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TITLE: An analysis of the physico-chemical and microbial quality of sachet water in Lilongwe, Malawi: Implication on public health and WASH policies

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APPROVAL PAGE

An analysis of the physico-chemical and microbial quality of sachet water in Lilongwe, Malawi: Implication on public health and WASH policies

DEDICATION

This work is dedicated to GOD, my family, my late grandparents, and loved ones for their constant support and care during my studies.

STATEMENT OF THE AUTHOR

I hereby declare that this thesis is the original outcome of my research, has been realized to the best of my knowledge and ability. This work has not been submitted for any previous degree or an award. The experimental work is almost entirely my work; the collaborative contributions have been indicated clearly and acknowledged. Due references have been provided on all supporting literature and resources.

Signature of candidate

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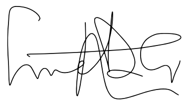
26.11.2020

CERTIFICATE OF APPROVAL

I declare that this work is from the student's effort and that it has been submitted this day with my approval.

Signature of supervisor



Pro. Emmanuel Amponsah Donkor

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
CV	Coefficient of variation
EC	Electrical conductivity
GoM	Government of Malawi
HWTS	Household Water Treatment and Safe Storage
JMP	Joint Monitoring Programme
KMU	Kiosk Management Unit
LWB	Lilongwe Water Board
MBS	Malawi Bureau of Standards
MDGs	Millennium Development Goals
MS	Malawi Standard
NGOs	Non-governmental Organisations
NSO	National Statistical Office
SADC	Southern African Development Community
SD	Standard Deviation
SDGs	Sustainable Development Goals
THA	Traditional Housing Area
UN	United Nations
UNDP	United Nations Development Program
UNICEF	United Nations Children's Fund
WASH	Water, sanitation, and hygiene
WHO	World Health Organisation
WUAs	Water Users Associations

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ABSTRACT

Informally sachet water is an important source of drinking water for the majority of people lacking access to public piped sources. In Malawi, sachet water is popular but not regulated, and information about its quality and hygienic practices followed during production are unclear and rarely available. This study investigated the physico-chemical and microbial quality of hand-filled sachet drinking water in Lilongwe City, Malawi, and its public health and WASH policy implications. The study deployed an experimental design to generate primary data and a mixed-method research to acquire information about the source of water used in sachet water production. The water samples (n = 90) were randomly purchased and obtained from sachet water producers in Areas 1, 18, 25, 36, 49, and 57. The samples were preserved in a sample carrier containing ice packs and transported to Government Central Water Laboratory (Lilongwe) to assess their physico-chemical and microbiological quality. The samples were analysed for pH, total dissolved solids (TDS), electrical conductivity (EC), turbidity, iron (Fe), Arsenic (As), Manganese (Mn), Nitrate (NO_3^-), Chloride (Cl^-), Fluoride (F^-), and *Escherichia coli* (*E-coli*) by using standard methods as outlined in APHA (2012) and Malawi Standard guidelines. Compliance with Malawi Standards 214 (2004) and WHO (2011) guidelines for drinking water was examined using sigma capability and error bar. An analysis of variance (ANOVA) was performed to assess the difference in water quality parameters between the location of sample collection. The results showed that pH, Cl^-, F^-, and Turbidity were significantly different between the location in Lilongwe ($p < 0.05$) while E.coli, EC, TDS, Mn, Fe, and NO_3^- were not. The majority of the samples (72.22%, n = 90) were contaminated with *E coli* and therefore failed to comply with both MS 214 (2004) and WHO 2011 permissible limit for drinking water quality. The results further showed that some sachet samples (32.22%, n = 90) did not comply with the MS 214 (2013) turbidity maximum limit of 1 NTU. Further, majority of the samples (97.78%, n = 90) had low fluoride levels below the minimum Malawi standard (214) of 0.70 mg/L while few samples (2.22% $n = 90$) from areas 1 and 57 were above the permissible limit set by both the aforementioned standards hence were non-compliant. Furthermore, few samples (8%, $n = 90$) from areas 18, 25, and 36 did not comply with the minimum permissible pH limit of 6.50 set by WHO guidlines. Since the country does not have regulations and legislation governing the production and marketing of sachet water, the study recommends the formulation of the same to safeguard the health of consumers. This study further recommends strict inspection of sachet water products from relevant government offices to improve sachet water quality. There is also a need for awareness campaigns aimed at civic educating sachet water producers on best hygiene practices during production to prevent contamination.

Keywords: Sachet water quality, physico-chemical, microbial, Lilongwe, Malawi, WASH policies

RÉSUMÉ

De manière informelle, l'eau en sachet est une source importante d'eau potable pour la majorité des personnes n'ayant pas accès aux sources publiques. Au Malawi, les sachets d'eau sont populaires mais non réglementés, et les informations sur sa qualité et les pratiques d'hygiène suivies pendant la production sont peu claires et rarement disponibles. Cette étude a examiné la qualité physico-chimique et microbienne de l'eau potable en sachet rempli à la main à Lilongwe City, au Malawi, et ses implications sanitaires et politiques. L'étude a déployé une conception expérimentale pour générer des données primaires et une conception de recherche à méthode mixte a été utilisée pour acquérir des informations sur la source d'eau utilisée dans la production d'eau en sachet. Les échantillons d'eau (n = 90) ont été achetés au hasard et obtenus auprès de producteurs d'eau en sachet dans les zones 1, 18, 25, 36, 49 et 57. Les échantillons ont été conservés dans un porte-échantillon contenant des blocs de glace et transportés au laboratoire central de l'eau du gouvernement. (Lilongwe) pour évaluer leur qualité physico-chimique et microbiologique. Les échantillons ont été analysés pour le pH, les solides dissous totaux (TDS), la conductivité électrique (CE), la turbidité, le fer (Fe), l'arsenic (As), le manganèse (Mn), le nitrate (NO_3^-), le chlorure (Cl^-), le fluorure (F^-) et Escherichia coli (E-coli) en utilisant les méthodes standard décrites dans les lignes directrices de l'APHA (2012) et du Bureau des normes du Malawi (MS) (2013). La conformité aux normes du Malawi 214 (2013) et aux directives de l'OMS (2011) pour l'eau potable a été examinée à l'aide de la capacité sigma et de la barre d'erreur. Une analyse de la variance (ANOVA) a été menée pour évaluer la différence des paramètres de qualité de l'eau entre les lieux de prélèvement de l'échantillon. Les résultats ont montré que le pH, le Cl^-, le NO_3^- et la turbidité étaient significativement différents entre les emplacements ($p < 0{,}05$) alors que les autres paramètres ne l'étaient pas. La majorité des échantillons (72,22%, n = 90) étaient contaminés par E. coli et ne respectaient donc pas les limites admissibles MS 214 (2004) et OMS 2011 pour la qualité de l'eau potable. Les résultats ont en outre montré que certains échantillons de sachets (32,22%, n = 90) n'étaient pas conformes à la limite de turbidité MS 214 (2004) de 1 NTU. La majorité des échantillons (97,78%, n = 90) présentaient de faibles niveaux de fluorure inférieurs à la norme MBS minimale de 0,70 mg / L tandis que peu d'échantillons (2,22% n = 90) des zones 1 et 57 étaient au-dessus de la limite autorisée fixée par les deux les normes susmentionnées n'étaient donc pas conformes. En outre, peu d'échantillons (8%, n = 90) des zones 18, 25 et 36 ne respectaient pas la limite de pH minimale autorisée de 6,50 fixée par les normes de l'OMS. Étant donné que le pays ne dispose pas de réglementations et de directives régissant la production et la commercialisation de l'eau en sachet au Malawi, l'étude recommande la formulation de celle-ci pour protéger la santé des utilisateurs. Cette étude recommande également une inspection stricte des produits d'eau en sachet par les bureaux gouvernementaux compétents afin d'améliorer la qualité de l'eau en sachet. Il est également nécessaire de mener des campagnes de sensibilisation visant à enseigner aux producteurs d'eau en sachet les meilleures pratiques d'hygiène lors de la production pour éviter la contamination.

Mots clés : Qualité de l'eau en sachet, physico-chimique, microbienne, Lilongwe, Malawi, politiquesWASH.

CHAPTER ONE: INTRODUCTION

1.1 Background

Many people in the developing world lack access to a safe water supply (Gonçalves et al., 2019). Globally, progress towards access to safe drinking water has accelerated under the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) (World Health Organization *et al*., 2015; UNESCO *et al.*, 2019). It is reported that between 2000 and 2015 global population using improved water resources rose from 81% to 89% (UNESCO *et al.*, 2019). However, lack of access to secure adequate drinking water remains a global issue. In 2015 alone 29 % of the global population (2.6 billion individuals) did not access improved drinking water sources, whereas 844 million people still lacked access and 144 million individuals were fetching drinking water from lakes and rivers (UNESCO *et al.,* 2019, WHO. 2015; WHO/UNICEF,2019). Of the 144 million individuals who were sourcing drinking water from ponds, rivers, and lakes, 58% lived in sub-Saharan Africa (UNESCO *et al*., 2019). Sub-Saharan Africa is reported to have made little progress towards improving access to improved drinking water with just 43% of its population currently having access to improved resources (WHO *et al*., 2015; Mkwate *et al.,* 2017).

Malawi is a nation in sub-Saharan Africa that has made some progress towards improving access to potable water to her population by about 67% (WHO/UNICEF, 2015; Mkwate *et al.,* 2017). However, access to potable water in the country still faces several challenges. Malawi government data indicate that 15% of people were still fetching drinking from unimproved sources, mainly from lakes, streams, or unprotected wells in 2018 (NSO, 2018).

In Lilongwe in particular, sheltered and dependable pipe water is accessible. However, Lilongwe Water Board (LWB) provides water services to about 77 percent of the city's population while the remaining 22% fetch drinking water from boreholes, shallow wells, streams, rivers, and unprotected wells (Boakye-Ansah *et al*., 2016). Water supplies in Lilongwe are often interrupted due to power cuts, inadequate water reserves, and outdated, crumbling infrastructure (Rowe, 2012.). When supply is interrupted, households seek alternative sources, sources that may be unsafe including sachet water. Consequently, to supplement supply water vendors are packaging and selling hand-filled sachet drinking water in the city. Low and middle-income earners are considering hand-filled sachet water a safer source of potable water largely due to its affordability and convenience compared to factory bottled water as such they are patronizing it (Manjaya *et al*., 2019). As a result, the production of sachet water has expanded enormously in the city but with unavailability of a legal framework to regulate the production, there is a dread that most of the sachets are produced under questionable hygienic environmental conditions.

Prior studies conducted on the safety of drinking water in Malawi have demonstrated that bottled water is of acceptable physico-chemical and microbiological quality while the nature of hand-filled sachet drinking water has been noted to be far-fetched (Manjaya *et al*., 2019; Chidya *et al*., 2019). Monney (2013) further concurs with Manjaya (2019) that sachet water to a larger extent does not satisfy microbiological quality guidelines for drinking water. In Nigeria for example, 30% of tested sachets were found to be contaminated with faecal coliforms (Manjaya *et al*., 2019). In Malawi, many sachet water vendors use tap water to produce the water sachets. However, with the report of microbiological contamination of tap water in Lilongwe (Boakye-Ansah *et al.*, 2016), it is uncertain whether the water sachets produced meetguidelines of WHO and the Malawi Bureau of Standards.

It is a well-known fact that inadequate access to safe drinking water and basic sanitation is the leading cause of diseases globally (WHO et al., 2015; Boakye-Ansah *et al.*, 2016). Diarrhoeal outbreaks claim about 1.5 million lives annually, the majority of which are under-five children (UNICEF,2017; .WHO *et al*., 2015). In Malawi, diarrhoea is the fifth leading cause of death among children under the age of five (Rowe, 2012). With a report of water vendors utilizing tap water in sachet water production and reports of sachet water contamination in West Africa (Fisher *et al.*, 2015; Oyelude & Ahenkorah, 2012; Dzodzomenyo *et al.*, 2018), it is important to understand and determine whether sachet water sold in Lilongwe meets the WHO and MBS regulatory standards for drinking water.

1.2 Problem statement

In Malawi, about half of all illnesses are related to waterborne diseases (Kosamu et al., 2012). This is evident in a government report which states that diarrhoea is the fifth leading cause of death among children under the age of five, mainly due to the drinking of unsafe water (Rowe, 2012). With concerns raised about the role of sachet water in exacerbating outbreaks of cholera and other waterborne diseases in Nigeria (Manjaya *et al.*, 2019; Oluwafemi & Oluwole, 2012), and with the expansion in the consumption of sachet water in major cities and towns, there is a possibility of producing products that are not fit for human consumption in light of fiscal interests. In Malawi formal water sachet manufacturers are non-existent (Manjaya *et al*., 2019). Informal vendors only use tap water or any source to tie plastic sachets which are then cooled in refrigerators or put in cooler boxes with ice blocks and later sold to consumers. The proliferation of these hand-tied sachet drinking water items brings up the issue regarding whether they are cleanly produced, particularly while considering the poor condition in the urban areas combined with sporadic monitoring of sachet water producers by regulating agencies (Boakye-Ansah *et al*., 2016). A study carried out in Ghana reported that some producers of sachet water even bundle untreated water into the sachet and sell them marked as cleaned water (Oluwafemi and Oluwole, 2012). Such propensities might be happening in Malawi since there are no or limited monitoring programs to check the quality of the sachet water.

Few research studies conducted in Malawi on packaged water have shown non-compliance in microbial and chemical composition as stipulated by the WHO standards. Chidya *et al.* (2019) investigated bottled water in Malawi and found that some bottled water samples did not comply with both MS and WHO guidelines. Manjaya *et al.* (2019) investigated the Microbiological quality of sachet water in Mwanza and found that some sachet water did not comply with MS and WHO guidelines. The study established that the sale and industry of sachet water in Malawi is not controlled by regulations as such it poses a health threat to consumers. This assertion contravenes the Consumer Protection Act of 2003 which calls for full protection of consumer's human rights. However, the study failed to evaluate the chemical and physical quality of sachet water which is progressively significant in evaluating the potability of water because of the health risks associated with hazardous chemical elements. For instance, mercury (Hg) and Arsenic (As) are known to cause poisoning, cancer, and damage to the liver and kidney while Lead (Pb) delays mental and physical development in children (Rahmanian *et al*., 2015).

Further, even without any sources of anthropogenic contamination, there is the potential for natural levels of chemical substances to be harmful to human health (Akoto & Adiyiah, 2007). Chemical parameters of drinking water tend to pose chronic health risks with some components like nitrates and nitrites having an acute impact such as cancer and damage to the liver, kidney, and nervous system. Physical parameters affect the aesthetic value of the drinking water and may as well complicate the removal of microbial pathogens.

Furthermore, many vendors using water from the Central Region and Lilongwe Water Board to fill the sachets believe the water is safe. However, a study conducted in 2016 by Boakye-Ansah reported that tap water was contaminated with faecal matter *(E. coli)* so results about water quality are only valid once at a time. The water quality may not be maintained in time due to different factors, like climate change and handling practices that can change the physico-chemical and microbiological composition of water sources. The fact that Malawi is experiencing rapid urbanization and increasing industrial activities when coupled with insufficient maintenance and distribution of pipe network for water supply may affect the quality of water sources and drinking water as well and thus may also alter the quality of hand-filled Sachet water in case no further purification is done during sachet water production. As such, the present study seeks to understand and determine whether sachet water sold in Lilongwe meets the WHO and MS regulatory standards for drinking water.

1.2. Aim of the study

1.2.1 Main objective

The main objective of the study was to assess the physico-chemical and microbial quality of sachet water in Lilongwe, Malawi, and its implications on public health and WASH policies.

1.2.2 Specific objectives.

a) To establish the sources and treatment of sachet water sold in Lilongwe city;
b) To determine the physico-chemical properties and microbial composition of the sachet water sold in Lilongwe city;
c) To produce scientific-based knowledge for stakeholders and policy makers that will help improve sachet water industry;
d) To evaluate the public health and policy implications on production and use of sachet water in the cities and urban centres by consumers

1.3 Research questions

i. What are the sources of drinking water and treatment options for water packed in sachets in Lilongwe?
ii. What are the physico-chemical and microbial characteristics of sachet water produced and marketed in Lilongwe city?

iii. Does the quality of sachet water produced and sold in Lilongwe confirm to acceptable quality in the standard guidelines of the World Health Organization and Malawi standards? (Is sachet water produced and marketed in Lilongwe contaminated? What is the extent of such contamination?)

iv. What are the implications of using sachet water on the health of consumers and WASH policies?

1.4 Significance of the study

The sale of plastic sachet water has gained prominence throughout the world of late, to a great extent because of open recognition that it is protected, tastes better, and has a superior quality contrasted with raw tap water (Halage *et a*l., 2015). Several studies have investigated sachet water quality and public health in Sub-Saharan Africa, but relatively few studies have been carried out in Malawi in general and Lilongwe in particular. It is, therefore, necessary to research in this field as the sachet water quality data and information generated from this study will provide evidence to regulatory bodies for formulation of stringent policies forcing the producers to improve water quality in case the study reveals that the quality is below standard. The data will also help WASH NGOs in their role of promoting access to improved water and sanitation in the cities and towns. Furthermore, the work will also add knowledge to academia on sachet water quality and provide background for further studies in this field. It will as well provide insights into the safety of an increasingly important source of water for consumption in Malawi and will inform policymakers seeking to regulate and monitor packaged sachet water in Malawi and elsewhere while ensuring the progressive realization of access to safe water. Finally, this study will likewise provide information into the water treatment alternatives currently being utilized by sachet water vendors and consequently the degree to which the nature of the sachet water sold in Lilongwe meets both the Malawi Bureau of Standards (2004) and WHO guidelines.

1.5 Scope and limitations

The study was conducted in Lilongwe the capital city of Malawi. Sachet water samples (90) were purchased from vendors after an oral interview following their consent to participate in the same. The samples were drawn from Area 1, 18, 36, 25, 47, and 57 only as such Small sample size will remitted the generalization of the research. In some areas, sachet water was not available during the sample collection period since it was the wet season. In Malawi, the sachet market dwindles during the wet season. The criteria for the selection were based on availability and not necessarily in line with a design that is most optimal for use but the areas were randomly selected. It will be necessary to conduct another study with a big sample size covering dry season since the current study was carried out during the rainy season. The research project was selected to match the scope of the program of study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Background information

Access to safe and clean water is fundamental to human health, an essential human right, and a part of effective policy for health protection for the community (World Health Organization, 2011). The importance of providing safe and clean water for health and development has been reflected in the outcome of a series of international policy forums such as the World Water Conference in Mardelplata, Argentina (WHO, 1977), the Alma-Ata primary Health care Declaration (WHO, 1978), the MDGs (WHO, 2000), and the Johannesburg World Summit for sustainable development (WSFSD, 2002). In general, available literature indicates that it is very important to provide safe drinking water to the people as a way of reducing waterborne diseases and hence improved health. Globally, drinking water of acceptable quality is considered fundamental in preventing the entry of harmful organisms into bodies (Ma & Ndonwi, 2015). As such monitoring and inspection of levels of quality water parameters in drinking water require serious attention as a slight difference from the permissible level for some elements may result in death or several forms of health problems for consumers (WHO, 2011).

Recently sachet water production and marketing have increased tremendously in developing countries due to its availability and affordability (Dada, 2011). Sachet water is easily fetched at a low cost, hence it has proved as an option to the inadequate and unsatisfactory provision of safe and clean water (Bosch *et al*., 2001). Access to potable drinking water as stated in Sustainable Development Goal (SDG) 6 cannot be overemphasized. Safe drinking water has always been considered to be water that has met national and international drinking water quality standards. Generally, it is the water with an accepted level of chemical, microbial, and physical properties that meet both WHO and national guidelines for drinking water quality (WHO, 2011). Specifically, in Malawi, safe drinking water is one that meets both the WHO and Malawi Bureau of Standards (MBS) (Mkwate *et al*., 2017).

In Malawi, sachet water is common but lacks production and marketing regulations, and quality and hygienic practices during processing are unclear (Manjaya, 2019). Recent studies in Nigeria and Ghana revealed that sachet water failed to comply with drinking water standards (Onweluzo & Akuagbazie, 2011, Dzodzomenyo *et al*., 2018). In Nigeria, for instance, 30% of sampled sachet water contained *Escherichia coli* beyond the WHO guidelines (Oluwafemi & Oluwole, 2012). The health impacts of drinking contaminated water are that individuals get exposed to the danger of contracting waterborne diseases. Recently, there have been rising worries over the role of hand-filled sachet water in aggravating flare-ups of waterborne illness in Nigeria (Manjaya *et al*., 2019). Potential health issues exist because of the microbial content of sachet water since water acts as a medium for the transmission of pathogenic microorganism (Fisher *et al*., 2015). Sachet water enjoys massive customer patronage from all segments of society due to its convenience, transportability, and affordability (Manjaya *et al.*, 2019). However few studies have been conducted in Malawi on the sachet water, as such information about the quality of this source of potable water is not clear and remains a mystery. It is therefore very important to carry out a study that will help establish the status of sachet water produced and sold in Malawi specifically in Lilongwe.

2.2 Importance of good quality water

Good physico-chemical and microbial quality of drinking water acts as a preventive mechanism for controlling the entry of harmful microorganisms and elements into the body. Even though some elements and organisms are harmless to human wellbeing, their presence in drinking water still has to be checked and monitored because some complicate the removal of particles or enhance microbial growth (WHO, 2011). Physico-chemical parameters in drinking water require serious attention as a slight difference out of permissible limit for some hazardous elements may result in death or several forms of disabilities on consumers (Akoto & Adiyiah, 2007). Analysis of microbes in drinking water provides information about coliforms and *Escherichia coli* which are always related to faecal contamination. Drinking water that is free from pathogens plays a vital role in controlling the mortality of vulnerable people especially children under five years old who are mostly affected by gastrointestinal disorder (WHO *et al*., 2015).

2.3 Improved and unimproved water supply systems

WHO (2011) guidelines define an improved drinking-water source as the one that protects it from contamination by its nature of design, and constriction especially from faecal material (WHO, 2011). It assumes that improved sources to a larger extent have a higher chance of supplying safe drinking-water, unlike unimproved sources. According to WHO (2011) guidelines for drinking-water quality, public improved, and unimproved water supply include the following;

a. Improved water supply technologies:

- Piped water
- Public standpipe
- Borehole and tube well
- Protected dug well
- Protected spring
- Rainwater collection

b. Unimproved water supply technologies:

- Unprotected well
- Unprotected spring
- Vendor-provided water
- Bottled water
- Tanker truck provision of water

(Source WHO 2011 guidelines)

Improved source: Kiosk (A) **Unimproved source: Unprotected well (B)**

Figure 1 (A – B): Example of improved (A) an unimproved (B) water source in Lilongwe (area 1 and 36)

2.4 Common drinking water sources in Malawi

Malawi household information regarding sources of drinking water in the dry season is used as a proxy of the general population welfare of the country (NSO, 2018). It is reported that about 85 % of the population in households use improved sources of drinking water which include piped water, public standpipes, tube/protected wells, and boreholes (NSO, 2018; NSO, 2015 - 16 MDHS). Over 61.7 % of the population use boreholes, 8.1 percent use community standpipe, and 10.3 percent use piped water into dwelling or plot as the main source of drinking water in the dry season (NSO, 2018). However, the same report shows that about 15.2 % of Malawians fetch drinking water from unimproved sources such as unprotected wells, springs, rivers/streams, ponds/lakes, dams, and others. The central region where Lilongwe is located has the second-highest number of people consuming water from unimproved sources at 16.5% after the northern region (NSO, 2018).

Data and information about access to safe and improved drinking water in Malawi vary depending on the sources. In 2015, a report by the World Bank showed that 95% of urban and 89% of the rural population had access to improved water sources. However, a report by WHO/UNICEF in the same year indicated that 67% of Malawians were accessing water from improved sources (W HO *et al.*, 2015). JMP figures show that in Malawi inequalities do exist between urban and rural access to improved water sources; urban access is about 96% while rural is 89% (Adams & Smiley, 2018). In rural areas, the majority of people depend on groundwater sources while in urban areas they depend on piped water sources (GoM, 2013; Mkwate *et al.*, 2017). However, despite these inequalities, the majority of Malawians depend on groundwater sources than the rest of the resources (NSO, 2018; Mkwate *et al.*, 2017).

Tap (A) **Borehole (B)**

Figure 2 (A – B): Pictures of some common sources of drinking water in Malawi

2.5 Problems associated with drinking contaminated water

Drinking water contaminated with chemicals and microbes poses a threat to the lives of people. The exposure to arsenic increases the risk of skin cancer, other skin lesions like hyperketorisis, and pigmentation change (Argos *et al.*, 2010). Water containing a high concentration of fluoride and nitrates above the recommended permissible limits may result in chronic health effects including kidney and liver damage, and nervous system disorders (Prüss-Ustün *et al.*, 2014). Excess fluorides in drinking water can lead to dental and skeletal fluorosis (Keramati *et al.,* 2019). Nitrates in drinking water can be dangerous to infants and lead to blue baby syndrome while magnesium though useful can cause diarrhoea for sensitive users and infants if over consumed (Cotruvo, 2018). Most strains of *E. coli* are innocuous, however, some can cause genuine sickness in people, for example, *E. coli* 0157/H7, which can cause deadly illness (Ishii & Sadowsky, 2008; Cotruvo, 2018).

2.6. Water quality standards

Ministry of Irrigation and Water Development is the responsible agency that formulates national standards for drinking water in Malawi (Boakye-Ansah *et al*., 2016). The agency is in charge of quality verification, certification, and standardization. Ministry of Irrigation and Water Development through its laboratories carries out tests of bottled water and natural mineral waters other than natural mineral water, tap water, groundwater, etc to ensure its safety for consumption and usage. The standards used by Ministry of Irrigation and Water Development for water quality are in line with WHO water quality guidelines as well as the Southern African development Community (SADC) water quality standards. The standards provide the required microbiological, chemical, and physical concentrations of drinking water. The following are some of the standards;

- Drinking water - MS 214 (2013)
- Boreholes and shallow wells - MS 733 (2005)
- Natural mineral waters - MS 560 (2004)
- Bottled drinking water other than natural mineral water - MS (699)

The Catalogue of Standards of MBS does not include criteria for sachet water products despite increased consumption of the same on the market (GoM, 2012). As such the result from this study will be compared with MS 214 which is the general guidelines for drinking water in Malawi. Table 1 provides a summary of some of the water standards in Malawi

Table 1: Safety standards set by WHO and MS for drinking water quality.

Parameter	Units	WHO	MS 214	MS 560	MS 699	MS 733
pH	NA	6.5 – 8.5	5.0 – 9.5	6.5 – 8.5	6.5 – 8.5	6.0 – 8.5
Conductivity	µS/cm)	NA	1500	400	1500	3500
Turbidity	NTU	5	1	5	1	25
NO_3^-	mg/L	50	10	50	NA	45
TDS	mg/L	1000	1000	1000	1000	2000
F^-	mg/L	1.5	1	0.2	NA	6
Cl^-	mg/L	250	200	150	200	750
Mn	mg/L	0.4	0.1	0.4	NA	1.5
Fe	mg/L	0.3	0.2	0.2	NA	3
As	mg/L	0.01	0.05	0.01	NA	0.05
E. coli	cfu/100 mL	0	0	0	0	0

WHO: *World Health Organisation*, MS*: Malawi Standard*, NA*: Not available*

2.7 Drinking-water quality parameters

Drinking water quality is determined by measuring the concentration of pollutes in the water. It involves analysing the physico-chemical, and microbiological parameters in water**.** Physical water quality comprises conductivity, taste, salinity, odour, temperature, turbidity, and solids. The chemical water quality includes inorganic constituents; Aluminium (Al), Calcium (Ca), copper (Cu), Magnesium (Mg), Manganese (Mn), chromium (Cr), Sodium (Na), Nickel (Nl), Iron (Fe), Lead (Pb), Zinc (Zn), and Potassium (K). It also comprises non-metallic constituents such as Fluoride (F^-), Nitrates (NO_3^-), Chloride (Cl^-), Sulphates (SO_4^{2-}) carbonic acid (CO_3^{2-}) hardness, and organic constituents as well which include pesticides and phenol. In contrast, the microbial water quality incorporates various biological microorganisms such as protozoa, viruses, bacteria, and algae (Fisher *et al*., 2015a). Consuming water that is contaminated with human faeces poses the greatest microbial risks (WHO, 2011). The greatest danger to human wellbeing from chemical contamination of water happens because of the build-up of heavy metals in the body, however, a few metallic and non-metallic constituents like nitrates and arsenic can cause prompt wellbeing impacts. Physical parameters influence the aesthetics and taste of the drinking water and complicate the removal of microbial pathogens (Cotruvo, 2018; WHO, 2011)

2.8 Physico-chemical and microbial indicators of packaged drinking water quality

This section includes only parameters that have been analysed within this present research. Sachet water falls in the category of packaged drinking water which also includes water packaged in cans, laminated boxes, and glass and plastic bags. WHO Guidelines for packaged water recommend that certain chemical constituents may be more readily controlled than in piped distribution systems, and stricter standards may, therefore, be preferred to reduce overall population exposure. However, some substances become more difficult to manage in packaged water than in tap water such as hazards associated with the nature of the packaged, higher temperatures and a longer period of storage both may even favour the growth of some microorganisms to higher levels (WHO, 2011). There are several ways in which water gets contaminated with different microbiological and physico-chemical contaminants as such diverse tests should be performed to analyse the level of contamination in the water (WHO, 2011). Generally, obtaining water of accepted quality entails carrying out tests for organic materials, non-metallic and metallic constituents, and microbial polluters. Therefore, water will be considered of accepted quality if microbial, physico-chemical tests including mineral level are well within the specified standard (Umar, 2006).

