BANANA BLOSSOMS PEELS ADSORBENT FOR THE REMOVAL OF MANGANESE IN WATER

NURUL NADIA BINTI RUDI

A thesis submitted in fulfillment
of the requirement for the award of the
Degree of Master of Engineering Technology

Faculty of Engineering Technology
Universiti Tun Hussein Onn Malaysia

JANUARY 2022

ACKNOWLEDGEMENTS

I would like to express sincere appreciation to my supervisor, Dr Mimi Suliza Binti Muhamad from Department of Civil Engineering Technology, Faculty of Engineering Technology for the support given throughout the duration of this study. Her valuable guidance, encouragement, and sharing expertise from start to finish of this study are highly appreciated.

I also wish to express my sincere thanks to the staffs from Faculty of Engineering Technology for providing me with all the necessary facilities for the research. Their help and support are unforgettable. Besides, I would like to show my gratitude to my fellow friends for sharing their pearls of wisdom and words of encouragement during the completion of this study. I am also immensely grateful to their comments on an earlier version of this thesis.

Finally, I would like to acknowledge with gratitude, the support and love of my family – my parents, Hj. Rudi Abd Bin Latiff and Zamdilaila Binti Ismail; my brothers and sister. They all kept me going, and this thesis would not have been possible without them.

ABSTRACT

Manganese is one of the persistent heavy metals detected in surface water lately that has become an environmental concern because manganese poses negative impacts to the ecosystem and water supply. This study investigates the effectiveness of banana blossom peels (BBP) as an adsorbent for the removal of manganese in water. The BBP adsorbent was activated via chemical treatment method. The Water Quality Index for Sungai Panchor revealed that the river is classified in Class II as clean river with the highest manganese concentration of 0.575 mg/L detected by using ICP-OES. FESEM-EDX analysis showed the morphology of BBP adsorbent was crimped with deeper dents, rough internals surface, and dense in nature, providing maximum surface area for the adsorption process. FTIR analysis confirmed the presence of carboxyl and hydroxyl groups in BBP adsorbent that contribute to the adsorption process. XRD analysis showed that the structure of the BBP adsorbent is amorphous. BET surface area of BBP adsorbent was 2.12 m^2/g with the total pore volume of 0.0139 cm^3/g and average pore diameter of 64.35 nm. Batch adsorption study evaluated the parameters affecting the adsorption process, which include pH, adsorbent dosage, initial manganese concentration, and contact time. The optimum condition was attained at pH 7, adsorbent dosage of 0.5 g, 10 mg/L initial manganese concentration, and 150 minutes contact time. The adsorption isotherm study demonstrated that the Langmuir isotherm model best fit BBP adsorption toward manganese with $R^2 > 0.9963$. The adsorption of manganese followed the pseudo-second-order kinetics representing the chemisorption process. The maximum desorption rate of 92% was achieved in the first cycle, with a recovery rate of 94.18% within 30 minutes using 0.1M HCl. The BBP adsorbent able to remove 55% manganese in Sungai Panchor water sample with an initial manganese concentration of 0.095 mg/L. This study suggests that BBP adsorbent has the potential to be used as an adsorbent for manganese removal in surface water**.**

ABSTRAK

Mangan adalah antara logam berat yang dikesan di dalam air sungai sejak akhir-akhir ini dan menjadi permasalahan kepada alam sekitar kerana mangan akan menyebabkan kesan negatif kepada ekosistem dan juga bekalan air. Kajian ini menyelidiki keberkesanan kulit jantung pisang (BBP) sebagai penjerap untuk menyingkirkan mangan di dalam air. Penjerap BBP telah diaktifkan melalui kaedah kimia dan haba. Hasil Indeks Kualiti Air untuk Sungai Panchor menunjukkan bahawa sungai itu diklasifikasikan sebagai Kelas II, dikategorikan sebagai bersih dengan kepekatan mangan tertinggi sebanyak 0.575 mg/L dikesan menggunakan alat ICP-OES. Analisis FESEM-EDX menunjukkan penjerap BBP adalah berkerut dengan lekukan yang dalam, permukaan dalaman yang kasar dan tebal secara semulajadi di mana menyediakan permukaan yang maksimum untuk proses penjerapan. Analisis FTIR penjerap BBP mengesahkan penglibatan kumpulan karboksil and hidroksil yang menyumbang kepada proses penjerapan. Analisis XRD menunjukkan bahawa struktur penjerap BBP adalah amorfus. Luas permukaan penjerap BBP adalah 2.12 m^2/g dengan jumlah pori 0.0139 cm^3/g dan diameter pori 64.35 nm. Eksperimen penjerapan berkumpulan menilai parameter yang mempengaruhi proses penjerapan termasuklah pH, dos penjerap, kepekatan mangan awal dan masa sentuhan. Keadaan optimum dicapai pada pH 7, dos penjerap 0.5g, kepekatan awal mangan 10 mg/L dan 150 minit masa sentuhan penjerapan. Kajian isoterma penjerapan menunjukkan bahawa model Langmuir merupakan model yang paling sesuai untuk penjerapan BBP terhadap mangan dengan $R^2 > 0.9963$. Penjerapan mangan mengikuti kinetik pseudo-kedua yang mewakili proses kemisorpsi. Kadar penyahjerapan maksimum sebanyak 92% dicapai dalam kitaran pertama dengan kadar pemulihan sebanyak 94.18% dalam 30 minit menggunakan 0.1M HCl. Penjerap BBP mampu menyingkir 55% kandungan mangan di dalam air Sungai Panchor dengan kepekatan awalan mangan 0.095 mg/L. Kajian ini menunjukkan bahawa penjerap BBP berpotensi digunakan sebagai penjerap untuk menyingkirkan mangan dalam air sungai.

CONTENTS

TITLE **i**

DECLARATION **ii**

ACKNOWLEDGEMENTS **iii**

ABSTRACT **iv**

ABSTRAK **v**

CONTENTS **vi**

LIST OF TABLES **x**

LIST OF FIGURES **xi**

LIST OF SYMBOL AND ABBREVIATIONS **xiii**

LIST OF APPENDICES **xvi**

CHAPTER 1 INTRODUCTION **1**

1.1 Background of Study 1

1.2 Problem Statement 3

1.3 Objectives 5

1.4 Scope of the Study 5

1.5 Significance of Study 6

CHAPTER 2 LITERATURE REVIEW **7**

2.1 Surface Water Quality 7

2.1.1 Heavy Metals Contamination in Surface Water 11

2.2 Manganese 12

2.2.1 Sources of Manganese Contamination 13

2.2.2 Occurrences of Manganese Contamination 17

2.2.3 Negative Impacts of Manganese 18
2.2.4 Water Treatment Technology for Manganese Removal 20
2.3 Adsorption Process 22
2.4 Development of Agricultural Waste as Low-Cost Adsorbents for Manganese Removal and Its Mechanism 32
2.5 Banana Blossom Peels 39
2.6 Adsorption Isotherms 43
2.7 Adsorption Kinetics 45
2.8 Desorption Process 49
2.9 Remarks 51

CHAPTER 3 METHODOLOGY 52
3.1 Flow Chart Methodology 52
3.2 Sungai Panchor Water Sample Characterisation 54
3.3 Synthesisation of Banana Blossom Peels Adsorbent 55
3.4 Characterisation of Banana Blossom Peels Adsorbent 61
3.4.1 Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-ray Spectroscopy (EDX) Analysis 61
3.4.2 Fourier Transform Infrared Spectroscopy (FTIR) 61
3.4.3 X-ray Diffraction Analysis (XRD) 61
3.4.4 Brunauer-Emmett-Teller (BET) Analysis 62
3.5 Batch Adsorption Experiment 62
3.5.1 Effect of BBP Dosage on Manganese Removal 63
3.5.2 Effect of pH on Manganese Removal 63

3.5.3 Effect of Initial Manganese Concentration on Manganese Removal 63
3.5.4 Effect of Contact Time on Manganese Removal 63
3.6 Langmuir and Freundlich isotherm 64
3.7 Largergren Kinetic Study 64
3.8 Batch Desorption Experiment 65
3.9 Adsorption Experiment using Sungai Panchor Water Sample 66
3.10 Data Analysis 66

CHAPTER 4 RESULTS AND DISCUSSION 67
4.1 Sungai Panchor Water Sample Characterisation 67
4.2 Characterization of BBP Adsorbent 69
4.2.1 FESEM-EDX Analysis 69
4.2.2 Fourier Transform Infrared Spectroscopy Analysis 71
4.2.3 X-ray Diffraction Analysis 76
4.2.4 Brunauer-Emmett-Teller Analysis 78
4.3 Batch Adsorption Study 79
4.3.1 Effect of BBP Dosage on Manganese Removal 80
4.3.2 Effect of pH on Manganese Removal 84
4.3.3 Effect of Initial Manganese Ion Concentration on Manganese Removal 89
4.4 Langmuir and Freundlich Isotherms 94
4.5 Kinetics Study 96
4.6 Desorption Study 98
4.7 Application of BBP Adsorbent for Manganese Removal from Surface Water 101

CHAPTER 5 CONCLUSION **103**

5.1 Conclusion 103

5.2 Recommendations 104

REFERENCES **108**

APPENDIX A **129**

APPENDIX B **132**

APPENDIX C **133**

VITA **134**

LIST OF TABLES

2.1	Drinking and raw water standard in Malaysia	8
2.2	National water quality standards in Malaysia	9
2.3	Major sources of manganese and other heavy metals from various industries	14
2.4	The occurrences of manganese in river in Malaysia	18
2.5	Comparison of various water treatment technologies for manganese removal	21
2.6	Factors affecting the adsorption process for manganese removal	29
2.7	Production of agricultural residue worldwide	33
2.8	Modification and mechanism of agricultural waste adsorbents for manganese removal	36
2.9	Adsorption isotherms and kinetics of manganese by various adsorbents	47
2.10	Desorption methods for adsorbents	49
3.1	Procedure of surface water characterization	56
3.2	Parameters tested in batch adsorption experiment	64
3.3	Working conditions for adsorption-desorption cycle	66
4.1	Parameter tested for water quality index (WQI)	68
4.2	Manganese concentration detected in Sungai Panchor	68
4.3	The comparison of FTIR analysis of banana-based adsorbent	75
4.4	Comparison of BBP adsorbent BET surface area with other agricultural waste adsorbent	79
4.5	Langmuir and Freundlich isotherm equilibrium parameters for manganese adsorption on BBP adsorbent	96
4.6	Pseudo-first order and Pseudo-second order parameters	98

