, AA, neem leaf powder and moringa leaf powder. All adsorbents were stored in room temeprature in glass reagent bottles. NaF stock solution dissolved with deionized water compose the synthetic water used in the experiments. NaF stock solution were made by dissolving 2.21 g NaF with 1.0 L deionized water, which results in fluoride concentration of 1000mg/L.

The adsorption capacity is encountered by vary adsorbent dosage for a 200 mL solution with a fixed fluoride concentration of 10 mg/L. In addition, for comparison one blank sample is conducted for all experiments with no adsorbent added. Fluoride concentration of 10 mg/L is obtained by adding 200 mL NaF 1 M using a pipette. pH is not adjusted and initial pH of deionized water is about 6-7. All experiments were conducted in room temperature (23.5 ± 1.2^oC). The aqueous solution NaF is mixed in a volumetric flask by dissolving 2 mL of NaF with 198 mL of deionized water. To distribute the fluoride, the volumetric flask is turned upside down ten times before pouring the aqueous solution into a reagent bottle containing the solid adsorbent. All the reagent bottle containing deionized water, NaF and adsorbent is mixed on a mechanical shaker at speed

250 rounds per minute. Agitation time vary depending on the experiment. After sufficient time has past, the reagent bottle is put to rest and pH is measured by a pH meter. While measuring pH, the electrode is slowly stirred in the aqueous solution to ensure homogeneous distribution. The samples are collected with a 20 mL syringe with a 0.2 µm filter and stored in 15 mL test tube. The samples are stored in the fridge until the residual fluoride concentration is detected by an ion chromatography machine .

Reused equipment, such as reagent bottles, volumetric flasks and beakers were washed twice with distilled water and once with deionized water before and after use.

Granular activated carbon

Granular Activated Carbon (GAC) used for this experiment is CarboTech Pool W 1-3 reactivated carbon. The GAC has a particle size distribution between 0.5 mm to 3.55 mm and iodine number of minimum 750 mg/g. The experiment conducted with GAC followed the procedure of Araga et al. (2017).

To encounter the effect of adsorbent dosage, seven experiments were done with GAC dosages ranging from 0.2 g to 1.8 g. The dosages were weighted in squared weight boats and transferred to the aqueous solution in reagents bottles. Fluoride concentration of the aqueous solution were 10 mg/L for all 7 experiments with a total aqueous solution of 200 mL. Previous studies observed that equilibrium were reached within 2 hours (Araga et al., 2017; Ravančić and Habuda-Stanić, 2015; Sheth and Gajjar, 2013), and therefore agitation time on the mechanical shaker was set to 2 hours.

For GAC the ion chromatography detected that almost no fluoride had been removed. Moreover, pH increased from 6 ± 0.5 to 10.8 ± 0.4. To figure out if the low fluoride adsorption capacity and the high increase in pH values were due to pollution, one experiment with washed GAC and one with unwashed GAC was conducted to compare results. In order to wash GAC, the solid GAC was mixed with deionized water in a 250 mL reagent bottle and put on stirrer for 2 hours before it GAC was filtered out with a 45 µm syringe filter . As washed GAC did not improve fluoride adsorption, nor reduced increase in pH, no further experiments were done with washed GAC.

To examine the effect of pH on fluoride adsorption efficiency by GAC, HCl were added to the solution in order to reduce pH levels. Nine experiments were conducted with constant GAC dosage (1.4 g), initial fluoride concentration (10 mg/L), total stock volume (200 mg) and time above 16 hours to ensure equilibrium were reached. Dosage of HCl varied from 0.0 mL to 5.0 mL 0.1 M HCl, which resulted in initial pH levels ranging from 2.8 to 5.9. As no improvement in adsorbed fluoride by GAC was observed with reduced initial pH no further experiments were done with GAC as an adsorbent.

Powdered activated carbon

Powdered Activated Carbon (PAC) used in this study is commercially available as Charcoal activated powder extra pure and has a surface area of 800-1500 m^2/g. As studies have revealed that PAC is a slightly more efficient agent for fluoride removal than GAC (see section 6.2.4), experiments with PAC as fluoride adsorbent were investigated.

Nine experiments were conducted with untreated PAC with fluoride concentration of 10 mg/L, total stock solution volume of 200 mg/L, agitation time of 2 hours and with variable adsorbent dosage ranging from 0.0 g to 1.8 g PAC. While measuring dosage of PAC on the weight, a large amount of PAC seemed to be lost on the weighing boat because of the small particle size of PAC. Thus, instead of measuring the weight of PAC on measuring boat and then pouring the solid PAC into the glass reagent bottle, the dosage of PAC were measured directly in the glass reagent bottle to avoid high losses of PAC and also to avoid unnecessary errors.

Activated alumina

Activated Alumina (AA) studied is commercially available as aluminum oxide- activated, basic, Brockmann I.

Six experiments with untreated AA as fluoride adsorbent were performed with various adsorbent dosages. All six experiments were composed of a total stock solution volume of 200 ml, fluoride concentration of 10 mg/L, agitation time of 2 hours and AA dosage ranging from 0.0 g to 3.6 g. High chlorine content was detected in the samples with untreated AA as an adsorbent. One sample with the same criteria and dosage of 2 g of washed AA was produced in order to see if washing of AA could reduce chlorine levels. The AA was washed with deionized water following the same procedure as the GAC, see 2.5.1. Both chlorine and fluoride levels decreased to some degree, but insignificantly taken errors into consideration.

Studies have shown that AA adsorption capacity is optimal at pH ranges between 4 and 6 **??**. To examine the effect of pH, two series distinguished by pH were performed. One series aimed for a pH of 4 and the other series aimed for pH 6. Both series consisted of five individual samples with a stock volume of 200 mL, initial fluoride concentration of 10 mg/L and adsorbent dosage ranging from 0.4 g to 3.6 g. Over a time interval of 5 hrs and 10 minutes on the mechanical shaker, the pH was manually adjusted to pH 4.0 $\pm$ 0.0 and pH 6.0 $\pm$ 0.1 every half hour by adding droplets of 0.1 M H_2SO_4 using a glass dropper. Ideally this would go on until pH stabilized at pH 4 and pH 6. After about 5 hrs no stabilization was observed, and the tests continued to shake at the mechanical shaker over night. Despite that pH stabilization never was obtained, after 21 hours on the mechanical shaker and eight pH readjustments the samples were collected as described in section2.5.1.

Acid-treated activated alumina

Acid treatment was performed according to Duan et al. (2014). The relation solid: 0.02 M : H_2SO_4 was set to 1:3 described by Duan et al. (ibid.). Simplified, 1 g 0.02 M H_2SO_4 equals 1 mL of 0.02 M H_2SO_4, and thus, 60 mL of 0.02 M H_2SO_4 was used to acid treat 20 g AA. Using mass balance, this equals 12 mL 0.1 H_2SO_4.

The solids and aqueous solution were merged in a 250 mL reagent bottle and placed on a mechanical shaker for two hours. As the solution was still basic, droplets of 1 M H_2SO_4 was added every 30 minutes and pH was measured to see if the solution was acidic. This was repeated for 6.5 hours because pH was unstable and slightly basic despite additional acid was supplemented regularly. The solution was left on the mechanical shaker over night, and readjusted the morning thereafter. After a total of more than 24 hours on the shaker with continuously readjusted pH with droplets of H_2SO_4 14 times, the solution turned slightly acidic. The total amount of acid in the final solution was 3.6 mL 1 M H_2SO_4 . The treated AA was washed with deionized water with a vacuum 45 µm filter. It was wash until the pH stabilized, which for this portion was seven times. When finished washing, the AA was transferred into a beaker by a washed plastic spoon. The beaker containing the acid treated-AA was put in a oven at 105 °C for two hours. Then it was set to rest for 15 minutes in a desiccator so moisture from the atmosphere did not interfere with the acid treated AA. Once cooled, the AA was weighted and put in the oven at 105 °C for 30 minutes and cooled down in the desiccator and weighted once again. If the weight does not changed the AA is considered dry .

With this batch of acid-treated AA the effect of dosage was examined with five samples with AA dosages ranging from 0.4 g to 3.6 g. The experiment followed the general procedure (see section 2.5.1) with agitation time 18 hours to ensure that equilibrium was reached.

To conduct more experiments a new batch of AA was acid treated, this time with solid: H_2SO_4 relationship originating from previous attempt described in section 2.5.1. 50 g AA was merged with 10 mL 1 M H_2SO_4 (see equation 2.1) for two hours at the mechanical shaker. The washing and drying were done the with the same procedure as previously described in section 2.5.1, except it dried in the oven for more than 4 hours.

$$\text{Volume of 0.1 M}H_2SO_4 = \frac{3.6mL}{20g} \cdot 50g \tag{2.1}$$

$$= 9mL \longrightarrow 10mL \tag{2.2}$$

With this new batch ten samples were conducted according to method described in section 2.5.1, with adsorbent dosages ranging from 0.1g to 3.6g and agitation time four hours. This was done to improve the isotherm curve.

Seven experiments were conducted with 2 g (10 g/L) H_2SO_4-treated AA each, 10 mg/L fluoride and various agitation time on mechanical shaker. From each experiment two samples were collected at different times, so all together 14 samples were collected with time intervals ranging from 5 minutes to 48 hours. This means from each reagent bottle two samples were collected at different agitation time. When the first sample was taken, the reagent bottle was placed back on the mechanical shaker and a new sample was collected after some time from the same solution. This reduce the solution amount for the second sample, and may influence the result. However, the change in volume was very small, thus the influence was insignificant.

Neem and moringa leaves

The leaves are collected in Haydom town near the Roman Catholic Church by 4CCP. The area has been used to grain maize, but is recognized as a clean area free for heavy pollution. It is close to a parking lot connected to the church, but no other traffic. After collected the leaves were dried in the sunlight, packed and sent from Arusha, Tanzania to Trondheim, Norway. Once arrived, the stem was removed and the leaves were manually crushed into powder using a cotton jute bag and a kitchen tool. To remove large substances, the leaf powder were filtered in a 710 µm filter.

The powder were washed with distilled water in 250 mL reagent bottles on a mechanical shaker for 2 hours. The water hold a strong colour and odour. In an attempt to dry the powder by vacuum filtration, the filter clogs rapidly. Filters of different sizes are tested, with little to no luck. The powder was eventually cleaned by many rounds of sedimentation. For this distilled water was used. Once the water with the powder was clean, the powder dried for more than 12 hours in the oven at $70^{o}C$.

Nine experiments were conducted as described in section 2.5.1 with washed neem leaf powder and nine with washed moringa leaf powder. Adsorbent dosage ranged from 0.0 g to 3.6 g leaf powder. Agitation time was two hours.

Alkali-treated leaves

Alkali treatment of the leaves was performed according to Dan and Chattree (2018) (moringa) and Jamode et al. (2004)(neem) which describes the same procedure for moringa and neem leaves. Alkali treatment were chosen because results presented by Dan and Chattree (2018) showed that alkali treated leaves exhibited better fluoride adsorption at pH 6-8 than acid treated leaves. Jamode et al. (2004) gently heated 40 g leaf powder and 400 mL 0.5 M NaOH for 20 minutes after boiling started. To simplify the process and make it more realistic to apply in rural settings, the same powder:NaOH relation was used, but the mixture were shaken on the mechanical shaker for two hours instead of boiling it. While alkali treating the leaves, PPCO reagent bottles were used since OH reacts with silicate which are in glass reagent bottles. After this treatment the mixture had a dark colour and a strong unpleasant odour. Still clogging the filter,the treated powder were washed by using sedimentation and coffee filters which was a slow process.

Eight experiments were conducted for both alkali treated- moringa and neem. The procedure was the same as described in section 2.5.1, with dosages ranging from 0.1g to 3.6 g. After treatment both leaves still coloured the water significantly and left an noticeably odour on the water.

2.5.2 Calculations

Overview of parameters used in the calculation with respective definitions is presented in table 2.1.

Adsorbent efficiency

$$\text{Adsorbent efficiency(\%)} = \frac{C_0 - C_e}{C_0} \cdot 100\% \tag{2.3}$$

Adsorption isotherms

The adsorption isotherms are derived from the adsorption capacity at equilibrium is calculated presented in equation 2.4. Further in elaboration on calculations are described

Table 2.1: Overview of the parameters used in calculations

Parameter	Definition	Unit
Isotherm calculations		
C_0	Initial concentration of adsorbate at time=0	mg/L
C_e	Equilibrium concentration of adsorbate	mg/L
q_e	Adsorption capacity, adsorbate adsorbed per unit weight of adsorbent at equilibrium	mg/g
V	Total volume of solution	L
M	Mass of adsorbent	g
Q_m	Maximum concentration of adsorbate adsorbed to adsorbent when surface sites are saturated with adsorbate	mg/g
b_e	Langmuir adsorption constant	mg/L
K_e	Freundlich adsorption capacity parameter	(mg/g)(L/mg)$^{1/n}$
n	Freundlich adsorption intensity parameter	-
Rate law		
Rate	Change in reactant concentration in respect of time	
k	Rate constant	L·mol^{-1} h^{-1} (2nd order)
$[A]$	Concentration of reactant A in aqueous solution	M
n	Reaction order	-
t	time	hrs

by Crittenden et al. (2012).

$$q_e = \frac{V}{M}(C_0 - C_e) \tag{2.4}$$

Langmuir adsorption isotherm

Langmuir formula is given in equation 2.5.

$$q_e = \frac{Q_m \cdot b_e \cdot C_e}{1 + b_e \cdot C_e} \tag{2.5}$$

For plotting purposes it is convenient to rearrange equation (2.5) to linear form shown in equation 2.6.

$$\frac{C_e}{q_e} = \frac{1}{b_e \cdot Q_m} + \frac{C_e}{Q_m} \tag{2.6}$$

Freundlich adsorption isotherm

Freundlich isotherm is presented as equation 2.7.

$$q_e = K_e \cdot {C_e}^{1/n} \tag{2.7}$$

Equation 2.8 is the linear form of equation (2.7).

$$\log(q_e) = \log(K_e) + \frac{1}{n}\log(C_e) \tag{2.8}$$

Rate law

Rate law is a an equation the relationship between concentration of the reactant and the the reaction rate (Flowers et al., 2019). Rate for one reaction is presented in equation 2.9 .

$$Rate = k[A]^n \tag{2.9}$$

Rate constant, k, depends on temperature and is particular for the specific reaction. Reaction order, n, must be determined experimentally. This study evaluate three reaction orders which are presented in table 2.2.
The representative order is determined by how well linear regression of plotted data fit the linearized form of zero, first and second reaction order by using the coefficient of determination, R^2. The curve fit for zero, first and second order are presented in appendix.

Table 2.2: Kinetic models of different reaction orders

Reaction order	n	Rate	Linear form
Zero order	0	k	$[A] = -kt + A_o$
First order	1	$k[A]$	$ln([A]) = -kt + ln([A]_0)$
Second order	2	$k[A]^2$	$1/[A] = kt + 1/[A]_0$

2.5.3 Sources of error

Experimental errors

The results presented are disturbed with instrumental and human made errors. Instrumental marginal errors can be calculated and detected, while determining accurate human errors are more of an challenge. An estimation of instrumental errors is presented below.

- All experiments were conducted in room temperatures. The temperature varied slightly from 23 ^oC to 25 ^oC. Studies indicate that fluoride adsorption is not significantly affected by marginal changes in temperature (Araga et al., 2017). This suggest that the marginal difference in temperature while conducting the experiments did not affect the residual fluoride concentration.

- Micro balances weight (VWR), which is used to measure adsorbent dosage has an accuracy of 0.001 g. This cause a marginal error of adsorbent dosage.

- 940 Professional IC vario which is used in this study to detect fluoride has a margin of error of 0.1 mg/L if not diluted. If it is diluted once (due to high concentrations) margin of error is 0.2 mg/L, when diluted twice margin of error is 0.3 and so on. This will affect the final reading of residual fluoride concentration. The IC setup in this study measures most accurately in the range from 1.0 to 10.0 mg/L. For fluoride concentrations below 0.3 mg/L the error bar can be large.

- Volumetric flasks which are used to measure stock solution of 200 mL have an accuracy of 0.15 mL. This effects total volume of solution and initial concentration of fluoride. Initial fluoride concentration heritage this margin of error, and consequently initial fluoride concentration in this experiment is 10 ± 0.75 mg/L.

With accuracy from IC and volumetric flasks taken into account the instumental margin of error cause an instrumental error of residual fluoride to be $\pm$ 0.85 mg/L.

However, presented in table B.1 the initial fluoride concentration is 9.848 ± 0.127 mg/L which has an error larger than $\pm$ 0.85 mg/L. Also, observed in graph 6.2 some adsorbents, especially moringa leaf powder and PAC, have an fluctuating behaviour indicating disturbances due to errors. This suggest that both instrumental and human made errors together contribute to inaccuracy.

Human errors

Human made errors affects the experiments in various degrees, where as some results may be almost without any human made errors, others may be greatly impacted with errors. Without doing the experiments multiple times to compare it is difficult to detect the impact of human errors. For this thesis experiments were only conducted once due to limited time, except H_2SO_4-treated AA with various adsorbent dosages which were conducted twice. Because they are only done once, it is difficult to determine the accuracy of the results. H_2SO_4-treated AA with various adsorbent dosages gave very similar results for both times the experiment was conducted. To future works should perform several trials for each experiment and average the results in order to strengthen reliability of results.

Some human made errors and their impact on the results are mentioned below.

- When measuring the adsorbent dosage, the powder is so light-weighted and due to electrostatic forces some falls outside on the weight. This causes an inaccuracy in adsorbent dosage. Some adsorbent were also lost measuring in squared plastic boats. To minimize effects of this, the lighter adsorbents were measured directly into the reagent bottles.

- Adsorbent may stick to the sides and cap of the reagent bottles. This was apparent for the leaves, because a large part of the leaves floated to the water surfaces. This causes loss of adsorbent dosage and the adsorbent dosage in the aqueous solution may not be accurately reported.

- Reagent bottles and volumetric flasks were reused. In between usages they were washed twice with distilled water and once with deionized water. However, fluoride may stick to the bottles from previous experiments and impact the fluoride concentration. To ensure this was not the case, blank tests were conducted which measure no fluoride content. Thus, this cause no noticeable error.
- Samples were often stored in the refrigerator over night. How this might have an impact on the results is unknown.
- When measuring fluoride adsorption with AA at pH 4 and pH 6 presented in graph 6.8, pH fluctuated. pH was readjusted every 30 minutes to desired pH but increased quickly after adjustment, causing pH to continuously fluctuate between desired pH and high pH levels. It was not possible to obtain a stable pH manually as pH did not stabilize with time. To avoid fluctuating pH Ku and Chiou (2002) used an automatic pH controller. The results presented in graph 6.8 on page 69 are strongly impacted by errors. Regardless, clear tendencies are observed and the graph gives a general illustration of the effect of decreasing pH.

Part I

Pump Scheme

Chapter 3

Remote monitoring and groundwater level variations

3.1 Introduction

To optimally exploit groundwater resources, it is useful to have a comprehensive understanding of the behaviour of the groundwater system. Sensors can register the groundwater level, which can be used to know if groundwater extraction is performed at a sustainable rate. Remote monitoring sensors were first introduced in the study area in 2018 but unfortunately the sensors were inoperative. New sensors were installed at the pumping stations in Basonyagwe and Mewadani in January 2020. Asklund (2020) wrote her master's thesis on the topic of remote monitoring in the study area and her results indicate that from January to June 2020 there was enough water in the well for larger extractions of water, without reducing the groundwater level. As the weather in Tanzania varies during the year it is interesting to see if this is true in the dry period as well. The research question is:

What are the variations in the groundwater level during the year and how can this information be utilized?

Firstly, factors influencing the groundwater level will be discussed. The result section includes graphs showing the groundwater level over the course of the last year and compare it with the precipitation. Subsequently, the results, the method of collecting data and sources of error will be discussed before a concluding part will wrap up the findings from this chapter.

3.2 Background

The master's thesis written by Asklund (2020) describes thoroughly how the remote monitoring system works, advantages and disadvantages with remote monitoring in rural areas, and presents data from the remote monitoring system from when it was installed in January 2020 until June 2020. A more general discussion of remote monitoring in rural areas can also be found in the project thesis leading up to this master's thesis: Bakken and Evang (2020). The remote monitoring configuration can be seen in figure 2.2 on page 8. As Asklund (2020) did extensive research on the functionality of remote monitoring in the study area, this thesis mainly focus on the groundwater level variations. It is nevertheless important to discuss the collection process of the data and if remote monitoring of the groundwater level is useful in the study area.

3.2.1 Groundwater level

Large quantities of water can be stored in the ground, making it a natural buffer for seasonal and yearly variability (Cobbing, 2020). The groundwater level is influenced by both natural and anthropogenic activities, mainly by precipitation and human extraction (Taylor and Alley, 2002). The groundwater level typically varies over the course of a year due to variations in precipitation and evaporation (Earle, 2019). It is common that natural and anthropogenic activities causing a decline in groundwater level coincides, because when there is little precipitation more groundwater is extracted as there are fewer opportunities to collect water elsewhere. Even though the water extraction from the groundwater increases in the dry season, it is common that the total water use decreases by lowering the quantities used for hygiene (Howard et al., 2020). Other natural reasons for decline in groundwater level is urban development, deforestation, and draining of wetlands, as they cause an increase in surface runoff and thus reduce groundwater recharge (Taylor and Alley, 2002).

Recharge of groundwater occurs where the ground is sufficiently permeable and is influenced by various factors, including climate, hydrology, geology and geomorphology (Rwebugisa, 2008). Often recharge areas contain coarsely grained sands which causes a high infiltration rate, and in fractured rocks the flow is mainly in few main flow paths (Le Borgne et al., 2007). The groundwater level usually varies more in upland recharge areas, while the groundwater level near the bottom of valleys usually shows less change (Earle, 2019). A higher permeability in the ground causes greater movement of groundwater and there is typically a larger difference between wet and dry season. There can also be fluctuations in groundwater level due to changes in atmospheric pressure and deformation of the aquifer, e.g., by earthquakes or earth tides but these changes are relatively small (ibid.).

The rate groundwater flows horizontally through an aquifer is called transmissivity. In large parts of sub-Saharan Africa (SSA), the transmissivity is low, making the borehole yield low and consequently the potential to extract water is also low (MacDonald, Bonsor, et al., 2012). Due to this MacDonald, Bonsor, et al. (ibid.) argue that groundwater in SSA is more feasible for small scale application, but Cobbing (2020) suggests that the potential is greater than first predicted because many boreholes have been installed with basic technology. She claims that with installation improvements the borehole yield can improve, e.g. by using solar-powered pumps instead of hand pumps.

In Tanzania it is common that recharge happens due to direct rainwater infiltration, preferential flows and through fractures (Kashaigili, 2010). In Singida and Manyara the ground that holds water mainly consists of weathered and fractured granites and gneisses, which has low permeability (ibid.). Mussa et al. (2020) found that recharge areas for the Singida semi-arid fractured aquifer are areas with high lineament density, cultivated areas, grassland and flat to gentle slopes.

Groundwater is less vulnerable to contamination than surface water as it is naturally treated through biological, mechanical and chemical processes in the ground (Earle, 2019). However, due to its slow movement the groundwater can be naturally contaminated by the aquifer media. The mineral content of the groundwater is influenced by the geochemical reactions occurring in the aquifer, which are affected by the residence time, type of rock, present minerals and the interaction between the rock and the water (MacDonald and Davies, 2000; Nwankwo et al., 2020). An example of this is found in some places in Eastern Africa where the ground contains high levels of fluoride, causing the fluoride level in the groundwater to increase (Mpenyana-Monyatsi et al., 2012; Mukanga et al., 2016). The groundwater can also be contaminated by anthropogenic sources, such as land use, fertilizer, sewage leakages and industry. It can take a long time to detect human contamination leaking into the groundwater, causing it to affect people's health and making it difficult to eliminate the pollution. The quality of the groundwater can vary greatly over short distances, making it hard to design a treatment plan (Edmunds and Shand, 2009).

