

TABLE OF CONTENT

COVER	
APPROVAL SHEET	
ACKNOWLEDGEMENTS	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	v
LIST OF TABLES	ix
LIST OF EQUATIONS	xi
LIST OF ABBREVIATIONS	xii
LIST OF APPENDICES	xix
ABSTRACT	xx
ABSTRAK	xxi
CHAPTER 1- INTRODUCTION	1
1.1 Background.....	1
1.2 Problem Formulation.....	5
1.3 Research Objectives.....	6
1.4 Scopes of Research.....	7
1.4.1 Scope of Research Area.....	7
1.4.2 Scope of Research Works.....	7
1.5 Excepted Outcomes.....	9
1.6 Authenticity of the Research.....	10
CHAPTER 2- LITERATURE REVIEW AND THEORETICAL	
BACKGROUND	15
2.1 Literature Review.....	15
2.1.1 Regional Geological Setting.....	15
2.1.2 Regional Hydrogeological Setting.....	22
2.2 Theoretical Background.....	32
2.2.1 Factors Governing on Groundwater Chemistry.....	32
2.2.2 Agents of Chemical Weathering.....	38
2.2.3 Weathering of Some Common Rock Forming Minerals and Their Products.....	39

2.2.4 Elements Mobility in Soil.....	40
2.2.5 Statistical Analyses.....	41
2.2.6 Soil Characterization Techniques.....	42
2.2.7 Principle of Chemical Weathering Indices.....	42
2.2.8 Hydrochemical Characterisation Tools.....	47
2.2.9 Principle of Soil Leaching.....	59
2.2.10 Selection of Laboratory Soil Leaching Test.....	62
2.2.11 Batch Leaching Test.....	62
2.2.12 Ion Chromatography Test.....	63
2.2.13 Parameters Controlling Laboratory Soil Leaching Tests.....	63
2.2.14 Sorption Efficiency of Soil.....	66
2.3 Hypotheses.....	66
CHAPTER 3 - RESEARCH METHODOLOGY.....	69
3.1 General.....	69
3.2 Research Equipment and Materials.....	69
3.3 Research Phases.....	71
3.3.1 Desk Study.....	71
3.3.2 Data Collection.....	72
3.3.3 Laboratory Works.....	74
3.3.4 Mineral Identification.....	75
3.3.5 Geochemical Data Analyses.....	76
3.3.6 Hydrochemical Evaluation Methods.....	77
3.3.7 Batch Leaching Experiment.....	81
3.3.8 Ion Chromatography Analysis.....	83
3.3.9 Data Analysis of Soil Leaching Properties.....	84
3.3.10 Data Evaluation and Interpretation.....	85
3.3.11 Data Compilation.....	86
CHAPTER 4 - GEOMORPHOLOGY AND SOIL CHARACTERISTICS.....	88
4.1 Geomorphology.....	88
4.2 Relation between Geochemical Composition and Mineralogy.....	94
4.3 Weathering Degree.....	96

4.4 Weathering Trend and Their Products.....	98
 CHAPTER 5 - GROUNDWATER FLOW AND HYDROCHEMICAL EVOLUTION..... 103	
5.1 Groundwater Flow.....	103
5.2 Spatial Distributions of Physical and Chemical Parameters of Groundwater.....	106
5.3 Hydrochemical Evolution.....	115
5.3.1 Hierarchical Cluster Analysis.....	115
5.3.2 Piper Diagram.....	125
5.3.3 Stuyfzand Method.....	129
5.3.4 Mineral Saturation Indices.....	137
5.3.5 Mass Balance Transport.....	142
5.3.6 Rock-water Interaction.....	147
 CHAPTER 6 - LABORATORY SOIL LEACHING TEST..... 154	
6.1 Effect of Agents on Desorption Efficiency.....	154
6.2 Effect of Leaching Time.....	159
6.3 Effect of pH.....	161
6.4 Comparison of Optimum Desorption Efficiency	161
 CHAPTER 7 - DISCUSSIONS..... 164	
7.1 Aquifer Lithology.....	164
7.2 Control of Natural Weathering To Mineral Alteration Reactions.....	165
7.3 Composition of Leachates and Interpretation of Batch Experiment	171
 CHAPTER 8 - CONCLUSIONS AND RECOMMENDATIONS..... 177	
8.1 Conclusions.....	177
8.2 Recommendations.....	178
REFERENCES.....	180
APPENDICES.....	190

