

الخلاصة

أجرت هذه الدراسة حول النيل الأزرق ما بين الكاملين و ودمدني في ولاية الجزيرة بوسط السودان, لتوضيح الخواص الهايدروجيولوجية و الهايدروكيميائية لمنطقة الدراسة.

تم تحليل البيانات الحقلية لعدد 200 بئر لتبيان الخصائص الهايدروجيولوجية و الهايدروكيميائية لمنطقة الدراسة . تبين أن أهم التركيبات الجيولوجية بالمنطقة هي: الصخور القاعدية الأساسية, تكوينات الحجر الرملي النوبي, تكوينات الجزيرة, رسوبيات الأودية المطمورة, رسوبيات الانهار و الرسوبيات الحديثة . تعتبر تكوينات الحجر الرملي النوبي أهم خزانات المياه الجوفية بالمنطقة و التي تعلو لاتوافقياً الصخور القاعدية الأساسية, و تنكشف في الجهة الشرقية لمنطقة الدراسة, و هي ذات خواص هايدرولكية متوسطة (النفاذية 397 متر² / اليوم, الموصلية الهايدرولكية 163 متر/ اليوم في منطقة البطانة بينما النفاذية 331 متر² / اليوم والموصلية الهايدرولكية 16 متر / اليوم في منطقة الجزيرة). كما نجد أن الخواص الهايدروكيميائية تشير إلي أن نوعية المياه مقبولة وفقاً للمعايير القياسية (متوسط الاملاح الذائبة الكلية 386 جزء من المليون بالبطانة, 332 جزء من المليون بالجزيرة). صنفت مياهها بأنها عذبة (مع وجود بعض الجيوب المالحة).

نوعية المياه تنتمي لمجموعة بيكربونات الصوديوم والكالسيوم بالبطانة ومجموعة بيكربونات الصوديوم بالجزيرة وتمتاز بان مياهها تصلح للزراعة من مجموعة قليلة الملوحة متوسطة معامل الامتصاص للصوديوم بالجزيرة و متوسطة الملوحة قليلة معامل الامتصاص للصوديوم بالبطانة.

تكوينات الجزيرة هي الخزان الاساسي في المنطقة غرب النيل الازرق, ترسبت لاتواذقيا فوق السطح المتعري من تكوينات الحجر الرملي النوبي بسمك يتراوح بين صفر و ثمانين متراً . المياه الجوفية بخزان الجزيرة شبه محصورة و نوعية مياهه جيدة (الاملاح الذائبة الكلية 380 جزء من المليون) و تصنف بانها من مجموعة بيكربونات الصوديوم و تصلح للزراعة اذ تنتمي للمجموعة متوسطة الملوحة قليلة معامل الإمتصاص للصوديوم.

الإتجاه العام لسريان المياه الجوفية من النيل الأزرق للشرق و الشمال الشرقي في منطقة البطانة و الشمال و الشمال الغربي في منطقة الجزيرة بانحدار هايدرولكي يبلغ (0.00288 و بالجزيرة و 0.0072 بالبطانة) . تقدر السعة التخزينية لتكوينات الحجر الرملي النوبي من المياه الجوفية بمنطقة الجزيرة ب 68.5×10^9 متر مكعب و بمنطقة البطانة 29.1×10^9 متر مكعب , بينما السعة التخزينية لتكوينات الجزيرة تبلغ 42.4×10^9 متر مكعب.

ABSTRACT

This study was carried out around the Blue Nile between Kamlin and Wad Medani in the Gezira State, Central Sudan, to characterize the hydrogeology and hydrochemistry of studied area.

In this study field data from 200 boreholes were analyzed to assess the hydrogeological and hydrochemical properties of the study area. The main geological sequences in the study area are:

Basement Complex, the Nubian Sandstone Formation, Gezira formation, Buried Chemical deposits Alluvium deposits and the superficial deposits.

