ASSESSING WILLINGNESS TO REUSE TREATED WASTEWATER FOR CROPS IRRIGATION, AND THE CONSUMPTION OF CROPS IRRIGATED WITH TREATED WASTEWATER: A CASE STUDY OF STUDENTS FROM UNIVERSITY OF GHANA AND ASHIAMAN MUNICIPALITY, GHANA

BY

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DECLARATION

I, Theophilus Amanor Kwabla, do declare that except for references to other people's work which I have duly acknowledged, this thesis is the result of my own research carried out at the Institute for Environment and sanitation Studies (IESS), University of Ghana under supervision.

I further affirm that this thesis has neither in whole nor in part been previously presented elsewhere for the award of another degree.

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ABSTRACT

All life forms including human need water resources in order to live healthy, promote sustainable development and ensure their well- being. The study assessed public willingness to accept and reuse treated wastewater as an alternative water resource to support the dwindling existing water resources for irrigation and the consumption wastewater irrigated crops. A social survey based on random sampling of 232 respondents in Ashaiman, capital of Ashaiman Municipality which has a well diverse population and 204 resident students at the University of Ghana, Legon was carried out as part of the study. Some physicochemical and microbiological analyses of the raw and treated wastewater over the study period were carried out using the American Public Health Association (APHA, 2005) standard methods. The microbiological quality of the cultivated lettuce crops which were irrigated with raw and diluted treated wastewater was also assessed using the Nordic Committee on Food Analysis (NMKL, 2005) standard methods. The study indicated that majority of the respondents, 95% and 92.6% in Ashaiman and at the University of Ghana respectively were willingness to use treated wastewater for irrigation of crops and consume farm produce using irrigated wastewater. Education was significantly associated with willingness to use treated wastewater for vegetable crop irrigation such that respondents with formal education in Ashaiman and at the University of Ghana were about four (4) times more willing than those with no formal education. Knowledge of wastewater treatment processes and effluent quality was also found to be significantly associated with willingness such

that respondents with some knowledge of wastewater treatment processes and of effluent quality were 0.3 times more willing to use treated wastewater for irrigation of crops and consume produce of wastewater than those without. However, age and sex did not have any significant association with willingness to reuse treated wastewater for irrigation of crops and the consumption of wastewater irrigated crops. The physicochemical quality parameters of the treated effluent were all within WHO/FAO guideline limits. The microbial quality of the treated effluent was $\leq 19.2\times10^3$cfu/100 ml for faecal coliform (FC) levels and $\leq 55.0\times10^2$ cfu/100 ml for *E.coli* levels. The study found no *E.coli* contamination in the treated wastewater irrigated lettuce since the results were < 10 cfu/ g. There were faecal coliform bacteria levels of ≤ 210 cfu/g recorded for one of the effluent treatments which also fell within the guideline limits of the International Commission on Microbiological Specifications for Foods (ICMSF) which allows for $\leq10^5$ /100 g of FC bacteria of fresh weight for unprocessed food crops. Hence, the treated wastewater was safe to be used for vegetable irrigation since the microbial quality of the lettuce was safe for consumption. The study recommends that Government and Non-Governmental agencies and other stakeholders should collaborate to educate and sensitize the general public on the potential of wastewater as a vital resource.

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DEDICATION

I dedicated this study to my wife, Lucy Danso Swatson and children; Nehemiah, Havilah, Raguel and Adna for their prayers, enormous sacrifices and endurance during my study period.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The need for water resources is fundamental to life, a necessity for food production, a vehicle for economic development and more so for the provision of critical ecosystem functions. As population grows, economic activities and human needs exert new constraints on water resources which tend to impose limits to water availability. Groundwater supplies have become an alternative but the world's aquifers are being over-exploited at an estimated rate of over 20%. This according to Gleick & Palaniappan (2010) has led to a 1% increment in freshwater withdrawal rate each year since the late 1980s especially in developing countries.

As reported by Drechsel & Evans (2010), urbanization is increasing at a fast rate due to population growth, lifestyle changes and increased exploitation of freshwater sources which has led to the generation of increased volumes of wastewater. This rapid global population growth which is accompanied by massive industrialisation and urbanization have brought about an ever-growing demand for freshwater sources.Wastewater management, environmental protection and food security issues in effect are on the increase as a result. The earlier practical solutions to these developments are sought through research and development, the better.

The phenomenon of the tragedy of the commons in which all natural resources are considered as public goods that belong to no one in particular hence can be exploited to the point of depletion is currently being played out on a global scale. The manner in which freshwater resources and other renewable resources are being exploited and used unsustainably raises concerns for the future. According to Hochberg & Brown (2015), each individual who adds up to the global population is estimated to take in not less than 0.5 tonnes of cereal grain, 0.05 tonnes meat or fish, 1 million litres of water, 0.3 tonnes of wood, 4.5 barrels of oil, 0.3 tonnes copper, and 0.2 tonnes phosphate fertilizer respectively. The effect of such intake would result in a net production of 5 tonnes of CO_2 and 4 tonnes of solid and liquid waste to be released by the individual into the environment. The broader picture is such that, since global population is expected to increase by 2.0 billion by 2050, which is from 7.1 billion to over 9.0 billion, the overall volume of resources to be consumed and its corresponding wastes to be generated requires planning, the need for alternative resources through recycling and reuse.

Connor *et al.* (2017) indicated that, failure to meet human needs for freshwater quality and quantity, proper sanitation, continuous contamination of freshwater resources with human and industrial wastes as well as issues of water scarcity and shortages are likely problems to be encountered. However, finding alternative resources such as treated wastewater for non-critical uses has become very critical and necessary. According to United Nations Educational Scientific and Cultural Organisation (2015) reports, treated wastewater reuse especially for irrigation will in turn free up or make available freshwater resources which

otherwise would have been used for agricultural purposes. This is because irrigated agriculture takes up about 70% of global water withdrawals and uses up to about 90% of water. In addition, since the volume of freshwater consumed by other non-essential uses like car washing, lawn management, cleaning, toilet flushing and other non-personal uses also add up to the pressure on freshwater resources, an alternative water resource would do a lot of good.

According to Rooijen *et al.* (2010), urban agriculture provides livelihood opportunities in addition to providing and promoting food security in low- income countries. The need for other sources of water such as treated wastewater reuse in urban farming and non-critical activities in both semi-arid and arid countries is to make up for water scarcity and water stress conditions and ease the demand on the dwindling freshwater resources.

Water scarcity and shortage issues would affect the prospects of the agricultural sector and economies at large. Dealing with the effects of drought, water scarcity and water stress and other climatic conditions require the need for more than a single water resource to keep the ever water-demanding agriculture activities alive and to feed the growing population. For this reason there is the need for a more integrated management of urban water resources including wastewater, as indicated by Scheierling *et al.*(2010). This would help to relieve the plight of the ever growing urban population in acquiring water for all competing uses.

The use of treated wastewater for irrigation in the absence of readily available freshwater sources could help to promote food security, create jobs, alleviate hunger, end poverty and ensure human well-being and sustainable development. This according to Jeong *et al.* (2016), helps in meeting and achieving United Nations Sustainable Development Goals (SDGs). The use of treatment wastewater for irrigation, for greener environment and for ensuring food security is based on user willingness and the factors which are associated with willingness. The safety of the wastewater irrigated crop for human consumption or human health risks is a major factor just as factors like the treated wastewater quality and source of the raw wastewater, trust in the treatment technology, perception, among others.

Jeong *et al.*, (2016) indicated that an estimated 4.5 million ha of farmland worldwide which is approximately 1.5-6.6% of the 301 million ha of global irrigated area utilizes wastewater which shows the potential of treated wastewater reuse especially in water stressed areas.

The development of agriculture in urban and peri-urban areas of Ghana for example is evident wherever land is available especially in areas close to streams and drains. In the city of Kumasi for instance, a system of irrigation which often uses polluted stream water is mostly practiced and has been estimated to irrigate about 11,500 ha of farmlands according to Qadir *et al.* (2010). The city of Accra, according to Keraita *et al.* (2012) which happens to be the administrative capital of Ghana accounts for the production of huge volumes of wastewater as a result of industrial and commercial activities within the

city. Urban farms are equally found everywhere close to big gutters where freshwater sources are not readily available. These urban farms mostly provide fresh vegetables for the urban dwellers.

According to Menegaki *et al*. (2007), Ecological sanitation is a concept which ensures the treatment of waste into useful and valuable resources with minimum risk of environmental pollution and little or no threat to human health. Ecological sanitation is seen as a system which serves as an intervention for a sustainable closed-loop approach where human excreta and wastewater are regarded as resources and not waste.

Disease-free products such as compost, treated wastewater, plant nutrients, biogas, are produced from what otherwise is known as waste through this process, according to Oteng-Ababio, (2014). Through this system waste management offers more benefits and incentives than costs.

According to Weldesilassie, et al. (2009), more than 1,260 farmers were involved in producing vegetables with wastewater on more than 1,240 hectares of farmland in the peri-urban areas of Addis Ababa. The study also reported the use of treated, partially treated, diluted and *untreated* wastewater irrigation on an estimated 20 million hectares of farmlands in developing countries as well.

1.2 Problem Statement

Food and Agricultural Organisation (FAO) of the United Nations; World Food Programme; International Fund for Agricultural Development (2014), reports indicate that water plays a major role in ensuring food and nutrition security. In addition, water makes it possible for the needs of 70% of the sub-Saharan African population who depend on Agriculture directly or indirectly to be met. Thus, the contributions made by water resources to life in general can neither be overlooked nor under estimated.

Vörösmarty *et al*. (2010), stated that, making sure that sufficient water supply reaches humans so as to meet their needs has been a challenge in every country of the world without exceptions. There are several incidences such as drought, climate change, population growth, etc., which threaten water security in nearly 80% of the global population. By augmenting existing supplies with non-conventional water sources, the use of treated wastewater would serve as a solution to the current and future water shortages and scarcity threats according to Tortajada & Ong (2016). The pressure on freshwater sources would be reduced by the use of non-conventional resources.

The United Nations Sustainable Development Goals are replete with aims and targets focusing on environmental protection, human wellbeing among others.

As per the UN-Water (2017) report on the Sustainable Development Goals (SDGs), target 6.3 especially calls for improved quality of water by cutting down pollution, putting a stop

to the dumping and releasing of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. The (SDG) #2 has a target of ensuring water and food security for all, (SDG) #1 also deals with ensuring no poverty, (SDG) #3 sees to the promotion of good health and wellbeing in all humans, SDG# 12 aims at ensuring the promotion of responsible use and production patterns. Making sure that water resources are used in a sustainable manner would ensures the achievement of all or most of the set targets and goals.

Keraita *et al*. (2012) reported that about 90% of the estimated quantity of vegetables consumed by urban dwellers in West Africa alone is irrigated with untreated wastewater or "polluted" water. This untreated wastewater is collected from drains/ gutters within or close to cities where wastewater treatments plants are unavailable and water stress conditions persist. Wastewater use for irrigation in cities is mainly for the production of vegetables including Cabbage (*Brassica oleracea* / capitata), Spring Onion (*Allium fistulosum*), Carrots (*Daucus carota* spp. *sativus*), Tomato (*Lycopersicon esculentum*), Onion (*Allium cepa*), Shallots (*Allium escalonicum*), Eggplant *(Solanum melongena*), local Spinach (*Amaranthus* spp), Cucumber (*Cucumis sativa*) and lettuce (*Lactuca sativa* L.) (Andoh 2008).

Treated wastewater comes as a viable alternative water resource which is being researched into a level where it is safe to drink, according to Khan & Roser, (2007). However, Tortajada & Ong (2016), did indicate that public acceptance and willingness to reuse is

still a critical barrier to the introduction of treated wastewater projects due to perceived health hazards (risks) and environmental impacts associated with treated wastewater/ recycled water reuse and the consumption of irrigated crops.

A study by Liu *et al*. (2016), reported the death of over 1.87 million children under 5 years old worldwide. One of the causes of the children's death was diarrhea, representing 19% of total child deaths, with 78% (1.46 million) occurring in Africa and South-East Asia in 2015. These deaths were attributed to wastewater (mostly untreated) reuse in irrigated agriculture and for other competing uses of water.

Mojid *et al*., (2010) indicated that treated wastewater quality issues can create real or perceived problems in agriculture. The quality of treated wastewater is mostly based on quality parameters or indicators like nutrient loads, dissolved oxygen levels, trace/heavy metals levels, and the presence and levels of pathogenic contamination, etc. Research-based scientific finding, field experiment, laboratory analysis and social survey are also required.

This study seeks to provide ample evidence that wastewater produced from liquid waste treatment plant like the Accra Sewage Improvement Project wastewater treatment Plant at the University of Ghana, Legon, is safe and could offer some respite with respect to water use for various purposes.

1.3 Research Objective

The main objective of the study was to assess willingness to reuse treated wastewater for irrigated agriculture and consumed crops irrigated with wastewater.

1.3.1 Specific objectives

Specific objectives are as follows:

1. Determine the safety of treated wastewater for vegetable crop irrigation
2. Assess the vegetative effect on the quality and yield of the treated wastewater irrigated crops.
3. Determine the factors which influence perception, willingness and acceptability of the use of treated wastewater for irrigation and the consumption of wastewater irrigated crops.
4. Assess knowledge and awareness of wastewater treatment and reuse.
5. Provide scientific data to aid policy direction and implementation.

CHAPTER TWO

LITERATURE REVIEW

The study was aimed at assessing public willingness to reuse treated wastewater and consume vegetable crops produced using irrigation water from a wastewater treatment plant. The study also aimed at providing scientific evidence as proof of the safety of the treated wastewater for use as irrigation source and for other non-critical uses.

The term wastewater is considered as any or a combination of the below listed:

- Used water from all domestic sources, these consist of black water including excreta, urine and faecal sludge as well as grey water which are kitchen and bathing wastewater
- Effluent or wastewater coming from commercial establishments sources such as offices, shopping malls and institutions, including schools and hospitals.
- Effluent or wastewater which is generated from the activities of factories, production and manufacturing plants, as well as from storm water and urban run-off during rainfalls.
- Effluent from agricultural, horticultural and aquaculture sources which consist of either dissolved or suspended matter which containing residual pesticides and synthetic fertilizers.

Connor *et al.* (2017), defined treated wastewater as wastewater that has been processed through a wastewater treatment plant up to a certain standard in order to reduce its pollution or health hazards. Reclaimed water or recycled water was also defined according to

Raschid- Sally & Jayakody (2008), as well as by Corcoran *et al.*, (2010) as treated wastewater that can officially be used under controlled conditions for beneficial purposes such as irrigation and other non-critical uses. These definitions are mostly used interchangeably in different places at different times depending on user discretion and circumstances prevailing.

2.1 Issues on wastewater

Wastewater according to Eggen *et al.* (2014), have attracted global attention since its generation in terms of volumes, composition with respect to source and quality, treatment and disposal or reuse affects human life and other natural resources most importantly sensitive ecosystems.

For any discussion on wastewater as a development issue to be undertaken, there is a need for a thorough assessment on the quality and quantity of the wastewater. A thorough assessment of wastewater requires data on the three most important basic requirements; generation data, treatment data and reuse data as indicated by Sato *et al.*(2013). Several studies in the past have shown that the provision of data on all the three basic requirements for a comprehensive global assessment by most countries have proven difficult. Sato *et al.*(2013), indicated in a study, to gather data and literature in published and electronic forms for some 181 countries, that a mere 55 countries were able to meet all three basic requirements with 69 countries meeting two out of the three while 57 countries provided no data on any of the three requirements. In all 37% of the data available was considered

as recent. The failure by these countries in providing the basic data needed creates difficulties in assessing the true state of wastewater as a global development issue in the absence of these data.

The need to treat wastewater has indeed become very pressing due to its benefits with respect to environmental protection, human health promotion, reuse as alternative water resource for irrigation and non-critical uses etc.

As indicated by Connor *et al.* (2017), only 70% of wastewater received from municipal and industrial sources undergoes treatment in countries with relatively high income. Volumes then reduce to 38% in upper-middle-income countries and then it further reduces to 28% in lower middle-income countries. With countries like Ghana which are in the lower-income category, only 8% of their total wastewater production undergoes any form of treatment. This is why it is often approximated that, over 80% of all wastewater produced globally is discharged untreated. This is no doubt an environmental pollution issue which should not continue unchecked. The protection of the environment through wastewater treatment is priceless.

Despite enormous benefits derived from the use of treated wastewater, reuse of untreated wastewater or improperly treated wastewater for irrigation and food crops (vegetable) production and for other uses pose challenges (Scheierling *et al.*, 2010). These challenges include microbial and chemical risks in cases of industrial wastewater, plant health risk, pollution of the environment and groundwater resources. About 200 million farmers use treated, partially treated and untreated wastewater to irrigate their crops in areas where

irrigation water is heavily polluted. Raschid- Sally & Jayakody (2008), stated that, an estimated 10 per cent of the world's population rely on foods grown with contaminated wastewater. A further study by Balkhair, *et al*. (2013), also found out that the use of municipal wastewater is common with countries of the Middle East and North Africa, Australia, and the Mediterranean, as well as with others like China, Mexico and the USA.

The practice has been most successful in urban and peri-urban areas, where fresh water is scarce and wastewater is easily available, generally free of charge, and where a nearby market for agricultural products is readily available. A study by Qadir *et al.*, (2010) cited a case in the Tula Valley of Mexico where 2400 kg organic matter, 195 kg nitrogen and 81kg phosphorus per ha per year were produced from wastewater irrigation. Since wastewater is currently a global development issue, comprehensive data on its generation, its treatment and quality as well as its intended uses are necessary for policy direction and decision making. This study provides scientific evidence of the quality of treated wastewater and its safety for irrigated vegetable crops farming and for other non-critical uses.

2.2 Wastewater in Sub- Saharan Africa Region

According to Asano *et al.*,(2007), as urban population in developing countries including Sub-Saharan Africa increase, more people tend to seek higher standards of living which require huge volumes of freshwater resources. In an effort to meet these needs of an ever

increasing urban population, greater volumes of freshwater is needed. In such situations, several threats and challenges like poor sanitation management, poor wastewater (including sewage) management, human health risks, water scarcity or stress conditions, etc., are common in these areas. Threats such as cholera, malaria, diarrhoea and other waterborne and sanitation related diseases are prone to be common as well.

WHO Expert Committee on Malaria, (2000), reported that many of Africa's urban dwellers are served by on-site sanitation systems. For example, countries like Ethiopia, Ghana, Mali and Tanzania have over 85% of their population involved in the use of on-site sanitation systems. Certain portions of some cities in Sub-Saharan Africa are sewered but only 1% of their wastewater receives any form of treatment. These onsite sanitation systems are mostly poorly designed hence overflows from them also commonly enter the city storm drainage canals. It has also been a challenge to maintain and rehabilitate plants to cope with the rise in populations of the urban areas in developing countries as was indicated by Keraita *et al.* (2003). Untreated or poorly treated wastewater used an as an irrigation source tend to pose health risks to users and consumers. The people who are mainly at risk are farming household, field workers and family, consumers and those living near the irrigated fields.

Keraita *et al.*, (2003) further stated that improperly managed sludge from septic tanks tend to pollute the environment of most cities. In addition to this, stormwater gutters also receive and channel greywater and other wastewater to larger drains and inner-city streams. All of these eventually end up in most cities and carry along with it improperly managed solid waste materials.

Qadir *et al.*, (2010) also supported the finding that, in most West African cities, not more than 10% of the generated wastewater from various sources is collected in piped sewage systems and given primary or secondary treatment. This study also aims at providing scientific proof of the essence and benefits of wastewater treatment for use as alternative irrigation source whiles promoting the principle of wastewater treatment in general.

2.3 Wastewater situation in Ghana

UNICEF, (2016) reported that, Ghana's sewage treatment system coverage was extremely low at 4.5%. The report indicated that, Tema a major industrial city in Ghana happens to be the only municipality which had a functioning sewerage treatment system for collection, treatment and discharge of wastewater.

Rooijen *et al.,* (2010) reported that the management of wastewater in Ghana is under the control of the Waste Management Department of the Metropolitan, Municipal and District Assembles (MMDAs). Since the existing wastewater and sludge treatment facilities were almost broken down and currently undergoing rehabilitation, household greywater is allowed into water bodies like rivers and lagoons such as the Odaw River which has a catchment covering about 60% of Accra (excluding Tema) and is heavily polluted. The challenges include dead river bodies. Examples of such dead rivers are the 'Odaw' River and the Korley lagoon in Ghana among others.

UNICEF, (2016) also indicated that a number of satellite sewerage systems exist in some areas of Accra such as Dansoman, Teshie-Nungua, Burma Camp, University of Ghana, Legon, Achimota School, and 37 Military Hospital and Ridge areas. The treatment facilities for both the Accra and Tema systems were broken down and were currently undergoing rehabilitation which means the collection, treatment and proper disposal/ discharge of generated wastewater is being compromised by lack or inefficient wastewater treatment infrastructure. This goes a long way to affect the quantity of wastewater treated before discharge.

According to Qadir *et al.* (2010) , industrial wastewater often contain elevated levels of metals, metalloids, and volatile or semi-volatile compounds compared to wastewater from domestic sources. Interestingly, wastewater from domestic sources is mostly harmful due to its pathogenic and nutrients load. The treatment of wastewater is necessary for the removal of the above mentioned to prevent environmental pollution and human health risk upon use.

Amoah *et al.,* (2009) found that an estimated 200,000 urban dwellers in the city of Accra eat “fast food” with raw lettuce leaves produced with highly polluted irrigation water daily knowingly or unknowingly.

Po *et al.,* (2003) indicated that an estimated volume of 20,000 cubic meters (20,000 m^3) of wastewater is generated each day in the city of Kumasi of which less than 10 per cent (10%) is collected for treatment. Aside the volume of wastewater which enters the sewerage system which is produced by approximately 8.0 per cent of Kumasi’s population,

grey water which is wastewater from kitchens and washrooms is discharged into open drains and stormwater gutters, without any form of treatment. Wastewater treatment is required in order to prevent environmental pollution from indiscriminate discharge or disposal of untreated wastewater. This relates to the specific objectives of assessing the safety of treated wastewater and irrigated crops which serve as scientific evidence to support the decision to use treated wastewater and in the end advocating for the practice of wastewater treatment in general.