LIST OF FIGURES

Figure	Page
Figure 1.1 Location map of the resarch area.....	8
Figure 2.1 Regional geomorphological map.....	16
Figure 2.2 Regional stratigraphic columns.....	19
Figure 2.3 Regional geological map.....	20
Figure 2.4 Regional hydrogeological map.....	23
Figure 2.5 Cross-section of Alluvial Aquifer Sub-system on Wates Groundwater Basin.....	25
Figure 2.6 Cross-section of Sand Dunes Aquifer Sub-system on Wates Groundwater Basin.....	26
Figure 2.7 Groundwater flow patterns of Wates Groundwater Basin.	28
Figure 2.8 Geoelectrical survey of Wates Groundwater Basin.....	28
Figure 2.9 Hydrostratigraphic aquifer system of Wates Groundwater Basin (east-west).....	29
Figure 2.10 Hydrostratigraphic aquifer system of the Wates Groundwater Basin (north-south).....	29
Figure 2.11 Regional groundwater level zone map.....	31
Figure 2.12 Regional electrical conductivity zone map.....	32
Figure 2.13 Gibbs diagrams showing three mechanisms of hydrochemical processes.....	35
Figure 2.14 An example plot of $Al_2O_3-(CaO^*+Na_2O)-K_2O$ ternary.....	44
Figure 2.15 An example plot of $Al_2O_3-(CaO^*+K_2O+Na_2O) - (Fe_2O_3+$ $MgO)$ ternary.....	46
Figure 2.16 Stiff diagram showing major ions concentrations of water samples.....	52
Figure 2.17 Box and whisker diagram showing major ions concentrations of water samples.....	53
Figure 2.18 Piper diagram showing the water types.....	53
Figure 2.19 Explanation of the hydrochemical types.....	55
Figure 2.20 Determination of water type, using the main cations and anions.....	57
Figure 2.21 Coding significant of chemical water types.....	58

Figure 2.22	Rate of carbonation in relation to wetting degree.....	61
Figure 2.23	Batch leaching procedure.....	63
Figure 2.24	Mechanisms of sorption processes: (a) adsorption and desorption.....	67
Figure 3.1	Diagram showing the stages of research methods.....	70
Figure 3.2	Distribution map of the drilling and water sampling sites in the research area.....	73
Figure 4.1	Geomorphological units in the research area.....	89
Figure 4.2	Drilling locations and geoelectric points in the research area	90
Figure 4.3	Detailed geological map based on drill log and geoelectric data in the research area	92
Figure 4.4	Ternary plot showing the oxides; Al_2O_3 -($CaO+Na_2O$) - K_2O	99
Figure 4.5	Ternary plot showing the oxides; Al_2O_3 - ($CaO+Na_2O$ + K_2O) - ($FeO+MgO$).....	100
Figure 5.1	Groundwater flow pattern based on the water level contour.....	104
Figure 5.2	Groundwater flow pattern and apatial distribution of major ions.....	104
Figure 5.3	Spatial distribution map of the pH values in the research area.....	108
Figure 5.4	Spatial distribution map of the electrical conductivity values in the research area.....	109
Figure 5.5	Spatial distribution map of the dissolved solids in the research area.....	109
Figure 5.6	Pie charts showing the concentrations of dominant ions from water samples of the research area.....	110
Figure 5.7	Spatial distribution map of sodium in the research area.....	111
Figure 5.8	Spatial distribution map of calcium in the research area....	112
Figure 5.9	Spatial distribution map of bicarbonate in the research area.....	113