The main aquifer in the area is the Nubian Sandstone formation which overlies unconformably the Basement Complex and crop out at the eastern part of the study area. The Hydraulic properties of this aquifer are moderate ($T = 397\text{m}^2/\text{d}$, $K = 163\text{m}/\text{d}$ at Butana area and $T = 331\text{m}^2/\text{d}$, $K = 16\text{m}/\text{d}$ at Gezira area). The hydrochemical properties indicate that the water quality is acceptable according to standard parameters (average TDS = 386 ppm at Butana area and 332 ppm at Gezira area) .It is classified as predominately fresh water with isolated pockets of brackish water and calcium sodium bicarbonates water type, class S1C2 for irrigation at Butana area, while at the Gezira area fresh water is classified as sodium bicarbonates water type and class S1C2 for irrigation purposes.

The Gezira formation is the main aquifer west of the Blue Nile River, and it rests unconformably over the Nubian sandstone formation erosional surface with a thickness ranging from zero to 80m.

The groundwater occurs under semi confined condition in the Gezira aquifer water is of good quality (TDS = 380ppm), and can be classified as sodium bicarbonate water type and class S1C2 for irrigation purposes.

The general groundwater flow directions are from Blue Nile towards east and northeast at Butana area, and north, northwest at

Gezira area with average hydraulic gradient 0.00288 and 0.00072 in Butana and Gezira area respectively. Estimated groundwater storage capacity of the Nubian Sandstone is 68.5×10^9 m³, at Gezira area 29.1×10^9 m³ at Butana area while in the Gezira aquifer is 42.4×10^9 m³.

ACKNOWLEDGEMENTS

I solely thank my God for the completion of this study.

I am indebted to my former supervisor professor Tawfig El Sadig Musa and I am prayer to Alla for him to soon recover from his illness..., for

his invaluable guidance, encouragement and stimulating criticism.

I am deeply grateful and particularly indebted to Dr. Abdalla Shigedi for his patient guidance and encouragement.

My thanks and gratitude to Dr. Yousif Ali, Dr. A. Hafiz, Dr. Yassin A/ Salam for their aid and compassion.

My acknowledgement is extended to Dr. Hassan Ibrahim, Dr. Mustafa Ahmed Ali, A/Razig Mukhtar, M. Khier Salih, Hilal El Fadil, Amar, Esia, Tayalla for their continuous assistance, stimulation, advice and support during the course of my study.

My gratitude extends to Etidal, Abbas, Mariam, Enam, Nafisa and I wish to express my appreciation to my colleagues and staff member of SDASCO, NWC, WES, WES-UNCIEF GWWD, especially Omer, Hassan, Faiza, Raja, Fatih El Rahman, Jamal, Safa, Tamador, Foad, Samuel, for their assistance in the field, and laboratory work.

I extend my gratitude to Zainab Yahia for her patience in typing majority of this thesis.

I wish also to express my gratitude to all the friends I did not mention and who encouraged me during the course of my study.

I am deeply indebted to my parents, brothers, sisters and to my wife, Nadia and my sons; Ahmed, Hamza, Musaab who accommodated and endured my long working hours during the course of the study, and gave me the strength and will through their love and support to complete this work.

TABLE OF CONTENTS

	PAGE
<i>Abstract:</i> (In Arabic)	I
<i>Abstract:</i>	II
<i>Acknowledgment:</i>	IV
<i>Table of contents</i>	V
<i>List of Tables</i>	VIII
<i>List of Figures</i>	XI
<i>List of Symbols and Abbreviations</i>	XVI

CHAPTER ONE: INTRODUCTION

1.1	General Overview	1
1.2	Problem Definition:	1
1.3	Objective of the Study:	3

CHAPTER TWO: LITERATURE REVIEW

2.1	Geological and Hydrogeological Review of Groundwater Sources in Sudan:	4
2.1.	General Geological Review:	4
1		
2.1.	Hydrological Properties of Sudan Geological Formations:	7
2		
2.1.2.1	Basement Complex :	7
2.1.2.2	Nubian Sandstone Series:	8
2.1.2.3	Umm Ruwaba Series:	8
2.1.2.4	Superficial Deposits:	9
2.1.	Groundwater Basins in Sudan:	10
3		
2.1.3.1	The Nubian Sandstone Basins:	11