LIST OF FIGURES

2.1 Classification of the river water quality in Malaysia in 2018 10
2.2 Trend of the river water quality status in Malaysia (2008 – 2020) 11
2.3 Projection of global manganese production (in million tons) from 2012-2022 15
2.4 Routes of manganese contamination 16
2.5 Adsorbent and adsorbate in adsorption process 23
2.6 The mechanism of physical and chemical adsorption 24
2.7 Steps involved in adsorption process 24
2.8 SEM images of (a) raw green tomato husk and (b) formaldehyde green tomato husk adsorbents 37
2.9 FTIR spectra of green tomato hush (H) and formaldehyde modified green tomato husk (FMH) adsorbent 38
2.10 FTIR spectra of (a) untreated SCB and (b) pretreated SCB with hydrochloric acid 38
2.11 Global production of bananas and other fruits 39
2.12 (a) Banana Blossom, (b) peels or bracts, (c) floret 40
2.13 SEM images of GBPs adsorbent (a) before and (b) after the manganese adsorption process 42
2.14 SEM images of BPAC adsorbent (a) before and (b) after the manganese adsorption process 42
3.1 Methodology flow chart of this study 53
3.2 Location of Sungai Panchor 54
3.3 Synthesisation process of BBP adsorbent 60
4.1 (a) Surface morphology and (b) EDX spectrum of pristine BBP adsorbent 70
4.2 (a) Surface morphology and (b) EDX spectrum of BBP adsorbent after manganese adsorption process 71

4.3	FTIR analysis of BBP adsorbent (a) before and (b) after manganese adsorption	74
4.4	XRD pattern of a BBP adsorbent (a) before and (b) after manganese adsorption	77
4.5	Nitrogen adsorption-desorption isotherms and pore size distribution curves (inset) of BBP adsorbent	79
4.6	Effect of BBP adsorbent dosage on manganese removal at pH 4 and manganese concentration of (a)10, (b) 30, and (c) 50 mg/L	81
4.7	Effect of BBP adsorbent dosage on manganese removal at pH 5.5 and manganese concentration of (a)10, (b) 30, and (c) 50 mg/L	82
4.8	Effect of BBP adsorbent dosage on manganese removal at pH 7 and manganese concentration of (a)10, (b) 30, and (c) 50 mg/L	83
4.9	Effect of pH on manganese removal at 0.1 g BBP dosage and manganese concentration of (a)10, (b) 30, and (c) 50 mg/L	86
4.10	Effect of pH on manganese removal at 0.3 g BBP dosage and manganese concentration of (a)10, (b) 30, and (c) 50 mg/L	87
4.11	Effect of pH on manganese removal at 0.5 g BBP dosage and manganese concentration of (a)10, (b) 30, and (c) 50 mg/L	88
4.12	Effect of initial manganese ion concentration on manganese removal at pH 4 and BBP dosage of (a) 0.1, (b) 0.3, and (c) 0.5 g	91
4.13	Effect of initial manganese ion concentration on manganese removal at pH 5.5 and BBP dosage of (a) 0.1, (b) 0.3, and (c) 0.5 g	92
4.14	Effect of initial manganese ion concentration on manganese removal at pH 7 and BBP dosage of (a) 0.1, (b) 0.3, and (c) 0.5 g	93
4.15	Langmuir isotherm for manganese adsorption of BBP adsorbent	94
4.16	Freundlich isotherm for manganese adsorption of BBP adsorbent	95
4.17	Pseudo-first order kinetic plots for manganese adsorption on BBP adsorbent	97
4.18	Pseudo-second order kinetic plots for manganese adsorption on BBP adsorbent	98
4.19	Desorption of manganese by BBP adsorbent	100
4.20	Recovery of manganese removal by BBP adsorbent	100
4.21	Manganese removal by BBP adsorbent in surface water sample	102

LIST OF SYMBOL AND ABBREVIATIONS

%	-	Percentage
cm	-	Centimeter
g	-	Gram
mg	-	Milligram
ml	-	Milliliters
L	-	Liters
V	-	Volume
µg/L	-	Microgram per liter
mg/L	-	Milligram per liter
mg/g	-	Milligram per gram
g/cm^3	-	Gram per centimeter cube
g/mol	-	Gram per mole
g/L	-	Gram per liter
g/mg.min	-	Gram per milligram minute
moles/L	-	moles per liter
rpm	-	Revolution per meter
λ	-	Lambda
^oC	-	Degree Celsius
s	-	Second
min	-	Minute
IQ	-	Intelligence Quotient
MT	-	Million tones
MOH	-	Ministry of Health
BBP	-	Banana Blossom Peels
DOE	-	Department of Environment
FESEM	-	Field emission scanning electron microscopy
EDX	-	Energy-dispersive X-ray spectroscopy

FTIR	-	Fourier-transform infrared spectroscopy
XRD	-	X-ray Diffraction
BET	-	Brunauer-Emmett-Teller
ICP-OES	-	Inductively coupled plasma – optical emission spectrometry
MLD	-	Million per day
INWQS	-	Interim National Water Quality Standards
NAHRIM	-	National Hydraulic Research Institute of Malaysia
Mn	-	Manganese
WHO	-	World Health Organization
APHA	-	American Public Health Association
EPA	-	United States Environmental Protection Agency
EC	-	Electrocoagulation
EO	-	Electrochemical oxidation
RO	-	Reverse osmosis
UF	-	Ultrafiltration
MF	-	Microfiltration
NF	-	Nanofiltration
PVA/CS	-	Polyvinyl alcohol/chitosan
ΔG^0	-	Gibbs energy change
ΔH^0	-	Enthalpy change
ΔS^0	-	Entropy change
kJ/mol	-	Kilo joule per mol
K	-	Thermodynamic equilibrium constant
T	-	Absolute temperature in Kelvin
R	-	Gas constant
NaOH	-	Sodium hydroxide
$NaHCO_3$	-	Sodium bicarbonate
H_2SO_4	-	Sulfuric acid
HNO_3	-	Nitric acid
H_3PO_4	-	Phosphoric acid
$NaNO_3$	-	Sodium Nitrate
Na_2EDTA	-	Disodium salt dihydrate

HCl	-	Hydrochloric acid
DO	-	Dissolve Oxygen
COD	-	Chemical oxygen demand
BOD	-	Biochemical oxygen demand
TSS	-	Total suspended solid
WQI	-	Water quality index
R^2	-	Correlation coefficient
K_L	-	Langmuir constant
K_F	-	Freundlich constant
N	-	Intensity
q_{max}	-	Adsorption capacity

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Correlation of adsorbent dosage with other parameters	129
B	Adsorption capacity	132
C	Master Gantt Chart	133

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water plays crucial role in human survivability and national development. Therefore, it has to be safe, clean and palatable for consumption (Alam *et al.*, 2018). Water supply in Malaysia is mainly extracted from surface water sources, particularly from a river and in some areas from groundwater sources (Moni *et al.*, 2017). In general, surface water with minimum treatment is potable if it is not affected by anthropogenic activities. However, rivers nowadays have been used as disposal routes for liquid and solid waste, mainly from residential, agricultural and industrial activities (Afroz *et al.*, 2014). The river water quality in Malaysia is worsening due to the rapid development in various sectors and population growth, contributing to the increase in water pollution. The pollution has made the water quality issue becomes a great concern, and access to clean water sources has become challenging over the years (Ashraf and Hanfiah, 2017; Ghani *et al.*, 2017).

Heavy metal pollution has gained public attention in recent decades due to its abundance, persistence, and toxicity in water that cause many environmental problems and pose a threat to human health when present in drinking water (Fallahzadeh *et al.*, 2017; Salam *et al.*, 2019). The situation worsens as heavy metals are not degraded naturally and persist in the sediment of water bodies (Paul, 2017). Industries that caused an abundance of production of heavy metal, such as the chemical manufacturing industry, mining, municipal effluents, and other anthropogenic activities, has contributed to heavy metal pollution (Salam *et al.*, 2019). Non-industrialised areas were also severely contaminated due to the widespread of heavy metals along the river (Wu *et al.*, 2016). Heavy metals such as manganese, copper, zinc, and iron are needed as nutrients in small quantities. However, these metals can cause deterioration to the human body at higher concentrations or excess consumption in the long term (Paul, 2017). Some heavy metals may have acute or chronic impacts when present in aquatic habitats, drinking water sources, and recreational water bodies (Huber *et al.*, 2016).

Manganese (Mn) is a trace metal that is found mainly as oxides, carbonates, and silicates in many different minerals, with pyrolusite (manganese dioxide) as the most common naturally-occurring form (Milatovic and Gupta, 2018). Manganese can be found abundantly in the earth's crust and water sources, which exist in a broad range of oxidation states and species in the water (Tobiason *et al.*, 2016). Manganese has been commonly detected in surface water which resulted in major water quality issues over the years. Manganese has been found in various types of agricultural, municipal, domestic and industrial wastewaters effluent (Marsidi *et al.*, 2018). Industries dealing with metals such as steel alloy production, battery manufacturing, pesticides, mine quarry operations and pharmaceuticals contributes to manganese pollution and its release to the environment, especially through wastewater discharges (Mthombeni *et al.*, 2016). Therefore, it is necessary to remove manganese from surface water.

The World Health Organization (2011) has set the standard of 0.05 mg/L as the maximum manganese concentration level in domestic water supplies. A high level of manganese in drinking water that exceeds the permissible value is considered unacceptable because it affects not only the aesthetic water quality, but also operational problems in the distribution systems, such as iron pipe corrosion. Manganese causes turbidity and a black-brown colour to drinking water (Tobiason *et al.*, 2016; Rose *et al.*, 2017). Excessive manganese accumulation in specific brain areas produces neurotoxicity, leading to degenerative brain disorder (Milatovic and Gupta, 2018). The initial toxic symptom associated with manganese is a psychiatric nature disorder known as *locura manganica* resembling schizophrenia, followed by a permanently crippling neurological (extrapyramidal) disorder that is clinically similar to Parkinson's disease (Bjørklund *et al.*, 2017).

High manganese concentrations have been found in some Malaysian rivers. The highest manganese concentration of 4.7 mg/L was detected at Kepayang River, Perak (Affandi and Ishak, 2018). Apart from that, high manganese concentrations that exceed the standard for raw and drinking water were also found in the Kelantan River Basin, Benut river, Sembilang River, Langat River, Kerian River, Semenyih River and

Sedili Kecil River (M. *et al.*, 2012; Al-Badaii *et al.*, 2016; Ismail *et al.*, 2017; O. Basheer *et al.*, 2017; Ibrahim *et al.*, 2020; Mohamed *et al.*, 2020b; Abdul Maulud *et al.*, 2021). The high manganese concentrations reported in these rivers could be attributed to mining activities, industrial sewage, agricultural activities, and also industrial effluents. Since water used mainly derived from surface water, the water source should be safe and palatable for consumption and drinking, without harmful contamination of manganese.