Extraction of groundwater through pumping can affect both the quality and quantity of water. Groundwater quality can be influenced by pumping by inducing water table oscillations causing oxidation of minerals, mobilisation of heavy metals and changes in alkalinity (ibid.). To avoid overextraction causing a decline in the groundwater level the optimum borehole yield should be assessed (MacDonald, Davies, et al., 2005). During pumping a cone of depression is created around the well causing a depression in the groundwater table or the potentiometric surface, and it is important that this does not cause the water level in the borehole to fall below the pump intake. The quantity of groundwater can be affected by unsustainable pumping rates.

Groundwater has a static and a dynamic water level, where static water level is the water level when no pumping is occurring, and dynamic water level is when pumping happens. This can be seen as static water level and pumping water level in figure 3.1, respectively. But the static water level is not static, as it varies due to variations in precipitation, evaporation and subsurface in- and outflow. The water balance should therefore be evaluated over the course of a year, since the groundwater level is influenced by the climate which has a recurring annual cycle.

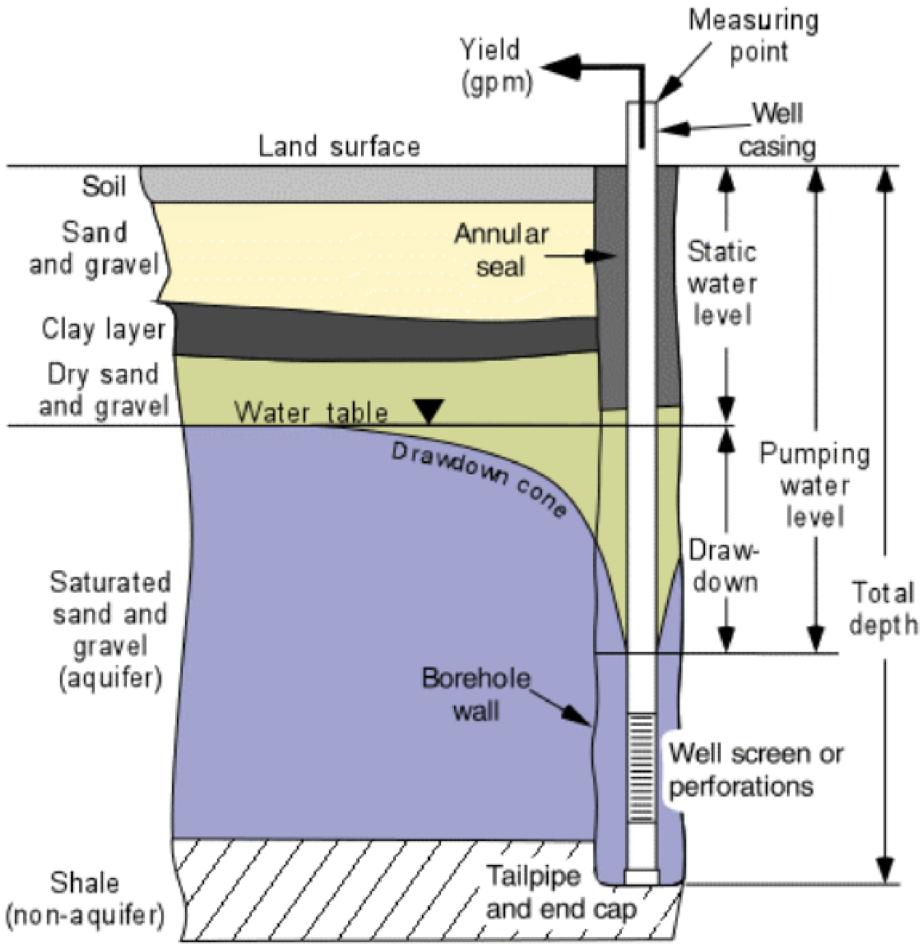

Figure 3.1: Illustration of how groundwater level surrounding a well is influenced by pumping (GWIC, 2021)

3.3 Results

The UNIK 5000 sensors measure the hydrostatic head and the values can be converted to know the depth of the water level within the well. An analogue signal in milliampere is proportional to the hydrostatic pressure of the water above the sensor and is converted to a digital signal by the Neuron mA Digitizer. The sensor produces a signal between 4-20 mA, which is equivalent to a measuring range of 0-100 m, meaning that a signal of 4 mA is equal to 0 m and a signal of 20 mA is equal to 100 m.

In Mewadani the UNIK 5000 sensor was installed 69 m below the borehole top and in Basonyagwe 70 m below the borehole top. To obtain the water level below the ground, the value of the hydrostatic head in meters of water column above the sensor shown in the user interface at neuronsensors.app must be subtracted from the depth where the sensor was installed. A higher hydrostatic head means more water is above the sensor, hence the groundwater level is higher. The time shown in the graphs at neuronsensors.app is the time in Norway, hence the time have to be adjusted for time difference between Tanzania and Norway, which varies between one and two hours during the year.

The El-Watch system converts the signal to hydrostatic head by using linear interpolation, showed in the equations below. In the user interface at neuronsensors.app the hydrostatic head is reported in meters.

$$H = \frac{H_{max} - H_{min}}{I_{max} - I_{min}} * (I - I_{min}) + H_{min} \tag{3.1}$$

where H = hydrostatic head (m)
H_{min} = 0 m
H_{max} = 100 m
I_{min} = 4 mA
I_{max} = 20 mA

Written with the relevant figures

$$H = \frac{100 - 0}{20 - 4} * (I - 4) + 0 = \frac{100}{16} * (I - 4) \tag{3.2}$$

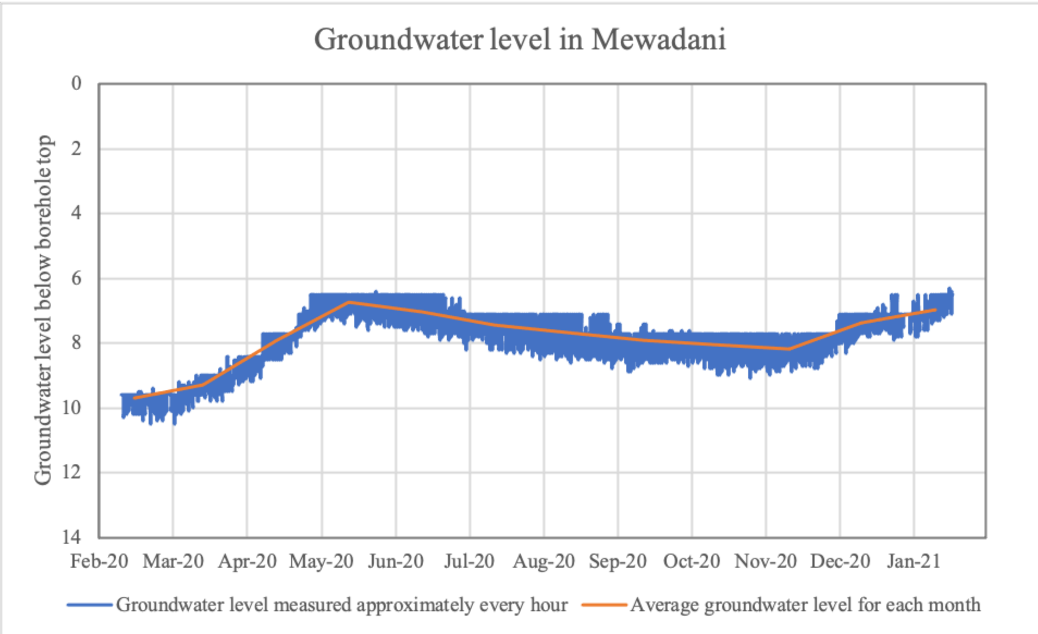

Figure 3.2: Groundwater level in Mewadani between February 2020 and January 2021 measured by UNIK 5000

As seen in figure 3.2 the water level in Mewadani rose from 10 m below the borehole top in February 2020 to 7 m in May, before it steadily declined to 8 m with a slight rise in December. Figure 3.3 shows that the groundwater level in Basonyagwe was approximately 20 m below the borehole top in February 2020 and rose to around 4 m at the

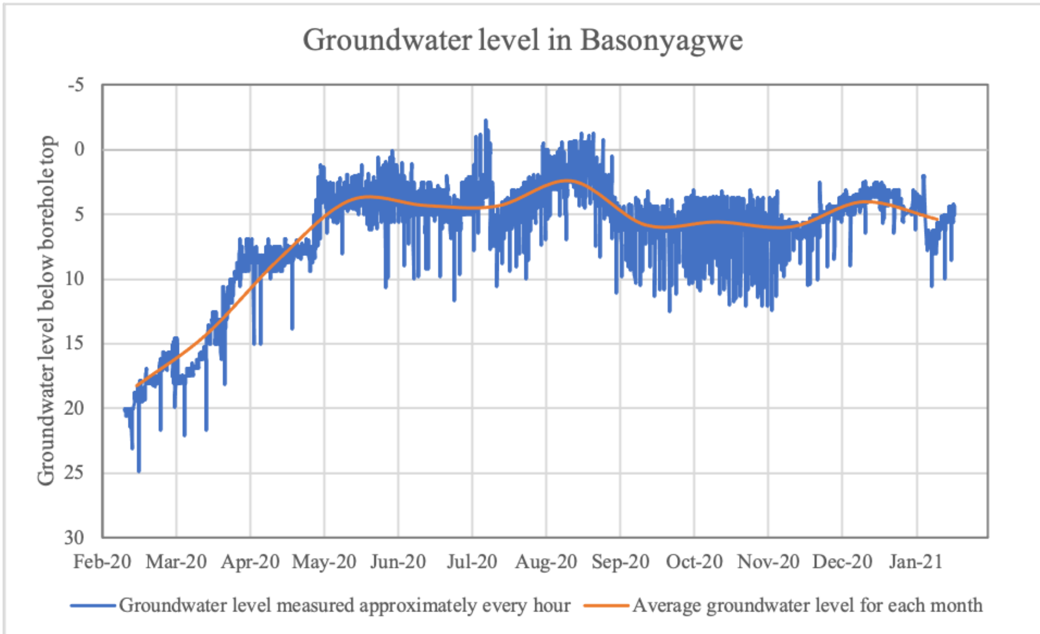

Figure 3.3: Groundwater level in Basonyagwe between February 2020 and January 2021 measured by UNIK 5000

beginning of May. Between May and July, the water level was relatively stable before it rose slightly before a decline to around 6 m until January 2021. From the graph it can be seen that at some points during July and August the groundwater level was above 0 m, which is unrealistic. This indicates that there is a discrepancy between the measured values and the real groundwater level.

The groundwater level should be seen in relation to precipitation data of the area. Borhara et al. (2020) combined a semi-review paper with their own analysis and found that observations and climate models of Tanzania do not coincide. There are few in-situ precipitation measurements in Tanzania (Luhunga et al., 2019), so they based their analysis on gridded data from Global Precipitation Climatology Centre (GPCC). Precipitation patterns in Tanzania vary greatly both in space and time but can be divided into two main zones: central-south-west and north-east. In the southern and western to central Tanzania there is one rainy season from November to May, while in the northern and eastern parts there is one rainy season from March to May described as the long rains and one rainy season from September to November named the short rains (Hamisi, 2013). Borhara et al. (2020) found that there has been a general decreasing precipitation trend in Tanzania since 1960 in the long rainy season and an increasing precipitation trend in the north-western Tanzania during the short rainy season. This trend has recently started to change, and their projections estimate that there will be an increase in precipitation in the future.

Figure 3.4 shows that the precipitation at Haydom during the last year has been higher than the average over the last 30 years. The location of Haydom was chosen as it lays in the middle of the study area. Until May the rainfall was considerably higher

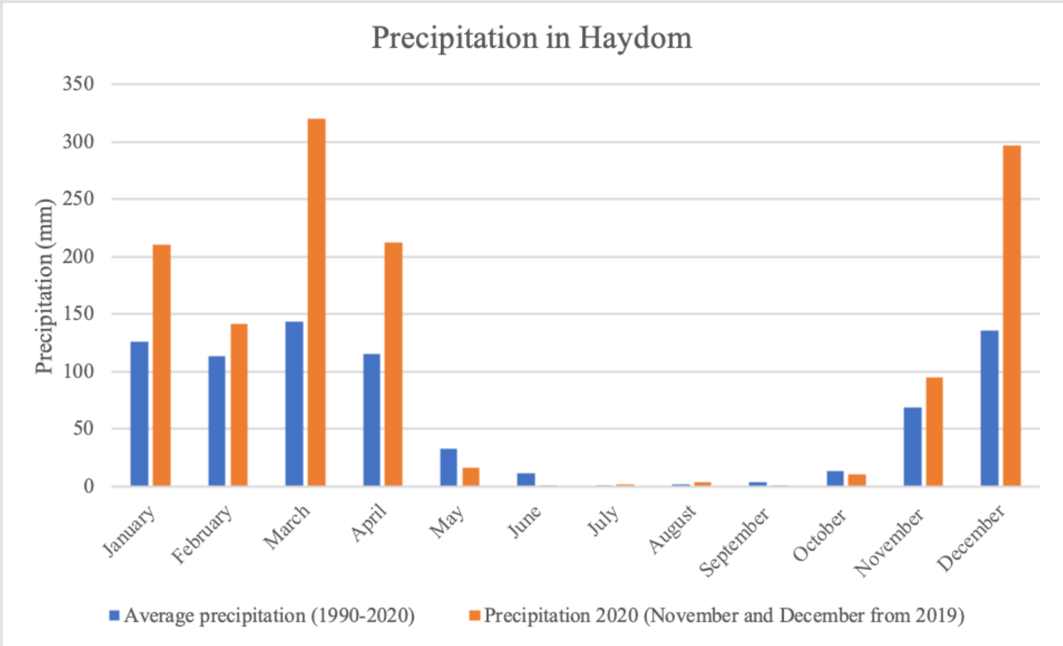

Figure 3.4: Precipitation in Haydom from the Climate Research Unit version CRU TS3.21 up to 2012 and the GPCC First Guess precipitation dataset from 2013 at coordinates (-4.20,35.00) (Camarillo-Naranjo et al., 2018)

than average, but when the long rains ended in May and until October the precipitation was lower. The precipitation showed for November and December in figure 3.4 is from 2019 as the data for 2020 is not yet available at www.globalclimatemonitor.org for the last two months of the year. The rainfall can explain why the water levels rose from January to April but remained relatively stable from May and onward. It is typically a delay between precipitation and rise in groundwater levels, where the time of delay is affected by physical properties of the aquifer.

3.4 Discussion

In this section the results will be discussed. Firstly, evaluation of the groundwater extraction potential and reasons for the groundwater level variations will be looked into. Next functionality of remote monitoring in the study area will be reviewed. To have a sense of how reliable the results are some assumptions and sources of error will be assessed, as well as the representativeness of the results.

3.4.1 Evaluation of the groundwater extraction potential

Groundwater is the safest drinking water source in the study area; thus the water availability is influenced by the amount of water present in the ground. Asklund (2020) found that from February to June 2020 the extraction rate was sustainable because the pump-

Village	Total Depth (m)	Pump Intake (m)	Drawdown (m)	# of Beneficiaries
Basonyagwe	112	100	36.09	3472
Mewadani	105	90	29.3	1830

Table 3.1: Technical details of the Boreholes at Basonyagwe and Mewadani Installed with solar power for WASH TCP

ing rate is lower than the recharge rate and the dynamic water level is higher than the pump intake by a reasonable margin. The static water level has natural seasonal variations and it was hypothesised that the groundwater levels would decline some time after the dry period started due to lower recharge. Surprisingly, figure 3.2 and 3.3 show that the groundwater level in both Basonyagwe and Mewadani increased during the observation period. This can be explained by more precipitation during the last year than normal. As seen in table 3.1 the pump intakes are 100 m and 90 m below borehole top at Basonyagwe and Mewadani, respectively. Both the groundwater levels are substantially higher than the pump intakes, which suggest that the extraction rate is sustainable and can potentially increase.

3.4.2 Reasons for differences in groundwater level variations between Mewadani and Basonyagwe

The rise in groundwater level in Basonyagwe was about 20 m, while the groundwater level in Mewadani is more stable with a maximum difference of 3 m. It is not known why the variations in Basonyagwe are much greater than those of Mewadani. One explanation can be that there is a difference in the porosity of the ground but well logs from Basonyagwe and Mewadani are unavailable, thus the geological composition around the wells is not known. Trust Engineering has conducted pumping tests and have well logs for Endagaw Chini, Murukuchida, Endamilay, Gidbyo and Munguli that shows the geological formation surrounding the boreholes. Basonyagwe lays between Endagaw Chini, Murukuchida and Endamilay, and in all of those three places the ground consists of layers with clay, shale and granite with some layers being highly fractured or weathered. Shale and granite have a low porosity, while clay has a high porosity but low permeability (Kruseman et al., 1990; Bear, 2013). As the ground in places surrounding Basonyagwe has a relatively low porosity it might be that the ground in Basonyagwe also has low porosity. A low porosity causes a larger change in groundwater level with the same amount of precipitation, hence this can be an explanation on why the variations in groundwater level in Basonyagwe are greater. In Gidbyo and Munguli the ground consists of sand, gravel, granite, silt, basalt and gneiss. The difference between the well logs shows that there are variations in the ground compositions in the area. It might be that the geological composition in Mewadani is more porous, consisting of sand, gravel and silt compared with Basonyagwe which might have more clay, shale and granite.

Basonyagwe is located near a topographic top in the area at 1738 m.a.s.l., and Mewadani is located at 1630 m.a.s.l. at the bottom of the valley (Worldelevations.com, n.d.). Thus, the larger variations in the water table at Basonyagwe may be because the well is located at an upland recharge area.

3.4.3 Remote monitoring in the study area

The main advantage with remote monitoring in this context is that one is presented with data about the system without having to travel to the pump (Swan et al., 2018). In the study area a few district engineers are responsible for many hundred pumps in a large geographic area and the road infrastructure is poor (personal communication with Eliminata Awet, Ahadi Mollel and James Mmbando 27.11.20). Remote monitoring in the study area can help 4CCP to save time by avoiding traveling to wells in order to know their condition and at the same time can give continuous information about the groundwater level. The technology for implementing remote monitoring is available, the mobile network is adequate to achieve a good data transfer, but it is uncertain how the system can be implemented in the operation and maintenance systems that are present at the pumping stations. Eliminata Awet, Ahadi Mollel and James Mmbando from 4CCP have expressed concerns that there is not sufficient knowledge on repair of the sensors. It is mainly Community Owned Water Supply Organisations (COWSOs) that are responsible for the sensors and they do not have the technical skills to maintain them. To fully take advantage of the potential of remote monitoring it is important that the remote monitoring is well integrated in the operation and maintenance framework. Due to the lack of technical skills among COWSO members, remote monitoring is likely primarily utilized by development organizations such as NCA to get an overview of the project and locate areas of improvement.

Pressure sensors (Neuron Pressure 0-2 bar, El-Watch) were installed in Basonyagwe, Mewadani and Endagaw Chini in the study area in January. Those measurements can be used to estimate the water level in the tanks. Ideally, measurements from these sensors should have been utilized to assess changes in extraction patterns between the rainy season and the dry season. Unfortunately, Asklund (2020) and Røer (2020) found that these data are difficult to utilize, as there are numerous uncertainties in the data. Some of the uncertainties are a result of the pressure sensor being placed between the shutter valve and the water tap, hence when the valve is closed the sensor will initially show the value of the hydrostatic pressure when the valve was shut, and if water is tapped the sensor records the atmospheric pressure. Another indication of the inaccuracies in the estimations is that sometimes the water level is shown to be higher than the water tanks, which is impossible.

Even though the measurements are imprecise they could have been used but, in addition, there have been some challenges with some of the sensors, as they have stopped recording measurements or are showing odd values. Both the sensors measuring water pressure in the tanks in Endagaw Chini and Basonyagwe show a constant value of 30 bar. This happened the 22nd of April in Endagaw Chini and the 29th of October in Basonyagwe. The reasons for the signal disturbances are unknown. The atmospheric pressure in Endagaw Chini was measured until the 12th of September 2020, but then it stopped recording. According to Elimintata Awet from 4CCP (personal communication 18.09.20) the station at Endagaw Chini was damaged due to a solar flare. Solar flares can damage off grid solar power systems as electromagnetic pulses influence the circuit technology. This means that the panels and batteries are typically unaffected, but inverters and charge controllers are at risk. Elimintata Awet said that both the solar inverter and pump control at Endagaw Chini got damaged. A technician was called upon to fix the sensor, but it is still out of use.

The El-Watch remote monitoring system converts the signal in milliampere obtained from the UNIK 5000 sensor to hydraulic head but cannot convert the hydraulic head to meters below borehole top (Asklund, 2020). This makes the El-Watch remote monitoring system less user-friendly.

Sometimes measurements from UNIK 5000 show that there is extraction during the night, which is impossible for the solar-powered pumps, as they have no battery and only work when there is sunlight. This indicates that there are some disturbances on the signal. This makes it less appropriate to use for monitoring pumping patterns, which could help identify whether a pump failure has occurred when the pump is not used or if additional investment could be justified if the pump is highly used. It is more suitable to monitor long-term variations in water level and can help identify declining water levels at an early stage so preventive measures can be implemented.

3.4.4 Sources of error

One important aspect of monitoring is to know if the measured data is equal to the real values. In this specific case this means if the registered groundwater level is similar to the real groundwater level. Asklund and Røer performed an initial control of the signals provided by the UNIK 5000 sensor in February 2020 by using an amperemeter, a Pocket Dipper and equation 3.2. They found that the values provided by the sensors were reasonably similar to the measured values. It could have been beneficial to also measure the hydraulic head with for example a TD-Diver to find an estimate of the validity of the measurements.

As seen in equation 3.2 the measuring range of the electric current is only 16 mA, so a small change in the signal will cause a relatively large change in the hydrostatic head. This means that the initial control of the sensors is of great importance, as a small error in the conversion between the current and hydrostatic head can cause the registered groundwater level to be shifted several meters. This might be an explanation of why the measured groundwater level in Basonyagwe was greater than the ground at some points. It can also be due to changes in barometric pressure and earth tides (Spane, 2002; Toll and Rasmussen, 2007). Other errors can be that the depth the sensors are located are different to the registered depth or that the pressure measurements become less accurate with time (Pleijter et al., 2015).

It is possible to download the data from neuronsensors.app to spreadsheets with either averaged values for each hour or to obtain all the recorded data, which is approximately every tenth minute. In graph 3.2 and 3.3, which presents the groundwater level at Mewadani and Basonyagwe over the course of a year, the averaged data is used as it is accurate enough when we are not interested in the diurnal variations but the trend over the year. This makes the graphs slightly less precise but minimizes the dataset substantially.

At some times data is lacking. The mobile network is mostly sufficient for data transmission within the study area, but one reason for the lacking in data can be poor mobile network which prevents data from being sent from the gateway to cloud storage. Mewadani has the poorest mobile network connection out of the three pumping stations and experiences some minor interruptions, which causes some lack of data usually lasting for a couple of hours (Asklund, 2020). Another reason can be that the sensors are not always registering the data at the specified time intervals.

3.4.5 Representativeness of the data

The precipitation data was provided by GPCC, which uses a global precipitation dataset (GPD) to estimate the precipitation. GPDs are based on data from satellites, reanalysis and interpolated observed data and are less accurate than rain gauges but can be beneficial in areas with limited or no precipitation data (Koutsouris et al., 2016). Mashingia et al. (2014) compared satellite estimates with available gauge data and found that even in a complex climate regime in north-eastern Tanzania the satellite estimates were good for determining large scale temporal variations, but that further research is necessary. They argue that there should be local calibration of the satellite data or merge satellite estimates with gauge observations to improve the accuracy of the precipitation estimates.

Taylor and Alley (2002) argue that long-term, systematic measurements of groundwater levels are essential to assess changes in groundwater levels over time, thus be able to evaluate the groundwater management. They state that it has been common practice to have fragmented measurements related to local projects, just like the one in this study, but that it is more effective to have a network of groundwater level monitoring wells to obtain a systematic and comprehensive measurements of groundwater level. It is particularly useful to monitor groundwater changes during periods of significant land-use change to understand hydrologic stresses acting on aquifers. Data collections for shorter time periods are mainly useful for determining aquifer hydraulic properties but to understand long-term effects on changes in the aquifer one should collect data over years to decades (Alley and Taylor, 2001).

