

ANALYSIS OF HE INFLUENCE OF DRINKING WATER TREATMENT PROCESSES ON DRINKING WATER TREATMENT BYPRODUCTS FORMATION USING FREE CHLORINE AND COD AS INDICATORS

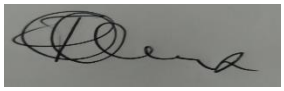
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JULY, 2021

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Abstract

it is evident that while disinfection increase the drinking water quality, by end of the day some disinfection by products are formed which are toxic to humans. Some of the disinfection byproducts are such as trihalomethanes and halo acetic acids. Although these byproducts don't have an immediate effect, they tend to accumulate in human bodies hence causing body disorders and diseases since they are carcinogenic. The main aim of the project was to assess the influence of water treatment processes on the formation of DBPs using proxy indicators (free chlorine and COD). The study was also done to assess the raw water characteristics, to evaluate the influence of filtration mechanisms/ systems on formation of DBPs as well as to investigate how treatment plant operating regimes affect DBPs formation. Both the free chlorine and the COD were measured using the thermo Orion method accepted the United States environmental protection agency (USEPA). The turbidity and pH for the raw water was found to be 102 ntu and 8.14 respectively while the COD for the raw water was found to be 1.72 whereas after GAC and sand filtration the value started to decrease and then increase thereafter showing production of disinfection byproducts. The study shows that combination of pre-chlorination and sand filtration yields the minimum disinfection byproducts compared to the other combinations.

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TABLE OF CONTENTS

DECLARATION BY CANDIDATE 5
LIST OF FIGURES AND GRAPHS 10
LIST OF TABLES 11
CHAPETER ONE 12
INTRODUCTION 12
1.1. BACKGROUND INFORMATION 12
1.2. PROBLEM STATEMENT 15
1.3. RESEARCH OBJECTIVES 15
1.3.1. Main objective 15
1.3.2. Specific objectives 15
1.4. RESEARCH QUESTIONS 15
1.5. SIGNIFICANCE OF TE STUDY 16
CHAPTER TWO 17
LITERATURE REVIEW 17
GRANULAR ACTIVATED CARBON (FILTRATION) 17
CHLORINATION 18
SAND FILTRATION 19
PRE-CHROLINATION 20
FREE RESIDUAL CHLORINE 20
CHEMICAL OXYGEN DEMAND 22
CHAPTER THREE 23
MATERIALS AND METHODS 23
3.1 Study design 23
3.2 Study area 26
3.3 Sample size and sampling method 26
3.4 Data collection and data collection tools 27
3.5 Data analysis 28
CHAPTER FOUR 29
RESULTS AND DISCUSSIONS 29
CHAPTER FIVE 38
CONCLUSIONS AND RECOMMENDATIONS 38
REFERENCES 39

ABBREVIATIONS

COD……CHEMICAL OXYGEN DEMAND

DBP……DISINFECTION BYPRODUCTS

THM……TRIHALOMETHANES

HAA……HALOACETIC ACIDS

CL……RESIDUAL CHLORINE

GAC……GRANULAR ACTIVATED CARBON

LIST OF FIGURES AND GRAPHS

Figure 1 showing research study workflow

Figure 2 showing drinking water treatment pilot plant setups

Figure 3 Map showing Lichenza river

Figure 4 showing raw water from Lichenza River before treatment

Figure 5 showing GAC filtered and prechlorinated water

LIST OF TABLES

Table 1 showing raw water characteristics

Table 2 showing measured values of the variables

Table 2 showing t-Test: Paired Two Sample for Means

CHAPETER ONE: INTRODUCTION

1.1. BACKGROUND INFORMATION

Disinfection of drinking water is important to prevent waterborne diseases. Since its introduction in the United States in the early 1900s, sterilization is believed to have contributed significantly to extending life expectancy to 29 years (Mackeown et al., 2020). The unintended consequence of sterilization is the formation of disinfection by-products (DBP), which are associated with adverse health effects such as bladder cancer, colon cancer, miscarriage, and birth defects.Several recent studies have shown that THM and HAA are the main DBPs formed after chlorination, but are not necessarily the cause of the toxicity associated with DBD formation. Multiple MON fractions can react to form THM and HAA, but the phenolic structure of MON has been shown to form haloacetaldehyde (For, Management & New, 2019). Free and bound amino acids, aldehydes and aromatic MON have been shown to form haloacetamides and haloacetonitrile. The presence of inorganic nitrogen, such as ammonia, nitrite, and nitrate, may be involved in the formation. Nitrogenous DBP (NDBP) is generally more toxic than non-nitrogenous DBP, but NDBP is currently not regulated.Numerous studies have shown that unregulated iodineDBP is generally more toxic than brominated DBP (BrDBP), much more toxic than chlorine analogues. The use of granular activated carbon (CAG) is well established to control THM and HAA. Because it can effectively remove the fraction of MON that acts as a precursor (Smith & Lynam, n. Research, GAC does not readily remove some NDBP precursors. The GAC column is located in the tributary.) Similar to GAC, although containing disinfectants, decreased disinfectant at the top of CAG columns and increased biomass in the remaining rows (Cuthbertson et al., 2019).Therefore, in addition to adsorption of DBP precursors, biodegradation plays a role in CAG treatment. Many drinking water plants use pre-oxidation (for example, pre-chlorination). This can lead to the formation of DBPs in the processing system. Pre-formatted DBPs; they can be removed with GAC, or with additional sterilization, can serve as precursor materials for the formation of other DBPs. One ability gain of preoxidation is transformation of NOM into intermediate fragrant halogenated DBPs, which can be greater effortlessly eliminated via way of means of GAC than large precursor molecules. GAC preferentially gets rid of

dissolved natural carbon (DOC) over dissolved natural nitrogen (DON), and it does now no longer cast off bromide(Vahala, 2002). Slow-sand water filtration isn't a brand new concept; it's been used for loads of years for its cappotential to lessen waterborne illnesses. It is expected that there are over 500,000 human beings in growing international locations presently the use of sluggish sand filters. Slow-sand water filters have many advantages: they do now no longer require chemicals, are effortlessly maintained, and are noticeably inexpensive(Sand, Use, & Sand, 2001). Slow-sand water filtration works thru mechanisms: robotically filtering micro organism thru the grains of sand, and the adsorption of micro organism to a biofilm layer called the schmuetzedecke, a German phrase for "grimy blanket". The schmuetzedecke layer paperwork some of the pinnacle few centimeters of sand withinside the water clear out out. The first technique of filtration for sluggish-sand water filters is a easy mechanical filtration. A particle of excellent sand is more or less 60 micrometers, and the gap among grains of very excellent sand is even smaller. Bacteria are regularly barely large than the areas among sand and soil particles. For example, Salmonella typhi is rod-fashioned and is just a few micrometers in duration and diameter. As water is surpassed thru the sluggish-sand clear out out, a number of the micro organism can be trapped in the areas among the sand, and water will keep to byskip thru. Trapped micro organism will then make contributions to the biofilm layer, the schmuetzedecke. The maximum crucial issue of a sluggish-sand water clear out out is the biofilm layer. Mechanically straining the microorganisms withinside the sand isn't almost as powerful because the filtering approaches that arise withinside the schmuetzedecke, which includes micro organism, algae, and different unmarried and a couple of mobileular organisms. Initial filtration performance with out a schmuetzedecke layer is more or less 60%(Clark, Pinedo, & Capuzzi, 2012). As greater microorganisms byskip thru the schmuetzedecke, new microorganisms adhere to the formerly deposited organic count number constructed up withinside the pinnacle layers of the sand. The important organic approaches that take vicinity withinside the pinnacle layers of the clear out out include "predation, scavenging, herbal death/inactivation and metabolic breakdown". These approaches are predicted to decorate over time, as "adulthood of the sand mattress is a important thing influencing particle and microorganism removals". An powerful biofilm layer takes among one to a

few weeks develop. Most of the filtration in a sluggish-sand clear out out happens at the clear out out surface, almost absolutely withinside the biofilm layer. However the intensity of the clear out out remains additionally critical to consider. A clear out out with a extra intensity permits the clear out out to be scraped and wiped clean earlier than extra sand is needed. There are different variables that may adjust the effectiveness of a slow-sand water clear out out: the dimensions of the sand debris, and the uniformity of the sand debris. The uniformity of the sand debris is represented through the uniformity coefficient, that's simply as critical as the dimensions of the sand grains(Kato, Asami, Utagawa, & Furumai, 2018). Over the closing 30 years, substantial studies efforts had been directed closer to growing our know-how of disinfection byproduct (DBP) formation, occurrence, and fitness effects. More than six hundred DBPs have now been pronounced withinside the medical literature, aleven though simplest eleven are presently regulated through the United States EPA. Various manipulate techniques are to be had to make certain that water utilities offer ok number one disinfection at the same time as minimizing DBPs withinside the distribution system. Some manipulate techniques recognition on options to chlorine for disinfection practices (e.g., chlorine dioxide, ozone, or UV for number one disinfection and chlorination for residual disinfectant), at the same time as others recognition on extra diploma of elimination of DBP precursors via supply water protection, superior coagulation, powdered activated carbon (PAC) adsorption, or granular activated carbon (GAC) adsorption, to call a few (States & Protection, 1994). However this task will recognition an awful lot on how halo acetic acids formation is suffering from pre-GAC chlorination and post-GAC chlorination techniques in addition to pre-sand filtration chlorination and post-sand filtration chlorination strategies in ingesting water treatment.

