UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF TREATED WASTEWATER IRRIGATION USING COCONUT FIBRE FOR SPINACH (Spinacia oleracea L.) VEGETABLE PLANTS

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By

ODOEMENA KENNETH IKENNA

Thesis Submitted to School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

January 2021

DEDICATION

This thesis is dedicated to my beloved parents for their endless love, support and encouragement.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia fulfilment of the requirement for the Degree of Master of Science.

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Chairman: Associate Professor MD Rowshon Kamal, PhD
Faculty: Engineering

This study focused on the assessment of urban wastewater for irrigation of vegetables after some degree of the quality enhancement of wastewater that is suitable for irrigation. The irrigation sector uses a vast amount of available freshwater resources. In urban areas, return flows from domestic uses can be reused for urban agriculture because of the availability of limited freshwater resources. Water and wastewater contain micro-nutrients such as oil, nitrogen and other harmful components. If the wastewater used for long-term in agricultural fields, it contributes to overloading of heavy metals nutrients and some pathogens from wastewater. Therefore, this study assesses the utilization of treated wastewater for irrigated Spinach vegetables. The source of wastewater used for this study from the catchment of Tasik Sri Serdang. The objectives of this study are; (i) to design and fabricate the coconut fiber filtration system for wastewater treatment in irrigation use, (ii) to characterize the suitability of irrigation use of wastewater and treated wastewater using WQI, and (iii) to assess the utilization of treated wastewater irrigation for growing Spinach vegetables. In order to achieve the specific objectives of the study, a simple coconut-fiber based wastewater filtration system was used for wastewater quality enhancement. Then, wastewater collected from Tasik Sri Serdang was analyzed physiochemical properties of water quality parameters in the laboratory before applying irrigation for Spinach vegetables. Six physiochemical parameters of Water Quality Index (WQI) were determined which include Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Dissolved Oxygen (DO), Ammonia Nitrogen (AN), and pH. In addition, the heavy metals contents in the wastewater were analyzed involving three major elements; Copper (Cu), Nickel (Ni) and Zinc (Zn).

Application of treated wastewater was applied to grow Spinach and assessed the effects of treated wastewater on growing Spinach vegetables. The concentrations of the six physiochemical parameters of treated wastewater of 35.67 mg/L BOD (Class V), 120.93 mg/L COD (Class V), 6.8 mg/L DO (Class II), 63.73 mg/L TSS (Class III), 16.57 mg/L AN (Class V) and pH 6.53 (Class II) were determined. While the heavy metals Cu, Ni and Zn were revealed to have concentrations of 3.01, 1.21, and 9.23 mg/L respectively. After determining physiochemical properties of wastewater, the concentrations of six WQI parameters were reduced by mixing water and enhanced the water quality to 8.6mg/L BOD (75.9%, Class IV), 38.2 mg/L COD (68.4%, Class III), 7.33 mg/L DO (7.8%, Class I), 31.37 mg/L TSS (50.8%, Class II), 1.14 mg/L AN (93.1%, Class IV) and pH 7.17 (9.7%, Class I). Enhanced overall WQI value achieved from 46.3 to 74.0 after treatment. All physiochemical parameters were obtained at least Class IV and better which is suitable and safe for irrigation. Heavy metals contents also reduced to 0.05, 0.02 and 4.93 mg/L for Cu, Ni and Zn, with a reduction of 98.4%, 98.1%, and 46.5%, respectively, while electrical conductivity (EC) of wastewater was reduced from the range of 5.9 - 6.6 dS/m to the range of 0.5 - 2.1 dS/m after treatment with coconut fiber filtration. Besides, the hydroponic method was applied to grow Spinach vegetables. The height of planted Spinach identified a maximum of 6.1 cm compared to only 5.3 cm for 21 days when planting Spinach under raw wastewater conditions. Treated wastewater hydroponic produced 6 to 7 plants leaves while raw wastewater hydroponic produced less number of leaves (4 to 6). Moreover, the overall weight of Spinach grown under treated wastewater at the end of growing stageswas measured to be 0.8 kg, much greater than only 0.5 kg of Spinach grown under raw wastewater. Spinach leaves were more vigorous and vibrant when applying treated wastewater for planting. However, a slight of inhibition of plant growth and less vibrant color of the leaves were observed when raw wastewaterwas used. This study recommends that treated wastewater using low-cost wastewater filtration system is feasible for urban vegetables irrigation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

