

**A STUDY ON HEAVY METALS DISTRIBUTION
IN MANGROVE SEDIMENT OF MENGGABONG,
SABAH**

SARVA MANGALA PRAVEENA



PERPUSTAKAAN
UNIVERSITI MALAYSIA SABAH

UMS

**THESIS SUBMITTED IN PARTIAL
FULFILLMENT FOR THE DEGREE OF
MASTER OF SCIENCE**

**SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
2008**

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS[@]

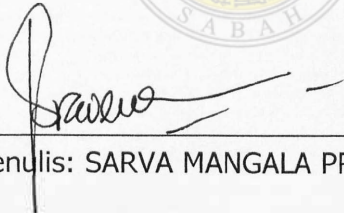
JUDUL: A STUDY ON HEAVY METALS DISTRIBUTION IN MANGROVE SEDIMENT OF MENKABONG, SABAH

IJAZAH: SARJANA SAINS

SESI PENGAJIAN: 2005-2007


Saya, SARVA MANGALA PRAVEENA mengaku membenarkan tesis sarjana ini disimpan di perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk pengajian saya.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. TIDAK TERHAD



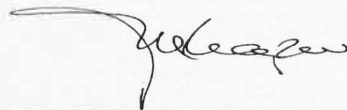
Penulis: SARVA MANGALA PRAVEENA

Disahkan oleh

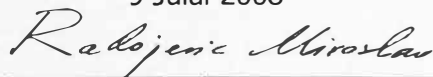


ANITA BINTI ARSAD
PUSTAKAWAN KANAN
UNIVERSITI MALAYSIA SABAH

TANDATANGAN PUSTAKAWAN



Penyelia: Prof Dr Mohd Harun Abdullah
9 Julai 2008



Penyelia: Prof Madya Dr Miroslav Radojevic
9 Julai 2008

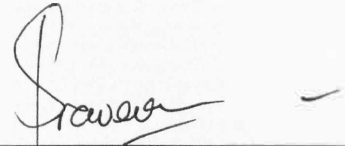
Tarikh: 2007

CATATAN: [@] Tesis dimaksudkan sebagai tesis Ijazah Doktor Falsafah dan Sarjana secara penyelidikan atau ddisertasi bagi pengajian secara kerja kursus dan penyelidikan, atau laporan Projek Sarjana Muda (LPSM)

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, summaries and references, which have been duly acknowledged.

30 March 2008



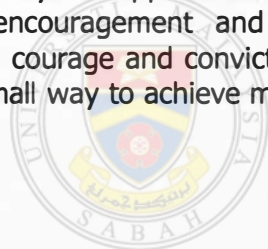
SARVA MANGALA PRAVEENA
PS05-001-021



UMS
UNIVERSITI MALAYSIA SABAH

ACKNOWLEDGEMENT

It is a pleasure for me to thank many people who made this thesis possible. First and foremost, I would like to thank God who is the essence of everything for giving me strength, wisdom and guidance during this study. I am deeply indebted to my supervisors Associate Professor Dr Miroslav Radojevic and Professor Dr Mohd Harun Abdullah whose comments, stimulating suggestions and encouragements helped me in all the time of research. Their overly enthusiasm and integral view on research and their mission for providing 'only high-quality work and not less', has made a deep impression on me. Special thanks to Professor Dr Amran Ahmed for his kind assistance in statistics and helping me with various applications of statistics to this study. I gratefully thank Mr Asram Ramun and Mr Neldin Jeffrey for their help in field samplings. Warmest thanks to "Skim Zamalah Yeoh Tiong Lay", Universiti Malaysia Sabah as a financial support for this postgraduate study. My respects and thanks to all the rest of the Mengkabong residents, Environmental Science lecturers, Environmental Science, Geology and Industrial Chemistry lab assistants (Mr Jalaludin Majalip, Mr Yusri Jasli and Mr Recyheidy Mohd Rashid, Mr Sufie) and friends especially to Mr Conelives Robert (EPD, Sabah), Miss Kamsia Budin, Mr Ahmad Zaharin Aris, Miss Baizurah and Mrs Dayang. To others who helped me directly and indirectly in this study, thank you very much for the kind help and kindness. Your help will always be appreciated. I cannot end without thanking my family, on whose constant encouragement and love I have relied throughout my time. Their unflinching courage and conviction will always inspire me, and I hope to continue, in my own small way to achieve my ambition. It is to them that I dedicate this work.