2.4 Wastewater Recycling and Reuse.

Oteng-Ababio, (2014) was of the view that wastewater treatment which was considered as preventing further damage to the aquatic environment, sensitive ecosystems now goes beyond to producing effluent or treated wastewater as an alternative water resource.

World Health Organization, (2006) report strongly supported the fact that wastewater if and when well managed can meet most, if not all, of the competing uses and non-critical demands for water. The World Water Council, (2012) report also considered wastewater as a resource owing to the benefits derived from its proper after treatments and enormous uses. Treated wastewater could therefore be a major sustainable water resource to serve competing uses if the required quality is met.

The competing demands for freshwater makes water a scarce commodity in many parts of the world especially in situations of escalating population growth in semi arid and arid

regions with dwindling freshwater sources (World Health Organization, 2006). This situation creates pressure on the already scares water resource as demand increases with increase in population.

Wastewater has many uses including irrigation of agricultural land, aquaculture, landscape irrigation, urban and industrial uses, recreational and environmental uses, artificial groundwater recharge, to mention a few (Asano *et al.*, 2007). These uses require huge amount of wastewater of varying quality depending on the specific use.

Amoah *et al*. (2009) found that, most vegetable crops sold within cities of developing countries such as in Accra and Kumasi in Ghana are produced using wastewater from urban areas. Gleick, (2003) also indicated that farmers find wastewater reuse as an important resource because of its rich nutrients and organic matter content coupled with the fact that it is reliable, readily available throughout the year.

Keraita, *et al.* (2008) indicate that, wastewater is mostly use in a diluted form or is often mixed with surface runoff and stream water for irrigation in most major cities like Kumasi and Accra in Ghana. However, untreated wastewater is mostly used by urban farmers which pose health implications on both the people who work on the farms and those who patronise the produce.

Positive impacts of wastewater irrigation on crop production as a result of its nutrient content and organic matter have been demonstrated beyond reasonable doubt (Parameswaran, 1999). Danso *et al.*, (2002) and Cornish & Kielen, (2004) also reported

that urban market farmers in the cities of Kumasi and Accra, Ghana, can earn 2-4 times more (average US$ 340/ha per season) than farmers who grew maize and cassava. Using treated wastewater for irrigated agriculture is attractive as urban and peri- urban fields are often conveniently located near city markets where the produce are sold, or are near urban-based buyers who purchase the produce directly from the (peri) urban plots. Agodzo, *et al.* (2003) estimated that, if just 10% of the approximately 280 million cubic meters (m^3) of wastewater from urban Ghana could be treated and used for irrigation, an estimated total irrigated area with treated wastewater alone could reach 4600 ha. Treated wastewater can easily be channelled to the fields from city drains, from a river, or from broken sewer lines or carried to the fields in watering cans. Averagely a farm size of about 0.5 ha has the potential to provide more than 9,200 farmers with income during the dry season in some peri-urban areas in Ghana.

Brown, (2005) reported that the demand and prices for fresh vegetables and dairy products increase as urban population and incomes of urban dwellers increase. Often, leafy crops like lettuce, cabbage, etc. produced for urban consumption are grown in and around urban areas due to the lack of refrigerated transportation. Danso *et al.*, (2002) stated that 90% of the lettuce and spring onions consumed in the city of Kumasi, Ghana, are produced within the city itself.

Wastewater reuse for irrigated agriculture and associated issues is currently undergoing policy considerations as indicated by Keraita *et al.*, (2012). The reports also indicated that Ghana's National Irrigation Policy encourages research on safe irrigation practices for

urban and peri-urban agriculture using treated wastewater. This initiative demonstrates the importance of the use of treated wastewater in urban and peri-urban agriculture and the Government's will to support and pursue it. However, the issue of inadequate comprehensive data on volumes generated and issues of perceived quality of the wastewater effluent as well as the volumes treated and reused for irrigated agriculture and other non- critical uses are issues to be considered.

2.5 Perceptions of treated wastewater reuse

The use of wastewater anywhere around the world is based on user knowledge and user perception which tend to influence user decision and the will to use treated wastewater and consume the irrigated crops as reported by Nancarrow *et al.*, (2008) as well as Angelik *et al.*, (2007). Willingness to use treated wastewater is key to the success of wastewater treatment projects.

Baghapour & Djahed, (2017) reported in a study that the source of wastewater, the treatment technology available, the quality before and after treatment as well as the intended use and health implications are some influential drivers of perception of wastewater reuse.

Po *et al*., (2003) also found out that some factors are associated with the perception of users of treated wastewater and consumers of treated wastewater irrigated crops. These factors include: Disgust or "yuck", with its associated health risk, intended use of the treated

wastewater, source of wastewater, preference of the user, level of trust in authorities and treatment technology or the available scientific knowledge of the system's efficiencies, user attitude towards the environment, total treatment cost considerations and socio-demographic factors.

Disgust or "Yuck" Factor:

Angyal, (1941) and Po *et al.*, (2003), mentioned the disgust emotion and defined it as the emotional discomfort generated from close contact with certain unpleasant stimuli. Things such as excrement, urine, saliva, dirt and mud, to mention a few, can commonly elicit disgust reactions from people. A disgust reaction in using recycled water or treated wastewater is likely to be generated from people's perceived 'dirtiness' of the water and their fear of contagions or personal contamination from using the water.

Associated Health Risks:

Nancarrow *et al.*, (2002) indicated that an important factor that influences public acceptance of the use of treated wastewater is the perceived human health risk associated with using the treated wastewater for irrigation agriculture and when it comes into contact with the skin. In the context of water reuse, the risk perception is often related to public health issues which are diseases caused by microbiological organisms and other contaminants which may be found in the treated wastewater.

Intended or Specific Use(s):

Jeffrey (2002), stated that the closer the recycled water is to human contact or ingestion, the more people are opposed to using the water.

The specific uses can also be associated with the disgust emotion in using recycled water. The acceptability of treated wastewater reuse for irrigated agriculture is less towards crops that are consumed unprocessed 'raw' or least processed by humans and animals.

Origin or source(s) of Wastewater:

Nancarrow *et al.,* (2002) indicated that the source of wastewater or water to be recycled, or 'use history' of the wastewater affects its acceptability and reuse. The reuse of greywater or treated wastewater especially from one's own household is more acceptable than water obtained from other public or secondary sources. The origin gives an indication of the contaminants contained in the wastewater.

The Issue of Choice:

Dishman *et al.,* (1989) found that the issue of choice is also an important determinant to which public acceptance of wastewater reuse is based. In areas with water shortage issues, people are more likely and readily willing to accept treated wastewater reuse because of the heightened awareness of the need to conserve water. In effect, the acceptability of wastewater reuse decreases substantially as the use moves from public areas to the home, and from toilet flushing, laundry, bathroom and kitchen uses to drinking.

Trust in the Authorities & Scientific Knowledge:

Nancarrow *et al.,* (2008) further indicated that trust in all the authorities involved in providing safe recycled or treated wastewater, scientific investigations, monitoring and evaluation as well as technologies could play a crucial role in determining public acceptance of wastewater reuse. Trust in the wastewater treatment plant to provide safe recycled water is one of the main reasons the public would be willing to use recycled water.

Attitudes towards the Environment:

Jeffrey (2002), found that individual attitude toward the environment may also play a crucial role in people's acceptance and reuse of treated wastewater. People who have undertaken water conservation measures in their homes are more prepared to reuse greywater for toilet flushing from different sources.

Cost of wastewater treatment:

Po *et al.,* (2003) found cost considerations as one of the main determining factors influencing treated wastewater reuse. NETWAS Uganda & Uganda, (2011) report, also concluded that consumers expect to offer less for a given quantity of recycled water due to its quality issues and the restrictions which people impose on its use. People would rather pay more for water they can trust in terms of its quality.

Socio-demographic Factors:

Some demographic characteristics play major roles in influencing public perception of wastewater reuse. Menegaki *et al.* (2007), found that the greatest opposition to most

wastewater reuse schemes is predicted to come from people of 50 years and over whereas people of ages below these years are more likely to accept the use of treated wastewater.

These factors influence user perceptions and decisions which tend to influence willingness to reuse treated wastewater for irrigated agriculture and consume the irrigated crops as relating to the objectives of this study. The study aims at assessing some of these factors as they relate to the purpose of study.

2.6 Challenges to wastewater treatment and reuse

One of the main challenges related to wastewater treatment in Africa is the overall lack of infrastructure for its collection and treatment, which results in the pollution of the limited surface and groundwater resources (Connor *et al.*, 2017). Comprehensive data on volumes and quality of commercial and industrial sources of wastewater production treated and use for irrigated agriculture and non-critical purposes is lacking (Gyampo, 2012). Knowledge in the wastewater treatment technology, human health risk assessment outcome, quality monitoring and regulations enforcement, safe use of the treated wastewater are also factors which affect wastewater treatment projects, wastewater reuse and consumption of wastewater irrigated crops.

Wastewater treatment in developing countries like Ghana and India is confronted with varying challenges such as the absence or lack of financial and technical resources as indicated by Qadir *et al.*, (2010). For this reason, developing countries make comprehensive wastewater collection and treatment a long term future strategy (Connor *et*

al., 2017). For example, countries like India and Pakistan only have 24% and 2% of their wastewater generated from households and industry receiving treatment with huge deficit in wastewater treatment gab (Oteng-Ababio, 2014). These two countries, according to a WHO (2006) report, discharge 76% and 98% of their generated wastewater untreated which calls for short term risk management and interim solutions in an effort to prevent adverse environmental and health impacts from wastewater irrigation. These short term solutions include user and consumer health protection through interventions at the farm level, post-harvest measures and public policies to motivate better management of wastewater. This study aims at providing scientific evidence as prove of the safety of the treated wastewater to support policy making and implementation with regards to wastewater treatment and reuse in Ghana.

A study carried out by Abraham *et al.* (2007), in some residential areas in the city of Accra indicated that about 53% of the population disposed of their grey-water directly into gutters and storm-drains and between 12% to 20% of the population throw their wastewater on the streets or outside and on their compounds respectively. These practices cause pollution of the environment and water bodies.

Obuobie *et al.*, (2006) also found that only 7 out of the 44 smaller wastewater treatment plants in Ghana are available and operational. These plants were said to serve about 5-7% of Accra's population. The largest, an Up-flow Anaerobic Sludge Blanket (UASB) plant which was operating at 30% of its capacity is now broken down and much of the collected sewage is discharged untreated into the sea.

According to Andoh (2008), wastewater reuse can have direct and indirect health impacts on users. Direct contact with untreated wastewater through flood or furrow irrigation can lead to increased helminth infection .*Ascaris lumbricoides* (roundworm), *Trichuris trichiura* (whipworm), *Ancylostoma duodenale* and *Nector americanus* (hookworm) are the most like ones. Buechler *et al.* (2006), examined the impact of untreated wastewater on human health, environment and income in Pakistan and reported incidence of higher hookworm infections in farmers and farm workers who use wastewater for irrigation than those who do not. Singh *et al.* (2010), also indicated that issue of public health risk mainly arises when vegetables or leafy crops grown with untreated wastewater are consumed unprocessed. This can be linked to health risks like cholera, typhoid fever, as well as to faecal bacterial diseases, bacterial diarrhoea and dysentery among consumers of wastewater-irrigated produce. The issue of municipal and industrial wastewater sources containing major chemical compounds as contaminants also pose threats to human health. This study aims at assessing the physicochemical and microbiological quality of the untreated and treated wastewater to serve as scientific evidence to prove the safety of the treated wastewater for reuse as an alternative irrigation water resource.

2.7 Wastewater and Sustainable Development Goals (SDGs)

This study and other similar studies would help to achieve the United Nations Sustainable Development Goal (SDGs) #6 of ensuring the availability and sustainable management of water and sanitation for all.

Tafadzwanashe *et al.* (2016), reported that wastewater treatment provides an opportunity to augment alternative water resources necessary for irrigated agriculture and other non-critical uses. Harnessing these resources would help to address food security, water security and agricultural productivity issues. An added environmental benefit would also be derived from better wastewater management by reducing nutrient pollution of our oceans and water bodies. In addition to poor sanitation and hygiene implicated as being the causes of death mostly in children who are less than 5 years in developing countries, wastewater management and improvement in environmental sanitation therefore needs to be taken seriously to promote healthy living.

Target 6.3 of the SDG #6, according to Andersson *et al.* (2016), is aimed at improving water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and increasing recycling and safe reuse globally by the year 2030. The achievement of this single target would have an overall positive effect in helping to achieve other water related Sustainable Development Goals (SDGs) such as SDG #1, SDG #2 and SDG #3.

A major reason for the degradation of natural watercourses relates to the poor management of excreta and wastewater treatment as was stated by the World Health Organization, (2006) reports. It is estimated that more than 90% of sewage in the developing world is discharged directly into rivers, lakes, and coastal waters without treatments of any kind.

Lüthi *et al.* (2011), found that phosphorus a nutrient which is essential to all living organisms and in the production food for humans never occurs in its pure form. It is always

bonded with other elements to form compounds. The use of treated wastewater for irrigation is one way to recycle phosphorus without mining at increasing rates to produce artificial fertilizer. The importance and benefits of wastewater treatment to man and the environment is without doubt. However, treated wastewater reuse according to Kiziloglu *et al*., (2008) as an alternative water resource for irrigated agriculture and other non- critical purposes depends on factors such as the availability of freshwater resources, users' knowledge, perception and willingness. Human health risks, quality of treated wastewater irrigated crops produced and whether those crops are processed or unprocessed before consumption are all factors of consideration. Public willingness to use treated wastewater for irrigated agriculture and the consumption of irrigated crops is influenced by some underlying factors.

The use of wastewater by urban farmers for vegetable crop irrigation in Ghana is on the increase due to the ever increasing demand by an ever increasing urban population without adequate freshwater sources or readily available and affordable municipal treated water supply poses varying human health risks to the farmers and the consumers of the produce. There are also perception issues such as; Disgust or "yuck", with its associated health risk, intended use of the treated wastewater, source of wastewater, preference of the user, level of trust in authorities and treatment technology or the available scientific knowledge of the system's efficiencies, user attitude towards the environment, total treatment cost considerations and socio-demographic factors. These are all factors influence willingness to use treated wastewater for vegetable irrigation and the consumption of irrigated crops.

In view of this ever growing urban population which needs to be fed, the urban farmer would use any readily available, easily accessible and affordable source of water for irrigation without regards to public health concerns. Aside the enormous environmental protection benefits derived from wastewater treatment, there are equally invaluable human health and economic benefits to be derived from the proper treatment, management and use of wastewater for vegetable crops irrigation and other competing uses.

CHAPTER THREE

MATERIALS AND METHODS

This study seeks to assess public willingness to reuse treated wastewater for irrigated agriculture and the consumption of the irrigated crops. The study further seeks to provide scientific evidence to prove the quality and safety of the treated wastewater and the irrigated crops through laboratory analyses and field experiment by the use of the following materials and general methods.

3.1 Study Area

Social survey conducted for study was done in Ashaiman, of the Ashaiman Municipality and at the University of Ghana, Legon. Ashaiman as a town and suburb has a well diverse population with lots of commercial, economic and industrial activities being carried out. University of Ghana, Legon campus also has a well diverse student population with varying levels of capacities and understanding. Both study areas are within the Greater Accra Region of Ghana.

Ashaiman town was selected because it has a well diverse population of people with varying levels of formal education, monthly income levels, and high dependency ratio. Ashaiman has relatively many urban farmers who grow vegetables in areas where fresh water sources are not readily available (Ghana Statistical Services, 2014). The views of this group of people on one hand would help achieve the objective of the study.

University of Ghana, Legon and students were selected because of their level of formal education which only varies in level of study and the programmes of study. The views of this group of people on another hand would help to achieve the objective of the study.

3.1.1a Ashaiman Municipality

The population of Ashaiman Municipality, according to the 2010 Population and Housing Census, is 190,972, representing 4.8% of the Greater Accra region's total population. The Ashaiman Municipality, with Ashaiman as the capital, can be located about 4km to the north of the industrial city of Tema and about 30km from the city of Accra, the capital of Ghana. Ashaiman covers a total land area of 45km^2. There are mostly sandy clay soils which are suitable for the cultivation of vegetables: okra, pepper, cabbage, cucumber are major vegetables produced in urban gardens. Most crop farmers in Ashaiman therefore cultivate these crops and market them to surrounding restaurants and hotels.

The relief of the area is generally flat and forms part of the Accra-Togo plains with annual rainfalls which ranges from 730mm to 790mm, which is lesser than that of University of Ghana, Legon. Major rain seasons start from April to July and then the minor from September to November is the minor rain season according to the Ghana Statistical Services,(2014) report, (Figure 3.1).

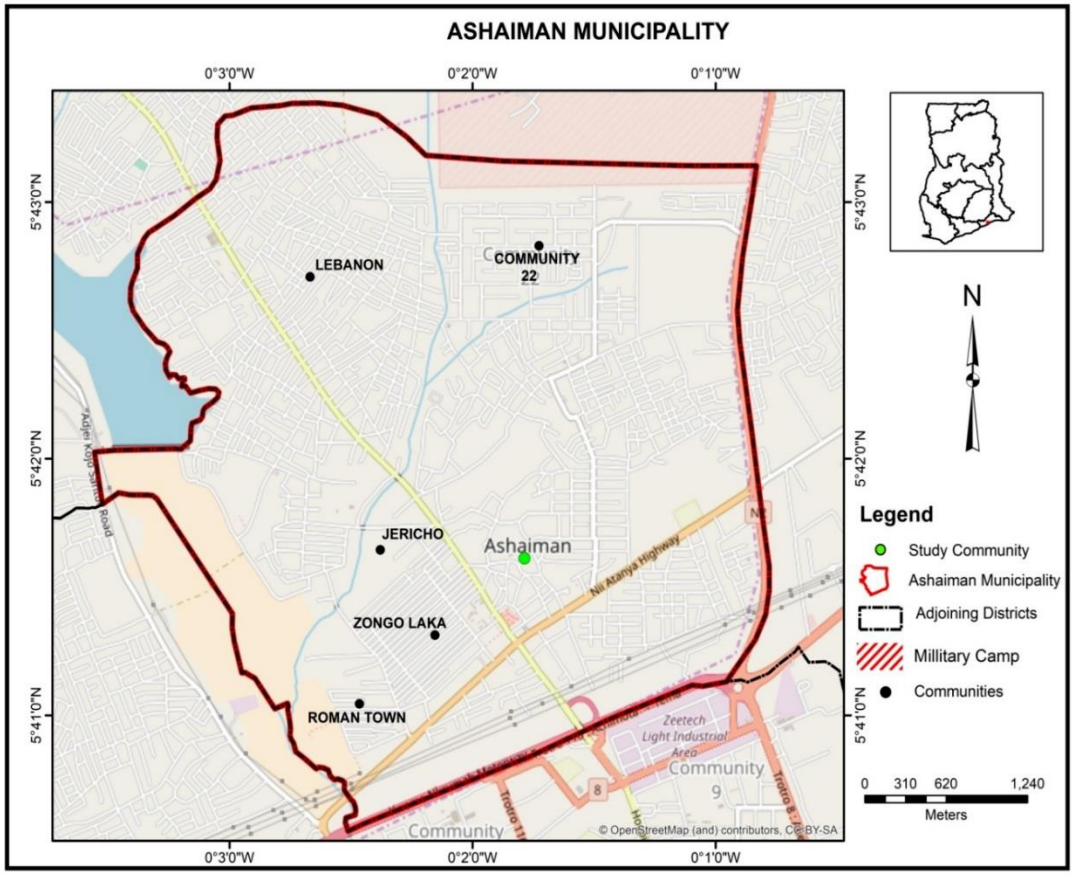


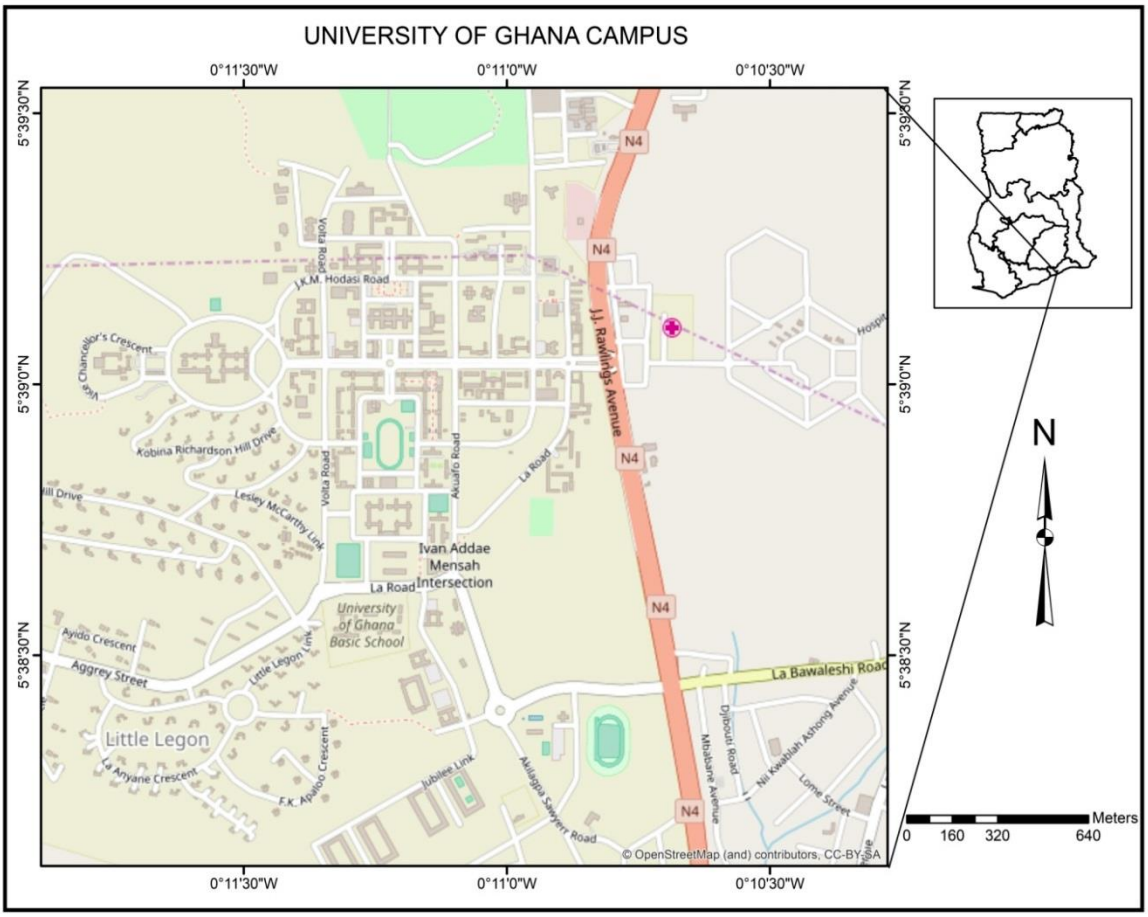
Figure 3.1: A map of study area of Ashaiman municipality showing Ashaiman and neighbouring communities

3.1.1b University of Ghana, Legon campus

The University of Ghana, Legon, is the largest of the Universities in Ghana. It is situated about 13 kilometres north-east of the capital of Ghana at an altitude of about 91 and 122 meters above sea level with an area coverage of about 13km^2. The area is characterized by a pronounced gradient of mean annual rainfall ranging from 733 mm to 1118 mm as described by Decher & Bahian, (1999). The mean annual rainfalls are greater in magnitude than that of the Ashaiman.