2.1.3.2	The Umm Ruwaba Basins:	12
2.1.3.3	The Alluvial Basins:	12
2.1.3.4	The Nubian / Umm Ruwaba Basins:	13
2.1.3.5	The Nubian / Basalt Basins:	13
2.1.3.6	The Groundwater flow in the Basins:	14
2.2	Regional Geology of The Study Area:	20
2.2.	General Geology Setting:	20
1		
2.2.	Basement Complex:	20
2		
2.2.2.1	Gneiss:	21
2.2.2.2	Butana Green Schist:	21
2.2.2.3	Granite:	22
2.2.2.4	Felsites:	22
2.2.	Sedimentary Deposits:	22
3		
2.2.3.1	The Nubian Sandstone Formation:	22
2.2.3.2	The Gezira Formation:	26
2.2.3.3	The Buried Channel Deposits:	27
2.2.3.4	Superficial Deposits:	28
2.2.	Structure and Tectonic Events:	28
4		
2.2.	Previous Work:	33
5		

CHAPTER THREE: MATERIALS AND METHODS

3.1	Characterization of Study Area:	36
3.1.	Location and Extent	36
1		
3.1.	Physiography:	36
2		
3.1.	The Soils and Natural Vegetation:	51
3		
3.2	Methods of Data Collection and Investigation:	52
3.2.	Field Work:	52
1		
3.2.	Laboratory Work:	53
2		
3.2.	Office Work and Methods of management and Investigation	53
3		
3.2.3.1	Geological and Hydrogeological Methods:	54

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1	Geological and Hydrogeological Aspects:	65
	4.1. General:	65
	1	
	4.1. Basement Complex:	76
	2	
	4.1. Nubian Sandstone Formation :	76
	3	
	4.1.3.1 Estimation and Evaluation of Nubian Sandstone Aquifer Hydraulic Parameters from Pumping Test Data	86
	4.1.3.2 Evaluation of N.S.S. aquifer parameters from variable Discharge rate pumping test.	109
	4.1. Gezira formation:	116
	4	
	4.1.4.1 Estimation and evaluation of the Gezira aquifer hydraulic parameters from pumping test data	120
	4.1.4.2 Evaluation of the Gezira aquifer parameters from variable discharge rate pumping test data:	129
	4.1. Berried channel deposits	135
	5	
	4.1. Alluvium deposits of the Blue Nile.	137
	6	
	4.1. Superficial deposits.	137
	7	
	4.1. Groundwater flow system.	138
	8	
	4.1. Estimation of groundwater storage capacity.	143
	9	
	4.1.9.1 Groundwater budget.	145
4.2	Hydrochemical aspects.	150
	4.2. General.	150
	1	
	4.2. Ranges of concentration of physical & chemical properties.	151
	2	
	4.2.2.1. Hydrogen ion concentration	151
	4.2.2.2. Electrical conductivity.	165
	4.2.2.3. Total dissolved solids.	168
	4.2.2.4. Total alkalinity.	174
	4.2.2.5. Total hardness.	176
	4.2.2.6. Calcium.	179
	4.2.2.7. Magnesium.	183

	4.2.2.8	Sodium.	185
	4.2.2.9.	Potassium.	189
	4.2.2.10.	Bicarbonates:	192
	4.2.2.11.	Sulphates.	197
	4.2.2.12.	Chloride.	199
	4.2.2.13.	Other constituents.	204
	4.2.2.14.	Conclusion.	209
4.2.		Hydrochemical characteristics:	210
3			
	4.2.3.1	Hydrochemical characteristics of the Blue Nile Water:	210
	4.2.3.2	Hydrochemical characteristics of the Gezira aquifer	210
	4.2.3.3	Hydrochemical characteristics of the Nubian sandstone Aquifer.	215
4.2.		Graphical representation of chemical analysis.	219
4			
	4.2.4.1	Piper trilinear diagram.	219
	4.2.4.2	Stiff's pattern:	224
	4.2.4.3	Schoeller diagram.	225
4.2.		Chemical classification of the groundwater.	229
5			
	4.2.5.1	Chemical classification based on the total Dissolved Solids.	229
	4.2.5.2	Chemical classification based on dominant constituent.	230
4.2.		Relationship of groundwater quality to use.	230
6			
	4.2.6.1	Drinking and domestic use.	230
	4.2.6.2	Agricultural uses.	234
CHAPTER FIVE: CONCLUSION & RECOMMENDATIONS			
5.1		Conclusion.	243
5.2		Recommendations.	248
		References.	249