3.4.6 Conclusion

Groundwater level measurements in Basonyagwe and Mewadani have been conducted over the course of a year from February 2020 to January 2021. The lowest groundwater levels were measured at the beginning of the study period. In both of the wells the groundwater level rose gradually until May, before the levels became relatively stable. It was hypothesised that the groundwater level would decline some time after the rain period ended as the recharge lowered but this did not happen. The measurements show that the groundwater levels are high and stable, thus the results demonstrate that it is safe to continue water extraction. This means that the reliability of water in the study area is not affected by the amount of groundwater available.

Sometimes the measurements from Basonyagwe show that the groundwater level is above the ground. This indicates that there are some inaccuracies in the groundwater level estimations. Nevertheless, the results indicate that the pumping rate is sustainable due to the stable and rising water level. Ideally, local water managers should be able to utilize the measured data directly. This is hindered by poor user-friendliness of the El-Watch system, where hydraulic head in meters is presented instead of the groundwater level, and by limited technical resources among the COWSO members, that are responsible for the water supply services. Inadequate technical skills affect the maintenance of the sensors. Several sensors have stopped functioning and the problems have not been fixed. Thus, for remote monitoring to be sustainable, investments should be made in building local technical competence.

Part II

Water Management

Chapter 4

Changes in water supply services

4.1 Introduction

Norwegian Church Aid (NCA) had already started its work in Tanzania when the first master's thesis concerning the study area was written in 2018. Since then, NCA, in collaboration with 4CCP, has contributed to building many new wells. Community Owned Water Supply Organisations (COWSOs) have a large responsibility in maintaining the water services in the villages, hence Misund and Møller (2019) did thorough research on COWSOs in the area and made a framework to evaluate the performance of the COWSOs. It was interesting to see if the performance of the COWSOs two years ago is reflected in the water supply and level of satisfaction today. To answer this, the following research question was investigated:

How is the relationship between the functionality of the Community Owned Water Supply Organisations in the past and the situation of the drinking water supply today?

To understand this the structure of the water sector in Tanzania will be presented, as well as findings from earlier master's theses. In the result section discoveries from the past regarding the performance of the COWSOs will be compared with responses to the survey conducted at the end of 2020. The results will be discussed, and summarized.

4.2 Background

4.2.1 Water management in Tanzania

Since the start of the millennium there have been major changes in the structure of the rural water sector in Tanzania. A revised National Water Policy (NAWAPO) was launched in 2002 and it was proclaimed a new era for the water sector, emphasizing decentralization in the water sector (Arvidson and Nordström, 2006). NAWAPO was a response to the poor performance of policies emphasizing free water and centralized management (Kwezi, 2020). The cornerstone of the new framework was 'decentralization by devolution' through community ownership, cost-recovery and community participation (Giné and Pérez-Foguet, 2008). This meant that planning and management of water services were arranged around water basins rather than on a regional level, so decisions were taken closer to the beneficiaries. Independent legal entities named Community Owned Water Supply Organisations (COWSOs) were established to locally operate and maintain the water supply systems in rural areas (MoW Tanzania, 2006). The COWSOs consist of ordinary villagers representing each sub village or water point. Local Government Authorities (LGAs) were responsible for overlooking COWSOs and provide technical support, as well as fund extensive repairs.

In theory the division of responsibilities between COWSOs, LGAs and the regional government was clearly defined, but it proved to be more challenging in practice (J. George et al., 2018). To tackle these and other challenges the Water Supply and Sanitation Act No. 5 of 2019 was introduced (URT, 2019). One of the main changes was that a new national agency named The Rural Water Supply and Sanitation Agency (RUWASA) was established. RUWASA is a direct link between LGAs and the Ministry of Water and is more practically involved in the planning and management of the rural water supply and sanitation services (Kwezi, 2019). To make sure that RUWASA and LGAs agree on the targets and how to reach them they will sign performance agreements. Follow-up procedures will also be put in place to regularly track the performance. Another change was that COWSOs were changed to CBWSOs; Community-Based Water Supply Organization, as village officials also were included in the organization. In this thesis the acronym COWSO is used for both COWSOs and CBWSOs, as the organizations are so similar and some of the villages still have the COWSO. COWSO was chosen over CBWSO, as this thesis is referring to results from before CBWSOs were introduced in the water sector. Hopefully, the structural reforms will push Tanzania to reach the WASH targets by improving the accountability for rural water services through professionalism.

4.2.2 Findings from previous master's theses

All the earlier master's students writing about the area have conducted interviews with the COWSOs. Martinsen (2018) asked general questions about the water condition to COWSO members and village leaders, in addition to interviewing the district water engineer in Mbulu, to get an overview of the situation. She studied how instalment of wells have impacted the rural communities in the NCA-supported villages in this area of Tanzania, as well as asking about the financing and evaluating the sustainability of the water supply. Misund and Møller (2019) continued the work done by Martinsen (2018) by interviewing and observing COWSOs, district engineers, NCA members, local authorities, community members, and doctors and dentists at Haydom Lutheran Hospital, in addition to conducting a willingness to pay survey. Asklund (2020) and Røer (2020) conducted interviews with COWSOs, public expenditure tracking system (PETS) committees, district water engineers, 4CCP, district commissioners, district executive directors and principals/teachers, as well as having a survey like that of Misund and Møller (2019).

The four master's theses have different focus areas, but all touch upon similar themes. In the surveys conducted in the autumn of 2020 a special emphasis was given to COWSOs and their performance. From earlier, the most in-depth analysis of the performance of the COWSOs was conducted by Misund and Møller (ibid.) and it is therefore found valuable to compare their results with responses given in the surveys performed as a part of this study. The performance of the eleven COWSOs that were interviewed and observed by Misund and Møller (2019) were evaluated and classified. The COWSOs were given a score of 0, 0.5 or 1 point on 14 different factors by Misund and Møller, that was believed to influence the sustainability and resilience of the water supply. A score of 0 reflects no attainment and 1 was full attainment. The scores were multiplied by the authors with a weighting factor of 1, 2 or 3 to reflect the relative importance of the factors on achieving a sustainable water supply. A high weighting was given to adequate funding of operation and management, and capital replacement. The weighting can be seen in table 4.1 and the scores in table 4.2. The COWSOs were divided into three categories based on their total score: red=0-16.5 points, orange=17-23.5 points and green=24-30 points. It was interesting to see if the score of the COWSOs from the evaluation of Misund and Møller (ibid.) was reflected in the opinion of the villagers in the respective communities.

Table 4.1: Weighting of factors used when assessing the COWSOs in 2019 from Misund and Møller (2019)

Factor	**Requirement**	**Weighting**
Improved source or not	To have a pump or having it installed before dry season in 2019	2
Creating COWSO before instalment of pump	The COWSO should be established before instalment of the pump	2
Number of people connected to water point	Should be within design criteria for hand pump or motorized pump	2
Gender balance in COWSO	Should be an equal distribution of men and women (more women is accepted)	1
Frequency and regularity of meetings	At least one meeting per month	1
Making regular reports	Must produce reports every 3 months	3
Taking minutes of meeting	Should take minutes of meetings every meeting	2
Creating a budget	To have a budget and financing plan with income and expenses	3
Being legally registered	COWSO must be legally registered	3
Having a bank account with funds in it	Must have bank account and 0,5 mill. TSH available	3
Strength of relationships with district engineer, PETS and village leaders	Committee should visibly cooperate with all three	3
Availability of back-up solution	Must have an alternative supply (storage tank is considered sufficient for solar powered pumps)	1
Access to technician and toolbox	Should have a technician and toolbox or be in direct contact with one	2
Having future plans and visions	Committee should have stated plans and a vision for the future	2

The assessment of the COWSOs was performed to provide an evaluation framework of the COWSOs to simplify progress tracking and assess in training of the COWSOs.

Table 4.2: Scoring of COWSOs made by Misund and Møller (2019)

Name of village	A	B	C	D	E	F	G	H	I	J	K
Improved source or not	2	2	0	1	2	1	1	2	0	2	2
Creating COWSO before instalment of pump	2	2	2	0	2	0	1	0	1	2	2
Number of people connected to water point	2	2		2	1	0	1	2		2	0
Gender balance in COWSO	1	1	1	1	1	0.5	1	0	1	0	1
Frequency and regularity of meetings	1	0.5	1	1	1	1	1	0.5	0	0.5	1
Making regular reports	1.5	1.5	0	3	3	1.5		3	3	1.5	3
Taking minutes of meeting			0	2	2			2	1	2	2
Creating a budget	1.5	3	0	0	3	1.5		1.5	0	0	1.5
Being legally registered	3	3	3	1.5	3	3	3	3	3	1.5	3
Having a bank account with funds in it	3	3	1.5	1.5	3	3	1.5	1.5	3	3	3
Strength of relationships with district engineer. PETS and village leaders	3	3	0	1.5	3	3	1.5	3	3	1.5	0
Availability of back-up solution	1	1		0.5	1	0	0	0	0	0	0
Access to technician and toolbox	1	2	0	0	2	0	2	0	0	0	0
Having future plans and visions	2	2	0	2	2	2	1	1	1	1	0
Total score	24	26	8.5	17	29	16.5	14	19.5	16	17	18.5

The aim was not to highlight COWSOs that performed poorly, so to avoid putting some villages in a negative light Misund and Møller (2019) anonymized the villages. The same anonymized names are used in this thesis.

4.3 Results

Residents in seven of the eleven villages where the COWSOs got a score in 2019 answered the survey from the autumn 2020. To be able to compare the villagers' opinion of the water sector and COWSO with the COWSO-score, a similar score-approach to the one conducted in 2019 was performed on responses from the community. A value was given to the different answer choices in the survey, where a value of 0 reflect that the respondent was very dissatisfied or to a small extent rely on the COWSO, while a value of 1 indicated that the respondent was very satisfied or trust the COWSO. The questions given in the survey related to this topic and the value given to the answer choices can be seen in table 4.3. All the questions were related to the subjective opinion of the asked individual; hence it reflected the impression of the water sector and not an objective evaluation. For each of the seven villages an average score was found for each question by summing the multiplication of the answer choice-value given in table 4.3 with the number of responses for each answer choice and divide it by the total number of respondents to that question in the village. An average of the community-scores were found to make it easier to compare with the COWSO-score. The community-scores can be seen in table 4.4. The colour of the cell indicates if the score was high or low, where a low score is coloured red, a medium score is orange and a high score is green, with a gradual transition.

In table 4.2 the scores of the factors were given for the COWSOs, but in the sum it does not take into account that some villages have not been given a score for all the factors. Hence, a missing value will be equal to a score of 0 in the total sum and may put a COWSO in a lower category than it should. If all the scores had been filled in it may have moved village F, G and I up from red to orange, as they were all close to the limit of 17 points. To avoid missing values influencing the categorisation of the COWSOs, the total score of a COWSO was divided by the sum of the weighting of the factors where the COWSO was given a value and multiplied with 100. This means that the new total score was the percentage score the COWSO achieved out of the maximum score it could have achieved with the number of questions answered. The new scores can be seen in table 4.5. To find new category limits the old limits were divided by 30 and multiplied by 100. That gives new limits of red: 0-56 points, orange: 57-79 points and green: 80-100 points. This change caused both village F and G to move up from group red to orange.

In table 4.6, the total scores from table 4.4were compared with the new scores of the COWSOs from table 4.5.

The regression line and coefficient of determination between the two values are shown in a scatter plot in figure 4.1. The regression illustrates the trend observed in the scatter plot and the correlation coefficient indicate how well the data gathers around the straight line. The scores were positively correlated, as a high COWSO-score show a high community-score, and vice versa.

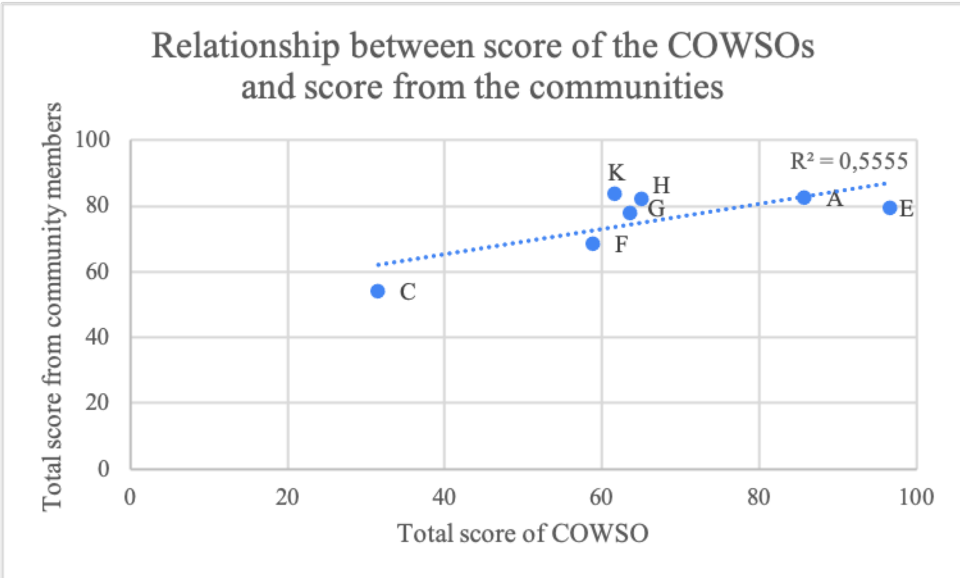

Figure 4.1: Relationship and coefficient of determination between the modified score given by Misund and Møller (2019) and the score drawn from answers from the communities

Table 4.3: Questions given to community members and their scores

Question	Alternatives	Score
How satisfied are you with your current water system?	Very satisfied	1
	Somewhat satisfied	0.75
	Neither satisfied nor dissatisfied	0.5
	Somewhat dissatisfied	0.25
	Very dissatisfied	0
How reliable is the well to continuously deliver potable water?	Very reliable	1
	Somewhat reliable	0.75
	Neither reliable nor unreliable	0.5
	Somewhat unreliable	0.25
	Very unreliable	0
Who would you contact if the pump stopped working?	A COWSO member	1
	Others	0
Who is responsible for maintenance and operation of the water pump in your community?	COWSO	1
	Others	0
How satisfied are you with the services provided by COWSO?	Very satisfied	1
	Somewhat satisfied	0.75
	Neither satisfied nor dissatisfied	0.5
	Somewhat dissatisfied	0.25
	Very dissatisfied	0
If you are dissatisfied with the water services, would you contact a COWSO member?	Yes	1
	No	0
Do you feel that feedback to the COWSO would lead to a change?	Yes	1
	No	0
Do you know how the revenue collected is spent?	Yes	1
	No	0
Do you believe the collected tariffs are spent responsibly?	Yes	1
	No	0

Table 4.4: Scores deduced from answers given by community members to a survey given in October-November 2020

Question from survey	A	C	E	F	G	H	K
How satisfied are you with your current water system?	60	77	61	61	79	82	81
How reliable is the well to continuously deliver potable water?	64	77	63	66	82	80	81
Who would you contact if the pump stopped working?	100	92	100	89	79	45	88
Who is responsible for maintenance and operation of the water pump in your community?	89	83	89	100	79	100	88
How satisfied are you by the services provided by COWSO?	69	42	75	70	82	89	81
If you are dissatisfied with the water services, would you contact a COWSO member?	100	58	94	89	100	100	94
Do you feel that feedback to the COWSO would lead to a change?	89	42	89	72	93	100	100
Do you know how the revenue collected is spent?	94	8	89	32	50	91	71
Do you believe the collected tariffs are spent responsibly?	78	8	56	39	57	55	71
Total score	83	54	79	69	78	82	84

Table 4.5: New scores given to COWSOs that take into account missing values. New category limits are red: 0-56 points, orange: 57-79 points and green: 80-100 points.

Name of village	A	C	E	F	G	H	K
Total score	24	8.5	29	16.5	14	19.5	18.5
Maximum possible score	28	27	30	28	22	30	30
Total score in percentage	86	31	97	59	64	65	62

Table 4.6: Comparison of the modified COWSO-score based on the score from Misund and Møller (2019) and the score drawn from answers from the communities

Name of village	A	C	E	F	G	H	K
Total score of COWSO (2019)	86	31	97	59	64	65	62
Total score from community members (2020)	83	54	79	69	78	82	84

Table 4.7: The values in the last column is the average of all the 283 responses of the survey. Water consumption is given in number of buckets per household and duration of functional downtime is given in days. [a] is data from Manfred Arlt in NCA from 2018, [b] is from Zachayo Makobero in NCA Tanzania, [c] is from WASH TCP 2015-2019 and [d] is from Asklund (2020)

Name of village	A	C	E	F	G	H	K	Average
Year of construction	2018	2018	2018	2017	2018	2019	2016	-
Number of people connected to water point	1200[a]	2300[a] 1900[b] 4226[c]	1330[a] 2869[b]	1065[a] 3065[c] 2300[d]	3000[a] 3387[b] 3904[c]	1236[c]	1927[a] 960[d]	-
Average yearly income	816 667	695 833	1 003 889	1 160 526	828 571	806 364	829 412	993 993
Water consumption rainy season	10	13	13	13	6	11	8	11
Water consumption dry season	15	20	17	18	8	9	13	14
Duration of functional downtime	1	0	2	1	9	76	1	9

4.4 Discussion

The results demonstrate that there is a relationship between the performance of the COWSO and the community members' opinion of the COWSO. It is likely that there are other factors influencing the opinion of the community members, which have not been considered when designing the assessment criteria. It is unattainable to quantify the impact of other factors but still important to discuss what these factors can be. To assess the research question reasons causing the results will be examined by investigating the surveys, and the validity and representativeness of the results will be reviewed.

4.4.1 General discussion of the results

In table 4.6 one can see that in village A both the COWSO-score and community-scores were high, and in village C and F both the scores were low. All the other villages have a medium score in both evaluations, except for village E that stands out, as the COWSO score was high, but the community-score was medium. The results are also illustrated in figure 4.1, and the results indicate that there is a correlation between the performance of the COWSO in 2019 and the community member's opinion of the COWSO and the water sector in 2020, seen by the proximity of the points to the regression line and the R^2-value of 0,56. This suggests that the criteria that Misund and Møller (2019) used for evaluating the COWSOs are likely to reflect the performance of the COWSO.

In general, people are quite satisfied with the current water system and the services provided by the COWSO. All the villages have a community-score higher or equal to 60/100 on the question regarding satisfaction with the water system. The questions regarding satisfaction of the COWSO and faith in feedback causing a change reflects the total score quite well, but the total score is a bit lower. Some exceptions are village H and K, which have a score of 100 points on faith in feedback causing a change, but a total score of 82 and 84, respectively. In the analysis the other questions are assumed to be able to reflect the opinion of the performance of the COWSOs, so it is interesting that there seems to be a correlation between the level of satisfaction of the COWSO and the total community-score.

Transparency has been found to be one of the most important factors for increasing willingness to pay for water services (Montgomery et al., 2009; Hutchings et al., 2015). Misund and Møller (2019) found that the willingness to pay was considerably lower in villages where the COWSO scored worse. Village C, F and G obtained a low score on the questions regarding whether they know how the revenue collected is spent and if they believe the tariffs are spent responsibly. The same villages are the ones with the lowest total scores. Except for village C, there is no strong correlation between those questions and how satisfied they are with the water services and the COWSO. Even in the villages where the people do not believe the tariffs are spent responsibly, most people are somewhat satisfied with the water services and the COWSO. This suggest that there is no clear association between level of satisfaction and faith that the tariffs are spent in a sensible way. It is obvious to speculate that this illustrates a general distrust in authorities' ability to spend money wisely. Village E have a high COWSO-score of 97 points and 89% said they know how the revenue is spent, but only 56% said they believe the tariffs are spent responsibly. This is a surprising finding, as one could believe that the high willingness to pay found by Misund and Møller (2019) was due to community members agreeing with the expenditures.

The analysis is based on people's opinion of the COWSOs and does not reflect the actual performance. Village E got 97 points on the COWSO evaluation, but scored considerably lower, only 79 points, at the community-score. Expectations tend to rise with increased standard of living, thus a reason for the low community-score can be that the villagers have gotten used to a well-structured COWSO and now have higher expectations. Out of the respondents in village E 78% answered that they do not have enough water to cover the basic needs in the dry season, which shows that even when the COWSO is well-functioning there are still challenges related to the water supply. Many people in the village have a long distance to the well as 83% have more than 1000 m to the water point. The long distance to the well was appointed the reason for collecting water from other sources than the water well by 59%. Another 23% said the reason was long queues in the dry period and the remaining 18% said there is not enough water in the well, which indicate that the water supply is insufficient.

The opposite is the case for village C that got the lowest COWSO-score with 31 points, but a community-score of 54. This indicates that even though there seems to be an overall correlation between the two scores, it is not true for all the villages. All the community members have answered that there is never a lack of water and that the pump has not stopped functioning due to technical reasons. Even though there is never a lack of water, 50% responded that there is not enough water to cover the basic needs in the dry season. This shows that although the existing wells function properly, a greater water supply is needed. This is in accordance with the comments at the end of the survey, where everyone mentioned that more wells are needed. It was commented that the wells should be in sub villages that do not already have a well, which implies that the problem is not just that there is was water shortage, but also that the locations of the wells were non-optimal. Out of the respondents in village C, 50% live more than 1000 m away from the water point and 56% said that the long distance to the well is the reason for collecting water from other sources. The average income in the village is 72% of the average income for all the respondents to the survey, and 44% said the reason for collecting water from other sources is the pump price. In the village 42% answered that they are very dissatisfied with the services provided by the COWSO. There is a clear distinction between the ones that are satisfied with the COWSO and the ones that are dissatisfied, as everyone in the first group believes that feedback to the COWSO would lead to a change and everyone in the second group do not. It is interesting that they have answered that the wells are performing well, as there is never a lack of water and the pumps have not had any technical issues, but that they are still dissatisfied with the COWSOs. One commented that more education and training of the water committee members is desired.

In table 4.7 various information about the communities which may influence the water services or the impression of the water services is presented. Village G has a lower average water consumption than the other villages. The answers on the other questions do not differ significantly from the average, so there is no apparent reason for the lower water consumption. It has a lower income than the average, but there are other villages that also have a low average income, but which have a higher water consumption. Different sources report different number of people connected to the water points, but it seems like village G is one of the places with most people connected to the water source. In the final comments most people mention that there is a need for an increase in the capacity, by providing more wells distributed throughout the area, to meet the demands and shorten the queues.

The stated water consumption is believed to be just the water fetched from the well. The water consumption is higher in the dry season compared with the rainy season for all villages, except village H. The higher consumption in the dry season is likely due to other water sources being available during the rainy season, such as rainwater, small rivers, and shallow wells.

Village H has a much longer duration of functional downtime than the other villages. Even though the downtime has been long, 91% said that the reliability of the well is somewhat or very reliable. Of all the respondents 47% answered that there is never a lack of water, while all the respondents in village H said that there is lack of water. 67% said the reason to collect water from other sources than the water well is a non-functional pump. It is surprising that the community-score is 82 and the level of satisfaction with the COWSO is 89, even though the downtime is so long.

4.4.2 Evaluation of method

What do the results tell?

The results indicate that there is a correlation between the performance of the COWSO and the community members' opinion of the COWSO, but to perform the evaluation different assumptions have been made. Can the posed questions really answer this question?

One of the assumptions is that the level of satisfaction with the water system and the villagers' opinion of the COWSOs are related. This assumption is based on findings from Montgomery et al. (2009) and Hutchings et al. (2015), among others. As seen in figure 4.2 the results from the survey imply that there is no correlation between the level of satisfaction with the water system and the level of satisfaction with the COWSO. This is particularly evident for village C. It is important to remember that the analysis is based on the people's opinion of the COWSO and does not reflect the actual performance. Community management became more widespread in the 1990's, but after some years critics started to spread, as it is said to put too much responsibility on the communities and to be a too simple solution to a complex challenge (Chowns, 2015; Hutchings et al., 2015; Whaley and Cleaver, 2017). That is one of the main reasons why there has been a resent structural change in the water sector in Tanzania, with the introduction of RUWASA. A more comprehensive discussion on community management can be found in Bakken and Evang (2020), and Misund and Møller (2019).