The campus can be divided as per land use types into four areas according to Kyerematen *et al.,* (2014): Residential Area (RA), Academic Area (AA), Botanical Garden (BG) and University Farm (UF). The Residential Area (RA) covers an area of about 5.5 km^2, which includes the students' halls, and hostel where the social survey was conducted, and chalets and bungalows housing staff. The Academic Area (AA) covers an area of about 1.8 km^2 and includes the central administration, lecture halls, offices for faculty, academic departments, libraries, restaurants and canteens. The Botanical Garden (BG), located north of the campus, covers an area of about 2.0 km^2, and is characterized by a large variety of plants including grasses, shrubs and trees. The University Farm (UF), is located adjacent to the Botanical Garden, covers an area of about 0.3 km^2, and has mainly mango and cashew trees, as well as food crops such as maize and vegetables This was where the field experimentation for the study crop was carried out as shown on the map in (Figure 3.2)

Figure 3.2: A map of study area at University of Ghana, Legon showing the various



division of land use types

3.1.2 Study population

The population for this study consisted of 232 respondents from Ashaiman, and 202 students at the University of Ghana, Legon campus who consented to be interviewed.

3.1.3 Exclusion Criteria

Non- students, visiting students and UG staff members (teaching and non-teaching) were excluded from the study so as to limit the scope only to students of the University of Ghana because of time and cost restraint. One of the objectives of the study was to assess the level of knowledge and perceptions of a student group and that of a diverse group wastewater treatment in general.

3.1.4 Sample size determination

The sample size for the study was estimated using the Cochran's formulae (Cochran,1977)

$$\boldsymbol{n = \frac{\left(z_{\frac{\alpha}{2}}\right)^2 * p * q}{e^2}}$$, Where; n = desired sample size

$z_{\frac{\alpha}{2}}$ = Reliability Coefficient for 95% confidence level which is usually set as 1.96

p = Population Proportion of households who have knowledge of wastewater treatment and are willing to use in the study areas.

q = (1-p)

e = the margin of error or *tolerable error*, represents the maximum acceptable difference between the estimate and the population value for a specified confidence level. For the purpose of this study, the tolerable error selected was 5% (0.05) to make up for respondent selection and questionnaires administration in order to maximize quality check on all other non-sampling errors

3.1.5 Pre-testing of Survey Instrument

Pre-testing of the survey instrument (questionnaire) was carried out at Madina, a suburb of Accra with a well diverse population. In this exercise 30 questionnaire were administered to respondents at random. All comments, responses and anomalies identified from the pre-testing exercise were used to review and prepare the final instruments for the study.

3.1.6 Sampling Design

The random sampling technique was used to select respondents of eighteen (18) years and above in Ashaiman whiles resident students of the University of Ghana, Legon campus (undergraduates and post- graduates) were selected for interview. This was because the subject of wastewater treatment and reuse concerns all categories of students of different backgrounds and disciplines so as to help achieve the objectives of the study.

Ashaiman was chosen for the study owing to the fact that it has dense population with a well diverse people of various ethnic background and other social characteristics. Resident students of the University of Ghana, Legon campus were chosen for the study because of the students' easy access and availability. Level of education and knowledge of issues involved in the study was the main reason for choice of the two areas. Ashaiman, (the municipal capital) was selected from the other suburbs of the municipality like Lebanon, Zenu, Jericho, Zongo Laka, etc.

The systematic sampling technique was employed to select households and commercial space occupants to be interviewed in Ashaiman. The sampling interval used was k=3, meaning every third household and commercial space in the cluster were chosen. After choosing the households and commercial space, a random sampling technique was used to

select the respondents (specific individuals) and interviewed for the social survey. The individuals who were selected by the simple random sampling technique and interviewed were 18 years and above.

In the case of the University of Ghana, a cluster of all the halls of residence on campus was obtained. The residential halls were put into 3 clusters i.e., the traditional halls, the African Union halls and other private halls of residence. Students interviewed were sampled from the residential halls. Resident students were randomly selected from the three clusters using a simple random sampling technique and interviewed with the aid of the structured questionnaire.

3.2 Data Collection

Figure 3.3 is a map of the University of Ghana, Legon campus which shows the location of the wastewater treatment plant and the University of Ghana Farm were wastewater sampling and field experimental work (cultivation of the lettuce) were carried out respectively.

3.2.1 Sampling and field experiment sites description

Wastewater samples were collected at the Accra Sewage Improvement Project (ASIP), a wastewater treatment facility located at University of Ghana, Legon. The facility which uses the sedimentation pond technology has an operating capacity of 8700 m^3/ day

The plant utilizes a four-step sedimentation pond process which comprises of the following: 3 anaerobic ponds, 3 facultative anaerobic ponds, 3 aerobic ponds and 3 maturation ponds making 12 in all. Wastewater samples were collected at the point of entry to the first treatment ponds (the anaerobic ponds) and after the last ponds (maturation ponds).

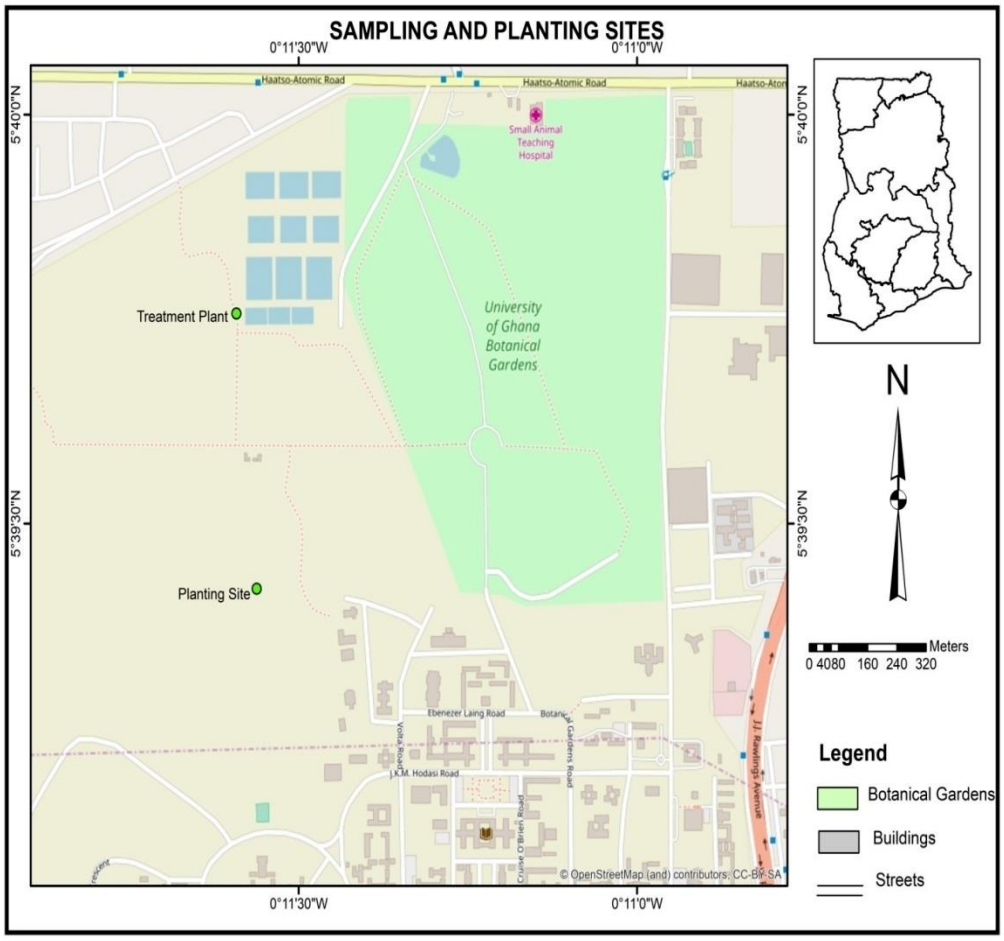


Figure 3.3: A map of the study area showing the wastewater treatment plant and University of Ghana farm (Source: Author's construct)

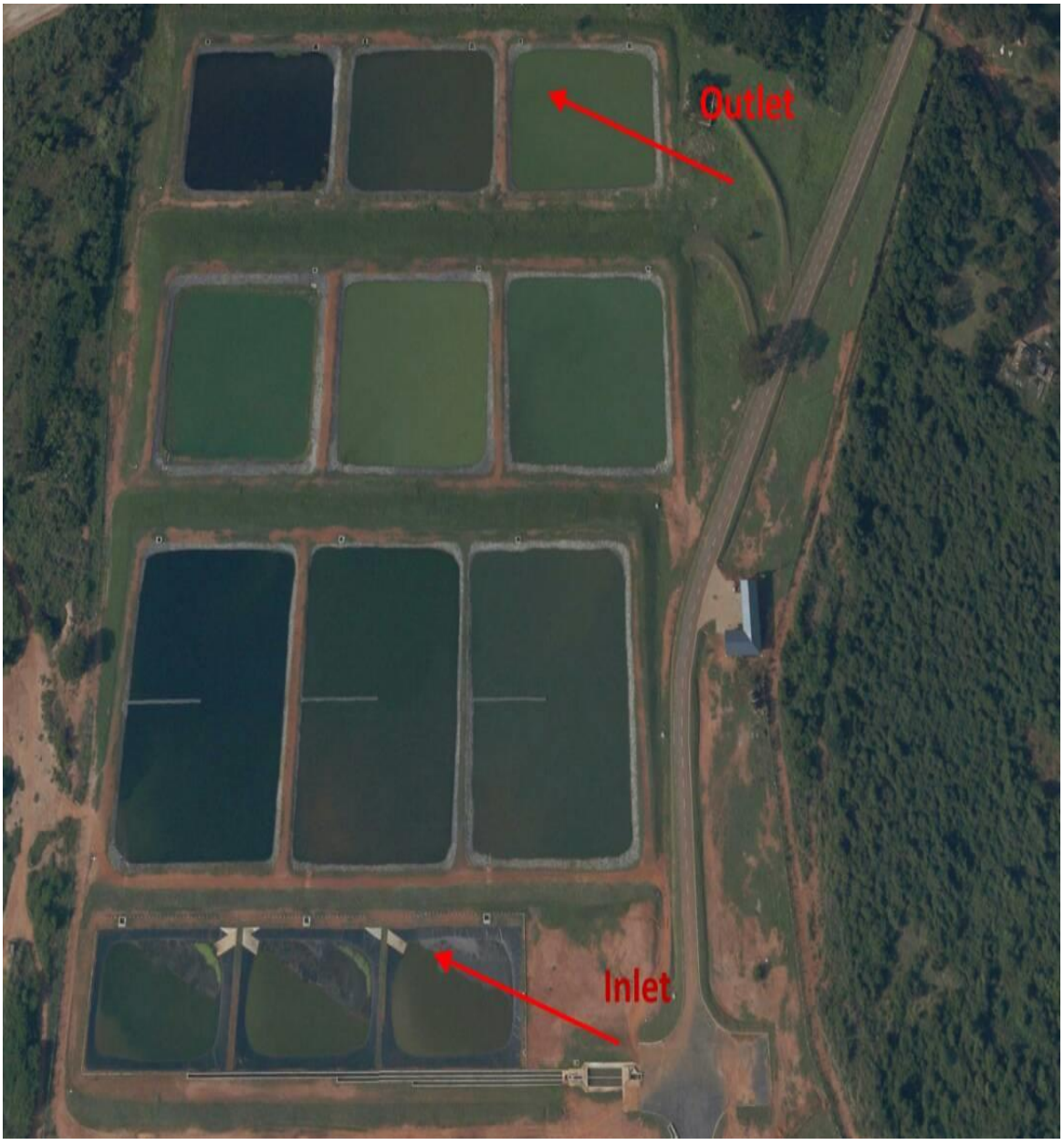


Plate 3. 1: A Google Earth view of the wastewater treatment plant showing all ponds from the inlet to the outlet

3.2.2 Water Sample collection

Two (2) samples of 1500 ml each of both influent (inlet) and effluent (outlet) were taken from the inflow point into the anaerobic pond and the final treated effluent prior to final discharge into a drainage system respectively (Plate 3.1). A volume 1500 ml of the wastewater samples of both the influent and the effluent was taken on monthly basis from February to July to analyse the physicochemical and microbiological quality respectively.

Samples for Dissolved Oxygen (DO) determination were collected using narrow-mouth glass-stopper BOD bottles of 300 ml capacity with tapered and pointed ground glass stoppers. Sampling was carefully done to avoid the dissolution of atmospheric oxygen. Dissolved Oxygen was fixed on the field using Winkler 1 and 2 solutions, (Manganous Sulphate Monohydrate $MnSO_4.4H_20$) and (Alkali-Iodide-Azide solution) respectively. Fixed samples in BOD bottles were transported to the laboratory under dark conditions in ice chest so as to prevent exposure to external light. Samples for BOD analysis were collected just as those for DO analysis but the in the case of DO samples were not fixed. Samples were then kept in ice chest and transported to the laboratory at 4^oC.

Samples for analysis of nutrients levels and other chemical parameters were collected using clean plastic bottles of one litre volume.

Samples for the determination of microbiological quality of both the influent and the effluent were collected into two clean 300ml pre-sterilized bottles each and stored at 4^oC in an ice chest. All samples were transported to the laboratory as soon as possible for analysis.

3.2.3 Analyses of Wastewater

Some physical parameters such as the temperature, pH, Electrical conductivity (EC), and turbidity of the wastewater effluent were assessed.

Some chemical parameters analyzed included, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate-Nitrogen, Total Phosphorous, Phosphate phosphorous and Nitrite were also analysed as well as trace/heavy metal such as zinc, lead, copper, and cadmium .

Microbiological parameters determined included: Total coliform (TC), Faecal Coliform (FC) and *Escherichia coli* (*E. coli*). Standard methods employed to determine specific / respective parameters are provided below.

3.2.3.1 Electrical Conductivity

Electrical conductivity of the wastewater effluent was analysed using the Laboratory Bench Conductivity Meter Method with Cyber scan PC 510**.** The reading was taken at the point of sample collection.

The conductivity cell and the beaker or vessel into which a portion of the sample is to be examined was thoroughly cleaned and rinsed. The instrument was calibrated using standard solutions prior to the analysis. The beaker was completely filled with sample. The cell was inserted into the beaker containing sample. When the wastewater sample and cell reach the same temperature, the indicated value was read off in µS/cm or mS /cm depending on the magnitude of the value.

3.2.3.2 Turbidity

Turbidity is an expression of the optical property of a solution which causes light to be scattered or absorbed.

The turbidity measurements of the wastewater samples using a Turbidimeter were carried out using the Nephelometric Method.

The 1500 ml sample was vigorously shaken and poured into a sample cell to at least 2/3 full. The appropriate range was selected using the range knob on the Turbidimeter (HACH 2100P). With a red light appearing, the next range was selected and the stable turbidity reading was recorded directly from the Turbidimeter.

3.2.3.3 pH

The Hydrogen ion concentration or pH levels of the wastewater effluent were determined (*in-situ*) using pH Meter (Suntex pH meter) and a Combination Electrode Method (APHA, 2005).

The electrode was connected to the meter and the system was calibrated using pH 4, 7 and 10 buffer solutions. Each buffer solution was brought to the same temperature as that of the effluent samples to be analysed. A beaker was then rinsed and filled with pH buffer solution. The electrode was immersed and stirred twice and left suspended in the solution for 1-2 minutes after which a stable reading was recorded. The electrode was withdrawn and rinsed with deionised water and shook gently to remove excess water. The above process was repeated using pH buffers 7 and 10 and the readings noted. The electrode was

withdrawn and again rinsed with deionised water and the pH calibration was checked. The pH of the samples was measured as such and the values recorded.

3.2.3.4 Dissolved Oxygen (DO)

The concentration of dissolved Oxygen in a given quantity of wastewater gives an indication of the potential of the wastewater to support life forms.

The Dissolved Oxygen concentration of the wastewater samples was analyzed using the Winkler Method (APHA, 2005)

To the already fixed wastewater sample in the DO bottle, 1.0ml conc. H_2SO_4 was added and the bottle was stoppered and mixed by inverting several times until complete dissolution occurred. The dissolved sample was then titrated with 0.025M $Na_2S_2O_3$ solution to a pale straw colour. Few drops of starch solution were added and titration continued to first disappearance of blue colour. For titration of 200ml sample, 1ml 0.025M $Na_2S_2O_3$ = 1mg DO/Litre.

3.2.3.5 Biochemical Oxygen Demand (BOD)

The Dilution Method (Winkler Azide Modification) was employed in determining the Biochemical Oxygen Demand (BOD) levels of the wastewater samples (APHA, 2005)

Wastewater samples were collected and incubated at 20^0C for 5 days. Dissolved oxygen (DO) level was measured before and after incubation. The BOD concentration was calculated from the difference between the initial and final dissolved oxygen concentration determinations. To the wastewater sample in BOD bottle, 2.0 ml of $MnSO_4$ was added

followed by 2.0 ml of Alkali-Iodide-Azide solution. The bottle was corked carefully to exclude air bubbles and shaken thoroughly by inverting several times. Precipitates were then allowed to settle after which, 2.0 ml of conc. H_2SO_4 was added. The bottle was corked again and inverted several times to dissolve the precipitate which produced an intense yellow colouration. 100.0 ml of the solution was then titrated with $Na_2S_2O_3$ to a pale yellow colour. 1.0 ml of starch was added as indicator. The titration was continued to the first disappearance of the blue colour. The BOD level was calculated as follows:

BOD_5, (mg/l) = (D1-D2)/P

Where D_1 = DO of sample immediately after preparation, mg/l, D2 = DO of sample after 5 day incubation at 20^0C, mg/l, P = Decimal volumetric fraction of sample used.

3.2.3.6 Chemical Oxygen Demand (COD)

In assessing the Chemical Oxygen Demand (COD) levels of the wastewater, Closed Reflux Method was used (APHA, 2005).

As a precautionary measure, all glassware needed were thoroughly washed and rinsed with 20% H_2SO_4 before use to prevent contamination. Afterwards, the samples were placed in culture tubes and digestion solutions (3.0 ml standard Potassium Dichromate and 7.0 ml Sulphuric acid) were added. Sulphuric acid reagent was carefully run down inside of vessel to form an acid layer under the sample-digestion solution layer. The tubes were tightly capped and inverted several times to mix completely then were placed in block digester and preheated to 150°C, and refluxed for 2hrs behind a protective shield. The samples were then cooled to room temperature and placed in vessels in a test tube rack. The culture tube

caps were removed and then a small Polytetrafluoroethylene (PTFE) covered magnetic stirrer was placed in the solution for stirring, it was followed by 1 to 2 drops of Ferroin indicator. Stirring was done rapidly using the magnetic stirrer while titrating with standard 0.1M Ferrous Ammonium Sulphate (FAS). The end point is a sharp colour change from blue green to reddish brown. In the same manner, the control which is known as a blank contains reagents and a given volume of distilled water equal to that of the sample was refluxed and titrated.

The chemical Oxygen Demand (COD) in mg/l was calculated as

COD as mg/L = (A-B) × M × 8000/ml sample

Where A = ml of FAS used for blank, B = ml of FAS used for sample, M = Molarity of FAS.

3.2.3.7 Phosphate Phosphorous

The determination of phosphate was carried out using the Stannous Chloride Method (APHA, 2005).

To a measured volume of 100 ml of the wastewater sample which is clear and free from colour was added one (1) drop of Phenolphthalein indicator in a flask. A volume of 4 ml of Molybdate reagent was again added after which 10 drops of stannous chloride reagent was also added with thorough mixing by shaking. The spectrophotometer was first zeroed with a blank solution which was made up of 2.0 ml of the standard phosphate solution transferred into a volumetric flask and diluted to 100 ml. After 10 minutes, but before 12 minutes, the test sample was inserted into the spectrophotometer and the absorbance was

measured at a wavelength of 690nm. From the calibration curve, the concentration of the wastewater samples was determined using their measured absorbance, mg/l.

3.2.3.8 Total phosphorous

The Total Phosphorous level of the wastewater effluent was determined using the Acid Persulfate` Digestion Method (APHA, 2005)

The reactor DR8200 was started and pre heated to 150^{o}C and the programme was started. 5.0 ml of the wastewater sample was transferred into the Total Phosphorous test vial and the content of the Potassium Persulfate pillow was added to the vial and caped. The vial was given a shake to dissolve the powder and then inserted into the reactor. The instrument timer was started and a 30 minutes reaction time was set. The vial was carefully removed from the reactor after the time expired and placed in a test tube rack for the vial to attain room temperature. To the vial at room temperature, 2 ml of 1.54N Sodium Hydroxide standard solution was added. The vial was caped and inverted to mix. The vial was cleaned and inserted into the 16-mm cell holder. The instrument was zeroed and read 0.00 mg/l PO_4^{3-}. The content of one PhosVer 3 powder pillow was added to the vial containing the test sample. The vial was caped and shook to mix for about 30 seconds for the powder to dissolve but not completely. A 2 minutes reaction time was started on the instrument and then the vial was cleaned and inserted into the 16-mm cell holder. The 'READ' buttom was pushed and the sample was measured within 2 to 8 minutes after the 2 minutes reaction time expired. The results were shown as in mg/l of PO_4^{3-}.

