UNIVERSITI PUTRA MALAYSIA

EFFECTIVENESS OF CONSTRUCTED WETLANDS ON WATER QUALITY IMPROVEMENT AT THE NATIONAL HYDRAULIC RESEARCH INSTITUTE OF MALAYSIA LAKE

ALIYU DANJUMA ALIYU

FS 2018 40

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By

ALIYU DANJUMA ALIYU

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

July 2018

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DEDICATION

To the memory of my late loving parents, for their unconditional love while alive on this earth.

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To my siblings, for their understanding, affections, prayers and wholehearted support.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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Chairman : Professor Rusea Go, PhD
Faculty : Science

The use of biological method of constructed wetlands to improve water quality of freshwater bodies in developing countries especially those in the tropical region with high water quality issues have been underutilized and reported. Therefore, the objective of this study is to establish the baseline water quality parameters concentrations of the NAHRIM lake, assess the effectiveness of the constructed wetlands in improving the water quality of the lake as well as determining the level of improvement in the water quality. Sampling and laboratory analysis of the lake water, constructed wetland water, sediment and plant samples were conducted according to the standard water, sediment and plants laboratory methods. Quality control and assurances were used to ensure the accuracy of the methods. ANOVA and Pearson correlation, in addition to water, sediment, plants indices were used to understand the parameters studied. The results shows the total mean concentration of dissolved oxygen (DO): 6.77±1.4mgL^{-1}, chemical oxygen demand (COD): 10.13±1.5mgL^{-1}, biochemical oxygen demand (BOD): 4.54±0.62mgL^{-1}, total suspended solids (TSS): 12.89±5.12mgL^{-1}, total coliform (8671±1762CFU/100mL), Fe (1.33±0.62mgL^{-1}), Mn (0.26±0.09mgL^{-1}) and Al (0.19±0.08mgL^{-1}) of water samples in the lake to be between the national water quality standard class I and II, and exhibited significant difference ($p<0.05$) across the sampling sites. The total mean concentration of COD (20.51±3.4mgL^{-1}), biochemical oxygen demand (5.04±1.8 mgL^{-1}), total suspended solids (53.91±23.72mgL^{-1}), pH (6.51±0.62mgL^{-1}), *E. coli* (6330±2053.23CFU/100mL), total coliform (65700±21884.4CFU/100mL) and Al (8.16±3.5mgL^{-1}) also shows a significant difference ($p<0.05$) in water samples across the wetland sampling sites. COD and BOD are in a strong positive significant correlation (r = 0.700**). Fe (7499.14±762.03mgkg^{-1}), Al (4753.24±990.8mgkg^{-1}), Mn (85.10±25.3mgkg^{-1}), Zn (15.74±4.17mgkg^{-1}), Cr (14±2.73mgkg^{-1}), Pb (3.11±0.78mgkg^{-1}), Ni (2.30±0.41mgkg^{-1}), Cu (1.56±1.1mgkg^{-1}) and Cd

(0.90±0.22mgkg^{-1}) also revealed a significant difference ($p<0.05$) in the sediment samples of the wetlands while Al and Fe (r = 0.933**), Cr and Ni (r = 0.84**), Cu and Fe (r = 0.886**) exhibited a very strong positive correlations. Ten heavy metals were observed for plants samples with total mean concentration of Fe (3338.5±3082mgkg^{-1}), Al (1071.91±944.6mgkg^{-1}), Mn (240±143.07mgkg^{-1}), Zn (25.94±17.21mgkg^{-1}), Ba (13.6±12.1 mgkg^{-1}), Cr (2.8±1.97mgkg^{-1}), Cu (1.86±1.33mgkg^{-1}), Ni (1.00±0.91mgkg^{-1}), Pb (0.8±0.71mgkg^{-1}) and Cd (0.78±0.17mgkg^{-1}) across their tissues. *Thalia* sp., *Cyperus papyrus*, *Nelumbo nucifera* have the best phytoremediation potential for the heavy metals. As compared with the previous study of the lake water pre-constructed wetlands period, with a reported mean of Water Quality Index (WQI) class III (63.01) status, there is an improvement in the water quality due to the achievement of the WQI class II (86.01) status suitable for recreation. This is attributed to the constructed wetland through its accumulation of more contaminants before they get to the lake. Thus, this study suggests that constructed wetlands improve water quality; and this method can be replicated in other lake.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KEBERKESANAN TANAH BENCAH BUATAN DALAM MENINGKATKAN KUALITI AIR DI TASIK INSTITUT PENYELIDIKAN HIDRAULIK KEBANGSAAN MALAYSIA (NAHRIM)