1.2. PROBLEM STATEMENT

In order to achieve high quality standard drinking water, in drinking water treatment plants several operational techniques including filtration and disinfection through chlorination are used. However, it has been found out that while disinfection increase the drinking water quality, by end of the day some disinfection by products are formed which are toxic to humans. Some of the disinfection byproducts are such as trihalomethanes and halo acetic acids(Al-shatri, Nuhu, & Basheer, 2014). In other countries or areas, they use pre-

chlorination and granular activated carbon treatment to treat drinking water while in Malawi chlorination and sand filtration are mostly used but then all these techniques produce a certain amount of disinfection by products hence there is a need to find out the levels of the disinfection byproducts (thus using free residual chlorine and COD as indicators) produced when these different operational techniques are used in order to achieve minimum levels of byproducts formation to improve the health safety of people using treated drinking water. The raw water was taken from lichenza river simulating shire river which is the main raw water source for treatment in the southern region.

1.3. RESEARCH OBJECTIVES

1.3.1. Main objective

- To assess the influence of drinking water treatment processes on the formation of DBPs using proxy indicators (free chlorine and COD).

1.3.2. Specific objectives

- To assess the raw water characteristics
- To evaluate the influence of filtration mechanisms/ systems on formation of DBPs
- To investigate how treatment plant operating regimes affect DBPs formation.

1.4. RESEARCH QUESTIONS

- How do operational conditions in drinking water treatment affect the formation of disinfection byproducts?
- What is the influence of filtration mechanisms on disinfection byproducts formation?
- How treatment plant operating regimes affect DBPs formation.
- What are the levels of the physical parameters in the raw water?

1.5. SIGNIFICANCE OF TE STUDY

The study was conducted to help fill the information gap that exist in terms of operational techniques and how they affect disinfection byproducts. Using free residual chlorine as an indicator to determine the levels of DBPs formation is going to simplify the determination of the DBPs formation levels since it is easy to analyze. The study will also help relevant decision makers to make informed decisions in order to protect human health.

CHAPTER TWO: LITERATURE REVIEW

GRANULAR ACTIVATED CARBON (FILTRATION)

GAC filters are hired as fixed-mattress absorbers including granular media filters or put up filters. It is an powerful barrier towards many dissolved contaminants found in water. GAC can preferentially soak up contaminants from water because of its massive floor area, floor chemistry and speedy adsorption kinetics. It can put off hydrophobic fraction of humic acids (HAs), decrease molecular weight humic- and fulvic acids. On the contrary, a few researcher have determined that decrease molecular weight be counted is greater amendable than better molecular weight be counted because of length exclusion effect. Therefore the adsorption NOM is in particular managed via way of means of the molecular length distribution of NOM and pore length distribution of carbon. Background NOM reduces the adsorption of hint stage contaminants. Therefore if the motive of putting in GAC filtration is to put off hint organics, then the clear out out need to be positioned as put up clear out out filtration unit. The predominant mechanism of adsorption onto GAC are adsorption of soluble NOM, bodily filtration of particulate NOM (Moona, 2017). Granular activated carbon (GAC) adsorption is well-installed for controlling regulated disinfection byproducts (DBPs), however its effectiveness for unregulated DBPs and DBP-related toxicity is unclear. In this examine, GAC remedy turned into evaluated at 3 complete-scale chlorination ingesting water remedy vegetation over extraordinary GAC provider lives for controlling sixty one unregulated DBPs, nine regulated DBPs, and speciated overall natural halogen (overall natural chlorine, bromine, and iodine). The vegetation represented a variety of affects, consisting of algal, agricultural, and commercial wastewater. This examine represents the maximum significant complete-scale examine of its type and seeks to cope with the query of whether or not GAC could make ingesting water more secure from a DBP perspective(Knezev, n.d.). Overall, GAC turned into powerful for doing away with DBP precursors and decreasing DBP formation and overall natural halogen, even after >22 000 mattress volumes of dealt with water. GAC additionally efficiently eliminated preformed DBPs at vegetation the usage of

prechlorination, consisting of extraordinarily poisonous iodoacetic acids and haloacetonitriles. However, 7 DBPs (normally brominated and nitrogenous) improved in formation after GAC remedy. In one plant, an growth in tribromonitromethane had substantial affects on calculated cytotoxicity, which best had 7-17% discount following GAC. While those DBPs are extraordinarily poisonous, the overall calculated cytotoxicity and genotoxicity for the GAC dealt with waters for the opposite vegetation turned into decreased 32-83% (throughout young-middle-antique GAC). Overall, calculated toxicity turned into decreased put up-GAC, with preoxidation permitting in addition reductions. According to Mackeown (2020), the presence of an intermediate chlorination step on this water remedy plant lets in to evaluate the performance of the complete-scale activated carbon filtration to put off DBPs. While preceding research determined that a few I-THMs had been eliminated via way of means of GAC filtration, scarce records at the elimination performance of I-DBPs in a complete scale ingesting water remedy plant is available(Krasner, Chih, Lee, Westerhoff, & Fischer, 2016).

CHLORINATION

Chlorine is the maximum broadly used disinfectant for the inactivation of waterborne pathogens in consuming water substances and traditionally has arguably made the finest contribution to the general public fitness safety of consumers. In addition to its use as a number one disinfectant put up treatment, the residual degree which stays withinside the distribution structures guarantees that the microbiological compliance may be pleasant confident to the client faucet in addition to safeguarding towards recontamination withinside the distribution system(Branz et al., 2017). Chlorination is a especially easy and fee powerful procedure which does now no longer require big technical information and that is able to managing deliver structures of various length through changing dosing structures or garage for chemical touch accordingly. In Ireland, chlorination has traditionally been carried out the usage of structures concerning the garage and dosage of chlorine fueloline. Some of those fueloline installations continue to be in energetic use and could require ongoing steering on their use for water disinfection and for control of related fitness and protection risks(Cuthbertson et al., 2019). However, because of the poisonous nature of chlorine fueloline, those installations have extreme fitness and protection risks,

which should be managed. The ongoing improvement and availability of different chlorination technology such as: liquid sodium hypochlorite garage and dosage structures; advances in electro chlorination era concerning the onsite batch manufacture of sodium hypochlorite has allowed Irish municipal and personal water providers to rethink those options whilst making plans new chlorination installations or upgrading current installations as a substitute for chlorine fueloline. Most of the more recent installations set up withinside the Irish marketplace now use those liquid hypochlorite technology as options to gaseous chlorination (Sorlini, Palazzini, Sieliechi, & Ngassoum, 2013).