PENILAIAN TERHADAP PENGAIRAN AIR SISA TERAWAT MENGGUNAKAN GENTIAN KELAPA UNTUK TANAMAN SAYUR BAYAM (*Spinacia oleracea L.*)

Oleh

ODOEMENA KENNETH IKENNA

Januari 2021

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Kajian ini bertumpu kepada penilaian terhadap air sisa bagi tujuan pengairan tanaman sayur setelah dilakukan penambahbaikan pada air sisa tersebut agar sesuai digunakan untuk pengairan. Sektor pengairan menggunakan sejumlah besar sumber air tawar yang ada. Di kawasan bandar, aliran balik dari penggunaan domestik boleh digunakan semula untuk pertanian bandaran disebabkan sumber air tawar yang terhad. Air dan air sisa mengandungi mikro-nutrien seperti minyak, nitrogen dan komponen-komponen berbahaya yang lain. Jika air sisa digunakan bagi jangka masa yang panjang dalam bidang pertanian, ia akan menyumbang kepada kandungan logam berat dan patogen yang berlebihan dari air sisa terbabit. Oleh itu, kajian ini menilai penggunaan air sisa terawat bagi penanaman sayur Bayam. Sumber air sisa yang digunakan untuk kajian ini diambil dari kawasan tadahan di Tasik Sri Serdang. Terdapat tiga objektif utama dalam kajian ini; (i) mencipta dan merekabentuk sistem penapisan air sisa berasaskan gentian kelapa untuk tujuan pengairan, (ii) mencirikan kesesuaian air sisa dan air sisa terawat untuk kegunaan pengairan berdasarkan kepada Index Kualiti Air (WQI), dan (iii) menilai penggunaan air sisa terawat bagi tujuan pengairan untuk penanaman sayur Bayam. Bagi mencapai objektif-objektif tersebut, satu sistem penapisan air sisa berasaskan gentian kelapa yang ringkas telah dicipta dan direkabentuk untuk rawatan air sisa. Sistem ini terdiri daripada kebuk penapisan dua peringkat padat dengan gentian kelapa. Kemudian, sampel air sisa yang diambil dari Tasik Sri Serdang telah dianalisis selepas rawatan bagi menentukan kualiti dan ciri-ciri fizikokimia sebelum diaplikasikan untuk pengairan. Enam parameter Indeks Kualiti Air (WQI) telah dianalisis, iaitu Keperluan Oksigen Biokimia (BOD), Keperluan