3.2.3.9 Nitrate-Nitrogen

Nitrate concentration of the wastewater was determined using the Hydrazine Reduction Method (APHA, 2005)

A 10 ml sample of the wastewater effluent or the aliquot was transferred into a clean test tube. 1.0 ml of 0.3M NaOH solution was added and mixed gently after which 1.0ml of a reducing mixture which is made up of 20.0 ml copper sulphate working solution and 16.0 ml hydrazine sulphate was added to 20.0 ml of 0.3M NaOH and mixed gently and heated at 60^0 C for 10min in a water bath. The mixture was cooled to room temperature and 1.0ml of colour developing reagent (made up of 25.0ml concentrated phosphoric acid and 3.75g sulphanilamide added to approximately 150ml of distilled water. 0.19g N-(1-naphthyl)-ethylenediamine dihydrochloride was then added after complete dissolution of the sulphanilamide and topped up to 250 ml with distilled water) was added. It was shaken to mix and the absorbance of the wastewater sample was read using UV/VIS spectrophotometer at a wavelength of 520 nm. A calibration curve was constructed with the standards prior to the readings for subsequent use.

3.2.3.10 Nitrite

The Nitrite levels of the wastewater samples was determined using the Diazotization Method (APHA, 2005)

A 10 ml wastewater effluent sample was pipetted into a test tube. 1 ml of colouring reagent which was prepared by dissolving 20g of sulfanilamide in 200 ml of concentrated phosphoric acid (specific gravity of 1.69) and then topping it up to1500 ml with demineralised water, 1.0g of N-l-naphthylethylenediamine dihydrochloride which is completely dissolved (warmed if necessary) was added to it and then made up to 2 liter mark with demineralised water was then added. The 1 ml of Brij-35 solution was added, shaken to mix and the absorbance of the wastewater sample was read at a wavelength of 410 nm.

3.2.3.11 Total Iron, Zinc, Lead, Copper, Cadmium

The presence of trace and heavy metals including Iron, Lead, Copper, Zinc and Cadmium in the wastewater effluent was determined using the Atomic Absorption Spectrophotometer (AAS) Method (APHA, 2005)

Specifically the Agilent Technologies 900Atomic Absorption Spectrophotometer with 50 mm burner was used. A sample solution was aspirated into a flame and atomized. A light beam was directed through the flame into a monochromator and unto a detector that measured the amount of light absorbed by the element in the flame. The sample was acidified to a pH less than 2 with Nitric acid (HNO_3). Measurement for each trace/ heavy metal and element contained in the wastewater sample was taken and recorded at its characteristic wavelength of 248.3 nm, 217 nm, 324.8 nm213.9 nm and 228.8nm for Iron, Lead, Copper, Zinc and Cadmium respectively.

3.3 Microbiological Analysis of Wastewater effluent samples

Microbiological analysis of wastewater effluent was necessary to assess the presence and concentrations of pathogenic organisms which indicates the level of contamination of the wastewater hence it safety for irrigated agriculture use.

The tests needed to assess and confirm coliform bacteria presence and level in wastewater effluent are basically three, namely; the presumptive, the confirmatory, and the complete tests. These tests were performed sequentially on each wastewater effluent sample under analysis to assess coliform bacteria which are known to be gram-negative, non-spore forming bacilli that ferment lactose with the production of acid and gas detectable following a 24-hour incubation period at 37^{o}C and 45^{o}C.

The presumptive test was specifically carried out in order to detect the presence of coliform bacteria. A known amount of the wastewater to be tested was added to a lactose fermentation broth containing an inverted gas vial known as Durham tubes. The medium also contains a surface tension depressant known as the bile salt which is used to suppress the growing of organisms other than coliform bacteria in addition to the lactose. Serial dilutions of the test samples were prepared in ten folds. The series consists of at least three groups, each composed of three tubes of the specified medium. The tubes in each group were then inoculated with the designated volume of the wastewater sample as described under the "procedure". Gas formation in any of the test tubes was considered a presumptive evidence of the presence and number of coliform bacteria in the sample which is expressed

as the Most Probable Number (MPN) test. The MPN is thus, an estimation of all the tubes which had the gas formation during the incubation period.

The test is considered positive (+) when ≥10% of gas appears in a tube in 24 hours.

The test is considered doubtful when gas development in a tube was after 48 hours.

The test is considered negative (-ve) when there is no gas in the tube in 48 hours.

A confirmatory test was carried out by using selective and differential culture media such as Eosin-methylene blue (EMB) or Endo agar into which there is a positive lactose broth tube obtained from the presumptive test will be streak. Eosin-methylene blue agar inhibits the growth of gram-positive organisms due to its dye methylene blue content. EMB forms a complex that precipitates out onto the coliform colonies, producing dark centres and a green metallic sheen in acidic environment. The Endo agar is a nutrient medium which contains the dye Fuchsin and forms a dark pink complex which turns the *E. coli* colonies and their surrounding medium to pink.

The microbial analysis of the wastewater sample has to be completed by examining the coliform colonies which appeared on the EMB or endo agar plates which were used for the confirmatory test. One isolated colony was first picked from the confirmatory test plate and was inoculated into a tube of lactose broth and then was used to streak on a nutrient agar slant to perform what is known as a Gram stain test. After the inoculation was done, the test was incubated at a temperature of 44^{o} C for 24 - 48 hours. The tubes showing acid and gas formation on the lactose broth indicated the presence of gram-negative bacilli

which are further confirmed as *E.coli* bacteria after microscopic examination. This according to APHA, (2005) constitutes the completed test.

3.4 Crop assessment

Lettuce seeds used for the study were of the Minetto variety and were obtained from Agri-Seed Company in Accra.

Crop quality assessment was carried out to assess the safety of the treated wastewater irrigated lettuce for human consumption as well as the effect the treated wastewater had the on the growth, development and yield of the crops.

Lettuce (*Lactuca sativa* L.*)*, a leafy vegetable was selected as the study crop because it is one of the mostly patronised and consumed leafy vegetable by the urban population. The maturity period for lettuce is relatively shorter which makes it possible for several seasons of planting and harvesting within the year. Lettuce is also one vegetable which is mainly consumed unprocessed or least processed, hence any contamination along the production chain from nursing to transplanting and harvesting, would be eventually carried on to the final consumers.

3.4.1 Experimental design

A Randomized Complete Block Design with four levels of treatment for lettuce cultivation was adopted. These levels of treatments were: Control, Undiluted effluent, 50:50 and 25:75 effluent dilutions (Table 3.1). Each level of treatment had 3 replications, making a total of

45 seedlings for each replication. This gave a` total of 135 seedlings for each of the four levels of treatment. In all 540 seedlings were planted with the middle column of 15 plants per each block used as the record plants to be sampled for analysis after harvest.

Table 3.1: Summary of the various effluent dilution options used for the cultivation of the lettuce in the study

Treatments	**Effluent to water ratio (Effluent : Water)**	**Percentage of effluent to water (%)**
Control (CTL)	0:1	0:100
EFF 100%	1:0	100: 0
EFF 50%	1:1	50:50
EFF 25 %	1:3	25: 75

3.4.2 Nursery Preparation and Practices

Lettuce seeds were nursed in an 80 cm ×80 cm box containing dried rice husk and mature chicken manure as substrate. Cultivation practices such as watering and stirring the media to loosen the beds were employed to manage the nursery till the seedlings were ready for transplanting four (4) weeks after emergence.

Plate 3.2: Lettuce seedlings ready for transplant after being nursed for four weeks

3.4.3 Treatment Application

The lettuce seedlings were transplanted after four weeks of nursing into plastic troughs of 12 m× 0.40 m dimension with coco peat and mature cow dung manure in the ratio of 3:2 respectively as the planting medium. Each trough was partitioned into four (4) equal parts with polyethene materials to prevent fluid from moving across partitions. The plants were watered twice daily for 10 days to allow for stabilization prior to treatment application. Each treatment occupied one portion of the four partitions of each trough as replicates.

The various levels of treatments options; 100%, 50%, 25% of wastewater effluent and Control were applied on the crops twice weekly for four weeks to the crops whiles maintaining the daily watering regime in between the treatment applications.

Plate 3.3: Experimental layout showing partitions representing the four levels of treatments

Plate 3.4: Experimental layout showing mature lettuce crops prior to harvest

3.4.4 Harvesting

The lettuce was harvested five (5) weeks after transplanting. Eight (8) plants were harvested from the middle of the inner rows of each partition (record plants), with the help of a hand fork. The harvested lettuce crops were put in well labelled poly bags and transported to the laboratories untreated in any way for analyses of vegetative parameters and microbiological quality. All harvests were done in the morning between the hours of 8:00 and 10:00 when the plants were fully turgid and succulent.

3.5 Data for lettuce growth parameters

Data on growth parameters of the lettuce were taken on fifteen (15) plants per treatment options which gave a total of five (5) plants for each of the three (3) replicates for each treatment option. These parameters include:

- Plant Height (PH)
- Number of leafs per plant (NL)
- Total fresh weight (TFwt)
- Fresh leaf weight (Lwt)
- Dry leaf weight (DLwt)
- Fresh stem weight (Swt)
- Dry stem weight (DSwt)
- Fresh root weight (Rwt)
- Leaf area (LA)
- Dry root weight (D Rwt)
- Head fresh weight

All plants were weighed using an electronic balance. The dry weights were obtained after the fresh weights were taken and the samples packed in labelled envelopes and oven dried at 70^{o}C for 96 hours after harvesting.

3.5.1 Microbiological Analysis on crops

Sample weighing and preparation

Lettuce samples were taken unprocessed in clean containers immediately to the Microbiological Laboratory of the CSIR- Food Research Institute, Accra after harvest. The lettuce samples were kept refrigerated at a temperature of 4.0^{o}C prior to microbial analysis.

The sample preparation and weighing room was sterilized with 70% ethanol. The 70% ethanol sterilization was carried out to take care of aerosols in the sample preparation and weighing room. The same was done in the other rooms for the same reason. Metal (apparatus) materials to be used for cutting and sampling were sterilized by flaming using naked flame.

Serial Dilution of Lettuce samples

10 gram of each lettuce sample was weighed on a KERN scale into sterile labelled Stomacher bags and then 90 ml of standardized Peptone Salt Solution (SPS) was added to make up 100 g ± 2.0 g of the total weight. This gave the first dilution of 10^{-1}. Stomacher equipment was used to homogenize the sample and the diluents solution. A total of 24 samples consisting of various parts of lettuce plants from all four treatments options and their respective replicates were obtained. Standardise Salt Peptone solution was the diluents used.

The primary dilutions (10^{-1}) containing the lettuce samples in Salt Peptone solution were taken to the UV- sterilized Laminar Flow bench and inoculation of the sample was carried

out aseptically into sterile Petri plates in 10 fold serial dilution points to a final dilution of 10^{-6}. 1.0ml of inoculum was dispensed into each labelled plate. The plates were labelled in this manner VRBLA / VRBLA, 37^{O} C, -1, 10/06.

About 10-15.0 ml of standardized Violet Red Bile Salt Lactose Agar (VRBLA) was cooled to a temperature of 45ºC ± 3ºC and poured on to the inoculum and swirled severally for homogeneity of sample and agar. The plates were allowed to set and then some more of the VRBLA agar was poured to overlay the first pour.

Note: The same Agar (VRBLA/VRBLA) was first used and for the overlay because the sample was not processed in any way after harvest in order the microbes were not stressed.

The plates were left for 45 minutes untouched to allow the culture media to set and then transferred to the incubators which have been sterilized using 70% ethanol solution according to test and temperature requirement for 24 hours. The samples for faecal coliform (FC) and *E.coli* detection were incubated at a temperature of 44º C and 37º C for Total coliform bacteria for 24 hours. The counts for coliform bacteria levels were enumerated after 24 hours of incubation using the colony counter and the results were recorded per the positives which are in accordance with the NMKL 44 (2004), 5th Ed. method.

$$\text{Population of coliform bacteria} = \frac{X}{\text{Y}} * \text{Z}$$

Where;

X = Number of tubes showing positive growth of gas formation and cloudiness

Y= Total number of tubes inoculated (5)

Z= Reciprocal of the dilution factor

The confirmatory test as required for the enumeration of coliform bacteria was carried out as follows. Five (5) colonies as shown in Plate 3.8 were picked from each viable / positive plate per sample and inoculated or sub-cultured into five (5) different Blue Green Bile Salt Broth (BGBSB) tubes containing inverted Durham tubes and incubated at 37^{o}C for 24hrs. Presence of coliform bacteria was confirmed with the production gas which displaces the broth in the tube and was recorded as colony forming units (CFU) per gram of the sample, cfu/gm.

The thermo tolerant bacteria count were as well enumerated after 24 hours of incubation at 44^{o} C using the colony counter and the results were recorded per sample, (Nordic Committee on Food Analysis (NMKL), 2005) and Moneim, *et al*. (2014).

Confirmatory test for faecal coliform counts

Five (5) colonies from each enumerated plate were inoculated (sub-cultured) into the E.*coli* broth containing inverted Durham tubes and incubated at 44^{o}C for 24hrs. Positive confirmation of faecal coliform bacteria presence was observed after 24hrs of incubation

as CO_2 gas was produced to displace the *E.C* broth in the tubes. The positives were estimated as a fraction of the total of the five inoculated tubes and recorded. This formed the basis for calculating the faecal Coliform Forming Units (CFU) present in 10 g of the fresh weight lettuce sample.

To further confirm the presence and enumeration of faecal coliforms, the following exercise was carried out.

A 0.1 ml the sample in the test tubes containing inverted Durham tubes which read positive (+ve) for the confirmation of faecal coliform presence was then sub- cultured into test tube containing 5.0 ml of standardized Tryptone broth (solution) aseptically and vortex (homogenized). The tubes were then incubated at 44^{o} C for 24hrs. The incubated sub-cultured test tubes with inverted Durham tubes were read after 24 hours of incubation for the presence of faecal coliform bacteria. The presence of faecal coliform bacteria was confirmed by CO_2 gas and cloudiness formation and a displacement of the broth in the Durham tubes.

Confirmatory test for presence and counts of *E.coli*

To further confirm the presence and enumeration of *E. coli*, the following exercise was carried out using the 'INDOLE' test.

Some drops (2-3) of the Kovac's reagent were dispensed into the test tubes containing confirmed presence of the faecal coliform bacteria after 24hrs incubation period. The presence of *E.coli* produced a red colouration ring meniscus upon the addition of this reagent. The coloured meniscus appears and disappears after about 2mins but reappears upon further addition of the Kovac's reagent. The absence of a coloured ring meniscus means the absence of *E.coli* which implied that all the enumerated bacteria at 44^{o} C are faecal coliform bacteria.

3.5.2 Data Processing and Analysis

Data processing for the wastewater measurements, lettuce growth parameters and all laboratory analysis was done using the Statistical Package for Social Sciences (SPSS) version 22.0 and Microsoft Excel. Descriptive statistics such as frequencies, cross tabulations were also used to describe the data. Logistic regression analysis, ANOVA and correlation analysis were the statistical tools used in the analysis of the data.

CHAPTER FOUR

RESULTS

4.1 Demographic characteristics of study subjects

The major characteristics of the respondents interviewed are presented in (Table 4.1). A total of 432 respondents were interacted with using a structured questionnaire. Of these, 230 respondents were in Ashaiman and 202, students at the University of Ghana, Legon campus. Nearly half of the respondents (49.1%) were males whiles the females were represented by 50.1% in Ashaiman. There were 56.9% males with 43.1% females of the total study population at the University of Ghana Legon campus. Majority (37.8%) of the respondents in Ashaiman were within the ages of 26-34 whiles at the University of Ghana, Legon, the majority (59.5%) were within 18-25 years. Education of the respondents in Ashaiman was diverse with 34.5% of the respondents having some level of secondary/vocational education. The majority, represented by 42.8% of the respondents have obtained some tertiary level education. At the University of Ghana, 66.5% of the respondents were undergraduate students (Bachelors) while 33.5% were graduate students / post graduate students. Majority of the respondents in both Ashaiman and at University of Ghana, Legon campus represented by 64.1% and 69.2% respectively were single and not married.

Table 4.1: Demographic characteristics of respondents for the Ashaiman Municipality and University of Ghana

ASHAIMAN			UNIVERSITY OF GHANA		
Variable	**Frequency**	**Percentage**	**Variable**	**Frequency**	**Percentage**
Age			Age		
18-25	77	33.5	18-25	120	59.5
26-34	87	37.8	26-34	57	28.2
35-43	40	17.4	35-43	23	11.4
44-60	24	10.4	44-60	2	1.0
>60	2	0.9	≤18	10	5.0
Sex			**Sex**		
Male	113	49.1	Male	115	56.9
Female	117	50.9	Female	87	43.1
Level of Education			**Level of Education**		
No Formal Education	3	1.3	Undergraduate	131	66.5
Primary School	9	3.9	Post-graduate	66	33.5
JSS/JHS	40	17.5			
Secondary/Vocational	98	42.8			
Tertiary	79	34.5			
Marital Status			**Marital Status**		
Married	78	33.8	Married	55	29.7
Single	148	64.1	Single	128	69.2
Divorced	2	0.9	Divorced	1	0.5
Separated	1	0.4	Others	1	0.5
Widowed	2	0.9			

Table 4.1 cont'd.

Income Levels / month			N/A		
<500	79	40.9			
501-1000	76	39.4			
1001-1500	31	16.1			
1501-2000	5	2.6			
>2001	2	1.0			
Religion			**Religion**		
Christian	185	80.1	Christian	172	86.0
Muslim	45	19.5	Muslim	28	14.0
Traditionalist	1	0.4			
Occupation					
Self Employed	97	42.4			
Student	52	22.7			
Civil servants	18	7.9			
Public Servants	33	14.4			
Others	29	12.7			

4.1.1 Knowledge, awareness and perceptions on wastewater treatment and reuse

The study results indicated that majority, represented by 89.9% of the respondents in Ashaiman positively were aware of wastewater treatment and reuse whereas 10.4% denied being aware of wastewater treatment and reuse when asked, (Fig. 4.1).

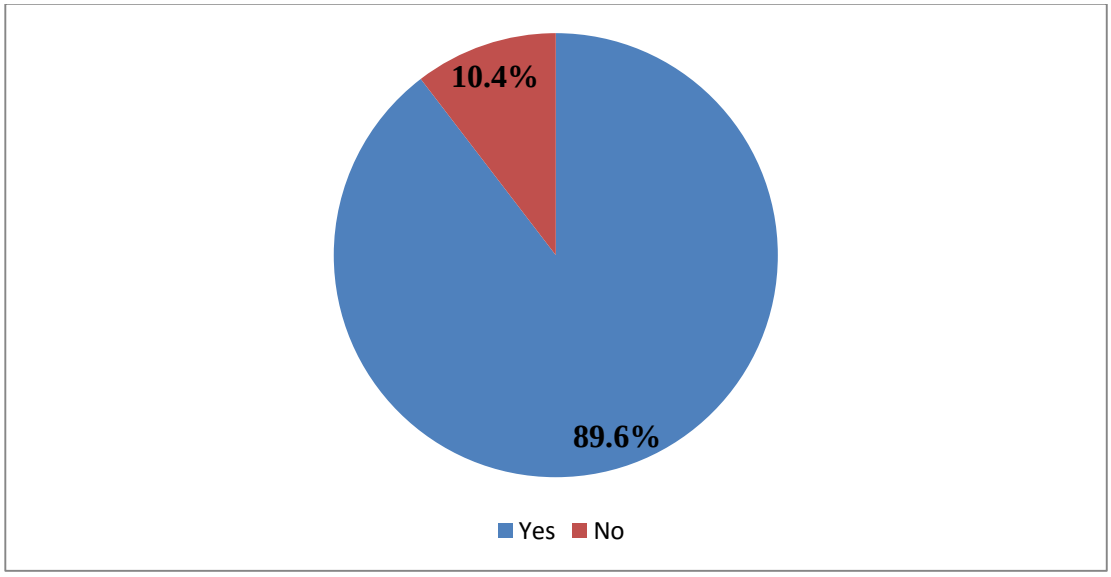


Figure 4.1: Percentage of respondents' response to the awareness of wastewater treatment and reuse in Ashaiman

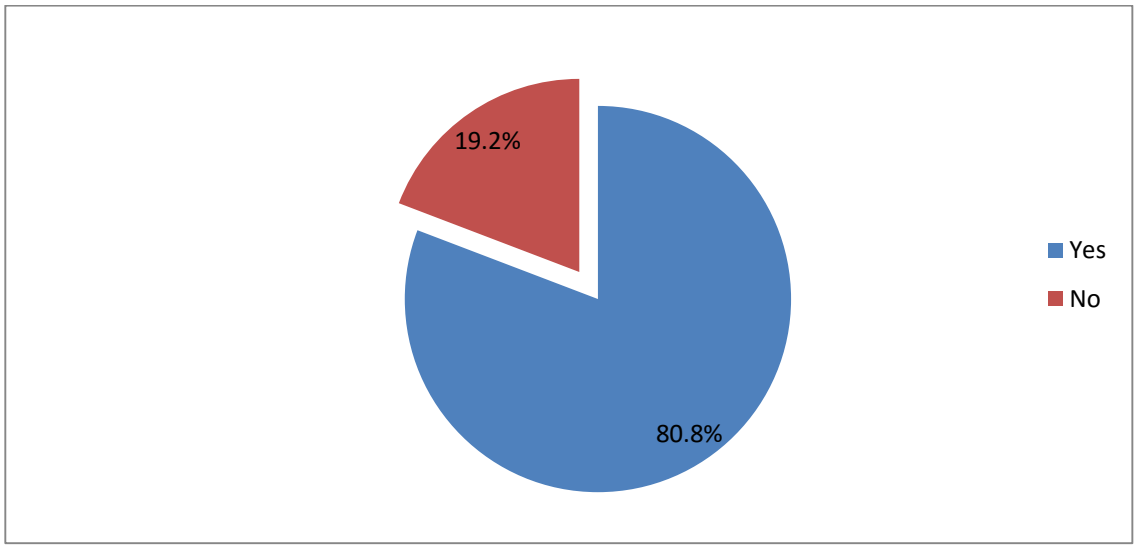


Figure 4.2: Respondents' knowledge of wastewater treatment and reuse at University of Ghana, Legon

4.1.2 Knowledge of wastewater treatment at the University of Ghana

Majority of the students interviewed at the University of Ghana, Legon represented by 80.8% (Fig. 4.2) expressed their knowledge of wastewater treatment processes by citing some known sources of wastewater, some familiar wastewater treatment processes, as well as some treated wastewater effluent quality issues. The minority, represented by 19.2% had no knowledge of wastewater treatment processes and reuse.