Another assumption is that there is a causality between the questions and the attitude of the villagers, meaning that the questions reflect the peoples' opinion of the performance of the COWSOs, but this might not be true. For example, in the analysis the question "Who would you contact if the pump stopped working?" is used to reflect

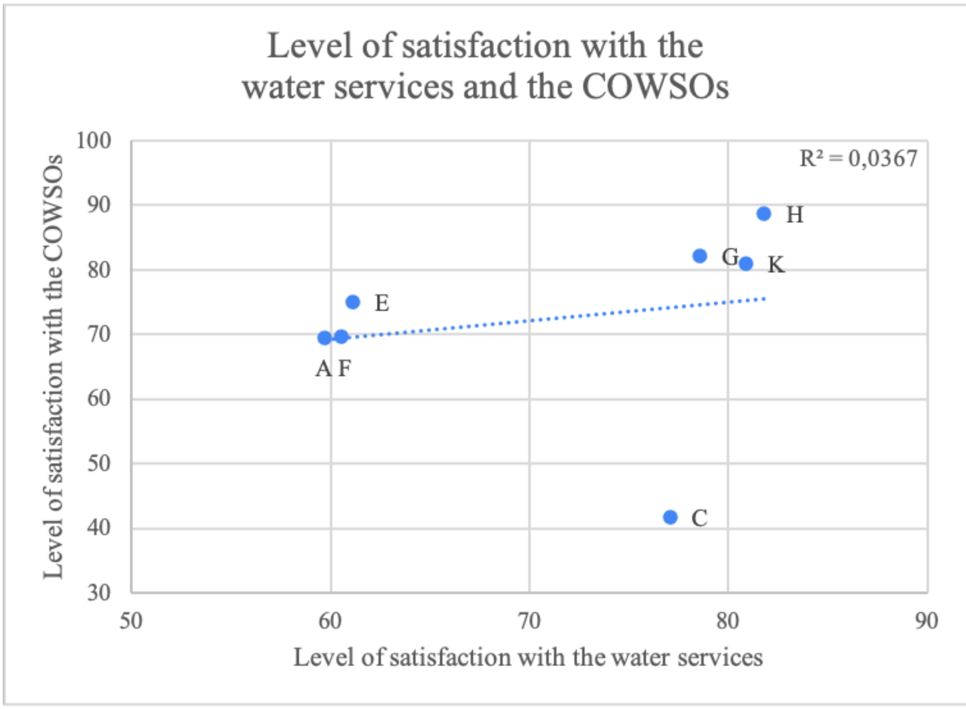

Figure 4.2: Comparison of level of satisfaction with the water services and level of satisfaction with the COWSOs

the trust in COWSO, but there might be other reasons for not contacting the COWSO or contacting someone else. Another question is "If you are dissatisfied with the water services, would you contact a COWSO member?", where the answers may be caused by other reasons than what can be causally linked to the COWSO. This is reflected in the question "Do you feel that feedback to the COWSO would lead to a change?", as all villages, except for K, have a lower or similar score on this question than on the question regarding if they would contact a COWSO member. The difference in the score tells that contact in itself does not imply trust, but because the questions are related and the scores are relatively similar, it is reasonable to believe that there is a correlation.

Certainty of the results

In this study, survey answers from this year are compared with scores made by Misund and Møller (2019). This means that we inherited both the qualities and the sources of error from the previous master's thesis. The scores given to the COWSOs are based on criteria made by Misund and Møller (ibid.), so even though the fulfilment of the criteria is an objective evaluation, the limits for the requirements and the weighting of the factors are based on subjective opinions.

Different weighting of the questions to the community was previously performed to see if it influenced the total average community-score, but it was found to have a low impact on the result. Therefore, it was decided not to use weighting as it adds another layer of uncertainty in the results.

Correlation analysis are especially sensitive to the sample selection (Altman, 1991). The coefficient of determination measures the degree of association, not how closely they agree. This means that R^2 shows how much of the variation in one of the variables is associated with variation in the other. A small sample size increases the uncertainty, and one might get a high R^2 value even if there is no correlation (ibid.).

Outliers may have a great impact on the coefficient of determination, especially in a small sample size (Asuero et al., 2006). On the scatter plot in figure 4.1 showing the relationship between the score of the COWSOs and the score from the communities, it can be seen that there are no clear outliers, as all the points are relatively close to the regression line. Causality cannot be deduced from a high coefficient of determination but must be understood in the light of probable relations (ibid.). This means that even though there seems to be a correlation, this might be due to chance.

Table 4.8: Number of respondents in the villages given a community-score

Name of village	A	C	E	F	G	H	K
Number of respondents	18	12	18	19	14	11	17

In table 4.8 the number of respondents for each village is presented. There are relatively few respondents from each village, which lowers the representativeness of the study. Most of the respondents are members of the village council and were asked to express the general opinion of the village, which was done to increase the representativeness, but nevertheless the responses were always subjective to the person asked. Both women and men were asked, but men were overrepresented by contributing with 61% of the responses. It was seen that there is little difference between the answers from men and women, hence it is likely that this does not impact the results. The average age of the respondents in the seven villages is 47 years. Røer (2020) found that many children are in charge of collecting water and they have not been asked, as the youngest respondent from the seven villages was 26 years old, which means they are not represented in the survey.

4.5 Conclusion

The data suggest that there is a positive correlation between the score the COWSOs got in 2019 and the score from the communities. This is showed by a positive regression line and an R^2 of 0,56. Even though the R^2 should be treated with caution, this proposes that the criteria that were used when evaluating the COWSOs in 2019 is related to the impression the villagers have of the COWSOs. This indicate that in villages with a well-functioning COWSO the community members have higher faith in the COWSO.

The analysis reveals that there is no correlation between the level of satisfaction with the water services and the level of satisfaction with the COWSOs. The results imply that there are other factors than the functionality of the COWSO that affect the level of satisfaction. Historically, COWSOs have been given much responsibility for the water supply services but this structure was criticized, which is why RUWASA was introduced in the water sector in Tanzania. The results from this study agree with the decision of a structural change in the water sector as it shows that a well-functioning COWSO does not imply a high level of satisfaction.

Chapter 5

Potential for Improvement

5.1 Introduction

As described in the previous chapter there have been large changes in the structure of the water sector in Tanzania the last two decades. The structure of the water sector relying on local water committees, COWSOs, has proven to contain limitations, thus The Rural Water Supply and Sanitation Agency (RUWASA) was established in 2019. Findings in the previous chapter show that there is no clear correlation between the level of satisfaction with the COWSO and the level of satisfaction with the water services. Therefore, it was interesting to find out which features are related to the level of satisfaction with the water system. This can enable concentrating the efforts made in improving the water services in areas that will have the greatest impact on the level of satisfaction. In this chapter the following research question was examined:

Where is the greatest potential for improvement in the water supply sector?

To investigate this question, research on common challenges within the rural water supply will be examined before results from our study will be presented and discussed in the light of potential for improvement and compared with former studies. At the end of the chapter the findings will be summarized.

5.2 Background

There are some common challenges that need to be given attention to be able to achieve SDG 6. Some recurring themes regarding challenges for achieving sustainable water solutions in rural areas are the need to understand the community demands, sufficient local financing and cost recovery, and functional operation and maintenance (Montgomery et al., 2009).

To comprehend the needs and demands of the community, it is important to take into consideration social, cultural and economic aspects. It is often challenging to assess the demands, as there will be varying needs within the community (Hutchings et al., 2015). There are several reasons to why people would use an unimproved water source in stead of a borehole, even though an improved source is available. Some of the aspects influencing the choice of water source and amount of water used is accessibility, reliability, availability, continuity and cost (Howard et al., 2020).

Some of the factors that have been most heavily investigated is how collection time and proximity to the water point influence the choice of water source and volume of water collected. Pickering and Davis (2012) found that a decrease in walking time to the water source drastically improves the health of children, and Hopkins (2015) investigated the optimal location of boreholes, taking into account that a higher number of boreholes decrease the distance between households and sources but increases the required water tariffs. A general relationship between travel time and water consumption was proposed by Cairncross and Cuff (1987) and has been widely referred to. The curve is illustrated in figure 5.1. It shows that when travel time to the water point increases, the water consumption decreases substantially. Both Rhoderick (2013) and Cassivi et al. (2019) conducted systematic literature review on the topic, and found that the relationship is less significant than earlier suggested. Misund and Møller (2019) and Røer (2020) found that this relationship is not evident in the study area in Tanzania. Even if distance to the water point do not impact water consumption, a smaller collection time yields benefits (Howard et al., 2020). Some advantages are that excessive time can be used for income generation, rest and homework (Cairncross and Cuff, 1987; Arku, 2010). It is therefore interesting to see how distance to the well is related to level of satisfaction.

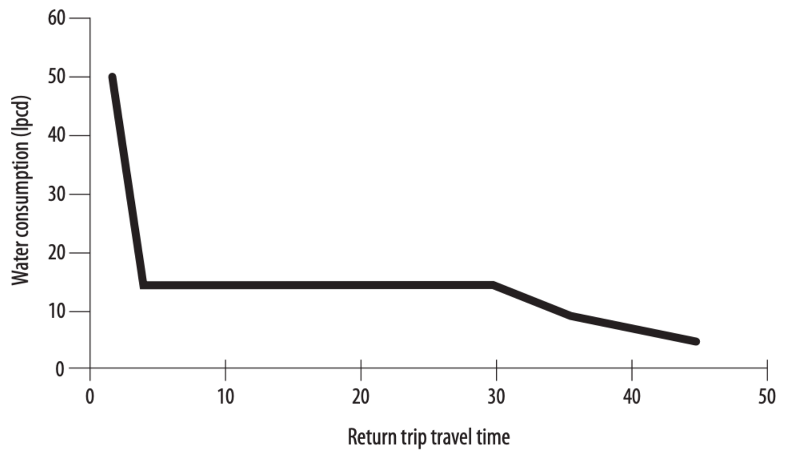

Figure 5.1: The Cairncross curve of travel time and water consumption (Howard et al., 2020)

The availability, reliability and continuity of water services are often connected. The availability of a water source treats whether water is present when needed, the reliability refers to if water is available at a water source at expected times and continuity concerns whether water is available without interruption (Howard et al., 2020). Joseph et al. (2019) have conducted extensive research on reasons for failures of water points in Tanzania, and investigated which factors that contribute to increasing the reliability of pumps. Their analysis is based on data from 2015 Tanzania Water Point Mapping.

They found that 29% of all water points are non-functional and about 20% of all water points in rural areas fail within the first year after installation. The likelihood of failure for groundwater pumps during the first year of construction is only 10%, but the failure rate increases sharply to almost 40% by the 10th year and decrease to 35% by 20 years after installation. Motorized pumps have a higher likelihood of failure than hand pumps and gravity water pumps, starting with 30% within the first year and increasing to 45% over the twenty-year period. It was also found that water points managed by COWSOs were more likely to fail than those managed by private operator or water authority. The management and choice of technology can be modified, but the non-modifiable factors, such as geographical zones and groundwater characteristics, also impact the reliability. The first years after construction the hydrogeological conditions are the factors that most influence the reliability of the water points.

It is common that water services fail due to inadequate financing of expenses related to operation, management and long-term replacements (Hutchings et al., 2015; Jiménez et al., 2017; Montgomery et al., 2009). Montgomery et al. (2009) found that the functionality of the water services increases when the local community is contributing financially. To receive local payment it is crucial to understand the willingness to pay (WTP) for the water service by the community. This way it is possible to set appropriate tariffs for adequate funding (Hutchings et al., 2015; Jiménez et al., 2017). Van Houtven et al. (2017) conducted a global meta-analysis on WTP and found that a higher income increases the WTP. They also emphasize that it is important to recognise and measure the economic benefits an improved drinking water service can bring. Kaliba et al. (2009) conducted a study in Singida and Dodoma region and found that there is a positive correlation between WTP and level of satisfaction with reference to the performance of the project. This shows that a person that is satisfied with the water service is more likely to be willing to use more resources on improving the service. From the study area Misund and Møller (2019) reported that there was a higher WTP if the source is located closer to the house and if the time spent fetching water decreases. Røer (2020) found that there was a positive correlation between level of satisfaction and WTP with an R^2 value of 0.98.

For many years improved coverage of water services was given attention, without emphasizing that the solutions should be sustainable. To achieve sustainable water solutions dynamic operation and management is crucial but historically it has been largely neglected (Montgomery et al., 2009). To establish a well-functioning water system interdependence between different levels of government and support from the national level is critical (Hutchings et al., 2015). To be able to utilize the cooperation between the different actors it is important to have a clear division of roles and responsibilities across providers, operators and managers (Jiménez et al., 2017).

Infrastructure asset management (IAM) is a conceptual framework that has gained acceptance in the water sector, which aims to find the optimum performance at the lowest possible cost at an acceptable level of risk (Boulenouar and Schweitzer, 2015). An IAM framework can help structure the operation and management. Misund and Møller (2019) made a suggestion to an updated IAM framework to be used in rural water sectors, with an emphasis on non-technical aspects of the water sector. As showed in the previous chapter, factors for achieving a sustainable and resilient water supply was evaluated, and their importance was incorporated by weighting the factors differently. The framework focused on the performance of the COWSOs but did not look into the perception of the water consumers. It is therefore interesting to look at which factors influence the level of satisfaction of the water services of the community members.

5.3 Results

The results are based on answers to the survey conducted in October-November 2020. Most of the results are based on responses from 283 community members. Figure 5.2 show the level of satisfaction with the current water system by the community members. It displays that 73% of the respondents are either very or somewhat satisfied. In figure 5.3 it can be seen that out of the 22 responses from COWSO members only 59% are very or somewhat satisfied. The percentage of respondents that are somewhat satisfied is similar in the two response groups but more of the COWSO members are neutral in their level of satisfaction towards the organization of the water sector.

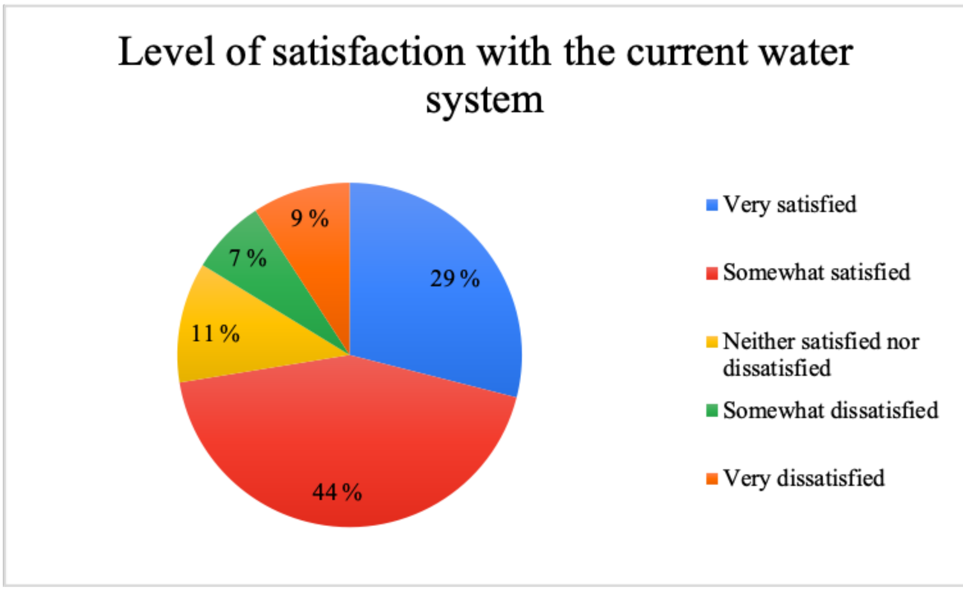

Figure 5.2: Level of satisfaction with the current water system of the 283 community members participating in the survey

People sharing traits or opinions were gathered in groups to review if any interrelationships could be detected. The groups presented in this chapter were decided based on the literature review and groups that we found stood out when analyzing the answers. The groups of people are established based on the community members' response to the question presented in figure 5.4.

The score on the level of satisfaction with the water system is calculated in the same manner as in the previous chapter, showed in table 4.3 on page 38. The value assigned to the answer choices vary from 0 points for responses of very dissatisfied to 1 point for very satisfied. To find the average level of satisfaction for a group, the number of respondents

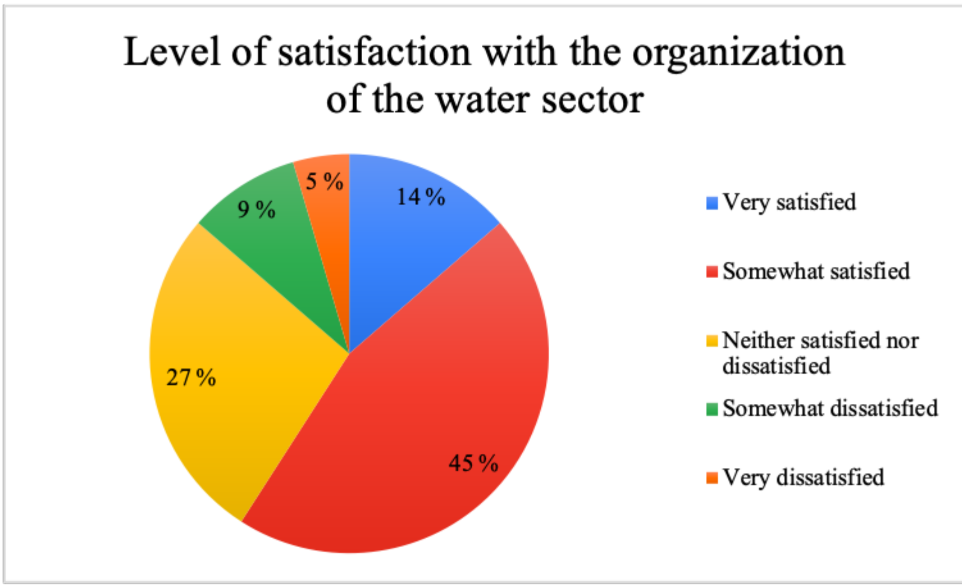

Figure 5.3: Level of satisfaction with the organization of the water sector of the 22 COWSO members participating in the survey

on each of the five answer choices is multiplied with the value of the answer choices and summed, before it is divided by the total number of respondents to the question and multiplied by 100. An example of the calculations of the average score for level of satisfaction can be seen in equation 5.1, based on the values from the 174 respondents that live more than 1000 m away from the well presented in table 5.1.

$$Satisfaction = \frac{51 * 1 + 61 * 0.75 + 26 * 0.5 + 11 * 0.25 + 25 * 0}{174} * 100 = 65 \quad (5.1)$$

Table 5.1: Information about the level of satisfaction of the group that live more than 1000 m away from the well

Level of satisfaction	Number of respondents	Answer choice score
Very satisfied	51	1
Somewhat dissatisfied	61	0.75
Neither satisfied nor dissatisfied	26	0.5
Somewhat dissatisfied	11	0.25
Very dissatisfied	25	0

The calculations are performed to get an impression of where the potential for improvement is greatest by finding out which groups are particularly dissatisfied. Figure 5.5 show the scores of different groups compared with the number of people in each group.

Name	Groups
	Distance to water point
A	0-300 m
B	301-1000 m
C	More than 1000 m
	Water source in the dry season
D	River
E	Dam
F	Local well
G	Natural spring
	Reason to collect water from other sources than the well
H	Long queue
I	Not enough water in the well
J	Pump price
K	Non-functional pump
L	Long distance to the well
	Level of satisfaction with COWSO
M	Very satisfied with COWSO
N	Somewhat satisfied with COWSO
O	Neither satisfied nor dissatisfied with COWSO
P	Somewhat dissatisfied with COWSO
Q	Very dissatisfied with COWSO

Figure 5.4: Different groups based on answers in the survey

An own graph for the the groups that scored below average on level of satisfaction is presented in figure 5.6. In the graph a high number of respondents indicates that many are dissatisfied. Thus, fewer respondents and a higher level of satisfaction is preferred. The background colour of the graph clarifies which groups should be prioritized for increasing the overall level of satisfaction, where efforts made to improve the opinion of people in groups in red areas is recommended.

The groups that are within the red area in figure 5.6 are group C, F, G, L, N and O. Group C are people with a distance of more than 1000 m to the well and group F and G uses local wells and natural springs as their water source in the dry season, respectively. Group L stated that they collect water from another source than the well due to a long distance to the well. Lastly, group N and O are related to the level of satisfaction with the COWSO, where people in group N are somewhat satisfied with the COWSO and group O are neither satisfied nor dissatisfied with the COWSO.

The distance to the well is a trait in both group C and L. In figure 5.7 the level of satisfaction with the water services is compared with the distance to the well.

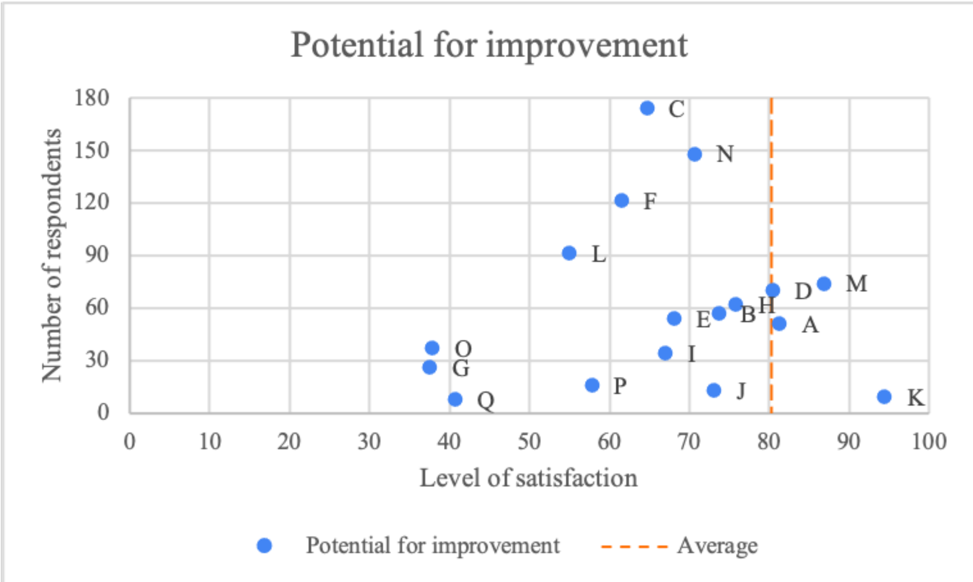

Figure 5.5: Score given for level of satisfaction with the water services compared with different groups of people. The average is for all of the 283 respondents

Figure 5.6: Level of satisfaction with the water services for the groups that scored below average

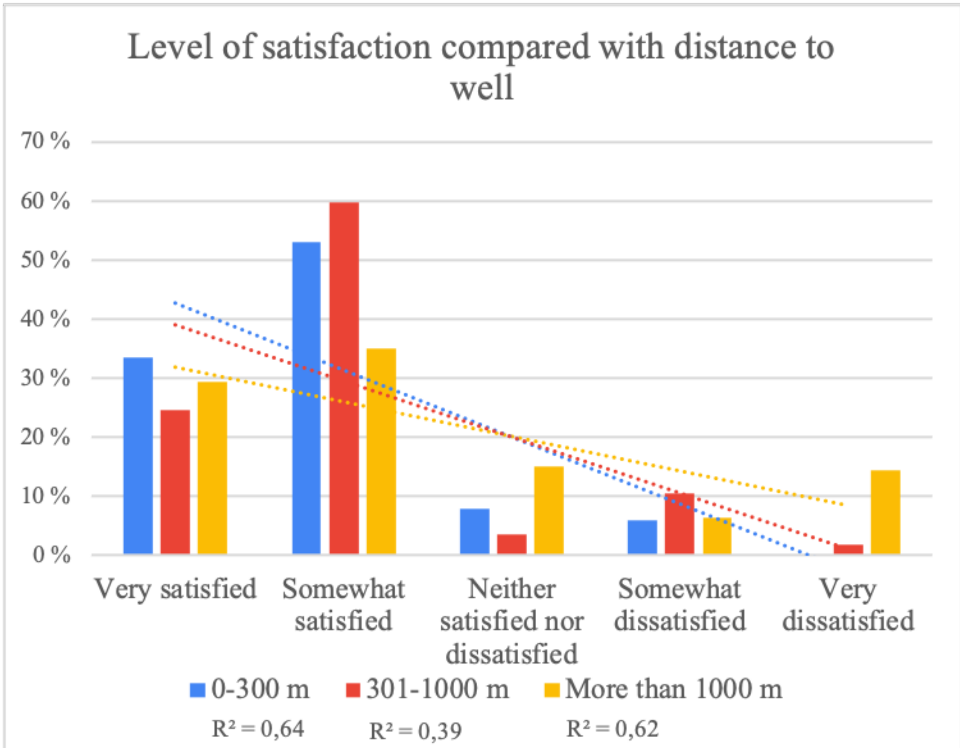

Figure 5.7: Level of satisfaction with the water services compared with the distance to the well

5.4 Discussion

The results disclose that the general level of satisfaction among the community members is high, with 73% either very or somewhat satisfied. Nevertheless, more than one out of four are dissatisfied, or neither satisfied nor dissatisfied. This suggests that there are deficiencies in the water supply system and actions to improve the level of satisfaction among the people that are dissatisfied should be performed.