UMS
UNIVERSITI MALAYSIA SABAH

ABSTRACT

A STUDY ON HEAVY METALS DISTRIBUTION IN MANGROVE SEDIMENT OF MENKABONG, SABAH

The distribution of selected heavy metals (Fe, Cu, Zn, Pb and Al), pH, salinity, electrical conductivity, organic matter, particle size and base cations (Na, K, Ca and Mg) in surface sediment of a mangrove forest situated on the northwest of Sabah were examined from March 2006 to November 2006 at high and low tides. The heavy metal levels, expressed as mg/kg in the studies area were scattered in the ranges: 1434-18360 for iron, 2-49 for copper, 12-93 for zinc, 13-69 for lead and 2410-35393 for aluminium. The Two-Way ANOVA results indicated that the underlying significant variations exist between stations at high and low tides. Results of Spearman correlation coefficient showed a large variety and complexity in these relationships at high and low tides. Multivariate statistics approach (factor analysis) was used to discover and interpret relationships between variables. At high tide, six factors were obtained, which accounted for nearly 70% of the total variance. The results of factor analysis groups at high tide contain salinity, electrical conductivity and clay in factor one, sand in factor two, Cu and K in factor three, Fe, Ca and Al in factor four, pH and Na in factor five as well as Pb in factor six. Whereas at low tide, seven factors were extracted and demonstrated the 77% of the total variance. The results of factor analysis groups at low tide contain silt, Al and Zn in factor one, Mg, Ca and Pb in factor two, Cu and clay in factor three, salinity and K in factor four, pH in factor five, Fe in factor six and Na in factor seven. Different types of indexes (enrichment factors (EF), Geoaccumulation Index (I_{geo}), pollution load index (PLI) and metal sediment pollution index, MSPI) were tested and compared to assess the contamination level. Based on these indexes, MSPI was chosen as having an advantage over the earlier indexes. MSPI uses PCA to interpret and calculated the pollution scores derived from the PCA results. The MSPI value indicates that the Mengkabong mangrove sediment is in excellent condition and confirms that it is in low contamination condition. Moreover, the mean of heavy metals were compared to several sediment quality guidelines (Washington Department of Environment, Australian and New Zealand Environment and Conservation Council (ANZECC), Swedish Environmental Sediment Quality, Screening Quick Reference Table (SQUIRT), Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones and Interim Sediment Quality Guideline for Hong Kong) in order to evaluate the degree to which the sediment-associated chemical status might adversely affect the aquatic organisms. The interim sediment quality values for Hong Kong were chosen and being the most appropriate guideline that meet the prioritization criteria consistent with international regulations and initiatives. However, site-specific, biological testing and ecological analysis of existing benthic community structure (crabs, mollusks, mudskippers) related to sediment contamination are needed for final decision making in the case of Mengkabong mangrove forest management.

KEYWORDS: Mangrove surface sediment, Statistical results, Indexes, Sediment quality guidelines

ABSTRAK

Taburan logam berat terpilih (Fe, Cu, Zn, Pb and Al), pH, saliniti, kekonduksian elektrik, bahan organik, saiz partikel and kation (Na, K, Ca and Mg) di dalam tanah permukaan sedimen hutan paya bakau yang terletak di Barat Laut, Sabah telah dikaji dari Mac 2006 hingga November 2006 pada keadaan air pasang dan air surut. Tahap logam berat ditunjukkan di dalam unit mg/kg di kawasan kajian berjulat: 1434-18360 bagi ferum, 2-49 bagi kuprum, 12-93 bagi zink, 13-69 bagi plumbum and 2410-35393 bagi aluminium. Keputusan "Two-Way" ANOVA menunjukkan bahawa perbezaan bererti wujud di antara semua stesen yang dikaji pada keadaan air pasang dan air surut. Keputusan pekali korelasi "Spearman" menunjukkan kepelbagaian yang besar dan kompleks wujud dalam perhubungan pada keadaan air pasang dan air surut. Kaedah statistik "multivariate" ("factor analysis") telah digunakan untuk mengenalpasti dan menerangkan hubungan yang wujud di antara semua parameter yang dikaji. Keputusan "factor analysis" pada keadaan air pasang, ia mengandungi saliniti, kekonduksian elektrik dan tanah liat di dalam faktor satu, tanah pasir di dalam faktor dua, Cu dan K di dalam faktor tiga, Fe, Ca dan Al di dalam faktor empat, pH dan Na di dalam faktor lima serta Pb di dalam faktor enam. Manakala, bagi keputusan "factor analysis" pada keadaan air surut, ia mengandungi tanah lempung, Al dan Zn di dalam faktor satu, Mg, Ca dan Pb di dalam faktor dua, Cu dan tanah liat di dalam faktor tiga, saliniti dan K di dalam faktor empat, pH di dalam faktor lima, Fe di dalam faktor enam dan Na di dalam faktor tujuh. Pelbagai jenis indeks ("Enrichment Factor" (EF), "Geoaccumulation Index" (I_{geo}), "Pollution Load Index" (PLI) and "Metal Sediment Pollution Index" (MSPI) telah diuji dan dibandingkan untuk mengetahui tahap pencemaran di tanah permukaan sedimen yang dikaji. Berdasarkan semua indeks yang telah dikira, MSPI telah dipilih sebagai indeks yang terbaik dari semua indeks yang telah digunakan. MSPI menggunakan keputusan PCA dalam menilai dan menghitung skor pencemaran. Nilai MSPI menggambarkan sedimen permukaan tanah paya bakau berada dalam keadaan yang sangat baik dan ia mengesahkan bahawa tahap pencemaran yang rendah di kawasan tersebut. Tambahan lagi, nilai min logam berat dibandingkan dengan beberapa garis panduan kualiti sedimen ("Washington Department of Environment", "Australian and New Zealand Environment and Conservation Council" (ANZECC), "Swedish Environmental Sediment Quality", "Screening Quick Reference Table" (SQUIRT), "Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones" dan "Interim Sediment Quality Guideline for Hong Kong") dalam menilai darjah berkait rapat dengan tahap kimia sediment tersebut yang boleh membawa kesan kepada organisma akuatik. "Interim Sediment Quality Guideline for Hong Kong" telah dipilih sebagai garis panduan yang paling sesuai yang memenuhi kriteria-kriteria utama sejajar dengan peraturan dan inisiatif antarabangsa. Walaubagaimanapun, lokasi spesifik, pemeriksaan biologi dan analisis ekologi terhadap komuniti benthik (ketam, moluska, ikan belacak) yang berkait rapat dengan pencemaran sedimen diperlukan dalam menentukan keputusan muktamad mengenai pengurusan hutan paya bakau Mengkabong.