SAND FILTRATION

Slow sand filtration has been used correctly in Europe for the reason that early 1900s, and remains a famous technique of treating municipal water elements. Research, and different observations, display that sluggish sand filtration can successfully eliminate cysts and coliform microorganism from uncooked water, and is an innovative, price powerful, low renovation remedy procedure. This device works first-rate as a part of a multi-barrier remedy approach. A sluggish sand clear out is constructed from a mattress of graded sand that is supported via way of means of a layer of gravel (Ngene & Tota-maharaj, 2020). This clear out media is restricted in a field with openings at each ends permitting water to waft in and out, even as running on a pinnacle-down, gravity basis. The filtration procedure - a shape of natural, organic water remedy - is used to eliminate solids, precipitates, turbidity (muddiness) and in a few instances bacterial debris that produce awful flavor and odor. Slow sand filtration is well-appropriate to deal with farm water elements which have affordable uncooked water quality. It is an excellent pre-remedy procedure for floor water containing parasites, microorganism and suspended solids. However, prescreening/settling can be required previous to filtering for water with a excessive algae awareness or could be very turbid. Slow sand filtration is likewise powerful at treating groundwater with excessive iron and sulphur gases (Eng, Bryant, & Tetteh-narh, 2015). With iron and dissolved gases eliminated, different procedures consisting of softening and demineralization, may be included into an average in-residence remedy

procedure. A sluggish sand clear out (SSF) is a method of treating water for ingesting water functions and includes filtering water thru a mattress of 'media' (typically sand). It is straightforward in design, production and operation. It includes a tank inner of which lies a 'mattress' of sand (i.e. media), supported via way of means of gravel, mendacity on a appropriate under-drainage floor. The clear out is restricted inside a tank, normally square or round in form and can be 2.five to four metres deep. Water enters on the pinnacle of the tank, in which it is living for some of hours because of the sluggish percolation of water thru the mattress of sand beneath. Water then passes thru a layer of gravel and the under-drainage (Water, 2005). Systems downstream of the clear out out vary, however easy structures might also additionally contain handiest a weir and clean water reservoir. Treatment of water in a SSF is basically performed via way of means of ecological procedures. Micro-organisms colonise the floor regions of the sand grains and feed on impurities within the water because it filters passed. This procedure gets rid of impurities from the water. The organic increase at the clear out out media and the cloth this is eliminated via way of means of the clear out out clogs the sand mattress, especially on the top floor of the mattress. Eventually the clear out out is simply too clogged for water to clear out through it and it need to be cleaned (e.g. via way of means of skimming). Periodically eliminating the pinnacle layer of sand via way of means of guide or mechanical 'skimming' (additionally called scraping) permits the clear out out to preserve to characteristic efficiently. The term among skimming is referred to as a SSF 'run'. The requirement for skimming is typically proven via way of means of an exponentially growing head loss (e.g. because of clogging on the sand's floor) and a related decline in SSF floor loading rate (possible waft rate) (Kato et al., 2018).

PRE-CHROLINATION

In consuming water remedy, prechlorination and protonation are regularly implemented to be able to manage micro-organisms and flavor and scent inflicting materials, which may also have an effect on organics elimination via way of means of pre-oxidation and adsorption in consuming water(Torabian, Ghadimkhani, Mehrabadi, Shokouhi, & Heidarzadeh, n.d.). The United States Environmental Protection Agency imposed

stringent rules governing chlorination of consuming water substances due to the fact this identical chemical, which had stored such a lot of lives, produced suspected cancer agents within the presence of obviously going on natural count number). Two corporations of those capability cancer agents are trihalomethanes (THMs) and halo acetic acids (HAAs). Both shape while chlorine reacts with herbal natural count number in uncooked water. According to the 1995 Community Water Systems Survey performed via way of means of americaA Environmental Protection Agency (USEPA), 14.2% of floor water remedy structures servicing a populace of 50,001-100,000 are the use of ClO2 as a predisinfectant as compared to 47.5% the use of chlorine, 15.5% the use of chloramines, and 5.4% the use of ozone (Yu & Xu, 2014).

FREE RESIDUAL CHLORINE

Although Geldreish (1996) has stated the loose chlorine residual among 1.2 mg/L to 0.three mg/L which could manipulate the wide variety of microbial at beneath a hundred and 500 for each milliliter sample, consuming water distribution machine (DWDS) within the tropical us of a have to be dealt with as a completely unique case due to the climate. The temperature round 25 - 35 oC is pretty ultimate for maximum microbes to develop and it additionally will increase the chlorine evaporation price that reduces the hypochlorous acid within the equilibrium reaction. The hydrochlorous acid is the hydrolyzed shape of chlorine in aqueous with robust functionality of killing extensive spectrums of pathogens. Strong daylight additionally reduces the hypochlorate balance via way of means of photo-degradation system (Nowell and Hoigne, 1992). Moreover, heavy rainfall obtained each yr at 1000-2000 mm additionally have an effect on the consistency of water remedy machine operation. This look at mentioned the chlorination system precept and exhibits the loose chlorine residual inside a consuming water distribution machine positioned in Peninsular Malaysia(Sarbatly & Krishnaiah, 2007). The chlorination system withinside the DWDS has been practiced in many nations to stumble upon the water bone diseases. It additionally beneficial as a disinfections agent, scent removal, algae re-increase protection, bleaching agent, will increase coagulation of the activated silica and stops the regrowth of the microbial (White, 1992). The advanced blessings of the chlorine as compared to different halogens chemical substances including bromine, and fluorine as disinfectant,

well-understood of its facet consequences to the human life. Besides, clean to shop and transport, aggressive price, non-stop prevention of microbial re-increase, and offers the only belongings to manipulate numerous pathogen spectrums. Despite the chlorine houses which could manipulate the water bone diseases, its facet consequences required rules and requirements to restrict to a minimal level. World fitness organization (WHO, 1993) set the loose chlorine residual in consuming water have to be round 0.2 - 0.three mg/L for 30 min touch time. The consuming water secure act 1974, modification 1986 (SWDAA) outlines that the loose chlorine have to be much less than 0.2 mg/L at any shipping points. Since the pioneering paintings of Rook (1974), many investigations have additionally been performed withinside the formation and the precursors of chlorination disinfection via way of means of-products (CDBPs) (Blatchley, 2003; Ge at al., 2006). Chlorine in water combines with herbal natural compounds NOM to yield a huge variety of CDBPs including trihalomethanes (THMs), halo acetic acids (HAAs), chlorophenols, phenolic acids, chlorinated quinines well-knownshows probably carcinogenic, teratogenic and mutagenic sports to human fitness (Yang and Shang, 2004). Therefore the United State Environmental Protection Agency (USEPA) (1994) has set the THMs have to now no longer more than 0.1 mg/L on the consumption point(Ghernaout & Elboughdiri, 2020).

CHEMICAL OXYGEN DEMAND

Chemical oxygen demand (COD) is described as the quantity of a distinctive oxidant that reacts with the pattern beneathneath managed conditions. The amount of oxidant ate up is expressed in phrases of its oxygen equivalence. Because of its specific chemical properties, the dichromate ion is the desired oxidant in Methods 5220B, C, and D; it's miles decreased to the chromic ion in those tests. Both natural and inorganic additives of a pattern are issue to oxidation, however in maximum instances the natural factor predominates and is of the more interest. If it's miles favored to degree both natural or inorganic COD alone, extra steps now no longer defined right here have to be taken to differentiate one from the other. COD is a described test; the quantity of pattern oxidation may be stricken by digestion time, reagent strength, and pattern COD concentration(Introduction, 1997). COD frequently is used as a dimension of pollution in wastewater and herbal waters. Other associated analytical values are biochemical oxygen demand (BOD), overall natural carbon

(TOC), and overall oxygen demand (TOD). In many instances it's miles viable to correlate or greater of those values for a given pattern. BOD is a degree of oxygen ate up via way of means of microorganisms beneath precise conditions; TOC is a degree of natural carbon in a pattern; TOD is a degree of the quantity of oxygen ate up via way of means of all factors in a pattern whilst complete (overall) oxidation is achieved. In a COD analysis, unsafe wastes of mercury, hexavalent chromium, sulfuric acid, silver, and acids are generated (Mkwate, Chidya, & Wanda, 2017). Methods 5220C and D lessen those waste troubles however can be much less correct and much less representative.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study design

The research study is an experimental study in which the levels of the measured variables were quantified hence having an experimental quantitative study design. The rea water was sampled from Lichenza River at Nansadi Bridge using the random grab sampling method. The physical parameters including pH, turbidity and temperature were measured onsite while the chemical oxygen demand and the residual free chlorine were determined in the laboratory. Data was analyzed using MS excel for figures and tables and some statistical tests.