Various treatment technologies have been developed to treat surface water that contains manganese. The adsorption process is one of the potential alternatives for low-cost and efficient methods to improve surface water quality (Burakov *et al.*, 2018). This process has been broadly studied to develop high selectivity and efficient adsorbent materials (Liu *et al.*, 2017b; Sajid *et al.*, 2018). Adsorption is a simple process that can be synthesised from waste materials (Jain *et al.*, 2016). The materials for adsorbents are relatively cheap, less toxic, easy to functionalise over other substrates, and highly efficient. Many factors affect the efficiency of adsorbents, including initial concentration, temperature, adsorbent dose, pH, contact time, and stirring speed (Cermakova *et al.*, 2017).

Banana blossom peels (BBP) are considered one of the new and potential materials for the adsorption of heavy metals (Padmaja, 2017). To date, investigations on banana blossom peel as adsorbent had only been studied on lake water sample. The results showed that BBP adsorbent was able to reduce 79.72% turbidity, 88.24% total solids, 90.15% electrical conductivity, and 61.01% chloride in the lake water sample (Gopakumar *et al.*, 2018). However, there is insufficient technical information regarding the synthesis process of the adsorbent, mechanism of the adsorption process and effects of parameters that govern the adsorption process. In order to produce a safe and cost-effective method in treating surface water containing manganese, this study investigates the synthesis process of BBP as an adsorbent.

1.2 Problem Statement

Sungai Panchor has been used as the water source for the people in Pekan Panchor, Muar, Johor since 2017 according to data by Department of Environment (DOE, 2018). In 2018, the Department of Environment Malaysia reported that Sungai Panchor was slightly polluted (Class III) with a water quality index (WQI) of 61 and needed extensive water treatment. The need for treatment is due to the anthropogenic activities resulted from agricultural runoff from palm oil plantations nearby, construction, domestic waste, residential, food stalls, and natural erosion (Rosman, 2016). The demand for clean water is increasing as the population of Pekan Panchor increases (DOSM, 2020). Furthermore, the anthropogenic activities had caused issues of nutrients and minerals contamination in the river, especially manganese ions. Hence, it is important to remove manganese from the river water by employing an effective treatment process.

Several techniques can be applied to remove manganese from water, including precipitation, coagulation/flocculation, ion exchange, membrane filtration, and oxidation (Patil *et al.*, 2016). All these methods have drawbacks of the expensive and complex process except for adsorption. Adsorption is preferable owing to cost-effectiveness and high efficiency in removing contaminants.

In the adsorption process, the adsorbents from agricultural waste must be pre-treated by chemicals to prevent secondary pollution and increase the adsorption capacity in terms of the existence of hydroxyl and carbonyl groups in their molecular structure. The use of natural agricultural wastes usually contributes to problems such as high concentration of chemical oxygen demand, biological oxygen demand, total organic carbon, and low adsorption capacity value. The problems are due to the released of soluble organic compounds in the plant resulting in secondary pollution (Acharya *et al.*, 2018).

This study intends to investigate the use of low-cost BBP adsorbent to remove manganese from water. The BBP is considered waste because only a few types of banana blossom are suitable to be consumed. The banana blossom has to be harvest to enhance the quality of banana fruits. The harvesting generates a significant amount of waste (Palomo, 2018). Moreover, the usage of banana wastes such as its peels and blossom peels are increasing. Hence, the utilisation of BBP would reduce the overall banana waste disposal problems.

Recent research on the utilisation of BBP as an adsorbent is very limited, and the only reported research was successfully conducted by Padmaja (2017) for dye removal. Understanding the capability of BBP as a new potential adsorbent to adsorb manganese can help in future studies. Furthermore, the major characteristics of banana blossom peel that contributes to the manganese removal are its chemical composition consisting of cellulose and lignin, which contain a variety of functional groups.

1.3 Objectives

This study aims to synthesise and evaluate the performance of the BBP adsorbent to remove manganese in water. It embarks on the following objectives:

(i) To synthesise BBP as an adsorbent using a chemical treatment method and characterise its physiochemical properties.
(ii) To investigate the effects of adsorbent dosage, pH, manganese initial concentration, and contact time toward manganese removal using the BBP adsorbent.
(iii) To elucidate the adsorption mechanism of BBP adsorbent by isotherm and kinetic study.
(iv) To determine the reusability of the manganese-loaded BBP adsorbent.

1.4 Scope of the Study

The scope of this study includes the collection of water samples conducted at Sungai Panchor, Muar, Johor, and the evaluation of water quality of Sungai Panchor. Furthermore, manganese concentrations in Sungai Panchor were detected for several weeks under different weather conditions.

BBP was synthesised as an adsorbent via a chemical treatment method using hydrochloric acid (HCl) and sodium hydroxide (NaOH). The BBP adsorbent was characterised before and after the adsorption process by using field emission scanning electron microscopy (FESEM), energy-dispersive X-ray spectroscopy (EDX) analysis, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD) analysis, and Brunauer-Emmett-Teller (BET) analysis.

The performance of BBP adsorbent in removing manganese was evaluated using batch adsorption experiments. The investigated parameters include the effects of adsorbent dosage (0.1g, 0.3g, 0.5g), pH (4, 5.5, 7), and manganese initial concentration (10 mg/L, 30 mg/L, 50 mg/L) toward contact time (5, 10, 30, 60, 90, 120, 150 min). The concentrations of manganese ions before and after adsorption were evaluated using inductively coupled plasma optical emission spectrometry (ICP-OES).

The adsorption isotherm data obtained at different manganese concentrations were analysed by the Langmuir and Freundlich isotherm models. The experimental data were further analysed using pseudo-first-order and pseudo-second-order models to elucidate the adsorption kinetic of manganese onto BBP adsorbent.

The reusability of BBP adsorbent was investigated using HCl as desorbing agent up to three desorption cycles. The potential application of the BBP adsorbent was evaluated in a batch adsorption study using surface water from Sungai Panchor to test manganese removal efficiency.

1.5 Significance of Study

The significance of this study to the field of water treatment technology is the new knowledge on the synthesis and application of BBP adsorbent for the removal of manganese. There have been many previous studies on the performances of various adsorbents for removing manganese. However, none have reported on the removal of manganese using BBP as a low-cost and environmentally friendly adsorbent.

Hence, this study intends to establish new knowledge on the effects of pH, adsorbent dosage, and manganese concentration against contact time using BBP adsorbent. This study also analysed in detail the manganese removal capability, characteristics, and mechanism involved in the adsorption process.

The knowledge on the synthesis of BBP adsorbent towards future research is important because it can be applied by the waterworks industry in Malaysia that demands economic and effective processes.

In addition, the BBP adsorbent has the potential to improve the quality of surface water by reducing manganese concentration. The porous surface structure and functional groups generated in the synthesis process can promote adsorption, thereby enhancing manganese removal by the adsorbent.

The toxicity caused by the excessive exposure and long-term effects of manganese in surface water on human health can be reduced. The BBP adsorbent is a new alternative towards an effective water treatment process in removing manganese from surface water.

CHAPTER 2

LITERATURE REVIEW

This chapter provides an overview of surface water contamination and information on heavy metal contamination caused by industrial activities. The occurrences of manganese, the negative impacts on living organisms, and the application of the adsorption process for its removal in water treatment are discussed in this chapter. After the adsorption, this chapter also explains the reusability process that helps maintain adsorbent performances. The adsorption mechanism of manganese ions and the adsorbent is further elucidated in isotherm and kinetic study.

Previous studies revealed the development of various agricultural waste as low-cost adsorbents to remove manganese, which provide insight for this study to improve the adsorbent properties. The utilisation of banana blossom peels (BBP) portrays a potential new adsorbent as described by its characteristics and efficiency. The application of BBP adsorbent is also possible for a future low-cost adsorbent in the water treatment process.

2.1 Surface Water Quality

Water is an essential component in life; for social and economic development (Ahmed *et al.*, 2014). It is needed for cell growth, body coolant, tissue protection, digestion, adsorption, excretory system, and maintaining a good weight (Marsidi *et al.*, 2018). In Malaysia, 98% of the total water used is mainly derived from the river, whereas the remaining 1% originates from groundwater (Lee Goi, 2020). In 2020, the population in Malaysia was approximately 32.7 million and projected to increase yearly (DOSM, 2021). Water usage in Malaysia was estimated to rise to approximately 25,455 million litter per day (MLD) in 2050. Nevertheless, the common issue of surface water is the sources that are prone to pollution and water level declined during the dry season (Kasim *et al.*, 2016). Most rivers in Malaysia have been used as dumping sites for toxic wastes, especially heavy metals discharged from industry (Daniel and Kawasaki, 2016). In regard to this, the Ministry of Health (MOH), Malaysia, has set guidelines for Malaysia standard drinking water quality and raw water quality, as shown in Table 2.1.

Table 2.1: Drinking and raw water standard in Malaysia (Ministry of Health Malaysia, 2012)

Parameter	**Group**	**Recommended Raw Water Quality**	**Drinking Water Quality Standards**
		Acceptable Value (mg/litre (unless otherwise stated))	**Maximum Acceptable Value (mg/litre (unless otherwise stated))**
pH	1	5.5 - 9.0	6.5 - 9.0
Turbidity	1	1000 NTU	5 NTU
Temperature	1	-	-
Ammonia Nitrogen	2	1.5	1.5
Chemical Oxygen Demand (COD)	2	10	-
Biochemical Oxygen Demand (BOD)	2	6	-
Manganese	2	0.2	0.1

Table 2.2 depicts the National Water Quality Standards for Malaysia according to its classes. Surface water quality could be gradually improved or upgraded to be a better water class based on the standard values of 72 parameters in 6 water use classes. The Interim National Water Quality Standards (INWQS) has defined six different river classes (I, IIA, IIB, III, IV, and V) based on their classification, descending water quality and uses. Class I is referred to as the best, while water quality for class IV is very poor.

Table 2.2: National water quality standards in Malaysia (INWQS, 2016)

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	>2.7
BOD	mg/l	1	3	3	6	12	>12
COD	mg/l	10	25	25	50	100	>100
DO	mg/l	7	5-7	5-7	3-5	<3	<1
pH	-	6.5-8.5	6-9	6-9	5-9	5-9	-
TSS	mg/l	25	50	50	150	300	300
Temperature	ºC	-	Normal	-	Normal	-	-
Turbidity	NTU	5	50	50	-	-	-
Manganese	mg/l	Absent	0.1	0.1	0.1	0.2	Above
Water Quality Index	-	<92.7	76.5-92.7	76.5-92.7	51.9-76.5	31.0-51.9	>31.0

Remarks:

Class I — Conservation of natural environment.
Water Supply I - Practically no treatment necessary.
Fishery I - Very sensitive aquatic species.

Class IIA — Water Supply II - Conventional treatment required.
Fishery II - Sensitive aquatic species.

Class IIB — Recreational use with body contact.

Class III — Water Supply III - Extensive treatment required.
Fishery III - Common, of economic value and tolerant species; livestock drinking.

Class IV — Irrigation.

Class V — None of the above.