Kata Kunci: Sedimen permukaan tanah paya bakau, Keputusan statistik, Indeks, Garis panduan kualiti sedimen

CONTENTS

	Page
TITLE	i
DECLARATION	ii
CERTIFICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
<i>ABSTRAK</i>	vi
CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES/ PHOTOS	xiii
LIST OF ABBREVIATIONS	xvi
LIST OF SYMBOLS	xvii
LIST OF APPENDIX	xix
CHAPTER 1: INTRODUCTION	1
1.1 Soil Chemistry	1
1.2 Soil Content	2
1.3 Objectives of the Study	4
1.4 Scope of Study	5
CHAPTER 2: LITERATURE REVIEW	6
2.1 “Wetlands” Definition	6
2.2 Mangrove Forest	8
2.3 Mangroves in Malaysia	13
2.4 Destruction of Mangroves	19
2.5 Mangrove Studies	22
2.6 Uniqueness of Mangrove Forest	23
2.7 The Need for Sustainable Mangrove Forest Management	24
2.8 Strategies for Future Research	26
2.9 Important Factors in Mangrove Research	27
2.9.1 Climate and Rainfall	27
2.9.2 Soil	28
2.9.3 Low and High Tide Level	30

2.9.4 Clay minerals	31
3.0 The Physico-Chemical Parameters	33
3.0.1 pH Value	33
3.0.2 Salinity	34
3.0.3 Electrical Conductivity	35
3.0.4 Organic Matter in Sediment	36
3.0.5 Particle Size	37
3.1 Heavy Metals	38
3.1.1 Aluminium	43
3.1.2 Copper	45
3.1.3 Iron	46
3.1.4 Lead	48
3.1.5 Zinc	49
3.2 Role of Mangrove Sediment in Metal Cycling	50
3.3 Heavy Metals Pollution in Mangrove Sediment	54
3.4 Previous Studies of Mangrove Sediment	56
3.5 Correlations between Heavy Metals	58
3.6 Chemical Processes Affecting the Behaviour and Bioavailability of Metals in Soils	59

CHAPTER 3: METHODOLOGY 62

3.1 Study Site	62
3.1.1 Importance of Mengkabong Lagoon	62
3.1.2 Climate and Geology Setting	63
3.1.3 Mangrove Vegetation of Mengkabong Lagoon	63
3.1.4 Pollution Sources in Mengkabong Lagoon	64
3.2 Sampling and Analysis	67
3.2.1 Sampling Strategy	67
3.2.2 Collection of Mangrove Sediment Samples	67
3.3 Analysis of Mangrove Sediment	67
3.4 Analytical Procedure Soil Physical Analysis	75
3.5 Analytical Procedure Soil Chemical Analysis	82
3.6 Atomic Absorption Spectroscopy (AAS)	89
3.7 Data Analysis	90
3.7.1 Statistical Approach	90
3.7.2 Indexes to Assess the Heavy Metals Pollution	91
3.8 Sediment Quality Standards	96