Oleh

ALIYU DANJUMA ALIYU

Julai 2018

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Penggunaan kaedah biologi tanah bencah buatan untuk meningkatkan kualiti air tawar di negara-negara membangun terutamanya di rantau tropika yang menghadapi isu kualiti air yang tinggi kurang dilaksanakan dan dilaporkan. Oleh yang demikian, objektif kajian ini adalah untuk mewujudkan nilai asas kepekatan parameter kualiti air dari tasik NAHRIM, menilai keberkesanan tanah bencah buatan dalam meningkatkan kualiti air tasik serta menentukan tahap peningkatan kualiti air. Persampelan dan analisis makmal bagi air tasik, air tanah bencah buatan, sampel sedimen dan tumbuhan telah dilaksanakan menggunakan kaedah standard air, sedimen dan kaedah makmal tumbuh-tumbuhan. Kawalan dan jaminan kualiti digunakan untuk memastikan ketepatan kaedah.Korelasi ANOVA dan Pearson berserta dengan indeks air, sedimen dan tumbuhan digunakan untuk memahami parameter yang dikaji. Keputusan menunjukkan jumlah kepekatan purata oksigen terlarut (DO): 6.77±1.4mgL^{-1}, permintaan oksigen kimia (COD): 10.13±1.5mgL^{-1}, permintaan oksigen biokimia (BOD): 4.54±0.62mgL^{-1}, jumlah pepejal terampai (TSS): 12.89±5.12mgL^{-1}, jumlah koliform (8671±1762CFU/100mL), Fe (1.33±0.62mgL^{-1}), Mn (0.26±0.09mgL^{-1}) dan Al (0.19±0.08mgL^{-1}) berada dalam lingkungan kelas kualiti air kebangsaan kelas I dan II, dan memperlihatkan perbezaan yang signifikan *($p<0.05$*) di kesemua tapak-tapak sampel. Jumlah kepekatan purata COD (20.51±3.4mgL-1), BOD (5.04±1.8mgL^{-1}), TSS (53.91±23.72mgL-1), pH (6.51±0.62mgL-1), *E. coli* (6330±2053.23CFU/100mL), jumlah koliform (65700±21884.4CFU/100mL) dan Al (8.16±3.5mgL^{-1}) juga menunjukkan perbezaan ketara (*$p<0.05$*) bagi kesemua tapak persampelan di tanah bencah. COD dan BOD mempunyai korelasi positif yang tinggi (r = 0.700**). Fe (7499.14±762.03mgkg^{-1}), Al (4753.24±990.8mgkg^{-1}), Mn (85.10 ± 25.3mgkg^{-1}), Zn (15.74±4.17mgkg^{-1}), Cr (14±2.73mgkg^{-1}) Pb (3.11±0.78mgkg^{-1}), Ni (2.30±0.41mgkg^{-1}), Cu (1.56±1.1mgkg^{-1}) dan Cd (0.90 ± 0.22mgkg^{-1}) juga menunjukkan perbezaan signifikan *($p<0.05$)* bagi sampel sedimen tanah bencah

manakala Al dan Fe (r = 0.933**), Cr dan Ni (r = 0.84**), Cu dan Fe (r = 0.886**) menunjukkan korelasi positif yang amat tinggi. Sepuluh logam berat diperolehi dari sampel tumbuhan dengan jumlah kepekatan purata Fe (3338.5±3082mgkg^{-1}), Al (1071.91±944.6mgkg^{-1}), Mn (240±143.07mgkg^{-1}), Zn (25.94±17.21mgkg^{-1} (13.6±12.1mgkg^{-1}), Cr (2.8±1.97mgkg^{-1}), Cu (1.86±1.33mgkg^{-1}), Ni (1.00±0.91mgkg^{-1}), Pb (0.8±0.71mgkg^{-1}) dan Cd (0.78±0.17mgkg^{-1}) hasil daripada kajian tisu mereka. *Thalia* sp., *Cyperuspapyrus*, *Nelumbonucifera* mempunyai potensi fitoremediasi terbaik untuk logam berat. Berbanding dengan hasil kajian sebelum pewujudan tanah bencah buatan yang melaporkan nilai purata Indeks Kualiti Air (WQI) kelas III (63.01), terdapat peningkatan dalam kualiti air melalui pencapaian kelas WQI II (86.01), yang lebih sesuai untuk kegiatan rekreasi. Ini adalah kerana tanah bencah buatan berjaya mengumpul lebih banyak bahan pencemar air. Oleh itu, kajian ini menunjukkan bahawa tanah bencah buatan dapat meningkatkan kualiti air; dan kaedah ini boleh direplikasikan di tasik-tasik yang lain.