REFERENCES

A. Akl, M. (2013) Removal of Iron and Manganese in Water Samples Using Activated Carbon Derived from Local Agro-Residues. *Journal of Chemical Engineering & Process Technology*, 04.

Abdeen Somaia, Z., Mohammad, G., and Mahmoud, M.S. (2014) Adsorption of Mn (II) Ion on Polyvinyl Alcohol/Chitosan Dry Blending from aqueous solution. *Environmental Nanotechnology, Monitoring & Management*, 14, 1–35. Elsevier B.V.

Abdeen, Z., Mohammad, S.G., and Mahmoud, M.S. (2015) Adsorption of Mn (II) ion on polyvinyl alcohol/chitosan dry blending from aqueous solution. *Environmental Nanotechnology, Monitoring and Management*, 3, 1–9. Elsevier B.V.

Abdelfattah, I., Ismail, A.A., Sayed, F. Al, Almedolab, A., and Aboelghait, K.M. (2016) Biosorption of heavy metals ions in real industrial wastewater using peanut husk as efficient and cost effective adsorbent. *Environmental Nanotechnology, Monitoring & Management*, 6, 176–183.

Abdić, Memić, M., Šabanović, E., Sulejmanović, J., and Begić, S. (2018) Adsorptive removal of eight heavy metals from aqueous solution by unmodified and modified agricultural waste: tangerine peel. *International Journal of Environmental Science and Technology*, 15, 2511–2518. Springer Berlin Heidelberg.

Abdul Maulud, K.N., Fitri, A., Wan Mohtar, W.H.M., Wan Mohd Jaafar, W.S., Zuhairi, N.Z., and Kamarudin, M.K.A. (2021) A study of spatial and water quality index during dry and rainy seasons at Kelantan River Basin, Peninsular Malaysia. *Arabian Journal of Geosciences*, 14.

Acharya, J., Kumar, U., and Rafi, P.M. (2018) Removal of Heavy Metal Ions from Wastewater by Chemically Modified Agricultural Waste Material as Potential Adsorbent-A Review. *International Journal of Current Engineering and*

Technology, 8, 526–530.

Acharya, S., Tazeen, H., and Birwal, P. (2019) Review On : Production of Natural Banana Blossom Concentrate. *International Conference on Eares 2019*, 8, 1–3.

Adekola, F.A., Hodonou, D.S.S., and Adegoke, H.I. (2016) Thermodynamic and kinetic studies of biosorption of iron and manganese from aqueous medium using rice husk ash. *Applied Water Science*, 6, 319–330.

Adeogun, A.I., Idowu, M.A., Ofudje, A.E., Kareem, S.O., and Ahmed, S.A. (2013) Comparative biosorption of Mn(II) and Pb(II) ions on raw and oxalic acid modified maize husk: kinetic, thermodynamic and isothermal studies. *Applied Water Science*, 3, 167–179.

Affandi, F.A. and Ishak, M.Y. (2018) Heavy Metal Concentrations in Tin Mine Effluents in Kepayang River, Perak, Malaysia. *Journal of Physical Science*, 29, 81–86.

Afroz, R., Masud, M.M., Akhtar, R., and Duasa, J.B. (2014) Water pollution: Challenges and future direction for water resource management policies in malaysia. *Environment and Urbanization ASIA*, 5, 63–81.

Afroz, R., Banna, H., Masud, M.M., Akhtar, R., and Yahaya, S.R. (2016) Household's perception of water pollution and its economic impact on human health in Malaysia. *Desalination and Water Treatment*, 57, 115–123.

Afroze, S. and Sen, T.K. (2018) A Review on Heavy Metal Ions and Dye Adsorption from Water by Agricultural Solid Waste Adsorbents. *Water, Air, & Soil Pollution*, 229, 225.

Agarwal, A., Upadhyay, U., Sreedhar, I., Singh, S.A., and Patel, C.M. (2020) A review on valorization of biomass in heavy metal removal from wastewater. *Journal of Water Process Engineering*, 38, 101602. Elsevier Ltd.

Ahmed, A.., Darweesh, M.., Mahgoub, F.., and Hamad, W.. (2019) Adsorption Kinetic Study for Removal of Heavy Metal from Aqueous Solution by Natural Adsorbent. *DJ Journal of Engineering Chemistry and Fuel*, 4, 12–26.

Ahmed, F., Siwar, C., and Begum, R.A. (2014) Water resources in Malaysia: Issues and challenges. *Journal of Food, Agriculture and Environment*, 12, 1100–1104.

Ahmed, M.J.K. and Ahmaruzzaman, M. (2016) A review on potential usage of industrial waste materials for binding heavy metal ions from aqueous solutions. *Journal of Water Process Engineering*, 10, 39–47.

Ahmed, S.A., El-Roudi, A.M., and Salem, A.A.A. (2015) Removal of Mn(II) from ground water by solid wastes of sugar industry. *Journal of Environmental Science and Technology*, 8, 338–351. Science Alert.

Aji, M.M., Gutti, B., and Highina, B.K. (2015) Application of Activated Carbon in Removal of Iron and Manganese From Alau Dam Water in Maiduguri. *Colombian Journal of Life Science*, 17, 35–39.

Al-Badaii, F., Abdul Halim, A., and Shuhaimi-Othman, M. (2016) Evaluation of dissolved heavy metals in water of the Sungai Semenyih (Peninsular Malaysia) using environmetric methods. *Sains Malaysiana*, 45, 841–852.

Al-Ghouti, M.A. and Da'ana, D.A. (2020) Guidelines for the use and interpretation of adsorption isotherm models: A review. *Journal of Hazardous Materials*, 393, 122383. Elsevier.

Al-Jubouri, S.M. and Holmes, S.M. (2017) Hierarchically porous zeolite X composites for manganese ion-exchange and solidification: Equilibrium isotherms, kinetic and thermodynamic studies. *Chemical Engineering Journal*, 308, 476–491.

Alaei Shahmirzadi, M.A., Hosseini, S.S., Luo, J., and Ortiz, I. (2018) Significance, evolution and recent advances in adsorption technology, materials and processes for desalination, water softening and salt removal. *Journal of Environmental Management*, 215, 324–344. Elsevier Ltd.

Alam, L., Mokhtar, M., Ta, G.C., Lee, K.E., and Latif, M.T. (2018) Environmental Scan and Framework of Watershed Risk Assessment in Malaysia. *Environmental Risk Analysis for Asian-Oriented, Risk-Based Watershed Management*, 105–121.

Ali, A. (2017) Removal of Mn(II) from water using chemically modified banana peels as efficient adsorbent. *Environmental Nanotechnology, Monitoring and Management*, 7, 57–63. Environmental Nanotechnology, Monitoring & Management.

Ali, A. and Saeed, K. (2015) Decontamination of Cr(VI) and Mn(II) from aqueous media by untreated and chemically treated banana peel: a comparative study. *Desalination and Water Treatment*, 53, 3586–3591.

Ali, A., Saeed, K., and Mabood, F. (2016a) Removal of chromium (VI) from aqueous medium using chemically modified banana peels as efficient low-cost adsorbent. *Alexandria Engineering Journal*, 55, 2933–2942. Faculty of Engineering, Alexandria University.

Ali, I. and Gupta, V.K. (2007) Advances in water treatment by adsorption technology. *Nature Protocols*, 1, 2661–2667.

Ali, I., Asim, M., and Khan, T.A. (2012) Low cost adsorbents for the removal of organic pollutants from wastewater. *Journal of Environmental Management*, 113, 170–183. Elsevier Ltd.

Ali, M.M., Ali, M.L., Islam, M.S., and Rahman, M.Z. (2016b) Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring and Management*, 5, 27–35. Environmental Nanotechnology, Monitoring & Management.

Ali, R.M., Hamad, H.A., Hussein, M.M., and Malash, G.F. (2016c) Potential of using green adsorbent of heavy metal removal from aqueous solutions: Adsorption kinetics, isotherm, thermodynamic, mechanism and economic analysis. *Ecological Engineering*, 91, 317–332. Elsevier B.V.

Aljeboree, A.M., Alshirifi, A.N., and Alkaim, A.F. (2017) Kinetics and equilibrium study for the adsorption of textile dyes on coconut shell activated carbon. *Arabian Journal of Chemistry*, 10, S3381–S3393.

Alvarez-Bastida, C., Martínez-Miranda, V., Solache-Ríos, M., Linares-Hernández, I., Teutli-Sequeira, A., and Vázquez-Mejía, G. (2018) Drinking water characterization and removal of manganese. Removal of manganese from water. *Journal of Environmental Chemical Engineering*, 6, 2119–2125. Elsevier B.V.

Ambrose, D.C.P., Sumithra, V., Vijay, K., and Vinodhini, K. (2018) Techniques to Improve the Shelf Life of Freshly Harvested Banana Blossoms. *Current Agriculture Research Journal*, 6, 141–149.

Anand, S. and Sharma, M. (2019) Product Development from Banana Blossom Powder and Indian Gooseberry Powder for Anaemic Adolescent Girls. *International Journal of Health Sciences anad Research*, 9, 273–278.

Anastopoulos, I., Bhatnagar, A., Hameed, B.H., Ok, Y.S., and Omirou, M. (2017) A review on waste-derived adsorbents from sugar industry for pollutant removal in water and wastewater. *Journal of Molecular Liquids*, 240, 179–188. Elsevier B.V.

Anastopoulos, I., Pashalidis, I., Hosseini-Bandegharaei, A., Giannakoudakis, D.A., Robalds, A., Usman, M., Escudero, L.B., Zhou, Y., Colmenares, J.C., Núñez-Delgado, A., and Lima, É.C. (2019) Agricultural biomass/waste as adsorbents for toxic metal decontamination of aqueous solutions. *Journal of Molecular Liquids*, 295.

Anu, Y. (2015) Bioremediation of wastewater using various sorbents and vegetable enzymes. *Research in Biotechnology*, 6, 16–23.

Ashraf, A., Bibi, I., Niazi, N.K., Ok, Y.S., Murtaza, G., Shahid, M., Kunhikrishnan, A., Li, D., and Mahmood, T. (2017) Chromium(VI) sorption efficiency of acid-activated banana peel over organo-montmorillonite in aqueous solutions. *International Journal of Phytoremediation*, 19, 605–613.

Ashraf, M.A. and Hanfiah, M.M. (2017) Recent advances in assessment on clear water, soil and air. *Environmental Science and Pollution Research*, 24, 22753–22754. Environmental Science and Pollution Research.

Awedem, W.F., Achu, M.B.L., and Happi, E.T. (2015) Nutritive Value of three varieties of banana and plantain blossoms from Cameroon. *Greener Journal of Agricultural Sciences*, 5, 052–061.

Ayawei, N., Ebelegi, A.N., and Wankasi, D. (2017) Modelling and Interpretation of Adsorption Isotherms. *Journal of Chemistry*, 2017.