2.8.1 The Power of Hydrogen

The power of hydrogen (pH) is a numerical expression of the concentration of hydrogen particles in water. It shows the degree of acidity or alkalinity of water. The various degrees are represented on a scale of 0 to 14, with 0 being most highly acidic, 14 generally alkaline, and 7 neutral (Cotruvo, 2018). Low and high pH levels are unwanted because of the destructive impact on metal pipes (WHO, 2011; DeZuane, 1996). The WHO guidelines for pH are set for decreasing corrosion in metal pipes and subsequently may not apply to sachet water. However, due to the utilization of city piped water for the manufacture of sachet products, it might increase the risk of contamination from copper and lead that can leach from appropriation pipes (Fisher *et al*., 2015). Elevated pH levels in the water decrease the viability of purification by chlorination, in this way requiring additional utilization of chlorine (WHO, 2011). The pH range of 6.5 – 8.5 in packaged water is aimed at achieving the maximum environmental and aesthetic benefits (Cotruvo, 2018; WHO, 2011). When the pH level of water is less than 7.0, corrosion of metallic water receptacles may occur, releasing metals into the drinking water. However, the toxicity of metals depends on their solubility and the presence of different types of anions and other cations but still, it is undesirable as it may cause health concerns if concentrations of such metals exceed recommended limits (WHO, 2011).

2.8.2 Electrical Conductivity

Pure water is certainly not a good transmitter of the electric current rather a good insulator (Mohsin *et al*., 2013). An increase in ions concentration is determined by the number of dissolved particles that enhance the electrical conductivity of water. The EC is the measure of liquid capacity to transmit the electric charge (Rusydi, 2018). It is affected by many factors like the temperature of the water, the nature and concentration of dissolved substances, and so on, that is why it has a close and positive relationship to TDS (Rusydi, 2018). In raw and potable water EC ranges between 50 – 500 µS/cm (DeZuane, 1996). However, there is no guideline value proposed by WHO for conductivity but MS recommends maximum value of 1500 µS/cm for potable water

2.8.3 Total dissolved solids

The Total Dissolved Solids represent the action or the aggregate sum of cations and anions present in the water. The tastefulness of water with a TDS level of not exactly around 600 mg/L is satisfactory; drinking-water turns out to be fundamentally and progressively unpalatable at TDS levels above 1000 mg/L (Shahid *et al.*, 2015). Elevated levels of TDS in water may pull in protests from consumers as it might cause scaling in family household appliances (WHO, 2011). The high concentration of TDS in drinking water may bring about gallstone, firmness of the joints, kidney stones, and should cause solidifying of supply routes and here and their blockage of courses in serious conditions in the body (Hussain *et al*., 2014).

2.6.4 Turbidity

Turbidity in water is brought about by suspended particles or colloidal issue that discourages light transmission through the water (WHO, 2011). In water, it emerges from the consideration of residue, earth, and natural suspended particles. Microorganisms, microscopic organisms, infections, and protozoa are joined to these particulates. The removal of turbidity by filtration will altogether decrease microbial contamination in treated water (Shahid *et al.,* 2015). The turbidity in drinking water is associated with its aesthetic and it influences the visual quality of the water by the consumer. Information is rising which shows an expanded danger of gastrointestinal diseases that associates with high turbidity in drinking water (WHO, 2011).

2.8.5 Nitrates

Naturally, nitrates are available in the environment and provide nutrients to plants (WHO, 2011). They are present in all plants at various concentrations and form part of the nitrogen cycle. The WHO guidelines recommend 50 mg/l of nitrates in drinking water. At this level, nitrates help to protect bottle-fed infants against methemoglobinemia (Fisher *et al*., 2015). Nitrates are converted to nitrites in infants that oxidize blood haemoglobin to methaemoglobin. The modified platelets no longer convey oxygen bringing about brain damage or suffocation. Epidemiological investigations have demonstrated a connection between high nitrate levels and gastric and stomach malignant growths in people (Dutt *et al*., 1987). Other studies reveal that high levels and long-term exposure to nitrate can inhibit iodine uptake, with the potential for an adverse effect on the thyroid (WHO, 2011). Therefore, it is very important to balance their potential risks with their potential benefits by keeping their levels within the recommended permissible limits.

2.8.6 Chloride

Chloride in water originates from overflow, industrial effluents, and saline intrusion (WHO, 2011). In nature, chlorides are disseminated as calcium ($CaCl_2$), potassium (KCl), and sodium (NaCl) (Shi *et al.*, 2011). Excessive chloride concentrations in water increase rates of corrosion of metals in the distribution system as well as the detectable salty taste in water, moreover it has been suspected to cause high blood pressure (WHO, 2011), and hence a guideline value of 250 mg/L has been recommended by both WHO and 200 mg/L by MBS. However, there is no set standard for chloride in drinking water because there is no known evidence that chlorides constitute any human health hazard. Previous studies in Malawi on surface and groundwater reported chloride levels below the WHO (2008) limit of 250 ml/L in drinking water (Sajidu *et al.,* 2007, Chavula and Mwalufu, 2007)

2.8.7 Fluoride

Fluorine is a commonly distributed element in Earth's crust (Cotruvo, 2018; WHO, 2011). It exists as fluoride in a few minerals, for example, cryolites, fluorapatite, and fluorspar. It is available in surface water yet elevated concentrations are frequently connected with groundwaters (Cotruvo, 2018). WHO guideline for fluoride of 1.5 mg/L have been set as a result of epidemiological evidence that concentrations above this value carry an increased risk of dental and skeletal fluorosis (WHO, 2011). According to previous studies, drinking water of high fluoride concentration can increase fluorosis prevalence (Azami-Aghdash *et al.,* 2013, Buzalaf, 2018; Alvarez-Bastida *et al.,* 2013 2016, Keramati *et al.,* 2019). The MS 214 recommends 1 mg/L of fluoride in drinking water. Baseline studies in Malawi reveal high fluoride levels in water mostly in some parts of Lilongwe, Karonga, Nsanje, Chikwawa, Mwanza, and Machinga (Sajidu *et al.,* 2004, Msonda, 2003)

2.8.8 Manganese

Manganese is among the metals that corrode with iron pipes and cause coloration of drinking water in the distribution system (Alvarez-Bastida *et al*., 2013). Presence of Mn in drinking water may result in sensory problems like stains, coloured water, and complaints by the consumer (WHO, 2011; Alvarez-Bastida *et al*., 2013). It is known that exposure to manganese may affect the functionality of the nervous system and may cause an irreversible Parkinson-like syndrome called manganism. Manganism is characterized by muscle pain, weakness, anorexia, and slow speech (Bouchard *et al.,* 2011). However, there are no WHO health-guidlines for Mn only the provisional guideline value for Mn is 0.05 mg/L (WHO, 2011). The MS recommends 0.2 mg/L of Mn in drinking water.

2.8.9 Arsenic

Arsenic is widely distributed in the earth's crust (Cotruvo, 2018). It exists in a range of oxidation states including; of –3, 0, +3, and +5 consistently as sulfides or metal arsenides or arsenates. It is found in groundwater as arsenite or arsenate salts. It is brought into drinking-water sources through the disintegration of normally happening minerals and metals. Although it is available in common water under the range of 1–2 µg/l, arsenic in drinking-water is a noteworthy reason for significant general medical issues as such it is viewed as a high priority parameter for screening in drinking-water sources (WHO, 2011). It is one of a kind in causing countless diverse harming impacts and, as more examinations are directed, all the more such impacts are found (Rahmanian *et al*., 2015). Until this point in time, contemplates have demonstrated that arsenic from drinking water can cause serious sicknesses including skin malignant growth; lung, bladder, and kidney tumours, and maybe other inner tumours; fringe vascular infection; hypertension; diabetes, and lethal harming (Smith & Steinmaus, 2009, Argos *et al*., 2010, Hopenhayn, 2006). WHO provisional guideline for Arsenic is 0.01 mg/L.

2.8.10 Iron

Naturally found in freshwaters at levels ranging from 0.5 to 50 mg/L, it may also exist in drinking-water as a result of the use of iron coagulants or the corrosion of steel and cast-iron pipes during water distribution (WHO, 2011). It is among the absolute most bountiful metals on earth. In water, it advances the development of "iron organisms," which obtain energy from the oxidation of ferrous iron to ferric iron and in the process store a foul covering on the pipes (Shahid *et al.*, 2015). According to WHO, iron is not of health concern at concentrations normally observed in drinking-water. Moreover, taste and appearance of water are affected below the health-based value as the minimum daily requirement for iron depends on age, sex, and physiological status. The WHO has set a provisional value of 0.3 mg/L (WHO, 2011) in drinking water while MS 214 recommends 0.2 mg/L.

2.8.11 *Escherichia Coli*

The microbial quality of drinking water has general health impacts on individuals such as it has pulled in incredible consideration internationally (Olaoye & Onilude, 2009). Assessment and monitoring of bacteria indicators, for example, *Escherichia coli*, total coliforms, and pseudomonas aeruginosa in drinking water are of paramount importance. Monitoring of *E. coli* is essential as it is viewed as a perfect indicator of faecal pollution in drinking water contrasted with other faecal coliforms. There are two key variables for picking *E. coli* as a progressively favoured indicator for the identification of faecal contamination in water; the finding that some faecal coliforms were not faecal in nature, and the advancement of improved testing techniques for *E. coli* (Odonkor and Ampofo, 2013). Thermotolerant coliform is also a better indicator but the fact that the population of this group of coliforms is composed predominantly of *E. coli* renders it a less reliable but acceptable index of faecal contamination. The presence of *E. coli* in water gives proof of ongoing faecal contamination (WHO, 2011). The World Health Organization recommends the complete absence of faecal forms in drinking water (Hermann *et al.,* 2018, WHO, 2011).

2.9 Sachet water production: Treatment options and quality targets

Hand-filled sachet water is an elective source of consumable water for individuals lacking access to improved protected and safe water in provincial and peri-urban (Manjaya *et al.*, 2019). In Malawi, hand-filled sachet water is common but lacks a legal framework to control and monitor its production and marketing. Indeed, even the quality of the water and sterile works during bundling are indistinct. In the sachet water industry, tap water is the main source of water used to fill the sachet (Okioga, 2007). Sachet water produced in small-scale industries is mainly treated by single or double filtration and aeration or sometimes disinfection is applied (Fisher *et al.*, 2015). The degree of treatment, for the most part, relies upon the source of water. However, in Malawi, most occasions faucet water is utilized without extra treatment and is sold in markets without leeway from the MS (Manjaya *et al.*, 2019).

In recent years sachet water production by small-scale enterprises has encountered an intense improvement in as far as the handling and processing of the raw water is concerned. These days small-scale producers treat water by air circulation, twofold, or single filtration utilizing porcelain atomic flame or layer filters (Stoler *et al.*, 2012). Ayokunle (2011) affirms that most littler activities comprise of an imported comprising a water treatment and sachet filling system situated in a home or shed utilizing metropolitan piped water as the raw water source. Most studies have indicated that the most commonly used water sachet treatment processes are microfiltration, activated carbon filtration, and UV disinfection. In Malawi, however, formal and certified water sachet manufacturers are non-existent (Manjaya *et al.*, 2019). Some informal vendors only use tap water to tie plastic sachets which are then cooled in refrigerators or put in cooler boxes with ice blocks and later sold to consumers. For the most part, to produce sachet water, a basin or bowl is utilized to get faucet water. Polythene sachets are opened either by scouring them with exposed hands or by blowing air into them by mouth. A cup is utilized to place the ideal volume of water in the sachet. It is then fixed by tying a bunch at the open end. This production process leaves space for bacterial contamination

Williams (2014) contends that the widespread use of packaged sachet water of unknown quality has raised potential public health concerns in Sierra Leone. Williams (2014) further agrees with Fisher (2015) that though Sierra Leone has legislation regulating packaged water, is not well coordinated as evidenced by unclear roles among government agencies. As such enforcing the regulations is much complicated.

2.10 Sachet water quality

Sachet water is one of the low-cost technological innovations of vended water in developing cities (Stoler *et al*., 2012). This innovation has led to the spread of sachet water to the developed world. However, the recent studies on the sachet water have highlighted the major dares in sustaining the quality of sachet water (Fisher *et al.*, 2015; Stoler *et al.*, 2012). A 2015 review of a hundred seventy studies conducted around the globe disclosed that packaged water was less likely to be contaminated than other improved drinking water sources including piped water (Williams *et al*., 2015). However, considerable diversity was observed across study areas with over 40% of studies reporting that plastic packaged water was of lesser quality than piped water.

Furthermore, the review established that there exists a considerable difference in the level of contamination of sachet water between developing and developed countries. Sachet water is more likely to be contaminated in low–income countries than in middle and high-income countries as low-income countries face more challenges in regulating and monitoring the sachet water industry (Feeser, 2014.). In developing countries sachet water enterprises who have gained recognition as a viable drinking water alternative operate either unregulated or unregistered (Dada, 2011). As a result, many studies investigating the bacteriological contamination of sachet water condemn the quality of sachet water sold by sachet water enterprise that they neither meet national standards nor international guidelines (Fisher *et al*., 2015). Sachet water may be contaminated at any point along the supply chain from the source to the consumer. Lack of treatment before packaging is constantly assumed as the potential source of contamination for packaged water (Thompson, 2015). Sometimes it is not necessary to treat water before packaging that is the case of mineral water. Mineral water is assumed safe without treatment as it is pulled from underground springs and bottled or bagged on-site (Fisher *et al*., 2015). Meanwhile, water from other sources like surface water requires prior treatment to eliminate potential contaminants. The application of various disinfection techniques for treating drinking water is mandatory as it helps eliminate potential pathogens for water from highly contaminated sources and it is highly recommended by WHO. This implies applying both chemical disinfection and filtration treatment options.

The majority of published papers on hand-filled packaged water have reported microbial contamination of the product (Stoler *et al.*; 2012, Ngwai *et al.,* 2010; Fisher *et al.,* 2015; Ma & Ndonwi, 2015). It is important to note that not every research has faulted hand-filled packaged quality to be contaminated although a bias exists toward reporting contamination of sachet water (Stoler *et al*., 2012). While sachet water quality continues to be a topic of interest, sachet water has the potential to improve access to safe clean drinking water in low-income countries to people by eliminating unsafe water storage in households (Stoler *et al.*, 2012).

2.11 Malawi policies and agenda on water, sanitation, and hygiene (WASH)

Drinking water should be safe, free from the concentration of chemicals, and other hazardous contaminants of a health concern as stated in the WHO Guidelines for drinking water quality (WHO, 2017). The United Nations member countries have pledged to achieve sustainable development goals (SDGs) by 2030 (UN, 2015), in addition to that, all African countries are also committed to achieving the Agenda 2063 (AUC, 2015). Those two initiatives have in their targets to ensure 100% coverage of improved water supply sources with full access, safety, and affordability. The SDGs goal 3 (target 9), goal 6 (target 1 and 3); and African Union's Agenda 2063, all seek to achieve full access to drinking water that should be safe, affordable, and free of chemicals as well as other hazardous contamination in reducing the number of deaths and illnesses (UN, 2015). The Southern African Development Community (SADC) through Region Water Policy and Region water strategy has been edging member states to have a social and economic responsibility of ensuring sustainable access to safe water supply for basic human needs in their respective countries (SADC Region *National Water Policy*, 2005.).

In this regard, Malawi like many other countries is striving to provide adequate and safe water to her citizens. The Malawi Growth and Development Strategy (MGDs) (2017 – 2022), Malawi‘s Vision 2020; and National Water and Sanitation Policy (2005 and 2006), National Environmental Health Policy all highlight the need to provide adequate and improved water and sanitation services as an important concept in improving the wellbeing of people (Rowe, 2012; Chidya *et al.*, 2016). While all these strategies and policies do promote improved access to water sanitation and hygiene, the National Health Policy (2013) does not contain details regarding environmental health activities, safe water, household water treatment, and safe storage or national strategic priorities such as the Essential Health Package (Rowe, 2012). Regarding the report of the Joint Monitoring Programme of WHO/UNICEF for Water Supply and Sanitation, in Malawi, in 2015, it was reported that 87% of the population had access to the improved drinking water means from protected sources and 41% had access to improved sanitation facilities (WHO/UNICEF, 2018; Cassivi *et al*., 2020). This could lower the demand for packaged water in the country. However, some people cannot stop questioning the quality of drinking water by taking into consideration insufficient maintenance of distribution pipes (Boakye-Ansah *et al*., 2016). The doubt can also be linked to the fact that the country is experiencing the fastest urbanization and increasing industrial activities (NSO, 2018).

The Malawi National Water Policy (2005) has articulated a new water sector vision of *'Water and Sanitation for All Always'*. One of the core quality focus areas is the provision of water of acceptable quality for all the needs in Malawi. The focus on quality is aimed at ensuring that people have access to potable water and sanitation services so that waterborne disease incidence is reduced (Ako *et al*., 2010). In terms of institutional roles, Ministry responsible for Water Affairs**,** Water Utilities, and Ministry responsible for Health is to monitor water quality, provide guidance concerning the quality of drinking water and Promote health and hygiene education in water and sanitation services (Water Resources Act, 2013; GoM, *National Water Policy*, 2005). The Ministry Responsible for Water Affairs has the sole responsibility of establishing standards, guidelines, and inspectorates to ensure the provision of potable water and control of pollution of water (GoM, *National Water Policy*, 2005). The absence of an independent regulator for drinking water quality and insufficient funds for inspection and absence of regulations and monitoring mechanisms in the water industry put at risk the majority of Malawi of contracting waterborne diseases.

National Environmental Health Policy's goal on WASH is to improve water quality, sanitation, and hygiene at the community, regional, and national levels. It has the following policy statements concerning WASH (Rowe, 2012);

- *The government shall monitor the quality of water from the source to the user's point.*
- *The government shall promote the treatment of water at the point of use.*
- *Government conduct surveillance of water, sanitation, and hygiene-related diseases*

(Source; National Environmental Health Policy draft document)

This policy has a strong commitment towards improving the status of water quality in Malawi especially packaged since it is providing direction on promoting the treatment of water at the point of use by promoting the use of HWTS as a preventive health strategy (Rowe, 2012). Unfortunately, the document is still in the “final draft” form, unsigned by policymakers.

CHAPTER THREE: MATERIALS AND METHODS

This chapter details the procedure that was used to gather and dissect information in the study. It includes the description of the study area, a research design, the target population, sample size, and sampling frame and data collection instruments that were used to inform the study. It further clarifies how data was gathered, processed, and analyzed.

3.1 Description of the study area

3.1.1 Location

The study was conducted in Lilongwe, the capital city of Malawi (Fig.1). The city is situated between 33.5 E – 34.5 E longitudes and 14.5 S – 13.5 S latitude at a height of 1050 m above sea level. It covers an all-out territory of 403 Km^2 with a population of 989,318 (NSO 2018). Lilongwe shares a boundary with four districts, namely; Dedza, Dowa, Mchinji, and Salima. It is likewise circumscribed by two neighbouring nations Mozambique and Zambia.

Figure 3: Map of Malawi showing Location of study area Lilongwe City (Kosamu *et al* 2013)

The mean yearly temperature ranges from 20 ˚C to 25 ˚C and the yearly normal precipitation from 800 – 900 mm. Lilongwe is confronting quick urbanization and is viewed as the quickest developing city in the country (Kuria, GoM Consult, 2013; Zeleza-Manda, 2009; Chidya *et al*., 2016).

3.1.2 Social-economic activities

Lilongwe was for the most part administrative centre until 2005 when head offices situated in Blantyre moved to the city (Kuria, GoM Consult,2013.). This development pulled in monetary activities to the city that bought about expanded business opportunities and population increase. Marketing, banking, retail trade, construction, transport, tourism, and tobacco manufacturing are the fundamental monetary activities in Lilongwe (Manda, 2015).

3.1.3 Settlement patterns

Fast social and monetary expansion has prompted a population increase from 669,532 in 2008 to 989,318 in 2018 with an annual increase rate of 3.8%. and a population density of 2,455 per km^2 (NSO, 2018). The city had a household of 230,265 at the same time. This is subdivided into 58 areas (Boakye-Ansah *et al.*, 2016). They are both formal and informal settlements in the city. Lack of formal housing has led to increases in the number of people living in informal settlements. According to the 2008 census report over 70% of the population was leaving in an informal settlement (NSO, 2008; Manda, 2015). The housing typology includes low-density, medium-density, high density permanent for intermediate income earners, and Traditional Housing Areas (THA) for low-income earners. Besides, there are informal settlements that are very high density (Kuria, GoM, Consult, 2013; Zeleza-Manda, 2009; Manda, 2015). Most of the inhabitants of the informal settlements are living in unacceptable housing conditions with the inadequate social infrastructure of access to the essential urban services including decent sources of water (Kuria, GoM, Consult, 2013.)

3.1.4 Water supply and sanitation

In Lilongwe, drinking water is supplied by Lilongwe Water Board (LWB) and packaged drinking water from various privately owned businesses. It is reported that the Board serves about 78% of the population (Boakye-Ansah *et al.*, 2016). In the informal settlements, water supply is delivered through communal water points, individual family associations, and booths run by Water Users Associations (WUAs), Kiosk Management Unit (KMU), and private operators (Zeleza-Manda, 2009). However, water from these sources is not sufficient to serve all the residents in the informal settlement as as result some residents depend on unprotected water sources, like rivers as complementary to water supplied by the Board (Kuria, GoM Consult, 2013; Zeleza-Manda, 2009). The LWB gets its water from upstream of the Lilongwe waterway at Malingunde (Kamuzu Dams 1 and 2) (Kosamu *et al*., 2013; Boakye-Ansah *et al*., 2016).

People also access drinking water from privately-owned companies. There are many bottled water brands in Lilongwe which include; Aquamist, SPA, Aqua-Pure, Cool Drop, Mkokomo, Zabo, Nestle Pure Life, Pure Zone, P-water, Premium Stillwater (Quench), Hayat, AquaA+, Nyika, and Real (Chidya *et al.,* 2019). Besides, taps and packaged drinking water, individuals in the city additionally depend on boreholes, sachet water, and unimproved sources like rivers. The quantity of sachet water producing organizations or merchants is not known since the industry is not regulated and the vast majority of vendors operate illegally (Manjaya *et al*., 2019).

Sanitation and refuse collection remain a challenge in major cities in Malawi (Zeleza-Manda, 2009). In Lilongwe, More than 75 percent of the population depends on pit latrines and the sewerage facilities cover just around 9 percent of the city (Kuria, GoM, Consult., 2013). Waste collection is inadequate due to the shortage of resources and refuses collection equipment. Most families, especially those belonging to slums, dispose of refuse in open space on river banks and alongside the road. Uncollected waste is common in Lilongwe's business areas which are a major contributor to environmental degradation in the city.

Figure 4: Picture showing waste problems in area 1

3.2 Research design and data collection methods

This study employed an experimental design and it deployed both qualitative and quantitative research methods. Primary data was collected by direct field observations, laboratory tests, oral semi interviews, and group discussions to identify the sources of water used by sachet producers. Secondary data was obtained from policy documents, and government reports through desk study.

3.3. Selection of areas and sampling procedure

All 58 locations in Lilongwe were eligible to participate in the study. All the locations had an equal chance of selection since the study deployed a random sampling procedure. Six of the 58 areas were randomly selected for involvement in the study. Using the randbetween (1,58) function in excel, a random area was selected. The method was repeated until all the six areas were chosen randomly. Areas 1 (Falls estate), 18, 25, 36, 49, and 57 (Chinsapo) were therefore selected as the study's locations. The study collected samples and information about sources of water bagged in the sachet. Sachet water samples in the areas under study were collected and went straight to the laboratory for analysis to determine the chemical, physical, and microbial content (values) of targeted parameters.

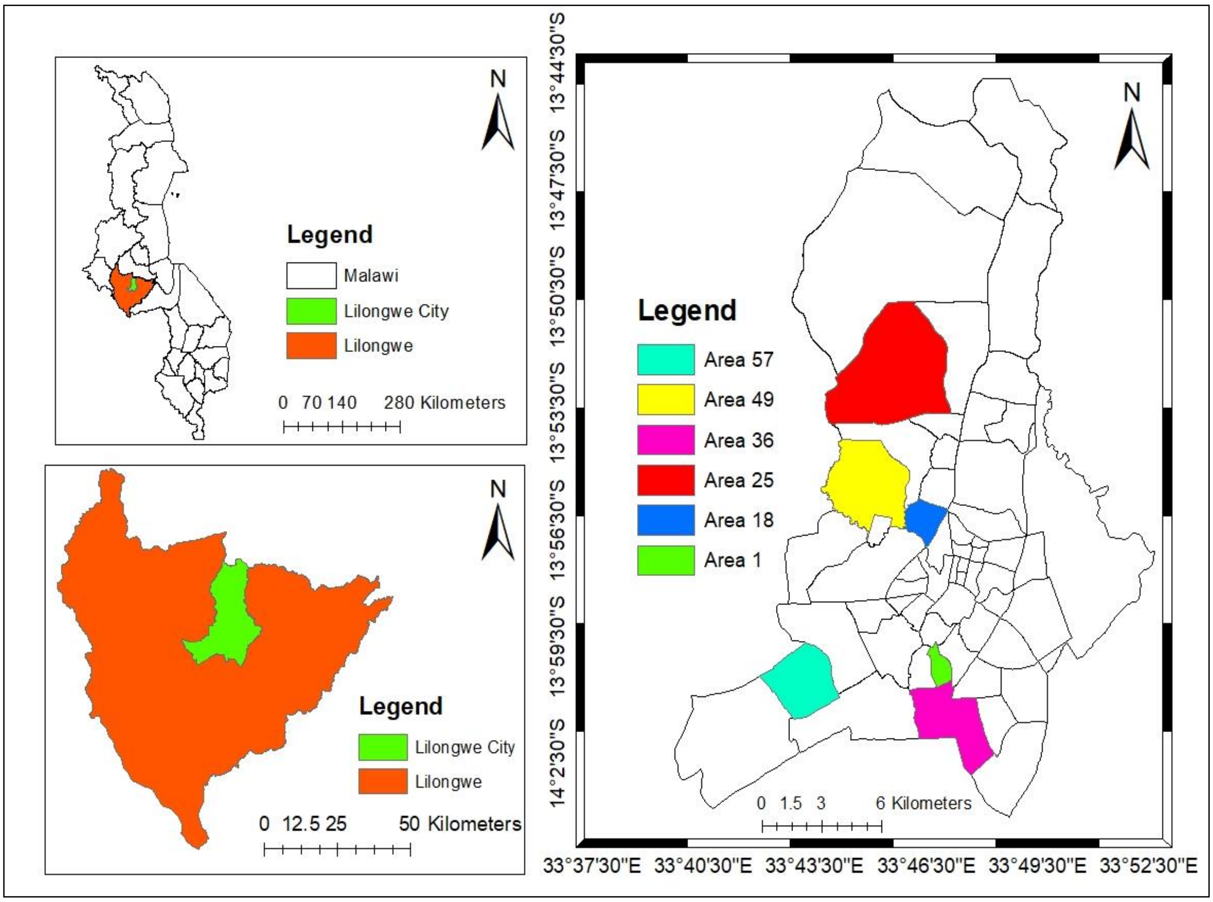


Figure 5: Map of Lilongwe city showing sample sampling locations

3.4. Sampling of sachet water

A total of 90 sachet water samples were collected in triplicate from water merchants in Lilongwe from March to May 2020. All samples were purchased randomly from sachet water vendors and shops in Lilongwe after oral interviews and getting consent. All the samples were kept in their unique tied polythene tube and set apart for distinguishing proof with letters from 1 to 15 for every Location. The samples were then transported to the Central Government Water Laboratory of the Ministry of Irrigation and Water Development in a sample carrier/cooler box containing ice packs for analysis.