CHAPTER 4: RESULTS AND DISCUSSION 99

4.1 Sediment Physico-Chemical Properties and Organic Matter	99
4.2 Particle Size Distributions	102
4.3 Heavy Metals and Base Cations Trends at Low and High Tides	104

4.4	Statistical Results of Interrelationships in Mengkabong Surface Sediment	124
4.4.1	Two-Way ANOVA	125
4.4.2	Spearman Rank Correlation (r) Results	127
4.4.3	Inter-Element Relationship between Metals and Base Cations	133
4.5	Analysis of Multivariate Data Using Factor Analysis (Principal Components Analysis, PCA)	135
4.5.1	Factor Analysis Application at High Tide	136
4.5.2	Factor Analysis Application at Low Tide	142
4.6	Evaluation of Sediment Pollution	146
4.7	Sediment Quality Guidelines	154
CHAPTER 5: CONCLUSIONS		162
CHAPTER 6: SUGGESTIONS		169
REFERENCE		170
APPENDIX		193
LIST OF PUBLICATIONS		216



UMS
UNIVERSITI MALAYSIA SABAH

LIST OF TABLES

		Page
Table 1.1	Contents of elements in soils, the Earth's Crust and sediment	3
Table 2.1	Wetlands classifications	8
Table 2.2	Estimation of mangrove areas from major mangrove holding countries (km ²)	9
Table 2.3	Mangrove area in top 16 countries	11
Table 2.4	Mangrove status by regions	11
Table 2.5	Estimates of mangrove areas from major mangrove holding countries (km ²)	12
Table 2.6	Area (ha) of mangrove forest reserves in Malaysia	18
Table 2.7	Classification of mangrove vegetation of Sabah	18
Table 2.8	Traditional uses of mangroves in Mida Creek	21
Table 2.9	The retention of heavy metals by some clay minerals	32
Table 2.10	Typical values for pH values of mangrove soils elsewhere	34
Table 2.11	The salinity in various mangrove forest	35
Table 2.12	Metals and the possibly interacting factors	40
Table 2.13	The crucial and non-crucial of heavy metals	43
Table 2.14	Sediment characteristics	51
Table 2.15	Principal aqueous species of environmentally important metal ions (only inorganic species are considered)	53
Table 2.16	Comparison of mangrove sediment levels (mg/kg) from around the world	57
Table 2.17	Comparison of mangrove sediment levels (mg/L) from around the world	58
Table 2.18	The trace metals that found co-precipitated with minerals in soils	60
Table 3.1	The sampling site location of surface sediments in the Mengkabong lagoon	70

Table 3.2	The climate condition during the sampling strategy	71
Table 3.3	A brief account of the methods used in this study	72
Table 3.4	Laboratory equipments, apparatus and chemicals used in this study	74
Table 3.5	Calibrations of the pH, electrical conductivity and salinity electrode	76
Table 3.6	Previous studies used aqua regia in heavy metals extractions	84
Table 3.7	Standard solution and measurement instrumental conditions used for the study	86
Table 3.8	Standard solution and measurement instrumental conditions used for the study	88
Table 3.9	Geoaccumulation index (Muller, 1979) of heavy metal concentration in sediment	94
Table 4.1	Descriptive basic statistics for physicochemical soil characteristics (ph, salinity, electrical conductivity) and organic matter at high tide (n=33)	99
Table 4.2	The comparison of physicochemical properties and organic matter (OM) content from mangrove around the world	102
Table 4.3	Descriptive basic statistics for physical and chemical sediment characteristics in mg/kg (n=33)	105
Table 4.4	Comparison of metal levels (mg/kg) in various mangrove environments	115
Table 4.5	Comparison of mangrove sediment levels (mg/L) from around the world	116
Table 4.6	Descriptive basic statistics of base cations (mg/kg) in mangrove surface sediment (n=33)	118
Table 4.7	High tide versus low tide relationships (n=33)	119
Table 4.8	Summary calculations of the combined (two-factors) ANOVA of the physico-chemical characteristics of the mangrove sediment	126
Table 4.9	Spearman rank correlation for Mengkabong surface sediments at high tide (n=33)	129
Table 4.1	Spearman rank correlation for Mengkabong surface sediments at low tide (n=33)	130