ACKNOWLEDGEMENTS

First and foremost, all glory and adoration are to Allah (SWT) for his benevolence, mercy and blessing and the capability to complete this research.

My appreciation goes to my supervisor, Professor Dr Rusea Go, for her advice, guidance, encouragement and dedication. Sincere thanks are extended to my Co-supervisors, Dr Hishammudin bin Omar and Pn. Syima Syazrin bint Sharifuddin for their patience, guidance, helpful suggestions and constructive comments.

I am appreciative of the support and opportunity that was given to me by Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria to undertake this program. Special thanks to the Tertiary Education Trust Fund (TETFUND), Abuja, Nigeria for the grant to undergo this program. My heartfelt gratitude goes to Encik Azroie, Encik Farrizie and Encik Zulazman as well as Cik Bashirah, Cik Norsalmi and other staffs of the National Hydraulic Research Institute of Malaysia for providing me with the assistance and working environment to accomplish this research. And to my supportive relatives- Alhaji S.N. Mayaki, Alhaji Muazu, Alhaji Ndaman, Hajiya Salamatu, Mrs. Jummai Alhassan (Labai), Mr. Ahmed Shehu and numerous others; I pray Allah should reward you immensely. My deepest gratitude goes to my bosses, Drs. Isah Chado, Adamu, K. M., Usman, I.B., Dadi-Mamud, N.J. and Adebola, M.O as well as other staffs of Biology Department, IBBUL, for their moral support. And finally, a big thank you to my dear colleagues at Universiti Putra Malaysia for their cooperation and help towards making this research a success.

I certify that a Thesis Examination Committee has met on 2 July 2018 to conduct the final examination of Aliyu Danjuma Aliyu on his thesis entitled "Effectiveness of Constructed Wetlands on Water Quality Improvement at the National Hydraulic Research Institute of Malaysia Lake" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

µs/cm	Micro siemens per centimeter
Al	Aluminum
ANOVA	Analysis of Variance
APHA	American Public Health Association
As	Arsenic
B	Boron
Ba	Barium
BCF	Bioconcentration Factor
BOD	Biochemical Oxygen Demand
Ca	Calcium
Cd	Cadmium
CEC	Cation Exchange Capacity
CF	Contamination Factor
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
CWs	Constructed wetlands
DO	Dissolved oxygen
DOE	Department of Environment
E.coli	*Escherichia coli*
EC	Electrical conductivity
ECP	Electro coagulation Process
EF	Enrichment Factor

Eh	Redox potential
EPA	Environmental Protection Agency
Fe	Iron
ICP – MS	Inductively Coupled Plasma- Mass Spectrometry
ICP-OES	Inductively coupled Plasma- Optical Electron Spectrometry
I_{geo}	Geoaccumulation Index
ILEC	International Lake Environmental Committee
ISQG	Interim Sediment Quality Guidelines
K	Potassium
meq/100g	Milliequivalent per 100gram
mg Kg^{-1}.dw	Milligram per Kilogram of dried weight
mg L^{-1}	Milligram per liter
Mg	Magnesium
mL	Milliliter
Mn	Manganese
MPN	Most Probable Number
Na	Sodium
NAHRIM	National Hydraulic Research Institute of Malaysia
NH_3-N	Ammoniacal Nitrogen
Ni	Nickel
NO_2-N	Nitrites
NO_3-N	Nitrates
NTU	Nephelometric Turbidity Unit
NWQS	National Water Quality Standard
PAH	Polyaromatic Hydrocarbon
Pb	Lead

PCB	Polycyclic biphenyl
PO	Phosphorus
ppm	Part per million
SF	Surface Flow
SSF	Subsurface flow
TDS	Total Dissolved Solids
TF	Translocation Factor
TSS	Total Suspended Solids
UN	United Nation
WHO	World Health Organization
WQI	Water Quality Index
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Overview

The presence of natural resources such as water has aided man in adapting to his environment. Their application in domestic, industrial, farming and recreational activities makes them an indispensable assets to man. However, these human activities in addition to the natural factors play an important role in the shrinking of water resources as well as the pollution of the water with substances that may have a direct effect on the health of the living organisms (Hogan, 2012).