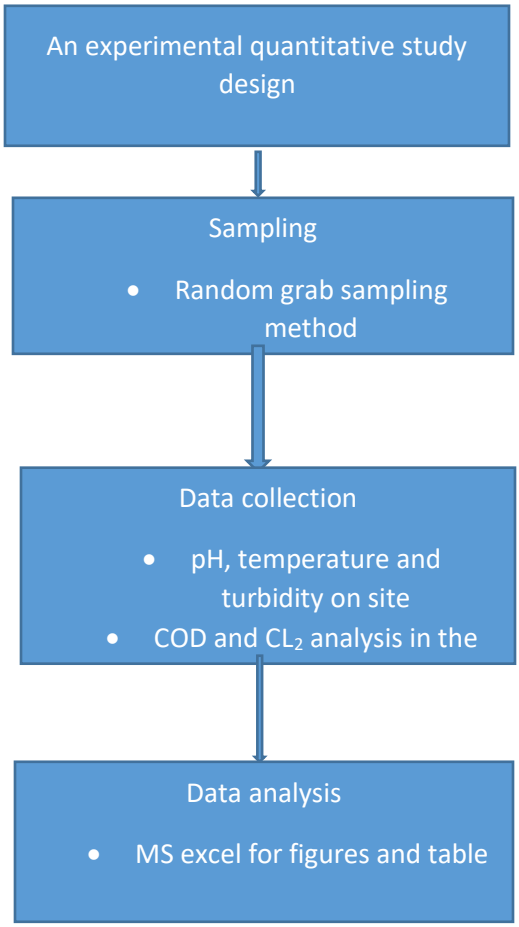


Figure 1 showing research study workflow

Experiment set up design

This research was an experimental quantitative research in which different operational techniques were used, analyzed as well as optimized in order to achieve minimum disinfection byproducts formation in other words levels of disinfection byproducts formation with regard to the operational technique will be analyzed.

Since it was an experimental research, a pilot plant was constructed in the laboratory. The pilot plant constituted combination of different operational techniques as follows:

- Prechlorination with slow sand filtration
- Prechlorination with GAC
- Post-chlorination with slow sand filtration
- Post chlorination with GAC

Set up 1

Raw water collected and put in a 20 L bucket. The bucket had two outlets with the same outflows of 1ml/min. The first outlet was directed straight to the sand filter which was constructed using a 2l bottle, sand and some gravel stones. The second outlet was directed straight to the granular activated carbon filter which was constructed using a 2l bottle, granular charcoal which was activated using nitric acid. The water from the two filters was collected in separate 5L containers. Using chlorine, the treated water was disinfected leaving a free residual chlorine of 1mg/L.

Set up 2

Chlorine was put in the raw water in the 20l bucket and the other processes were just as in set up 1.

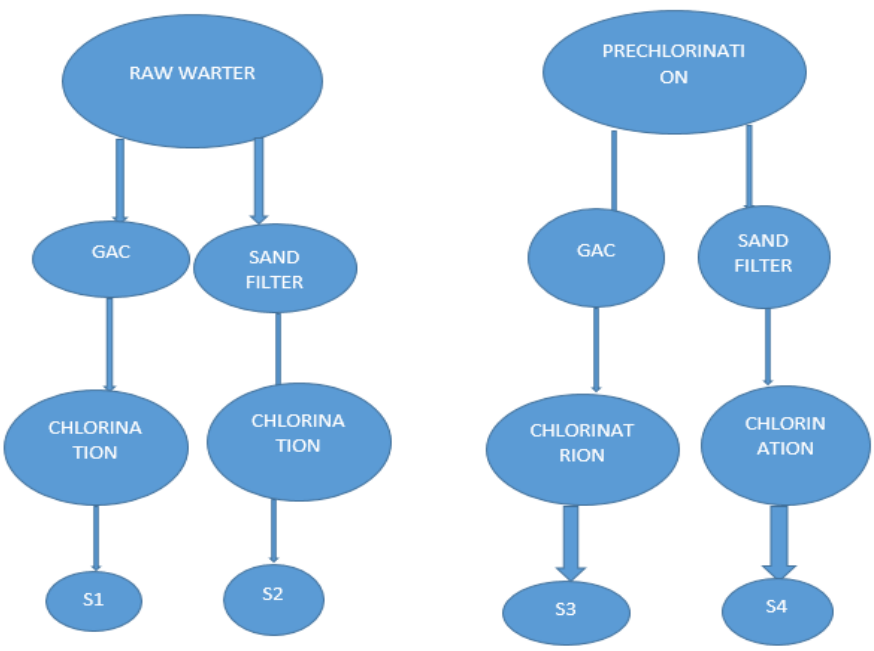




Figure 2 showing drinking water treatment pilot plant setups

3.2 Study area

Raw water that was used in this research was taken from Lichenza River in Thyolo district in southern region of Malawi. The water was treated and analyzed in the environmental quality testing laboratory at the Malawi University of science and technology. The physical parameters of the raw water were measured on site.

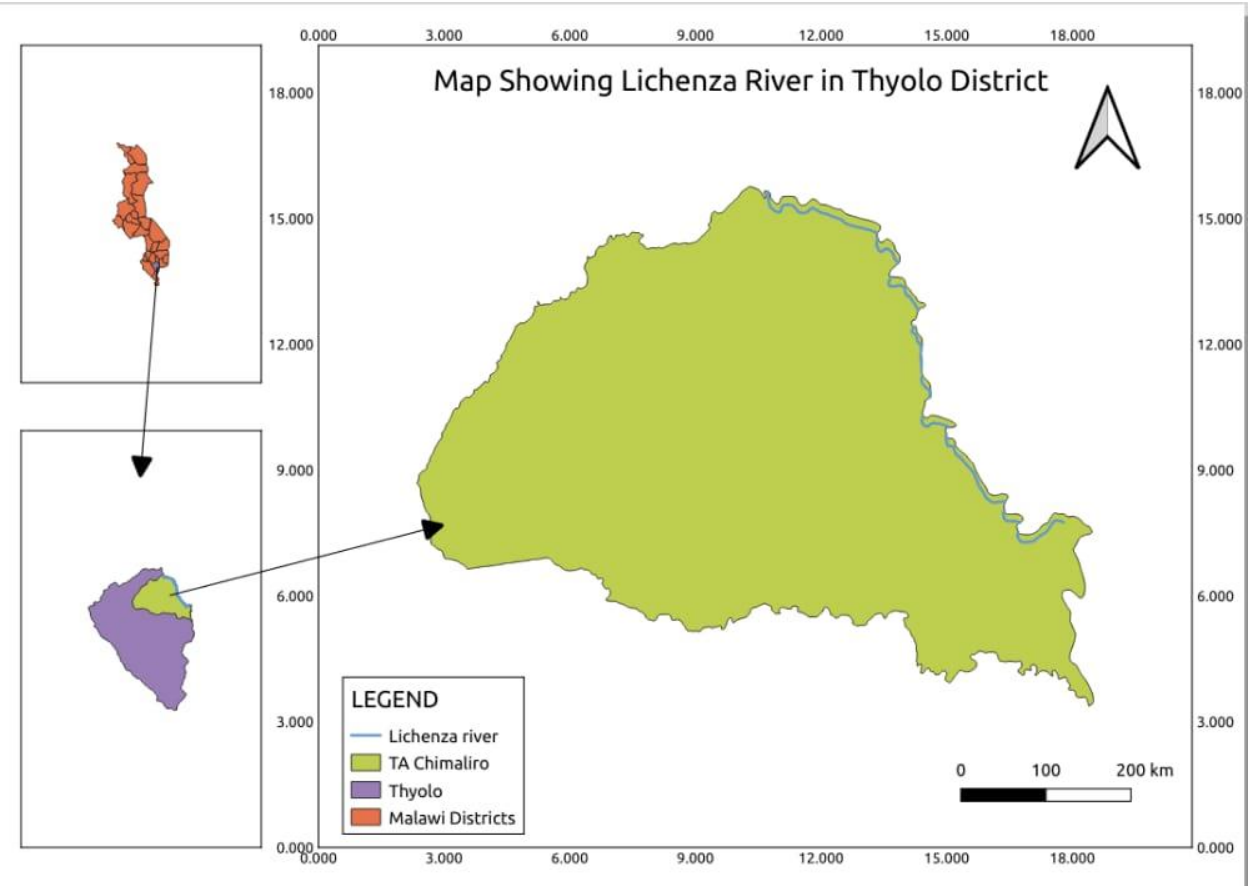


Figure 3 Map showing Lichenza river

3.3 Sample size and sampling method

The operational conditions resulted into 13 samples in which the residual chlorine and the COD were analyzed and random grab sampling method was used. In total, there were 13 samples, 1 sample was the raw water and the 12 were obtained after treatment in consideration of the operational conditions.

3.4 Data collection and data collection tools

PH and temperature was measured using a multi probe aqua meter while turbidity was measured using the turbidity HT 1000 spectrophotometer.