Table 4.1	Correlation coefficient in surface sediment reported in this and other studies	131
Table 4.12	Rotation component matrix at high tide	138
Table 4.13	Rotation component matrix at low tide	143
Table 4.14	Geoaccumulation indexes (Mullaer 1979) of heavy metals concentration in sediment of Mengkabong mangrove forest	152
Table 4.15	The Pollution Load Index for Mengkabong mangrove sediment	152
Table 4.16	The MSPI value for Mengkabong sediment	153
Table 4.17	Average concentration values of five important heavy metals obtained in this study with Marine Sediment Quality Guidelines	156
Table 4.18	Sediment guidelines and definitions used in SQUIRT	158
Table 4.19	Mean Value of heavy metals at high tide (HT) and low tide (LT). All concentration in mg/kg	158
Table 4.20	Screening Quick Reference for heavy metals in marine sediment. All concentration in mg/kg (Buchman, 1999)	158
Table 4.21	Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones according to Caeiro <i>et al.</i> (2005)	159
Table 4.22	Classification of sediments by the heavy metal concentrations (mg/kg) according to the Classification System from the Hong Kong Protection Department (Tam and Wong, 2000)	160

LIST OF FIGURES/ PHOTOS

	Page	
Figure 2.1	Distribution Mangroves Worldwide	10
Figure 2.2	Mangrove distributions in Peninsular Malaysia	15
Figure 2.3	Distributions of mangrove Forests in Sabah	15
Figure 2.4	Distributions of mangrove Forests in Sarawak	16
Figure 2.5	A mature and extensive mangrove forest often has zones	17
Figure 2.6	Mangroves - an integrated management system	25
Figure 2.7	The rainfall data for Tuaran district	28
Figure 2.8	Formation of pyrite oxidation during high and low tides	31
Figure 2.9	Tetrahedral and octahedral sheet	32
Figure 2.10	Composition of soil organic matter	36
Figure 2.11	Particle size limits of different U.S textural classification systems	38
Figure 2.12	Triangular diagram relating proportions of sand, silt, and clay to particle size classes	39
Figure 2.13	The soil-plant system with dynamics of heavy metals	43
Figure 2.14	Simple schematic breakdown of common al-complexes	44
Figure 2.15	Chemical equilibrium between zn and soil components	50
Figure 2.16	The simplified biogeochemical cycle for trace metals	52
Figure 2.17	The sediment pore waters and overlying waters	54
Photo 3.1	Dominant species in Salut and Mengkabong Lagoon	64
Figure 3.1	Location map of the studied area, Mengkabong lagoon, Tuaran District, Sabah	65
Figure 3.2	Aerial views of sampling stations in Mengkabong lagoon	69
Figure 3.3	The flow of methodology diagram	73
Figure 3.4	The steps involved in physicochemical properties determination	77

Figure 3.5	The steps involved in organic matter determination	78
Figure 3.6	The steps involved in determination of particle size	81
Photo 3.2	Parr Bomb as a closed-vessel procedure	83
Figure 3.7	Preparation of aqua regia	85
Figure 3.8	Procedure of aqua regia digestion	85
Figure 3.9	Procedure of heavy metals determination for AAS	86
Figure 3.10	Procedure of exchangeable cations	88
Figure 3.11	The basic instrumental components in AAS	89
Figure 3.12	Diagram of hollow cathode lamp	89
Figure 3.13	Details of factor analysis	91
Figure 4.1	pH, salinity, electrical conductivity (EC) and organic matter distributions at low and high tide for each location	100
Figure 4.2	Granometric fraction of Mengkabong mangrove sediment at high and low tides	104
Figure 4.3	Spatial distribution of Zn at high and low tides in Mengkabong mangrove forest	106
Figure 4.4	Spatial distribution of Cu (mg/kg) at high and low tides in Mengkabong mangrove forest	107
Figure 4.5	Spatial distribution of Al (mg/kg) at high and low tides in Mengkabong mangrove forest	108
Figure 4.6	Spatial distribution of Fe at high and low tides in Mengkabong mangrove forest	109
Figure 4.7	Spatial distribution of Pb (mg/kg) at high and low tides in Mengkabong mangrove forest	110
Figure 4.8	Typical reactions of cations and anions with surface bound hydroxyl groups at the water-oxide interface	113
Figure 4.9	Spatial distribution of Na (mg/kg) at high and low tides in Mengkabong mangrove forest	120
Figure 4.10	Spatial distribution of K (mg/kg) at high and low tides in Mengkabong mangrove forest	121