Lake is a type of water resources that are designated as places of reflection, recreation, and rehabilitation in addition to serving as storm water retention pond in some instances, but as with all other water bodies, they are being subjected to an increasing pressure and stress by contaminants which results in most of them being degraded (USEPA, 2009). Malaysia has about 90 lakes created to serve the nation in different capacities (Sharip *et al.*, 2008) with the water quality of the majority of them classified as polluted (Mohkeri, 2002). Contaminants like heavy metals and other organic substances are found in discharges/effluents from different sources that include atmospheric deposition, runoff from impervious areas, sewerage treatment plants, and mining industries as well as agro-allied industries (Jackson *et al.*, 2012; Mburu *et al.*, 2013) that usually end up in the water resources, resulting in the degradation of the water quality.

Constructed wetlands (CWs) are biologically designed ecosystems which are imitations of natural wetlands that serve as biofilters to remove various ranges of substances such as nutrients, xenobiotics - a foreign substances that are present within a biological system when they are not expected to be present(Nor Aripin, 2008), organic pollutants, and trace metals from industrial and domestic wastewater discharges within a semi-controlled environment (Brix, 1997; Maine *et al.*, 2007; Vymazal *et al.*, 2010; Zhi and Ji, 2012). CWs are currently being studied for their water quality improvement of different water bodies in different part of the world (Saeed *et al.*, 2012; Zhang *et al.*, 2012; Avila *et al.*, 2013; Martin *et al.*, 2013; Mouru*et al.*, 2013).

1.2 Statement of research problems

Among the importance of freshwater ecosystem like lake is its suitability for aquaculture, sources of food, recreational activities and education. However, due to the climatic changes, anthropogenic activities and rapid expansion in infrastructural development, the available freshwater ecosystem are becoming polluted (UN Water,

2008). The infrastructures usually in the forms of mills, plants, sewerage treatment plants, housing estates as well as domestic and agricultural activities exerts threats to the freshwater quality (Lee *et al.,* 2006; Baha-Elden*et al.,* 2008; Mokhtar *et al.,* 2009b and Juhair*et al.,* 2011). These have been the situations in tropical countries especially the developing ones, where the treatment of effluents before being discharged into water bodies is of low priorities (Konnerup *et al.,* 2011). Moreover, very little information has been reported on the deployment of CWs as contaminant treatment media in the developing countries despite its relative acceptance in the other part of the world (Bojcevska and Tonderski, 2007).

NAHRIM have a pond with natural lake-like features that serve as the storm water retention ponds and the recreational needs of the staffs. The water quality in this pond was affected by the pollution from sewerage treatment plant, sullage water from the administrative office, hydraulic laboratory and runoff from the impervious area surrounding the ponds as well as erosion during heavy rainfall with the combined discharge rate of the contaminants of 163.82m^3/ day (NAHRIM, 2012). Wetlands were constructed to check these contaminants from the sources before getting to the lake. However, assessments of remediation potential of the wetlands with respect to NAHRIM lake water quality improvement have not been carried out. Hence, an attempt was made in this study to assess the effectiveness of NAHRIM constructed wetlands in improving NAHRIM lake water quality to stipulated standard for lake water bodies, designed for recreational contacts by the Department of Environment National Water Quality Standard.

1.3 Objectives of the research

Thus, the objectives of this research are:

1) To establish the baseline concentrations of the water quality parameters and heavy metals of the NAHRIM Lake.
2) To evaluate the remediation process of the NAHRIM Constructed wetlands through the assessment of accumulation of heavy metals and other parameters in the wetlands aquatic plants, the sediments and water components.
3) To determine the level of water quality improvement at the lake through comparison of the water quality data pre and post constructed wetlands.

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