Azimi, A., Azari, A., Rezakazemi, M., and Ansarpour, M. (2017) Removal of Heavy Metals from Industrial Wastewaters: A Review. *ChemBioEng Reviews*, 4, 37–59.

Badrealam, S., Darrell, V.C., Dollah, Z., Mohamed Latiff, M.F.P., and Handan, R. (2019) Adsorption of manganese and zinc in synthetic wastewater by tea waste (TW) as a low cost adsorbent. *Journal of Physics: Conference Series*, 1349.

Baird, R.B., Eaton, A.D., and Rice, E.W. (2013) *Standard Methods for the Examination of Water and Wastewater*. P. in: *American Public Health Association*. 23rd edition. American Public Health Association, American Water Works Association, Water Environment Federation, 522–527 pp.

Bangaraiah, P. (2018) Biosorption of Manganese using Tamarind fruit Shell Powder as a Biosorbent. *Research Journal of Pharmacy and Technology*, 11, 4313.

Baral, S.S., Das, N., Roy Chaudhury, G., and Das, S.N. (2009) A preliminary study on the adsorptive removal of Cr(VI) using seaweed, Hydrilla verticillata. *Journal of Hazardous Materials*, 171, 358–369.

Bediako, J.K., Sarkar, A.K., Lin, S., Zhao, Y., Song, M.H., Choi, J.W., Cho, C.W., and Yun, Y.S. (2019) Characterization of the residual biochemical components of sequentially extracted banana peel biomasses and their environmental remediation applications. *Waste Management*, 89, 141–153. Elsevier Ltd.

Begum, Y.A. and Deka, S.C. (2019) Chemical profiling and functional properties of dietary fibre rich inner and outer bracts of culinary banana flower. *Journal of Food Science and Technology*, 56, 5298–5308. Springer India.

Bjørklund, G., Chartrand, M.S., and Aaseth, J. (2017) Manganese exposure and neurotoxic effects in children. *Environmental Research*, 155, 380–384.

Bouchard, M.F., Surette, C., Cormier, P., and Foucher, D. (2018) Low level exposure to manganese from drinking water and cognition in school-age children. *NeuroToxicology*, 64, 110–117. Elsevier B.V.

Van der Bruggen, B. (2014) Freundlich Isotherm. Pp. 1–2 in: *Encyclopedia of Membranes* (E. Drioli and L. Giorno, editors). Springer Berlin Heidelberg, Berlin, Heidelberg.

Burakov, A.E., Galunin, E. V., Burakova, I. V., Kucherova, A.E., Agarwal, S., Tkachev, A.G., and Gupta, V.K. (2018) Adsorption of heavy metals on conventional and nanostructured materials for wastewater treatment purposes: A review. *Ecotoxicology and Environmental Safety*, 148, 702–712. Elsevier Inc.

Carolin, C.F., Kumar, P.S., Saravanan, A., Joshiba, G.J., and Naushad, M. (2017) Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review. *Journal of Environmental Chemical Engineering*, 5, 2782–2799. Elsevier B.V.

Cermakova, L., Kopecka, I., Pivokonsky, M., Pivokonska, L., and Janda, V. (2017) Removal of cyanobacterial amino acids in water treatment by activated carbon adsorption. *Separation and Purification Technology*, 173, 330–338. Elsevier B.V.

Chatterjee, A. and Abraham, J. (2019) Desorption of heavy metals from metal loaded sorbents and e-wastes: A review. *Biotechnology Letters*, 41, 319–333. Springer Netherlands.

Chen, L., Fang, Y., Jin, Y., Chen, Q., Zhao, Y., Xiao, Y., and Zhao, H. (2015) Biosorption of Cd2+ by untreated dried powder of duckweed Lemna aequinoctialis. *Desalination and Water Treatment*, 53, 183–194.

Chowdhury, Z.Z. (2013) Preparation , Characterization and Adsorption Studies of Heavy Metals Onto Activated Adsorbent Materials Derived From Agricultural Residues Thesis Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy Department of Chemistry F. 1–42.

Crini, G., Lichtfouse, E., Wilson, L.D., and Morin-Crini, N. (2019) Conventional and non-conventional adsorbents for wastewater treatment. *Environmental Chemistry Letters*, 17, 195–213. Springer International Publishing.

Dai, Y., Sun, Q., Wang, W., Lu, L., Liu, M., Li, J., Yang, S., Sun, Y., Zhang, K., Xu, J., Zheng, W., Hu, Z., Yang, Y., Gao, Y., Chen, Y., Zhang, X., Gao, F., and Zhang, Y. (2018) Utilizations of agricultural waste as adsorbent for the removal of contaminants: A review. *Chemosphere*, 211, 235–253.

Dalai, C., Jha, R., and Desai, V.R. (2015) Rice Husk and Sugarcane Baggase Based Activated Carbon for Iron and Manganese Removal. *Aquatic Procedia*, 4, 1126–1133. Elsevier B.V.

Daniel, R. and Kawasaki, N. (2016) The Distribution of Heavy Metals and Nutrients along Selangor River and its Adjacent Mining Ponds, Malaysia. *International Journal of Advances in Agricultural and Environmental Engineering*, 3, 3–6.

Das, B., Mondal, N.K., Bhaumik, R., and Roy, P. (2014) Insight into adsorption equilibrium, kinetics and thermodynamics of lead onto alluvial soil. *International Journal of Environmental Science and Technology*, 11, 1101–1114.

Department of Environment Malaysia (DOE). (2018) *Environmental Quality Report 2018*. 176 pp.

Dion, L.A., Saint-Amour, D., Sauvé, S., Barbeau, B., Mergler, D., and Bouchard, M.F. (2018) Changes in water manganese levels and longitudinal assessment of intellectual function in children exposed through drinking water. *NeuroToxicology*, 64, 118–125. Elsevier B.V.

DOE. (2020) *Environmental Quality Report 2020*. Malaysia, 1–180 pp.

DOSM. (2020) *Poket Stats Negeri Johor*. Malaysia, 77 pp.

DOSM. (2021) Department of Statistics Malaysia Current Population Estimates 2020. *Department of Statistics Malaysia*, 1–3.

Du, X., Zhang, K., Xie, B., Zhao, J., Cheng, X., Kai, L., Nie, J., Wang, Z., Li, G., and Liang, H. (2019) Peroxymonosulfate-assisted electro-oxidation/coagulation coupled with ceramic membrane for manganese and phosphorus removal in surface water. *Chemical Engineering Journal*, 334–343. Elsevier B.V.

Edwin Basson. (2019) *World Steel in Figures 2019*. Beijing, China, 1–17 pp.

Elaveniya, E. and Jayamuthunagai, J. (2014) Functional, Physicochemical and anti-oxidant properties of dehydrated banana blossom powder and its incorporation in biscuits. *International Journal of ChemTech Research*, 6, 4446–4454.

Elhafez, S.E.A., Hamad, H.A., Zaatout, A.A., and Malash, G.F. (2017) Management of agricultural waste for removal of heavy metals from aqueous solution: adsorption behaviors, adsorption mechanisms, environmental protection, and techno-economic analysis. *Environmental Science and Pollution Research*, 24, 1397–1415. Environmental Science and Pollution Research.

Esfandiar, N., Nasernejad, B., and Ebadi, T. (2014) Removal of Mn(II) from groundwater by sugarcane bagasse and activated carbon (a comparative study): Application of response surface methodology (RSM). *Journal of Industrial and Engineering Chemistry*, 20, 3726–3736. The Korean Society of Industrial and Engineering Chemistry.

Fallahzadeh, R.A., Ghaneian, M.T., Miri, M., and Dashti, M.M. (2017) Spatial analysis and health risk assessment of heavy metals concentration in drinking water resources. *Environmental Science and Pollution Research*, 24, 24790–24802. Environmental Science and Pollution Research.

FAO, F. and A.O. of U.N.R. (2020) *Prospect for global production bananas and tropical fruits 2019-2028*. 1–14 pp.

Fatemeh Seyedpour, S., Rahimpour, A., Mohsenian, H., and Taherzadeh, M.J. (2018) Low fouling ultrathin nanocomposite membranes for efficient removal of manganese. *Journal of Membrane Science*, 549, 205–216. Elsevier B.V.

Fathi, A., Gahlan, A.A., and Farghaly, O.A. (2020) Decontamination of Copper and Manganese from Aqueous Media by Untreated and Chemically Treated Sugarcane Bagasse : A Comparative Study. *Chemistry of Advanced Materials (CAM)*, 5, 15–33.

Fatimah, P. (2014) How To Prepare Banana Blossom. *Vegan MIAM*. <https://veganmiam.com/how-to/how-to-prepare-banana-blossom> (10 September 2019).

Feizi, M. and Jalali, M. (2015) Removal of heavy metals from aqueous solutions using sunflower, potato, canola and walnut shell residues. *Journal of the Taiwan Institute of Chemical Engineers*, 54, 125–136. Elsevier Ltd.

Fiyadh, S.S., AlSaadi, M.A., Jaafar, W.Z., AlOmar, M.K., Fayaed, S.S., Mohd, N.S., Hin, L.S., and El-Shafie, A. (2019) Review on heavy metal adsorption processes by carbon nanotubes. *Journal of Cleaner Production*, 230, 783–793.

de Freitas, G.R., da Silva, M.G.C., and Vieira, M.G.A. (2019) Biosorption technology for removal of toxic metals: a review of commercial biosorbents and patents.

Environmental Science and Pollution Research, 26, 19097–19118. Environmental Science and Pollution Research.

Fu, F. and Wang, Q. (2011) Removal of heavy metal ions from wastewaters: A review. *Journal of Environmental Management*, 92, 407–418. Elsevier Ltd.

Ganesan, P., Lakshmi, J., Sozhan, G., and Vasudevan, S. (2013) Removal of manganese from water by electrocoagulation: Adsorption, kinetics and thermodynamic studies. *Canadian Journal of Chemical Engineering*, 91, 448–458.

García-Mendieta, A., Olguín, M.T., and Solache-Ríos, M. (2012) Biosorption properties of green tomato husk (Physalis philadelphica Lam) for iron, manganese and iron-manganese from aqueous systems. *Desalination*, 284, 167–174. Elsevier B.V.

Gautam, R.K., Mudhoo, A., Lofrano, G., and Chattopadhyaya, M.C. (2014) Biomass-derived biosorbents for metal ions sequestration: Adsorbent modification and activation methods and adsorbent regeneration. *Journal of Environmental Chemical Engineering*, 2, 239–259. Elsevier B.V.

Gedam, A.H. and Dongre, R.S. (2015) Adsorption characterization of Pb(ii) ions onto iodate doped chitosan composite: equilibrium and kinetic studies. *RSC Advances,* 5, 54188–54201. Royal Society of Chemistry.

Gerke, T.L., Little, B.J., and Barry Maynard, J. (2016) Manganese deposition in drinking water distribution systems. *Science of the Total Environment*, 541, 184–193. Elsevier B.V.