4.1.3 Knowledge of wastewater treatment and reuse in Ashaiman

As shown in fig.4.3, 60.9% of the respondents in Ashaiman had knowledge of wastewater and wastewater treatment processes. The majority cited wastewater treatment plants known to them as well as some by- products of the wastewater treatment process. The other 39.1% of the respondents in Ashaiman did not have any knowledge on wastewater treatment processes and reuse.

From Table 4.2, respondent's level of income per month was observed to be significantly associated with their knowledge of wastewater and wastewater treatment in Ashaiman.

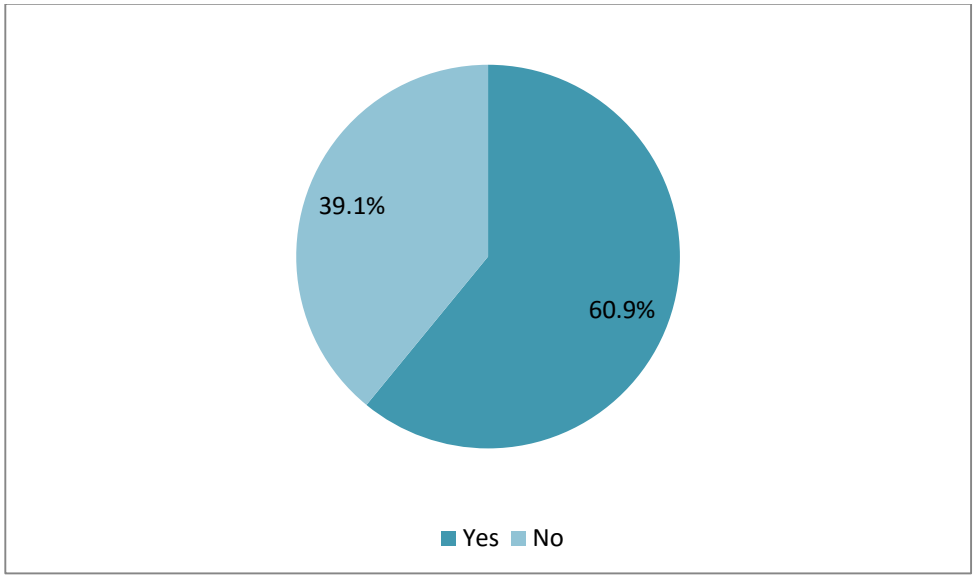


Figure 4. 3: Percentage of respondents' level of knowledge of wastewater treatment and reuse in Ashaiman

Table 4.2: Multiple logistic regression analysis of knowledge of wastewater treatment in association with Demographic characteristics in Ashaiman

Variable	Coefficient	P-Value	Odds Ratio	95% C.I.
Gender	-0.001	0.998	0.999	(0.522, 1.913)
Level of Education	0.096	0.599	1.101	(0.769, 1.577)
Income level	-0.820	0.001*	0.440	(0.276, 0.703)

**Significance at (P <0.05)

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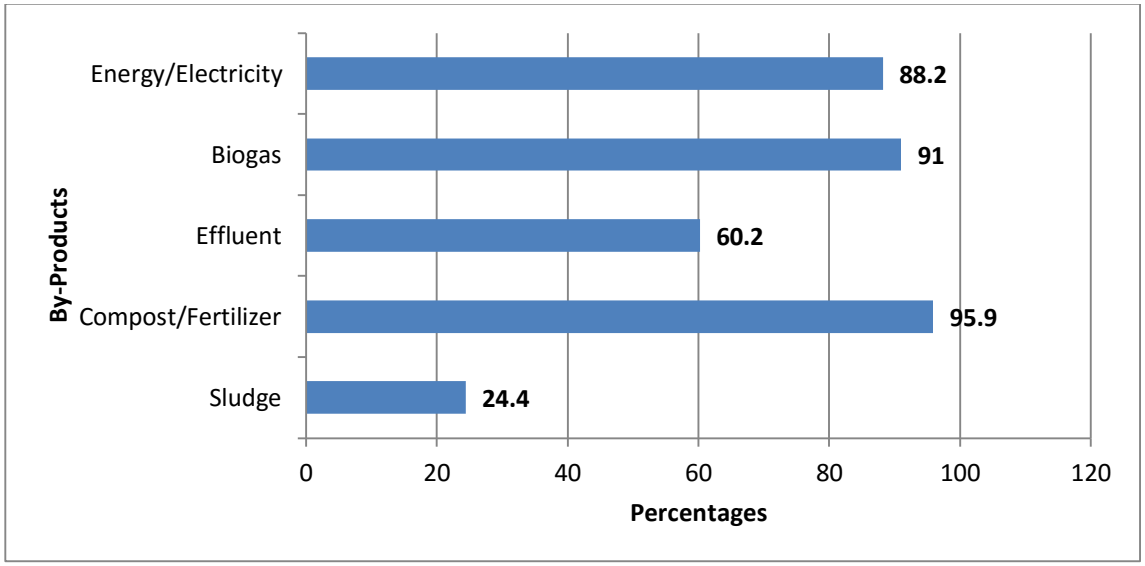

Figure 4. 4: Percentage respondents' knowledge of wastewater treatment and its by-products in Ashaiman and University of Ghana

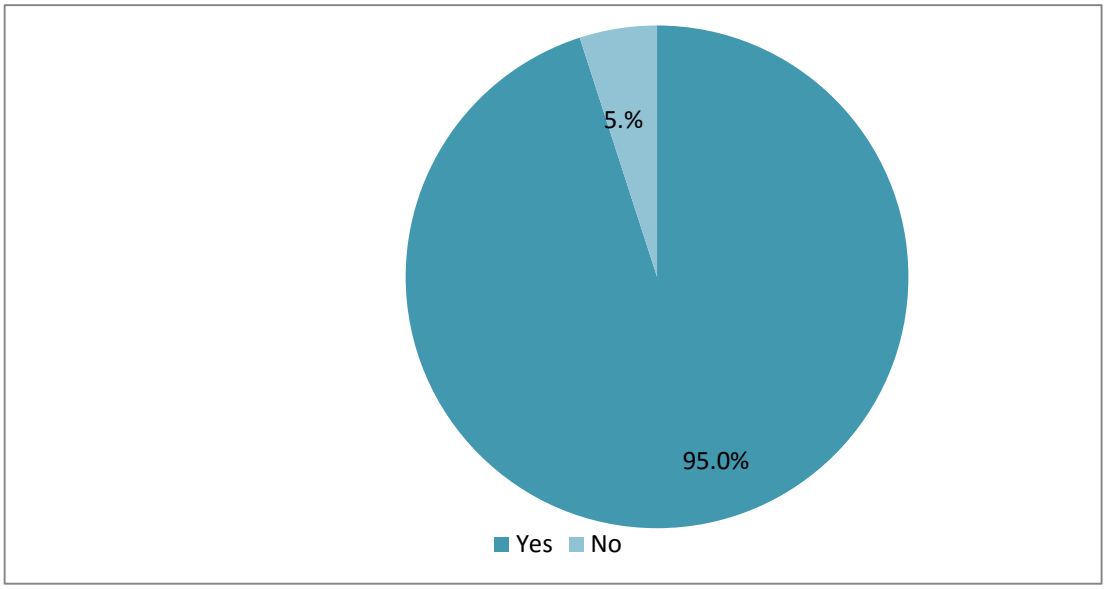

Figure 4. 5: Percentage of respondents' perception of treated wastewater reuse as resource in Ashaiman

From figure 4.4, majority of the respondents both in Ashaiman and at the University of Ghana, Legon campus had knowledge of some by- products of wastewater treatment process. Knowledge of the production of organic compost as one by-product of wastewater treatment and of biogas production and treated wastewater (effluent) and as a by-product of wastewater treatment was 95.9%, 91% and 60.2% respectively.

4.1.4 Perceptions of wastewater treatment and reuse in Ashaiman and at University of Ghana, Legon campus

Majority of the respondents in Ashaiman (95%) affirmed that wastewater treatment as a process is a necessity of life and that treated wastewater effluent can serve as an alternative water resource. The other 5% of the respondents were of the view that wastewater cannot be reused (Fig. 4.5). The majority (95%) were of the view that, since urban municipal treated water supply is not equitably distributed, it creates water scarcity and shortage issues in most urban areas. Treated wastewater could be readily available and as a cheaper alternative water resource.

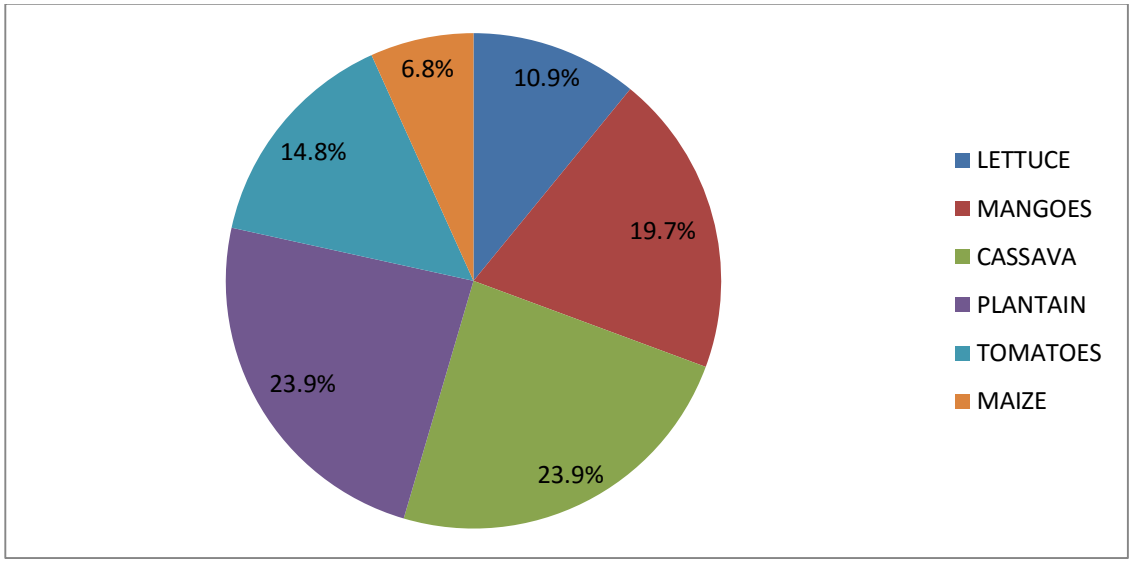

Figure 4. 6: Percentages of respondents' perceptions towards the reuse of treated wastewater as irrigation source for different crops at the University of Ghana, Legon

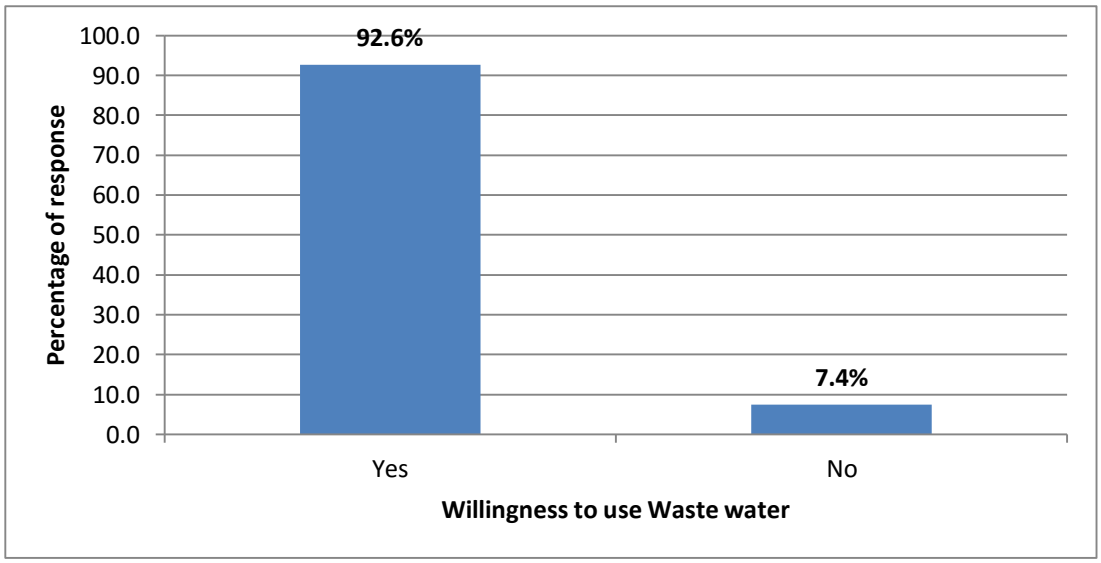

Figure 4. 7: Percentages of respondents' willingness to reuse treated wastewater for irrigation purposes in Ashaiman

4.1.5 Willingness to use treated wastewater and consume irrigated crops in Ashaiman

Respondents' willingness to reuse treated wastewater for irrigation as shown in figure 4.7 indicated that majority of the respondents in Ashaiman represented by 92.6% affirmed their willingness to utilize treated wastewater for irrigation while the minority (7.4%) were unwillingness to reuse treated wastewater.

Respondent's level of education was found to be significantly associated with their willingness to reuse treated wastewater for irrigated agriculture and consume irrigated crops in Ashaiman, Table 4.3.

4.1.6 Willingness to use treated wastewater and consume irrigated crops at University of Ghana, Legon campus

Table 4.4 represents the significance respondent's level of awareness of wastewater treatment being at ($P<0.05$) to their willingness to consume treated wastewater irrigated crops. Some demographic characteristics and factors such as respondents' age, gender, student's status (level of study), knowledge and awareness of wastewater treatment processes were ran against their willingness to reuse treated wastewater and consume irrigated crops in order to determine whether or not there is any significant association.

Table 4.3: Multiple logistic regression analysis of willingness to use treated wastewater and consume irrigated crops associated with demographic distribution for Ashaiman

Variable	Coefficient	P-Value	Odds Ratio	95% C.I.
Gender	1.371	0.095	3.939	(0.786, 19.735)
Level of Education	1.355	0.034*	3.877	(1.107, 13.578)
Income level	-0.360	0.372	0.697	(0.316,1.539)
Awareness of waste treatment	-0.072	0.950	0.931	(0.1, 8.644)

**Significance at (P <0.05)

Table 4. 4: Multiple regression analysis of willingness to use treated wastewater and consume irrigated crops against Demographic characteristics in University of Ghana

Variable	Coefficient	P-value	Odds Ratio	95% confidence level
Age	-0.124	0.831	0.883	(0.282, 2.769)
Gender	0.067	0.915	1.070	(0.312, 3.674)
Student status	0.245	0.797	1.278	(0.198, 8.268)
Knowledge of wastewater	-1.415	0.055	0.243	(0.057, 1.028)
Awareness of wastewater treatment	-1.363	0.036**	0.256	(0.071, 0.915)

**Significance at (P <0.05) or 95% confidence Interval (C.I)

4.2 Assessment of the effluent quality from wastewater treatment plant at the University of Ghana, Legon.

The safety of treated wastewater effluent from the Accra Sewage Improvement Project Wastewater Treatment Plant at the University of Ghana, Legon campus as a safe irrigation source for vegetable production was determined by an assessment of some physicochemical and microbiological parameters internationally recognised as indicators for safe wastewater reuse.

4.2.1 Physicochemical parameters

Results of the physical parameters measured as part of quality assurance study on the treated wastewater effluent are presented in this section. Figure 4.8 indicates the average Electrical Conductivity (EC) levels of the wastewater stream before and after treatment for the period of study. The EC levels of the untreated wastewater as measured ranged from 970µS/cm to 1.09 mS/cm. The EC levels of the treated wastewater effluent also ranged from 592 µS/cm to716 µS/cm. The EC levels of the treated wastewater effluent were compared to the WHO standard guideline limits of 1500 µS/cm for effluent discharge.

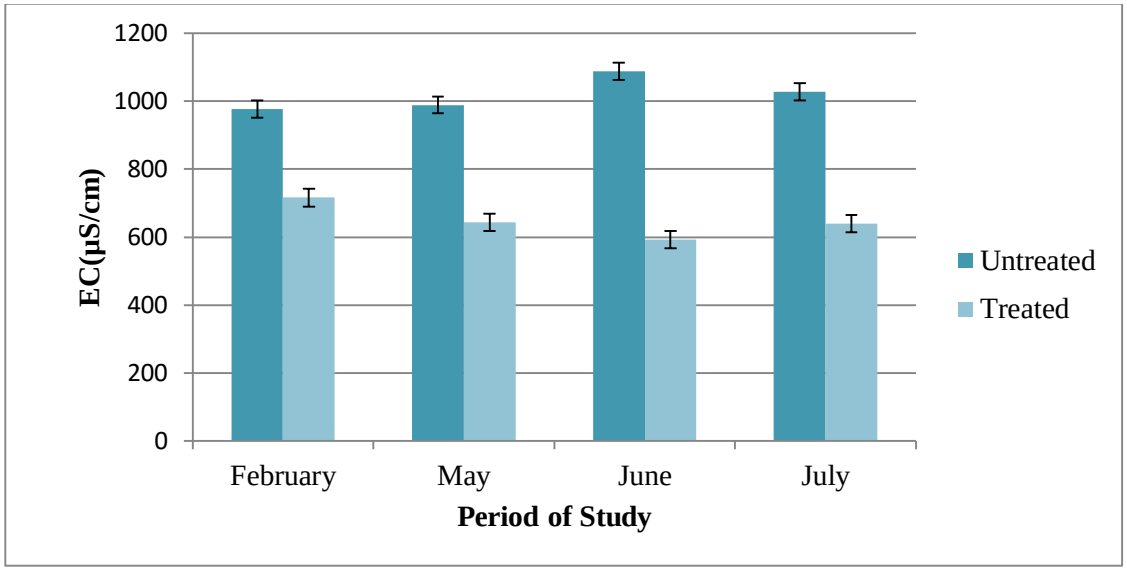

Figure 4. 8: The electrical conductivity levels of wastewater untreated and treated over study period

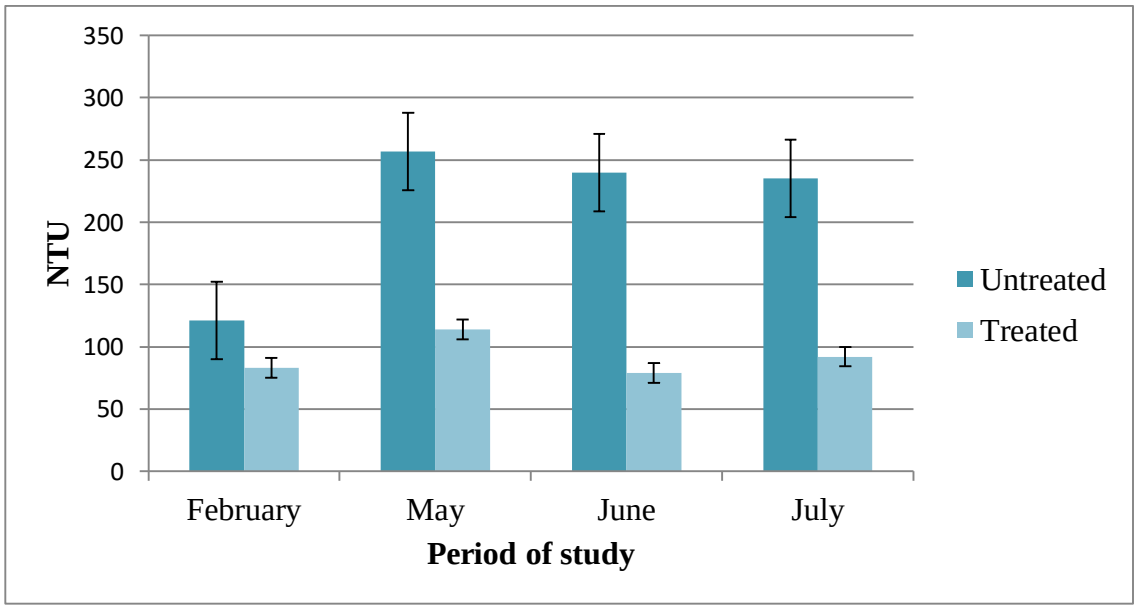

Figure 4. 9: The turbidity levels of wastewater stream over the period of study

The mean turbidity levels of the untreated wastewater ranged from 120 NTU to 240 NTU as compared to the EPA standard of 75 NTU for safe effluent discharge. The treated wastewater effluent had mean turbidity levels ranging from 79 NTU to 114 NTU. Thus, the turbidity of the treated wastewater though did not meet EPA standards but was very close to the acceptable value. This is an estimated 40% to 70% reduction in turbidity of the wastewater effluent as a result of the wastewater treatment process (Fig. 4.9).

Figure 4.10 shows a summary of mean pH levels of the treated and untreated wastewater effluent over the study period. The highest pH level of 8.07 was observed in the month of February for the treated effluent whiles the lowest, 7.73 were observed in the month of July. Interestingly, the pH levels of both treated and untreated wastewater effluent were within the EPA acceptable range of 6.00- 9.00 for effluent discharge. This has to do with the source of the raw wastewater.

4.2.2 Chemical Parameters

The chemical parameters of wastewater effluent assessed were for DO, BOD, COD, and Phosphate Phosphorous, Total Phosphorous (TPO_4-P), Nitrate-Nitrogen (NO_3-N) and Nitrite (NO_2N) levels.

The results of these parameters as analyzed for both the untreated and treated effluent over the study period are shown in the following section.