LIST OF TABLES

		PAGE
Table 2.1	Geology of Sudan – Table of succession.	6
Table 3.1	Recharge of Blue Nile, Rahad Dinder Rivers.	40
Table 3.2	Water level at different points along Blue Nile course.	41
Table 3.3	Mean annual rainfall at Wad Medani station (1961 – 1990).	43
Table 3.4	Climatological normals at Khartoum station (1961 – 1995).	48
Table 3.5	Climatological normals at Wad Medani station (1961 –1995).	49
Table 4.1	Well inventory.	66
Table 4.2	Geological sequences of study area.	74
Table 4.3	Depth of boreholes west Blue Nile.	82
Table 4.4	Depth of boreholes east Blue Nile.	83
Table 4.5	Discharge rate of Nubian sandstone aquifer west Blue Nile area	85
Table 4.6	Discharge rate of Nubian sandstone aquifer east Blue Nile area.	87
Table 4.7	Specific capacity of Nubian sandstone aquifer east Blue Nile area.	88
Table 4.8	Specific capacity of Nubian sandstone aquifer east Blue Nile area (statistics).	89
Table 4.9	Specific capacity of Nubian sandstone aquifer west Blue Nile area.	90
Table 4.10	Specific capacity of Nubian sandstone aquifer west Blue Nile area.	94
Table 4.11	Transmissivity of Nubian sandstone aquifer west Blue Nile (Thies’s Method.	95
Table 4.12	Transmissivity of Nubian sandstone aquifer west Blue Nile (statistic).	98
Table 4.13	Transmissivity of Nubian sandstone aquifer west Blue Nile (Jacob Method).	99
Table 4.14	Transmissivity of Nubian sandstone aquifer west Blue Nile area.	101
Table 4.15	Transmissivity of Nubian sandstone aquifer east Blue Nile (Thies’s Method).	100

	PAGE
Table 4.16	Transmissivity of Nubian sandstone aquifer east Blue Nile (statistics). 101
Table 4.17	Transmissivity of Nubian sandstone aquifer east Blue Nile (Jacob Method). 102
Table 4.18	Transmissivity of Nubian sandstone aquifer east Blue Nile area. 103
Table 4.19	Hydraulic conductivity of Nubian sandstone aquifer east Blue Nile area. 105
Table 4.20	Hydraulic conductivity of Nubian sandstone aquifer west Blue Nile area. 106
Table 4.21	Hydraulic conductivity of Nubian sandstone aquifer east Blue Nile area. 107
Table 4.22	Hydraulic conductivity of Nubian sandstone aquifer east Blue Nile area (statistics). 108
Table 4.23	Step draw down data of Nubian aquifer (Gezira area). 112
Table 4.24	Step draw down data of Nubian aquifer (Butana area). 113
Table 4.25	Results of variable discharge rate of Nubian aquifer. 115
Table 4.26	Discharge rate of Gezira formation. 119
Table 4.27	Specific capacity of the Gezira aquifer. 120
Table 4.28	Specific capacity of the Gezira aquifer (statistics). 121
Table 4.29	Transmissivity of Gezira aquifer (Thies's Method). 122
Table 4.30	Transmissivity of Gezira aquifer (statistics). 123
Table 4.31	Transmissivity of Gezira aquifer (Jacob Method). 124
Table 4.32	Transmissivity of Gezira aquifer. 125
Table 4.33	Hydraulic conductivity of Gezira aquifer. 127
Table 4.34	Hydraulic conductivity of Gezira aquifer (statistics). 128
Table 4.35	Step – draw down data of Gezira aquifer. 131
Table 4.36	Results of variable discharge rate of Gezira. 134
Table 4.37	Thickness of wells penetrated channel deposits. 136
Table 4.38	Hydraulic gradient west Blue Nile area. 141
Table 4.39	Hydraulic gradient east Blue Nile area. 141
Table 4.40	Estimation of groundwater storage capacity of the Gezira aquifer. 144