Oksigen Kimia (COD), Jumlah Pepejal Terampai (TSS), Oksigen Terlarut (DO), Nitrogen Ammonia (AN) dan pH. Tambahan pula, kandungan logam berat dalam air sisa turut dianalisis, melibatkan tiga unsur utama; Kuprum (Cu), Nikel (Ni) dan Zink (Zn). Aplikasi air sisa terawat untuk penanaman Bayam telah dijalankan dan prestasi pengairan berasaskan air sisa terawat telah dinilai selanjutnya. Sebelum rawatan dijalankan ke atas air sisa, kepekatan enam parameter WQI telah ditentukan bernilai purata 35.67 mg/L BOD (Kelas V), 120.93 mg/L COD (Kelas V), 6.8 mg/L DO (Kelas II), 63.73 mg/L TSS (Kelas III), 16.57 mg/L AN (Kelas V) dan pH 6.53 (Kelas II). Sementara logam berat Cu, Ni dan Zn masing-masing didedahkan berada pada kepekatan 3.01, 1.21 dan 9.23 mg/L. Berikutan dari rawatan air sisa tasik, kepekatan enam parameter WQI telah berjaya dikurangkan dan ditambahbaik kepada 8.6 mg/L BOD (75.9%, Kelas IV), 38.2 mg/L COD (68.4%, Kelas III), 7.33 mg/L DO (7.8%, Kelas I), 31.37 mg/L TSS (50.8%, Kelas II), 1.14 mg/L AN (93.1%, Kelas IV) and pH 7.17 (9.7%, Kelas I), menambahbaik nilai WQI daripada 46.3 kepada 74.0 setelah rawatan. Semua parameter ini sekurang-kurangnya berada pada Kelas IV dan lebih baik, memberi petunjuk bahawa air sisa terawat sangat sesuai dan selamat untuk tujuan pengairan. Sementara itu, kandungan logam berat telah berkurangan kepada hanya 0.05, 0.02 dan 4.93 mg/L masing-masing untuk Cu, Ni dan Zn, dengan peratus pengurangan masing-masing sebanyak 98.4, 98.1 dan 46.5%, manakala kekonduksian elektrik (EC) air sisa telah berkurangan daripada julat 5.9 - 6.6 dS/m kepada julat 0.5 - 2.1 dS/m selepas rawatan melalui penapisan gentian kelapa. Kaedah hidroponik menggunakan Sistem Wick telah diaplikasikan untuk penanaman Bayam. Ketinggian maksimum Bayam yang ditanam menggunakan air sisa terawat mencecah 6.1 cm, berbanding hanya 5.3 cm apabila ditanam menggunakan air sisa mentah. Hidroponik menggunakan air sisa terawat menghasilkan 6 hingga 7 helai daun pada tumbuhan, sedangkan hidroponik menggunakan air sisa mentah menghasilkan daun yang lebih sedikit (5 hingga 6 helai). Tambahan pula, berat keseluruhan Bayam yang ditanam menggunakan air sisa terawat pada akhir peringkat pertumbuhan ialah 0.8 kg, jauh lebih besar berbanding hanya 0.5 kg Bayam yang ditanam menggunakan air sisa mentah. Daun Bayam dilihat lebih lebat dan segar apabila air sisa terawat digunakan untuk penanaman. Akan tetapi, sedikit unsur pembantutan pada Bayam dan daun Bayam yang kelihatan lebih pucat telah diperhatikan setelah air sisa mentah digunakan untuk penanaman. Kajian ini mengesyorkan bahawa air sisa terawat menggunakan sistem penapisan air sisa kos rendah boleh dilaksanakan untuk pegairan pengairan tanaman di bandar.

ACKNOWLEDGEMENTS

I wish to thank God Almighty first and foremost from whom all blessings, life and wisdom flow. Without whom, it would absolutely be impossible for me to either start or complete this thesis.

My profound gratitude and heartfelt thanks to my dedicated supervisor, Associate Professor Dr MD Rowshon Kamal for his continuous support, high level of patience, tolerance, motivation, immense knowledge and excellent supervision. His continuous guidance and meaningful advice were of help to me throughout the course of this study.

My sincere thanks go to my co-supervisors, Professor Ir. Dr. Hasfalina bt. Che Man and Dr. Amimul Ahsan whose guidance throughout this thesis has made successful and for many insightful conversations during the development of the ideas in this thesis, and for helpful comments on the text. I appreciate especially the sound technical counsel and your kindness.

Not forgotten the entire staff of the department of Biological and Agricultural Engineering, Universiti Putra Malaysia for their kindness, advice and assistance in my experimental and analyses work.

I remember with fondness and am grateful to my beloved children, Michelle Olaedo Odoemena and Joseph Ikenna Odoemena for their smiles and hugs they have given me throughout the period of the thesis work. I thank my beloved wife, Susilawati Sinurat Odoemena for her loving inspiration, prayers, and encouragement that made me strong. Thanks also for being there despite your tight schedule and enabling me to complete this work.

My profound gratitude goes to my beloved parents, Mazi Joseph Odoemena and Ezinne (Mrs) Rita Odoemena for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

I also deem it necessary to express my sincere appreciation to friends and colleagues for sharing with me their friendships, knowledge and assistance throughout of this project.

Finally, I appreciate my brothers Kingsley Okezie Odoemena and Charles Obinna Odoemena, sisters, nieces, nephews, aunts and cousins who showed so much needed concern.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the Degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 06 May 2021

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LIST OF ABBREVIATIONS

Ag	Silver
Ag_2SO_4	Silver sulfate
Al	Aluminium
AN	Ammonia Nitrogen
APHA	American Public Health Association
As	Arsenic
B	Boron
BAF	Biological aerated filter
BOD	Biochemical oxygen demand
Ca	Calcium
$CaCl_2$	Calcium chloride
Cd	Cadmium
Cl	Chlorine
Co	Cobalt
COD	Chemical oxygen demand
Cu	Copper
DO	Dissolved oxygen
DOE	Department of Environmental
EC	Electrical conductivity
FAO	Food and Agriculture Organization
FAS	Ferrous ammonium sulfate solution
FBR	Fluidized-bed reactor
$Fe(NH_4)_2(SO_4)_2$	Ferrous ammonium sulfate (powder)
$FeCl_3$	Ferric chloride