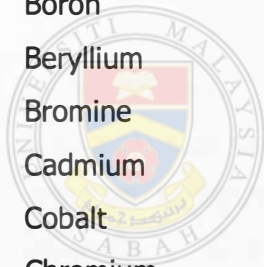
Figure 4.11	Spatial distribution of Ca (mg/kg) at high and low tides in Mengkabong Mangrove Forest	122
Figure 4.12	Spatial distribution of Mg (mg/kg) at high and low tides in Mengkabong mangrove forest	123
Figure 4.13	Scree plot for each component numbers at high tide	136
Figure 4.14	Results of factors 1, factor 2 and factor 3 in sediment of Mengkabong mangrove forest at high tide	139
Figure 4.15	Results of factors 4, factor 5 and factor 6 in sediment of Mengkabong mangrove forest at high tide	140
Figure 4.16	Scree plot for each component numbers at low tide	142
Figure 4.17	Results of factors 1, factor 2 and factor 3 in sediment of Mengkabong mangrove forest at low tide	144
Figure 4.18	Results of factors 4, factor 5, factor 6 and factor 7 in sediment of Mengkabong mangrove forest at low tide	145
Figure 4.19	The EF of heavy metals in Mengkabong mangrove sediment at high tide	148
Figure 4.20	The EF of heavy metals in Mengkabong mangrove sediment at low tide	149
Figure 4.21	Copper, lead and zinc anthropogenic and lithogenic proportion in Mengkabong mangrove sediment at high tide	150
Figure 4.22	Copper, lead and zinc anthropogenic, and lithogenic proportion in Mengkabong mangrove sediment at low tide	151
Figure 4.23	Rubbish thrown indiscriminately into the sea by villagers	157
Figure 4.24	Rubbish thrown by villagers drifted to the seaside	157
Figure 4.25	Houses built on the sea rubbish thrown indiscriminately under the house	157

LIST OF ABBREVIATIONS

EC	Electrical Conductivity
OM	Organic Matter
Sa	Salinity
HNO ₃	Nitric Acid
SPSS	Statistical Package for Social Science
PCA	Principal Component Analysis
EF	Enrichment Factor
I_{geo}	Geo-accumulation Index
PLI	Pollution Load Index
MSPI	Marine Sediment Pollution Index
CF	Concentration Factors
ANZECC	Australian and New Zealand Environment And Conservation Council
SQG	Sediment Quality Guidelines
ISQGs	Interim Sediment Quality Guidelines
SQUIRT	Screening Quick Reference Table
CEC	Cation Exchange Capacity
ICP	Inductively Coupled Plasma
USEPA	United States Environmental Protection Agency
AAS	Atomic Absorption Spectroscopy
FAAS	Flame Atomic Absorption Spectroscopy
APHA	American Public Health Association
EIA	Environmental Impact Assessment
KKIP	Kota Kinabalu Industrial Park
DOM	Dissolved Organic Matter
DO	Dissolved Oxygen

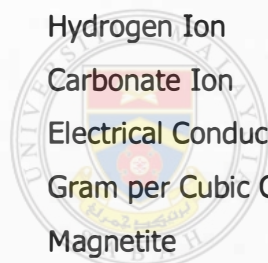
LIST OF SYMBOLS

O	Oxygen
Si	Silicon
Al	Aluminium
Fe	Iron
C	Carbon
La	Lanthanum
Li	Litium
Pb	Lead
P	Phosphorus
Ca	Calcium
K	Potassium
As	Arsenic
B	Boron
Be	Beryllium
Br	Bromine
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cs	Cesium
Cu	Copper
Ca	Calcium
K	Potassium
Mn	Manganese
Na	Sodium
Rb	Rubidium
S	Sulfur
Sc	Scandium
Sn	Tin
Sr	Strontium
Th	Thorium
Ti	Titanium



UMS
UNIVERSITI MALAYSIA SABAH

U	Uranium
V	Vanadium
Zn	Zinc
μm	Micrometer
Ni	Nickel
Mg	Magnesium
Mm	Millimeter
Ha	Hectare
%	Percentage
km^2	Square kilometer
USA	United States Of America
$^{\circ}\text{C}$	Celsius
SOM	Soil Organic Matter
HCO_3^-	Bicarbonate
T_2O_5	Tetrahedral Cation
H^+	Hydrogen Ion
CO_3^{2-}	Carbonate Ion
EC	Electrical Conductivity
g/cm^3	Gram per Cubic Centimetre
Fe_3O_4	Magnetite
Fe_2O_3	Hematite
mg/dl	Milligrams per deciliter
mg/kg	Milligram/kilogram
$\mu\text{S}/\text{cm}$	Microsiemen /centimeter
Ppm	Part per million
G	Gram
=	Equals to
ms^{-1}	Meters per second
mL	Milliliter
Mg	Milligram
A-A	Air–Acetylene
$\text{N}_2\text{O-A}$	Nitrous Oxide – Acetylene