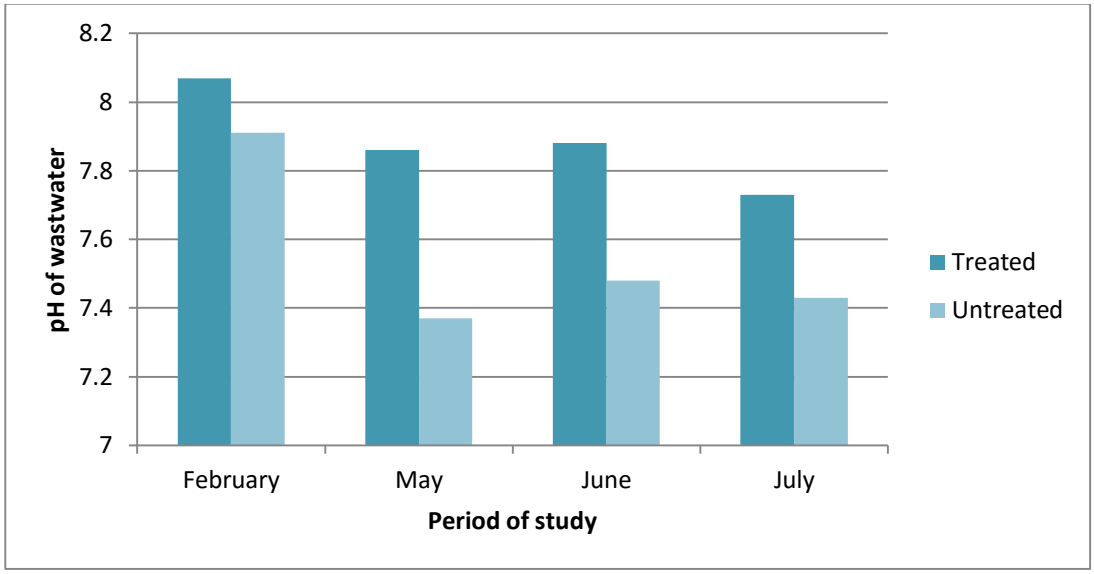

Figure 4. 10: pH levels of the wastewater stream over study period

Table 4.5: Nutrient load range of the treated wastewater over study period

Parameter	Determined ranged (mg/l)
Nitrate- Nitrogen	0.042 - 0.215
Nitrite	0.001 - 0.531
Phosphate Phosphorous	0.78 - 1.93
Total Phosphorous	1.34 - 5.96

The Dissolved oxygen (DO) levels for the untreated wastewater at the beginning of the study period in February was 5.5 mg/l but declined with time till there was nothing left by the month of July. The DO levels of the treated wastewater were 7.6 mg/l for the month of February and 1.26 mg/l for the month of July, where the untreated wastewater gave 0 mg/l.

Figure 4.11 shows how the mean DO levels of treated and untreated wastewater measured against each other for the period of study.

The BOD levels analysis of the untreated wastewater effluent is as shown in Fig.4.13. This gave indication of the high loads of degradable organic matter in the wastewater effluent with levels ranging from 197.0 mg/ l to 310.0 mg/l.

The BOD levels of the treated wastewater subsequently indicated showed the extent to which the wastewater treatment plant had reduced the organic loads content of the wastewater with load levels ranging from 11.4 mg/l to 27.2 mg/l.

Other parameters of interest including the nutrient load of the treated wastewater effluent were also determined and the results are presented in table 4.5. These levels relate favourably to EPA/ WHO standard limits for wastewater reuse and effluent discharge.

The correlation analysis of the physicochemical parameters as shown in Appendix 2 revealed a significant positive relationship at ($P<0.05$) between COD and BOD levels. This means an increase in COD levels will also cause a corresponding increase in the BOD levels and vice versa. Another significant but negative relationship was observed between total Phosphorous levels and the pH, in that while the pH levels of the treated wastewater

effluent decreases, it causes a corresponding increase in the total Phosphorous levels and vice versa. Another significant but negative relationship was found to exist between the phosphate phosphorous and DO levels. The relationship indicates that, an increase in the Phosphate Phosphorous levels of the treated wastewater effluent would cause a corresponding decrease in the DO levels.

Figure 4.11 shows the mean DO levels of both treated and untreated wastewater effluents over the study period. Dissolved Oxygen (DO) levels of the untreated wastewater effluent for the period of study were 5.5 mg/l, 2.2 mg/l, 0.2 mg/l, and 0.0 mg/l for February, May, June and July respectively with post treatment levels as follows: 7.6 mg/l, 3.2 mg/l, 1.6 mg/l and 1.26 mg/l.

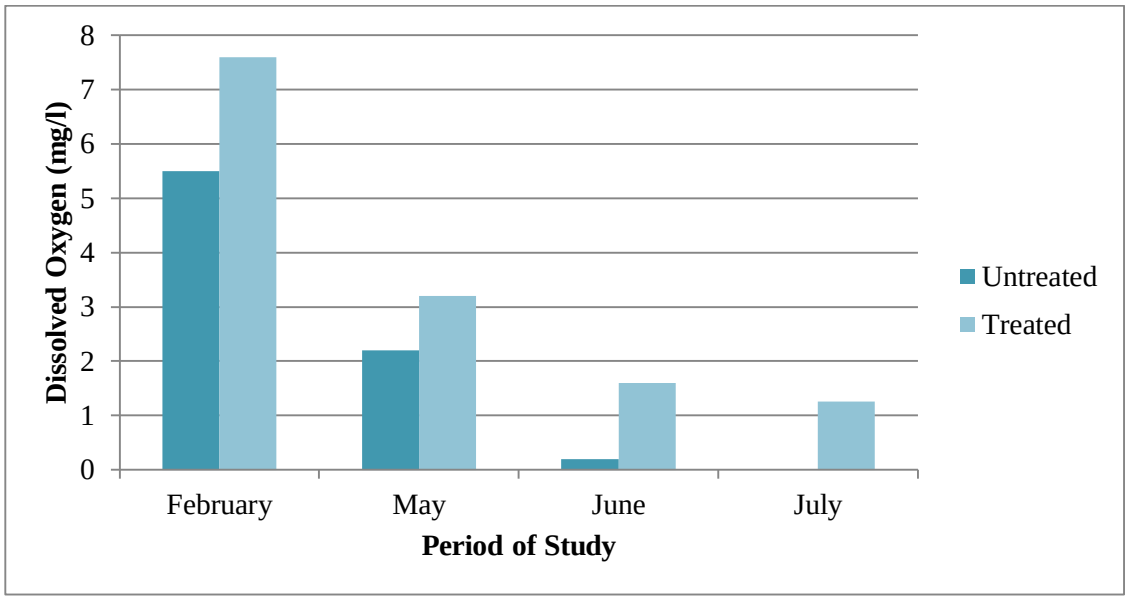

Figure 4. 11: Dissolved Oxygen levels for the treated and untreated wastewater effluent over period of study

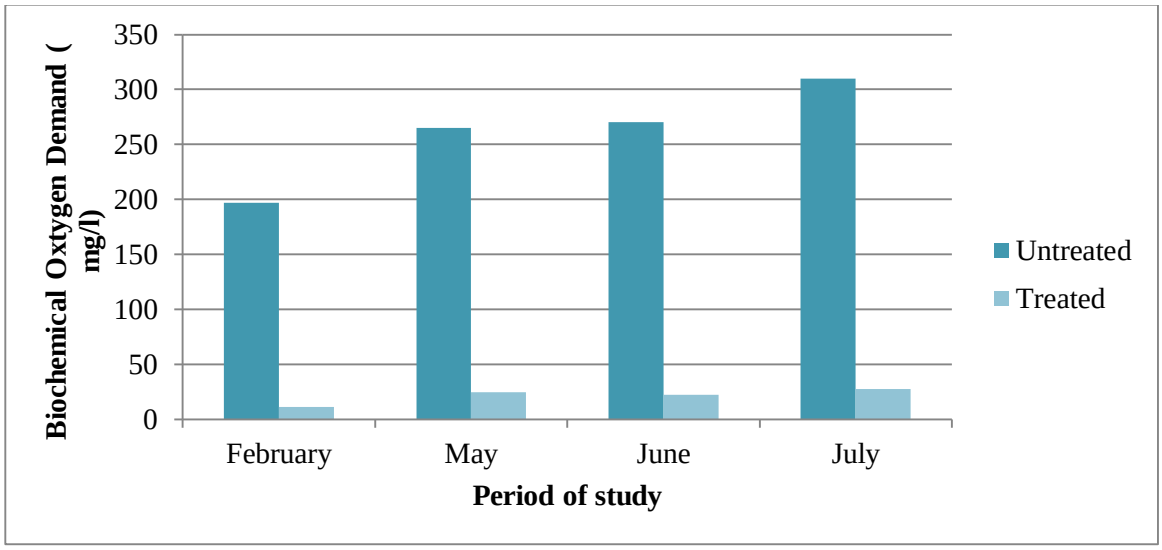

Figure 4. 12: Biochemical Oxygen Demand levels for the treated and untreated wastewater effluent over the period of study

Figure 4.12 shows the mean BOD levels of both treated and untreated wastewater effluents for the study period. The results showed a trend of increasing BOD levels, from 197.0 mg/l in February to 310.0 mg/l in July. These levels however reduced after the treatment process to 11.4 mg/l and 27.2mg/l for February and July respectively. The BOD levels of the treated effluent compares favourably to EPA guideline standards of 50.0 mg/l for effluent discharge.

Figure 4.13 shows a summary of means for COD levels of both treated and untreated wastewater effluent as assessed over the study period. The mean COD levels of the untreated wastewater effluent measured were 532 mg/l and 894 mg/l for February and July respectively. Both values exceed the EPA acceptable value of 250.0 mg/l. This is contrary to the treated wastewater mean COD levels with the highest value of 146.0 mg/l recorded in the July which compares favourably to the EPA standards.

Figure 4.14 shows a graphical presentation of the values of the mean Phosphate Phosphorous concentrations for the treated and untreated wastewater effluent over the study period. The Phosphate Phosphorous levels of the untreated effluent ranged from 1.45 mg/l in February to 3.61 mg/l in July, with the values of the treated effluent between 0.78 mg/l in February and 1.93 mg/l in July

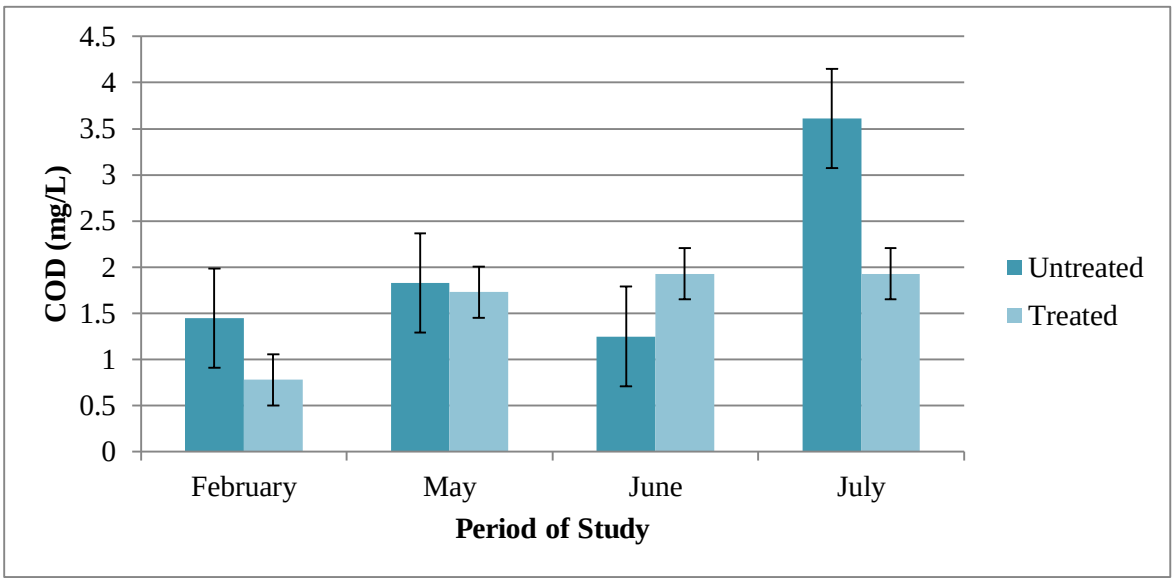

Figure 4. 13: Chemical Oxygen Demand levels of the treated and untreated wastewater effluent over the study period

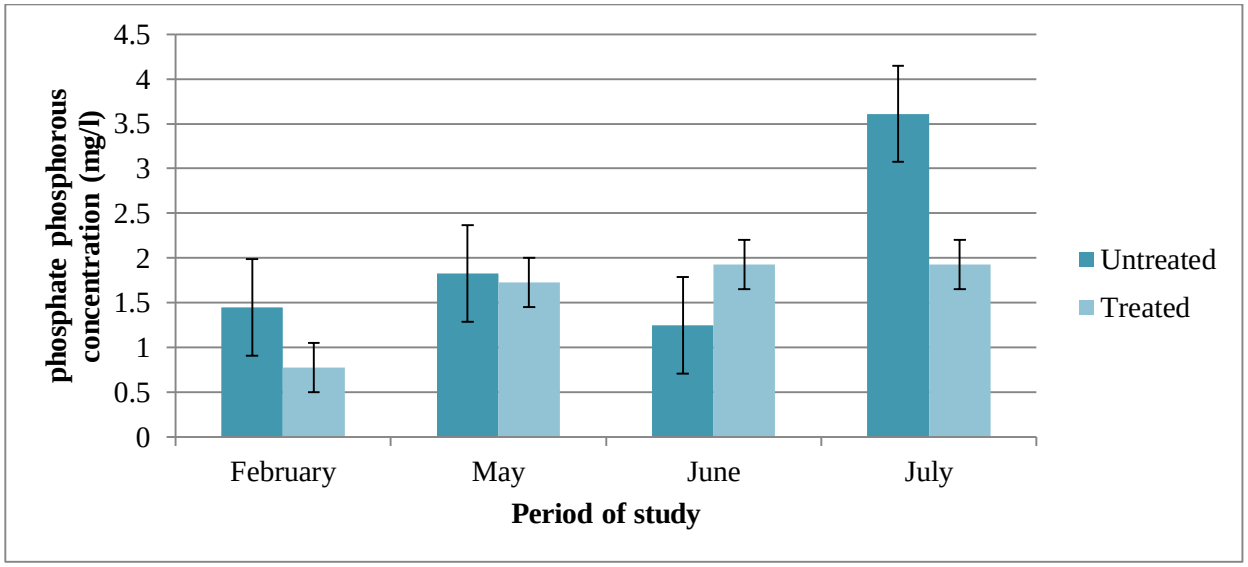

Figure 4. 14: Phosphate Phosphorous levels for the treated and untreated wastewater effluent over the study period

The mean total Phosphorous levels of the untreated effluent from February to July were 4.20 mg/l, 5.08 mg/l, 3.47 mg/l and 5.96 mg/l respectively while the treated wastewater effluent levels were 1.34 mg/l, 4.78 mg/l, 2.31 mg/l and 3.18 mg/l for the respective months (Fig. 4.15).

Figure 4.16 represents the nutrient Nitrate-Nitrogen levels determined in the untreated and treated wastewater effluent. The untreated wastewater effluent recorded Nitrate- Nitrogen values up to 0.215 mg/l while that of the treated wastewater effluent recorded levels up to 0.194 mg/l over the study period.

Figure 4.17 presents the nutrient Nitrite levels determined in the untreated and treated wastewater effluent. The untreated effluent recorded Nitrite levels of 0.215 mg/l for February and 0.146 mg/l for July with the treated wastewater effluent giving levels of between 0.042 mg/l and 0.194 mg/l for the period of the study.

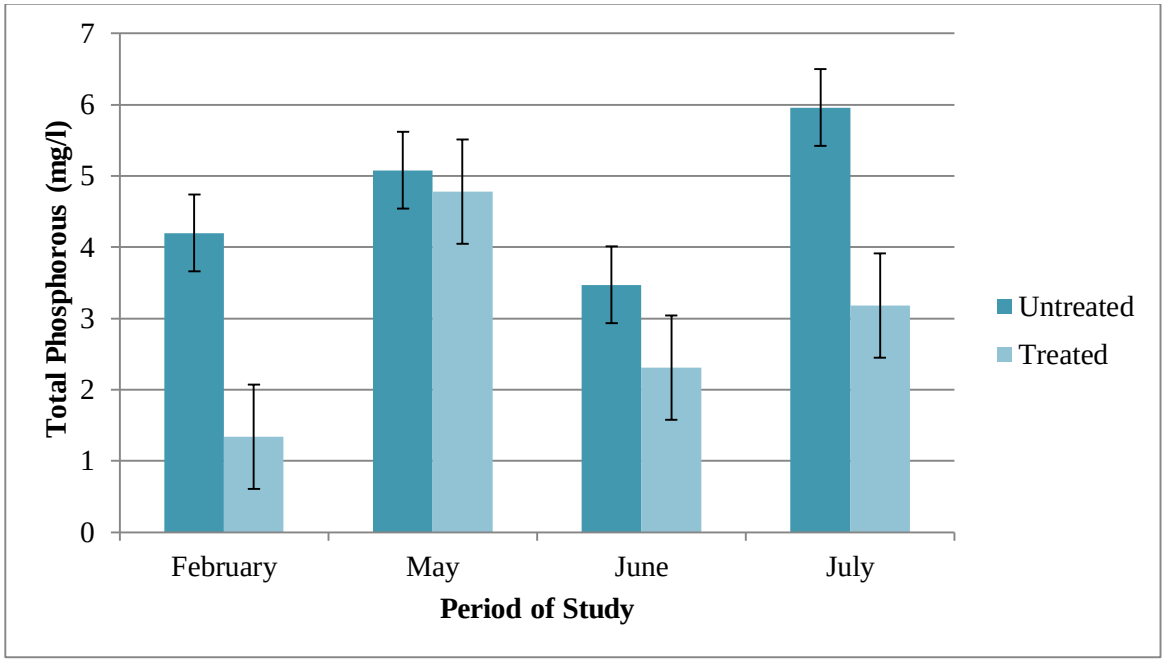

Figure 4. 15: Total phosphorous levels for the treated and untreated wastewater effluent over study period

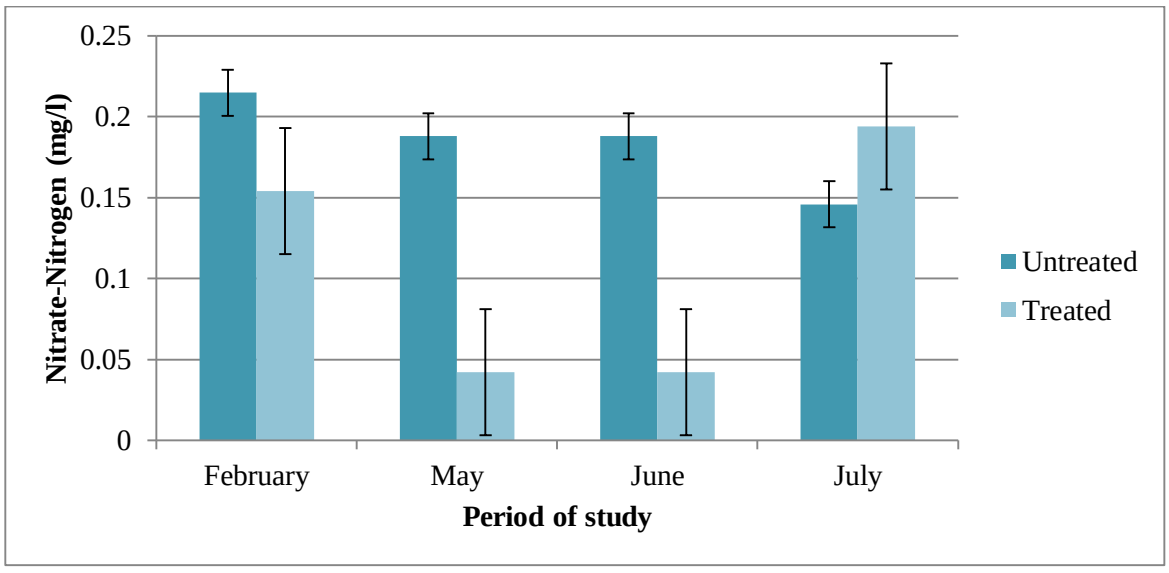

Figure 4. 16: Nitrate-Nitrogen levels for the treated and untreated wastewater effluent over study period

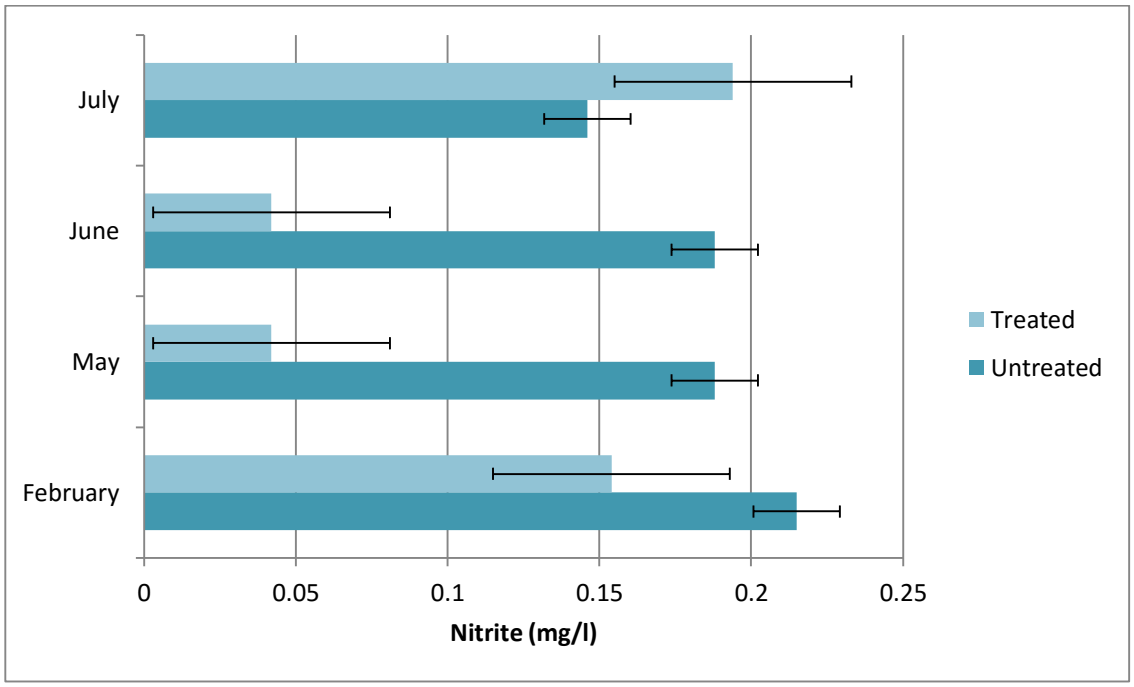

Figure 4. 17: Nitrite levels for the treated and untreated wastewater effluent over study period

Table 4.6 indicates levels of trace /heavy metals present in the wastewater and determined concentrations. Iron was detected but in concentrations of between 0.387 mg/l and 0.721mg/l. The treated effluent had iron concentrations within the ranges of 0.129 mg/l and 0.631 mg/l. Zinc was also detected concentrations of between 0.01 mg/l and 0.173 mg/l in the case of untreated/ raw and treated wastewater samples.