Figure 6: Picture showing sachet water sample collection from sellers in Area 1 and 25

3.5 Analytical methods and water quality analyses

All reagents and synthetic chemicals used in the research were of analytical grade, sourced from accredited providers including TCHNO PHARMCHEM, India, Sartorius Stedim Biotech GmbH, Germany and VETROTECNICA, Uruguay. Distilled and deionized water was used in dilutions, rinsing of apparatus, and preparation of standard solutions. All the selected physico-chemical and microbiological analyses were done according to Standard Methods (APHA, 2012). The accompanying physico-chemical and microbiological water quality parameters were analysed according to Standard Methods (APHA, 2012): pH, TDS, EC, Fe, NO_3^-, Cl^-, F^-, As, turbidity, and faecal coliform bacteria. For instance, Method 9222 was used to analyse *E. Coli* and 2130 B for Turbidity. Except for nitrate, Iron, Arsenic, and Manganese, all other physico-chemical parameters were analysed using non-acidified aliquots. Microbial analysis was conducted to check for the presence of faecal coliform using membrane filtration.

3.6 Physico-chemical and microbial water quality analysis

3.6.1 Determination of pH

A pH meter (HI 9125), pre-calibrated with buffer solutions of pH 4.01 and 7.01 (VETROTECNICA, Uruguay), was used to measure the pH values of the sachet water samples. A sample volume of about 50 mL was pulled from each sample and filled into a clean glass beaker and the electrode was immersed into it while swirling the beaker gently. When the reading was steady, pH of the sample was recorded. The probe of the meter was rinsed with distilled water and scrubbed with a clean tissue paper after every determination. This was done to prevent cross-contamination. The procedure was followed for the analysis of all samples.

3.6.2 Determination of EC and TDS

The EC (µS/cm) and TDS (mg/L) were determined by Multi-Meter (HI 991300, Hanna Instruments, Romania). Before the EC/TDS analysis, the meter was well-calibrated with Hanna HI7031 Conductivity Standard Solution (1413µS/cm at 25ºC). About 50 mL of water sample was filled in a clean glass measuring beaker and the conductivity meter probe was then embedded into the container. The reading was taken and recorded in the µS/cm unit after the fixed value showed up on the screen. The probe of the meter was rinsed with distilled water and scrubbed with a clean tissue paper after every determination. This was done to prevent cross-contamination. The procedure was followed for the analysis of all samples. The procedure was repeated for all samples.

3.6.3 Determination of turbidity

Turbidity (NTU) was determined by a turbidimeter (Hl 88703, WAGTECH) which was calibrated by standard solutions ranging from 0.2 NTU, 10 NTU, 100 NTU, to 1000 NTU (Nephelometric Turbidity Units) by filling continuously 4 clean sample cells with very much blended standard solution. It was then adjusted to measurement mode and utilized. A 10 mL aliquot of each sample was measured and poured into the curette of turbidity meter and the individual perusing taken. This procedure was repeated until all samples were analysed.

3.6.4 Determination of Nitrates

The Nitrate component of the samples was measured using a UV VIS spectrophotometric method. The water sample 5 mL was pipetted into a clean 250 mL beaker and 2 mL of sodium salicylate was added.

The mixture was dried on a boiling water bath. After drying, 1 mL of sulphuric acid was added. The 10-minute reaction period was allowed and thereafter the mixture was diluted to approximately 50 mL using distilled water. Then 10 mL (25% w/v) of sodium hydroxide was added. It was then quantitatively transferred to a 100 mL volumetric flask and topped to mark. Then the concentration of nitrate (mg/L) was measured using a spectrophotometer (CECIL CE 7400, 7000 SERIES, CECIL INSTRUMENTS CAMBRIDGE, ENGLAND) UV VIS) at the wavelength of 410nm.

3.6.5 Determination of Chloride

Chloride was determined by titration with standard silver nitrate solution (0.0141N) using potassium chromate as an indicator. Silver chloride was quantitatively precipitated before red silver chromate was formed. An aliquot of 50 mL of the sample was poured into a conical flask. About 0.5 mL of K_2CrO_4 indicator was added and then the mixture was titrated using a standardized $AgNO_3$ solution of 0.01 M until faint reddish-brown colour appeared and titre (T) was noted. This procedure was repeated until all samples were analysed. Using the following formula, chloride was calculated

$$CI^- = \frac{(T) \times N \times 35.540}{SV} \qquad \textit{(Equation 1)}$$

where $T =$ mL titration for sample

$N =$ Normality of $AgNO_3$

$SV =$ Sample Volume

3.6.6 Determination of Fluoride

Fluoride was determined using the SPADNS spectrophotometric technique. Fluoride particles reacted with zirconium dyes, Zr-SPADNS (sodium 2-(parasulphophenylazo)-1,8-dihydroxy-3,6-naphthalene disulphonate) to produce a coloured complex. Soon after the development of color, the absorbance of the subsequent coloured complex was then determined using a UV-Vis spectrophotometer (HACH DR/3000) at 570 nm wavelength. A sample (10.0 mL) was pipetted from the water sample into a clean & dry 10 mL sample cell. Another sample cell containing 10.0 mL of deionized water was prepared as a blank. SPADNS reagent solution (2 mL) was added into each one of the above-prepared sample cells and twirled to blend, then left for a minute to allow the reaction to occur. In the wake of setting the machine, the sample was brought into the cell holder containing a blank after cleaning the cell with a reasonable clean tissue and the spot was secured with the instrument's top. Zero was clicked on the meter for the display to show zero (0.00 mg/L). Then the prepared sample was inserted into the cell holder, covered with an instrument cap, and the instrument operated to obtain a reading of the concentration fluoride displayed in mg/L. This procedure was repeated until all samples were analysed.

3.6.7 Determination of Fe

Fe was determined by Atomic Absorption Spectrometer (AS) (Pg. Instrument AA 500). Before the Fe determination, the instrument was calibrated with 0.5 mg/L, 1.0 mg/L, 1.5 mg/L and 2.0 mg/L concentration of industrial made standards. 10mL of the iron stock solution (1000ppm) was pipetted into a 100 mL volumetric flask and filled to the mark with deionised water to make a solution of 100ppm. From this solution, volumes of 0.5, 1.0, 1.5, and 2.0 mL were pipetted into four different 100ml volumetric flasks in that order and filled to the mark with deionised water to make 0.5 ppm, 1.0 ppm, 1.5 ppm, and 2.0 ppm working solutions which were run on the AAS followed by water samples

3.6.8 Determination of Mn

Mn was determined by Atomic absorption spectrometer (Pg. Instrument AAS 500). Before, Mn determination, the instrument was calibrated with 0.5 mg/L, 1.0 mg/L, 1.5 mg/L, and 2.0 mg/L concentration of industrial made standards. 10 mL of the iron stock solution (1000ppm) was pipetted into a 100 mL volumetric flask and filled to the mark with deionised water to make a solution of 100 ppm. From this solution, volumes of 0.5, 1.0, 1.5, and 2.0 mL were pipetted into four different 100 mL volumetric flasks in that order and filled to the mark with deionised water to make 0.5 ppm, 1.0 ppm, 1.5 ppm, and 2.0 ppm working solutions which were run on the AAS followed by water samples.

3.6.9 Determination of As

Arsenic was determined by Metalyser (MH 3000 METALYSER) where one sachet of HM 3 Buffer was added to the sample analysis beaker followed by the addition of 70 mL of a sample AS50 standard to the mixture before sample analysis was done.

3.6.10 Microbial water quality analysis

The membrane filtration method for bacteriological investigation was used to analyse faecal coliforms. The study used Membrane-Lauryl Sulphate Broth media, (TCHNO PHARMCHEM, India). 100 mL of water from each sample was filtered through a special cellulose nitrate filter (Sartorius Stedim Biotech GmbH, Germany; 0.45 μm pore size). Petri dishes containing filter membranes and selective nutrient media (M-Lauryl Sulphate Broth) for *E. coli* were then incubated at 44.5°C for 24 hours. This temperature is known to be ideal for the development of bacteria. The analysis for faecal coliform organisms per 100mL was reported in terms of cfu/100mL. Physical tallying of bacteria colonies was done using a colony counter (Bibby Stuart Scientific Ltd., Stone, UK). Colonies representations formed from each plate were picked for microscopy tests to confirm their identity. Faecal coliforms (FC) are microscopic organisms that originate specifically from the intestinal tract of warm-blooded animals (WHO, 2011; Chidya *et al.,* 2019). The presence of *E. coli* in any water source gives an indication of Faecal contamination and the presence of disease-causing microorganisms (WHO, 2017).

$$Colonies/100ml = \frac{N \times 100}{DF} \qquad \text{(Equation 2)}$$

where $N =$ Number of colonies

$DF =$ Dilution factor

3.7. Quality control and reliability of results

Glass bottles for microbial analysis used in this study were flushed with distilled water and afterward autoclaved at 121°c for fifteen minutes to guarantee sterility. Furthermore, the samples were analysed in triplicate. To guarantee the quality, water samples were transported to a laboratory in a sample carrier containing ice packs and analysed within 24 hours. Besides, samples were analysed using standard techniques. The apparatus and equipment were calibrated before use, a blank sample and spiked samples were included for the study, and a reference laboratory was utilized for approval of the findings. Moreover, the test was carried out at a reputable Central Water laboratory of the Ministry of Irrigation and Water Development where both staff and equipment are certified.

3.8 Data management and statistical Analysis

Data obtained from the laboratory was subjected to data analysis using Microsoft Excel sheet and SPSS version 21. Bar graph, coefficient of variance, and sigma capability analysis were performed using Microsoft Excel (2016). Descriptive statistical analyses such as histogram, mean, median, ranges, whisker, and boxplot were performed using SPSS. The SPSS was used to generate error bars and to perform multivariate statistical, ANOVA, and correlation analyses. Error bars, bar graphs, and sigma capability were used to compare the quality of sachet water to regulatory standards. Multivariate statistical analyses such as Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA) were used to determine associations present in the chemical composition of the water quality data set. Analysis of variance (ANOVA) was performed to check if there was any significant difference in physical, microbial, and chemical concentration of sachet water from various locations. Correlation analysis (Pearson's correlation r, $p = 0.05$, and $p = 0.01$) was performed to determine relationships amongst water quality parameters and locations.

3.9. Ethical approval

The study was approved by the Pan African University Institute of Water and Energy Sciences; University of Abou Bekr Belkaid in Algeria in line with the General Conduct of Research and Ethical requirement and University Research Code of Conduct.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Physico-chemical and microbial characteristics of sachet water

Table 2 provides a summary of results on the physico-chemical and microbial characteristics of sachet water in the study in Lilongwe. Absence of standards for sachet water quality in Malawi means the results were compared to WHO (2011) guldlines and MS 214 (2013) standards for drinking water.

Table 2: Summary of physico-chemical and microbial characteristics of sachet water samples compared to local standard (MS 214) for drinking water (*n = 90*)

Parameters	Units	Min.	Max.	Mean	Med.	SD	CV	Std.D	MS 214
pH	NA	6.15	8.02	7.32	7.42	0.39	0.053	5.6	5.0 - 9.5
EC	µs/cm	105	515	155	152	40.61	0.262	33.1	1500
TDS	mg/L	63	309	93	91	24.35	0.262	37.2	1000
Turbidity	NTU	0.01	4.99	0.94	0.69	0.90	0.954	0.1	1.00
Cl^-	mg/L	8.8	39.6	16.64	15.8	5.27	0.32	34.8	200
F^-	mg/L	0.02	2.55	0.41	0.37	0.31	0.76	1.9	1.00
NO_3^-	mg/L	0	2.72	0.08	0.02	0.30	3.70	33.6	10
Fe	mg/L	0.004	0.663	0.089	0.055	0.115	1.29	10.9	0.20
Mn	mg/L	0.002	0.604	0.013	0.002	0.065	5.00	1.3	0.10
As	mg/L	BI	BI	BI	BI	NA	NA	NA	0.05
E. coli	cfu/100mL	0	3166	266	21	682	3	0.39	0

WHO: *World Health Organisation*, MS: *Malawi Standard*, Std.D: *Standard deviation,* CV: *coefficient of variance*, SC: *sigma capability*

The summary in Table 2 shows that pH scored a mean concentration of 7.32 and a standard deviation of 0.39 which implied that the data points were not spread out from the average point. The minimum and maximum pH ranges were 6.15 and 8.02, respectively. The coefficient of variation for pH was 5.3% of the standard deviation which supports the fact the data points were not spread out from the mean. There existed a high disparity for electrical conductivity values. The mean distribution was 155µS/cm with a standard deviation of 40.6, respectively. This indicates that data points were largely spread out from the mean. The assertion is supported by a larger coefficient of variation of 26.2 % of the standard deviation.

The summary further indicates that the total dissolved solid scored a mean of 93 mg/l and a standard deviation of 91mg/l. The coefficient of variation was 26.2 %. This meant that data points were widely spread out from the mean and this was further supported by a large range 63 – 309 mg/l. The same trend was observed for turbidity. The mean concentration of turbidity was 0.94 NTU and a standard deviation of 0.90 respectively. The coefficient of variation was 95.4 % of the standard deviation. This meant that data points were widely spread out from the mean.

The descriptive statistical summary for anions (Cl^-, NO_3^-, F^-) is provided in Table 2. The summary indicates that Cl^-, F^- and NO_3^- scored mean concentrations of 16.65, 0.41, and 0.08 mg/l with the standard deviations of 5.21, 0.31, and 0.30, respectively. The coefficient of variation for Cl^-, F^- and NO_3^- were 32%, 76%, and 3.75 respectively of the standard deviation. This meant that the data points were widely spread out from the mean.

The Fe had a mean, median, and standard deviation values of 0.089 mg/l, 0.055 mg /L and 0.115 mg /L, respectively. The coefficient of variations was 129% of the standard deviation. The spreading apart of the mean and standard deviation explain the observed spreading out of data points. The same trend was observed for manganese meanwhile Arsenic was not detected during laboratory analysis.

The mean counts of coliforms were 266 cfu/100 mL with a standard deviation of 682 while the minimum and maximum value count ranged from 0 to 3166 cfu/100 mL. The coefficient of variation was larger. The wide gap between mean and standard deviations meant the data points were widely spread out from the mean. The data points exhibited a high level of variability with a coefficient of variation (CV) of 2.56.

4.2 Physico-chemical characteristics of sachet water based on locations

4.2.1 Physical characteristics of sachet water

Table 3 shows the results for the mean concentration of physical quality parameters; Turbidity, EC, TDS, and pH. In this study, Turbidity fell under the range of 0.11 to 4.99 NTU with an average of 0.92 NTU. However, between locations, it ranged from 0.42 to 1.51 NTU. The lowest mean turbidity value (0.44 NTU) was recorded in area 49 whilst the highest was registered in 57 (1.51 NTU). The Analysis of variance showed that turbidity varied significantly between locations ($p < 0.05$). Generally, a considerable number of water samples (67.78%, n = 90) had accepted turbidity levels as recommended by both MS 214 and WHO guidelines for drinking water.

The pH fell under the range of 6.15 to 8.02 and a mean of 7.31. However, between locations, the range was between 6.76 to 7.64. The analysis of variance showed that pH varied significantly between locations ($p < 0.05$). The results further indicate that some samples (8%, n = 90) from areas 18, 25, and 36 were slightly acidic as their pH level was below 7 on the pH scale. pH complied with MS 214 and WHO 2011 guidlines. The fact that pH complied with regulatory standards is further supported by the computed sigma capability of pH which is above 3 (Table 2). A parameter with SC above 3 will generally meet the regulatory standard. The higher the SC value the more compliant the parameter is. A parameter with a sigma capability (SC) above 3 will have a minimum value that is greater than the regulatory value (Table 2).

Meanwhile, EC fell under the range of 105 to 515 µS/cm and a mean of 155µS/cm. However, between locations, it was in the range of 147 to 175 µS/cm and did not vary significantly between locations ($p < 0.05$). Areas 1 and 49 recorded the lowest and highest electrical conductivity mean values of 147 µS /cm and 177 µs /cm respectively. EC complied with national standard MS 214 and WHO 2011 guidelines. The computed sigma capability of EC is above 3 (Table 3). A parameter with Sigma capability above 3 will generally meet the regulatory standard. The higher the SC value the more compliant the parameter is. A parameter with a sigma capability above 3 will have a maximum value that is greater than the regulatory value (Table 4).

In this study, TDS fell under the range of 63 mg/L to 309 mg/L and an average of 93 mg/L. However, between locations, the range was from 88 mg/L to 108 mg/l. Area 49 registered the highest mean value for TDS while the lowest mean value was recorded in area 36. All samples complied with MS 214 and WHO 2011 guidelines. The computed sigma capability of TDS is above 3 (Table 2). A parameter with SC above 3 will generally meet the regulatory standard. The higher the Sigma capability value the more compliant the parameter is. A parameter with a sigma capability greater than 3 will have a maximum value that is greater than the regulatory value. TDS and EC showed no significant difference ($p < 0.05$).

Table 3: Comparative results of physical characteristics of sachet water between the different location of sample collection

Area	pH			TDS (mg/L)			EC (µS/cm)			Turbidity (NTU)		
	min	max	mean	min	max	mean	min	max	mean	min	max	mean
A1	7.26	8.02	7.64	63	99	88	105	166	147	0.11	4.99	0.81
A18	6.15	7.48	6.76	71	106	90	119	176	150	0.09	2.01	0.79
A25	6.24	7.51	7.31	82	96	90	137	169	151	0.21	2.38	0.98
A36	6.44	7.54	7.21	82	110	91	136	184	152	0.27	3.84	1.03
A49	6.98	7.86	7.54	69	309	105	115	515	175	0.01	2.44	0.42
A57	7.24	7.63	7.41	89	104	93	148	174	156	0.54	4.4	1.51
WHO 2011	6.5	8.5	NA	Nh	NA	NA	NA	NA	NA	NA	≤ 5	NA
MS 214	5	9.5	NA	450	1000	NA	700	1500	NA	0.1	1	NA

WHO: *World Health Organisation*, MS: *Malawi Standard*, NA: *not applicable, n = 15*,

4.2.2 Chemical characteristics of sachet water

Table 4 shows the results for the mean concentration of chemical quality parameters; chloride, fluoride, and nitrates. The highest mean chloride concentration (22.93 mg/L) was recorded in area 1 and lowest in area 57, indicating that all measured chloride levels were within the recommended limits of 200 mg/L. The same can be said for fluoride which recorded the highest mean concentration (0.55 mg/L) in area 57 and minimum concentration (0.19 mg/L) in area

36. The concentration of fluoride in all areas was below the minimum MS 214 low bound of 0.7 mg/L. Area 49 recorded the highest mean nitrates concentration (0.18 mg/L) while area 1 registered the lowest mean concentration (0.01 mg/L). In all the areas except for fluoride, all other chemical parameters complied with the standards. Only chloride and fluoride showed a significant difference ($p < 0.05$) while nitrates showed no significant difference ($p > 0.05$).

Table 4: Comparative chemical characteristics of sachet water between different areas of sample collection

Area	Cl^- (mg/L)			F^- (mg/L)			NO_3^- (mg/L)		
	min	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**
A1	12.30	39.60	22.93	0.15	2.55	0.50	0	0.04	0.01
A18	11.20	18.50	14.99	0.14	0.69	0.50	0	0.35	0.06
A25	16.40	19.90	18.34	0.33	0.72	0.50	0.01	0.25	0.12
A36	12.30	21.10	16.19	0.02	0.39	0.19	0	0.3	0.09
A49	12.70	22.80	15.57	0.05	0.46	0.23	0	2.72	0.18
A57	8.80	20.20	11.89	0.31	1.19	0.55	0	0.03	0.012
WHO 2011	NA	250	NA	NA	1.5	NA	NA	50	NA
MS 214	100	200	NA	0.7	1	NA	27	44.3	NA

WHO: *World Health Organization*. MS: *Malawi Standard*, NA: *not applicable, n = 15*,

4.2.3 Heavy metal elements characteristics of sachet water

Table 5 shows the results for the mean concentration of chemical parameters; Iron, manganese, and Arsenic. The results show that the highest mean iron concentration (0.12 mg/L) was recorded in area 18 while the lowest (0.02 mg/L) was registered in area 36. Meanwhile, area 1 registered the highest Mn concentration (0.04 mg/L), and areas 18 and 49 recorded the lowest value (0.01 mg/L) while in areas 25 and 36 it was not detected. In all sachet water samples, no Arsenic was detected during laboratory analysis. Meanwhile, there was no significant difference for Iron, and manganese ($p < 0.05$). Table 5 gives a comparative description of mean concentrations recorded for metal elements.

Table 5: Comparative results of heavy metal characteristics of sachet water between different areas of sample collection

Area	Fe (mg/L)			Mn (mg/L)			As (mg/L)		
	min	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**
A1	0.05	0.32	0.12	0	0.6	0.04	BI	BI	BI
A18	0	0.34	0.11	0	0.02	0.01	BI	BI	BI
A25	0.01	0.47	0.08	BI	BI	BI	BI	BI	BI
A36	0.01	0.07	0.02	BI	BI	BI	BI	BI	BI
A49	0.01	0.27	0.08	0	0.04	0.01	BI	BI	BI
A57	0	0.66	0.11	0	0.07	0.02	BI	BI	BI
WHO 2011	NA	0.30	NA	NA	0.20	NA	NA	0.05	NA
MB 2011	0.01	0.20	NA	0.05	0.10	NA	0.005	0.01	NA

WHO**:** *World Health Organization*, MS: *Malawi Standard*, NA: *not applicable, n = 15, BI= Below detection*

4.3 Microbial water quality of sachet water in different location of sample collection

All samples collected from all six areas showed microbial contamination. Water sachet samples were contaminated with fecal coliforms (*E. coli*). The contamination ranged from 4cfu/100 mL to 780 cfu/100 mL. These values were far above the recommended limit of 0cfu/100 mL set out by MBS and WHO. Across the areas, faecal coliform showed no significant difference ($p < 0.05$). Table 6 shows the mean values of sachet water samples for the microbial parameter in different locations of sample collection.

Table 6: Comparative results of microbial characteristics of sachet water between different areas of sample collection

Area	*E. coli* (cfu/100 mL)		
	min	**max**	**mean**
A1	0	215	84
A18	0	3165	728
A25	0	2500	176
A36	0	2000	251
A49	0	35	3
A57	2	2300	318
WHO 2011	0	0	NA
MS 214	0	0	NA

WHO: *World Health Organisation*, MS: *Malawi Standard,* NA: *Not applicable*

4.4 Frequency distribution of characteristics of sachet water

Figures 8 – 9 show the frequency distribution of the analysed water quality parameters. The data for all parameters except pH are skewed, meaning that data sets were asymmetric around the mean or median, with extreme values extending out longer in the right direction. When extreme values extend the right tail of the distribution, as with figures 8 to 9, the data is said to be skewed to the right. Thus, for the data that is showing positive skewness, the mean exceeds more than 50 percent of the data set. The standard deviation is also inflated by data in the tail.