Ghani, M., Adlan, M.N., Kamal, N.H.M., and Aziz, H.A. (2017) Site suitability for riverbed filtration system in Tanah Merah, Kelantan-A physical model study for turbidity removal. *AIP Conference Proceedings*, 1892.

Ghannem, N., Gargouri, D., Sarbeji, M.M., Yaich, C., and Azri, C. (2014) Metal contamination of surface sediments of the Sfax–Chebba coastal line, Tunisia. *Environmental Earth Sciences*, 72, 3419–3427.

Ghoneim, M.M., El-Desoky, H.S., El-Moselhy, K.M., Amer, A., Abou El-Naga, E.H., Mohamedein, L.I., and Al-Prol, A.E. (2014) Removal of cadmium from aqueous solution using marine green algae, Ulva lactuca. *Egyptian Journal of Aquatic Research*, 40, 235–242. National Institute of Oceanography and Fisheries.

Goher, M.E., Hassan, A.M., Abdel-Moniem, I.A., Fahmy, A.H., Abdo, M.H., and El-sayed, S.M. (2015) Removal of aluminum, iron and manganese ions from industrial wastes using granular activated carbon and Amberlite IR-120H. *Egyptian Journal of Aquatic Research*, 41, 155–164. National Institute of Oceanography and Fisheries.

Gopakumar, A., Narayan, R., Ajay Nagath, S., Nishanthan, P., Mohammed, R.S., and Chandran, S.S. (2018) Waste water treatment using economically viable natural adsorbent materials. Pp. 17699–17703 in: *Materials Today: Proceedings*. Elsevier Ltd.

Gunatilake, S.K. (2015) Methods of Removing Heavy Metals from Industrial Wastewater. *Journal of Multidisciplinary Engineering Science Studies (JMESS)*, 1, 12–18.

Gupta, H. and Gupta, B. (2016) Adsorption of polycyclic aromatic hydrocarbons on banana peel activated carbon. *Desalination and Water Treatment*, 57, 9498–9509.

Gupta, V.K., Nayak, A., and Agarwal, S. (2015) Bioadsorbents for remediation of heavy metals: Current status and their future prospects. *Environmental Engineering Research*, 20, 1–18.

HACH. (2017) Nitrogen , Ammonia; USEPA Nessler Method 8038. 1–6.

Hassan Omer, N. (2020) Water Quality Parameters. *Water Quality - Science, Assessments and Policy*, 1–18.

Haynes, E.N., Sucharew, H., Hilbert, T.J., Kuhnell, P., Spencer, A., Newman, N.C., Burns, R., Wright, R., Parsons, P.J., and Dietrich, K.N. (2018) Impact of air manganese on child neurodevelopment in East Liverpool, Ohio. *NeuroToxicology*, 64, 94–102. Elsevier B.V.

Hegazy, I., Ali, M.E.A., Zaghlool, E.H., and Elsheikh, R. (2021) Heavy metals adsorption from contaminated water using moringa seeds/ olive pomace byproducts. *Applied Water Science*, 11, 1–14. Springer International Publishing.

Herawati, D., Santoso, S.D., and Amalina, I. (2018) Kondisi Optimum Adsorpsi-Fluidisasi Zat Warna Limbah Tekstil Menggunakan Adsorben Jantung Pisang. *Jurnal Sain Health*, 2, 1–7.

Hokkanen, S., Bhatnagar, A., and Sillanpää, M. (2016) A review on modification methods to cellulose-based adsorbents to improve adsorption capacity. *Water Research*, 91, 156–173.

Hossain, A., Ngo, H., Guo, W., and Nguyen, V. (2012) Biosorption of Cu(II) From Water by Banana Peel Based Biosorbent: Experiments and Models of Adsorption and Desorption. *Journal of Water Sustainability*, 2, 87–104.

Hossen, M.F., Hamdan, S., and Rahman, M.R. (2015) Review on the risk assessment of heavy metals in Malaysian clams. *Scientific World Journal*, 2015.

Huang, Y.F., Ang, S.Y., Lee, K.M., and Lee, T.S. (2015) Quality of Water Resources in Malaysia. P. 13 in: *Research and Practices in Water Quality*. IntechOpen.

Huber, M., Welker, A., and Helmreich, B. (2016) Critical review of heavy metal pollution of traffic area runoff: Occurrence, influencing factors, and partitioning. Elsevier B.V. *Science of the Total Environment*. <http://dx.doi.org/10.1016/j.scitotenv.2015.09.033>.

Ibrahim, N., Aziz, H.A., and Yusoff, M.S. (2015) Heavy metals concentration in river and pumping well water for river bank filtration (RBF) system: Case study in Sungai Kerian. *Jurnal Teknologi*, 74, 59–67.

Ibrahim, T.N.B.T., Othman, F., and Mahmood, N.Z. (2020) Baseline Study of Heavy Metal Pollution in a Tropical River in a Developing Country. *Sains Malaysiana*, 49, 729–742.

Idrees, M., Batool, S., Ullah, H., Hussain, Q., Al-Wabel, M.I., Ahmad, M., Hussain, A., Riaz, M., Ok, Y.S., and Kong, J. (2018) *Adsorption and thermodynamic mechanisms of manganese removal from aqueous media by biowaste-derived biochars*. P. in: *Journal of Molecular Liquids*. Elsevier B.V, 373–380 pp.

Iftekhar, S., Ramasamy, D.L., Srivastava, V., Asif, M.B., and Sillanpää, M. (2018) Understanding the factors affecting the adsorption of Lanthanum using different adsorbents: A critical review. *Chemosphere*, 204, 413–430.

Ihsanullah, Abbas, A., Al-Amer, A.M., Laoui, T., Al-Marri, M.J., Nasser, M.S., Khraisheh, M., and Atieh, M.A. (2016) Heavy metal removal from aqueous solution by advanced carbon nanotubes: Critical review of adsorption applications. *Separation and Purification Technology*, 157, 141–161. Elsevier B.V.

INWQS. (2016) National Water Quality Standards For Malaysia CLASS UNIT Sourse : EQR2006 National Water Quality Standards For Malaysia. 1–4.

Isabel Wagner. (2018) Manganese Ore Mine Production Volume Worldwide From 2012 To 2022. *Statista*. <https://www.statista.com/statistics/247615/global-production-of-manganese-ore/> (10 September 2019).

Isagba, E.S., Kadiri, S., and Ilaboya, I.R. (2017) Yam Peels as Adsorbent for the Removal of Copper (Cu) and Manganese (Mn) in Waste Water. *Nigerian Journal of Environmental Sciences and Technology*, 1, 230–243.

Ismail, A., Harmuni, H., and Mohd, R.R.M.A.Z. (2017) Removal of iron and manganese using granular activated carbon and zeolite in artificial barrier of riverbank filtration. P. 020056 in: *Advanced Materials Engineering and Technology*.

Ismail, A.F., Khulbe, K.C., and Matsuura, T. (2019) *RO Membrane Fouling*. P. in: *Reverse Osmosis*. 189–220 pp.

Jacob, J.M., Karthik, C., Saratale, R.G., Kumar, S.S., Prabakar, D., Kadirvelu, K., and Pugazhendhi, A. (2018) Biological approaches to tackle heavy metal pollution: A survey of literature. *Journal of Environmental Management*, 217, 56–70. Elsevier Ltd.

Jain, C.K., Malik, D.S., and Yadav, A.K. (2016) Applicability of plant based biosorbents in the removal of heavy metals: a review. *Environmental Processes*, 3, 495–523.

Jeirani, Z., Sadeghi, A., Soltan, J., Roshani, B., and Rindall, B. (2015) Effectiveness of advanced oxidation processes for the removal of manganese and organic compounds in membrane concentrate. *Separation and Purification Technology*, 149, 110–115. Elsevier B.V.

Jin, W., Du, H., Zheng, S., and Zhang, Y. (2016) Electrochemical processes for the environmental remediation of toxic Cr(VI): A review. *Electrochimica Acta*, 191, 1044–1055. Elsevier Ltd.

Joseph, L., Jun, B.M., Flora, J.R.V., Park, C.M., and Yoon, Y. (2019) Removal of heavy metals from water sources in the developing world using low-cost materials: A review. *Chemosphere*, 229, 142–159. Elsevier Ltd.

Kale, A.E., Mandake, M.B., and Chitodkar, V.D. (2017) Removal of Heavy Metals using Adsorption Process- A Review. *International Journal of Advance Engineering and Research Development*, 4, 1–6.

Kanamarlapudi, S.L.R.K., Chintalpudi, V.K., and Muddada, S. (2018) Application of Biosorption for Removal of Heavy Metals from Wastewater. *Biosorption*.

Kasim, N., Mohammad, A.W., and Abdullah, S.R.S. (2016) Performance of membrane filtration in the removal of iron and manganese from Malaysia's groundwater. *Membrane Water Treatment*, 7, 227–296.

Katsumi, T. (2015) Soil excavation and reclamation in civil engineering: Environmental aspects. *Soil Science and Plant Nutrition*, 61, 22–29.

Kebabi, B., Terchi, S., Bougherara, H., Reinert, L., and Duclaux, L. (2017) Removal of manganese (II) by edge site adsorption on raw and milled vermiculites. *Applied Clay Science*, 139, 92–98. Elsevier B.V.

Khadse, G.K., Patni, P.M., and Labhasetwar, P.K. (2015) Removal of iron and manganese from drinking water supply. *Sustainable Water Resources Management*, 1, 157–165. Springer International Publishing.

Kim, H., Ko, R.A., Lee, S., and Chon, K. (2020) Removal efficiencies of manganese and iron using pristine and phosphoric acid pre-treated biochars made from banana peels. *Water (Switzerland)*, 12, 1–13.

Kobielska, P.A., Howarth, A.J., Farha, O.K., and Nayak, S. (2018) Metal–organic frameworks for heavy metal removal from water. *Coordination Chemistry Reviews*, 358, 92–107. Elsevier B.V.

Kouzour, S., El Azher, N., Gourich, B., Gros, F., Vial, C., and Stiriba, Y. (2017) Removal of manganese (II) from drinking water by aeration process using an airlift reactor. *Journal of Water Process Engineering*, 16, 233–239. Elsevier Ltd.

Kulshreshtha, D., Ganguly, J., and Jog, M. (2021) Manganese and movement disorders: A review. *Journal of Movement Disorders*, 14, 93–102.

Kumar, G.V.S.R.P., Rao, K.S., Yadav, A., Kumar, M.L., and Sarathi, T.V.N.P. (2018) Biosorption of copper (II) and manganese (II) from waste water using low cost bio adsorbents. *J. Indian Chem. Soc.*, 95, 1–8.