Table 4. 6: Results for trace/ heavy metal parameters of wastewater effluent over the study period

Parameter (mg/l)	February		May		June		July		
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	WHO/FAO Guideline Values
Iron	0.47	0.63	0.39	0.64	0.316	0.129	0.721	0.286	0.3
Copper	<0.01	<0.01	< 0.010	< 0.01	<0.01	<0.01	<0.01	<0.01	2.0
Zinc	0.01	0.018	0.018	0.099	0.051	0.032	0.173	0.054	0.03
Lead	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.005
Cadmium	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.003

The situation for the other trace / heavy metals; Copper, Lead, and Cadmium was different. All three trace metals were non- detected in the wastewater, ie <0.01 mg/l, <0.005 mg/l and <0.002 mg/l for copper, lead, and cadmium respectively.

4.2.3 Microbial assessment of the untreated and treated wastewater effluent

The microbial quality of wastewater is very important in assessing wastewater for reuse. The pre-treatment quality level is important as it gives an indication of the composition and concentration of the microbes present in the effluent while the post- treatment quality is of utmost importance as it indicates the efficiency of the treatment plant and safety of the effluent. The microbial parameters measured in this study included TC, FC and *E.coli*.

Figure 4.18 represents the mean value of Total Coliform (TC) levels of both treated and untreated wastewater effluent over the period of study. The February samples contained the highest levels of TC bacteria for both of the treated and untreated effluent respectively. However, there was an appreciable decrease in levels between the treated and untreated wastewater 65.0 $\times 10^5$ cfu/100 ml to 83.7 $\times 10^3$cfu/100 ml treated). Total coliform levels of the untreated effluent were 624.0×10^5 cfu / 100 mL, 14.0×10^4 cfu / 100 ml and 13.02×10^4 cfu/100 ml for the months of May, June and July respectively. The total coliform levels of the treated wastewater effluent for the respective periods are as follows; 12.8×10^3 cfu/ 100 ml, 30.2×10^3 cfu/ 100 ml and 37.4×10^3 cfu/100 ml.

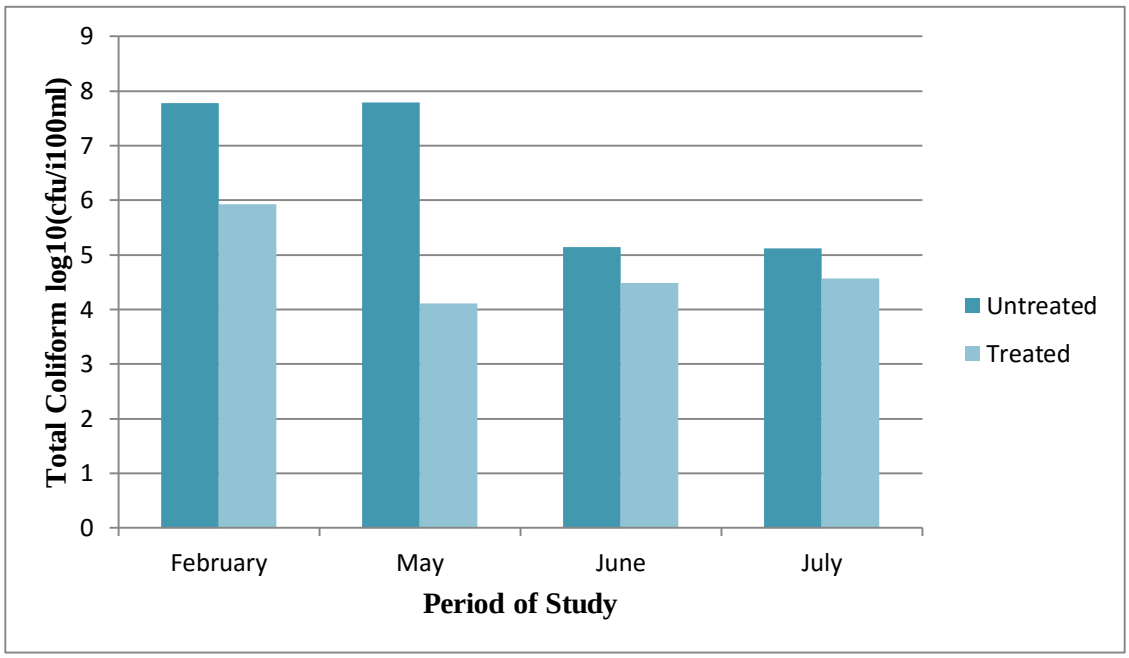

Figure 4. 18: Total Coliform bacteria levels for the treated and untreated wastewater effluent over study period

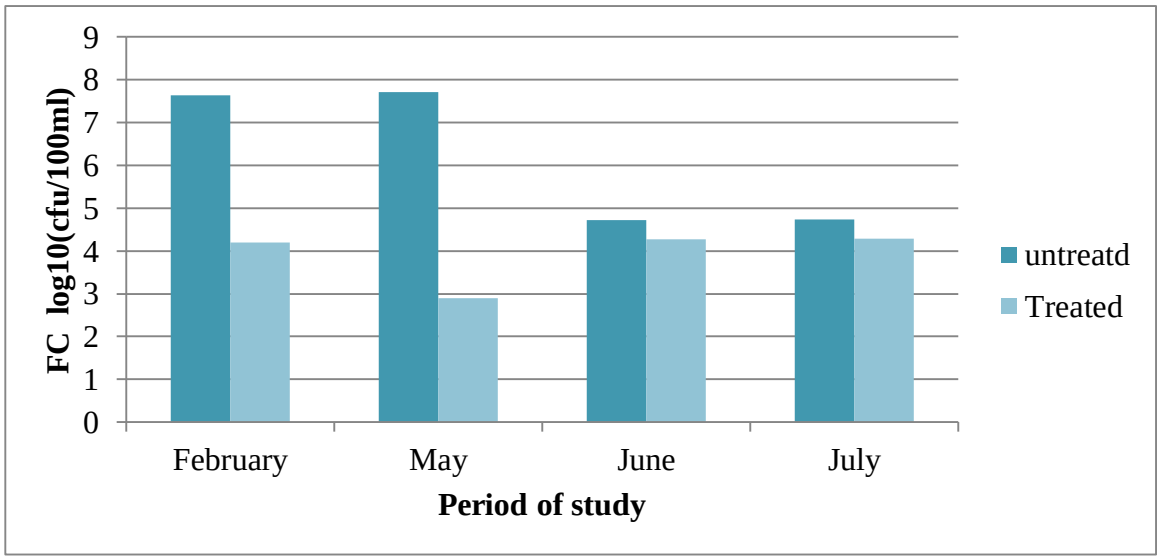

Figure 4. 19: Faecal coliform bacteria levels for the treated and untreated wastewater effluent over period of study

Figure 4.19 shows a bar chart of the mean faecal coliform bacteria (FC) levels of the treated and untreated wastewater effluent over the period of study. Faecal coliform levels of the untreated wastewater effluent was 429.0×10^5 cfu/ 100 ml, 516.0×10^5 cfu/100 ml, 52.0×10^3 cfu/ 100 ml, 53.7×10^3 cfu /100 ml. The treated effluent had faecal coliform bacteria levels of 16.0×10^3 cfu/ 100 ml, 8.0×10^2 cfu/100 ml, 18.6×10^3 cfu/100 ml and 19.2×10^3 cfu/100 ml respectively February, May, June and July.

Figure 4.20 shows a summary of the presence and mean concentrations of *E.coli* for the treated and untreated wastewater effluent over the study period. The mean *E.coli* levels of the untreated effluent for the study period were 85.0×10^5 cfu/100 ml, 49.0×10^5 cfu/100ml, 37.0×10^3 cfu/100ml and 45.6×10^3 cfu/100ml from the month of February to the month of July respectively. The concentration *E.coli* of the treated wastewater stream are as follows; 10.0×10^2 cfu/100ml, 1.0×10^2 cfu/100 ml, 44.0×10^2 cfu/ 100 ml and 55.0×10^2 cfu/ 100 ml respectively.

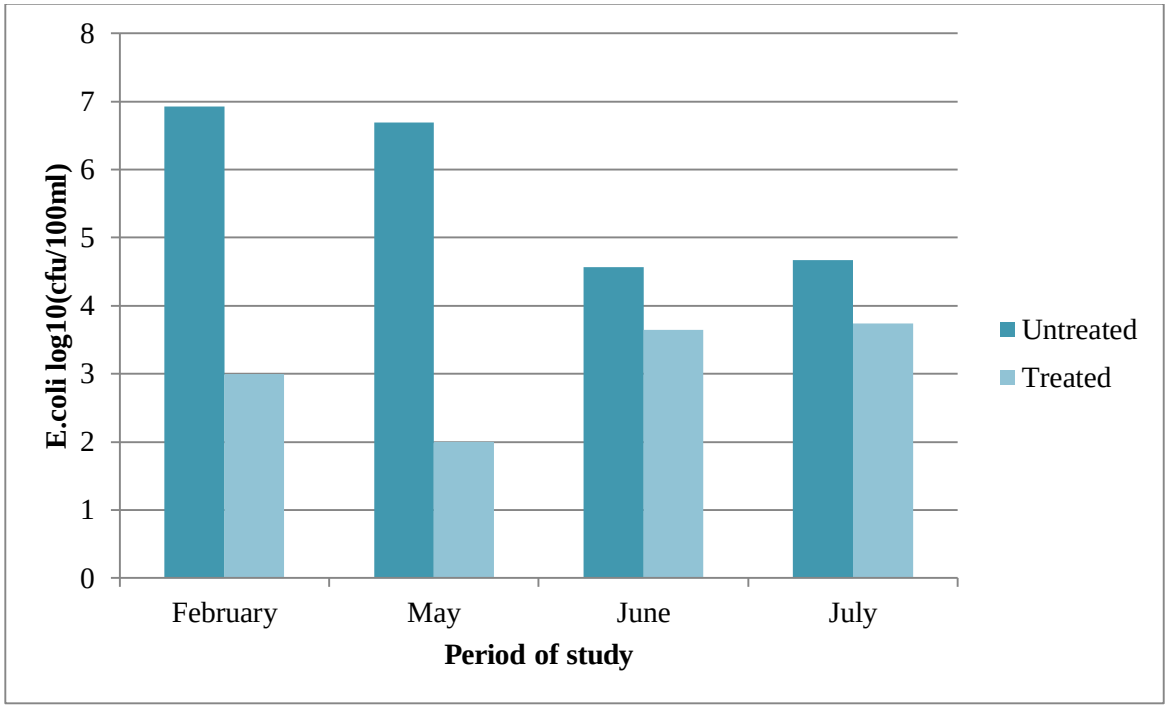

Figure 4. 20: E.coli levels for the treated and untreated wastewater effluent over the period of study

4.3 Crops growth analysis

Lettuce (*Lactuca sativa*), Minetto variety was cultivated using effluent from the Accra Sewage Improvement Project wastewater treatment plant from February to July and the parameters measured included leaf weight, plant height, leaf area, stem weight, head weight, root weight, fresh weight and number of leaves. The results obtained are presented here.

Table 4.7 shows a summary of the means for number of leafs, leaf area, leaf weight, stem weight, head weight, root weight, fresh weight and plant height per crop for the four levels of treatment.

The average number of leaves for all four levels of treatments ranged between 20 and 25. The mean plant height also ranged between 19.1cm and 23.0 cm for all the four levels of treatments. The mean total fresh weight of the lettuce crop ranged from 114.8g to 170.8g. The weights measured for the dried biomass for the lettuce after dryness (Table 4.8). The individual measurements of fresh and dried lettuce for all the four levels of treatments are shown in appendix.

Table 4. 7: Mean vegetative parameters measured for fresh lettuce for the four levels of treatments

Treatments	TLwt. (g)	PH (cm)	LA (cm^2)	TSt.wt. (g)	H wt. (g)	TRwt. (g)	TFwt. (g)	NL (leafs)
Control (CTL)	95.40	23.0	5530.2	30.42	125.94	3.54	170.84	25
100% Effluent (EFF 100)	92.10	19.13	3969.17	17.15	109.25	4.70	122.61	20
50% Effluent (EFF50)	111.30	21.13	4581.54	20.62	131.89	7.98	141.54	22
25% Effluent (EFF 25)	111.35	20.87	3716.18	20.53	131.88	2.52	114.80	22

TLwt= Total mean leaf weight, PH= mean plant height, LA= mean leaf area, TSt. wt. = Total mean stem weight, H wt. = Total mean head weight, T R wt. = Total mean root weight, TFwt. = Total mean fresh weight, NL= Total mean number of leaves.

Table 4. 8: Mean vegetative parameters for dried lettuce for the four levels of treatments

Treatment options/ Replication	DLwt (g)	D R wt(g)	DSt. Wt (g)	TD wt.(g)
Control (CTL)	5.48	0.59	1.22	7.30
100% Effluent	4.21	0.73	0.96	5.90
50% Effluent	4.77	1.05	1.00	6.81
25% Effluent	3.81	0.42	0.79	5.03

Dried for 72 hours at 75^{o}C; DLwt= Total Mean Dried weight, D R wt. = Total Mean Dried Roots weight, DSt. Wt= Total Mean Dried Stem weight, TD wt= Mean Total Dried weight

An Analysis of Variance (ANOVA), Table 4.10 carried out to test whether there were statistically significant differences between and within the vegetative parameters for the various treatments, i.e., control (CTL), 100% effluent treatment (EFF 100%), 50% effluent treatment (EFF50%) and 25% effluent treatment (EFF 25%) revealed that there was no statistically significant difference ($P>0.05$) between the vegetative parameters measured across the various levels of treatments.

4.3.2 Microbial analysis

Microbial analysis was conducted on the lettuce to establish the microbial concentrations. The results of the mean concentrations of Total coliform bacteria, faecal coliform bacteria and *E.coli* are summarized below in Table 4.9.

Table 4. 9: Microbiological quality of the harvested fresh lettuce crops for the four levels of treatment

Treatment and Replicates	**Coliform count (cfu/g)Mean**	**Coliform count Log_{10} (cfu/g)**	**Faecal coliform (cfu/g)Mean**	**Faecal coliform Log_{10} (cfu/g)**	***E.coli* (cfu/g)Mean**
CTL	10.93×10^2	2.026	81.66	2.39	<10
EFF100	<10	<10	<10	0	<10
EFF50	2.356×10^3	3.20	210	0.93	<10
EFF25	566.66	1.076	<10	0	<10

Table 4.9 shows the results for the mean of microbiological parameters: TC, FC and *E.coli* for the fresh lettuce crop irrigated with treated wastewater. The results show mean total coliform concentrations of up to 10.93×10^2 cfu/ g for the control treatment, <10 cfu/g for the 100% effluent treatment option, 23.56×10^2 cfu/g for 50% effluent treatment and 566.67 cfu /g for the 25% effluent treatment respectively.

The faecal coliform concentrations assessed in a given quantity of the lettuce crop were as follows; 81.67cfu/g for control treatment, <10 cfu/g for 100% effluent treatment, 210 cfu/ g for the 50% effluent treatment and < 10 cfu/g for the 25% effluent treatment.

The presence and concentrations of *E. c*oli was given as; Nil or <10 cfu/g for the control (CTL) samples, 100% effluent, 50% effluent and 25% effluent treated samples respectively.

In general, the microbial quality of the treated wastewater effluent irrigated lettuce contained <10 cfu/g of *E.coli* and ≤ 210 cfu/g of faecal coliform bacteria even when irrigated with concentrated and undiluted treated wastewater effluent. There were microbial counts for some diluted effluent treatment which could be attributed to other external factors such as cross contaminations since the harvested lettuce was neither washed with fresh water nor treated in any way to take care of aerosols or external contamination.

CHAPTER FIVE

DISCUSSION

Issues relating to wastewater reuse have engaged the attention of many researchers globally, especially considering the dwindling freshwater sources with looming climate change effects.

Though many aspects of the acceptance of the potential of wastewater as a resource have been studied, a scientific support for people to accept and willingly use wastewater and its products is lacking especially in our local settings.

This study provides that scientific support.

5.1 Knowledge, awareness and factors associated with willingness to reuse treated wastewater

This study sought to assess the willingness and acceptance to use treated wastewater for irrigated agriculture and consume irrigated crops. The study revealed that majority of the respondents in Ashaiman and at the University of Ghana, Legon are willing to use treated wastewater for irrigated agriculture and as well consume crops irrigated with wastewater. In line with this study finding a study carried out in south-western USA, Sun Corridor in Arizona by Browning-Aiken *et al.*, (2011) indicated that more than 80% of the respondents expressed their willingness to use treated wastewater for public or home garden irrigation when asked.

This study found willingness to use treated wastewater being significantly associated with public knowledge and awareness of the wastewater treatment process. This study indicated that majority of the respondents had knowledge about wastewater treatment and processes and some by-products of economic benefits. This finding favourably compares with a study by Alhumoud & Madzikanda (2010), on the Sulaibiya wastewater treatment plant in Kuwait, which showed that general knowledge about wastewater treatment processes was significantly related to greater willingness and acceptance to treated wastewater use for irrigated agriculture and the consumption of irrigated crop. Further, in a study which was carried out by Baghapour *et al.* (2017), in the city of Shiraz , Iran indicated that people who were more aware of the wastewater treatment processes, as well as the physical, chemical and biological quality of the treated wastewater were generally more willing to use treated wastewater for irrigated agriculture and consume irrigated crops among other uses. The need to further educate and bring awareness to our people through enhanced effort would promote the use of wastewater to free more fresh water for critical uses.

It is believed that better income levels affect wastewater re-use. This study revealed that monthly income level was significantly associated with willingness to accept and use treated wastewater for crop irrigation as well as the consumption of the irrigated crops. In line with this finding, a study by Hoornweg & Bhada-Tata (2012), on global and country by country municipal solid waste management revealed a significant association between monthly income levels and willingness to reuse treated wastewater. It concluded that people of lower monthly income levels generated less waste hence had higher tendency to

practice informal recycling and reuse initiatives. However, a similar study by Garcia-Cuerva, *et al.* (2016), in the United States of America assessed public perceptions on water shortages, conservation behaviours and support for water reuse observed that higher income levels were associated with higher levels of willingness and acceptance to use treated wastewater for irrigated agriculture and the consumption of irrigated crops. Contrary to the finding of this study, Fielding *et al.*,, (2018) in reviewing global literature investigating factors associated with public acceptance of recycled water concluded that there was no significant association between the two.

Gender, according to this study is not significantly associated with willingness or acceptance of treated wastewater use for irrigation purposes and the consumption of irrigated crops. This was in contrast to previous studies carried out by Baghapour *et al.*, (2017) in the city of Shiraz , Iran and another by Bakopoulou *et al.*,(2010) in Greece, in the Thessaly region. These studies revealed that, men generally were more willing to accept new and risky technologies and processes and therefore were more willing to use treated wastewater for irrigated agriculture and consume irrigated crops.

This study is reporting that perception is a factor that influences the willingness to accept and use treated wastewater for irrigation because it was evident when respondents were asked to choose crops they were willing to irrigate using treated wastewater as well as consume. More than 67% of the respondents chose crops like plantain, mangoes and cassava while less than 33% chose crops like lettuce, maize and tomatoes. These groups of crops are processed differently and therefore this perception. This was supported by

Nancarrow *et al.* (2008) and (Nancarrow *et al.* (2009), in which behavioural models were used to predict communities' intended behaviour in relation to proposed wastewater recycling schemes. These studies concluded that close personal contact triggered perceptions of disgust feelings among users with regards to the use of treated wastewater for irrigation purposes and for more personal uses.

Human health risks issues were also significantly associated with willingness to use treated wastewater for irrigated agriculture and the consumption of irrigated crops. This study revealed that respondents were more willingly inclined to use treated wastewater for irrigation of crops which were processed before consumption and less willing for crops consumed raw or least processed, naturally because of human health risk concerns. In line with this study, a previous studies by Alhumoud *et al*. (2003) to assess wastewater reuse practices in Kuwait, and another by Dolnicar *et al.*,(2010) in a case study of Toowoomba, in Australia both concluded that, public opposition due to human health risk concerns defeated alternative water projects and affected public willingness to accept the use of alternative water resources. Indeed risk to human health had been the major concern of the opposition to wastewater reuse for variety of uses by humans. However, the potential of wastewater as an invaluable resource for certain less critical uses is evident.

Education was significantly associated with willingness to use treated wastewater for irrigated agriculture and the consumption of wastewater irrigated crops in this study. The study revealed that respondents at any level of formal education were more willing to accept and use treated wastewater for irrigated agriculture and consume the irrigated crops,

in contrast with respondents without any form of formal education. In contrast to the current study findings, similar studies by Bakopoulou *et al.*, (2010) and Baghapour *et al.*, (2017) revealed that there were no significant association between education and willingness to accept and use treated wastewater for irrigation and the consumption of irrigated crops. The difference in outcomes could be the subject of further investigation as it is generally believed that education in any form provides better insight to the understanding of issues like wastewater reuse as it is becoming a critical subject.

5.2 Safety of the use of treated wastewater as an irrigation source for crop production

The safety of the treated wastewater as an irrigation source for crop production was one of the key objectives of this study in view of its impact on human health and lives.

This study found the measured mean levels of micronutrients Fe, Cu, Zn and heavy/ trace metals Pb and Cd in the treated wastewater as within the allowable limits of World Health Organization ,(2006). A previous study by Khan *et al.*,(2008) in Beijing , China recorded higher levels of heavy / trace metals deposits in irrigated soils and foods as a result of wastewater irrigation. Thus, the treated wastewater is somewhat safe for use as an alternative water resource.