5.4.1 Distance to the well

Howard et al. (2020) have defined the water access to be inadequate when the distance to the water point is more than 1000 m or the total collection time is more than 30 minutes. Out of the 283 respondents from the community member 61% answered that they live more than 1000 m away from the well. This implies that water accessibility is of great concern in the study area. Both group C and L are related to the distance to the well and both have a level of satisfaction below average and are in the red area in figure 5.6. Figure 5.7 shows that almost all of the respondents that are very dissatisfied live more than 1000 m away from the well, and all have a distance of more than 300 m to the well. Earlier research from the study area have demonstrated that there is no correlation between the water consumption and the distance to the water point but that the WTP is higher if the distance to the water point is shorter (Misund and Møller, 2019; Røer, 2020). The R^2 values presented in figure 5.7 are high for a distance up to 300 m and more than 1000 m, of 0.64 and 0.62 respectively. The R^2 value for a distance between 301-1000 m is lower, with a value of 0.39. An explanation of the differences in the R^2 values may be that the distance greatly plays in on the level of satisfaction when the distance is short or long, but that when the distance is intermediate there are other factors influencing the level of satisfaction. That there seems to be a correlation between level of satisfaction and distance to the well are in agreement with the results found by Røer (2020). Even though the level of satisfaction seems to have a positive correlation with the distance to the well, figure 5.7 shows that most people are satisfied even out of the group of people that have a long distance to the well.

Hopkins (2015) conducted research to find the optimal situation of water pumps but the location of wells is influenced by the hydrogeological conditions. In the study area the location of the wells are mainly based on natural conditions, so even if an optimal theoretical location is found by balancing WTP and distance to source the solution may not be feasible.

5.4.2 The level of satisfaction with the COWSO

As the COWSOs were considerably reviewed in chapter 4 it was interesting to see if similar trends could be detected in the presentation of potential for improvement for all of the villages, not just the seven discussed in the previous chapter. Both group N and O are related to the level of satisfaction with the COWSO, and are in the red area in figure 5.6. As community ownership and management have been highlighted as success criteria for sustainable water supply in many articles, one could expect that the groups that are dissatisfied with the COWSOs also are dissatisfied with the water services in general. Group N are somewhat satisfied with the COWSO and group O are neither satisfied nor dissatisfied with the COWSO. The ones that are very dissatisfied with the COWSO also have a low score on level of satisfaction with the water services but based on the criteria for prioritization in this study it should not be prioritized as it is in the orange and not red area.

The suggestions on prioritization from these findings are not reasonable. It seems counterintuitive to focus attention on those that are somewhat satisfied with the COWSOs above those that are very dissatisfied with the COWSOs. There might not be a causation even though it can look like there is a correlation. When looking closer on the position of the point representing group O in figure 5.6 it can be seen that the group consists of few persons, only 37. Studies conducted on few people are less representative and the results greatly depend on the individuals taking part in the study. Group N consists of 148 persons and is therefore more representative of the group. Because of the large size of group N it seems wise to focus attention on them. Even though there are many people in group N it can be seen that they have a satisfaction level of 71, which is close to the average level of 80. Since the results from the previous chapter suggest that COWSOs have limited impact on the performance of the water sector, it may be sensible to prioritize other groups.

5.4.3 Factors influencing choice of water point

Gross and Elshiewy (2019) found that the distance to the water source, the price of water, and the subjective quality of the water influence the choice of water source. The impact of distance has been discussed above. Group J represents a group of people choosing to use other sources than the well due to the price of pumping. The group is located in the bottom right corner of figure 5.6, which implies that there are few people in this group and they are just below the average level of satisfaction. This suggests that the price of the water decides choice of water source to a small extent. The results reveal that group F and G, which uses local wells and natural springs as water source in the dry season, respectively, should be prioritized to increase the overall level of satisfaction of the community members. Group G only consists of 26 people, thus similar to group O it has a low representativeness. Therefore, it is recommended to focus on increasing the level of satisfaction of group F. This can be done by prioritizing locating new water points closer to households that rely on water from local wells.

5.5 Conclusion

In this chapter the features related to level of satisfaction with the water system was revealed. This was done to enable concentrating the efforts made in improving the water services in areas that will have the greatest impact on the level of satisfaction. The groups that should be prioritized for increasing the overall level of satisfaction was revealed by comparing the average score on level of satisfaction within a group with how many people belong to the group. Group C and L are related to a long distance to the well and both groups have a low level of satisfaction. This suggest that having a water source close to the household increases the level of satisfaction with the water system. Group F uses local wells as a water source in the dry season, and its low score in the assessment of potential for improvements implicates that local wells are unsatisfactory as a drinking water source.

Part III

Fluoride Removal

Chapter 6

Fluoride adsorption

6.1 Introduction

Many Tanzanian groundwaters experience excessive fluoride levels which can cause harmful health effects for the Tanzanian population. At the same time, existing fluoride removal methods are expensive and not readily available. Therefore there is a need to investigate a novel, cheap and locally available fluoride removal method. The aim with this chapter is to evaluate fluoride adsorption efficiency of various adsorbents in order to supplement an assessment of appropriate fluoride removal methods in Tanzanian settings, which will be further discussed in chapter 7. Even though determining adsorption efficiency is only one aspect of such an assessment, it is a demanding task requiring thorough examination and lab experiments which is presented in this chapter by answering the following research question:

What is the fluoride adsorption efficiency of various adsorbents in lab-facilities?

This chapter opens with a literature review about fluoride, adsorption, and various adsorbents used in a lab experiment conducted in this thesis. Thereby the lab experiments is described. Fluoride adsorption percentage for various adsorbents, adsorption capacity, and reaction rate for H_2SO_4-treated activated alumina are presented in the *Results* section and further evaluated in the *Discussion*.

6.2 Background

6.2.1 Health impact and recommended values

In order to ensure sustainable and satisfactory water supply services, available drinking water need to be sufficient and of satisfactory quantity. Groundwater has the potential to supply drinking water in sufficient quantities as discussed in chapter 5. However, many places in Tanzania untreated groundwater has failed to deliver satisfactory quality due to natural occurring high fluoride concentrations (WHO, 2019; Mseli et al., 2019). Fluoride consumption in permissible dosages is beneficial to humans and strengthens dental

Table 6.1: Fluoride health impact (Dissanayake, 1991)

Concentration of fluoride	Impact on health
Nil	Limited growth and fertility
0.0 - 0.5 mg/L	Dental caries
0.5 - 1.5 mg/L	Promotes dental health resulting in healthy teeth, prevents tooth decay
1.5 - 4.0 mg/L	Dental fluorosis (mottling of teeth)
4.0 - 10.0 mg/L	Dental fluorosis, skeletal fluorosis (pain in back and neck bones)
> 10.0 mg/L	Crippling fluorosis

and skeletal development. However, too high exposure of fluoride can cause diseases such as dental, skeletal or crippling fluorosis (WHO, 2017; Thole, 2013). The impact of fluoride consumption on health is presented in table 6.1. In alignment with this, World Health Organization (WHO) recommends a guiding upper limit of fluoride concentration in drinking water of 1.5 mg/L (WHO, 2017). WHO (ibid.) suggests that countries with high intake of groundwater, such as countries with warm climate, or intake of fluoride via other sources (i.e. food) should consider to implement an even lower target for fluoride levels. Nonetheless, Tanzanian standard allow a maximum of 4 mg/L which is the highest fluoride target selected by any country (TZS, 2003; WHO, 2018). Experiments in this study aim for a fluoride concentration of 1.5 mg/L in concordance with WHO standard and table 6.1. Fluoride concentrations above 1.5 mg/L are referred to as excessive fluoride levels.

6.2.2 Fluoride

In aqueous solutions the element fluorine is most commonly found as the anion fluoride (F^-). Two features make fluoride particularly challenging to remove from aqueous solution. First, it is very stable as fluoride ion. It has an electron configuration equal to the noble gas neon Ne and is therefore particularly stable as its simplest ionic form, F^-. Fluoride is characterized as a weak base and is the most electron-negative atom. Due to these features fluoride is likely to strongly hold on to its electrons and will not easily participate in acid-base reactions. Secondly, fluoride has a high affinity for water. Fluoride is highly reactive with hydrogen containing compounds and can easily form hydrogen bonds with H attached to O/N. This causes a high affinity between fluoride and water, and defines fluoride as very hydrophilic. In terms of size and charge, F^- reassembles hydroxide ion OH^- and can therefore exchange OH-groups in adsorption processes.

6.2.3 Adsorption

One of the most common fluoride removal methods is adsorption. Compared to other fluoride removal methods, such as electrodialysis, reverse osmosis, ion exchange and precipitation, adsorption is considered to be cheap, easily applicable and readily avail-

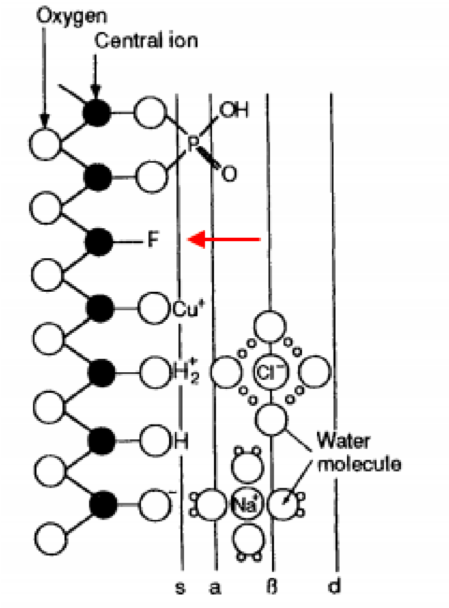

Figure 6.1: A schematic portrayal of the hydrous oxide surface, showing planes associated with surface hydroxyl groups ("s"), inner-sphere complexes ("a"), outer-sphere complexes ("β"), and the diffuse ion swarm ("d")(Sposito, 1984)

able (Kut et al., 2016). Adsorption of fluoride is exhibited in three processes. a) Fluoride is transferred from the aqueous phase onto the adsorbent surface by diffusion or weak bindings. This process is slow and limits the speed of adsorption. In addition, fluoride has a high affinity towards water which makes it more challenging to transfer fluoride from aqueous phase to solid phase which further slows down the process. b) When fluoride is close to the surface of the adsorbent, diffusion will adsorb fluoride to the inner porous surface. c) Usually, the species which undergoes the adsorption (called adsorbates) will adsorb onto the inner porous surface by weak bonds, such as Van der Waals bonding (Crittenden et al., 2012). The characteristics of fluoride, such as its stable state, small size, and high affinity for water, make it difficult for fluoride to be adsorbed by weaker bonds and fluoride is more often adsorbed by exchanging surface functional groups. Because of its similarity to hydroxyl (OH^-) groups, fluoride can be adsorbed by exchanging surface hydroxyl-groups (Fan et al., 2003).
Figure 6.1 illustrates how fluoride binds to an hydrous oxide surface. While Na and Cl can bind to the surface with weak binding at some distance apart from the surface, fluoride have to become very close to the surface. Its strong affinity to water makes obtaining this closeness challenging. Figure 6.1 also shows that opposed to other elements, fluoride have to bind directly to the central ion. This is done by exchanging existing functional groups. This complicates the process because the existing bond between the functional group and the surface have to break, in addition to fluoride bond to form.

The efficiency of adsorption depends on several factors, such as adsorbent type, pH, temperature, contact time, ionic content etc. In general will large porosity and small granule size of the adsorbent increase the surface area and is favorable for adsorption. For a given pore volume smaller pores results in a higher overall porosity. Smaller adsorbent size is desirable in terms of adsorption, nonetheless it is more difficult to remove by filtration or sedimentation (Crittenden et al., 2012).

6.2.4 Adsorbents in this study

Activated carbon

Activated carbon (AC) is commonly used worldwide and is readily available commercially as well as inexpensive. Activated carbon is processed carbon in order to increase porosity and inner surface area. Activated carbon can be produced by any products with high carbon content and low inorganic matter, such as wood (Mwakabona et al., 2014), groundnut shell (Sheth and Gajjar, 2013), seeds, bone char (Abe et al., 2004) and more on. Studies have revealed that activated carbon based on animal bone char has better fluoride adsorption capacity than activated carbon based on vegetal matter (Abe et al., 2004; Hernandez-Montoya et al., 2007). Both vegetal carbon and bone char activated carbon contains hydroxyl groups which are exchangeable with fluoride as explained previously. In addition, bone char contains calcium phosphate which during the adsorption process can exchange the phosphate ion with fluoride and the calcium phosphate is transformed to calcium fluoride (Abe et al., 2004; Morgan and Stumm, 1995). Fan et al. (2003) reported that fluoride has large affinity towards calcium. Vegetal AC is a non-polar solvent and consequently its main fluoride removal mechanism is physical adsorption with weak Van der Waals bindings. Carbon is hydrophobic, opposed to fluoride which is hydrophilic (Gonçalves et al., 2010). It is found in literature that unmodified vegetal-based activated carbon is not an efficient fluoride adsorbent (Abe et al., 2004; Hernandez-Montoya et al., 2007; Rashid and Bezbaruah, 2020).
Commercially, activated carbon exists as Granular Activated Carbon (GAC) or Powdered Activated Carbon (PAC) which are distinguished by size. GAC mean particle size usually ranges from 0.5 to 3 mm, while PAC ranges from 20 to 50 µm (Crittenden et al., 2012). Sheth and Gajjar (2013) observed that PAC had a slightly higher adsorption capacity than GAC. This correlates with other studies reporting a correlation with reduced adsorbent size and increasing fluoride adsorption efficiency (Jamode et al., 2004; Parlikar and Mokashi, 2013).

Activated alumina

Activated Alumina (AA), commonly referred to as alumina, is processed aluminium oxide (AL_2O_3) in order to increase porosity and inner surface area. It is known as one of the most efficient fluoride adsorbent and used extensively worldwide. However, its use is less common in poor rural areas as AA is considered a relatively expensive adsorbent. As a hydrous oxide, figure 6.1 portrays fluoride adsorption for AA. However, in comparison to AC, AA is naturally hydrophilic and attracts F^-, making it easier for F^- to approach the surface. Due to its configuration, fluoride has a strong affinity to form complexes with metals with low polarization such as Al^{3+}. Fluoride has a stronger affinity towards aluminium than O^- and can therefore exchange OH-surface groups (Morgan and Stumm, 1995). AA is highly pH-dependent, requiring pH adjustment both before and after adsorption treatment which increases the costs. For pH greater than 7 fluoride adsorption will decrease drastically (Arfin and Waghmare, 2015). For acidic environments, both the surface charge of AL_2O_3 and the aluminium-fluoride complexes are positively charged and therefore adsorption of fluoride is unattainable due to electrostatic repulsion. Optimal pH-range for Activated Alumina is pH 4.0 to 6.0 (Ku and Chiou, 2002). For low pH ranges dissolved $Al-F^-$complexes can be dissolved which is undesirable (S. George, Gupta, et al., 2012; Ghorai and Pant, 2005).

Neem leaves

Research about neem leaves as a fluoride adsorbent is limited to lab experiments. neem leaves has not yet been applied in the field, but studies have revealed that neem leaf powder is a promising fluoride adsorption agent and its potential should be further investigated (Bharali and Bhattacharyya, 2015; Jamode et al., 2004; P.S et al., 2017). neem leaf powder has a large specific surface area compared to other plant-based adsorbents, but still significantly smaller specific surface area than commercial available adsorbents, such as GAC and PAC. neem leaf powder is slightly acidic in nature, with low cation exchange capacity and reportedly a high anion exchange capacity (Bharali and Bhattacharyya, 2015). These characteristics suggests that neem leaf powder provides substantial anion exchangeable sites to adsorb anions such as fluoride. It has been suggested that functional groups attached to the adsorbent surface, such as hydroxyl, alkyl, carbonyl etc., are contributing to fluoride adsorption through the process of ion exchange. Previous research agree that adsorption capacity by neem leaf powder is strongly affected by pH (Bharali and Bhattacharyya, 2015; Jamode et al., 2004; P.S et al., 2017; Singh and Cb, 2018). However, optimal pH range and adsorption behaviour is reported conflictingly. While Bharali and Bhattacharyya (2015) and Singh and Balomajumder (2015) report a fluoride adsorption peak for pH range 5-7 with pH 7 as optimal, Jamode et al. (2004) reports an optimal pH of 2 with linearly decreasing adsorption capacity with increasing pH. Time of equilibrium is relatively short for previous research and is reported between 40 and 180 minutes (Singh and Balomajumder, 2015; Jamode et al., 2004).

Moringa olefeira leaves

Several studies have researched moringa seeds as a fluoride adsorbent and revealed that moringa seeds exhibit effective fluoride adsorption (Parlikar and Mokashi, 2013; Magroliya and Trivedi, 2017; Pandey et al., 2020). moringa leaves as a fluoride adsorbent have been researched to a much lesser extent. Pandey et al. (2020) reported that moringa leaves extract significantly improved water quality parameters, including fluoride concentration. Dan and Chattree (2018) evaluated the potential of acid and alkali treated moringa leaves powder to adsorb fluoride. Both treatments resulted in efficient fluoride adsorption at a neutral pH with alkali-treated leaves performing the highest fluoride adsorption. Both treatments resulted in optimal adsorption capacity at extreme pH values. While alkali treated moringa leaves have increasing adsorption capacity for increasing pH values, lower pH values were favourable for adsorption by acid treated leaves. Reported equilibrium time was 150 minutes (Dan and Chattree, 2018).

Chemical modifications

Chemical modification such as alkali and acid treatment is often used to increase adsorption efficiency. Such treatment will cleanse the pores for pollution and external salts and make more available adsorption sites for fluoride. Acid-and alkali treatment changes the surface characteristics of the adsorbent and can add functional surface groups for the fluoride to exchange with during the adsorption process. Acid treatment cause pH to decrease which limits growth of microorganisms, while alkali treatment cause an increase in pH levels. Acid and alkali treatment will push optimal pH to more extreme values, and readjusting pH after treatment might be necessary. However, for many adsorbents chemical modification is decisive in order to adsorb fluoride.

Duan et al. (2014) reported that H_2SO_4-treatment AA increased maximum adsorption capacity almost 2.4 times compared to unmodified AA. During treatment ${SO_4}^{2-}$ ions are adsorbed by electrostatic forces onto the surface of AA. As F^- has a stronger affinity towards aluminium than ${SO_4}^{2-}$, a possible ion-exchange reaction between ${SO_4}^{2-}$ and F^- can occur (Morgan and Stumm, 1995). Duan et al. (2014) reported high amounts of free ${SO_4}^{2-}$ ions in the aqueous solution after treatment which indicates that the ${SO_4}^{2-}$ ions have been exchanged with fluoride. Chemical modification of AA should occur between pH 5-6 to avoid dissolution of free aluminium complexes in the aqueous solution, especially in acidic environments (Ku and Chiou, 2002).

Jamode et al. (2004) claims that also non-conventional adsorbents, such as leaves, require alkali or acid treatment to increase adsorption efficiency and remove lignin.

6.2.5 Ion chromatography

Ion chromatography (IC) is used to identify charged molecules. It differentiate the molecule depending on their attraction toward the ion exchanger. The process is depending on three interacting phases; the stationary phase, the mobile phase called eluent and the analyte. The stationary phase have opposite charge as the analyte and have an attractive force on the ionic analytes. The eluent has the same charge as the ionic analyte and cause repulsion due to similarly charged ions in elute as the analyte. IC differentiate ions in the analyte based on the ionic interaction between the three phases. There are two types of ion exchanger, cation-exchange and anion-exchange. Because fluoride is an anion, anion-exchange is used to detect fluoride. Anion exchange uses a positively charged stationary phase to attract negatively charged ions and negatively charged eluent (Bahadir, 2013).

6.3 Results

All results are based on equations elaborated in section 2.5.2 on page 13 and calculations presented in Appendix B.

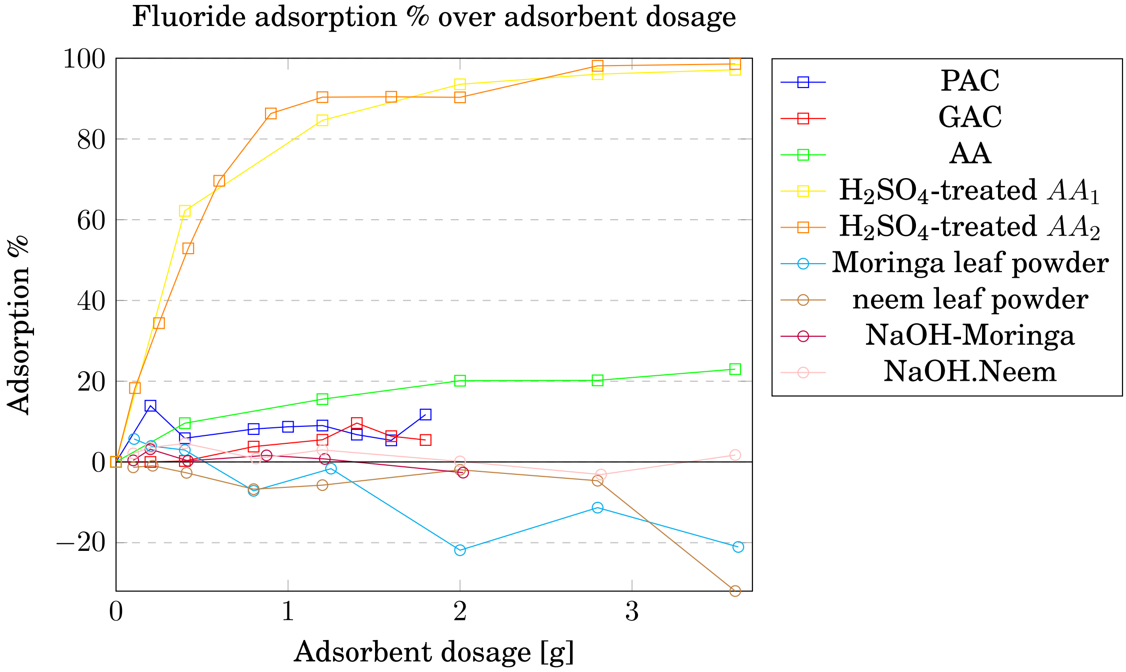

Figure 6.2: Fluoride adsorption (%) by various adsorbents

6.3.1 Adsorbent efficiency of various adsorbents

As presented in graph 6.2, PAC, GAC and alkali-treated neem and moringa leaf powder exhibited no fluoride adsorption. Untreated neem and moringa leaf powder added significant amounts of fluoride to the aqueous solution. Untreated AA exhibited low fluoride adsorption, while the two batches of H_2SO_4-treated AA efficiently adsorbed fluoride and removed up to 98% of initial fluoride.

As only H_2SO_4-treated AA showed promising results, the following presented results are based on H_2SO_4-treated AA.