Residual free chlorine measurement

The free residual chlorine was determined using the dpd method in which 10ml sample was reacted with DPD number 1 and quantified using HT 1000 spectrophotometer.

COD measurement

Cod was determined using the Thermo Orion Method CODL00 and CODH00 accepted by the United States environmental protection agency (USEPA, 2003). In this method, Samples, standards, and blanks were heated at 150 +/- 2 0C in a closed reactor for two hours in the presence of acid dichromate solution. The COD was quantified using the MD 100 spectrophotometer.

Pilot-plant process flows

The pilot plant was designed and located in the Malawi University of science and technology environmental quality testing laboratory. The process flows included pre-treatment (pre-chlorination), sedimentation, sand filtration (GAC filtration in another set up) and post-chlorination. Pre-treatment will be done by the use of chlorine (chlorination).

Disinfection

Free chlorine stock solution was prepared using sodium hypochlorite solution. The disinfection was done leaving a free residual chlorine of 1mg/L in both setups. Samples in both setups where at different time scales starting at t=0 where samples were collected just after initial disinfection. The other samples were taken after 30mins and also after 2hrs in both setups. COD and free chlorine concentrations were measured using the standard thermo Orion method. In the pre chlorination setup, chlorine was initially put in the raw water to achieve a residual chlorine of 1mg/L.

3.5 Data analysis

Data was analyzed using MS Excel for figures and tables. The variations were assessed using Analysis of Variance (ANOVA).

CHAPTER FOUR: RESULTS AND DISCUSSIONS

In order to characterize the raw water, the physical parameters were measured and below are the findings:

PARAMETER	VALUE
TURBIDITY (NTU)	102
PH	8.14
TEMPERATURE (^{0}C)	19.3
COD (mg/L)	1.72

Table 1 showing raw water characteristics

Temperature, COD and pH were within the drinking water standards while the turbidity exceeded the maximum allowable limit of 5NTU. The initial COD of the river shows that the part of the river where the water was sampled is less polluted since it falls within the range of 1- 4 mg/L. high turbidity levels of the river maybe be a result from the human activities taking place along and in the river more especially sand mining and irrigation of farms along the river.

After running the system using the post chlorination technique, the variables were measured and the results were recorded in the table below showing results at different test times (T=0mins, T=30mins, T=120mins)

T=0			
PARAMETERS	**RAW**	**GAC**	**SAND**
TURBIDITY (NTU)	102	2	3
PH	8.14	7.7	9
COD (mg/L)	1.72	0.6	0.8
CHLORINE (mg/L)	0	1	1
T=30mins			
PARAMETERS	**RAW**	**GAC**	**SAND**
TURBIDITY	102	2	3

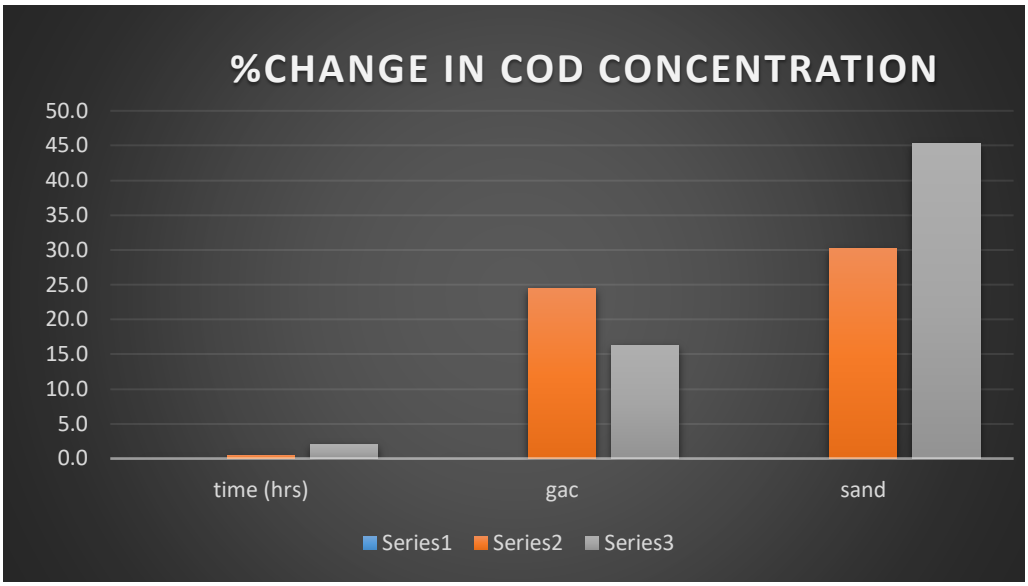
PH	8.14	7.6	8.8
COD (mg/L)	1.72	1.98	2.23
CHLORINE (mg/L)	0	0.5	0.6
		T=160min	
PARAMETERS	**RAW**	**GAC**	**SAND**
TURBIDITY	102	2	3
PH	8.14	7.7	8.7
COD (mg/L)	1.72	2.4	2.9
CHLORINE (mg/L)	0	0.4	0.3

Upon running the systems in both setups using pre-chlorination technique, the water that was collected was disinfected and tests were run to obtain the following values:

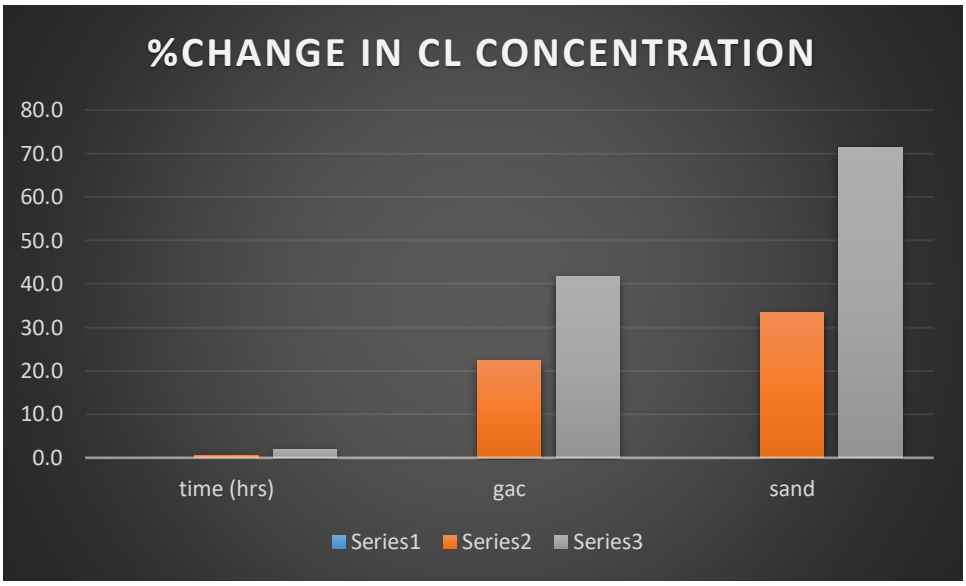
		T=0mins	
PARAMETERS	**RAW**	**GAC**	**SAND**
TURBIDITY	102	2	2
PH	8.14	7.3	7.8
COD (mg/L)	1.72	1.21	0.84
CHLORINE (mg/L)	0	1.03	1.05
		T=30mins	
PARAMETERS	RAW	GAC	SAND
TURBIDITY	102	2	2
PH	8.14	7.3	7.8
COD (mg/L)	1.72	1.3	1.2
CHLORINE (mg/L)	0	0.8	0.7
		T=120mins	
PARAMETERS	**RAW**	GAC	SAND
TUBIDITY	102	2	2
PH	8.14	7.2	7.8
COD (mg/L)	1.72	2	2.5
CHLORINE (mg/L)	0	0.6	0.3