	PAGE
Table 4.41	Estimation of groundwater storage capacity of the Nubian sandstone aquifer. 144
Table 4.42	Estimation of groundwater Abstraction in the study area: 148
Table 4.43	Hydrochemical properties. 152
Table 4.44	Hydrogen ion concentration statistics. 163
Table 4.45	Electrical conductivity statistics. 166
Table 4.46	Total dissolved solids statistics. 169
Table 4.47	Total alkalinity. 174
Table 4.48	Total hardness (statistics). 176
Table 4.49	Total hardness of Gezira & Nubian aquifer. 179
Table 4.50	Calcium ion (statistics). 180
Table 4.51	Magnesium ion (statistics). 183
Table 4.52	Sodium ion (statistics). 185
Table 4.53	Potassium ion (statistics). 189
Table 4.54	Bicarbonates (statistics). 193
Table 4.55	Sulphate (statistics). 198
Table 4.56	Chloride (statistics). 200
Table 4.57	Fluoride (statistics). 205
Table 4.58	Nitrogen components (statistics). 205
Table 4.59	Summary of physical and chemical constituents results 213
Table 4.60	Classification based on TDS. 229
Table 4.61	Standards limits inorganic constituents in drinking water. 231
Table 4.62	Maximum recommended ion concentration (Davis & Dewiest 1966). 232
Table 4.63	Salinity classification as TDS. 232

LIST OF FIGURES

	PAGE
Figure 2.1	Groundwater basins in Sudan. 15
Figure 2.2	Regional geological map of study area. 17
Figure 2.3	Structural contour map depth to basement. 18
Figure 2.4	Cross – section A – A': 19
Figure 2.5	Cross – section B – B' 20
Figure 2.6	Map showing the location of the rift–basins in the east central Sudan. 30
Figure 2.7	Areal distribution of late Jurassic–Early cretaceous syn–rift basins and magnetic activities in the Sudan. 31
Figure 3.1	Map of Sudan showing location of studied area. 37
Figure 3.2	Topographical map of the Gezira area. 39
Figure 3.3	Blue Nile – Rahad recharge. 41
Figure 3.4	Mean annual rainfall at Khartoum & Wad Medani station (1961 – 1990). 45
Figure 3.5	Rainfall at Wad Medani station (1961 – 1990). 45
Figure 3.6	Annual rainfall isohyets lines Gezira area (1961 – 1990). 47
Figure 3.7	Temperture degree at Wad Medani & Khartoum. 46
Figure 3.8	Evaportranspiration at Wad Medani & Khartoum. 50
Figure 4.1	Locations of wells in the study area. 73
Figure 4.2	Hydrogeological map of studied area. 75
Figure 4.3	Geological cross – section A – A'. 77
Figure 4.4	Geological cross – section B – B'. 78
Figure 4.5	Geological cross – section C – C'. 79
Figure 4.6	Depth of boreholes west Blue Nile area. 83
Figure 4.7	Depth of boreholes east Blue Nile area. 84
Figure 4.8	Discharge rate of Nubian sandstone aquifer west Blue Nile area. 85

		PAGE
Figure 4.9	Discharge rate of Nubian sandstone aquifer east Blue Nile area.	86
Figure 4.10	Specific capacity of Nubian sandstone aquifer east Blue Nile area.	88
Figure 4.11	Specific capacity of Nubian sandstone aquifer west Blue Nile area.	90
Figure 4.12	Example of graph used for computing transmissivity of Nubian sandstone aquifer east Blue Nile area by Thise's Method.	93
Figure 4.13	Example of graph used for computing transmissivity of Nubian sandstone aquifer west Blue Nile area by Thise's Method.	92
Figure 4.14	Example of graph used for computing transmissivity of Nubian sandstone aquifer east Blue Nile area by Jacob's Method.	96
Figure 4.15	Example of graph used for computing transmissivity of Nubian sandstone aquifer west Blue Nile area by Jacob's Method.	97
Figure 4.16	Transmissivity of Nubian sandstone aquifer west Blue Nile by Thies's Method.	95
Figure 4.17	Transmissivity of Nubian sandstone aquifer west Blue Nile by Jacob Method.	98
Figure 4.18	Transmissivity of Nubian sandstone aquifer west Blue Nile area.	100
Figure 4.19	Transmissivity of Nubian sandstone aquifer east Blue Nile by Thies's Method.	101
Figure 4.20	Transmissivity of Nubian sandstone aquifer east Blue Nile by Jacob Method.	102
Figure 4.21	Transmissivity of Nubian sandstone aquifer east Blue Nile area.	104
Figure 4.22	Hydraulic conductivity of Nubian sandstone aquifer west Blue Nile.	107
Figure 4.23	Hydraulic conductivity of Nubian sandstone aquifer east Blue Nile.	109