Figure 5.10	Spatial distribution map of chloride in the research area...	114
Figure 5.11	(a) Dendrogram for the groundwater samples showing the division into three clusters, (b) Stiff diagram showing the median composition (meq/L) of groundwater in three clusters, and (c) Box plots of TDS and EC for groundwater in three clusters.....	117
Figure 5.12	Cluster map showing spatial diatribution of groundwater facies.....	118
Figure 5.13	Hydrochemical process along flow direction based on the ratios of (a) $\text{Cl}^-/\text{HCO}_3^-$ and $\text{SO}_4^{2-}/\text{HCO}_3^-$, and (b) $(\text{Ca}^{2+} + \text{Mg}^{2+})/(\text{Na}^+ + \text{K}^+)$	124
Figure 5.14	(a) Piper diagram describing the chemical composition of water samples for the study area; (b) Pie chart of mean concentrations of ions (meq/L) showing alkaline earth metals ($\text{Ca}^{2+} + \text{Mg}^{2+}$) exceed alkaline metals ($\text{Na}^+ + \text{K}^+$), and weak acids ($\text{CO}_3^- + \text{HCO}_3^-$) greatly exceed strong acids ($\text{SO}_4^{2-} + \text{Cl}^-$).....	126
Figure 5.15	Determination of bicarbonate water type in the research area according to Stuyfzand method; (a) fresh moderately hard calcium bicarbonate with no salt water intrusion.....	131
Figure 5.15	Determination of bicarbonate water type in the research area according to Stuyfzand method; (b) fresh moderately hard calcium bicarbonate with no salt water intrusion	132
Figure 5.16	Determination of sodium mixed water type in the research area according to Stuyfzand method.....	134
Figure 5.17	Determination of sodium chloride water type in the research area according to Stuyfzand methoda.....	135
Figure 5.18	Plot of the saturation indices of (a) relevant minerals of STA 25, 20, 19 vs TDS, and (b) relevant minerals of STA 16 and 11 vs TDS.....	141
Figure 5.19	Groundwater flow paths representing the hydrochemical evolution in the research area.....	141
Figure 5.20	Gibbs plots indicating the mechanism of groundwater chemistry in the research area; (a) $(\text{Na}^+ + \text{K}^+) / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})$ versus TDS and (b) $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$ versus TDS....	144

Figure 5.21	Bivariate plots showing the hydrochemical processes of (a) Na^+ versus Cl^- , and (b) Na^+/Cl^- versus EC.....	150
Figure 5.22	Bivariate plot showing the Ca^{2+} versus SO_4^{2-} of gypsum Dissolution.....	151
Figure 6.1	Effect of agents on the adsorption and desorption efficiency of chloride in STA 24.....	157
Figure 6.2	Effect of agents on the adsorption and desorption efficiency of chloride in STA 19.....	158
Figure 6.3	Changes of pH over time for adsorption efficiency of adsorbent.....	161
Figure 6.4	Changes of pH over time for desorption efficiency of adsorbents.....	162
Figure 6.5	Comparison of Optimum desorption efficiency of adsorbents...	162

LIST OF TABLES

Table		Page
Table 1.1	Comparison of the researches.....	11
Table 2.1	Distribution of the depth to groundwater level in Kulon Progo.....	30
Table 2.2	Clay minerals and their properties affecting on cation exchange capacity.....	37
Table 2.3	Interpretation of the coefficients of variation and determination.....	41
Table 2.4	Summary of common chemical weathering indices.....	43
Table 2.5	The comparison between the Inverse Distance Weight and Kriging methods.....	49
Table 2.6	Classification of main water type based on the chloride (Cl ⁻) concentration.....	56
Table 2.7	Determination of hardness code based on total hardness...	56
Table 2.8	Determination of cation exchange code.....	57
Table 3.1	List of equipment used in the research.....	71
Table 4.1	Geomorphological units and their characteristics in the research area.....	89
Table 4.2	Correlation coefficients (r) of selected major elements of the studied samples (n=8).....	95
Table 4.3	Chemical weathering degree in the study area (Nesbitt and Young, 1990).....	98
Table 5.1	Statistical summary of physicochemical parameters compared to WHO standard for drinking water.....	107
Table 5.2	Summary statistics of major hydrochemical variables of cluster groups based on dominant ions.....	120
Table 5.3	Pearson correlation matrix of the physicochemical parameters of groundwater samples.....	122
Table 5.4	Hydrochemical zoning of groundwater quality in the research area.....	127
Table 5.5	Summary of interpretation results of groundwater chemistry in the research area according to the multivariate statistical and graphical methods.....	137

Table 5.6	Statistical summary of thermodynamic calculations using PHREEQC.....	135
Table 5.7	Mineral saturation indices along the groundwater flow path in the Fluviomarine Plain.....	140
Table 5.8	Mineral saturation indices along the groundwater flow path in the Sand Dunes Units.....	140
Table 5.9	Mass balance transport obtained from PHREEQC showing the mole transfer from one water type (STA 24) to the next (STA 20).....	145
Table 5.10	Mass balance transport obtained from PHREEQC showing the mole transfer from one water type (STA 20) to the next (STA 19).....	146
Table 5.11	Mass balance transport obtained from PHREEQC showing the mole transfer from one water type (STA 16) to the next (STA 11).....	147
Table 6.1	Physical properties of natural and modified solutions with HCl and NaOH in representative samples for batch leaching test.....	156
Table 6.2	Adsorption and desorption efficiency of dissolved chloride ions in STA 24.....	155
Table 6.3	Adsorption and desorption efficiency of dissolved chloride ions in STA 19.....	158
Table 7.1	Mineral alteration reaction of STA 24 in the Fluviomarine Plane.....	166
Table 7.2	Mineral alteration reaction of STA 20 in the Fluviomarine Plane.....	167
Table 7.3	Mineral alteration reaction of STA 19 in the Fluviomarine Plane.....	169
Table 7.4	Mineral alteration reaction of STA 16 in the Sand Dunes Units.....	170
Table 7.5	Mineral alteration reaction of STA 11 in the Sand Dunes Units.....	170