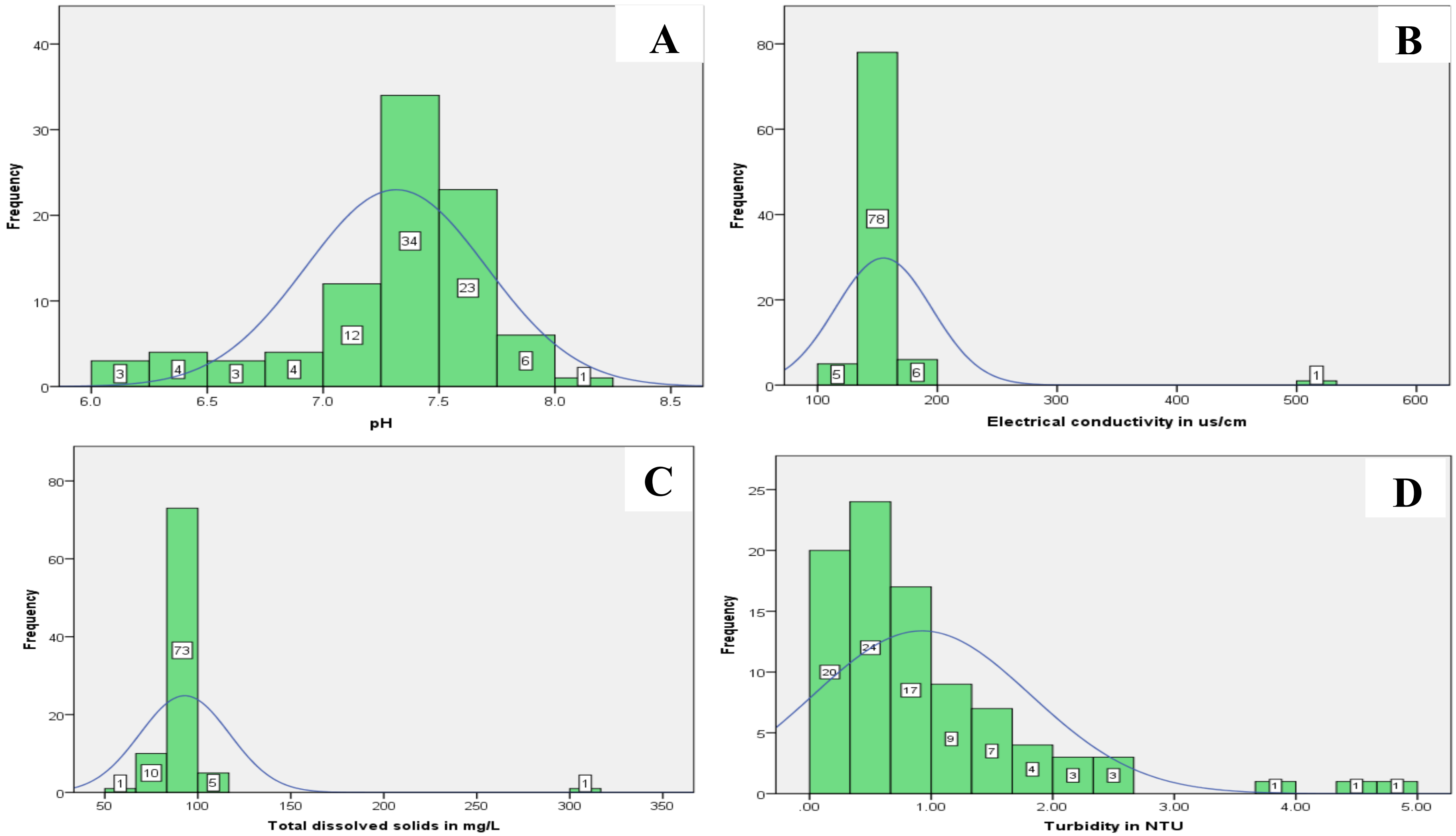


Figure 7: **Frequency distribution of pH (A), EC (B), TDS (C), and turbidity (D)**

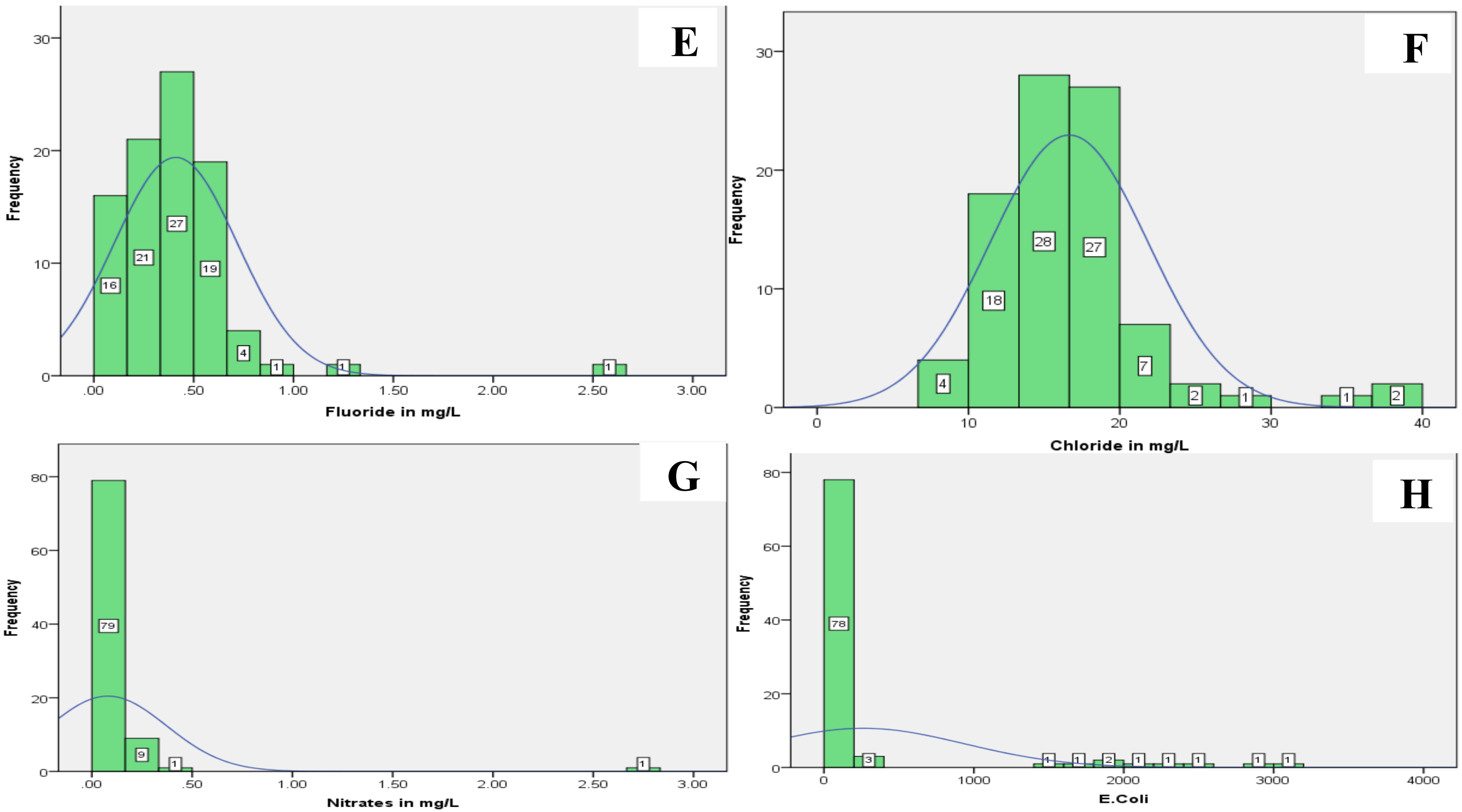


Figure 8: **Frequency distribution for F^- (E), Cl^- (F), NO_3^- (G), and *E. coli* (H)**

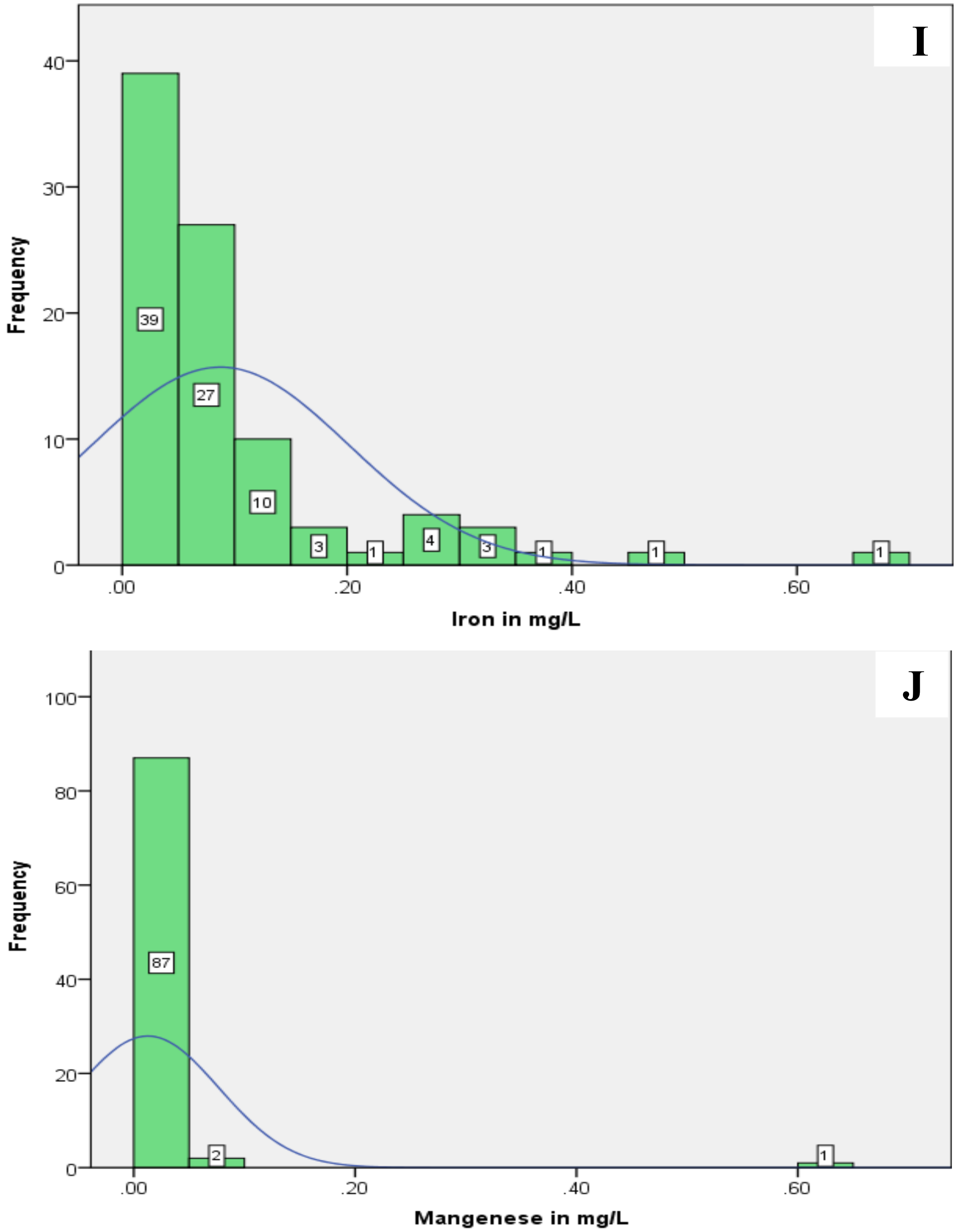
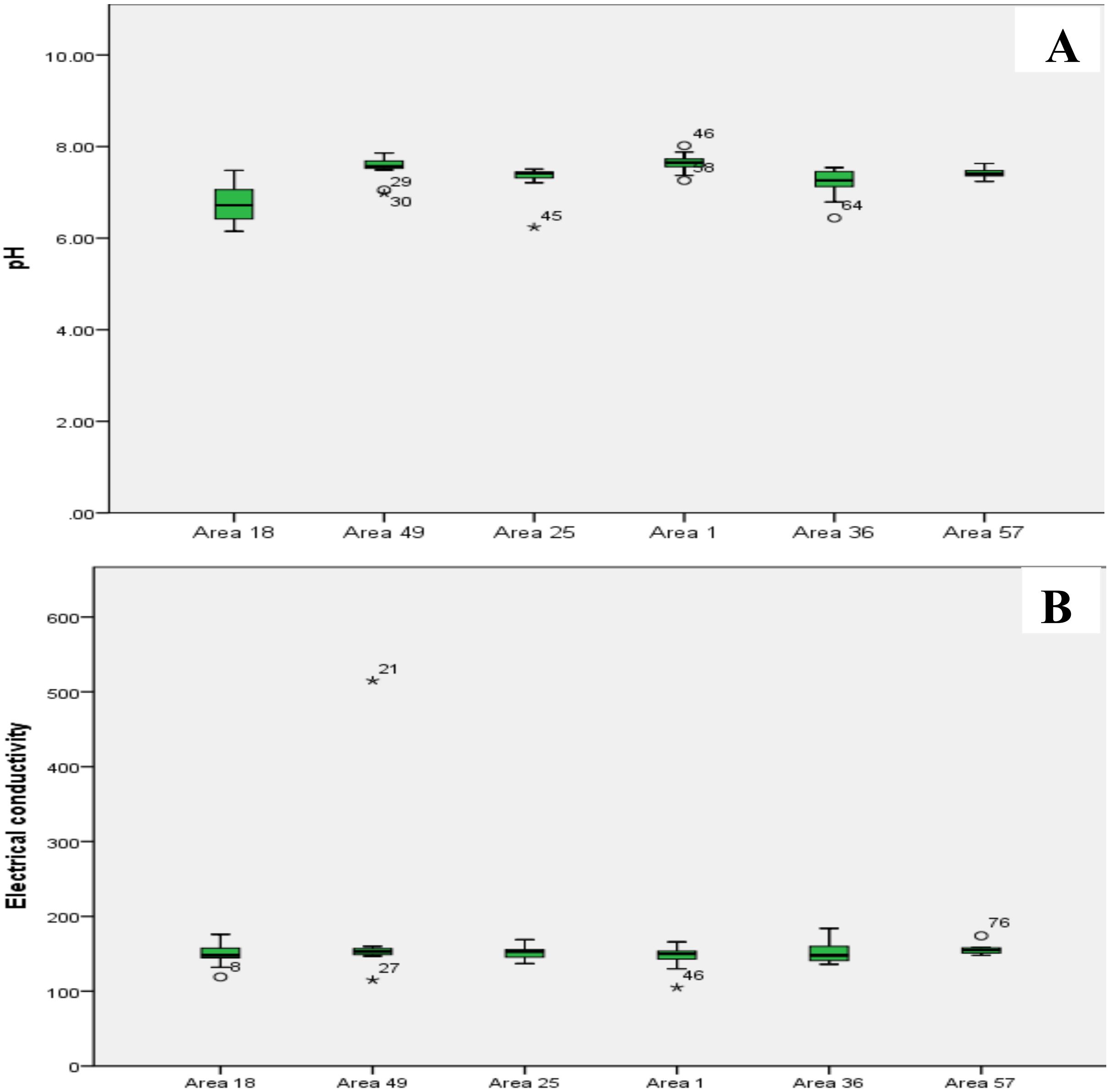
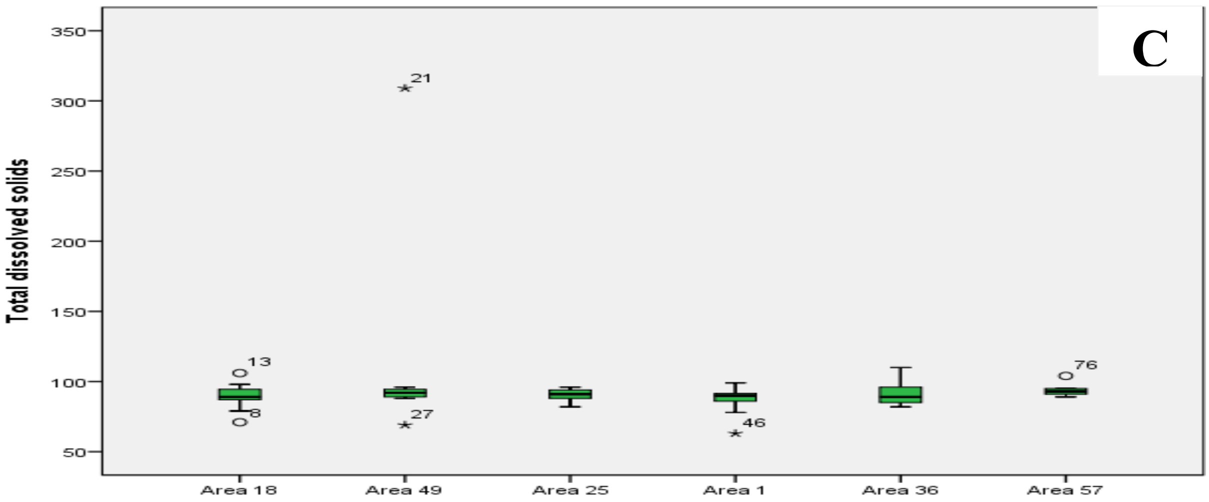


Figure 9: **Frequency distribution for Iron (**I**) and Manganese (**J**)**

Box and Whisker plot was deployed to further understand the distribution of the data set. Boxplot is a valuable graphical presentation for summarizing the dispersion of data (Helsel *et al*., 2002). Figures 10 to 13 shows a boxplot of water quality parameters clearly showing median, skewness, and outlying values in asterisk. The occurrence of outside or outlier values more frequently than anticipated gives a fast-visual sign that data may not originate from a normal distribution. Generally, the dataset collected in this study showed fewer outliers and positive skewness. Water resources data tend to be positively skewed (Helsel *et al*., 2002).





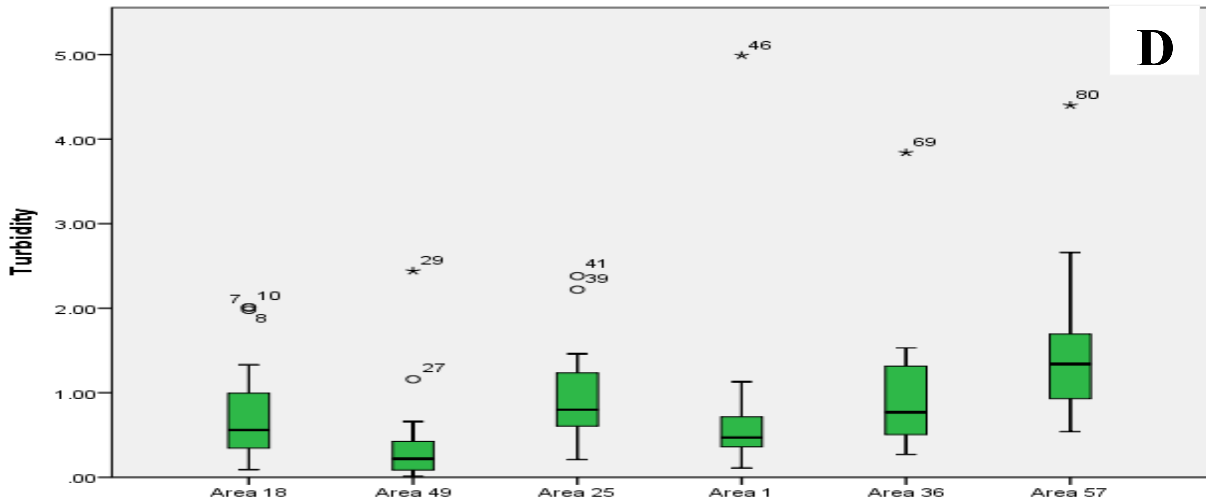
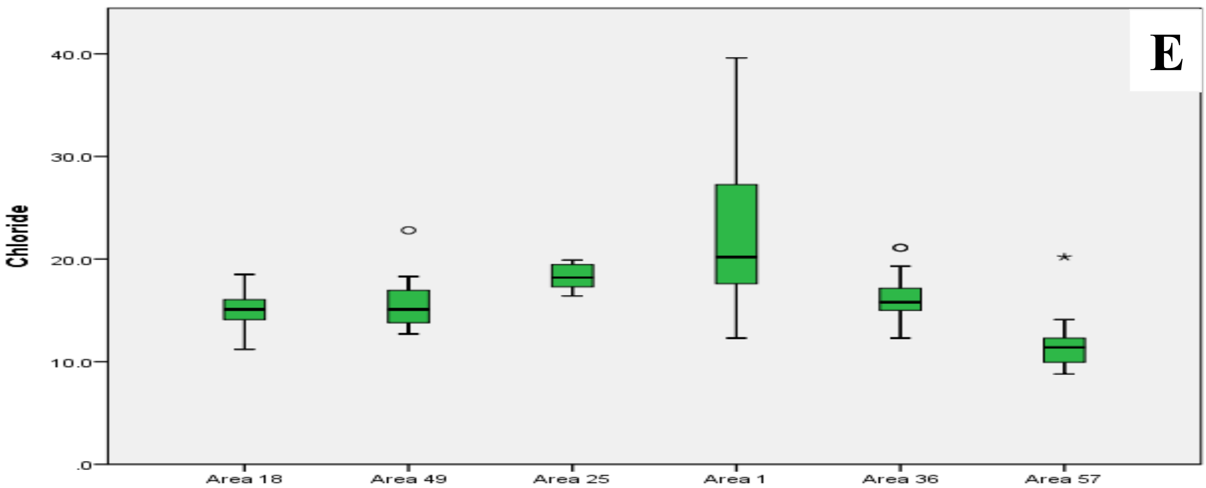
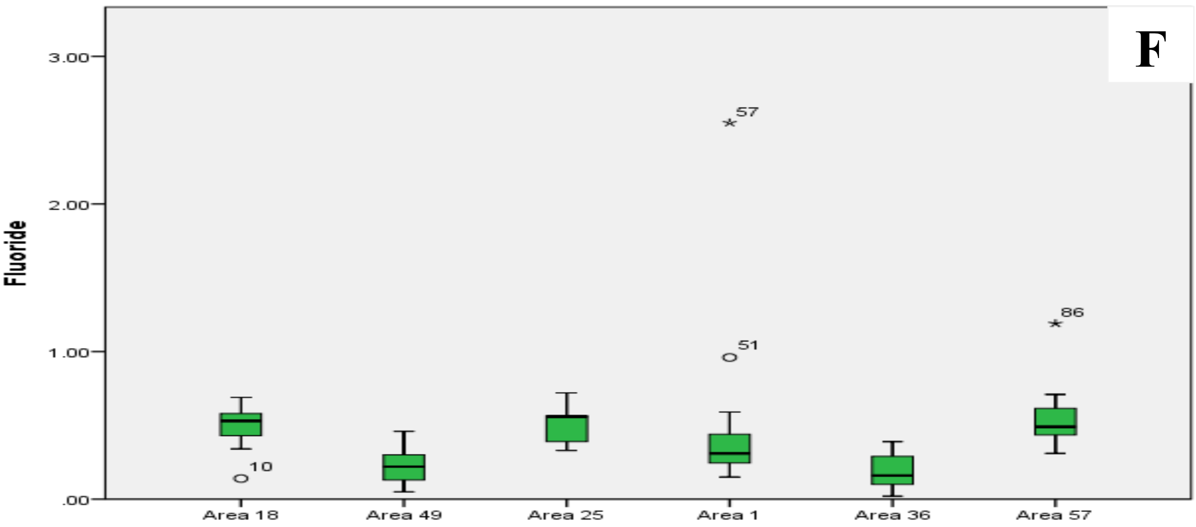


Figure 10: Box and Whisker plots for physical parameters: pH (A), EC (B), TDS (C), and Turbidity (D)





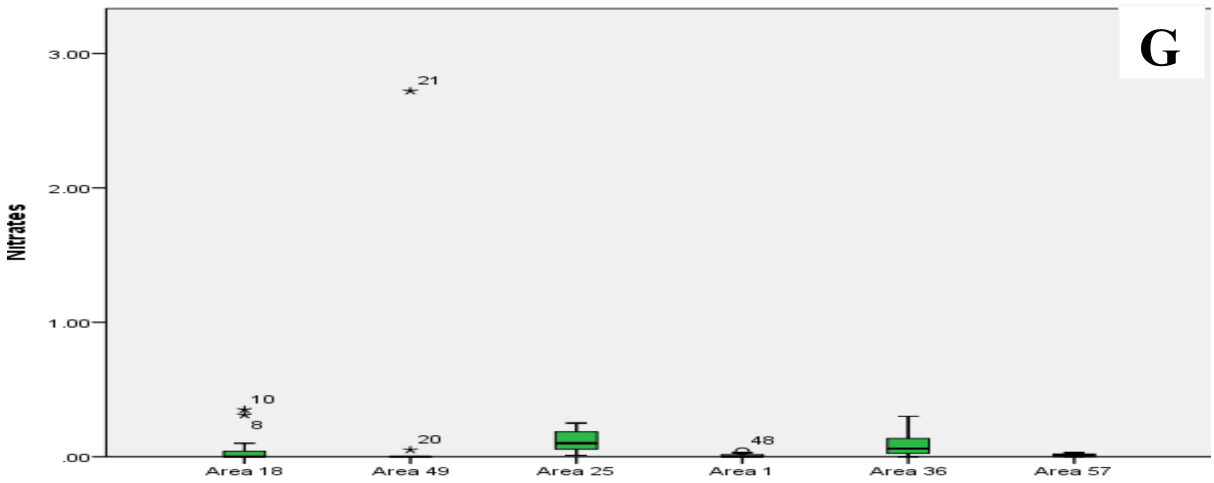
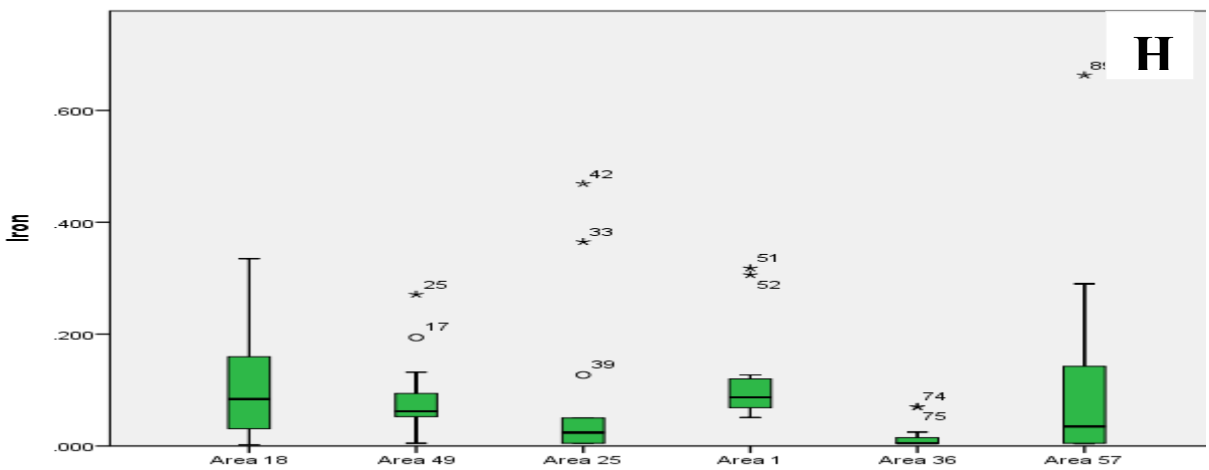


Figure 11: Box and Whisker plots for chemical parameters: Chloride (E), Fluoride (F), and Nitrates (G)



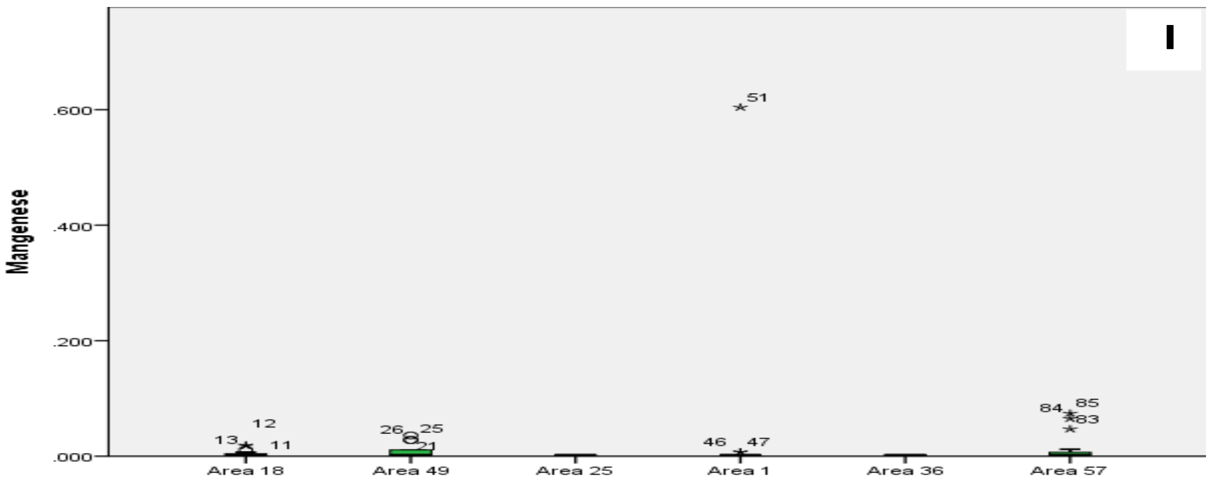


Figure 12: Box and Whisker plots for metal elements: Iron (H) and Manganese (I)

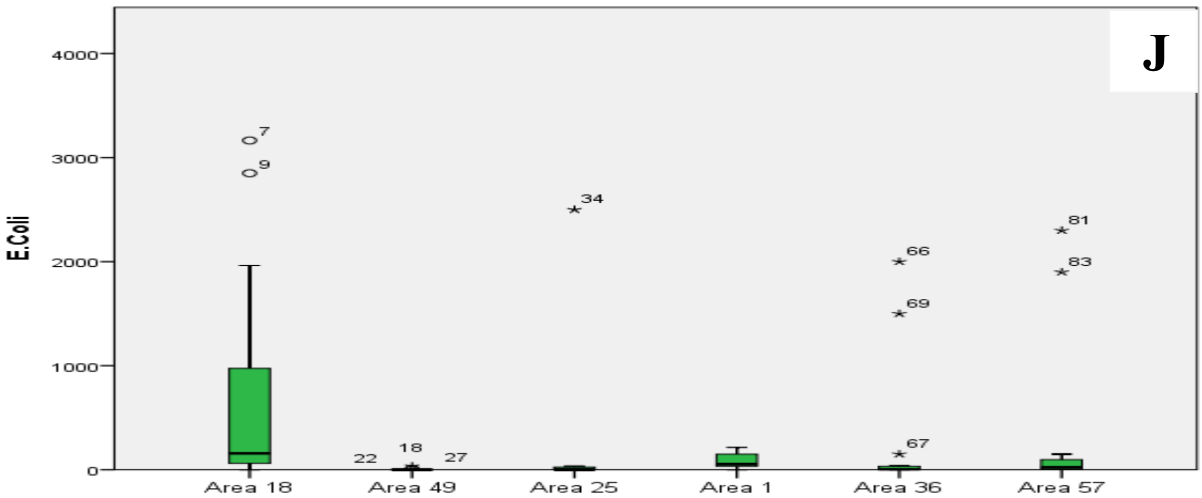


Figure 13: Box and Whisker plots for microbial parameter: *E. coli* (J)

4.5 Results of analysis of Variance (ANOVA) for sachet water samples

Table 7 present the results for analysis of variance for sachet water samples. The results show that only pH, Cl^-, F^-, and turbidity were significantly different ($p < 0.005$) across the locations of sample collection while the rest of the parameters were not.