Kusrini, E., Kinastiti, D.D., Wilson, L.D., Usman, A., and Rahman, A. (2018) Adsorption of lanthanide ions from an aqueous solution in multicomponent systems using activated carbon from Banana Peels (Musa Paradisiaca L.). *International Journal of Technology*, 9, 1132–1139.

Lakherwal, D. (2014) Adsorption of Heavy Metals: A Review. *International Journal of Environmental Research and Development*, 4, 41–48.

Lata, S. and Samadder, S.R. (2016) Removal of arsenic from water using nano adsorbents and challenges: A review. *Journal of Environmental Management*, 166, 387–406.

Latour, R.A. (2015) The Langmuir isotherm: A commonly applied but misleading approach for the analysis of protein adsorption behavior. *Journal of Biomedical Materials Research - Part A*, 103, 949–958.

Lee Goi, C. (2020a) The river water quality before and during the Movement Control Order (MCO) in Malaysia. *Case Studies in Chemical and Environmental Engineering*, 100027. Elsevier Ltd.

Lee Goi, C. (2020b) The river water quality before and during the Movement Control Order (MCO) in Malaysia. *Case Studies in Chemical and Environmental Engineering*, 2, 100027. Elsevier Ltd.

Lee, I., Hwang, H., Lee, J., Yu, N., Yun, J., and Kim, H. (2017) Modeling approach to evaluation of environmental impacts on river water quality: A case study with Galing River, Kuantan, Pahang, Malaysia. *Ecological Modelling*, 353, 167–173. Elsevier B.V.

Leizou, Elijah, K., Ashraf, M.A., and Ahmad Jalal Khan Chowdhury, H.R. (2018) Adsorption Studies of Pb2+ And Mn2+ Ions on Low-Cost Adsorbent: Unripe Plantain (Musa Paradisiaca) Peel Biomass. *Acta Chemica Malaysia*, 2, 11–15.

Lenntech. (2016) Manganese (Mn) - Chemical Properties, Health and Environmental Effects of Manganese. <https://www.lenntech.com/periodic/elements/mn.htm> (15 September 2019).

Lenntech. (2017) Turbidity. *Lenntech Water treatment & purification*. <https://www.lenntech.com/turbidity.htm> (26 September 2019).

Li, X., Yu, X., Liu, L., Yang, J., Liu, S., and Zhang, T. (2021) Preparation, characterization serpentine-loaded hydroxyapatite and its simultaneous removal performance for fluoride, iron and manganese. *RSC Advances*. .

Liu, L., Li, T., Wu, M., and Yu, H. (2017a) Determination of Manganese(II) with Preconcentration on Almond Skin and Determination by Flame Atomic Absorption Spectrometry. *Analytical Letters*, 50, 135–147.

Liu, L., Tan, S. (Johnathan), Horikawa, T., Do, D.D., Nicholson, D., and Liu, J. (2017b) Water adsorption on carbon - A review. *Advances in Colloid and Interface Science*, 250, 64–78.

Liu, Y., Hu, L., Tan, B., Li, J., Gao, X., He, Y., Du, X., Zhang, W., and Wang, W. (2019) Adsorption behavior of heavy metal ions from aqueous solution onto composite dextran-chitosan macromolecule resin adsorbent. *International Journal of Biological Macromolecules*, 141, 738–746. Elsevier B.V.

M., S.-O., A.K., A., Y., N., and M., A. (2012) Metal concentrations in Sungai Sedili Kecil, Johor, Peninsular Malaysia. *Journal of Tropical Marine Ecosystem*, 2, 15–23.

MA, N., K, O., and Chinelo, G. (2018) Critical Issues of Sustainability Associated with Quarry Activities. *Aspects in Mining & Mineral Science*, 1.

Mahmoodi, N.M., Taghizadeh, M., and Taghizadeh, A. (2018) Mesoporous activated carbons of low-cost agricultural bio-wastes with high adsorption capacity: Preparation and artificial neural network modeling of dye removal from single and multicomponent (binary and ternary) systems. *Journal of Molecular Liquids*, 269, 217–228. Elsevier B.V.

Mahmoud, M.S. (2014) Banana Peels as an Eco-Sorbent for Manganese Ions. *International Journal of Agricultural and Biosystems Engineering*, 8, 1183–1189.

Mahmoud, M.S., Ahmed, S.M., Mohammad, S.G., and Abou Elmagd, A.M. (2014) Evaluation of Egyptian Banana Peel (Musa sp.) as a Green Sorbent for Groundwater Treatment. *International Journal of Engineering and Technology*, 4, 648–659.

Maia, L.S., Duizit, L.D., Pinhatio, F.R., and Mulinari, D.R. (2021) Valuation of banana peel waste for producing activated carbon via NaOH and pyrolysis for methylene blue removal. *Carbon Letters*. Springer Singapore.

Maina, I.W., Obuseng, V., and Nareetsile, F. (2016) Use of Moringa oleifera (Moringa) Seed Pods and Sclerocarya birrea (Morula) Nut Shells for Removal of Heavy Metals from Wastewater and Borehole Water. *Journal of Chemistry*, 2016.

Manap, N., Sandirasegaran, K., Syahrom, N.S., and Amir, A. (2019) Analysis of Trace Metal Contamination in Pahang River and Kelantan River, Malaysia. *MATEC Web of Conferences*, 266, 04003.

Marcus, J.B. (2013) Vitamin and Mineral Basics: The ABCs of Healthy Foods and Beverages, Including Phytonutrients and Functional Foods. Pp. 279–331 in: *Culinary Nutrition*.

Marque, T.L., Alves, V.N., Coelho, L.M., and Coelho, N.M.M. (2013) Assessment of the use of Moringa oleifera seeds for removal of manganese ions from aqueous systems. *BioResources*, 8, 2738–2751.

Marsidi, N., Abu Hasan, H., and Sheikh Abdullah, S.R. (2018) A review of biological aerated filters for iron and manganese ions removal in water treatment. Elsevier. *Journal of Water Process Engineering*. <https://doi.org/10.1016/j.jwpe.2018.01.010>.

Meseldzija, S., Petrovic, J., Onjia, A., Volkov-Husovic, T., Nesic, A., and Vukelic, N. (2020) Removal of Fe2+, Zn2+ and Mn2+ ions from the mining wastewater by lemon peel waste. *Journal of the Serbian Chemical Society*, 85, 1371–1382.

Miah, M.R., Ijomone, O.M., Okoh, C.O.A., Ijomone, O.K., Akingbade, G.T., Ke, T., Krum, B., da Cunha Martins, A., Akinyemi, A., Aranoff, N., Antunes Soares, F.A., Bowman, A.B., and Aschner, M. (2020) The effects of manganese overexposure on brain health. *Neurochemistry International*, 135.

Milatovic, D. and Gupta, R.C. (2018) Manganese. Pp. 445–454 in: *Veterinary Toxicology: Basic and Clinical Principles: Third Edition*. Third Edit. Elsevier Inc.

Milatovic, D., Gupta, R.C., Yin, Z., Zaja-milatovic, S., and Aschner, M. (2017) Manganese. Pp. 567–581 in: *Reproductive and Developmental Toxicology* (R.C. Gupta, editor). Second Edi. Elsevier Inc., KY, United States.

Millati, R., Cahyono, R.B., Ariyanto, T., Azzahrani, I.N., Putri, R.U., and Taherzadeh, M.J. (2019) Agricultural, Industrial, Municipal, and Forest Wastes. Pp. 1–22 in: *Sustainable Resource Recovery and Zero Waste Approaches*. Elsevier B.V.

Ministry of Health. (2012) Drinking Water Quality Standard. *Engineering Services Division, Malaysia*, 4–6.

Mohamed, R.M., Hashim, N., Abdullah, S., Abdullah, N., Mohamed, A., Asshaary Daud, M.A., and Aidil Muzakkar, K.F. (2020a) Adsorption of Heavy Metals on Banana Peel Bioadsorbent. *Journal of Physics: Conference Series*, 1532.

Mohamed, R.M.S.R., Jais, N.M., Tajuddin, S.A.M., Al-Gheethi, A.A.S., Kassim, A.H.M., and Abdullah, M.E. (2020b) Determination of Heavy Metal Concentration of Benut River at Simpang Renggam, Johor. P. in: *IOP Conference Series: Earth and Environmental Science*.

Moni, S.N., Aziz, E.A., and Malek, M.A. (2017) Introduction of water footprint assessment approach to enhance water supply management in Malaysia. *AIP Conference Proceedings*, 1892.

Mthombeni, N.H., Mbakop, S., and Onyango, M.S. (2016) Adsorptive Removal of Manganese from Industrial and Mining Wastewater. *2016 Annual Conference on Sustainable Research and Innovation*, 4–6.

Munagapati, V.S., Wen, J.C., Pan, C.L., Gutha, Y., Wen, J.H., and Reddy, G.M. (2020) Adsorptive removal of anionic dye (Reactive Black 5) from aqueous solution using chemically modified banana peel powder: kinetic, isotherm, thermodynamic, and reusability studies. *International Journal of Phytoremediation*, 22, 267–278. Taylor & Francis.

Nwachukwu MA, K, O., and Chinelo, G. (2018) Critical Issues of Sustainability Associated with Quarry Activities. *Aspects in Mining & Mineral Science*, 1.

O. Basheer, A., M. Hanafiah, M., and J. Abdulhasan, M. (2017) A Study on Water Quality From Langat River, Selangor. *Acta Scientifica Malaysia*, 1, 01–04.

Omorogie, M.O., Babalola, J.O., and Unuabonah, E.I. (2016) Regeneration strategies for spent solid matrices used in adsorption of organic pollutants from surface water: a critical review. *Desalination and Water Treatment*, 57, 518–544.

Omri, A. and Benzina, M. (2012) Removal of manganese(II) ions from aqueous solutions by adsorption on activated carbon derived a new precursor: Ziziphus spina-christi seeds. *Alexandria Engineering Journal*, 51, 343–350. Faculty of Engineering, Alexandria University.

Othman, N., Mohd-Asharuddin, S., and Azizul-Rahman, M.F.H. (2013) An overview of fruit waste as sustainable adsorbent for heavy metal removal. *Applied Mechanics and Materials*, 389, 29–35.

Padmaja, M. (2017) Comparative Study of Low Cost Adsorbents in the Elimination of Methylene Blue Dye from Aqueous Solutions. 3, 1396–1401.

Palomo, E. (2018) When to Cut the Flower From a Banana Plant. *SFGate, Hearst Communications Inc.* <https://homeguides.sfgate.com/prune-banana-palm-tree-58058.html> (18 December 2020).

Parmalee, N.L. and Aschner, M. (2016) Manganese and aging. *NeuroToxicology*, 56, 262–268. Elsevier B.V.

Pathak, P.D., Mandavgane, S.A., and Kulkarni, B.D. (2015) Fruit peel waste as a novel low-cost bio adsorbent. *Reviews in Chemical Engineering*, 31, 361–381.