UMS
UNIVERSITI MALAYSIA SABAH

LIST OF APPENDIX

	Page	
Appendix A	Physico-chemical Properties, Organic Matter and Granometric Fractions of Mengkabong Lagoon Surface Sediment at High Tide	193
Appendix B	Physico-chemical Properties, Organic Matter and Granometric Fractions of Mengkabong Lagoon Surface Sediment at Low Tide	194
Appendix C	An Overview of Fluxes and Driving Forces behind Nutrient and Organic Matter Dynamics in the Mangrove Tidal Creek	195
Appendix D	Mean Value of heavy metals in Mengkabong Lagoon Surface sediment at High Tide (mg/kg)	196
Appendix E	Mean value of heavy metals in Mengkabong Lagoon Surface Sediment at Low Tide (mg/kg)	197
Appendix F	Calibration Graph for Al, Cu and Fe	198
Appendix G	Calibration Graph for Pb and Zn	199
Appendix H	Mean value of base cations in Mengkabong Lagoon Surface Sediment at High Tide (mg/kg)	200
Appendix I	Mean Value of Base Cations in Mengkabong Lagoon Surface Sediment at Low Tide (mg/kg)	201
Appendix J	Calibration Graph for K and Na	202
Appendix K	Calibration Graph for Ca and Mg	203
Appendix L	High Tide versus Low Tide Relationships for Studied Variables (n=33)	204
Appendix M	High Tide versus Low Tide Relationships for Studied Variables (n=33)	205
Appendix N	Tests of Normality at High Tide	206
Appendix O	Tests of Normality at Low Tide	207
Appendix P	Levene's Test of Equality of Error Variances	208
Appendix Q	Total Variance Explained At High Tide	209
Appendix R	Component Matrix at High Tide	210

Appendix S	Total Variance Explained at Low Tide	211
Appendix T	Component Matrix at Low Tide	212
Appendix U	Calculation of EF to Assess the Antropogenic and Lithogenic Contribution	213
Appendix V	Sediment Quality Rating For Each of The Variables Selected From The Principal Component Analysis for MSPI Calculation	214
Appendix W	The Weight Calculation for Each Selected Variables for MSPI Calculation	215



UMS
UNIVERSITI MALAYSIA SABAH

CHAPTER 1

INTRODUCTION

1.1 SOIL CHEMISTRY

Soil chemistry is the branch of soil science that deals with the chemical composition, chemical properties and chemical reactions of soils. Soils are heterogeneous mixtures of air, water, inorganic and organic solids, microorganisms (both plant and animal in nature) and water capable of supporting plant life on the earth's surface (Sparks, 1995; Manahan, 2000). Soil chemistry has traditionally focused on the chemical reactions in soils that affect plant growth and plant nutrition. On the other hand, beginning in the 1970s to now, there are increasing concerns about inorganic and organic contaminants in water and soil as well as the impacts on plant, animal and human health. Soil chemistry is concerned with chemical reactions involving these phases (solid, solution and gas). For an example, carbon dioxide in air combined with water acts to weather the inorganic solid phase. Chemical reactions between the soil solids and the soil solution influence both plant growth and water quality (Sparks, 1995).

Environmental soil chemistry is the study of chemical reactions between soils and environmentally important plant nutrients, radionuclides, metals and organic metals. Knowledge of environmental soil chemistry is fundamental in predicting the fate of contaminants in the surface and subsurface environments. An understanding of the chemistry and mineralogy of organic and inorganic soil components is vital to

comprehend the array of chemical reactions that contaminants may undergo in the soil environment. These reactions, which may include equilibrium and kinetic process such as dissolution, precipitation, polymerization, adsorption/ desorption and oxidation-reduction, affect the solubility, mobility, form and the toxicity of contaminants in soils and in surface waters and groundwaters. Knowledge of environmental soil chemistry is also useful in making sound decision and also cost effective decision about remediation of contaminated soils (Sparks, 1995).

1.2 SOIL CONTENT

Soil is the final product of the weathering of parent rock and the decomposition of organic matter; the action of physical, chemical, and biological processes on rocks that produce mainly clay minerals. The organic portion of soil consists of plant biomass in various stages of decay. High populations of bacteria, fungi, and animals such as earthworms may be found in soil. Soil contains air spaces and generally has a loose texture. The solid fraction of typical productive soil is approximately 5% organic matter and 95% inorganic matter. Some soils, such as peat soils, may contain as much as 95% organic material. Other soils contain as little as 1% organic matter (Manahan, 2000).