Table 7. Summary of results for the analysis of variance (ANOVA) for sachet water samples

Parameters	**P-Value**
pH	0.000
Electrical conductivity	0.457
Total dissolved solids	0.439
Chloride	0.000
Fluoride	0.001
Nitrates	0.566
Turbidity	0.030
Iron	0.135
Manganese	0.502
E. coli	0.051

4.6 Source of water for sachet water production and treatment options

The main source of potable water used to produce sachet water as observed in the study area was treated water from public drinking water system (Lilongwe Water Board). All interviewed sachet water sellers reported utilizing tap water when producing sachet water. This water is treated at the water treatment plant through screening, coagulation, flocculation, sedimentation, filtration, and chlorination (Kosamu *et al.*, 2013; Boakye-Ansah *et al.*, 2016). The vendors reported that no further treatment was done before packaging tap water in a sachet. Generally, to deliver sachet water, a basin or bowl is utilized to fetch tap water. The sachet is opened either by scouring with hands or blowing air inside by mouth. A cup is used to fill the desired volume of water in the sachet and the polythene tube is then fixed by tying a bunch at the open end.

Although sellers claimed using faucet water in sachet water production the water was contaminated with faecal matter. This could be a result of a lack of strict adherence to hygienic practices during sachet water production as observed during a visit to some production sites in the Tsoka market in Lilongwe. Other related studies also have attributed a lack of strict adherence to hygienic conditions during production as the main reason for sachet water feacal contamination (Dodoo *et al.*, 2006; Halage *et al.*, 2015). There is also the possibility that tap water used in the production of sachet water was contaminated before packaging as observed in the study conducted in Malawi, Ghana, and Nigeria by (Boakye-Ansah *et al.,* 2016; Stoler *et al.*, 2012; *Dodoo et al.,* 2006). A study conducted in Lilongwe on quality supplied by Lilongwe Water Board found that 10 % of the tap water samples and 59% of kiosk samples were all contaminated with *E. coli* (Boakye-Ansah *et al.,* 2016). It is therefore highly recommended that sachet water producers should be treating tap water before packaging. Figure 8 shows sachet water production and storage in Lilongwe.

A (Initiation) **B (Packaging)**

C (Finished Product) **D(Storage)**

Figure 14 (A – D): Pictures showing sachet production process and storage in Lilongwe (Tsoka Market)

4.7 Water quality of Sachet water products in Lilongwe

The results suggest that the majority of sachet water products produced in Lilongwe failed to comply with MS 214 and WHO 2011 guidline for E. coli at the time that they were produced (table 6). However, they did not pose chemical contaminants at concentrations posing a substantive risk to human health (tables 2,3,4 and 5). The following section discusses the water quality sachet water products in Lilongwe

4.7.1 Physico-chemical quality: pH, Turbidity, EC, TDS, Chloride, Fluoride, Nitrates , Iron, Manganese, and Arsenic

a) **Turbidity**

The variations in turbidity amongst the locations compared to the Malawi standard (214) and WHO (2011) guidelines are shown in Figures 15 and 16**.** Most of the samples from area 57 (66.67%, *n* = 15) scored values above the MS 214 (2013) guideline of 1 NTU (Figure F). A considerable number of samples from areas 25, 36 and 18 (40%, *n* = 15), (33.33%, *n* = 15), and (26.67%, *n* = 15) recorded turbidity level above the MS 214 (2013) of 1 NTU (Figures C, D and B). Very few samples from areas 1 and 49 (13.33%, *n* = 15) also scored turbidity concentration values above the MS 214 (2013) guideline of 1 NTU (Figure A and E). In general, mean values for areas 36 and 57 were above the MS 214(2013) maximum limit of 1 NTU while the remaining areas complied with the aforementioned standard (figure 15). Overall, a considerable number of water samples (67.78%, *n* = 90) complied with MS 214 guidelines for drinking water. However, some sachet water (32%, n = 90) was not suitable for human consumption due to elevated turbidity levels. High turbidity in sachet water suggests problems in the filtration process in the public water treatment plant (LWB) where sachet producers fetch water for the production of sachet water. Previous studies also have found that the turbidity of drinking water from the Lilongwe Water Board was above the MS 214 value of 1.0 NTU (Boakye-Ansah et al., 2016). Turbidity in drinking water is normally used as a proxy measure for microbiological contamination (WHO, 2011; Boakye-Ansah et al., 2016). Turbdide water most associated with microbiological contamination which poses health risks to consumers (Farooq et al., 2008).

The present finding is consistent with reports of an elevated level of turbidity in sachet water products from West African countries like Ghana and Nigeria (Danso-Boateng & Frimpong, 2013, Omole *et al.*, 2015). However, these results contradict similar studies conducted in

Uganda and Ghana (Halage *et al*., 2015; Dodoo *et al*., 2006) which found that all the samples complied with both national and international guidelines for drinking water. Turbidity decreases disinfection efficiency as it shields organisms and much of water treatment is directed at removing particulate matter before disinfection (WHO, 2011). Elevated turbidity also affects the acceptability of drinking water by the consumer due to visible cloudiness.

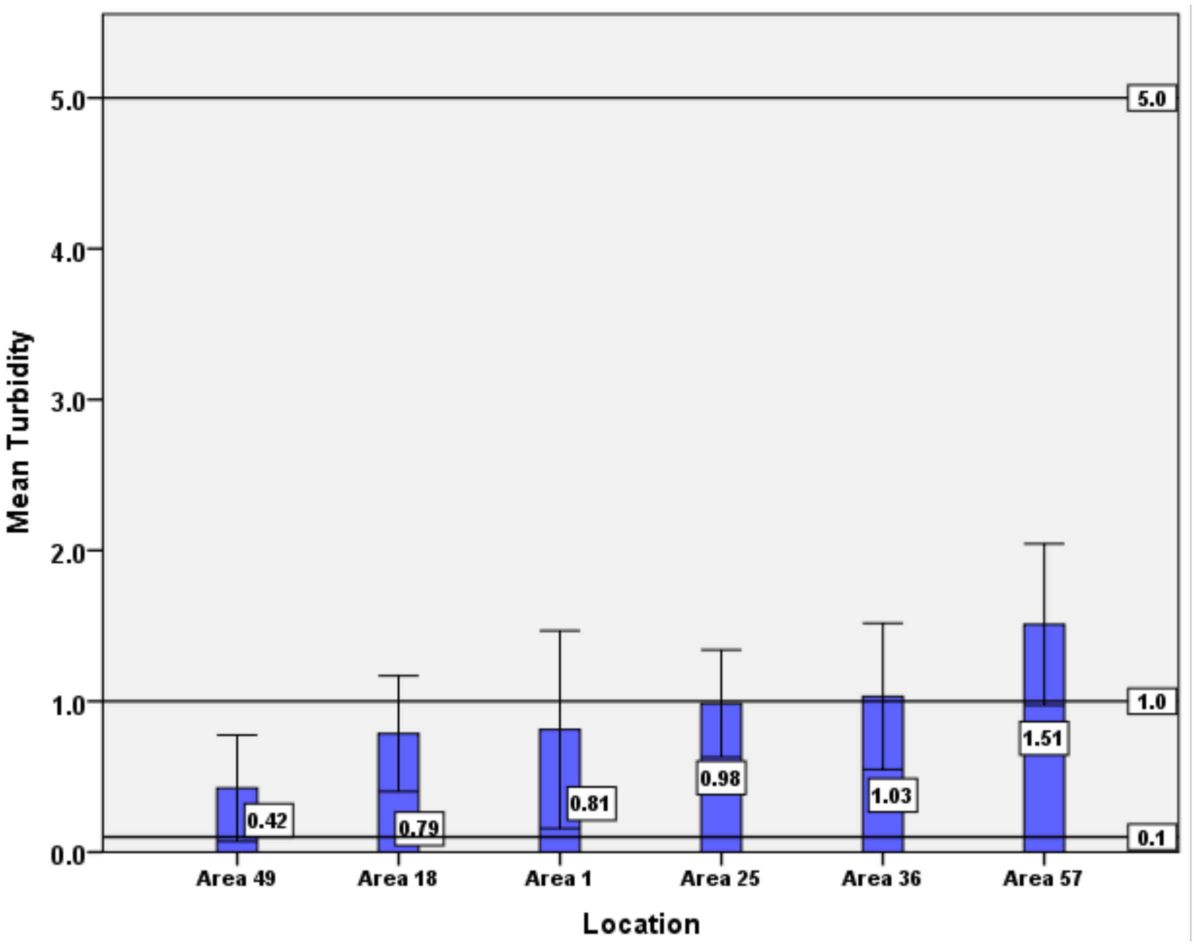


Figure 15: Mean plots with error bars of sachet water quality (Turbidity) in different areas compared to M 214 and WHO standards

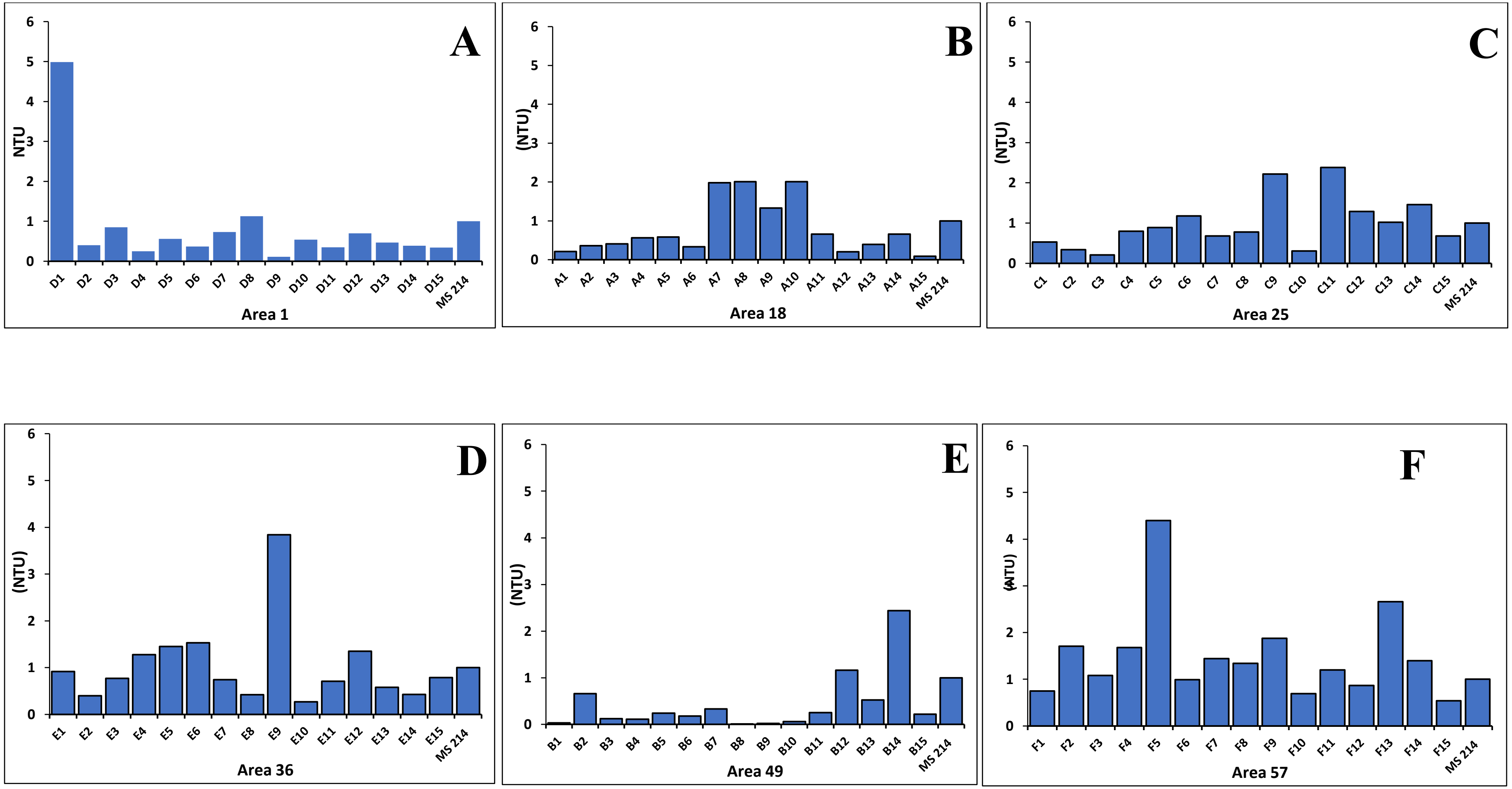


Figure 16 (A – F): Variation in water quality (Turbidity) of sachet water in different areas compared to M 214 standard

b) **pH**

The variations in pH in different sampling sites compared to the 214 (2013) Malawi standard and WHO (2011) are shown in Figures 17 and 18. pH ranged from 6.75 to 7.64 in all locations of sample collection. pH concentration of sachet water samples in area 18 was slightly acidic (6.76) while areas 1, 25, 36, 49, and 57 (7.64,7.31,7.21,7.55 and 7.41) were slightly alkaline. pH values were within the MS permissible limit of 5.0 to 9.50 for all of the samples (100%, *n* = 90). However, few samples (8%, *n* = 90) from areas 18, 25 and 36 reported pH below and above permissible limit of 6.50 WHO guidlines hence were noncompliant. Other sachet water studies have reported pH values below standards in Sierra Leone with some values as lower as 4.0 (Fisher *et al*., 2015). Further, a similar study conducted in Georgia, USA reported that 42% of sachet water samples fell outside an acceptable limit for pH concentration in drinking water. However, findings from this study contradict similar studies that reported pH compliance to standards in sachet water in Ghana and Uganda, respectively (Oyelude & Ahenkorah, 2012; Halage et al., 2015). The WHO guidelines for pH (6.5 – 8.5) seek to address the problem of corrosion in metal pipes as such may not be relevant to sachet water. However, use of piped water when producing sachet water as reported in this study may correspond to heightened risk of contamination from metals that can leach from distribution pipe (Fisher *et al*., 2015a). The variation reported values of pH in this study may be attributed to changes that occur in water distribution systems as reported by other studies (Boakye-Ansah et al., 2016). The measurement of pH is done to determine the corrosiveness of the water (WHO, 2011). Drinking water with a pH below 6.5 is acidic and therefore corrosive.

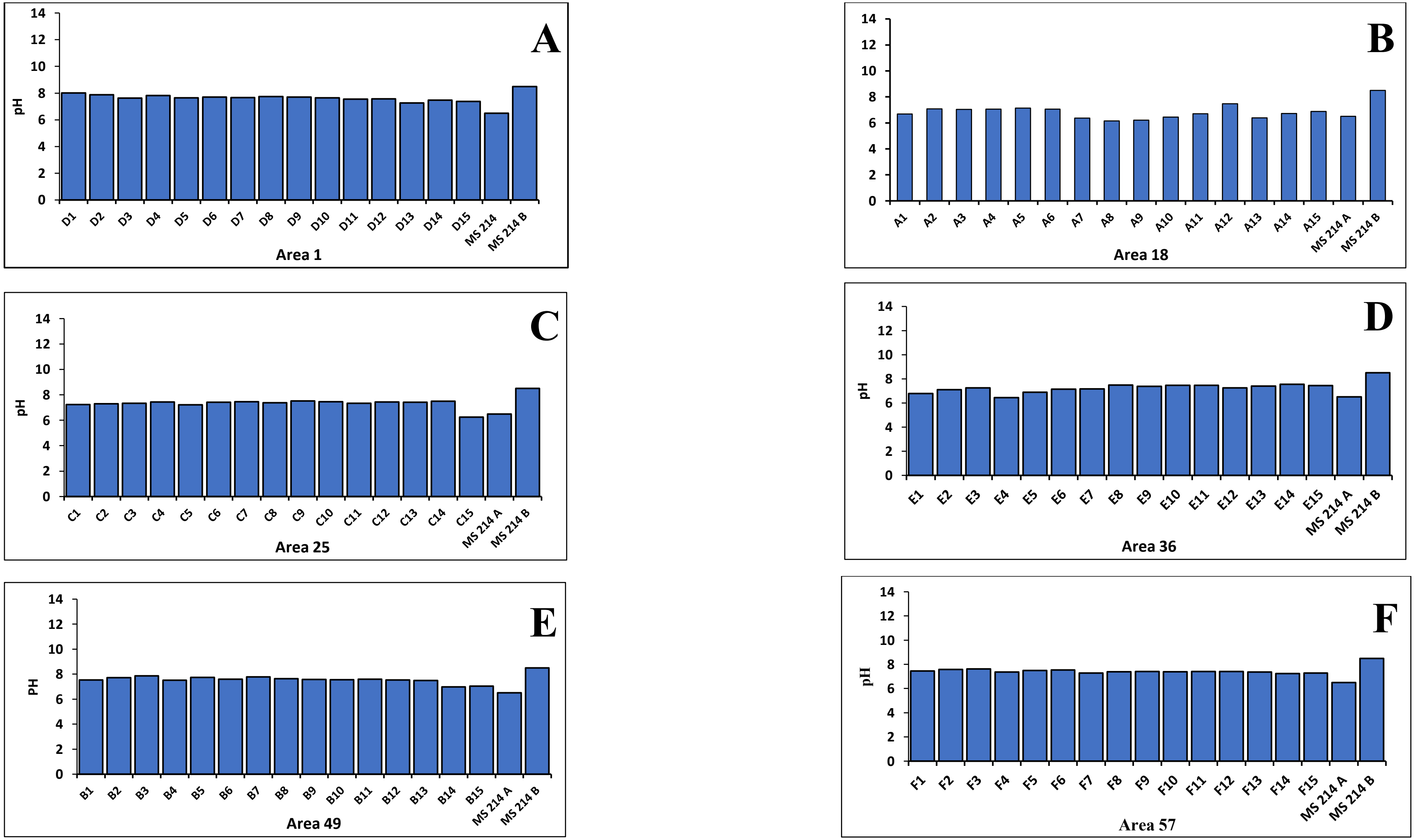


Figure 17 (A – F): Variation in water quality (pH) of sachet water in different areas compared to M 214 standard

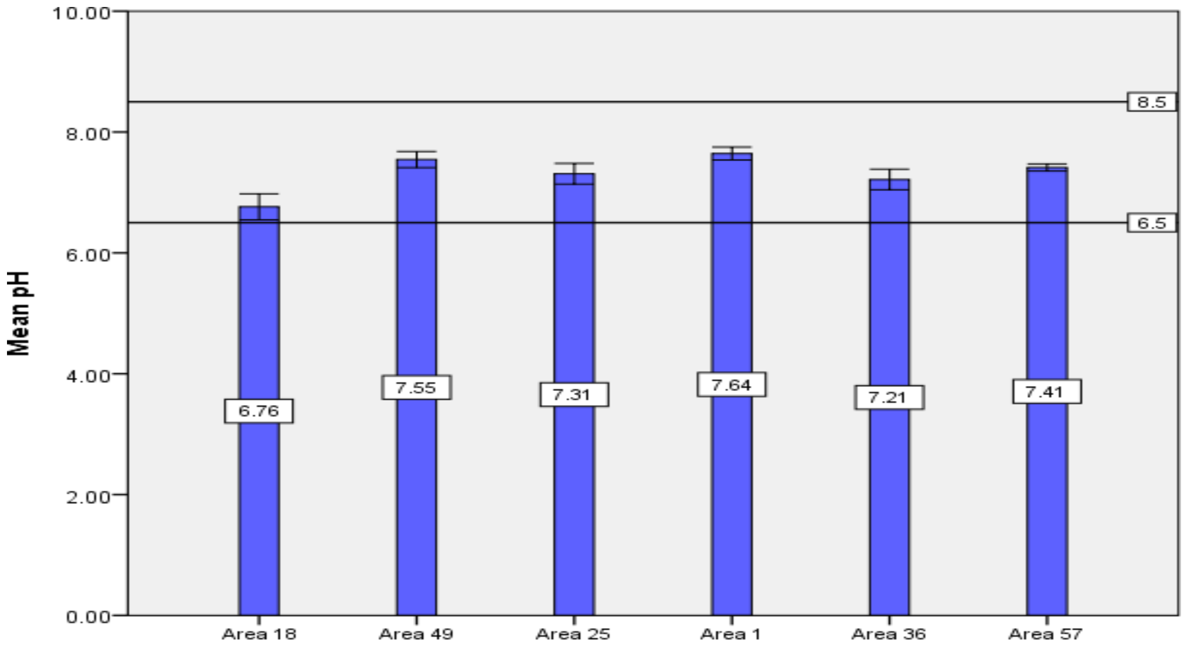


Figure 18: Mean plots with error bars of sachet water quality (pH) in different areas compared to M 214 and WHO standards

c) **Electrical conductivity**

The variations in EC in different sampling sites compared to the 214 (2013) Malawi standard and WHO (2011) are shown in Figures 19 – 20**.** All mean values of EC were within the permissible range set by MS 214 (2013) and WHO (2011) of 1500 µS/cm. There was minimal variation in electrical conductivity concentration with the 175µs/cm value recorded in area 49 and the minimum 147 µs/cm in area 1. This, therefore, means that the capacity of samples from area 49 to conduct electricity is slightly higher than the capacity of samples from area 1. It also means that there are many dissolved salts in samples from area 49 and fewer in samples from area 1. The conductivity of most freshwater ranges from 10 to 1,000 µS/ cm but in polluted waters may surpass 1,000 µS/cm (Chapman, 1992). This led to the conclusion that sachet water in the study area was not polluted. The results concur with other similar studies conducted in Cameroon and the United States of America USA (Ma & Ndonwi, 2015; Mako et al., 2014). Figures 20 and 21 present mean values of EC plotted against areas and MS and WHO guidlines. However, findings from this study contradict similar studies that reported EC non-compliance to standards in sachet water in Ghana (Dodoo et al., 2006).

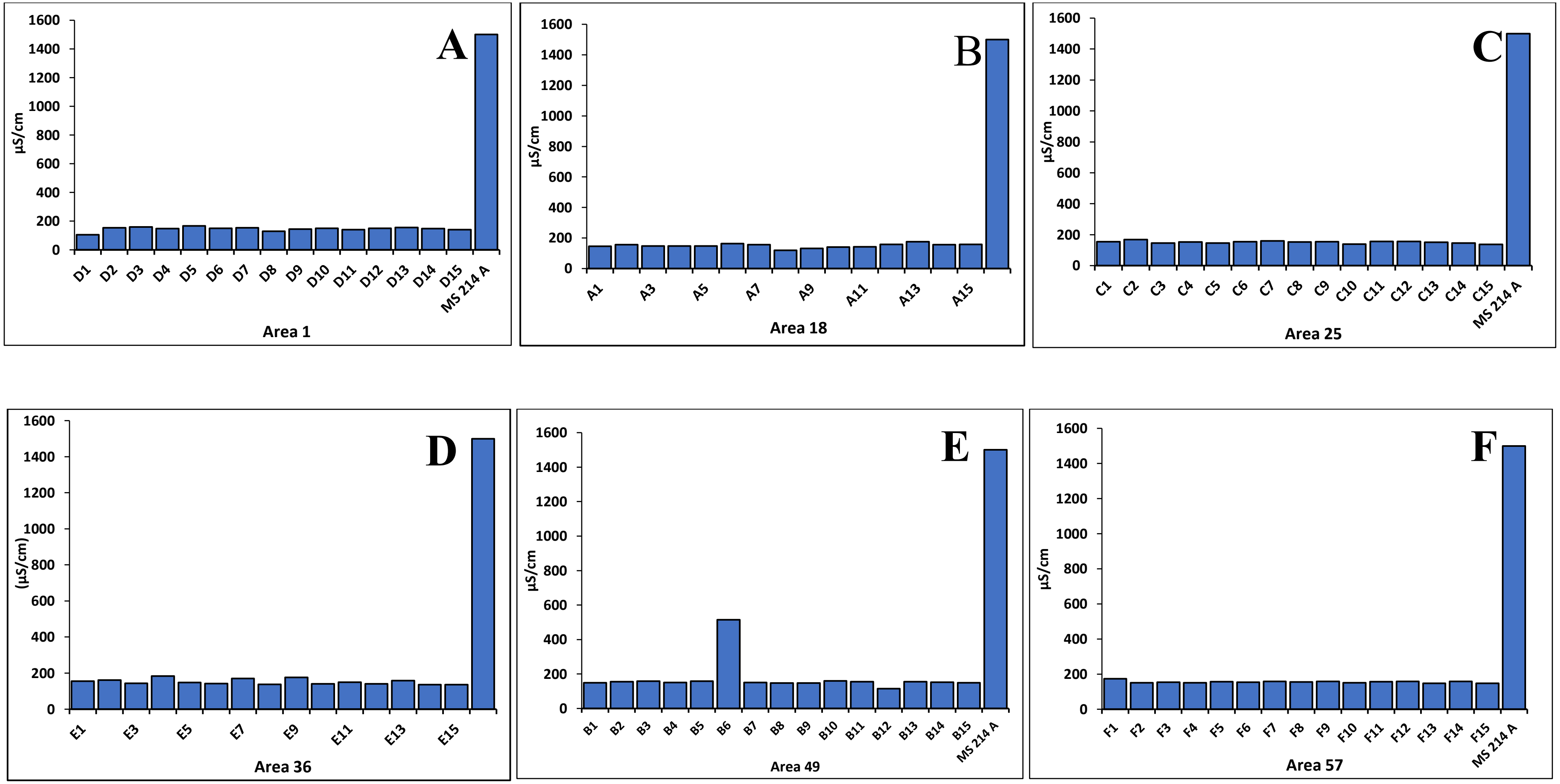


Figure 19 (A – F): Variation in water quality (Electrical Conductivity) of sachet water in different areas compared to MS 214 standard

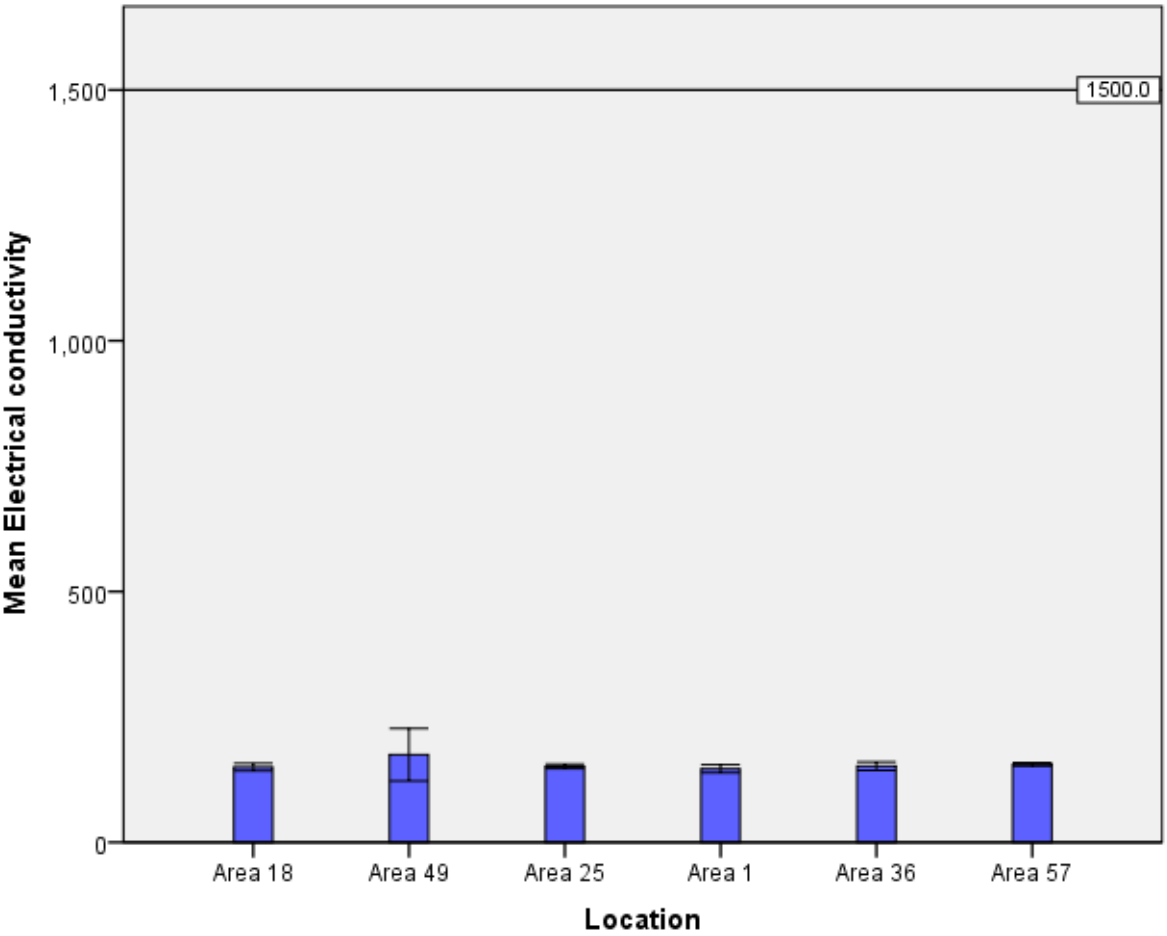


Figure 20: Mean plot with error bars of sachet water quality (EC) in different areas compared to M 214 and WHO standards

d) **Total dissolved solids**

The variations in TDS in different sampling sites compared to the 214 (2013) Malawi standard and WHO (2011) guidelines are presented in Figures 21 and 22**.** There was minimal variation in TDS concentration with the 88 mg/L value recorded in area 49 and the minimum 88 µS/cm in area 1. These values were within the maximum permissible limit of 1000 mg/L for TDS set by WHO (2011) and MS 214 (2013). Total dissolved solids is a measure of the level of dissolved solids in water and it influences the taste of drinking water (Onweluzo & Akuagbazie, 2011). Lower TDS means softer drinking water. However, water with extremely low concentrations of TDS may also be unacceptable to some consumers because of its flat insipid taste and make it not advisable to people with a high nutrient diet. All samples had good quality water in terms of TDS. A related study reported TDS compliance to standards in Ghana (Oyelude & Ahenkorah, 2012). The sachet water produced and sold in Lilongwe falls in the EU mineral classification range of 50 – 500 mg/L for TDS. The water type belonging to this class is called low mineral concentration water. All the samples (n = 90) had TDS falling under this water type.