FOMCA	Federation of Malaysian Consumers Associations
H_2SO_4	Sulfuric acid
H_3BO_3	Boric acid
HAB	Harmful algal bloom
Hg	Mercury
$HgSO_4$	Mercury sulfate
K	Potassium
$K_2Cr_2O_7$	Potassium dichromate
K_2HPO_4	Potassium hydrogen phosphate
KH_2PO_4	Potassium dihydrogen phosphate
Mg	Magnesium
$MgSO_4$	Magnesium sulfate
$MnSO_4$	Manganese sulfate
N	Nitrogen
Na	Sodium
$Na_2B_4O_7$	Sodium tetraborate
$Na_2S_2O_3$	Sodium thiosulfate
NaI	Sodium iodide
NaN_3	Sodium azide
NaOH	Sodium hydroxide
Ni	Nickel
NRC	National Research Council
NWSC	National Water Services Commission (SPAN)
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead (plumbum)
RBC	Rotating biological contactor

RW	Reclaimed water
SBR	Sequencing batch reactor
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
TSS	Total suspended solids

CHAPTER 1

INTRODUCTION

1.1 Research Background

Over the last few years, Malaysia has strengthened the process of development of the country by changing its economy. As a result of rapid change, urban ruralmigration and population growth, wealth has also led to increased pollution which could have an impact on the environment and, in particular, on people. More than 2 billion people live in countries with high water pressure, with about 4 billion people experiencing severe water shortages for at least one month of the year (Lundy et al., 2020). Urban wastewater is known as household wastewater or a combination of household wastewater with industrial wastewater and/or rainwater (Azeez and Olufemi, 2017; Lundy et al., 2020). Factors such as climate change and population growth have resulted in severe droughts in areas where intensive farming is the main economic activity.

With a growing global population, the imparity between water supply and demand is widening and approaching such alarming rates that in some parts of the world it poses a danger to human life (Chuck et al., 2016; Luciano et al., 2017; Angela et al., 2018; Pompilio et al., 2017). Reuse of reclaimed water (RW) for irrigation of agriculture seems to be an excellent solution to water scarcity (Mart et al., 2019). Both wastewater and sludge contain valuable resources, predominantly water, nutrients (nitrogen, phosphorus, potassium, etc.), organic carbon and related energy that can be recovered for many purposes. Water is the most important and abundant wastewater asset and, if treated appropriately, can be used as a substitute for fresh water (Drechsel et al., 2015). Sewage-related contaminants consist of biochemical oxygen demand (BOD), suspended solids and ammonia, TSS, COD, BOD, Pb, pesticides, industrial chemicals, solvents and other organic pollutants (Comber et al., 2019; Low et al., 2016). Metals with densities above 5 g/cm^3 are commonly referred to as heavy metals,such as cobalt (Co), copper (Cu), lead (Pb), etc, (Low et al., 2016).

The threat posed by heavy metals has become increasingly unfit for human consumption by many water bodies worldwide. Low et al. (2016) found that in Malaysia around 73 lakes were created to meet the nation's water requirements. However, from the study, most lakes were classified as polluted and important parameters of water quality were beyond the level allowed by Malaysia's Department of Environment (DOE). The reuse of treated municipal wastewater (reclaimed water) as a means of alleviating water scarcity in irrigated agriculture is gaining increasing political interest, particularly in areas where water demandmanagement measures have proved insufficient. Azman et al. (2010) found thatthe total volume of municipal and industrial wastewater produced in Malaysia is 2.97 billion cubic meters per year.