Pathak, P.D., Mandavgane, S.A., and Kulkarni, B.D. (2017) Fruit peel waste: Characterization and its potential uses. *Current Science*, 113, 444–454.

Patil, D.S., Chavan, S.M., and Oubagaranadin, J.U.K. (2016) A review of technologies for manganese removal from wastewaters. Elsevier B.V. *Journal of Environmental Chemical Engineering*. <http://dx.doi.org/10.1016/j.jece.2015.11.028>.

Paul, D. (2017) Research on heavy metal pollution of river Ganga: A review. *Annals of Agrarian Science*, 15, 278–286. Elsevier Ltd.

Racette, B.A., Gross, A., Criswell, S.R., Checkoway, H., and Searles Nielsen, S. (2018) A screening tool to detect clinical manganese neurotoxicity. *NeuroToxicology*, 64, 12–18. Elsevier B.V.

Rashid, H. and Yaqub, G. (2017) Bioadsorbents and filters for removal of heavy metals in different environmental samples-A brief review. *Nature Environment and Pollution Technology*, 16, 1157–1164.

Razak, M.R., Aris, A.Z., Zakaria, N.A.C., Wee, S.Y., and Ismail, N.A.H. (2021) Accumulation and risk assessment of heavy metals employing species sensitivity distributions in Linggi River, Negeri Sembilan, Malaysia. *Ecotoxicology and Environmental Safety*, 211, 111905. Elsevier Inc.

Renu, M.A., Singh, K., Upadhyaya, S., and Dohare, R.K. (2017) Removal of heavy metals from wastewater using modified agricultural adsorbents. *Materials Today: Proceedings*, 4, 10534–10538. Elsevier Ltd.

Revellame, E.D., Fortela, D.L., Sharp, W., Hernandez, R., and Zappi, M.E. (2020) Adsorption kinetic modeling using pseudo-first order and pseudo-second order rate laws: A review. *Cleaner Engineering and Technology*, 1, 100032. Elsevier Ltd.

Rose, P., Hager, S., Glas, K., Rehmann, D., and Hofmann, T. (2017) Coating techniques for glass beads as filter media for removal of manganese from water. *Water Science and Technology: Water Supply*, 17, 95–106.

Rosman, P.S. (2016) Water quality assessment of muar river using environmetric techniques and artificial neural networks. *ARPN Journal of Engineering and Applied Sciences*, 11, 7298–7303.

Rumsby, P., Rockett, L., Clegg, H., Jonsson, J., Benson, V., Harman, M., Doyle, T., Rushton, L., Wilkinson, D., and Warwick, P. (2014) Speciation of manganese in drinking water. *Toxicology Letters*, 229, S120.

Sajid, M., Nazal, M.K., Ihsanullah, Baig, N., and Osman, A.M. (2018) Removal of heavy metals and organic pollutants from water using dendritic polymers based adsorbents: A critical review. *Separation and Purification Technology*, 191, 400–423.

Salam, M.A., Paul, S.C., Shaari, F.I., Rak, A.E., Ahmad, R.B., and Kadir, W.R. (2019) Geostatistical distribution and contamination status of heavy metals in the sediment of Perak River, Malaysia. *Hydrology*, 6, 1–19.

Sandjo, L.P., dos Santos Nascimento, M.V.P., de H. Moraes, M., Rodrigues, L.M., Dalmarco, E.M., Biavatti, M.W., and Steindel, M. (2019) NOx-, IL-1β-, TNF-α-, and IL-6-Inhibiting Effects and Trypanocidal Activity of Banana (Musa acuminata) Bracts and Flowers: UPLC-HRESI-MS Detection of Phenylpropanoid Sucrose Esters. *Molecules*, 24, 4564.

Sarojam, P. (2010) *Analysis of Wastewater for Metals using ICP-OES*. 1–10 pp.

Senthil Kumar, P., Vincent, C., Kirthika, K., and Sathish Kumar, K. (2010) Kinetics and equilibrium studies of Pb2+ ion removal from aqueous solutions by use of nano-silversol-coated activated carbon. *Brazilian Journal of Chemical Engineering*, 27, 339–346.

Shafiq, M., Alazba, A.A., and Amin, M.T. (2018) Removal of heavy metals from wastewater using date palm as a biosorbent: A comparative review. *Sains Malaysiana*, 47, 35–49.

Singh, N. and Gupta, D.S.K. (2016) Adsorption of Heavy Metals : A Review. *International Journal of Innovative Research in Science, Engineering and Technology*, 5, 41–48.

Singh, N.B., Nagpal, G., and Agrawal, S. (2018) Environmental Technology & Innovation Water purification by using Adsorbents : A Review. *Environmental Technology & Innovation*, 11, 187–240. Elsevier B.V.

Singh, S., Kumar, V., Datta, S., Dhanjal, D.S., Sharma, K., Samuel, J., and Singh, J. (2020) Current advancement and future prospect of biosorbents for bioremediation. *Science of the Total Environment*, 709, 135895. Elsevier B.V.

Sohn, S. and Kim, D. (2005) Modification of Langmuir isotherm in solution systems - Definition and utilization of concentration dependent factor. *Chemosphere*, 58, 115–123.

Sulyman, M., Namiesnik, J., and Gierak, A. (2017) Low-cost adsorbents derived from agricultural by-products/wastes for enhancing contaminant uptakes from wastewater: A review. *Polish Journal of Environmental Studies*, 26, 479–510.

Surovka, D. and Pertile, E. (2017) Sorption of iron, manganese, and copper from aqueous solution using orange peel: Optimization, isothermic, kinetic, and thermodynamic studies. *Polish Journal of Environmental Studies*, 26, 795–800.

Tavlieva, M.P., Genieva, S.D., Georgieva, V.G., and Vlaev, L.T. (2015) Thermodynamics and kinetics of the removal of manganese(II) ions from aqueous solutions by white rice husk ash. *Journal of Molecular Liquids*, 211, 938–947. Elsevier B.V.

Tiwari, M.K., Bajpai, S., Dewangan, U.K., and Tamrakar, R.K. (2015) Assessment of heavy metal concentrations in surface water sources in an industrial region of central India. *Karbala International Journal of Modern Science*, 1, 9–14. Elsevier Ltd.

Tobiason, J.E., Bazilio, A., Goodwill, J., Mai, X., and Nguyen, C. (2016) Manganese Removal from Drinking Water Sources. *Current Pollution Reports*, 2, 168–177. Current Pollution Reports.

Tumin, S.A. and Shaharudin, A.A.A. (2019) Banana : The World ' s Most Popular Fruit. *Khazanah Research Institute*. <http://www.krinstitute.org/What_We_Are_Reading-@-Banana-;_The_Worlds_Most_Popular_Fruit.aspx> (10 September 2019).

Uddin, M.K. (2017) A review on the adsorption of heavy metals by clay minerals, with special focus on the past decade. *Chemical Engineering Journal*, 308, 438–462. Elsevier B.V.

Vaddi, D., Subbarao, M.V., and Muralikrishna, M.P.S. (2019) Removal of manganese(II) from aqueous solution by chemically activated Thuja Occidentalis leaves carbon (CATLC) as an adsorbent: Adsorption equilibrium and kinetic studies. *Physical Chemistry Research*, 7, 11–26.

Vakili, M., Deng, S., Cagnetta, G., Wang, W., Meng, P., Liu, D., and Yu, G. (2019) Regeneration of chitosan-based adsorbents used in heavy metal adsorption: A review. *Separation and Purification Technology*, 224, 373–387. Elsevier.

Walker, D.B., Baumgartner, D.J., Gerba, C.P., and Fitzsimmons, K. (2019) *Surface Water Pollution*. P. in: *Environmental and Pollution Science*. 3rd edition. Elsevier Inc., 261–292 pp.

Wiens, J. (2018) Chemical vs. Physical Adsorption. *study.com*. <https://study.com/academy/lesson/chemical-vs-physical-adsorption.html> (4 October 2019).

Wong, K.W., Yap, C.K., Nulit, R., Hamzah, M.S., Chen, S.K., Cheng, W.H., Karami, A., and Al-Shami, S.A. (2016) Effects of anthropogenic activities on the heavy metal levels in the clams and sediments in a tropical river. *Environmental Science and Pollution Research*, 24, 116–134. Environmental Science and Pollution Research.

Woodard & Curran, I. (2006) Waste Characterization. Pp. 83–126 in: *Industrial Waste Treatment Handbook*. second. Elsevier.

World Health Organization. (2011) Manganese in Drinking-water. Pp. 1–21 in: *Guidelines for Drinking-Water Quality*. Fourth Edi. Geneve, Switzerland.

Worldsteel Association. (2019) Global steel demand continues to grow in slowing economic environment. *World Steel Association AISBL*. <https://www.worldsteel.org/media-centre/press-releases/2019/worldsteel-short-range-outlook-april-2019.html> (24 September 2019).

Wu, Q., Zhou, H., Tam, N.F.Y., Tian, Y., Tan, Y., Zhou, S., Li, Q., Chen, Y., and Leung, J.Y.S. (2016) Contamination, toxicity and speciation of heavy metals in an industrialized urban river: Implications for the dispersal of heavy metals. *Marine Pollution Bulletin*, 104, 153–161. Elsevier B.V.

Ying, A.S. (2019) *Progress of water environment governance in Malaysia*. 1–29 pp.

Zaher, K. and Hammam, G. (2014) Correlation between Biochemical Oxygen Demand and Chemical Oxygen Demand for Various Wastewater Treatment Plants in Egypt to Obtain the Biodegradability Indices. *International Journal of Sciences: Basic and Applied Research*, 13, 42–48.

Zanella, O., Tessaro, I.C., and Féris, L.A. (2014) Desorption- and decomposition-based techniques for the regeneration of activated carbon. *Chemical Engineering and Technology*, 37, 1447–1459.

Zhang, Y., Zhao, J., Jiang, Z., Shan, D., and Lu, Y. (2014) Biosorption of Fe(II) and Mn(II) Ions from Aqueous Solution by Rice Husk Ash. *BioMed Research International*, 2014, 1–10.

Zhao, M., Xu, Y., Zhang, C., Rong, H., and Zeng, G. (2016) New trends in removing heavy metals from wastewater. *Applied Microbiology and Biotechnology*, 100, 6509–6518. Applied Microbiology and Biotechnology.

Zou, Y., Wang, X., Khan, A., Wang, P., Liu, Y., Alsaedi, A., Hayat, T., and Wang, X. (2016) Environmental Remediation and Application of Nanoscale Zero-Valent Iron and Its Composites for the Removal of Heavy Metal Ions: A Review. *Environmental Science and Technology*, 50, 7290–7304.

Zyl, H.J. van, Bam, W.G., and Steenkamp, J.D. (2016) Identifying Barriers Faced by Key Role Players In The South African Manganese Industry. *SAIIE27 Proceedings*, 1–12.