Table 2 showing measured values of the variables

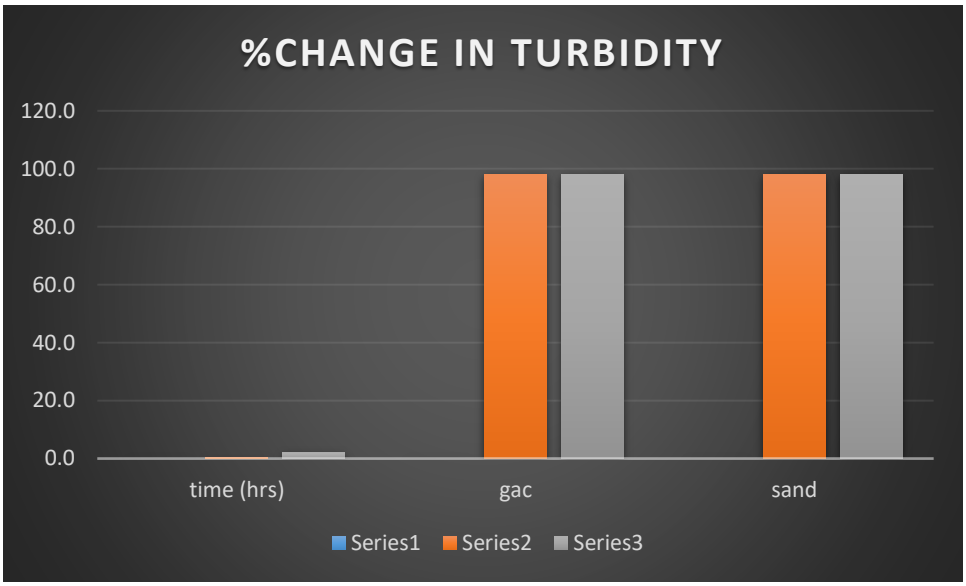
In the pre chlorination setup, the measured variables were recorded and the absolute %changes in concentrations are plotted below for different operating conditions:



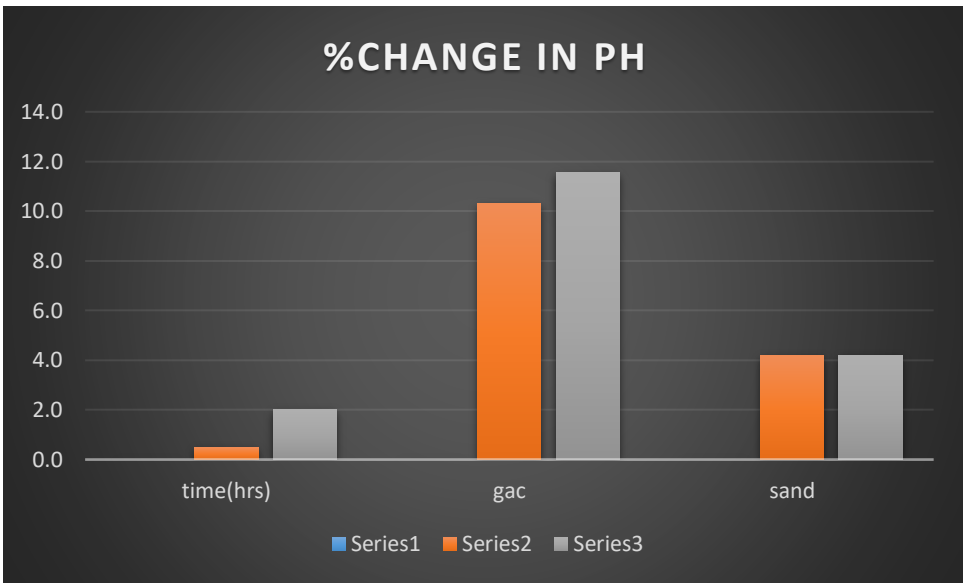
Graph 1 showing %changes in COD concentration over time



Graph 2 showing %change in chlorine concentration over time



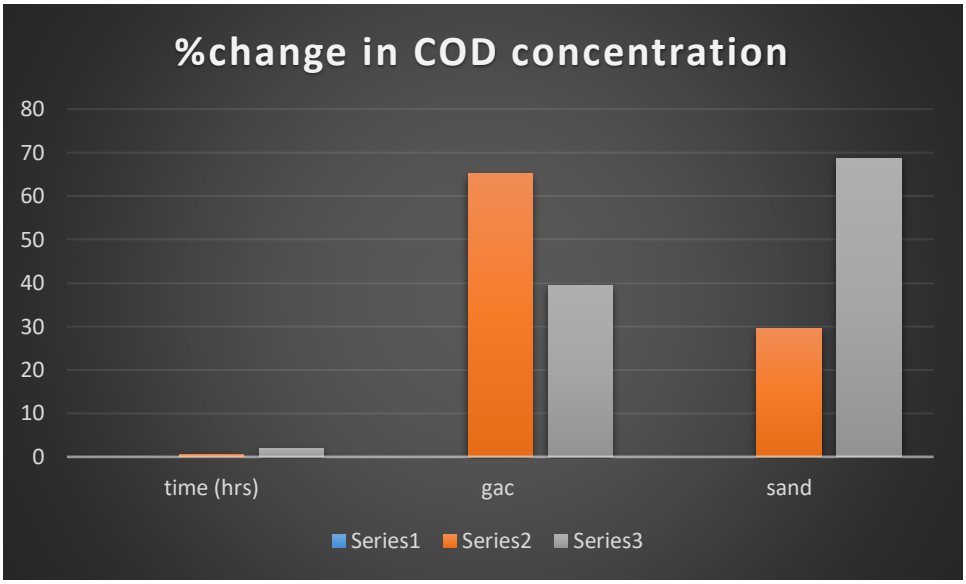
Graph 3 showing %change in turbidity over time



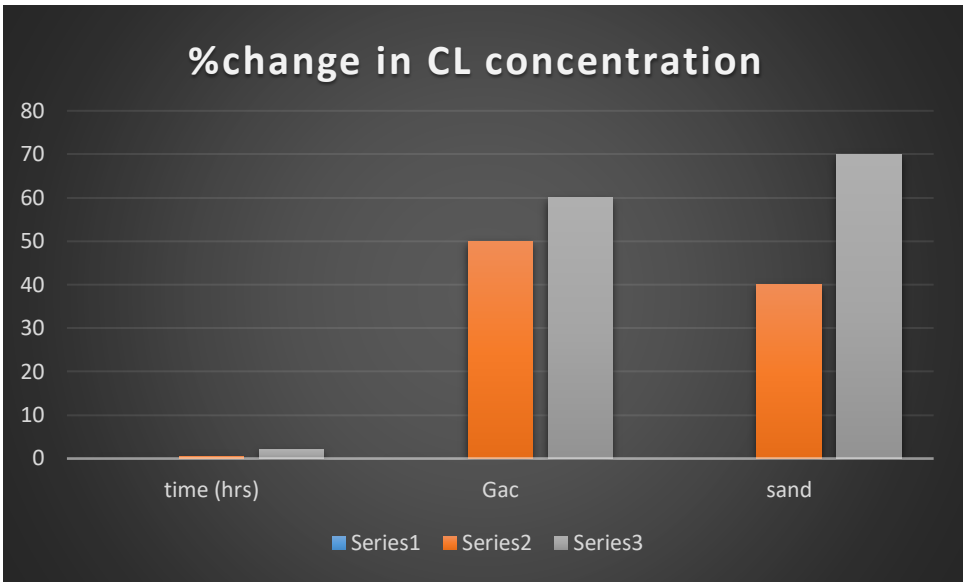
Graph 4 showing %change of pH over time

the graphs above shows that there is a huge %change in residual chlorine and COD in prechlorinated water passing through sand filtration than the one passing through granular activated carbon. This indicates that more disinfection byproducts are formed in the sand filtration setup than in the GAC setup. This is portrayed in the increase in the COD levels and the decrease in the residual chlorine in the system over time.