The concentration and composition of the dissolved components in water and the amount of water used affect irrigation quality (Bohamad and Ahmed, 2005). Malaysia's Environment Department (DOE) has made a frenzied effort to monitor and maintain a reasonable level of pollution around the catchment areas of the reservoir. In 2009, roughly 1,063 water quality monitoring stations were chosen and approximately 577 water bodies were surveyed, of which 54% were classified as safe, 36% were "slightly contaminated" and 10% were classified as polluted water (Low et al., 2016). Irrigation of recycled wastewater has both positive and negative environmental effects and the use of treated wastewater in agriculture with proper planning and management could be beneficial to the environment (WHO, 2006). In Malaysia diet, vegetables are becoming highly important. Over the years, vegetable consumption per capita has increased (Unal et al., 2014). It is known that leafy vegetables, including Spinach, produce relatively high amounts of water, so their water requirement is comparatively high during the life cycle (Jabeen et al., 2019).

Recycling of wastewater is an essential component of water demand management, promoting high-quality freshwater protection and reducing both environmental contamination and total water production costs (Eman et al., 2016). One of the current techniques is the use of treated wastewater for irrigation purposes (Angela et al., 2018). Use portion of treated wastewater for agriculture and industrial business helps to relieve pressure on conventional water resources.

In this study, hydroponic system was adopted for the growth of Spinach using the raw wastewater as well as the treated water from Tasik Sri Serdang Lake, Malaysia. In order to provide mechanical support, hydroponics is a method of growing plants in nutrient solutions with or without the use of an inert medium such as gravel, vermiculite, rock wool, peat moss, sawdust, coir dust, coconut fibre, etc. Hydroponics are efficient soilless plant growth systems that are known to be suitable for increased resource performance and better food production sustainability in controlled environments (Gruda 2009; Lakhiar et al. 2018; Savvas and Gruda 2018). In addition to the significant environmental control in modern greenhouses, hydroponic irrigation enhances the water supply and nutrient by controlling the method of irrigation and nutritional availability (Halbert-Howard et al., 2020).

1.2 Problem Statement

Increase in water pollution in Malaysia consequently is reducing the availability of freshwater resources (Siang et al., 2018). In addition, wastewater is usually ignored as return flows for urban agriculture by wastewater recycling application management. Wastewater is traditionally cleaned in a centralized water treatment plant with blackwater (Kai et al., 2018; Mah et al., 2009). Therefore, in order to achieve sustainable development of water resources, Malaysia needs to carefully manage its freshwater resources and to focus on return flows from wastewater. Unfortunately utilizing the wastewater for reuse in field irrigation and farming practices comes with disadvantages. Many studies have shown that a number of organic and inorganic pollutants exist in urban effluents, with heavy metals occurring (Cd, Pb, Mn, Cu, Zn, Fe and Ni) meanwhile, when the exposure period is high, these heavy metals cannot be degraded and are very harmful to animals and plants (Lundy et al., 2020; Low et al., 2016). Several physiological parameters, such as chlorophyll content, tissue water content and membrane stability, are generally measured under water deficit conditions as signs of improved plant growth and development (Jabeen et al., 2019). The presence and translocation of organic micro contaminants (OMCs) to plants in wastewater may pose a risk of human exposure. Generally, it has been found that the amount of wastewater produced by humans significantly exceeds the capacity for cleaning up the environment and is not necessarily good for human health and safety. As populations increase by leaps and bounds, it places more pressure on the environment and threatening sources of fresh water supplies, it is crucial to utilize wastewater for urban agriculture. Moreover the reuse of agro-industrial wastewater in crop irrigation highlights potential challenges that may arise in the vegetable and manufacturing sectors with the closed system, while the reuse of household wastewater in vegetable irrigation identifies crude irrigation problems, especially in developing countries (Adejumoke et al., 2019). Therefore, in order to minimize the potential risk from utilizing the wastewater, a feasible filtration system for wastewater quality enhancement for irrigation use urban agriculture is blooming.

1.3 Aim and Objectives

The study aims to assess treated wastewater irrigation using coconut fiber for Spinach (*Spinacia oleracea L.*) vegetable production.

The objectives of this research work are:

1. To design and fabricate the coconut fiber filtration system for wastewater treatment in irrigation use.
2. To characterize the suitability of irrigation use of wastewater and treated wastewater using WQI.
3. To assess the utilization of treated wastewater irrigation for growing Spinach vegetables.

1.4 Scope of the Study

In this study, the quality of wastewater used for irrigation is determined by conducting experiments according to the quality standard parameters outlined by Malaysia's Department of Environmental (DOE). There are seven (7) main parameters required, which include Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Dissolved Oxygen (DO), Ammonia Nitrogen (AN), pH and heavy metals analysis.