6.3.2 H_2SO_4-treated activated alumina isotherm

Adsorption isotherms are used to describe the affinity of an adsorbate (in this study: fluoride) towards an adsorbent. In other words, it quantifies the amount of adsorbate adsorbed by a given amount of adsorbent at equilibrium and at a constant temperature. Langmuir isotherms model and Freundlich isoterm model are evaluated in this thesis to calculate adsorption capacity. The Langmuir adsorption isotherm describes an homogeneous adsorption process with fixed number of sites on the adsorbent. Each individual site can only bind one molecule at most and when all the individual sites are occupied the capacity is full. This is also called mono-layered accumulation (Crittenden et al., 2012). Freundlich isotherm can apply to both mono- and multilayered adsorption. Each adsorption site can adsorb several molecules. Fruendlich isotherm is based on the assumption of heterogeneous adsorption (Dan and Chattree, 2018). The adsorption process is said to be favourable if Freundlich adsorption intensity parameter, n, is between the range of 1 < n < 10 (Dan and Chattree, 2018). The applicability of the isotherm models is evaluated based on the coefficient of determination, R^2.

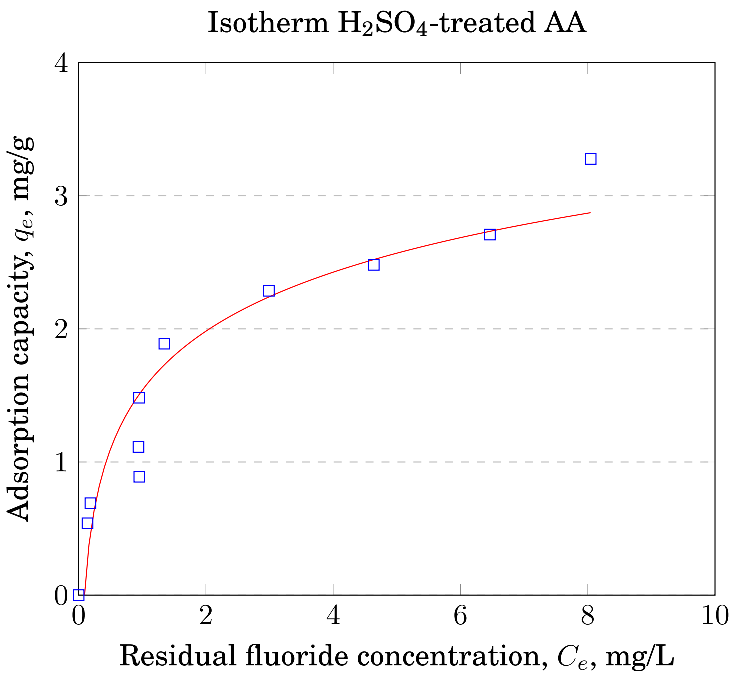

Figure 6.3: Isotherm curve for H_2SO_4-treated AA

Table 6.2: Summary of Langmuir and Freundlich constants

Langmuir constants			
Q_m	b_e	q_e	R^2
1.29	-4.62	1.52	0.812
Freundlich constants			
n	K_e	q_e	R^2
2.27	1.33	3.43	0.929

Table 6.3: Summary of isotherm adsorption capacity and curve fitness

Isotherm	q_e [mg/g]	R^2
Freundlich	3.43	0.929
Langmuir	1.52	0.812

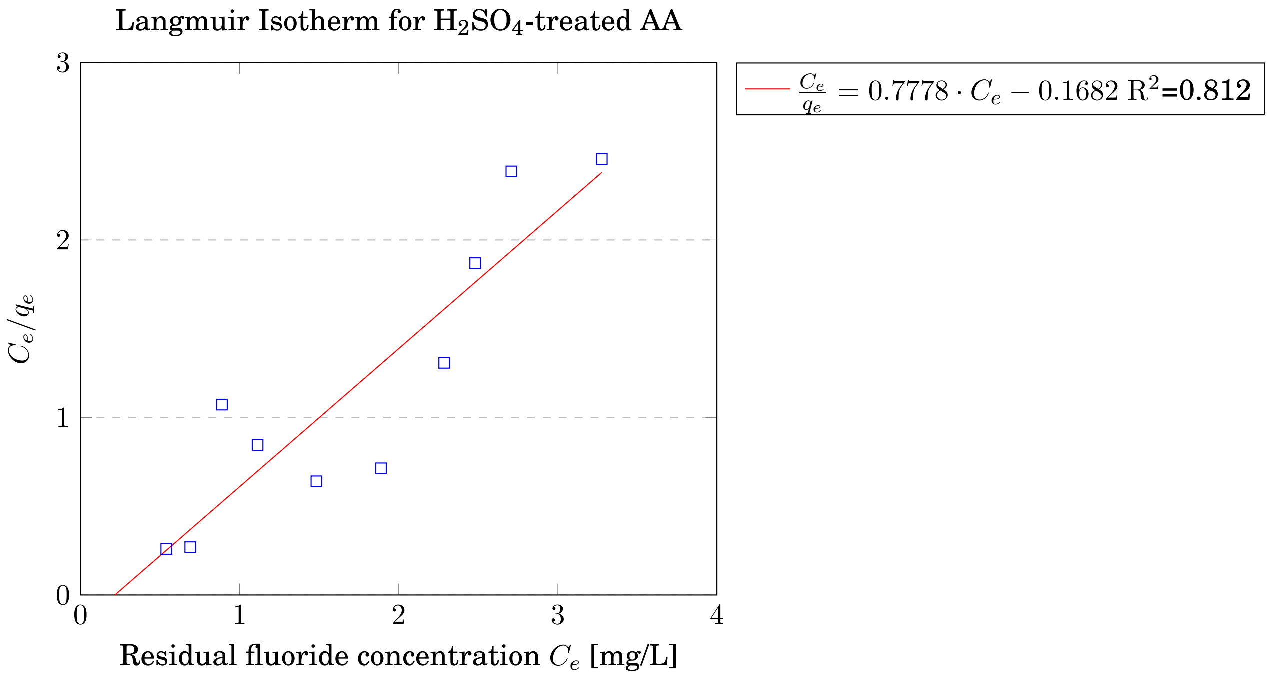

Figure 6.4: Langmuir H_2SO_4 AA

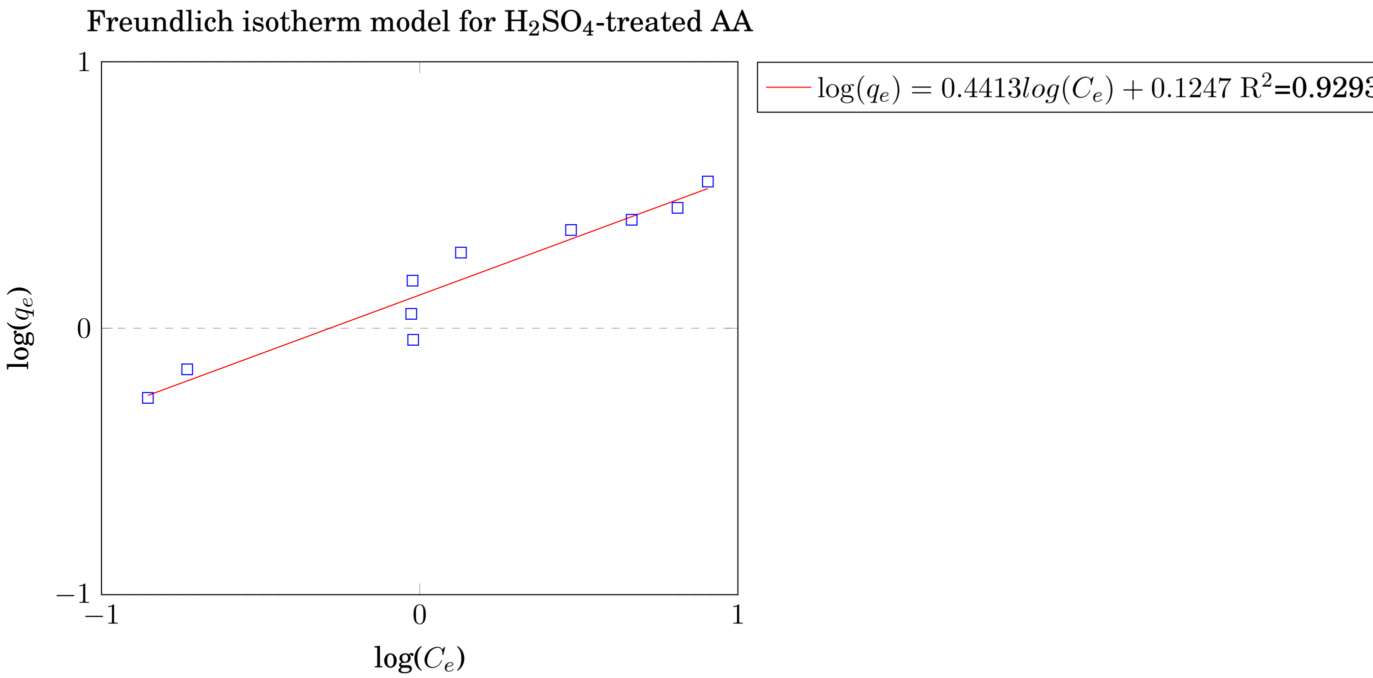

Figure 6.5: Freundlich isotherm for H_2SO_4-treated AA

Table 6.4: Summary

Reaction order	k	R^2
Zero order reaction	0.263	0.394
First order reaction	0.461	0.767
Second order reaction	1.19	0.961

Seen in table 6.3, Freundlich has the best curve fit based on R^2. Freundlich adsorption intensity parameter, n, equals 2.27 is between the range of 1-10 and indicates favourable fluoride adsorption by H_2SO_4-treated AA.

6.3.3 The effect of time

Rate law is used to mathematical express how concentration of the reactant affects the reaction rate (Flowers et al., 2019). Reaction order, n, must be determined experimentally by curve fitting shown in appendix.

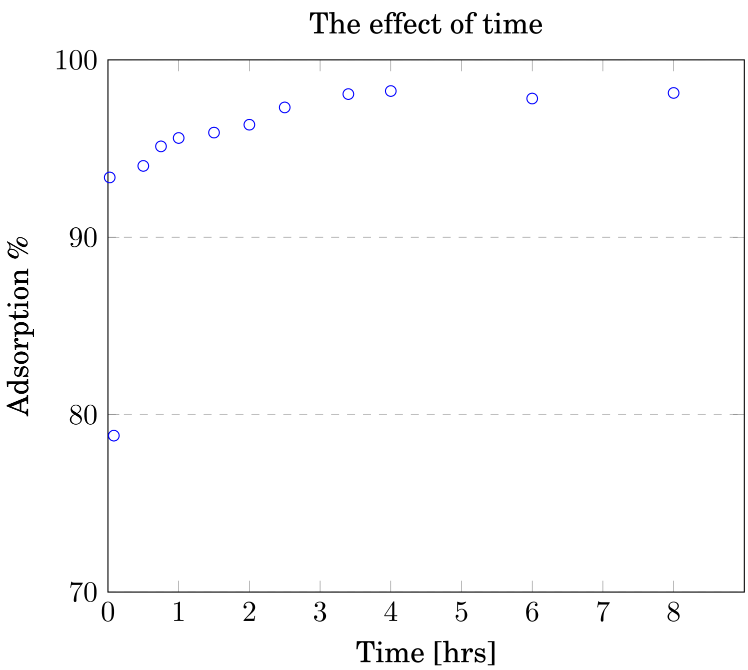

Figure 6.6: Fluoride adsorption (%) by H_2SO_4-treated AA over time (hrs)

The plotted data has a good fit for second order reaction ($R^2 \pm 0.961$). Therefore reaction rate of H_2SO_4 treated AA can be described by second order reaction. The rate constant equals 1.19 (L·mol^{-1} h^{-1}).

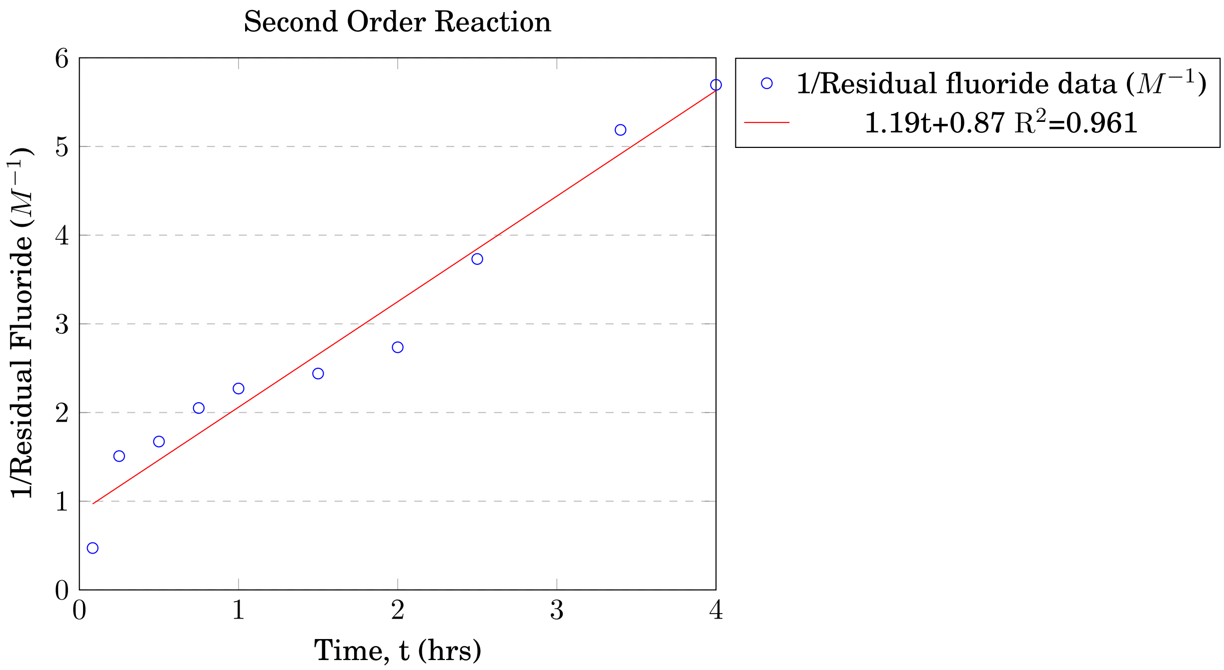

Figure 6.7: Second order reaction rate for fluoride adsorption by H_2SO_4-treated AA

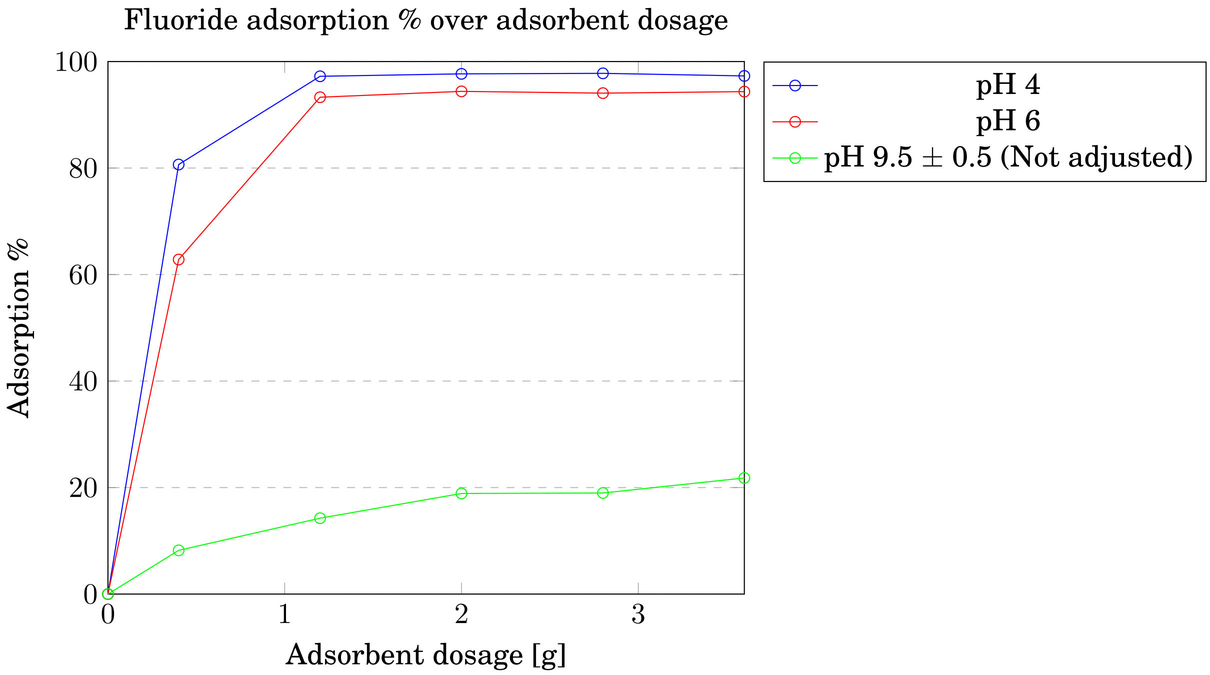

Figure 6.8: Fluoride adsorption % vs. adsorbent dosage for unregulated AA at unmodified pH (pH 9.5 ±0.5), pH 4 and pH 6

6.3.4 The effect of pH

Graph 6.8 shows that fluoride adsorption by unmodified AA increases drastically with pH reduction. This aligns with findings from literature in section 6.2.4 on page 62.

6.4 Discussion

This section aims to answer the research question: *What is the fluoride adsorption efficiency of various adsorbents in lab-facilities?*
The section will evaluate adsorption efficiency of AC, moringa and neem leaf powder and AA. To get a more specific evaluation of fluoride adsorption efficiency exhibited by H_2SO_4-treated AA, the section reviews adsorption capacity, the effect of time and pH on fluoride adsorption by H_2SO_4-treated AA. Finally the section will evaluate the method and potential errors affecting the results presented.

Activated carbon

The results presented in graph 6.2 shows that GAC exhibit negligible fluoride adsorption. At most GAC removed up to 11% of initial fluoride, which is not sufficient to meet the WHO recommendation.

Its low adsorption efficiency can be explained by the chemical properties of activated carbon. Vegetal activated carbon depends on physical adsorption with weak bindings in order to adsorb fluoride. As explained in section 6.2.3, physical adsorption is not enough to adsorb fluoride alone. Activated carbon often contains hydroxyl groups on its surface. This presents the opportunity for fluoride to exchange the hydroxyl group and this way be adsorbed onto activated carbon. However, for this exchange to take place, fluoride have to be drawn very close toward the activated carbon surface. As fluoride is hydrophilic it will surround itself with water molecules. Contradictory, carbon is hydrophobic and will repel water molecules away from its surface. Therefore it is highly unlike for fluoride to get sufficiently close enough to the AC surface for the exchange to take place in the first place without further energy needed.

According to result from this thesis GAC is ineffective to remove fluoride by adsorption. The results are supported by Hernandez-Montoya et al. (2007) and Abe et al. (2004). Hernandez-Montoya et al. (2007) results revealed adsorption capacity below 15% for eight different commercially available vegetal GAC. Abe et al. (2004) measured fluoride removal percentage by varies commercial activated carbon based on wood to range from 6.6-16%. Higher fluoride adsorption was presented by Sheth and Gajjar (2013). Sheth and Gajjar (ibid.) reported GAC maximum fluoride removal as 25.5%. Sheth and Gajjar (ibid.) conducted experiments with initial 2 mg/L fluoride. Lower initial fluoride may explain higher adsorption capacity. The effect of initial fluoride dosage is not discussed in this thesis. The higher removal efficiency may also be caused by various source of carbon.

In addition to poor fluoride removal, GAC increased pH levels. A dosage of 1.4 g GAC increased pH from 5.7 to 11.2. This requires readjustment of pH and is undesirable. However, this is measure in deionized water. As deionized water are without ions and have no buffer capacity, small variations in ions may change the pH significantly. Natural water have a higher buffer capacity and increase in pH caused by GAC would likely not be as significant.

Studies indicates that fluoride adsorption efficiency for GAC will improve with decreasing pH (Daifullah et al., 2007). Experiments were conducted with initially reduced pH by adding HCl. No improvement in fluoride adsorption was observed for these samples. However, adjusting pH was only done prior to the experiment and not during. After two hours of agitation time pH had increased from 2.8 to 10.3. This indicates that pH increased rapidly after GAC was added, and adsorption with lower pH levels were never properly examined. Thus, the low fluoride adsorption by GAC for pH adjusted solutions may caused by pH quickly stabilizing at high pH levels. Permanent lowering of pH could influence the fluoride adsorption. To achieve a more stable pH throughout the lab-experiment GAC could be acid-treated or pH readjusted continuously.

Studies reveal that PAC exhibit better fluoride adsorption than GAC (Sheth and Gajjar, 2013; Jamode et al., 2004; Parlikar and Mokashi, 2013). Therefore it was expected that PAC would present better results than GAC. Overall, PAC performed slightly better fluoride adsorption than GAC, but the data plots were more fluctuating indicating errors influencing the results. Thus, improved adsorption capacity by PAC from GAC is negligible, and both adsorbents fail to sufficiently remove fluoride. Like GAC it consist of vegetal carbon and fluoride capacity is limited. One noticeable change is that PAC did not influence initial pH. This suggest that the two activated carbons are based on different source of carbon. Studies indicates that PAC would be more efficient at lower pH values.

Moringa and neem leaves

Neither moringa nor neem leaf powder exhibited any fluoride adsorption at all. In fact, leaf powder added a substantial amount of fluoride, increasing the amount by up to 32%. This reveals that the leaf powder hold fluoride ions which are released into the aqueous phase. The increase in fluoride indicates that the powder contains pollution. The pollution might origin from the surrounding area or through water entering the tree. Groundwater with high concentration of fluoride might also directly affect the tree and its leaves. Pollution might also arrive from transporting and preparing the leaves. The leaves were transported and crushed in a cotton jute bag and might be polluted with matter from the cotton jute bag. Adhered dirt, pollution and other matters were attempted removed by washing the leaves with distilled water. However, the leaves were dried in an oven which is usually used to dry sand with an air fan. This might also be a source of additional pollution.

In order to remove pollution, the leaves were alkali-treated with NaOH. Illustrated by graph 6.2, the alkali treatment successfully removed the additional fluoride added by the leaves. However, after treatment the leaves still failed to exhibit fluoride adsorption. Contradictory, Dan and Chattree (2018), Jamode et al. (2004), and P.S et al. (2017) successfully adsorbed fluoride by NaOH-treated neem and moringa leaves. With an initial fluoride concentration of 2 mg/L Jamode et al. (2004) observed 82% fluoride removal by alkali-treated moringa leaves at pH 8, while P.S et al. (2017) observed 60 % fluoride removal by alkali-treated neem leaves at pH 8 with initial fluoride concentration of 10 mg/L. The two studies observed conflicting effect of pH. In comparison to this thesis Dan and Chattree (2018), Jamode et al. (2004), and P.S et al. (2017) gently heated the leaf powder in NaOH solution for 20 minutes after boiling. In the present study, the leaf powder were mixed on a mechanical shaker for two hours without any heating process.

The leaf powder: dosage NaOH relationship were the same for all studies. The heating process might have changed the chemical and physical characteristics of the leaves which this study were not able to do without the heating process. This can explain why alkali treated neem and moringa leaf powder were not able to adsorb any fluoride in this present study, while other studies reveals a high fluoride adsorption for alkali treated neem and moringa leaves (Dan and Chattree, 2018; Jamode et al., 2004; P.S et al., 2017). Other differences between this current study and studies presenting high fluoride removal are only marginal and would have negligible effects on the results. Therefore it is reason to believe that the different results are caused by boiling the leaf and NaOH solution versus only mechanical mixing the solution. With preparations described in section 2.5.1 neem and moringa leaf powder are not efficient fluoride adsorbents.

Activated alumina

Untreated AA adsorbed up to 23% of initial fluoride with a dosage of 3.6 g AA. AA showed considerably improved fluoride adsorption efficiency compared to previous adsorbents examined in this thesis. This can be explain by fluorides high affinity for aluminium, as explained in section 6.2.4. Regardless of improved adsorption efficiency, the adsorption capacity is still too low to meet WHO recommendation of 1.5 mg/L fluoride. Thus, untreated AA is not a qualified adsorbent to remove sufficient amounts of fluoride. Like GAC, this dosage of AA increased pH from pH 6.5 (deionized water) to pH 10 which is an unfavourable effect.