The microbial quality of the treated wastewater effluent as an irrigation source in this study was a critical factor due to predisposition to health risks associated with the use of

wastewater. The measured mean levels for the microbiological quality of the treated wastewater as an irrigation source was ≤ 37.4×10^3 cfu/100 ml for Total coliform (TC) bacteria, ≤ 19.2×10^3 cfu/100ml for faecal coliform (FC) bacteria , and ≤ 55.0×10^2 cfu/100ml for *E.coli*. The faecal coliform level of the treated wastewater in this study measured favourably with the WHO guideline limits for irrigation wastewater of ≤ 1000 faecal coliform bacteria/100 ml in unrestricted irrigation and ≤ 10^5 faecal coliform bacteria/100 ml as recommendations for restricted irrigation where adult farm workers are exposed to spray irrigation according to the World Health Organization, (2006) report.

5.3 Safety of treated wastewater irrigated crop for human consumption

The need to provide scientific evidence that it is safe to consume products of wastewater usage is core to this study.

The microbial quality assessment of the wastewater irrigated lettuce in this study was a further confirmatory analysis to determine the safety of the treated wastewater as an irrigation source. The current study results gave faecal coliform levels of ≤ 210 cfu/ g for only one of the effluent irrigation options. The *E.coli* levels for all four treatment options were < 10 cfu/g. The recommended guideline limits of the International Commission on Microbiological Specifications for Foods (ICMSF) allows for ≤ 1000000 FC bacteria/100 g fresh weight for vegetables eaten uncooked according to Blumenthal *et al.*, (2000). In contrast to this, a previous study carried out by Keraita *et al.*,(2003) in the city of Kumasi, Ghana, recorded extremely high levels of vegetable contamination in the region of 10^7–10^9

cfu/g of FC count and concluded that, eating one gram of raw lettuce from the Kumasi markets is almost equivalent of eating a similar amount of fresh faeces. The current study finding on the faecal coliform levels of the irrigated lettuce revealed no human health risk in consuming lettuce irrigated with treated wastewater and with no financial losses as compared to a previous study by Paramithiotis et al. (2017), in the USA which recorded several incidence of fresh vegetable and fruits recall as a result of *E. coli* contamination. The need to assure consumers or the public through further investigations with same crops or with others is eminent to conclude this case.

The growth and yields of irrigated crops in this study was significantly affected by some water quality indicator parameters such as the Electrical conductivity (EC) levels, pH levels, plant macronutrients levels of the soil medium or irrigation water. This study measured EC levels between 590µS/cm and 760µS/cm which were within EPA guideline value of 1500 µS/cm for effluent discharge and the required level for the study crop. EC levels are indications of the salinity levels of the wastewater. The effects of irrigation water and soil medium salinity level on crops are crops specific. A study carried out by Kiziloglu *et al.,* (2008) on calcareous soils in Turkey indicated that , if the EC levels of the irrigation treated wastewater source were below 700µS/cm they would not affect plant growth. However, irrigation water with EC levels up to 3000µS/cm and above cause damage to the crops.

The treated wastewater pH levels in this study was between 7.7 to 8.1, these levels were within the WHO allowable limits of 6.5-8.5 for effluent discharge and irrigation source water. Irrigation water with pH levels outside this region have a higher tendency of affecting the mobility of heavy metals in the soils hence making the mobile metals to be absorbed by crops and further contaminate water sources/ bodies during runoffs according to the World Health Organization,(2006) report.

The macronutrients levels of the treated wastewater effluent in this study were ≤ 4.78 mg/l, ≤ 0.215 mg/l, ≤ 0.531 mg/l and ≤ 1.93mg/l for Total Phosphorous, Nitrate-Nitrogen, Nitrite and Phosphate Phosphorous levels respectively. This study results fell within the WHO guideline limits for effluent discharge. Hussain *et al.*,(2002) stated that, the macronutrients in irrigation water or soils promote the growth and development of plants (crops). Instances where nutrients contents of nitrogen and phosphorus are high in irrigation water source could pollute ground water sources and other fresh water sources during runoffs. The study further indicated that, salts accumulation in the root zone has harmful impacts on soil health and affects crop yields. In the end, leaching of these salts below the root zone may occur resulting in soil and groundwater pollution.

The turbidity of the treated wastewater as measured for an irrigation source may not be too critical a parameter. The turbidity of the treated wastewater as an irrigation source measured averagely between 65.0- 86.0 NTU. The turbidity of the treated wastewater is

considered when the intended use is for other competing water uses other than irrigation as indicated by Jeong, Kim, & Jang,(2016).

The Dissolved oxygen (DO) levels in the treated wastewater effluent as an irrigation source for the purpose of this study may not be too critical a quality indicator parameter. But for multipurpose or competing uses such as aquaculture, environmental protection, etc., the Dissolved Oxygen (DO) level of treated wastewater becomes a quality indicator parameter which determines the extent of pollution and whether or not the treated wastewater effluent can support aquatic life and other life forms. This study measured DO levels for the treated wastewater at 7.6 mg /l which was indicative of its life support potentials as a water resource. The BOD and COD levels of the treated wastewater effluent also measured between 27.2 mg/l and 146.0 mg/l respectively which compared favorably with WHO acceptable limits of 50 mg/l and 250 mg/l for BOD and COD levels respectively. The BOD levels in treated wastewater was used as an index for its organic matter content estimation, while COD provides an indication of the total oxygen demand in digesting/ decomposing both organic and inorganic matter in the treated wastewater effluent. At higher BOD and COD levels, dissolved oxygen levels are consumed to depletion through decomposition creating anaerobic conditions and a more polluted wastewater.

This study has provided ample evidence that wastewater produced from liquid waste treatment like the Accra Sewage Improvement Project wastewater treatment Plant at

University of Ghana, Legon could offer some respite with respect to water use for various purposes.

The crop production could be regarded as a critical area in view of potential health risks, especially when considering crops that are not processed or least processed before consumption like lettuce and other leafy vegetables. This study has provided a lead into the reason why the public should be willing to consume some of these crops produced this way.

Generally, the physicochemical quality of the wastewater used in this study is of good quality to be used to support crop production.

The need to carry out more thorough investigation to confirm crops production as well as use for lawn management, car washing and other domestic chores will help to save the freshwater for more critical human usage like drinking, bathing and cooking for a better tomorrow.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

This study has provided a basis for use of wastewater for crop production, and other less critical uses.

I. The treated effluent microbiological quality was within the WHO guideline limit of ≤1000 FC bacteria/100 ml and ≤10^5 FC bacteria/100 ml for unrestricted irrigation and restricted irrigation where adult farm workers are exposed to spray irrigation in some instance.

II. Though the microbial quality fell within the guideline limits, there were some significant levels of FC and *E.coli* levels which call for corrective measures to avoid further contaminations. Notwithstanding, the wastewater treatment process is effective and hence the treated wastewater effluent is safe for use as an irrigation source.

III. Though the physicochemical and microbiological quality of the effluent met most of the WHO guideline limits, turbidity levels did not. This could be attributed to the introduction of materials during some maintenance work which was carried out on some of the ponds during the course of the study. However, turbidity levels are not too critical with irrigation water sources.

IV. The lettuce crops were not washed with fresh water during harvest before sending to the microbiology laboratory for analysis yet the guideline limits of the ICMSF were met. This confirms the safety of the irrigated crops for human consumption.

V. Public willingness and acceptance of the use of treated wastewater for irrigated agriculture and the consumption of crops produced have increased over time especially in areas where freshwater sources are not readily available. Some factors such as perceptions of the origin/ source of wastewater, human health issues which affect wastewater reuse, education (formal or informal), knowledge and awareness of the wastewater treatment process were all found to be significantly associated with the use treated effluent.

VI. However, factors such as age and gender were found by this study not to be significantly associated with willingness to reuse treated wastewater and consume irrigated crops.

VII. There may yet be other factors of academic importance like age, environmental protection consciousness, religious inclination, etc., which may have significant associations with the use of treated wastewater and consumption of irrigated crops that this current study could not cover due to time and capacity constraints. These could be investigated.

VIII. Finally, the microbial and physicochemical quality of the treated wastewater effluent used in the irrigation of lettuce for this study could be said to be safe for

use as irrigation water source. Moreover, public perceptions which are associated with the use of wastewater for irrigation purposes as well as for other non-critical uses and the consumption of irrigated crops have been addressed by the general quality of the irrigated lettuce.

6.2 RECOMMENDATION

I. There is a need for planned and effective refresher trainings and sensitization programmes for farmers on issues of Good Agricultural Practices (GAP) as well as post harvest hygienic practices in order to reduce the risks of cross contamination as a result of the use of treated wastewater reuse.

II. There is a need for capacity building and planned investment into wastewater treatment plants and its related infrastructure (quality assurance, storage, transport, etc.) to ensure readily available, easily assessable and safe treated wastewater as irrigation sources in fresh water scarce areas to help feed the ever growing population.

III. There is the need for thorough and application based research into local, cost effective, energy efficient and environmental friendly technologies and applications in wastewater treatment and its distribution (transportation) as well as its safe reuse/ application as an alternative water resource for all competing water uses.

IV. Further advance studies; epidemiological, Quantitative Microbial Risk Assessment among others are recommended to be carried out to assess the safety of the treated effluent for irrigation of sensitive crops over longer study periods and on a much broader scope of study.

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APPENDIX 1

UNIVERSITY OF GHANA, LEGON

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

Survey Instrument for Ashaiman

Questionnaire No ……

Preamble

This questionnaire is to gather information on the knowledge, perception, acceptability and willingness to use waste treatment by-products. The purpose of this instrument is restricted to academics/research for an MPhil degree in Environmental Science from University of Ghana, Legon. The information obtained would be used solely for the purpose stated above and not for any other purpose. Please read attached participants consent note to accept/reject participation before the interview begins/otherwise.

Please tick where appropriate.

SECTION A: Background of Respondents

1. Age: [1] 10-18 [2] 19-25 [3] 26-34 [4] 35-43 [5] 44-60 [6] > 60

2. Gender: [1] Male [2] Female

3. Educational background: [1] No formal Education [2] Primary School [3] J.S.S. / JHS [4] Secondary [5] Tertiary [6] others…….

4. Religion: [1] Christian [2] Muslim [3] Traditionalist [4] Others ……..

5. Occupation: [1] Education [2] Health worker [3] Construction [4] Mining [5] Trading [6] Private sector [7] Agriculture [8] Student [9] Teaching staff [10] Non teaching staff
6. Income status: [1] < GHS 500 [2] 501- 1000 [3] >1000

7. Marital status: [1] Married [2] Single [3] Divorced [4] Separated [5] Widowed [6] Others……..

8. Number of people in household: [1] < 3 [2] 4-7 [3] 8-10 [4] > 10

SECTION B: GENERAL KNOWLEDGE ABOUT WASTE MANAGEMENT AND TREATMENT

9. Do you separate your solid waste into categories?

   [1] YES [2] NO

10. Please give your reason(s) for your choice in Question 9

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    ……

11. Which of the following as waste management options are you aware of?

    i. Disposing(land filling) [1] YES [2] NO [3] NOT SURE

    ii. Composting [1] YES [2] NO [3] NOT SURE

    iii. Recycling [1] YES [2] NO [3] NOT SURE

    iv. Incineration [1] YES [2] NO [3] NOT SURE

12. Do you know what becomes of your sewage once the septic tank is emptied by a tanker?

    [1] Yes [2] NO [3] NOT SURE

13. Please indicate how and where the sewage (including faeces) you generate is disposed of?

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14. Is waste treatment necessary in our lives?

[1] YES [2] NO

15. Please indicate the reason(s) for your choice in Question 9.

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16. Do you know what becomes of the waste you generate?

[1]YES [2] NO

17. Are you aware of any that waste can be treated?

[1] YES [2] NO

18. Do you know of any waste treatment plant in Ghana?

[1] YES [2] NO

19. If yes, please indicate the name(s) and location of the plant (s)?

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……

20. How long have you known about the waste treatment plant?

[1] < 1 year [2] 1-3 years [3] 4-7years [4] > 7 years

21. How did you get to know about the waste treatment plant?

[1] Religious Meetings [2] Media [3] Friends [4] Family Members [5] District Assembly [6] Others……

22. What type of waste is treated by the waste treatment plant (s) named above?

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SECTION C: WASTE AS A RESOURCE

23. Why must waste be treated?

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24. What would you be willing to use treated waste water for?

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25. Please indicate your reasons for the choice in Question 24

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26. Will you be willing to use treated waste water effluent for irrigation (agriculture)?

[1] YES [2] NO

27. Please give your reason(s) for your choice in Question 26

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28. Which crops will you cultivate using treated waste water?

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29. In your opinion, how does the use of treated wastewater and faecal compost benefit cropping?

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30. Which of these would you be willing to use for crops cultivation?
    [1] Inorganic fertilizer [2] Organic compost [3] treated waste water effluent [4] faecal compost [5] None

31. Please indicate your reason(s) for your choice(s) in Question 23
    ……
    ……
    ……
    ……

32. Please indicate the degree to which you agree or disagree with the following statements relating to sanitation practices

Perception	Strongly Disagree 1	Disagree 2	Don't know 3	Agree 4	Strongly Agree 5
Effluent has a bad smell					
It has detrimental effects on Human health					
It is culturally unacceptable to use faecal compost in crop production					

The use of effluent waste water for the cultivation of crops leaves traces on the produce					
The use of effluentwaste waterwill help in improving sanitation					
The use of effluent waste water in cropping will increase crop yield					
Treated wastewater effluent can be reuse for other purposes					
Waste treatment brings out the resource components of waste.					
Waste treatment makes available raw materials at a reduced cost to the environment.					

33. Do you know the following as some waste treatment products?

Sludge [1] YES [2] NO

Compost / Fertilizer [1] YES [2] NO

Effluent [1] YES [2] NO

Biogas [1] YES [2] NO

Energy / electricity [1] YES [2] NO

34. Which of the by-products in (Q33) would you be willing to use?

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35. Please indicate your reason(s) Question 34

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36. How do you intend to use the product(s) of your choice?

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37. Are you willing to pay for the product(s)

[1] YES [2] NO

38. Which waste treatment product are you willing to pay for?

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39. Are there benefits to be derived from waste treatments?

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40. If yes, what are the benefits?

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APPENDIX 2

UNIVERSITY OF GHANA, LEGON

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

Survey Instrument Questionnaire No ……

Preamble

This questionnaire is to gather information and aid in assessing knowledge, perception, acceptability and willingness to use recycled/ treated wastewater. The purpose of this instrument is restricted to academics/research for an MPhil degree in Environmental Science from University of Ghana, Legon. The information obtained would be used solely for the purpose stated above and not for any other purpose. Please read attached participants consent note to accept/reject participation before the interview begins/otherwise.

Please tick where appropriate.

SECTION A: Background of Respondents

Age: [ ] 18-25[ ] 26-34 [ ] 35-43 [ ] 44-60 [ ] > 60

Gender: [1] Male [2] Female

Are you are a student of the university? [1] Yes [2] No

If yes for Question 3, [1] Undergraduate [2] Graduate

If you answered No for question 3, please specify your role within the university community?

[1] Faculty staff [2] Non-Teaching Staff [3] others…

Religion: [1] Christian [2] Muslim [3] Traditionalist [4] Others.

Program of study if yes was answered for Question 3

[1] Humanities [2] Social Sciences [3] Applied Sciences [4] Health Sciences

Residence status: [1] Resident [2] Non Resident

Marital status: [1] Married [2] Single [3] Divorced [4] Separated [5] Widowed [6] Others….

SECTION B: GENERAL KNOWLEDGE AND PERCEPTION ON WASTEWATER AND WILLINGNESS TO USE

Do you know what wastewater is? [1] Yes [2] No

Please indicate the sources of wastewater you are aware of?

(I)……

(ii)…….

(iii)……

(iv)……..

In your opinion, what constitutes wastewater?

[1] Organic matter [2] water [3] Pathogens/ microbes [4] faecal matter [5] others

Are you willing to use wastewater?

[1] Yes [2] No

Are you aware wastewater that can be treated/ recycled?

[1] Yes [2] No [3] Not sure

Given the following types of recycled water with respect to quality:

Type 1: Recycled water with about 30-40% of organic matter removed (less odor, slightly colored, etc.)

Type 2: Recycled water with about 95% of organic matter and pathogens/ microbes removed (No odor, no colour)

Type 3: Recycled water with about 99% of organic matter removed and completely disinfected (No odor, no colour)

Which type(s) of the recycled water above would you be willing to use for irrigation?

[1] Type 1 [2] Type 2 [3] Type 3 [4] None [5] All

Are you willing to pay for the recycled water type of your choice?

[1] Yes [2] No

Please choose as many as applicable in Questions 17-19

What would you be willing to use recycled wastewater type 1 for?

[1]Flushing of toilets [2] Irrigation of crops / vegetables [3] Irrigation of lawn/ garden [4] None [5] other….

What would you be willing to use recycled water type 2 for?

[1]Flushing of toilets [2] Irrigation of crops / vegetables [3] Irrigation of lawn/ garden [4] none [5] other …….

What would you be willing to use recycled water type3 for?

[1]Flushing of toilets [2] Irrigation of crops / vegetables [3] Irrigation of lawn/ garden [4] none [5] other …..

Are you willing to pay for the recycled water type of your choice?

[1] Yes [2] No

If No in Question 20, please indicate the recycled/ treated wastewater type(s) that you are not willing to pay for?

[1] Type 1 [2] Type 2 [3] Type 3

Are you willing to pay more or less for the use of recycled/ treated wastewater?

[1] Same as [2] More than [3] less than

Do you know of any wastewater treatment/ recycled plant in Ghana?

[1] Yes [2] No

If yes, please indicate the name(s) and location of the plant (s)?

……

……

…….....

.....

How long have you known about the waste treatment plant?

[1] < 1 year [2] 1-3 years [3] 4-7years [4] > 7 years

How did you get to know about the waste treatment plant?

[1] Religious Meetings [2] Media [3] Friends [4] Family Members [5] District Assembly [6] Others……

Would you be willing to consume recycled water irrigated crops?

[1] Yes [2] No [3] Not sure

Which of the following recycled water irrigated crops would be willing to consume?

[1] Lettuce [2] Mangoes [3] cassava [4] Plantain [5] Tomatoes [5] Maize

How much are you willing to pay to consume recycled wastewater irrigated farm produce.

[1] More than [2] Lesser than [3] Same as

SECTION C: PERCEPTIONS ON PRODUCTS OF WASTEWATER

As a consumer, are you willing to purchase other products from wastewater treatment?

(Compost, sludge, biogas, etc)

[1]Yes [2] No

Please indicate the degree to which you agree or disagree with the following statements relating to sanitation practices

Perception	Strongly Disagree 1	Disagree 2	Don't know 3	Agree 4	Strongly Agree 5
Recycled water has bad smell					
The use of recycled wastewater has detrimental effects on Human health					
It is culturally **unacceptable** to use recycled wastewater in crop production					
The use of recycled waste water for the cultivation of crops leaves traces on the produce					
The use of recycled waste water will help in					

improving environmental sanitation					
The use of recycled waste water in cropping will increase crop yield(productivity)					
Recycled wastewater can be reuse for other purposes					
Waste treatment makes available raw materials at a reduced cost to the environment.					
The use of recycled wastewater helps to reduce the stress on existing water resources					
The use of recycled wastewater for irrigation saves cost of fertilizer application.					

Which of the following human uses would not require water for drinking standards? Please tick as many as apply to you.

[1] Irrigation of lawn/ garden [2] irrigation of crops [3] road construction [4] general construction [5] None [6] All

Are there personal benefits to be derived from the use of recycled wastewater?

[1] Yes [2] No

If yes for Question 33, what are these benefits?

…… ……

……

…… ……

……

Are there environmental benefits to be derived from the treatment and use of recycled wastewater?

[1] Yes [2] No

APPENDIX 3

Correlation analysis for the physicochemical parameters of the treated effluent

	Turbidity	pH	Conductivity	DO	BOD	COD	Phosphorous	Total Phosphorous (TPO4-P)	Nitrate-Nitrogen (NO3-N)	Nitrite-(NO2-N)
Turbidity	1									
pH	-0.93	1								
Conductivity	0.91	-0.76	1							
Dissolved Oxygen (DO)	-0.29	0.61	0.05	1						
BOD	0.95	-0.91	0.94	-0.27	1					
COD	0.96	-0.92	0.94	-0.30	0.99*	1				
Phosphorous	0.31	-0.63	-0.02	-0.99*	0.30	0.33	1			
Total Phosphorous (TPO4-P)	0.93	-1.00*	0.76	-0.61	0.91	0.92	0.63	1		
Nitrate-Nitrogen (NO3-N)	0.67	-0.44	0.55	0.10	0.41	0.43	-0.13	0.46	1	
Nitrite-Nitrogen (NO2-N)	-0.29	0.61	0.06	1.00	-0.25	-0.28	-0.99**	-0.60	0.07	1

APPENDIX 4

Analysis of Variance (ANOVA) on the lettuce vegetative parameters

An

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
NL	Between Groups	34.667	3	11.556	1.127	0.394
	Within Groups	82.000	8	10.250		
	Total	116.667	11			
T L wt	Between Groups	935.673	3	311.891	.124	0.943
	Within Groups	20163.434	8	2520.429		
	Total	21099.107	11			
T st wt	Between Groups	294.866	3	98.289	1.238	0.358
	Within Groups	635.168	8	79.396		
	Total	930.034	11			
T R wt	Between Groups	48.401	3	16.134	2.021	0.190
	Within Groups	63.850	8	7.981		
	Total	112.251	11			
PH	Between Groups	19.467	3	6.489	.994	0.444
	Within Groups	52.240	8	6.530		
	Total	71.707	11			
T F wt	Between Groups	5594.441	3	1864.814	.873	0.494
	Within Groups	17093.238	8	2136.655		
	Total	22687.679	11			
LA	Between Groups	5861950.062	3	1953983.354	.873	0.494
	Within Groups	17910583.932	8	2238822.991		
	Total	23772533.993	11			
H wt	Between Groups	1030.328	3	343.443	.101	0.957
	Within Groups	27324.817	8	3415.602		
	Total	28355.145	11			