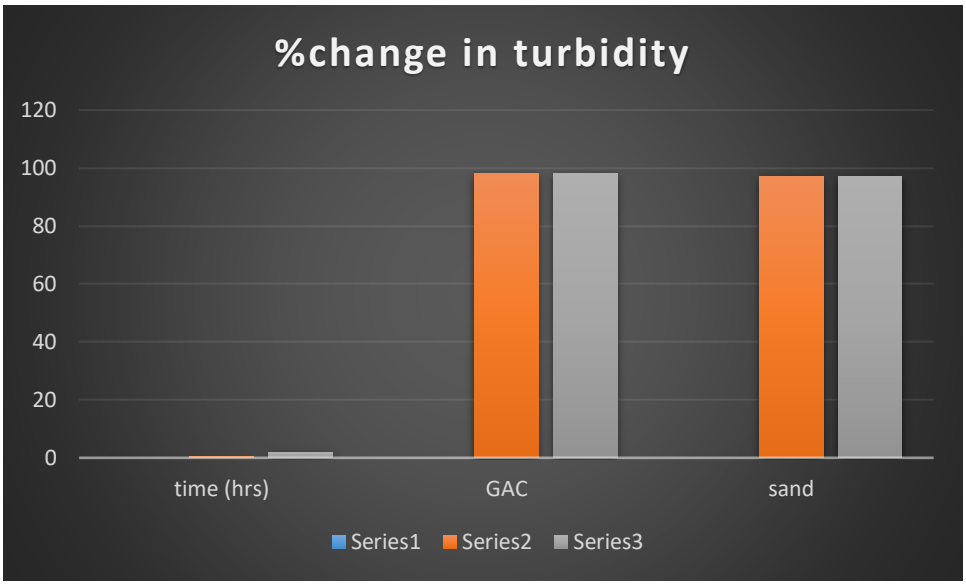
In the post chlorination setup, the measured variables were recorded and the absolute %changes in concentrations are plotted below for different operating conditions:



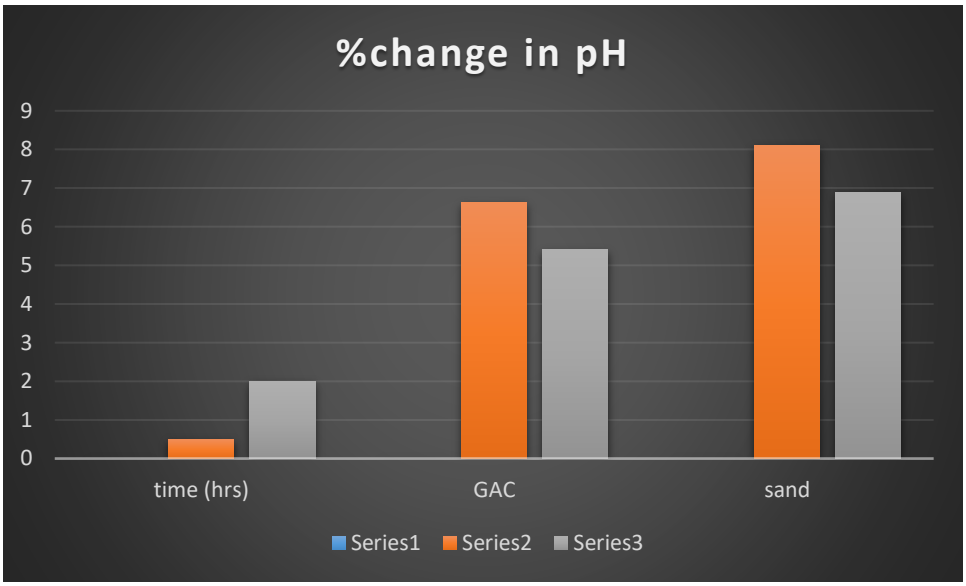
Graph 5 showing %change in COD concentration over time



Graph 6 showing % change in CL concentration over time



Graph 7 showing %change in turbidity over time



Graph 8 showing %change in pH over time

Just as in pre chlorination, sand filtration mechanism in post chlorination setup shows higher increase in %change in both COD and chlorine. There is much increase in the COD values over time and there is a major decrease of chlorine in the water. This also indicates that more disinfection byproducts are being formed in the water going through sand treatment than in the one going through GAC. This is so because granular activated carbon treatment also significantly enhances removal of the organic material which may otherwise react with the chlorine to form byproducts.

The pH and the turbidity were not significantly different in the water from the two setups. The two systems shown a higher removal % of turbidity of about 98%.

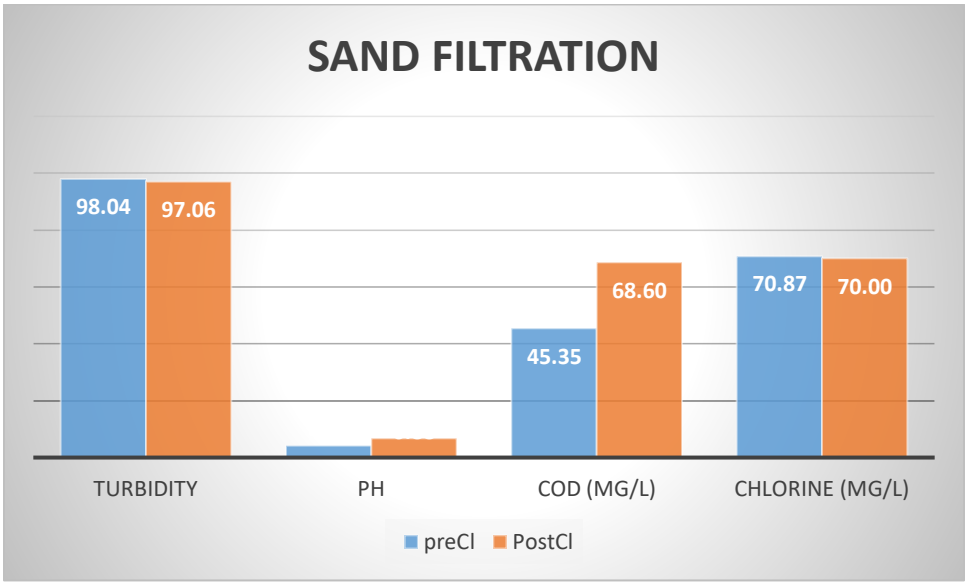
This evidently shows that GAC treatment is more efficient in minimizing the formation of disinfection byproducts than using sand filtration.

	2	*2*
Mean	2.976364	3.09
Variance	7.818885	9.5569
Observations	11	11

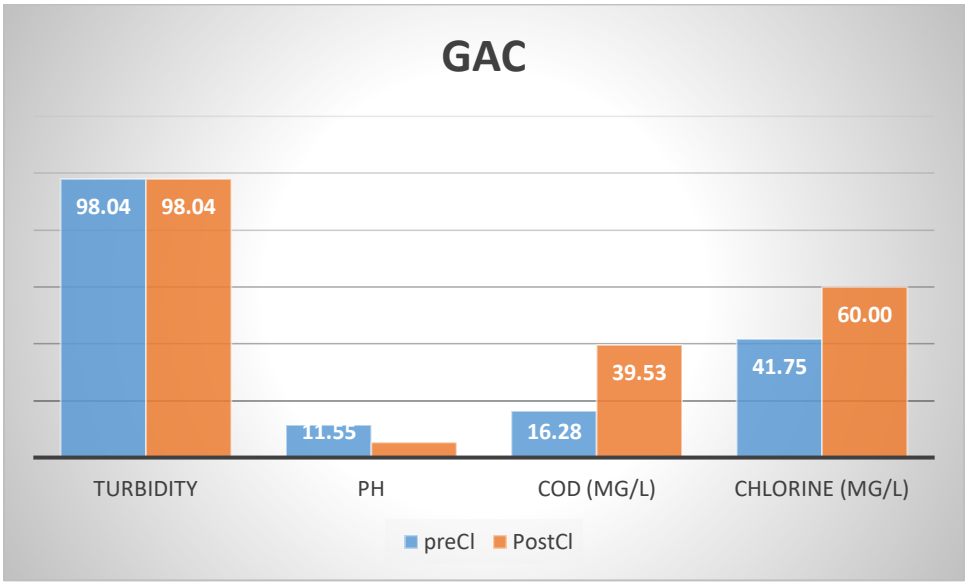
Pearson Correlation	0.998011
Hypothesized Mean Difference	0
df	10
t Stat	-1.08114
P(T<=t) one-tail	0.15251
t Critical one-tail	1.812461
P(T<=t) two-tail	0.30502
t Critical two-tail	2.228139

Table 3 showing t-Test: Paired Two Sample for Means

The following are the graphs summarizing the % changes in variables at different operating regimes in the two systems:



Graph showing %changes in variables when using GAC



Graph showing % change in variables when using GAC

The graphs above shows different %changes in the variables at different operating regimes. Using pre chlorination technique and granular activated carbon filtration mechanisms yields the minimum %change in the variables especially the indicator variables (COD and CL). It shows a 16% increase in COD after 2hrs compared to a 39% increase in COD when using sand. It also shows a 40% decrease in residual chlorine compared to a 60% decrease when using sand. This indicates that using prechlorination and granular activated carbon helps in minimizing the formation disinfection byproducts.