In order to increase fluoride adsorption AA was treated with H_2SO_4.The dosage needed was substantially higher than in the procedure described by Duan et al. (2014) to achieve a acidic solution. Seen from graph 6.2 acid treatment gave outstanding results, removing up to 98% of initial fluoride. Acid treated AA increased fluoride adsorption by more than 4.2 times unmodified AA. This is more improvement observed by Duan et al. (ibid.) which reported that H_2SO_4-treatment AA increased maximum adsorption capacity almost 2.4 times compared to unmodified AA.

The improved results may caused by lowering of pH. During experiments with acid-treated AA pH ranged between 6-7. Previous studies reveals an optimum pH between 4-6 and claim almost no fluoride adsorption for pH levels above pH 8 (Ku and Chiou, 2002; Arfin and Waghmare, 2015). Untreated AA increased pH up to 10. Beyond pH 8, the presence of Al^{3+} will not form complexes with F^- because aluminium hydroxide complexes are predominating and F^- will occur as free fluoride ions in the aqueous solution (Ku and Chiou, 2002). Additionally will functional surface groups be negatively charged at high pH values and repel F^- (Morgan and Stumm, 1995).

The improved fluoride adsorption can also be due to addition of ${SO_4}^{2-}$. During acid treatment ${SO_4}^{2-}$ ions are adsorbed by electrostatic forces onto the surface of AA. As F^- has a stronger affinity towards aluminium than ${SO_4}^{2-}$, a possible ion-exchange reaction between ${SO_4}^{2-}$ and F^- can occur (ibid.). Duan et al. (2014) reported high amounts of free ${SO_4}^{2-}$ ions in the aqueous solution after treatment which indicates that the ${SO_4}^{2-}$ ions have been exchanged with fluoride. This is also seen in the present study, were increasing amount of free ${SO_4}^{2-}$ ions were observed with increased dosage of H_2SO_4-treated AA, indicating that ${SO_4}^{2-}$ at the surface of AA were exchanged with fluoride in the aqueous phase. Further, treated AA will be discussed.

6.4.1 Adsorption capacity

Adsorption capacity gives a specific indication of how efficient an adsorbent exhibit fluoride adsorption in relation to adsorbent dosage. Thus, adsorption capacity is relevant to calculate to evaluate the efficiency of various adsorbents. Adsorption capacity is calculated through determining isotherm model. This was a more challenging task than anticipated because the data obtained from experiments with activated carbon, untreated AA and leaves was not able to produce a satisfactory isotherm curve. An isotherm curve should have a clear flattening trend, which was not detected by any of the mentioned adsorbents. Only H_2SO_4-treated AA gave satisfactory data to produce an isotherm curve and therefore adsorption capacity is only calculated for H_2SO_4-treated AA.

Experiments with various dosages of H_2SO_4-treated AA are used to determine adsorption isotherm model. This is done twice with two different batches of H_2SO_4-treated AA. Freundlich and Langmuir isotherm are evaluated in order to calculate the adsorption capacity. Freundlich has the best curve fit for both batches. Both Langmuir and Freundlich had a relatively high R^2 which suggests a good fit for both isotherm models. However, negative Langmuir constant reveals that Langmuir model can not be used to describe fluoride adsorption onto treated AA. This is evident in that Langmuir adsorption capacity shows poor correlation with observed data. Freundlich adsorption capacity (3.43 mg/g) shows a strong association with observed data. Thus, fluoride adsorption on H_2SO_4 can be described by Freundlich adsorption isotherm according to results. This indicates heterogeneous and multilayered adsorption. This correlated with previous studies (**fito.Said**; S. George, Pandit, et al., 2010). Also, Freundlich adsorption intensity parameter indicates that H_2SO_4-treated AA is a favourable fluoride adsorbent.

6.4.2 The effect of time

The effect of time on fluoride adsorption shows the adsorption efficiency in relation to time. To give a more specific indicator on how fast fluoride is adsorbed by H_2SO_4-treated AA reaction rate is calculated.

H_2SO_4-treated AA showed a very high removal rate already within a few minutes. After 5 minutes 78.8 % of initial fluoride was removed, and after 15 minutes 93.4% was removed and the curve already starts to flatten out. The WHO recommendation was met within 15 minutes. Maximum of 98.2 % was removed by 4 hours. This indicates that H_2SO_4 is a very efficient fluoride adsorbent.

The adsorption rate clearly favours second order reaction rate. This result corresponds to results presented by Duan et al. (2014). It reveals that concentration of fluoride changes the reaction rate to the power of two. More specifically, the rate has a linear relationship with fluoride concentration to the power of two with a rate constant of 1.19 ($L{\cdot}mol^1\ h^1$), presented by equation B.6. The low rate factor indicates a fast fluoride adsorption process.

6.4.3 The effect of pH

Portrayed in graph 6.8 pH impacts the adsorption efficiency significantly, therefore pH dependency is relevant to examine in terms of fluoride adsorption efficiency. High adsorption efficiency at neutral pH is preferred so no pH readjustment is needed. GAC, PAC, leaf powder or untreated AA exhibit satisfactory fluoride adsorption at this pH range. However, it is discussed in literature that lower pH ranges may increase fluoride adsorption(Daifullah et al., 2007). This is supported by results presented in graph 6.8 which shows fluoride adsorption for untreated AA at unregulated pH (pH 9.5 ± 0.5), pH 4 and pH 6. This graph is strongly impacted by errors as explained in sector 2.5.3. Regardless, it shows a clear correlation between increasing fluoride adsorption and decreasing pH.

This study is done in the light of a possible novel fluoride adsorption method in rural Tanzania where resources are limited. Therefore, adjusting pH disfavoured as it complicates the process. H_2SO_4 exhibit high fluoride adsorption at neutral pH without changing the pH noticeably. This quality makes H_2SO_4-treated AA to an attractive fluoride adsorbent.

GAC and untreated AA increased pH values to about pH 10. However, pH of deionized water is sensitive and easily disturbed as buffer capacity is low. This suggest that GAC and untreated AA might not influence pH in natural waters as much as reported in this thesis. The effect of adsorbent on pH makes GAC and unmodified AA unfavourable fluoride adsorbents, regardless of adsorption capacity.

6.4.4 Evaluation of method

This study focuses on adsorbent dosage, agitation time and pH dependency for various adsorbents, because these factors affect fluoride adsorption the most (Araga et al., 2017). Apart from adsorbent dosage, time and pH impacting fluoride adsorption, studies also reveal that initial fluoride concentration and temperature influence fluoride adsorption efficiency. Due to limited time, the effect of initial fluoride concentration and temperature was not examined.

Initial fluoride concentration
Previous studies have observed increasing initial fluoride concentrations correlated with a decreasing rate constant for modified AA which indicates a faster fluoride adsorption process. Increasing adsorption capacity have been reported together with decreasing initial fluoride concentration for various adsorbents (Duan et al., 2014; P.S et al., 2017). This indicates that the adsorbents would exhibit improved fluoride adsorption for lower initial fluoride concentration.

Effect of temperature
In terms of effect of temperature on fluoride adsorption, studies reported conflicting results. While A. M. George and Tembhurkar (2018) reported higher adsorption capacity for higher temperatures for Ficus leaf, most studies observed a negative correlation between temperature and adsorption capacity, indicating that high temperature is not

favourable for fluoride adsorption (P.S et al., 2017; Tomar and D. Kumar, 2013). Despite conflicting results, most studies agree that temperature does not have a significant effect on fluoride adsorption capacity.

Adsorbent pollution
Non commercial adsorbents were washed prior to experiments. Adsorbent can adhere pollution and external salts which blocks available adsorption sites, can compose competitive ions and pollute the water. Pollution can change water characteristics such as increase in pH values which have been detected in the experiments. In order to examine whether low adsorption capacity by GAC was due to pollution, GAC was washed three times with deoinized water to remove pollution. Washed GAC did not perform better fluoride adsorption than unwashed GAC and pH increased drastically for both washed and unwashed GAC. This indicates that the low fluoride adsorption and increase in pH cause by GAC is not due GAC characteristics, and not to pollution. Untreated and treated leaves colored the water noticeably. This suggests that the leaves were not sufficiently washed prior to conducting the experiments. A sample was conducted with thoroughly washed untreated and treated leaves to see the effect on fluoride adsorption. Color was significantly reduce, while fluoride adsorption were not affected. Like GAC, this indicates that poor fluoride adsorption is not due to pollution, but the characteristics of the leaves.

6.5 Conclusion

This chapter aimed to answer research question: *What is the fluoride adsorption efficiency of various adsorbents in lab-facilities?*

Fluoride adsorption efficiency of various adsorbents is an important step to find a reliable fluoride removal method in rural settings in Tanzania. To determine adsorption efficiency of various adsorbents is a challenging and time consuming task and requires conducting lab experiments on various adsorbents. Therefore, it has been thoroughly discussed in this thesis, even though it only covers one aspect of assessing a fluoride removal method in Tanzanian settings.

To evaluate fluoride adsorption efficiency fluoride adsorbed(%) by various adsorbents gives a general indication of their fluoride adsorption efficiency, illustrated in graph 6.2. Although errors inflict the lab results, the graph gives a strong indicator of fluoride adsorption efficiency of GAC, PAC, alkali treated- and untreated neem and moringa leaf powder and untreated and acid treated AA. Acid treated AA was the only adsorbent able to meet WHO recommendation of 1.5 mg/L fluoride. Untreated AA achieved noticeable fluoride adsorption, while GAC and PAC only accomplished marginal fluoride adsorption. Additional fluoride added to the aqueous solution by untreated neem and moringa indicated that the leaf powder was polluted. Alkali treatment cleaned the leaves for external fluoride, but failed to improve adsorption capacity for the leaf powder. Studies reveal that the leaf powder can obtain higher fluoride capacity with different proceeding of alkali treatment than exhibited in the present thesis.

Since H_2SO_4-treated AA is the only adsorbent performing satisfactory fluoride removal, a more thorough examination of its fluoride adsorption efficiency was conducted.

Isotherm models were used to examine fluoride adsorption efficiency in relation to adsorbent dosage. H_2SO_4-treated AA favoured Freundlich isotherm, with a Freundlich adsorption intensity parameter of 2.27 indicating favourable adsorption. Adsorption capacity for H_2SO_4-treated AA calculated with Freundlich isoterm is 3.43 mg/g.

Rate law was used to evaluate fluoride adsorption efficiency for H_2SO_4-treated AA in terms of time. The data clearly favoured second order reaction according to calculations indicates a fast fluoride adsorption process.

H_2SO_4-treated AA exhibit satisfactory fluoride adsorption for neutral pH and does not affect pH noticeable, hence it does not acquire pH adjustment prior, nor post fluoride adsorption process.

H_2SO_4-treated AA adsorption capacity, reaction rate and well performing at neutral pH all makes H_2SO_4-treated AA an efficient fluoride adsorbent.

Chapter 7

Potential of neem and moringa as fluoride removal adsorbents

7.1 Introduction

Because of high fluoride levels together with poor availability of appropriate fluoride methods, cases of fluorosis have been detected in Tanzania. This urges the need of a suitable fluoride removal method for poor, rural Tanzanian settings. Since the use of leaves have been encouraged as a novel fluoride removal method by previous studies, this thesis aims to answer the following research question:

What is the potential of neem and moringa leaves to remove fluoride from groundwater in poor, rural settings?

This chapter starts of by discussing fluoride and fluoride removal methods in the light of rural Tanzanian challenges. Then, *Discussion and results* reviews the potential of implementing and operating fluoride treatment in the light of social aspects. This is followed by an evaluation concerning practical use of neem and moringa as fluoride adsorbents based on the lab experiment conducted in this thesis. A critical evaluation of solving applied challenges with experimental research from laboratory facilities is presented before the chapter finishes off with conclusion.

7.2 Background

Fluoride are introduced to the groundwater through natural sources, such as chemical weathering and volcanic emissions, or industrial impacts for example the use of phosphate fertilizers. In Tanzania, volcanic activity in the East African Rift Valley cause the high fluoride levels. (Bakken and Evang, 2020).

By collecting 595 fluoride data points from boreholes throughout Tanzania, Malago (2017) observed a mean fluoride concentration of 3.07 ± 8.31 mg/L in the Tanzanian groundwater. Manyara region, where Haydom is located, has the second highest fluoride concentration in Tanzania after Arusha region. Mean fluoride concentration in Manyara region was reported to be 7.98 ± 5.73 mg/L with a median of 11.80 mg/L, exceeding both WHO (1.5 mg/L) and Tanzanian national standard (4.0 mg/L) noticeably (Malago, 2017; TZS, 2003). Tanzania houses the highest national upper fluoride concentration limit in the world (WHO, 2018). Natural high occurrences of fluoride along with poor availability of appropriate fluoride removal methods would cause Tanzania to abandon 30% of their water sources if they were to lower the limit to WHO guideline value of 1.5 mg/L (Malago, 2017).

Despite advancement in fluoride treatment research it still compose a challenge amongst underprivileged people in developing communities (WHO, 2018). Due to inappropriate fluoride removal methods for poor rural settings the groundwater is often not treated for fluoride despite high fluoride concentration. Onipe et al. (2020) reports that households of low socioeconomic status in rural areas are most prone to exposure of high levels of fluoride because they often depend on groundwater as their source of water. Furthermore, people in poor areas are particularly vulnerable to flourosis because their general mineral intake is low (Nwankwo et al., 2020). Consequently, Tanzanian villagers ingest excessive amounts of fluoride and are prone to fluorosis. High fluoride concentrations in groundwater have been linked to severe cases of dental and skeletal fluorosis in Tanzania by Jarvis et al. (2012). This confirms that many places in Tanzania groundwater needs to be treated for fluoride prior to consumption.

A fluoride removal method should satisfy the following conditions in order to be appropriate in poor, rural Tanzanian settings.

- Sufficiently efficient to reduce fluoride levels within an acceptable range.
- Be cheap in both cost and power demand. It follows that is should be locally available in order to avoid additional costs due to storage and transportation.
- Be easily applicable, operated and maintained without requiring a high level of professionalism so the locals are able to take responsibility for management.
- Not increase collateral effects in terms of water quality, such as additionally taste, odour, colour or organic materials. It is favourable if the method reduce any of these water characteristics in addition to removing fluoride.
- Lastly, the method should be environmentally friendly also regarding its disposal. Thus it is favourable to minimize chemicals used in the method.

Several methods to reduce fluoride levels have been studied, such as coagulation/precipitation, electrolysis, ion exchange, and reverse osmosis. Adsorption is the most commonly used method because of its easy application, readily availability and that it do not require high level of professionalism to maintain and operate. As many commercial available adsorbents are too expensive, researchers are urging the need for a locally available, cheap, easily applicable adsorbent to use for developing, poor small scale water supply systems. Most commonly used is activated alumina due to its proven high efficiency of fluoride removal which is confirmed in chapter 5. However due to high cost activated alumina is rarely used in developing settings (Srimurali et al., 1998). Non-conventional adsorbents, such as leaves, have been reported as suitable adsorbents for fluoride removal, but with varied adsorption efficiency (Dahi, 2016; Bharali and Bhattacharyya, 2015; S. Kumar et al., 2007).

In order to reduce fluoride levels in Tanzania, Nalgonda technique was initially introduced. However, the method has several downsides. It requires imported chemicals, high amount of alum and has a sludge problem which is difficult to handle at community level. After showing disappointing results, the Nalgonda technique has more or less been abandoned in Tanzania (Dahi, 2016).

Today, bone char filters are most common to remove fluoride at small community scale in Tanzania. Bone char filters are commercially available and the Ministry of Tanzania have launched domestic bone char filters which are disseminated to households and schools. Despite its extensive usage in Tanzania, the bone char process also comes with disadvantages. It is reported as in-affordable for poor populations, education is needed to operate and maintain, frequent surveillance of filters is required and its removal efficiency is limited where fluoride occurs together with high bicarbonate levels (ibid.). More problematic is that it is considered unhygienic as it can harbor bacteria. In some areas, the use of bone is intolerable due to religious and traditional views. Thus, there is a need to develop an efficient, locally available, cheap, easily maintained and operated, environmental friendly and socially acceptable fluoride method.

7.3 Discussion and results

When evaluating the potential of a fluoride removal method in rural Tanzania several aspects have to be taken into consideration. Therefore the potential of implementation of a fluoride removal method is first discussed in the light of social aspects followed by an evaluation of the potential of practical application based on the lab experiment conducted in this thesis.

7.3.1 Awareness

Idini et al. (2020) reports that socially acceptance by rural communities and municipalities for a novel technology is a challenge. Therefore, first step of an assessment of potential implementation is studying the attitude towards a novel fluoride removal method amongst the villagers.

In Endanachan and Munguli it has been observed fluoride concentrations above the Tanzanian standard limit of 4 mg/L, illustrated in figure 7.1. Regardless, according to the survey conducted in this thesis does most of the correspondents in the two villages respond that excessive fluoride is not a problem in their village, showed in figure 7.2. In Endanachan no one responded that fluoride was a problem. This demonstrates that the villagers are not aware that excessive fluoride levels is a challenge in their village. Education and raised awareness amongst villagers is necessary if fluoride is to be removed at a household level.

When presented with the question which applied to all communities if anything were done in their community to reduce fluoride levels, most correspondents answered that nothing was done. The few responding "Yes" said fluoride was removed by boiling or adding chlorine to the water. Since such measures do not reduce fluoride levels, this reveals misleading knowledge on how to treat fluoride in drinking water.

This implies that without further education about fluoride, villagers would not take the initiative to remove fluoride properly themselves. A solution could be to educate villagers about occurrences and consequences of high fluoride levels. Another alternative is that groundwater fluoride treatment is handled at a regional level.

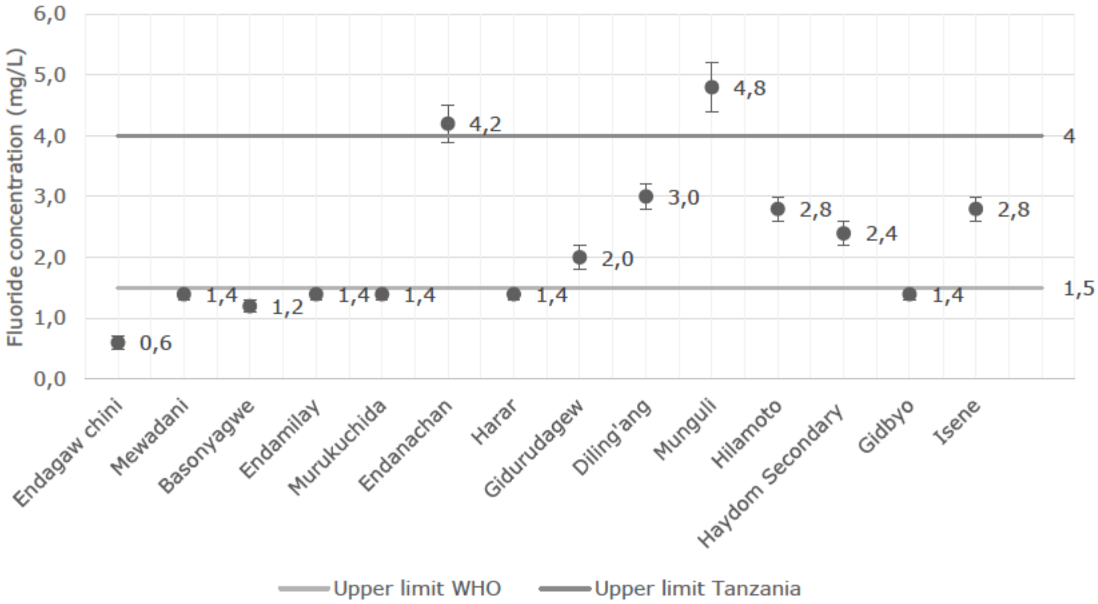

Figure 7.1: Fluoride concentration of water samples from 14 pumping stations (Asklund, 2020)

Responsibility of fluoride treatment

As seen in figure 7.3 the survey reveals that the majority of the community and the COWSO prefer fluoride treatment to be dealt with at regional level, that is by the RUWASA. Also, all three correspondents from RUWASA agreed that RUWASA should be in charge of fluoride treatment.

In order for the RUWASA to operate fluoride removal, the villagers have to be willing to pay for the additional service. It can be assumed that willingness to pay is closely related to awareness of excessive fluoride levels. Conflicting with this assumption, figure 7.4 shows that willingness to pay is high regardless of low awareness. 90% of the correspondents said they were willing to pay more for water to remove fluoride. As the large majority would be willing to pay for fluoride treatment there is a potential for fluoride removal to be economically sustainable and profitable.

Low awareness amongst villagers, high willingness to pay and a general concurrence

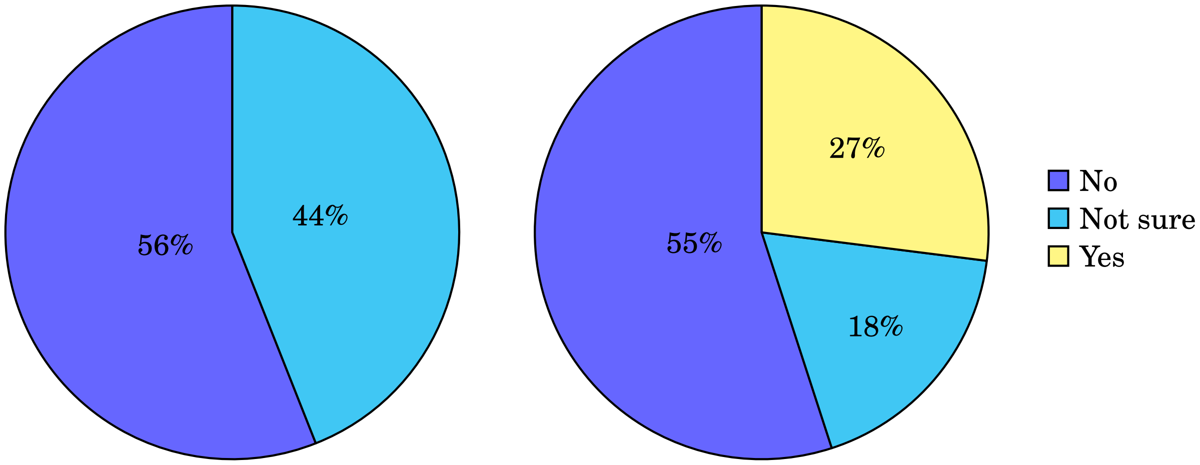

Figure 7.2: Is excessive levels of fluoride in the groundwater a problem in your community? (left: Endanachan(18 correspondent) right: Munguli(11 correspondents))

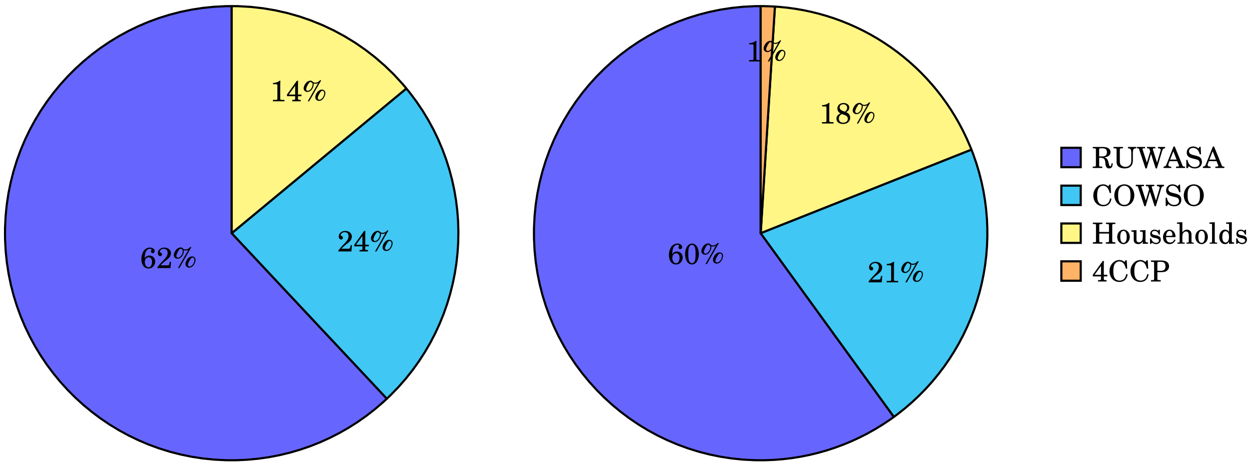

Figure 7.3: Who should be responsible for removing fluoride from the drinking water? (Left: Responses from COWSO (22 correspondents). Right: Responses from community(283 correspondents)

that the RUWASA should be in charge of fluoride treatment, all points to that fluoride removal should be managed at a regional level, rather than at household level.