	PAGE
Figure 4.24	Example of variable discharge rate pumping test graph of well No. (42) Nubian sandstone aquifer west Blue Nile area. 110
Figure 4.25	Example variable discharge rate pumping test graph of well No. (143) Nubian sandstone aquifer east Blue Nile area. 111
Figure 4.26	Isopach map of Gezira formation. 118
Figure 4.27	Discharge rate of Gezira formation. 119
Figure 4.28	Specific capacity of the Gezira aquifer. 121
Figure 4.29	Transmissivity of Gezira aquifer (Thies's Method). 123
Figure 4.30	Transmissivity of Gezira aquifer (Jacob Method). 125
Figure 4.31	Transmissivity of Gezira aquifer. 126
Figure 4.32	Hydraulic conductivity of Gezira aquifer. 129
Figure 4.33	Example variable discharge rate graph of Gezira aquifer: 130
Figure 4.34	Depth water map. 140
Figure 4.35	Sub-areas of the Gezira & Nubian sandstone aquifers. 142
Figure 4.36	PH of Nubian sandstone aquifer west Blue Nile area. 163
Figure 4.37	PH of Gezira aquifer. 164
Figure 4.38	PH of Nubian sandstone aquifer east Blue Nile area. 164
Figure 4.39	EC of Nubian aquifer Gezira area. 167
Figure 4.40	EC of Nubian aquifer at Butana area. 167
Figure 4.41	EC of Gezira aquifer. 168
Figure 4.42	TDS of Nubian aquifer at Gezira area. 169
Figure 4.43	TDS of Nubian aquifer at Butana area. 170
Figure 4.44	TDS of Gezira aquifer. 170
Figure 4.45	Aerial distribution of TDS Gezira aquifer. 172
Figure 4.46	Aerial distribution of TDS Nubian aquifer. 173
Figure 4.47	Total alkalinity of Nubian aquifer Gezira area. 175
Figure 4.48	Total alkalinity of Nubian aquifer Butana area. 175
Figure 4.49	Total alkalinity of Gezira aquifer. 175

	PAGE
Figure 4.50	Total hardness Nubian aquifer Gezira area. 176
Figure 4.51	Total hardness Nubian aquifer Butana area. 177
Figure 4.52	Total hardness Gezira aquifer. 178
Figure 4.53	Calcium ion Nubian aquifer Gezira area. 180
Figure 4.54	Calcium ion Nubian aquifer Butana area. 180
Figure 4.55	Calcium ion Gezira area. 182
Figure 4.56	Aerial distribution map of calcium ion (Nubian aquifer). 181
Figure 4.57	Aerial distribution map of calcium ion Gezira aquifer. 181
Figure 4.58	Magnesium ion Nubian aquifer, Gezira area. 182
Figure 4.59	Magnesium ion Nubian aquifer Butana area. 184
Figure 4.60	Magnesium ion Gezira aquifer. 184
Figure 4.61	Sodium ion Nubian aquifer Gezira area. 186
Figure 4.62	Sodium ion Nubian aquifer Butana area. 187
Figure 4.63	Sodium ion Gezira aquifer. 187
Figure 4.64	Aerial distribution of sodium ion, Nubian aquifer. 188
Figure 4.65	Aerial distribution of sodium ion, Gezira aquifer. 190
Figure 4.66	Potassium ion Nubian aquifer Gezira area. 191
Figure 4.67	Potassium ion Nubian aquifer Butana area. 191
Figure 4.68	Potassium ion Gezira aquifer. 192
Figure 4.69	Bicarbonates, Nubian aquifer, Gezira area. 194
Figure 4.70	Bicarbonates, Nubian aquifer, Butana area. 194
Figure 4.71	Bicarbonates Gezira aquifer. 197
Figure 4.72	Aerial distribution of bicarbonates Nubian aquifer. 195
Figure 4.73	Aerial distribution of Gezira aquifer. 196
Figure 4.74	Sulphate Nubian aquifer Gezira area. 198
Figure 4.75	Sulphate Nubian aquifer Butana area. 199
Figure 4.76	Sulphate Gezira aquifer. 199
Figure 4.77	Chloride Nubian aquifer Gezira area. 203
Figure 4.78	Chloride Nubian aquifer Butana area. 203
Figure 4.79	Chloride Gezira aquifer. 204