LIST OF EQUATIONS

Equation		Page
Equation 2.1	Silicate weathering from albite to kaolinite.....	36
Equation 2.2	Silicate weathering from anorthite to kaolinite.....	36
Equation 2.3	Cation exchange reaction.....	37
Equation 2.4	Reverse ion exchange reaction.....	37
Equation 2.5	Dissolution of halite.....	38
Equation 2.6	Dissolution of gypsum.....	38
Equation 2.7	French hardness degree.....	55
Equation 2.8	Correction for sea water contribution.....	56
Equation 2.9	Acid-base reaction.....	60
Equation 2.10	Laboratory soil leaching process.....	63
Equation 3.1	Ion balance error.....	77
Equation 3.2	Plagioclase weathering with $[(Na^+ + K^+) - Cl^-] / [(Na^+ + K^+) - Cl^-] + Ca^{2+}$	81
Equation 3.3	Cation adsorption capacity in equilibrium stage ⁺	84
Equation 3.4	Cation adsorption capacity in percentage.....	84
Equation 3.5	Cation desorption capacity in percentage.....	85
Equation 5.1	Hydrochemical Reaction of silicate sediment and carbonic acid.....	118
Equation 5.2	Hydrochemical Reaction from cluster 1 to cluster 2.....	119
Equation 5.3	Hydrochemical Reaction from cluster 2 to cluster 3.....	121
Equation 5.4	Reaction between CO ₂ and H ₂ O.....	130
Equation 5.5	Reaction between HCO ₃ and Ca.....	131
Equation 5.6	Reaction between halite and marine clay.....	133
Equation 7.1	Mineral alteration reaction of STA 24.....	166
Equation 7.2	Mineral alteration reaction of STA 20.....	167
Equation 7.3	Mineral alteration reaction of STA 19.....	169
Equation 7.4	Mineral alteration reaction of STA 11.....	169
Equation 7.5	Mineral alteration reaction of STA 11.....	170

LIST OF ABBREVIATIONS

General Abbreviation	Description
A-CN	- Aluminium oxide - calcium oxide + sodium oxide
A-CN-K	- Aluminium oxide - calcium oxide + sodium oxide potassium oxide
A-CNK-FM	- Aluminium oxide - calcium oxide + sodium oxide + potassium oxide - iron oxide + magnesium oxide
A-CNK	- Aluminium oxide - calcium oxide + sodium oxide + potassium oxide
A-K	- Aluminium oxide - potassium oxide
ArcMap	- Program to create, edit and analyze the geospatial data
B	- Brackish water type
Bs	- Brackish to salt water type
BEX	- Base exchange index
CAI	- Chloro Alkaline Index - an indicator of ion exchange process between groundwater and its host materials
CaO*	- Calcium in silicate-bearing minerals
CIA	- Chemical index of alteration - a measure of the degree of chemical weathering included potassium
CIW	- Chemical index of weathering - a measure of the degree of chemical weathering without potassium
CEC	- Cation exchange capacity
CaX ₂	- Calcium ions adsorbed by clays
C ₁	- Cluster one - bicarbonate water type
C ₂	- Cluster two - semi-bicarbonate water type
C ₃	- Cluster three - brackish to salty water type
C _e	- Concentration of ions at equilibrium
C _i	- Initial concentration of ion
CN	- Calcium oxide plus sodium oxide