The median and range of elemental content of soils from around the world are given in Table 1.1. The elements that are found in the highest quantities are oxygen (O), silicon (Si), aluminium (Al), iron (Fe), carbon (C), calcium (Ca), potassium (K), nickel (Ni) and magnesium (Mg). These are also major elements found in earth crust and in sediments. Oxygen is the most prevalent element in the earth crust and in soils. It comprises about 47% of the earth's crust by weight and greater than 90% by volume (Sparks, 1995). The inorganic components of soils represent more than 90% of the solid components. Properties such as size, surface area and charge behavior greatly affect many important equilibrium and kinetic reactions and processes in soils (Manahan, 2000).

Table 1.1: Contents of elements in soils, the Earth's crust and sediment

Element	Soils (mg/kg)	Earth Crust (mean) ^c	Sediments (mean) ^c
	Range ^{a, b}		
Al	700 – 300, 000	82, 000	72, 000
As	< 0.1 - 97	1.5	7.7
B	< 20 – 300	10	100
Ba	10 – 5, 000	500	460
Be	< 1 – 40	2.6	2
Br	< 0.5 – 110	0.37	19
C, Total	600 – 500, 000	480	29, 400
Ca	100 – 500, 000	41, 000	66, 000
Cd	< 0 - 2	0.11	0.17
Cl	< 0 – 1800	130	190
Co	< 3 – 70	20	14
Cr	1 – 2000	100	72
Cs	< 0 - 20	3	4.2
Cu	< 1 - 700	50	33
F	< 10 – 3, 700	950	640
Fe	100 - > 550,000	41, 000	41, 000
Ga	< 5 – 100	18	18
Ge	< 0.1 – 50	1.8	1.7
I	< 0.10 – 25	0.14	16
K	50 – 63, 000	21, 000	20, 000
La	< 30 – 200	32	41
Li	< 3 - 350	20	56
Mg	50 - > 100, 000	23, 000	14, 000
Mn	< 2 – 10, 000	950	770
Mo	< 3 – 40	1.5	2
N	< 0 – 5, 000	25	470
Na	< 150 – 100, 000	23, 000	5, 700
Nb	< 6 – 300	20	13
Nd	< 4 - 300	38	32
Ni	< 2 - 750	80	52
O	-	474, 000	486, 000
P	< 20 – 6, 800	1, 000	670
Pb	< 10 - 700	14	19
Rb	< 20 – 1, 000	90	135
S, Total	< 30 – 48,000	260	2, 200
Sb	< 0.20 – 10	0.2	1.2
Sc	< 0.5 -55	16	10
Se	< 0.011 – 4.3	0.05	0.42
Sn	< 1- 200	2.2	4.6
Sr	< 4 – 3, 000	370	320
Th	1 - 35	12	9.6
Ti	70 – 25, 000	5, 600	3, 800
U	0.29 - 11	2.4	3.1
V	< 7 - 500	160	105
Y	< 10 - 250	30	40
Yb	< 0.04 – 50	3.3	3.6
Zn	< 1 – 2, 900	75	95
Zr	< 20 – 2, 000	190	150

^a Shacklette & Boerngen (1984). Represent analyses from soils and other surficial materials from throughout the continental United States. ^{b,c} Bowen (1979)

The inorganic components of soils include both primary and secondary minerals which range in size (particle diameter) from clay-sized colloids ($< 2 \mu\text{m}$ or 0.002 mm) to gravel ($> 2\text{mm}$) and rocks. A mineral can be defined as a natural inorganic compound with definite physical, chemical and crystalline properties ionically bonded and their structures based on Pauling's Rules. The primary mineral is the one that has not been altered chemically since deposition and crystallization from molten lava. Examples are quartz and feldspar while in smaller quantities minerals such as micas, olivines and many more. A secondary mineral results from weathering of primary mineral, either by alteration in the structure or from reprecipitation of product weathering (dissolution) of primary mineral.

Common secondary minerals are aluminosilicate minerals. The nature of the parent material is the main factor determining the present soil type and soil chemical properties. The bedrock at the presented sites are either acid metamorphic rock (gneiss), or the more basic petrified sedimentary deposits (sandstone or shales). Ionic bonds are formed when an ion interacts with another ion of opposite charge in the mineral structure to form a chemical bond. Covalent bonds are those which share electrons. Most chemical bonds have a combination of ionic and covalent Character. For an example, the Al-O bond is approximately 40% covalent and 60% (Sparks, 1995).

1.3 OBJECTIVES OF THE STUDY

The present research objectives are stated as follows:.

- i. To determine selected heavy metals (Fe, Cu, Zn, Pb and Al), pH, salinity, electrical conductivity, organic matter, particle size and base cations (Na, K, Ca and Mg) in mangrove sediments at low and high tide.
- ii. To examine the relationship between heavy metals and base cations with soil chemical and physical parameters during high and low tides.