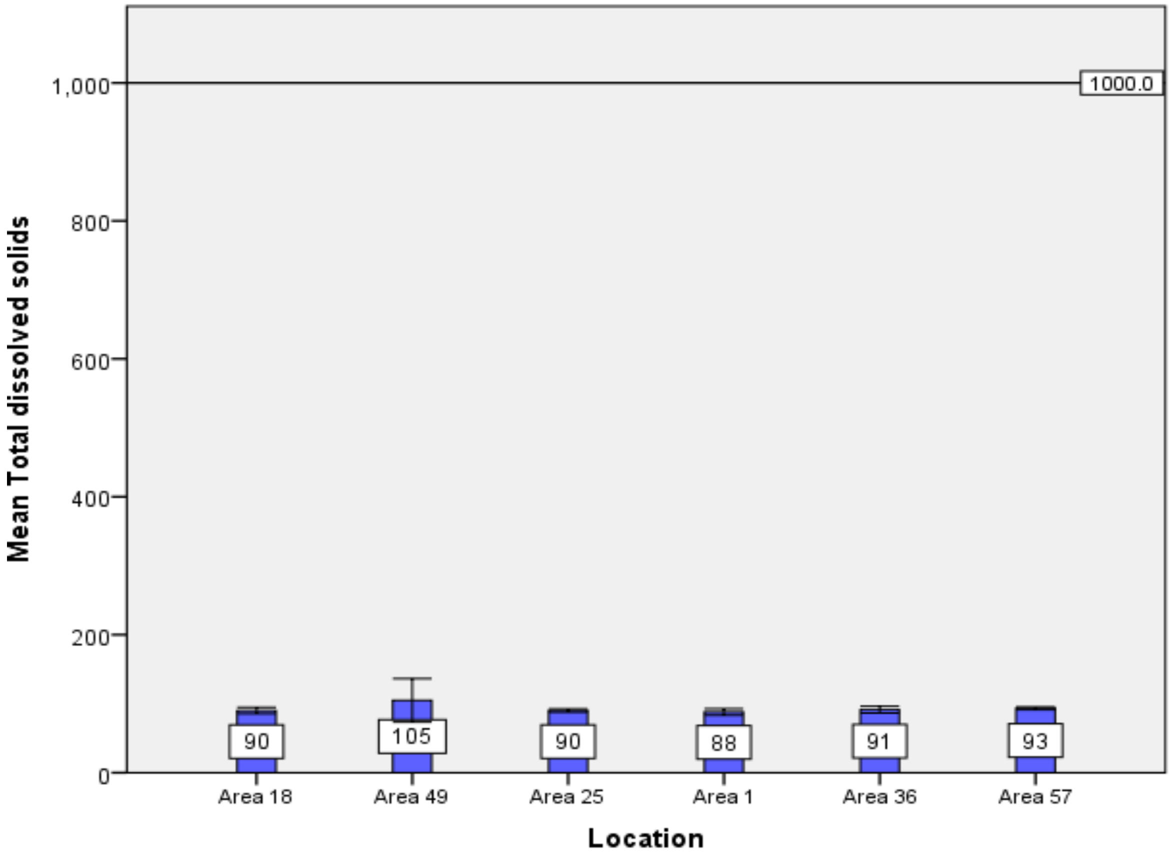


Figure 21: Mean plot with error bars of sachet water quality (TDS) in different areas compared to M 214 and WHO standards

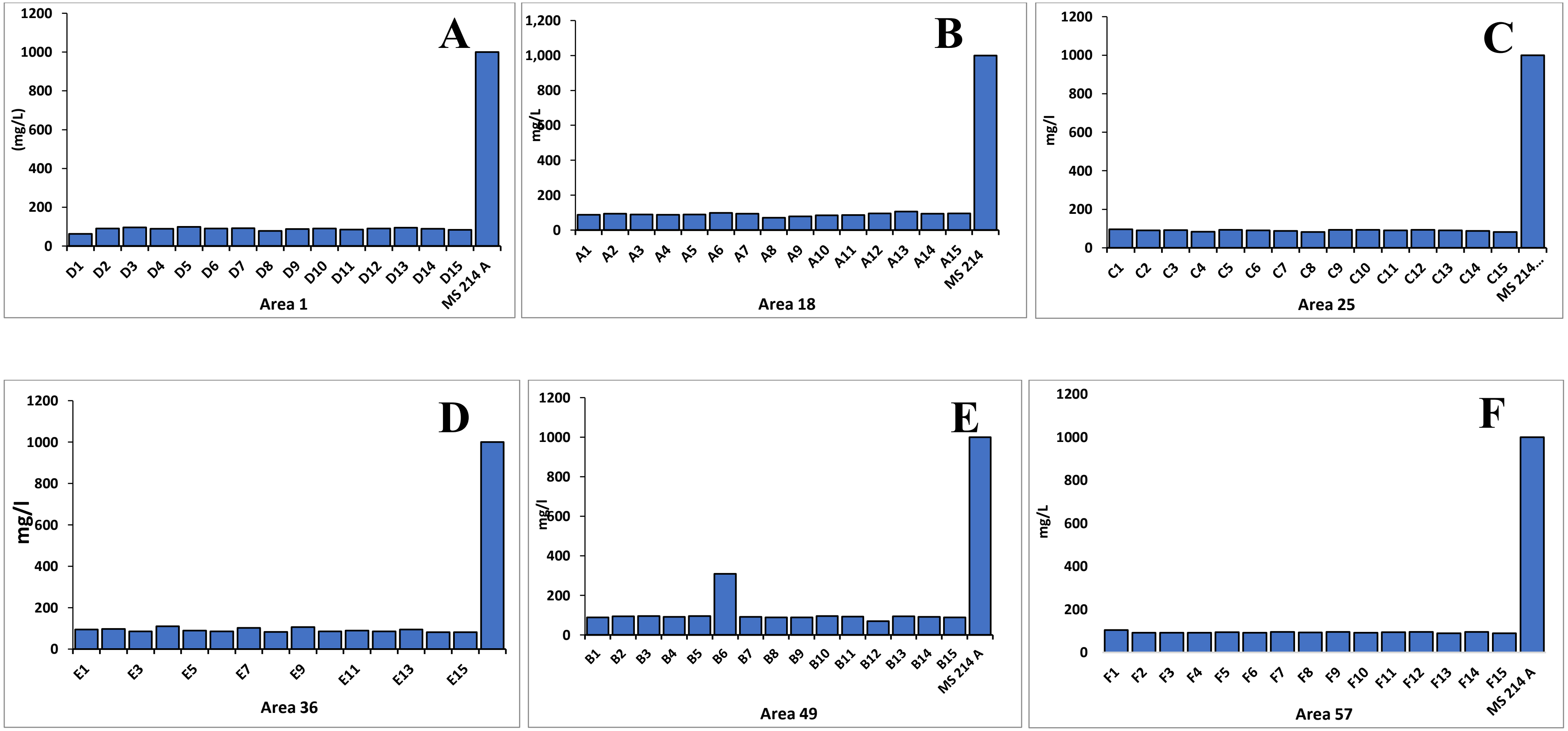


Figure 22 (A – F): Variation in water quality (Total Dissolved Solids) of sachet water in different areas compared to MS 214 standard

e) **Chloride**

The variations in chloride in different sampling sites compared to the 214 (2013) Malawi standards and WHO (2011) guidelines are shown in Figures 23 and 24**.** Chloride showed very little variation across the location of sample collection with a maximum value of 22.93 mg/L in area 1 and the minimum 11.89 mg/L in area 57. WHO (2011) guidelines and MS 214 (2013) recommend 250 mg/L and 200 mg/L respectively as the maximum chloride level in drinking water, as such the samples in this present study complied with the aforementioned guidelines. This present study concurs with a similar study carried out in Cameroon which reported chloride compliance to WHO (2011) permissible limit (Hermann *et al.*, 2018; Dodoo et al., 2006). However, the study established that chloride levels, despite satisfying the MS 214 and WHO 2011 standards requirements, the chloride concentration was very low, may be due to exposure to sunlight during sales (Hermann *et al.*, 2018). Chloride is an important inorganic anion contained in variable concentrations in natural water usually in the form of salts of sodium (NaCl) and potassium (KCl). An excess amount of chloride, if consumed over a while, can constitute a health hazard (Oyelude & Ahenkorah, 2012). The water samples in this present study possessed low chloride ion levels hence pose no health risks to cosnumers. The low chloride ion levels could be as a result of the sachet water being exposed to sunlight during sales.

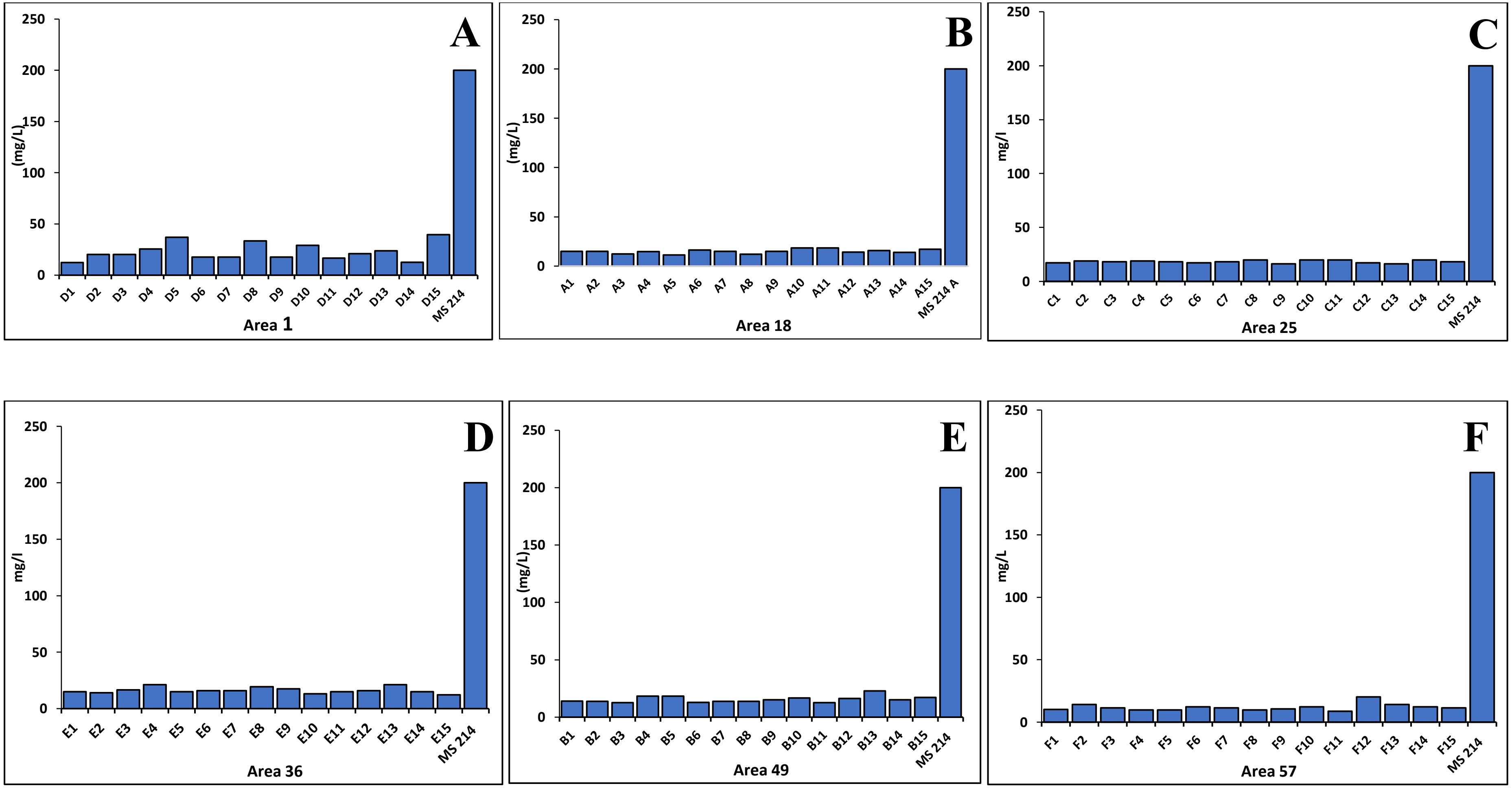


Figure 23 (A – F): Variation in water quality (Chloride) of sachet water in different areas compared to MS 214 standard

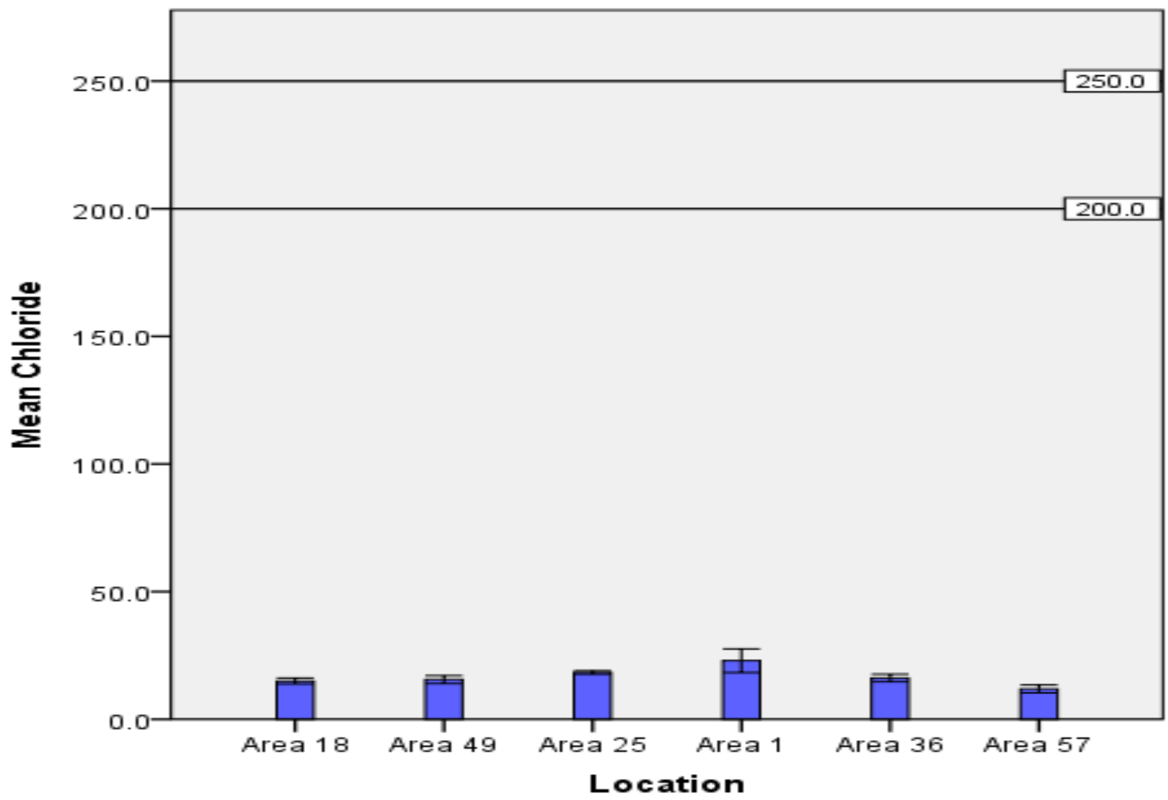


Figure 24: Mean plot with error bars of sachet water quality (Cl^-) in different areas compared to M 214 and WHO standards

f) **Fluoride**

The variations in fluoride in different sampling sites compared to the 214 (2013) Malawi standards and WHO (2011) guidelines are shown in Figures 25 – 26**.** Fluoride in drinking water may be beneficial or detrimental depending on its concentration and the total amount ingested (Oyelude & Ahenkorah, 2012). If ingested excessively, chronic and toxic effects of fluoride are observed as dental fluorosis and skeletal abnormalities (Buzalaf, 2018). Fluoride is an essential element in water for building healthy teeth when up to 1 mg/L. It is beneficial especially to infants and young children for calcification of dental enamel when present within the WHO (2011) permissible range of 1.5 mg/L (Oyelude & Ahenkorah, 2012). Fluoride showed very little variation across sample collection location with a maximum of 0.55 mg/l in area 57 and a minimum of 0.19 mg/L in area 36. Generally, F^- values were below the MS and WHO permissible limit of 1.0 mg/L and 1.5mg/L for the majority of samples (97.78%, n = 90). However, few samples (2.22%, n = 2) from areas 1 and 57 were above the permissible limit set by both the aforementioned standards hence were non-compliant.

In this present study, sachet water samples in all the areas of sample collection scored fluoride ion concentration value below the minimum recommended level of 0.70 mg/L by MS 2014. With a mean of 0.41 mg/L (Table 2), all the samples tested in this study fell outside the minimum limit level of fluoride in drinking water by MS 214. This present study concurs with another study that reported low Fluoride concentrations in sachet water in Ghana (Oyelude & Ahenkorah, 2012). Considering that the weather of Lilongwe is not hot all year round and the inhabitants, on the average, tend to consume fewer volumes of water during the winter season, it is likely that the low the concentration of fluoride ions in the water samples recorded in area 36 and 49 may affect the consumers negatively because the cumulative effect of the less volume of water taken during the winter season may not compensate for the low concentration of fluoride ions in the water samples

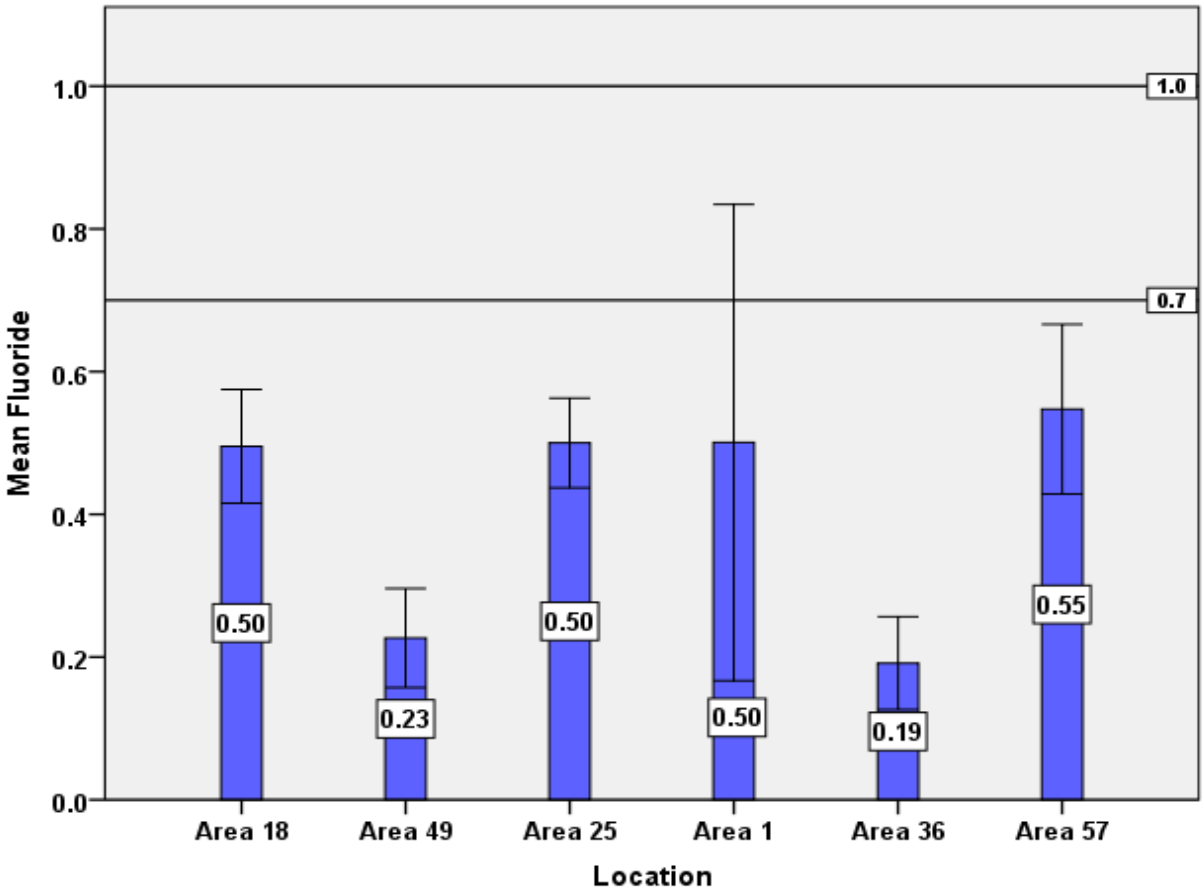


Figure 25: Mean plot with error bars of sachet water quality (Fluoride) in different areas compared to M 214 and WHO standards

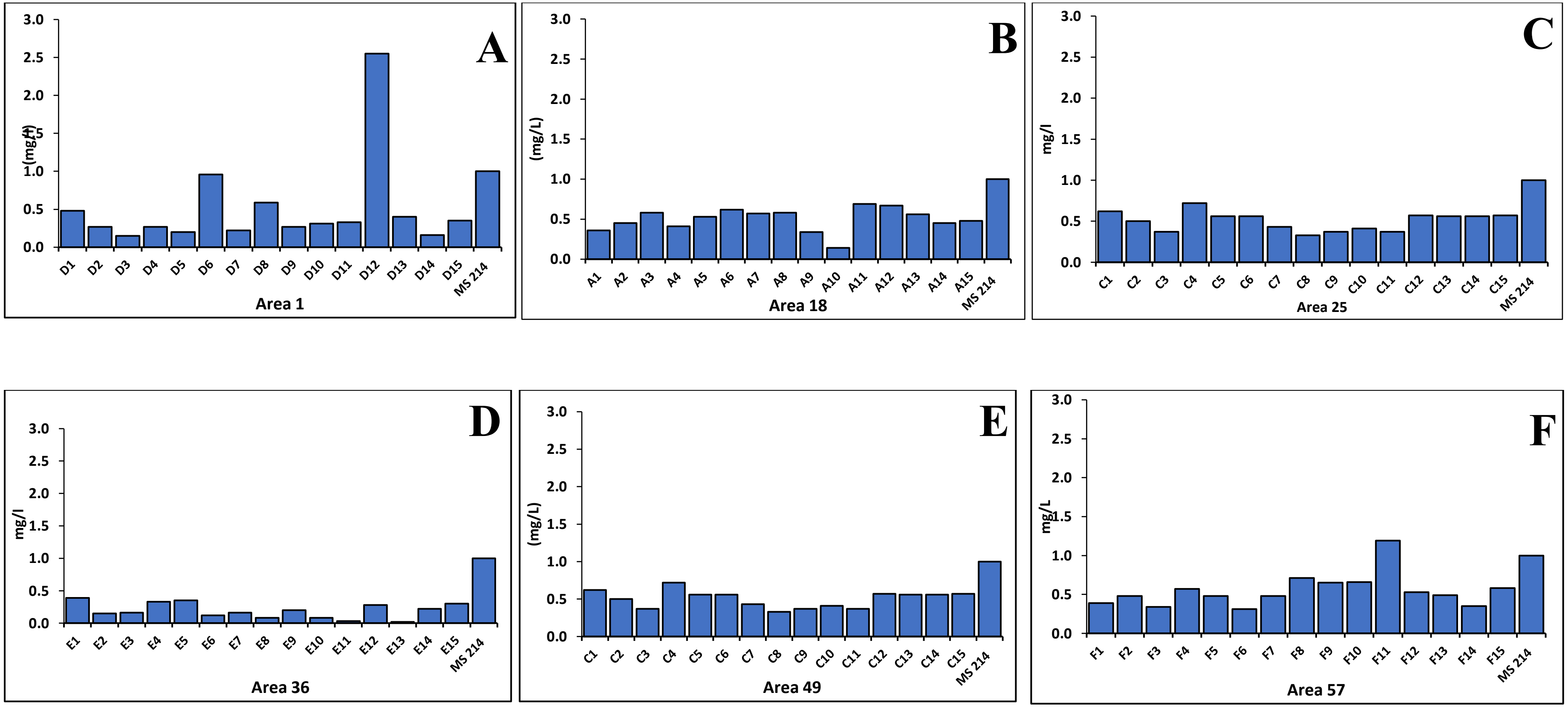


Figure 26 (A – F): Variation in water quality (Fluoride) of sachet water in different areas compared to MS 214 standards

g) **Nitrates**

The variations in nitrates in different sampling sites compared to the 214 (2013) Malawi standard and WHO (2011) are shown in Figures 27 – 28**.** Nitrates showed very little variation across sample collection locations with a maximum of 0.18 mg/L in area 49 and a minimum of 0.01 mg/L in area 1. All the water samples generally possessed very low levels of nitrate ions below 10 mg/L hence there are no fears of methemoglobinemia health risks resulting from the consumption of sachet water by consumers. Nitrate can occur in surface waters and groundwater. Surface waters can contain nitrates from runoff of agricultural fertilizers, which could have periodic peaks associated with planting season or rainfall, or from upstream sewage discharges (Cotruvo, 2018). Concentrations above 44.3 mg/L as nitrates ions in drinking water are known to result in methemoglobinemia in infants less than six months old (WHO, 2011). However, CI^- concentration in all sachet water samples fell under the range of 0.0 – 2.72 mg/L. A concentration of more than 5 mg/L NO_3^- N in water demonstrates contamination by human beings. With an average of 0.08 mg/L, the sachets were deemed to be suitable for human consumption. Related studies where nitrate was reported to be complying with standards was reported in Cameroon (Hermann *et al.*, 2018). However,findings from this study contradict similar studies that reported nitrate non-compliance to standards in sachet water in Ghana (Dodoo et al., 2006)