CO ₂	- Carbon dioxide
CV	- Coefficient of variation
E	- Sand Dunes and Swales - a geomorphological unit
EC	- Electrical conductivity
<i>et al.</i> ,	- And others
etc.	- Usage instead of giving a complete list
F	- Fresh water type
Fb	- Fresh to brackish water type
Fe ³⁺	- Ferric iron
F _m	- Fluvio-marine Plain - a geomorphological unit
FM	- Magnesium and iron oxides corner
GPS	- Global Positioning System
H	- Hypersaline water type
h	- Hour for leaching time
H ⁺	- Hydrogen ion
HCA	- Hierarchical cluster analysis - a statistical technique grouped similar water chemical data
HCl	- Hydrochloric acid
H ₂ CO ₃ ⁻	- Carbonic acid
H ₂ O	- Water
H ₃ O ⁺	- Hydronium ion
H ₂ SO ₄	- Sulfuric acid
H ₄ SiO ₄	- Silicic acid - aqueous silica
<i>i.e</i>	- Statement for something in different words
IC	- Ion chromatography
ICP-MS	- Inductively Coupled Plasma Mass Spectrometry
IDW	- Inverse distance weighted
K	- Hydraulic conductivity
LOI	- Loss on ignition
L/S	- Solid to liquid ratio
m	- Mass of adsorbent (soil)
M ₁	- Beach - a geomorphological unit

M ₂	- Beach Ridges - a geomorphological unit
Max.	- Maximum
Min.	- Minimum
NaOH	- Sodium hydroxide
NaX	- Sodium ions adsorbed by clays
NH ₄	- Ammonium
n, No.	- Numbers
Na ₂ CO ₃	- Sodium carbonate
NE-SW	- North east to south west
O ₂	- Oxygen
OH ⁻	- Hydroxide
pH	- Hydrogen ion concentration
PHREEQC	- pH reaction equilibrium calculation
PIA	- Plagioclase index of alteration
PWI	- Product of weathering index
q _e	- Ion amounts that are adsorbed on soil surface
q _{max}	- Maximum adsorption capacity of ions
r	- Pearson's correlation coefficient
R	- Ruxton chemical weathering index
R ²	- Simple linear regression
R _L	- Equilibrium parameter for Langmuir isotherm
REE	- Rare earth elements
rpm	- Rim per minute
S	- Silica content, Storativity of water within aquifer and Salt water type
SD	- Standard deviation
SI	- Saturation index of mineral
SPSS	- Statistical package for social sciences
STA	- Sampling location number
T	- Temperature and Transmissivity of water through aquifer materials
TDS	- Total dissolved solids

TH	- Total hardness
V	- Volume of solution and vogt chemical weathering ratio
vs	- Versus
WHO	- World Health Organization
WIP	- Weathering index of parker
XRD	- X-ray Diffractometer
°	- Degree
'	- Minute
"	- Second
Ø	- Phi
/	- Meaning of “or”
θ	- Theta
-	- Minus, dash and no data
+	- Plus

Units Abbreviation	Description
°C	- Degree Celsius
g	- Gram
km	- Kilometer
km ²	- Kilometer square
L/g	- Litre per gram
L/mg	- Liter per milligram
m	- Meter
mL	- Milliliter
meq/L	- Milliequivalent per liter
mg/g	- Milligram per gram
mg/L	- Milligram per liter
meq/100 g	- Milliequivalent per 100 grams
ppm	- Parts per million
µm	- Micrometer
Ωm	- Ohm meter
µS/cm	- Microsiemens per centimeter

%	- Percent
wt. %	- Weight percent
<	- Less than
>	- Greater than
≤	- Less than equal
≥	- Greater than equal
√	- Square root

Major Elements Abbreviation	Description
Al ₂ O ₃	- Aluminium oxide
BaO	- Barium oxide
Cr ₂ O ₃	- Chromium (III) oxide
Fe ₂ O ₃	- Ferric oxide (Hematite)
FeO	- Iron oxide
TiO ₂	- Titanium dioxide
K ₂ O	- Potassium oxide
MgO	- Magnesium oxide
MnO	- Manganese Oxide
Na ₂ O	- Sodium oxide
P ₂ O ₅	- Phosphorus pentoxide
SiO ₂	- Silicon dioxide
SrO	- Strontium oxide

Minor Elements Abbreviation	Description
Ba	- Barium
Cr	- Chromium
Cs	- Cesium
Ga	- Gallium
Hf	- Hafnium
Nb	- Niobium
Rb	- Rubidium
Sn	- Tin
Sr	- Strontium

Ta	- Tantalum
Th	- Thorium
U	- Uranium
V	- Vanadium
W	- Tungsten
Zr	- Zirconium

Rare Earth Elements Abbreviation	Description
Ce	- Cerium
Dy	- Dysprosium
Er	- Erbium
Eu	- Europium
Gd	- Gadolinium
Ho	- Holmium
La	- Lanthanum
Lu	- Lutetium
Nd	- Neodymium
Pr	- Praseodymium
Sm	- Samarium
Tb	- Terbium
Tm	- Thulium
Y	- Yttrium
Yb	- Ytterbium