Regional level can manage a higher level of professionalism required by the removal method because of available technicians and resources. Regional technicians hare responsible for multiple boreholes and can not manually manage fluoride removal at each borehole. Thus, the fluoride removal method needs to be easily operated and require low level of maintenance.

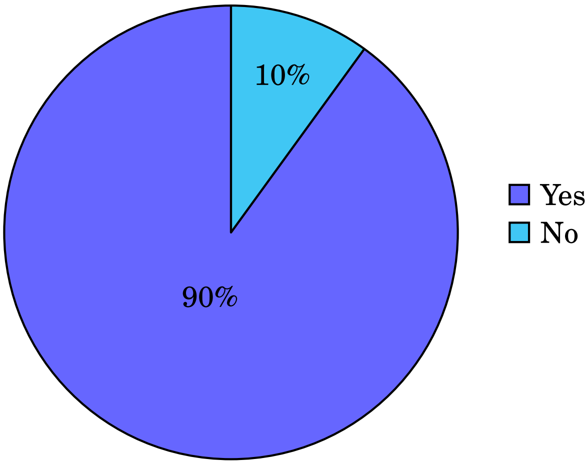

Figure 7.4: Would you be willing to pay more for the water to remove fluoride from the drinking water? (283 correspondents)

7.3.2 Neem and moringa leaves as fluoride adsorbents

With the aim to suggest an easily maintained and operated fluoride method, an adsorption experiment with neem and moringa leaves has been carried out and examined.

Leaves as a novel adsorbent have been encouraged by several studies (Bharali and Bhattacharyya, 2015; S. Kumar et al., 2007; P.S et al., 2017; Parlikar and Mokashi, 2013; Dan and Chattree, 2018). The encouragement is closely related to its local availability and low cost. Opposed to bone char, leaves are socially acceptable to use in potable water because leaves are commonly used for tee and does not offend any religious views. This thesis focuses on neem and moringa leaves as potential fluoride adsorbents.

Both neem and moringa leaves are extensively available in Tanzania. Consequently there is no additionally expenditure related to transportation and storage. This makes the leaves easily attainable and low cost adsorbents.

Experiences from lab experiment

4CCP rapidly collected 2 kg of leaves without any complications reported. In addition to high cost and availability, previous adsorbent preparations have been stated to be too energy consuming (personal communication with Gislar Kifanyi 07.09.20). In this thesis, the preparation of leaves where conducted with the aim to be simple, and require as little energy and time as possible, see section 2.5.1. The leaves were dried in the sun and manually crushed in a cotton jute bag, requiring no additional energy at all. Figure 7.5 shows moringa leaves after they were manually crushed.

To prepare the leaf powder up until this point was a simple process. A challenge first presented itself when washing the powder. When mixed with water, the leaf powder gave a strong colour to the water which indicated a need of washing the powder. Preferably, the leaves should have been washed before it was crushed into powder, but this was not done due to miscommunication. Because of soluble pigments prewashing the

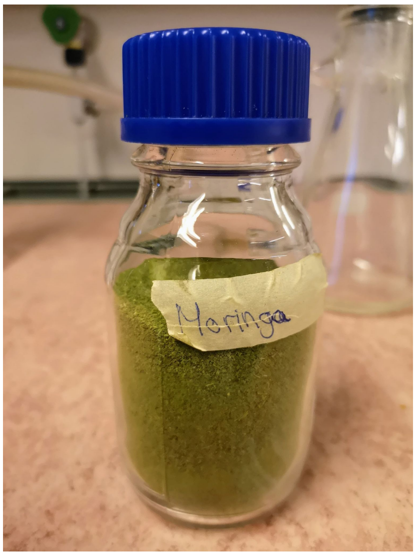

Figure 7.5: Unwashed moringa leaf powder

powder would probably be necessary in both cases. The leaf powder can be washed using filtration or sedimentation. Dan and Chattree (2018) and Jamode et al. (2004) washed leaf powder with filtration until the water was clear. The same procedure was attempted for this thesis. The powder clogged the filters, making it a time consuming process. In addition, a significant amount of water was used in order to wash the leaf powder. Sedimentation was also carried out to wash the leaf powder. In order to clear the water it was necessary to decant the solution multiple times. Some of the leaf powder was lost in this time consuming process. During the lab, it became clear that a large amount of water was necessary to wash small amounts of leaf powder using either filtration or sedimentation. In the light of rural Tanzanian challenges, using a large quantity of water to produce adsorbent is unrealistic as water is a limited resource. Preferably, the water used to clean the leaves should be free from fluoride. Thus, it is paradoxical to use treated water in order to treat water.

After the intent to wash the leaves, the water treated with leaves acquired a strong colour and odour as seen in figure 7.7. This implies that more thorough washing of the leaves is necessary.

According to experiments conducted in this thesis, untreated moringa and neem leaves exhibit no fluoride adsorption. Quite the opposite, more fluoride was observed after treatment with leaves than initially. Thus, with the described preparation presented in section 2.5.1, moringa and neem leaf powder failed to exhibit fluoride adsorption and the method was more resource demanding than anticipated.

Studies report improved fluoride observation with alkali and acid treatment (Dan and Chattree, 2018; Jamode et al., 2004). For this, the leaves had to be washed exhaustively once again. Figure 7.6 shows the colour after alkali treatment. As seen, the colour was deep and an intense, sharp odour was detected. Compared to first time washing the leaf powder, the colour and odour was stronger when washing the leaves after alkali

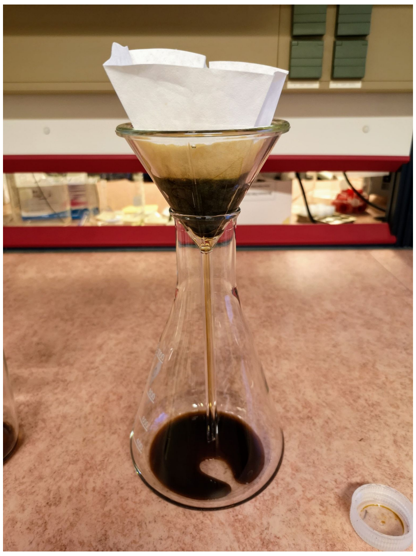

Figure 7.6: Filtrating leaves after Alkali treatment

treatment. Water was washed through the filter until it was clear. Therefore cleaning the leaf powder for after alkali treatment required more water and was in general a time demanding process.

The leaves were then dried in an oven for several hours, which is both time and energy consuming. Alternatively, the leaves can be sun dried to save energy.

Water still gained colour and odour when it was treated with H_2SO_4-modified moringa and neem, as well as unmodified leaf powder, shown in figure 7.7.

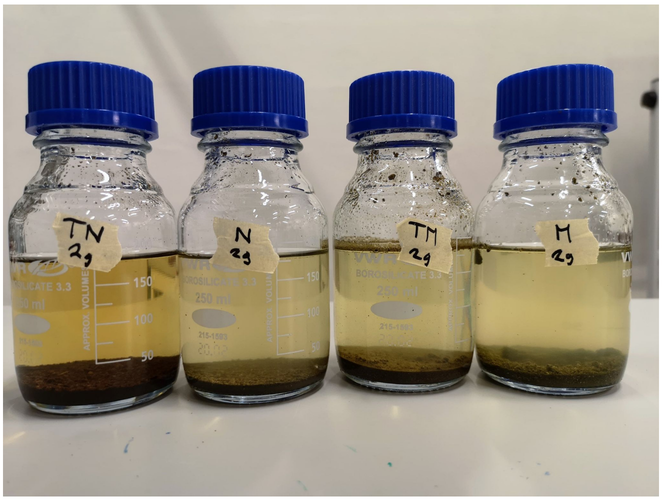

Figure 7.7: Gained colour after treatment with leaves

Concluded in chapter 6, leaves need to be heated in NaOH-solution in order for alkali treatment to enhance fluoride adsorption. This will increase the complexity of the

Figure 7.8: Mold growing on neem leaf powder

preparation of the leaves further.

After less than 10 days, mold was observed on the neem leaf powder as seen in figure 7.8. This indicates that the leaf powder can not be stored for longer periods of time.

Because of low adsorption capacity and challenges related to the process leaves are not an potential fluoride adsorbent according to the lab experiment conducted in this thesis.

Bridging lab experiments and field applications

Looking through fluoride adsorption research one could catch the impression that there are tremendous solutions of non conventional methods for poor rural settings. However, examining applied fluoride treatment in Tanzania the impression is quite the opposite and the need of a novel and cheap fluoride method is still urgent. This shows that there exist a large gap between experimental research and practical experiences.

In alignment with this, observations from this thesis strongly indicates that lab measures are difficult to apply in the field. Lab assessment are only done for small dosages of adsorbent and does not consider larger scale operations. Great amount of clean water is used to wash small dosages of leaf powder. It is unrealistic to used the same amount of water for large scale operations. The leaf powder was difficult to wash by filtration and sedimentation. No easily applied method to thoroughly wash and dry leaf powder was established in this thesis.

A strong colour and odour was detected in this thesis. It was also seen that the leaf powder could not be stored in room temperature for longer time. Neither of this observations have been reported in previous studies, as most studies are narrowed down to determine theoretical fluoride adsorption efficiency.

Chemical modifications have been suggested to enhance fluoride adsorption capacity for leaf powder. Chemical treatment of the leaf powder would increase complexity of the method and requires chemicals, equipment and resources. Initially, leaves were encouraged as a novel method because it was low cost, locally available, socially acceptable and environmental friendly. Chemicals are not as locally available and easily obtained as leaves, and would therefore raise the price of the leaf powder. In addition, disposal would not be as environmental friendly because the added chemicals are not as safely disposed as organics. Alkali or acid treatment fluoride adsorption optimum was observed at extreme pH values Jamode et al. (2004). pH adjustment prior and post treatment should be avoided because it increases complexity of the method.

As developing an applied fluoride removal method covers more than obtaining satisfactory fluoride efficiency, more research should focus on bridging the gap between experimental research and practical application, operation and maintenance.

7.4 Conclusion

In order to evaluate the potential of moringa and neem leaves a lab experiment was conducted with the aim to suggest an appropriate method for poor rural Tanzanian settings. A potential method requires complex leaf treatment using large volume of water, chemicals and equipment. In field, these requirements cause the method to be not as easily applicable, low cost nor locally available than anticipated. Therefore according to this study, results shows using neem and moringa as fluoride adsorbents has low potential to remove fluoride for rural settings in Tanzania by using neem and moringa leaf powder.

To evaluate the potential of a fluoride removal method in poor rural settings in Tanzania more aspects have to be considered in addition to adsorption efficiency.

The potential of a novel fluoride method also depends on effort from the community. Therefore awareness, willingness to pay and who should be responsible for fluoride treatment was examined. Results from this thesis indicate that there is a high potential to implement a fluoride method operated and maintained at a regional level.

Research should aim attention to practical implementation and bridge the gap between experimental research and field application.

Chapter 8

Collective conclusion

This thesis has seized to evaluate and detect opportunities to improve the groundwater reliability in Hanang, Mbulu and Mkalama districts in Tanzania in terms of availability, management and quality.

Availability

The data from remote monitoring sensors in Basonyagwe and Mewadani showed that the groundwater level has risen during the last year, even though extraction through pumping is performed. There has been more precipitation the last year compared with the average rainfall from the last 30 years, which means that it is probable that the groundwater level is higher than normal. Still, as the groundwater level increased from February to May 2020 and was relatively stable from May to January 2021 in both of the villages, it shows that the pumping does not reduce the groundwater level substantially and further extraction can be performed.

Management

According to the survey, 73% of the respondents of the community members are very or somewhat satisfied with the current water system. Our results reveal that a well-functioning Community-Owned Water Supply Organization (COWSO) will increase the faith the community members have in the COWSO but will not necessarily increase the community members' level of satisfaction with the water services. The level of satisfaction is therefore proven to be influenced by other factors than the performance of the COWSO.

This study found that the level of satisfaction is strongly influenced by the distance to the well and having to use a local well as a non-improved water source in the dry season. Focusing effort on improving water access to people living far away from an improved water source and to people using local wells as their drinking water source in the dry season, will increase the level of satisfaction significantly.

Fluoride removal

Excessive levels of fluoride threaten groundwater reliability in terms of quality. H_2SO_4-treated activated alumina (AA) exhibit high fluoride adsorption. However, fluoride removal with H_2SO_4 treated AA is too costly to adopt in rural Tanzanian settings. According to this thesis, adsorption with low-cost neem and moringa leaves are not suitable as a fluoride removal method in rural Tanzania due to advanced preparation necessary to exhibit satisfactory fluoride adsorption.

This research shows that groundwater in the study area is reliable in terms of availability but that lack of adequate water supply management hamper sufficient and continuous drinking water supply. In areas where excessive fluoride levels occur, groundwater is not reliable in terms of quality due to lack of appropriate fluoride removal methods. With the aquifer, a non-modifiable factor, being adequate for providing water in Tanzania, the government can focus on management in their work on ensuring the entire population access to clean water.

Chapter 9

Future work

This thesis has left some challenges unresolved and revealed other challenges yet to be studied.

The remote monitoring systems in Mewadani and Basonyagwe are still operating. To better understand the impact of extraction, climate change and land use changes on groundwater it is necessary to monitor groundwater level over several years. Thus, a continuation of groundwater level monitoring can be utilized to improve groundwater management. Monitoring groundwater level can also detect correlations between the geological conditions and groundwater capacity, which can ease the process of choosing locations for wells.

One of the main challenges addressed in this study is that many people live far away from an improved water source. Future studies can make models for how to provide sufficient water to people living far from a well. Cost-analysis and capacity-analysis of dispatching of water versus constructing new wells would provide valuable information.

Results from this thesis show that people's level of satisfaction with the water services is not reflected in the level of satisfaction with the COWSO. Therefore, it is valuable to carry out an analysis comparing people's level of satisfaction with an objective evaluation of the performance of the water services, in contrast to the subjective evaluation of water services conducted in this thesis.

Future assessments about water management should include sanitation and hygiene in order to get a more comprehensive picture of all aspects concerning the WASH-situation. Protecting water sources from faecal contamination impacts water supply quality significantly.

WASH-related diseases are often caused by poor sanitation and hygiene, thus it is insufficient to only evaluate water supply to improve health. Good hygiene decelerates infection rate, which is of particular importance as a global pandemic is prevailing.

This study is limited to just aim attention at water supply and does not focus on water demand. As water resources are scarce, optimized water resource allocation and water usage should be further studied. Reuse of water is essential to optimize water usage. An assessment on how to reduce water demand would be of significant importance.

This study was not successful at suggesting an appropriate fluoride adsorption method for rural Tanzanian settings. Hence, novel, locally available, and low-cost adsorbents should be further investigated. Research can focus on applicability in rural settings and carry out cost assessment for the entire fluoride removal procedure including the adsorbent preparation. Some adsorbents of interest are moringa seeds (Magroliya and Trivedi, 2017), neem stem charcoal, brick powder, and biochar from industrial and agricultural waste (Yadav et al., 2006; Jamode et al., 2004; Tomar and D. Kumar, 2013; Trivedi and Magroliya, 2017)

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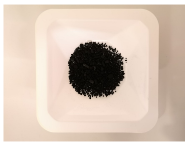
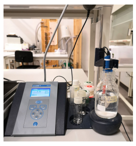
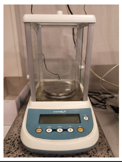
Appendices

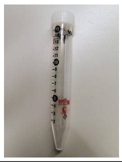
Appendix A

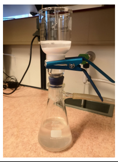
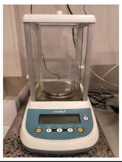
Laboratory equipment

Table A.1: Lab equipment

Laboratory equipment	
Adsorbents:	
GAC	
PAC	
Activated Alumina	
Neem leaf powder	
Moringa leaf powder	
Chemicals:	
NaF 1M	

H_2SO_4 0.1 M and 1 M	
HCl 0.1 M	
NaOH 1M	
Measuring devices:	
940 Professional IC Vario Metrohm	
hach- sension pH meter	
Micro balances weight VWR	
Equipment for adsorption experiment;	
Mechanical shaker	
VWR borosilicate beakers	
Plastic square weight boat	
Wash bottle with deionized water	

VWR borosilicate 3.3 Reagent bottle, 250 ml	
Volumetric flasks 200 mL $\pm$ 0.15 VWR	
Pipette (finnpipette) 1-5ml	
Dropper with pipette bulb	
Light duty tissue wipers	
Syringe	
0.2 µm syringe filter, VWR	
0.2 µm test tubes, 50 mL, VWR	
Rubber stopper	
Timer	
Plastic spoons	
Kimtech nitrile Single use laboratory gloves	
Lab coat	

Lab Safety goggles	
Distilled water	
Deionized water	
Equipment for adsorbent washing and chemical modification:	
Vacuum filter	
Weight	
PPCO bottles, 200 mL	
Funnel	
Dessicator	

Appendix B

Fluoride calculations

B.1 Isotherm fitting

Adsorption capacity, q_e is derived from equation 2.4 with initial concentration of fluoride (mg/l), C_0, equal 9.848 mg/L from table B.1. This is plotted in graph 6.3.

Langmuir Isotherm fitting

Presented in section 2.5.2, Langmuir isotherm exist as equation 2.6 in linear form.

$$\frac{C_e}{q_e} = \frac{1}{b_e \cdot Q_m} + \frac{C_e}{Q_m} \tag{2.6}$$

Merging equation 2.6 and linear regression from Langmuir equation results in equation B.1.

$$\frac{C_e}{q_e} = C_e \cdot 0.7778 - 0.1682 \tag{B.1}$$

From the slope and intersection from equation B.1, the Langmuir parameters are calculated as shown:

Table B.1: Equilibrated blank data

Sample No.	Initial Fluoride concentration (mg/L)
1	9.813
2	9.906
3	9.690
4	9.985
Average:	**9.848**
Std:	0.1268

$$\frac{1}{Q_m} = 0.7778$$
$$\longrightarrow \mathbf{Q_m} = 1.286$$

$$\frac{1}{b_e \cdot Q_m} = -0.1682$$
$$\longrightarrow \mathbf{b_e} = -\mathbf{4.624}$$

In order to reduce 10 mg/L to 1.5 mg/L:

$$q_e = \frac{Q_m \cdot b_e \cdot C_e}{1 + b_e \cdot C_e} \tag{2.5}$$
$$q_e = \frac{0.7778 \cdot -0.1682 \cdot (10 - 1.5)}{1 - 0.1682 \cdot (10 - 1.5)}$$
$$\longrightarrow \mathbf{q_e} = \mathbf{1.517 mg/g}$$

B.2 Freundlich isotherm fitting

From section 2.5.2 Freundlich isotherm is linearly presented by equation 2.8.

$$\log(q_e) = \log(K_e) + \frac{1}{n}\log(C_e) \tag{2.8}$$

By merging equation 2.8 and the linear regression from graph 6.5, equation B.2 present itself as shown:

$$\log(q_e) = 0.4413 \cdot \log(C_e) + 0.1247 \tag{B.2}$$

From the slope and intersection from equation B.2, the Freundlich parameters are calculated as shown:

$$\frac{1}{n} = 0.4413$$
$$\longrightarrow \mathbf{n} = \mathbf{2.266}$$

$$log(K_e) = 0.1247$$
$$\longrightarrow \mathbf{K_e} = \mathbf{1.333}$$

To reduce 10 mg/l to 1.5 mg/l:

$$q_e = K_e \cdot {C_e}^{1/n} \tag{2.7}$$
$$= 1.333 \cdot C_e^{0.4413}$$
$$q_e = 1.333 \cdot (10 - 1.5)^{0.4413}$$
$$\longrightarrow \mathbf{q_e} = \mathbf{3.427 mg/g}$$

Table B.2: Summary of Freundlich parameters

n	K_e	q_e	R^2
2.266	1.333	3.427	0.9293

Figure B.1: Zero order reaction rate for fluoride adsorption by H_2SO_4-treated AA

B.2.1 Reaction order fitting

Graph B.1, graph B.2 and graph B.3 illustrates curve fitness to zero, first and second order reaction rate respectively.

The plotted data has a good fit for second order reaction ($R^2 \pm 0.961$). Therefore reaction rate of H_2SO_4- treated AA can be described by second order reaction by equation B.3 and in linear form by equation B.4.

$$Rate = k[F^-]^2 \tag{B.3}$$

Table B.3: Summary

Reaction order	R^2
Zero order reaction	0.394
First order reaction	0.767
Second order reaction	0.961

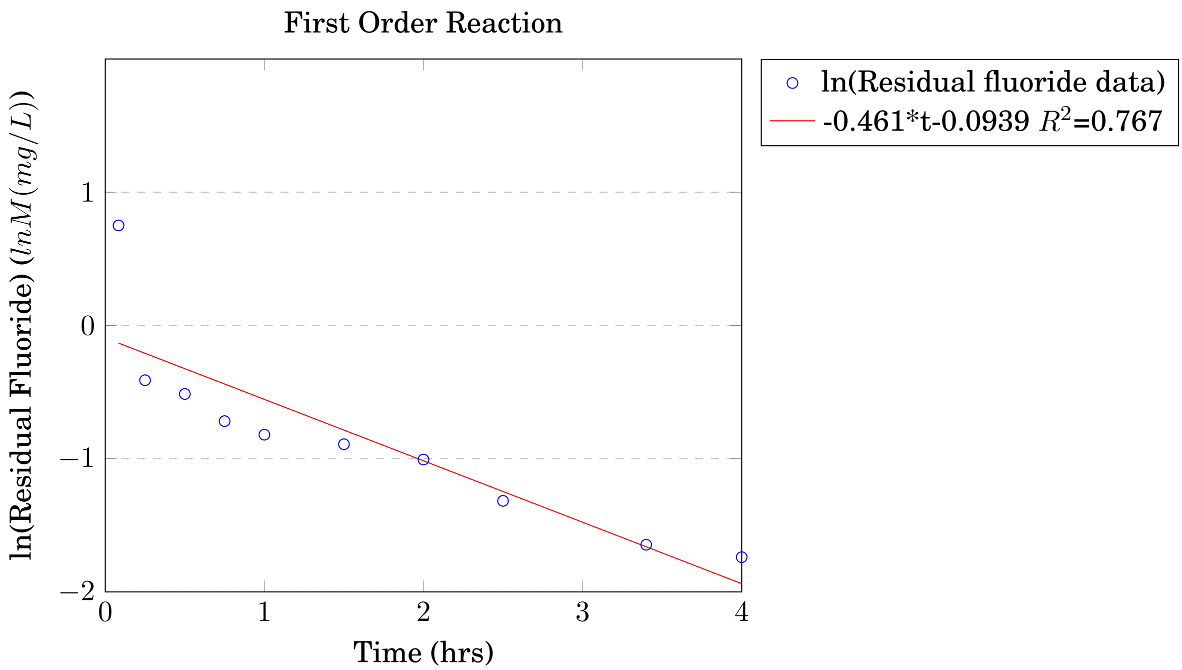


Figure B.2: First order reaction rate for fluoride adsorption by H_2SO_4-treated AA

Figure B.3: Second order reaction rate for fluoride adsorption by H_2SO_4-treated AA

$$\frac{1}{[F^-]} = kt + \frac{1}{F_0^-} \tag{B.4}$$

$$\frac{1}{[F^-]} = 1.19t + 0.87 \tag{B.5}$$

By merging equation B.4 and equation B.5, the slope determines the rate constant. Thus, the rate constant equals 1.19 . Based on equation B.3 the reaction rate for H_2SO_4-treated AA is described by equation B.6.

$$Rate = 1.19[F^-]^2 \tag{B.6}$$

Evang and Bakken

Reliable Water to Rural Districts in Tanzania

NTNU

Norwegian University of
Science and Technology