Figure 3 showing raw water from Lichenza River before treatment

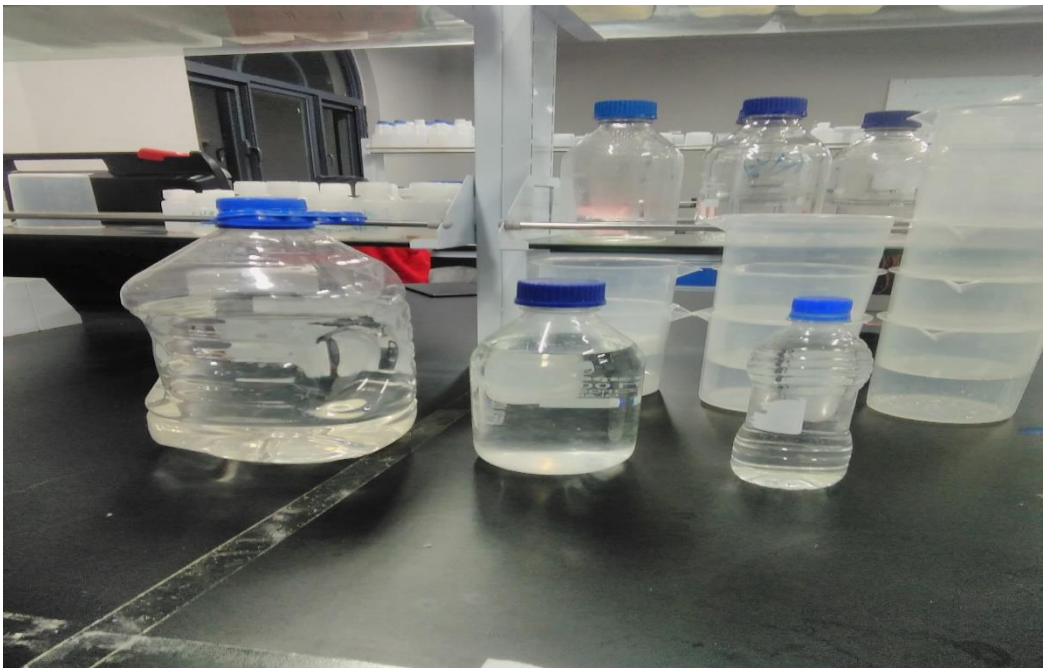


Figure 4 showing GAC filtered and prechlorinated water

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

The most frequently utilized technique for demobilizing pathogens remains disinfection. This is a fundamental stage in drinking water treatment as it removes the hazards related to water-borne diseases like typhoid and cholera. Therefore, disinfecting water employing chemical oxidants such as chlorine has been one of the main public health progresses through the previous century. During the time that this preserves the residual concentrations of disinfectant for the control of microbes, it may greatly elevate the generation of disinfection by-products (DBPs)(Ghernaout & Elboughdiri, 2020).

There are different drinking water treatment mechanisms employed in effort to provide safe drinking water to the public including pre chlorination, post chlorination, granular activated carbon filtration and sand filtration. All these mechanisms produce a certain amount of byproducts(Cuthbertson et al., 2019).

The use of prechlorination and granular activated carbon treatment is therefore the best treatment combination in minimizing the drinking water treatment byproducts formation. There is a need for a monitoring programme for the drinking water treatment byproducts in order to protect the public health from diseases caused by the byproducts. Attention has to be paid on how to significantly reduce the byproducts formation as well as treatment of these byproducts has to be done.

REFERENCES

Al-shatri, M. A., Nuhu, A. A., & Basheer, C. (2014). *Determination of Haloacetic Acids in Bottled and Tap Water Sources by Dispersive Liquid-Liquid Microextraction and GC-MS Analysis*. *2014*.

Branz, A., Levine, M., Lehmann, L., Bastable, A., Ali, S. I., Kadir, K., … Lantagne, D. (2017). *Chlorination of drinking water in emergencies : a review of knowledge to develop recommendations for implementation and research needed*. *36*(1).

Clark, P. A., Pinedo, C. A., & Capuzzi, S. J. (2012). *Slow-sand water filter : Design , implementation ,*. (June). https://doi.org/10.12659/MSM.883200

Cuthbertson, A. A., Kimura, S. Y., Liberatore, H. K., Summers, R. S., Knappe, D. R. U., Stanford, B. D., … Richardson, S. D. (2019). *Does Granular Activated Carbon with Chlorination Produce Safer Drinking Water? From Disinfection Byproducts and Total Organic Halogen to Calculated Toxicity*. (June). https://doi.org/10.1021/acs.est.9b00023

Eng, J. A. C., Bryant, I. M., & Tetteh-narh, R. (2015). *Journal of Advanced Using Slow Sand Filtration System with Activated Charcoal Layer to Treat Salon Waste Water in a Selected Community in Cape Coast , Ghana*. *5*(4). https://doi.org/10.4172/2090-4568.1000135

For, G., Management, D. Q., & New, F. O. R. (2019). *Chapter 15 : Treatment processes , disinfection*. (May), 1–86.

Ghernaout, D., & Elboughdiri, N. (2020). *Disinfection By-Products : Presence and Elimination in Drinking Water*. *7*, 1–20. https://doi.org/10.4236/oalib.1106140

Introduction, A. (1997). *5220 CHEMICAL OXYGEN DEMAND (COD)* 5220 B . Open Reflux Method*. (5000), 14–19.

Kato, R., Asami, T., Utagawa, E., & Furumai, H. (2018). Pepper mild mottle virus as a process indicator at drinking water treatment plants employing coagulation-sedimentation , rapid sand fi ltration , ozonation , and biological activated carbon treatments in. *Water Research*, *132*, 61–70. https://doi.org/10.1016/j.watres.2017.12.068

Knezev, A. (n.d.). *Microbial Activity in Granular Activated Carbon Filters in Drinking Water Treatment*.

Krasner, S. W., Chih, T., Lee, F., Westerhoff, P., & Fischer, N. (2016). *Granular Activated Carbon Treatment May Result in Higher Predicted Genotoxicity in the Presence of Bromide Granular Activated Carbon Treatment May Result in Higher Predicted Genotoxicity in the Presence of Bromide*. (October 2017). https://doi.org/10.1021/acs.est.6b02508

Mackeown, H., Gyamfi, J., Vital, K., Marnix, K., Dumoulin, D., Verdickt, L., … Dumoulin, D. (2020). *Formation and removal of disinfection by-products in a full scale drinking*

water treatment plant To cite this version : HAL Id : hal-02399687.

Mkwate, R. C., Chidya, R. C. G., & Wanda, E. M. M. (2017). Assessment of drinking water quality and rural household water treatment in Balaka District , Malawi. *Physics and Chemistry of the Earth*, *100*, 353–362. https://doi.org/10.1016/j.pce.2016.10.006

Moona, N. (2017). *Partial renewal of granular activated carbon filters for improved drinking water treatment Department of Architecture and Civil Engineering*.

Ngene, S. E., & Tota-maharaj, K. (2020). *Effectiveness of Sand Filtration and Activated Carbon in Oilfield Wastewater Treatment*. (June). https://doi.org/10.14445/23945370/IJCER-V7I2P102

Sand, S., Use, W. H. Y., & Sand, A. S. (2001). *S LOW S AND WHY USE A SLOW SAND*. (June).

Sarbatly, R. H. J., & Krishnaiah, D. (2007). *Free chlorine residual content within the drinking water distribution system*. *2*(8), 196–201.

Smith, D., & Lynam, K. (n.d.). *Determination of Haloacetic Acids in Water by GC / µECD Using Agilent J & W DB-35ms Ultra Inert and DB-XLB Columns Application Note*. 1–10.

Sorlini, S., Palazzini, D., Sieliechi, J. M., & Ngassoum, M. B. (2013). *Assessment of Physical-Chemical Drinking Water Quality in the Logone Valley (Chad-Cameroon)*. 3060–3076. https://doi.org/10.3390/su5073060

States, U., & Protection, E. (1994). *& EPA Water Quality Standards Handbook : Second Edition & EPA Water Quality Standards Handbook : Second Edition*. (August).

Torabian, A., Ghadimkhani, A. A., Mehrabadi, A. R., Shokouhi, M., & Heidarzadeh, R. (n.d.). *Effect of preozonation and prechlorination on total organic carbon removal in surface water treatment in Iran*. *103*, 305–314. https://doi.org/10.2495/WRM070291

Vahala, R. (2002). *TWO-STEP GRANULAR ACTIVATED CARBON FILTRATION in Drinking Water Treatment*.

Water, T. (2005). *Slow Sand Filters About water-e*.

Yu, W., & Xu, L. (2014). *Pre-treatment for ultrafiltration: Effect of pre-chlorination on membrane fouling*. (October). https://doi.org/10.1038/srep06513