All the procedures involved in conducting the experiments are according to the standard methods used as outlined in Standard Methods for the Examination ofWater and Wastewater (APHA, 2013). The quality of the wastewater to be usedin irrigation is concluded after the completion of all these tests and hence furtherassessment is carried out to find out whether the wastewater is suitable to be used in irrigation directly or a certain degree of pre-treatment required before it is applied in irrigation.

The study also involves the design fabrication and application of filtration system for wastewater in irrigation of vegetables, the coconut fibre is used as the filtration mechanism to reduce contaminant level in wastewater and hence its hazard before it can be used safely for irrigation. The physical and chemicals characteristics of treated wastewater is determined and referred to the water quality guidelines enforced by DOE in order to check the suitability of using treated lake wastewater for irrigation of Spinach. As such, the quality of Spinach produced is to be assessed in terms of growth rate and the color of Spinach leaves and the use of treated wastewater is to be justified for Spinach planting and further comparing it to the yield and quality of Spinach if the untreated wastewater is used instead.

1.5 Significance of Study

Wastewater was used to ensure adequacy of available water as part of fair greensystems. Reuse of wastewater in plant irrigation has been recognized as appropriate and necessary, especially where intensive farming is considered necessary for conversion and poverty alleviation. Since water management to develop farming programs does not require a high expectation of rigidity and ethics such as portable drinking water, the use of purified and desalinated sewage for water system purposes will be advantageous.

Sewage and its substitute material can be commonly used for water systems, and its reuse can bring positive benefits to the farming community. All of these are the meaningful effect that this study could have on the future of the agricultural industry in order to maintain good water body management, in particular, for developing countries with a highly-growing population, it urges the authorities to implement systematic and efficient water management.

1.6 Thesis Outline

Overall, this thesis consists of five (5) sections. Beginning with Chapter 1 and ended with Chapter 5. In Chapter 1, the introduction and overview of the study is presented. The chapters outlined the research background; problem statements related to the study objectives and further elaborate the significance of the study for future use.

Chapter 2 presents the literature review with the extensive study and works done on various topics related to the current study which will help and give general ideas on how the study should be done and what to expect from the outcomes. There are basically a number of major topics to be covered, starting from the introduction to the literature review section. The subsequent major topics are the guidelines and policies on irrigation of wastewater; coconut fibre and its importance on filtration treatment analysis; definition of heavy metals; existing approaches for regulating wastewater reuse in agriculture; advantages of treated and untreated wastewater reuse; disadvantages and drawbacks in utilizing treated and untreated wastewater for irrigation; suggestive measures to mitigate impact of using treated and untreated wastewater; chemical guidelines for wastewater reuse; and potential impacts of wastewater use in agriculture.

The Chapter 3 of this thesis explains in details the methodology, procedures as well as materials involved throughout the study. The first part focused on the raw materials and chemicals used. The second part emphasizes on reagents and their preparation process in order to be used in the study, especially for wastewater quality analysis. To characterize and analyze the wastewater quality, several parameters and tests (physical and chemical) is carried out and a full procedure for each test is explained in details. Following the quality analysis, a filtration system design for the wastewater is explained and further application in vegetable planting is outlined step by step, followed by a final quality assessment of the outcomes (vegetable growth and yield) in which the detailed procedures is included.

Chapter 4 is the results and findings from the whole study and the discussion. The findings is cross-referred or compared to other similar studies previously done by researchers in order to justify the significance of the findings and hence gives credit to the current study. The main parts of Chapter 4 consist of the results obtained from lake wastewater, characterization, analysis and subsequently affect the application of fabricated filtration system in treating lake wastewater. The chapter further focuses on the outcomes of applying wastewater for vegetable planting by observing the vegetable growth and yield and hence the quality of harvested vegetable will be recorded and discussed in details.

Chapter 5 is the conclusions for the whole study where the major findings are presented in summary. In addition to the conclusions, there are recommendations that are deemed necessary or possible for other researchers to continue the topic of study in the future.

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PUBLICATION

Kenneth Ikenna Odoemena, Md Kamal Rowshon and Hasfalina Binti Che Man (2020). Advances in utilization of wastewater in agricultural practice: A Technical *Irrigation and Drainage,* 69(1), 149**–**163. **Published (Q2)**

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