Major Ions Abbreviation	Description
Al ³⁺	- Aluminium
Br ⁻	- Bromide
Ca ²⁺	- Calcium
Cl ⁻	- Chloride
CO ₃ ²⁻	- Carbonate
HCO ₃ ⁻	- Bicarbonate
K ⁺	- Potassium
Mg ²⁺	- Magnesium
Na ⁺	- Sodium
NO ₃ ⁻	- Nitrate

PO_4^{3-}	- Phosphate
SO_4^{2-}	- Sulfate

Water Types

Description

B4-NaCl (-)	- Brackish extremely hard sodium chloride water with salinization
Ca-Cl	- Calcium - chloride
Ca-HCO ₃	- Calcium - bicarbonate
Ca-SO ₄	- Calcium - sulphate
CaNO ₃	- Calcium - nitrate
F1- (CaHCO ₃) ₂ Ø	- Fresh moderately hard calcium bicarbonate with no base exchange
F2-(CaHCO ₃) ₂ Ø	- Fresh hard calcium bicarbonate with no base exchange
K-NO ₃	- Potassium - nitrate
Na-Cl	- Sodium - chloride
Na-Ca-HCO ₃	- Sodium - calcium - bicarbonate
Na-HCO ₃	- Sodium - bicarbonate
Na-SO ₄	- Sodium - sulphate
Na-HCO ₃	- Sodium - bicarbonate
Na - Mix	- Sodium - mixed water type
NH ₄ -SO ₄	- Ammonium - sulphate

Chemical Composition of Minerals

Description

$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$	- Kaolinite
$\text{Ca}(\text{Al},\text{Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_{2.n}(\text{H}_2\text{O})$	- Montmorillonite
$\text{CaAl}_2\text{Si}_2\text{O}_8$	- Anorthite
$(\text{Ca},\text{Na})_2(\text{Mg},\text{Fe},\text{Al})_5(\text{Al},\text{Si})_2\text{O}_6$	- Augite
$\text{Ca}_2\text{Na}(\text{Mg},\text{Fe})_4[(\text{Al},\text{Fe})(\text{Si},\text{Al})_4\text{O}_{11}]_2(\text{OH})_2$	- Hornblende
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	- Gypsum
Fe_2O_3	- Hematite
$\text{NaAlSi}_3\text{O}_8$	- Albite
NaCl	- Halite
SiO_2	- Quartz

LIST OF APPENDICES

Appendix		Page
Appendix 1	Sampling locations from the research area and various analyses in this study.....	186
Appendix 2 (a)	Physicochemical characteristics (mg/L) of the ground-water samples from each location of the research area....	187
Appendix 2 (b)	Physicochemical characteristics (meq/L) of the ground-water samples from each location of the research area....	188
Appendix 3	Mineralogical types identified by X-ray Diffraction analysis.....	189
Appendix 4	Major, trace and rare earth elements (REE) data of ICP-MS analysis.....	193
Appendix 5	Hydrostratigraphy in each unit of geomorphology based on the geoelectric data.....	194
Appendix 5 (a)	Hydrostratigraphy of the Beach Unit (M ₁) based on the geoelectric data.....	195
Appendix 5 (b)	Hydrostratigraphy of the Sand Dunes and Swale Unit (E) based on the geoelectric data.....	196
Appendix 5 (c)	Hydrostratigraphy of the Old Beach Ridges Unit (M ₂) on the geoelectric data.....	197
Appendix 5 (d)	Hydrostratigraphy of the Fluvio-marine Plain Unit (F _m) based on the geoelectric data.....	199
Appendix 6	Spatial distribution maps of major ions in the groundwater of the research area.....	201
Appendix 7	Distribution histograms of variables and their correlation with field parameters.....	204
Appendix 8	Stiff diagrams of each sampling location in the research area.....	209
Appendix 9	Data on the measurements of groundwater characteristics in the research area.....	216
Appendix 10	Classification of the water types based on the Stuyfzand method.....	217
Appendix 11	Results of Mineral Saturation Indices (SI) using PHREEQC Interactive 3.4.0 Package Software.....	224
Appendix 12	Rock-water Interaction Calculations.....	253
Appendix 13	Effect of leaching time on the extraction of chloride under different pH values.....	254