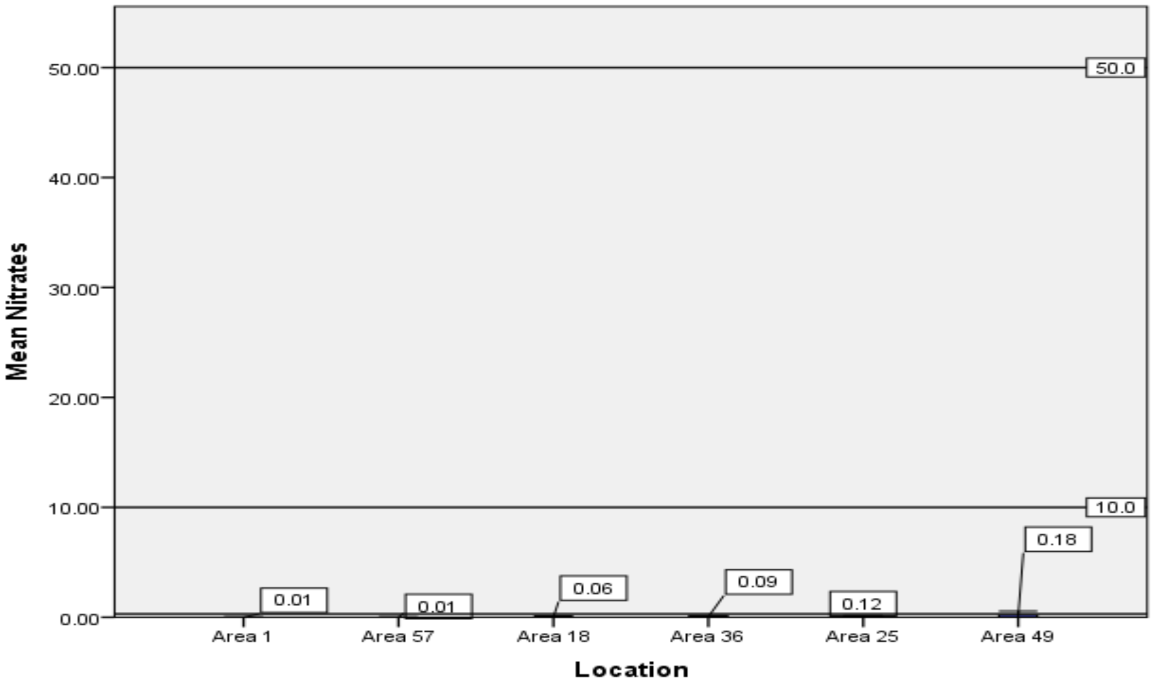


Figure 27: Mean plot with error bars of sachet water quality (Nitrates) in different areas compared to M 214 and WHO standards

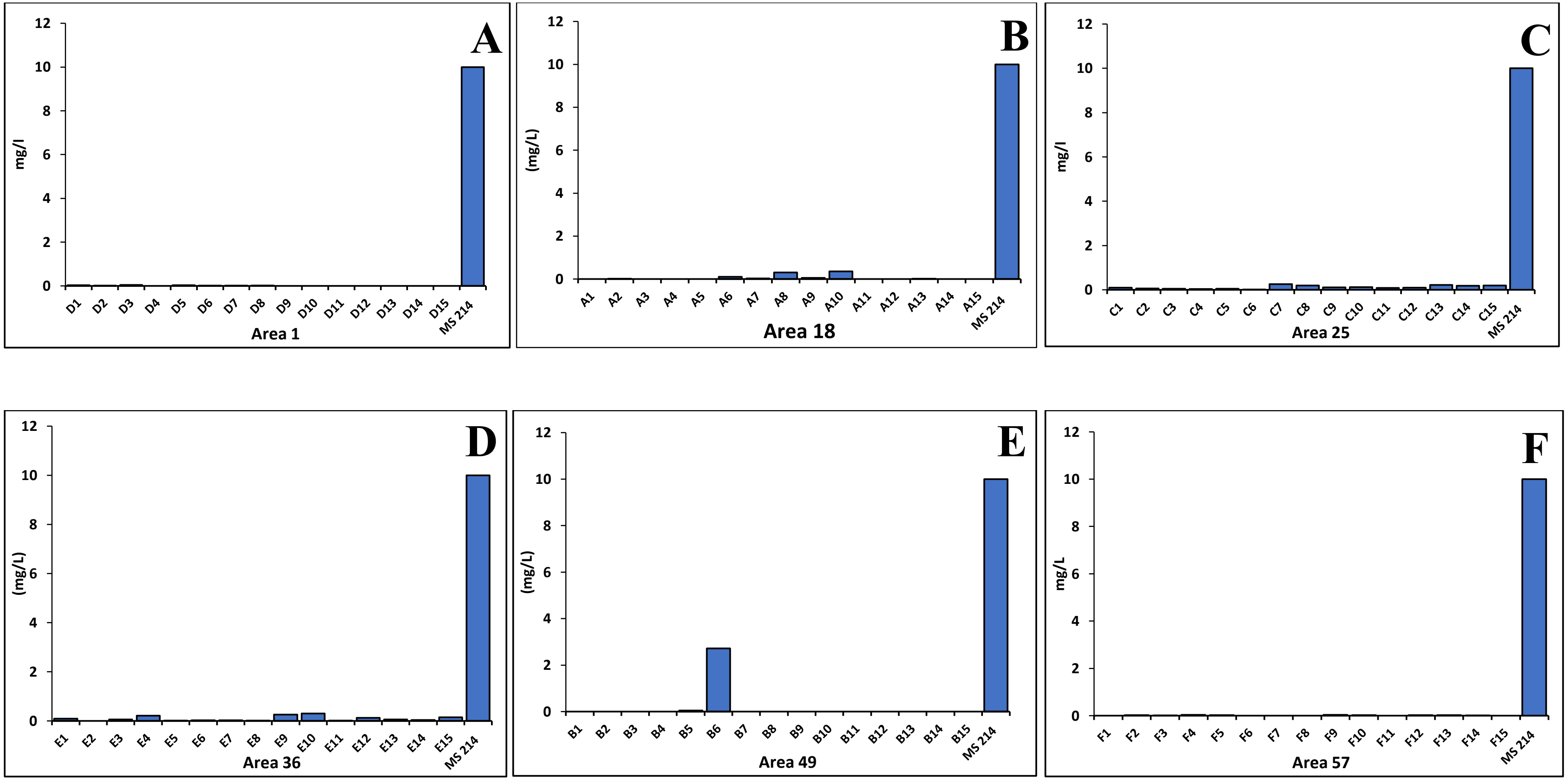


Figure 28 (A – F): Variation in water quality (Nitrates) of sachet water in different areas compared to MS 214 standard

h) **Iron**

The variations in pH in different sampling sites compared to the 214 (2013) Malawi standards and WHO (2011) standard are shown in Figures 29 – 30. (Fe) concentration ranged from 0.02 to 0.12 mg/L in all sachet water. Fe values were within the MS and WHO permissible limit of 0.2 and 0.3 mg/L for the majority of samples. However, some samples (12.22%, n = 90) from areas 1, 18, 25, 36, and 57 were above the minimum MS for drinking water. The finding that some sachet water products sold in Lilongwe city failed to meet the applicable Fe levels in drinking water is consistent with other studies that have reported high Iron concentrations in sachets of water. A recent study conducted in the Nigerian states of Lagos and Ogun found that 36% of sachet water samples exceeded 0.3 mg/L concentration by 117% to 228% (Omole *et al.*, 2015). The presence of Iron (Fe) in substantial quantity can impact brownish color to laundered clothing and plumbing fittings, it can also make the water unsuitable for food processing with consequence health hazards (Sheshe & Magashi, 2015).

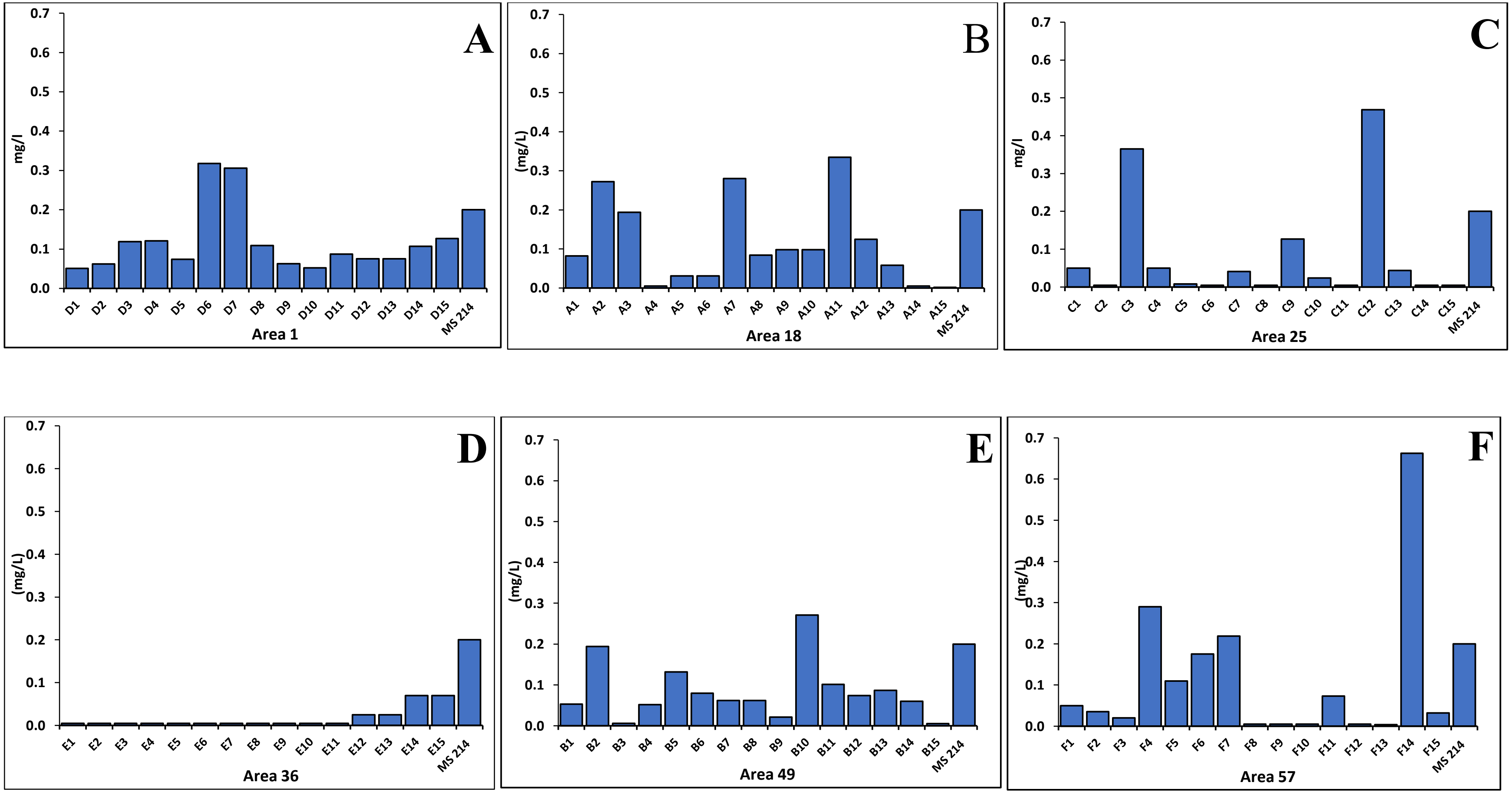


Figure 29 (A – F): Variation in water quality (Iron) of sachet water in different areas compared to M 214 standard

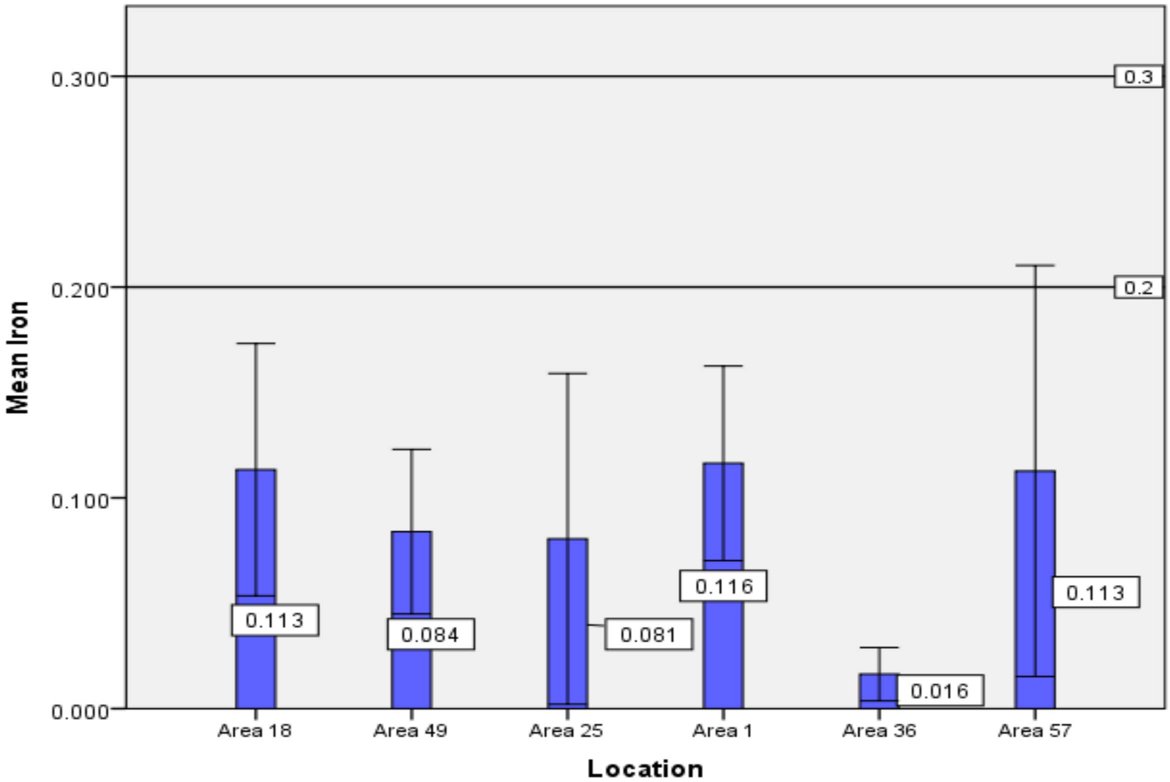
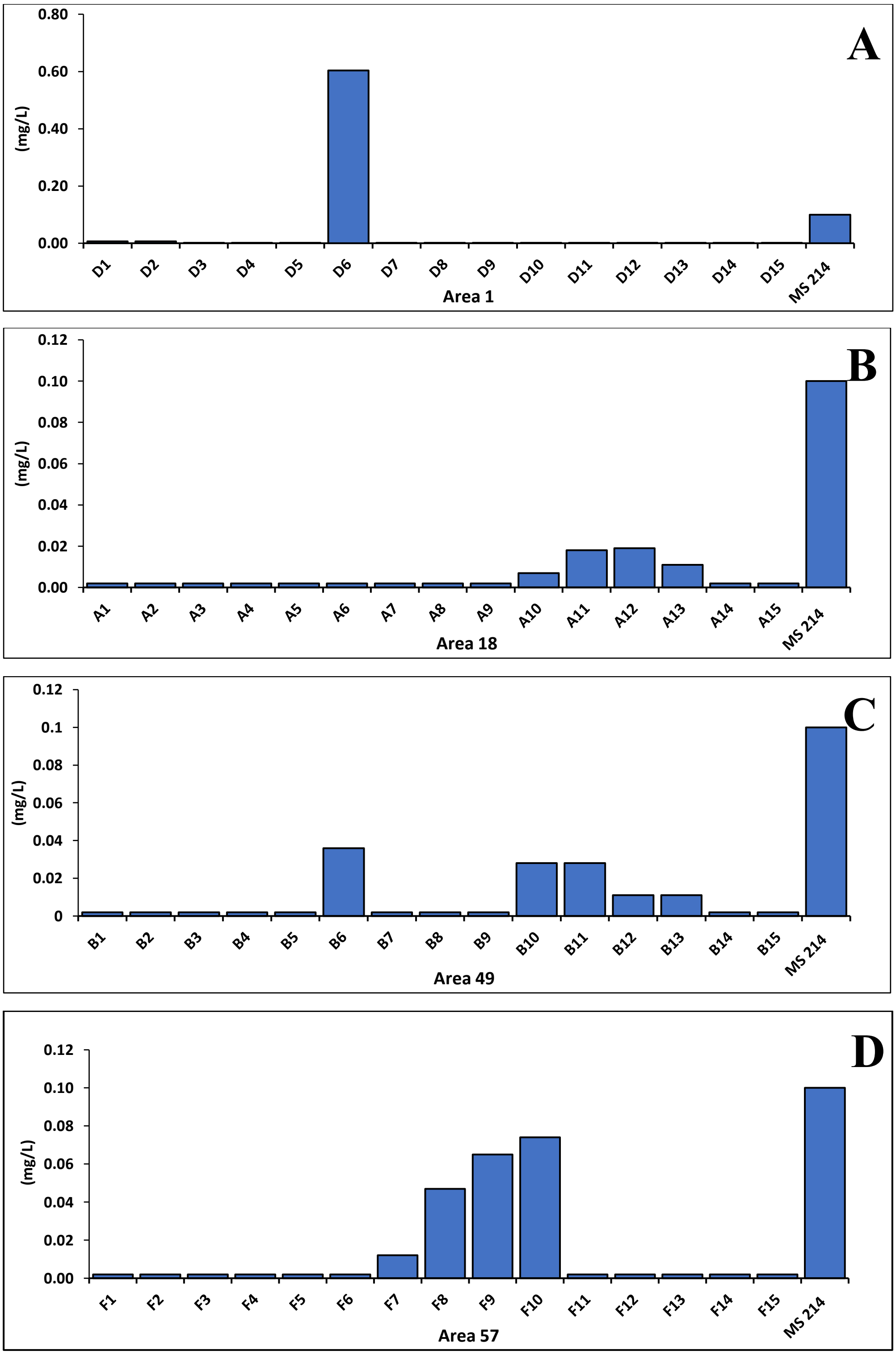


Figure 30: Mean plot with error bars of sachet water quality (Iron) in different areas compared to M 214 and WHO standards.

i) **Manganese**

The variations in Mn in different sampling sites compared to the 214 (2013) Malawi standard and WHO (2011) guidelines are shown in Figures 31 – 32**.** Mn concentration ranged from 0.01 mg/L in area 49 to 0.04 mg/L in area 1. However, in Area 25 and 36, Mn was not detected, as such reporting values of 0 mg/L were adopted. In areas where Mn was detected, it complied with 0.10 mg/L and 0.4 mg/L permissible limit for both MS and WHO standards. Mn did not vary significantly ($p < 0.05$) across the locations of sample collection. While chronic exposure to high manganese concentrations has been associated with neurological and cognitive impairment, the concentrations reported in this study probably do not represent a substantial risk to consumers (Fisher *et al.*, 2015). Related studies in which Mn was not detected or was recorded in the smallest amount have been reported in Nigeria (Sheshe & Magashi, 2015)



D

Figure 31 (A – D): Variation in water quality (Manganese) of sachet water in different areas compared to MS 214 standard

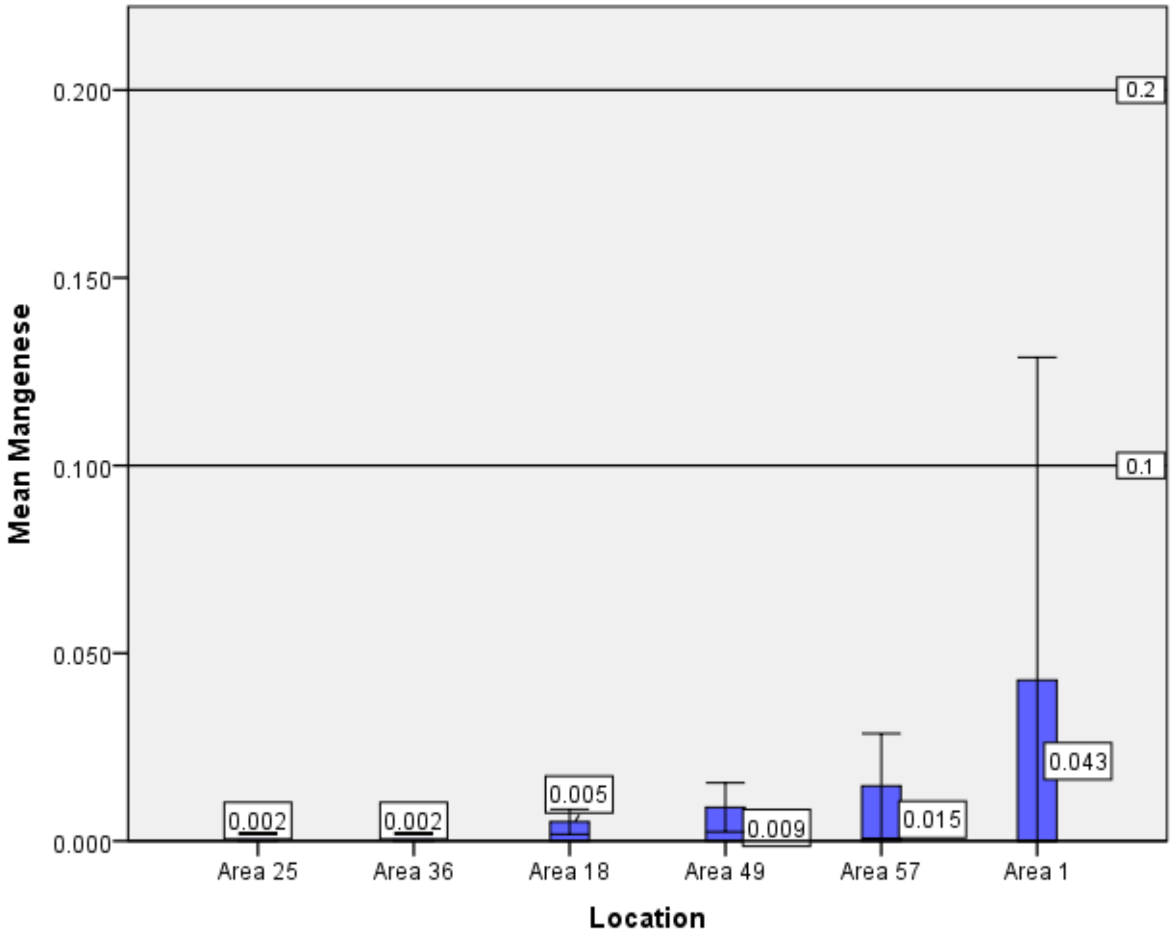


Figure 32: Mean plot with error bars of sachet water quality (Manganese) in different areas compared to M 214 and WHO standards

j) **Arsenic**

Skin, bladder, and lung cancer, as well as keratosis, have been identified from exposures to inorganic arsenic at high levels in water in Bangladesh and Taiwan (Cotruvo, 2018). However, In this study, arsenic was not detected as such the dangers of exposure to elevated levels of arsenic by Lilongwe residents consuming sachet water is minimal. Related studies result in which no arsenic was detected in sachet water drinking was reported in Cameroon and Nigeria (Ma & Ndonwi, 2015; Sheshe & Magashi, 2015).

4.8 Microbiological water quality of sachet water (*E. Coli*)

There was a wide variation in the levels of faecal contamination recorded in different locations of sample collection. In this research faecal coliform *(E. Coli)* was the only indicator that was used to measure sachet water contamination. *E. coli* and faecal bacteria are the common indicator organisms that are the nexus between sewage contamination and potential human pathogen contamination of drinking water (Cotruvo, 2018). Results obtained in this study indicate that sachet water produced and sold in various parts of Lilongwe city was contaminated with faecal coliforms hence failed to comply with MS 214 (2013) and WHO (2011) guidlines, as shown in Table 2 and 6 and figures 33 – 34. The contamination ranged from 3 cfu/100 mL in area 49 to 728 cfu/100 mL in area 18.

The MS 214 (2013) and WHO (2011) guidelines recommend the colony counts of 0 per 100 mL for E.coli in drinking water. From the results obtained in this study, majority of samples (72.22%, n = 90) scored values above the recommended limit of 0 cfu/100 mL, as such it did not comply with the aforementioned standards. Water for human consumption is not supposed to contain any type of pathogenic bacteria. Pathogenic bacterial contamination in drinking water leads to outbreak of water related diseases like diarrhoea, dysentery and cholera (Nabeela et al., 2014). Detection of *E. coli* in sachet water signifies recent sewage or sanitary contamination (Cotruvo,2018; WHO, 2011). The sachet water involved in this study might have been contaminated due to poor hygiene during production as observed during sample collection and therefore had unacceptable quality at the time of sampling in as far as disease-causing microorganisms are concerned.

Related studies in which *E. coli* were isolated in sachets of water were reported in Accra and Bolgatanga municipality in Ghana, Freetown, Sierra Leone, Nsuka town in Nigeria, Southwestern Nigeria, and Mwanza, Malawi (Dzodzomenyo *et al.,* 2018; Fisher *et al.*, 2015; Oyelude & Ahenkorah, 2012; Onweluzo & Akuagbazie, 2011; Manjaya *et al.*, 2019). In contrast, *E. coli* were not detected in sachet water studies conducted in Kumasi, Ghana, Ibadan, and Ogbomosho, Nigeria, Yaoundé, Cameroon, and Kampala, Uganda (Danso-Boateng & Frimpong, 2013; Airaodion, 2019; Hermann *et al.*, 2018; Halage *et al.,* 2015). This may suggest improvement in methods of treating sachet water and good hygiene practices.

The presence of *E. coli* in sachets of water can be related to several reasons including the source of water used, improper storage, hygienic practices observed during production, and high-temperature conditions (Halage *et al.*, 2015). In Lilongwe, the possibility of regrowth of microbes is high considering the average temperature which may be as high as 25°C. A study conducted in the United States of America demonstrated that microbes replicate more easily between 25°C and 37°C (Halage *et al.*, 2015). Similarly, a study which was carried out in

Freetown, Sierra Leone, demonstrated that the multiplication of microorganisms in sachet water was due to the growth of existing ones within the sachets of water (Fisher *et al*., 2015). There are also reports of unhygienic practices observed during sachet water production. For instance, Oluwafemi and Oluwole (2012) in their study observed that some vendors were blowing plastic bags to force the sachets to open. The above findings suggest the need for water authorities to intensify monitoring activities and enforce strict hygienic practices to improve sachet water quality.

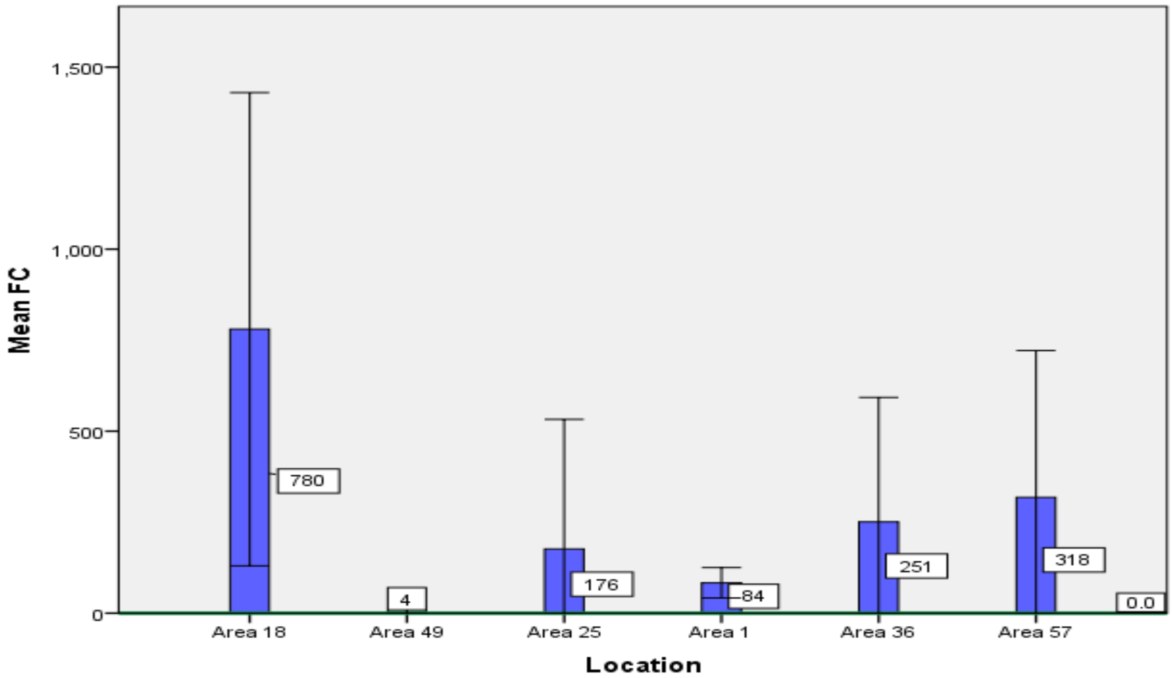


Figure 33: Mean plot with error bars of sachet water quality (Faecal coliform) in different areas compared to M 214 and WHO standards

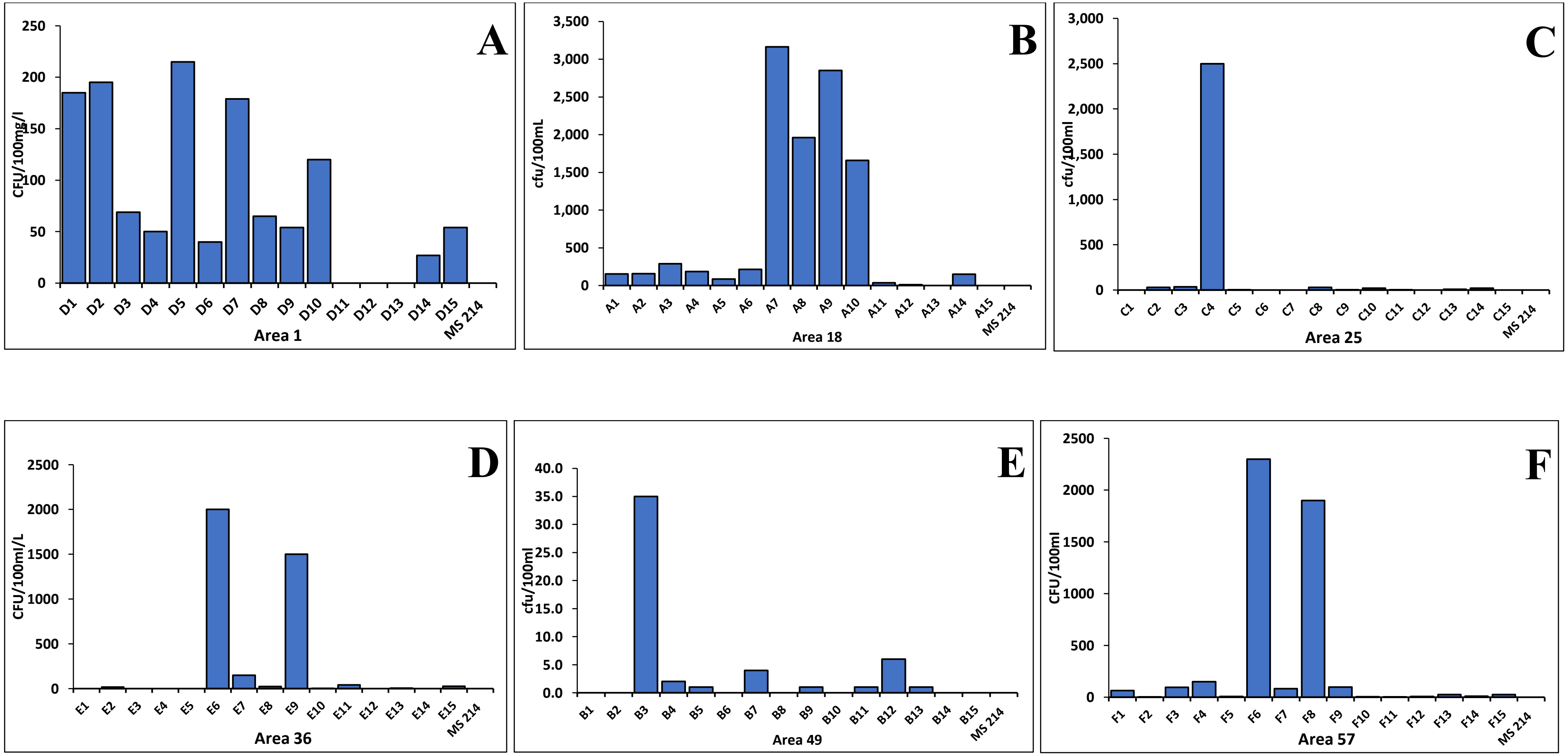


Figure 34 (A – F): Variation in water quality (*E. coli*) of sachet water in different areas compared to M 214 standard

4.9 Classification of different sachet water

4.9.1 Hierarchical Cluster Analysis (HCA)

Figure 35 shows the results of the hierarchical cluster analysis (dendrogram) of different sachet water based on analysed physico-chemical and bacteriological parameters. The dendrogram was produced based on similarities between quality parameters as indicated by the Pearson correlation coefficient. The analysis of the dendrogram revealed that the sachet water from the different locations could be grouped into two homogeneous clusters. Cluster I comprised only of sachet water produced in area 18 while the second cluster had sachet water from areas 1, 25, 36, 49, and 57. From figure 36 area 18 has a unique physico-chemical and bacteriological composition although all sachet water producers reported using faucet water from LWB during production. This may be due to deterioration of water quality during transport and distribution resulting in differentiated water quality within the same water supply network (Boakye-Ansah *et al.,* 2016). Cluster 2 produced two sub-clusters; cluster A (areas 25, 36, and 57) and cluster B (Area 1 and 49). These clusters comprised sachet water with close or similar physico-chemical and microbial composition.

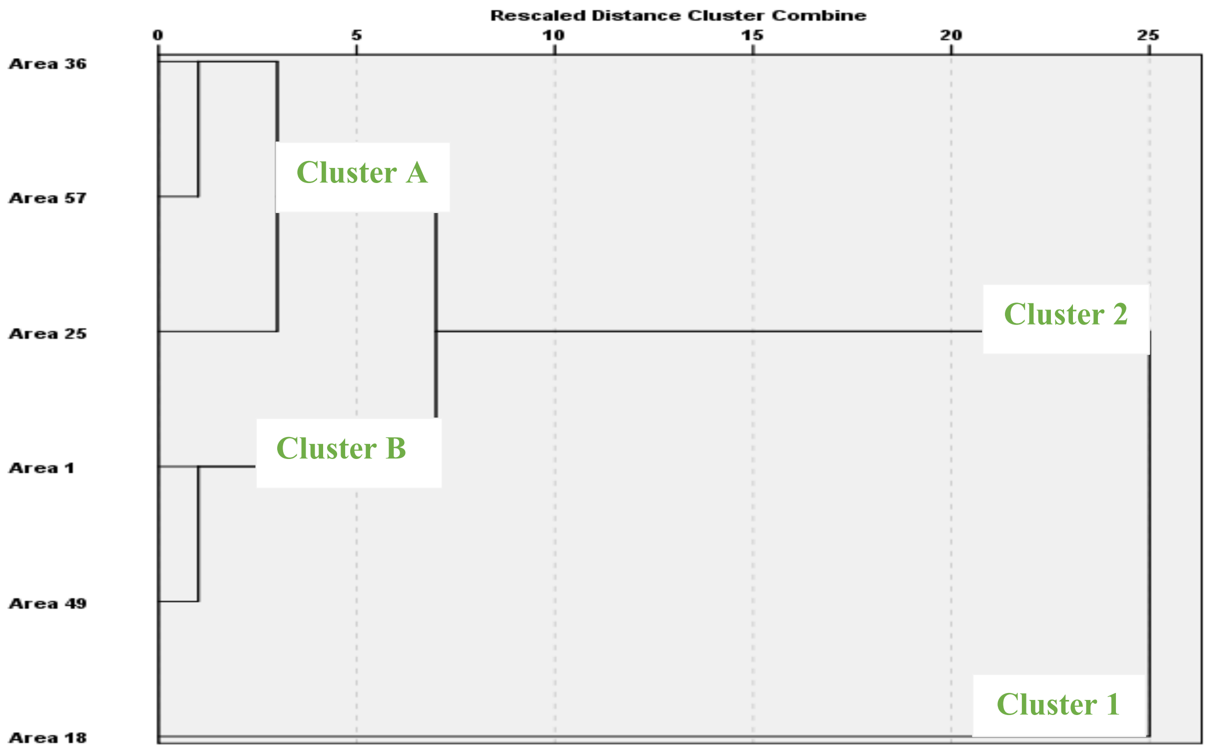


Figure 35: Hierarchical classification (HAC) of water sachet based on evaluated physico-chemical and microbial parameters.

4.9.2 Principal Component Analysis (PCA)

Table 7 provides a summary of the principal component analysis of sachet water. The sachet water from six locations gave Bartlett's test of sphericity 590.06 and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of 0.67. This value is higher than the recommended KMO of 0.50 – 0.60 for PCA (Chidya *et al.*, 2019). Varimax normalization procedure for eigenvector rotation produced three principal components (PC1, PC2, and PC3). These three components explained about 58.85% of the total variance observed. PC1 was associated with TDS, EC, and NO_3^- explaining about 29% of the total variance. Strong positive loadings were observed for EC (0.99), TDS (0.99), and NO_3^-. The results correspond to correlation analysis in which significant correlation exists between these parameters (r = 0.01 and 0.05, $p < 0.05$). PC2 was associated with turbidity and *E. coli* and explained about 16.13 % of the total variance. Only moderate strong positive loadings existed between these two parameters; Turbidity (0.58 NTU) and *E. coli* (0.78). PC 3 explained a total variance of 13.60% with moderate positive loading of three parameters namely fluoride (0.61 mg/L), Iron (0.61 mg/L), and Manganese (0.75 mg/L).

Table 8: Water quality parameters of sachet from 6 locations.

	Component Analysis		
Parameter	**PC 1**	**PC 2**	**PC 3**
pH	0.08	-0.67	0.13
Electrical conductivity	**0.99**	0.04	0.00
Total dissolved solids	**0.99**	0.03	0.01
Chloride	-0.09	-0.46	-0.17
Fluoride	-0.02	0.12	**0.61**
Nitrates	**0.95**	0.15	-0.05
Turbidity	-0.16	**0.58**	0.05
Iron	-0.01	0.02	**0.61**
Manganese	0.06	-0.15	**0.75**
E. coli	-0.11	**0.75**	0.02
Eigen Value	2.91	1.61	1.36
% Variance	29.13	16.13	13.60
Commutive %	29.13	45.26	58.85

PC = *Principal component*, sample size n = 90

4.9.3 Correlation Matrix

The degree of a linear relationship between two water quality parameters can depict whether they are related or not. If the correlation exists, then the correlation coefficient (r) signifies the degree of correlation, whether positive or negative. Table 9 presents correlation matrix for different sachet water parameters. From table 9, there is a strong positive correlation between EC and TDS exist ($r = 0.99$, $p < 0.01$). These present findings concur with previous studies which also found that EC and TDS correlate (Rusydi, 2018 ; Thirumalini & Joseph, 2009). In general, the TDS – EC relationship is given by equation TDS = (0.55 to 0.7) EC (Thirumalini & Joseph, 2009). In this study, the correlation ratio was found to be 0.6 (figure 36) which was within the acceptable range of 0.55 to 07 for fresh water which other studies have established (Rusydi, 2018 ; Thirumalini & Joseph, 2009).

Further, there is also another excellent association of NO_3^- with EC and TDS ($r = 0.913$, $p < 0.01$) respectively. This relationship is a proof of the fact that nitrate is a principal ion contributer of TDS along with other major cations and anions such as carbonate, bicarbonate, chlorides, fluorides, sulphates, nitrates, sodium, potassium, calcium, and magnesium (EPA, 1976; Ramanaiah *et al.,* 2006.). The present study also shows mild but positive association between Manganese and Fluoride ($r = 0.21$, $p < 0.05$) and between turbidity and *E. coli* ($r = 0.27$, $p < 0.01$). Some studies have reported a significant correlation between turbidity and microorganisms (Boakye-Ansah *et al.,* 2016; Farooq *et al.,* 2008).

Table 9: Linear coefficient of correlation (r) among the various parameters in sachet water

	pH	**EC**	**TDS**	**CI^-**	**F^-**	**NO_3^-**	**Turbidity.**	**Fe**	**Mn**	***E. coli***
pH	1									
EC	0.063	1								
TDS	0.06	**0.994****	1							
CI^-	0.118	-0.08	-0.08	1						
F^-	-0.043	-0	-0.01	-0.049	1					
NO_3^-	-0.016	**0.913****	**0.911****	-0.064	-0.032	1				
Turbidity	-0.078	-0.13	-0.13	-0.195	0.07	-0.02	1			
Fe	0.023	0	0.012	-0.034	0.09	-0.05	-0	1		
Mn	0.116	0.04	0.043	-0.023	**0.209***	0.017	-0.07	0.21	1	
E. coli	-.384**	-0.07	-0.09	-0.097	0.022	0.011	**0.271****	0.06	-0.03	1

*** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed*

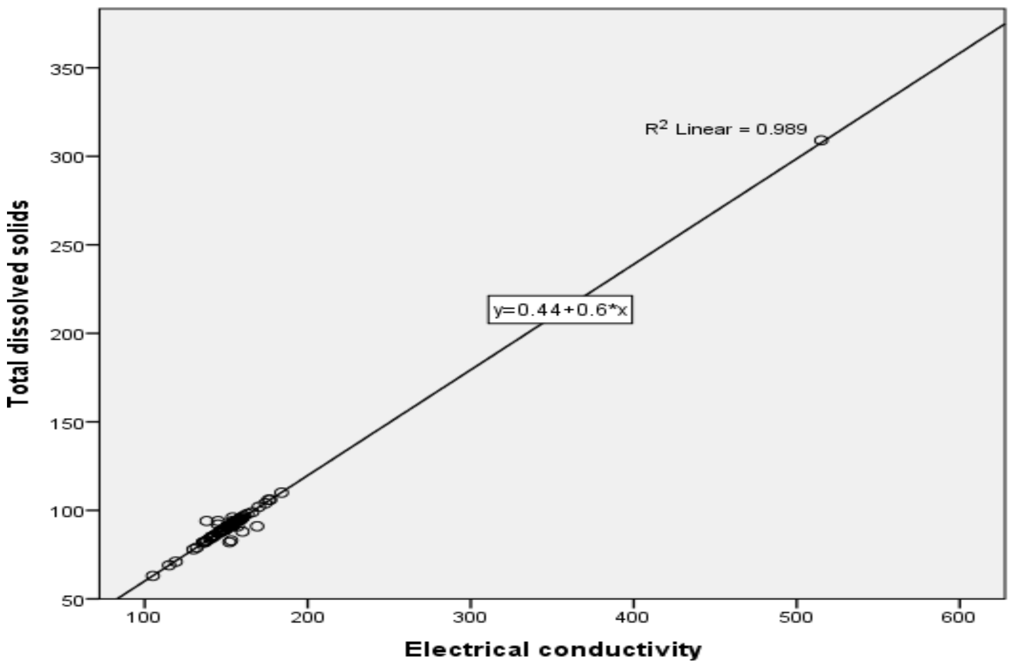


Figure 36:TDS – EC relation for sachet water

4.10 Implications on Public Health

The bacteriological contamination of drinking water supplies signifies major human health risks as it transmits diseases causing pathogens especially those originating from faecal matter (Boakye-Ansah *et al.,* 2016). In Kampala *E. coli* and other faecal matter were associated with an outbreak of typhoid fever in 2015 (WHO 2105; Halage 2015). In this study, the majority of the samples (72.22%, *n* = 90) were contaminated with *E. coli* exceeding both the national (MS 214) and international (WHO 2011) accepted levels of faecal contamination in drinking water. The WHO standard recommends the complete absence of faecal coliform in drinking water (WHO, 2011). Among them are some harmful bacteria like *E. coli* 0157/H7 which causes illness of different types in people including; bloody diarrhoea, haemolytic uremic syndrome infections, and haemorrhagic colitis (Cotruvo, 2018; Ishii & Sadowsky, 2008). Further, Exposure to faecal polluted water can cause gastroenteritis, respiratory, eye, ear, and skin-related illnesses (Santo Domingo & Sadowsky, 2007). There are reports of an outbreak of waterborne diseases from the intake of water contaminated with microbial bacteria in Kenya and Nigeria (Osiemo *et al*., 2019; Oluwafemi & Oluwole, 2012).

Table 9 provides the risk level classification for sachet water in Lilongwe based on WHO 1997. From the table, 22.22% of the samples represented low, 27.78 % an intermediate, 12.22%, high and 10 % very high health risk for consumers.

Table 10: Classification for *E. coli* in sachet water supplies

Risk Level [1997]	CFU/100mL	*E. coli*
Conformity	0	27.78%
Low	0 -10	22.22%
Intermediate	10 - 100	27.78%
High	100 - 1000	12.22%
Very High	> 1000	10%

Contamination of water with faecal bacteria can be assessed in public health and economics as it results in illness and death and also increases the use of sick leave (Santo Domingo & Sadowsky, 2007). Waterborne diseases are more devastating in developing countries as they put extra pressure on already overburdened health care systems in these countries (Nabeela et al., 2014). Globally, the WHO estimates that 3.4 million people die as a result of water-related diseases, making them the leading cause of disease and death around the world (Osiemo *et al.*, 2019; WHO *et al.*, 2019). In Malawi, diarrhoea is the fifth leading cause of death among children under the age of five, and 17% of the population still consumes water from unimproved sources (Rowe, 2012.). The consumption of contaminated sachet water may be exacerbating the problem. This alarming state of sachet water quality in Lilongwe city is risking the lives of consumers from contracting waterborne diseases, hence the need to improve sachet water production, inspection, and storage practices.

The Ministry of Agriculture, Irrigation, and Water Development need to intensify public health awareness campaigns on sachet water producers to adhere to hygienic practices during production, storage, and marketing of sachet water. Through the department of water quality, it must ensure consumers are protected from dubious sachet water products to curb incidences of water-borne diseases. The departments should ensure that sachet water producers are adequately providing improved access to clean and safe sachet water to consumers. In this regard, there is a great need for sachet water producers to be introduced to conventional household water treatment methods. This will enable them to be treating water before packaging.

In this present study, water samples from the majority of samples (97.78%, $n = 90$) possessed mean fluoride ion concentrations below the minimum recommended level of 0.70 mg/L by MS 214 . On average all recorded fluoride concentrations were of 0.41 mg/L. Fluoride is an essential element in water for building healthy teeth when up to 1 mg/L. It is beneficial especially to infants and young children for calcification of dental enamel when present within the WHO (2011) permissible range of 0.5 to 1.5 mg/L (Oyelude & Ahenkorah, 2012). The weather of Lilongwe is not hot all year round and the inhabitants, on the average, tend to consume fewer volumes of water during the winter season. It is therefore likely that the low concentration of fluoride ions in the water samples may affect the consumers negatively, because the cumulative effect of the less volume of water taken during the winter season may not compensate for the low concentration of fluoride ions in the water samples. It is therefore imperative that sachet water producers should ensure sachet water adheres to MS permissible limits of fluoride in drinking water to prevent negative health impact.

Some samples (32.22%, n = 90) did not comply with MS 214 guidelines for turbidity in drinking water. As such, they were not suitable for human consumption according to the aforementioned standard. Turbidity decreases disinfection efficiency as it shields organisms and much of water treatment is directed at removing particulate matter before disinfection (WHO, 2011). Elevated turbidity also affects the acceptability of drinking water by the consumer due to visible cloudiness. Although turbidity has insignificant health implications at the concentration found in potable water, it signifies the presence of contaminants that may be of health concern to consumers (WHO, 2011). An association between turbidity and gastrointestinal illness exists in some literature (De Roos *et al.*, 2017; WHO, 2011; Chidya *et al.*, 2019). Consequently, the higher turbidity levels recorded in this present study should be of health concern to consumers.

Few samples (8%, n = 90) from areas 18, 25 and 36 did not comply with the minimum permissible limit of 6.50 for pH in drinking water set by WHO standards hence were noncompliant. WHO guidelines for pH (6.5 – 8.5) are aimed at minimizing corrosion in metal pipes in the distribution system (Fisher *et al*., 2015c). It may not be relevant to sachet water. However, sachet water vendors in Lilongwe use municipal piped water for the production of sachet water. This may correspond to the heightened risk of contamination from lead, copper, and other metals that can leach from distribution pipes. As such sachet water sold in Lilongwe should be periodically monitored by local water utilities to grant its safety for consumption.

In this present study, chloride, nitrates, Arsenic, manganese, electrical conductivity, and total dissolved solids were within the permissible limit set by both MBS and WHO guidelines hence may not pose a health risk to consumers. But still frequent monitoring and surveillance is needed to maintain acceptable quality.

4.11 Implications on WASH policies

The outcome of this study has significant policy implications for packaged sachet water production and marketing regulations in Malawi since its consumption is considerable. The presence of *E. coli* in sachet water suggests contamination and that the water is not suitable for human consumption. There is a need to improve sachet water production, inspection, handling, and storage practices. One way would be increased regulatory oversight on the sachet water industry (Fisher *et al.*, 2015c). The priority should be placed on microbial safety over the physico-chemical parameters. The oversight should among other things include monitoring and surveillance of the sachet water. Further, training and education of producers and retailers to adhere to hygienic practices during the production and marketing of sachet water should be provided as well. Furthermore, there should be provisions for the identification and removal of contaminated sachet water products from the markets, of course, this would be problematic considering the nature of the sachet water industry in Malawi. The regulatory efforts should aim at improving the quality of sachet water . This calls upon the relevant authorities to establish an independent regulator for drinking water quality in the Water resources management unit in the Ministry of Agriculture, Irrigation, and Water development.

Despite the growing consumption of sachet water in Malawi, monitoring, surveillance and inspection programs for this source have not been established to gather data on this vital drinking water option. Monitoring of sachet water production and sale and safety by the authority and concerned stakeholders will be an initial step in regulating the sachet water industry in Malawi.

Sachet water products have the potential of supplying potable water to a large population in the under-served setting. As such, recognition of sachet water by regulators and policymakers as a significant source of drinking water is necessary (Williams *et al.*, 2015). However, the current situation of the nonexistence of legislation and regulation for sachet water products in Malawi and subsequent enforcement is irregular. There is need to formulate and enforce sachet water production and marketing legislation and regulations. Current sachet water has the potential to transmit waterborne diseases. Legislative and regulatory frameworks on sachet water offer an opportunity for the government to capitalize on the potential public health benefits associated with this source (Fisher et al., 2015c). Sachet water products are prevalent in urban and peri-urban areas in Malawi as such it may be necessary to include it in national regulations as the case with bottled water. There is a need to set national standards for sachet water quality, hygienic production, packaging, and distribution. This would set as a minimum level of contamination that is acceptable and outline requirements for sachet water producers to meet (Williams *et al*., 2015). The Ministry of Agriculture, Irrigation and Water development through the department of Water quality, therefore, should establish guidelines for sachet water. To promote its implementation the department should make sure that free standards for water quality and hygienic production of sachet water are available to producers as a starting point for policymakers interested in establishing national sachet water regulations.

It should be noted that the national sanitation policy promotes safe handwashing practices to achieve the universal practice of handwashing with soap at certain key times. This practice should be promoted among the sachet water producers to build hygienic behaviour and culture. The Ministry of Agriculture, Irrigation and Water Development and health practitioners must conduct a mass awareness campaign and civic education amongst the sachet vendors sensitize sachet water producers on best practices for producing the product.

The National Environmental Health Policy likewise advances WASH, through its arrangement objective of improving water sanitation and cleanliness at the community, public, and business establishments. The government is commanded to monitor the quality of drinking water from various sources including sachet water. This, therefore, calls upon the different departments to guarantee drinking water available on the market meets the required guidelines for consumption. The strategy urges the legislature to advance the treatment of water at the point of use. This likewise calls upon the administration to advance the treatment of sachet water by merchants before bundling and selling in the city. The approach advocates for the usage of Household Water Treatment and Safe Storage (HWTS) as a preventive health strategy. HTWS should be introduced to sachet water producers as they offer cost-effective and ideal methods for improving water quality. Chlorination and ceramic filters have been recommended HWTS methods in Malawi due to the residual protective effect of chlorine or filters lined with colloidal silver. However, the National Environmental Health Policy is in draft form.

4.12 Ways of improving sachet water quality

From microbiological water quality tests conducted in this present study, it is very clear that sampled sachet water was microbiologically contaminated, therefore it requires more attention in improving the quality through treatment, appropriate storage, and handling practices. Considering the extent of *E. coli* contamination in sachet water and following a method of categorizing drinking water as presented by WHO (2004/2011) hand-tied sachet water in the study area could be categorized as "poor or D" since 72.22% of samples were contaminated. It requires improvement in production, handling, and storage practices. The following low- cost ways could be implemented to improve hand-tied sachet quality.

Table 13 provides some low-cost technologies that sachet water producers can deploy to improve quality.

Table 11: Summary of some Low-cost strategies for treatment water

Methods	Strengths	Weakness
Biosand filter	Require no use of chemicals Simple to use Made from local materials Reduces bacteria and protozoa Cost once Minimizes diarrheal risks	Turbidity affect disinfection efficiency Filter ripening Frequent maintenance Ineffective removal of virus Provide no residual protection
Pressure filter	Minimize turbidity It is thick and easy to use	Frequent maintenance; Frequent filter media replacement requirement; Susceptible to clogging
Chlorination	Inexpensive Provides residual protection Can reduce most microbes Documented health Improvements	Water quality improvement; Taste problem disinfection efficacy is affected by turbidity Not suitable for cryptosporidium removal Hard to determine the proper dosage Not suitable for treating highly turbid water
Boiling	High disinfection efficiency Social acceptance is high; Simple to use; Deactivation of microbes	Provide no residual protection No epidemiological evidence Expensive The complete treatment is guaranteed only after boiling
Ceramic filters	Locally made simple to use Improve the turbidity of treated water Reduce protozoa and bacteria	Provide zero residual protection; Metal leaching of some elements like arsenic; Susceptible to breakage; Frequent maintenance Varying quality of Ceramic filters

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Sachet water plays an important role in providing readily accessible water to the general public in Malawi. However, the quality of this water must be of paramount interest to all producers, consumers, and regulatory authorities alike. The study revealed that except for a low level of fluoride ions and high turbidity above MS 214 (2005) standards in some samples, sachet water sold in Lilongwe city possessed good physico-chemical characteristics. However, the bulk of sachet water was contaminated with coliform bacteria (*E. coli*). Generally, 72.78 % of sampled sachets recorded elevated *E. coli* concentration in. The presence of faecal coliforms in sachet water raises concern over the wholesomeness of an important source of drinking water to the general public in this city. It is, therefore, necessary for sachet water products to be properly treated and handled to meet the WHO and national standards for drinking water. To minimize the problem of poor quality of sachet water, government agencies like the MBS and central water laboratory, city assembly, and water utilities should ensure that packaged water vendors comply with good manufacturing practices by formulating and implementing regulations for the sachet water industry.

5.2 RECOMMENDATIONS

Based on the outcome of the study, there is a need to protect the health of customers by reducing health risks associated with drinking contaminated water. Several appropriate recommendations have suggested for stakeholders to take actions:

- Due to elevated faecal contamination of sachet water revealed in the study, it is recommended that frequent monitoring of sachet water / packaged water and other sources be carried out to assess the levels of the microorganism in drinking water.
- The consumer must be sensitized about the health risks of drinking sachet water.
- Sachet water vendors should be educated on best practices of production and marketing of sachets.
- MBS and Central water laboratory and city council should be monitoring sachet water quality and production practices activities routinely.
- Due to the informal nature of the sachet water industry, there is a need to formulate and implement regulations, policies, and laws governing water, sanitation, and hygiene in the

industry and government agencies like the MBS and central water laboratory, city assembly, and Water Utilities should ensure that packaged water vendors comply with good manufacturing practices and the regulations

- The National environmental health policy promotes WASH, through its policy goal of improving water quality, sanitation, and hygiene at the community, public, and business institutions. The policy advocates for the implementation of Household water treatment and safe storage (HWTS) as a preventive health strategy. This calls upon the government to promote the treatment of sachet water by vendors before packaging and marketing on the street using HWTS. This study recommends that the National environmental health policy which in the draft phase should be signed by policymakers to facilitate the promotion of WASH in the country
- The Water Resources Management unit which is tasked with water quality in the Ministry of Agriculture, Irrigation, and water development should establish an independent regulator for drinking water quality. Currently, the absence of an independent regulator for drinking water quality is inconsistent with the government policy goal of providing people with water of acceptable quality.

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