	PAGE
Figure 4.80	Aerial distribution of chloride Nubian aquifer. 201
Figure 4.81	Aerial distribution of chloride Gezira area. 202
Figure 4.82	Fluoride, Nubian aquifer Gezira area. 206
Figure 4.83	Fluoride Nubian aquifer Butana area. 206
Figure 4.84	Fluoride Gezira aquifer. 207
Figure 4.85	Nitrate (NO_3^{-2}) 208
Figure 4.86	Nitrite (NO_2^{-1}) 208
Figure 4.87	Ammonia(NH_3^{-1}) 208
Figure 4.88	Hydrochemical water types of the Gezira aquifer. 214
Figure 4.89	Hydrochemical types of the Nubian sandstone aquifer. 218
Figure 4.90	Piper diagram – Gezira aquifer. 221
Figure 4.91	Piper diagram – Nubian sandstone aquifer Gezira area. 222
Figure 4.92	Piper diagram – Nubian sandstone aquifer Butana area. 223
Figure 4.93	Schoeller diagram – Gezira aquifer. 226
Figure 4.94	Schoeller diagram – Nubian sandstone aquifer Gezira area. 227
Figure 4.95	Schoeller diagram – Nubian sandstone aquifer Butana area. 228
Figure 4.96	Wilcox diagram – Gezira aquifer. 238
Figure 4.97	Wilcox diagram – Nubian aquifer, Gezira area. 239
Figure 4.98	Wilcox diagram – Nubian aquifer, Butana area. 240
Figure 4.99	Distribution of classes of groundwater for irrigation within Gezira aquifer. 241
Figure 4.100	Distribution of classes of groundwater for irrigation within Nubian aquifer. 242

LIST OF SYMBOLS & ABBREVIATIONS

NWC	= National Water Corporation.
RWC	= Rural Water Cooperation.
Gezira Area	= Study Area, West Blue Nile.
Butana Area	= Study Area, East Blue Nile.
Exp. Of Conc.	= Expression of concentration.
SAR	= Sodium adsorption.
WHO	= World Health Organization.
ppm	= Part per million.
epm	= Equivalent part per million.
epm%	= Percentage of equivalent part per million.
a.m.s.L.	= Above mean sea level.
F.A.I.R.	= Cation–anion imbalance ratio.
GWV	= Groundwater by windows software program.
S. C.	= Specific capacity.
T	= Transmissivity.
Q	= Well discharge (groundwater flow discharge).
DS	= Maximum drawdown.
K	= Hydraulic conductivity.
b	= Aquifer saturated thickness.
S_w	= Draw down.
t	= Time since pumping started.
r	= Distance from the center of the pumped well to a point where draw down measured.
S	= Coefficient of storage.
BQ	= Aquifer loss (laminar flow).
CQ^2	= Well loss (turbulent flow).
h_1, h_2	= Hydraulic head.
L	= Distance.

Q_{sc}	=	Groundwater storage.
A	=	Average aquifer thickness.
n_e	=	Effective porosity.
i	=	Hydraulic gradient.
W	=	Aquifer width.
A_{act}	=	Actual cross-section area.
A	=	Total cross-section area.
V_a	=	Actual velocity.
V	=	Apparent velocity.
EC	=	Electrical conductivity.
TDS	=	Total dissolved solids.
TH	=	Total hardness.
T. ALK	=	Total alkalinity.
PH	=	Hydrogen ion concentration.
Na^+	=	Sodium ion.
K^+	=	Potassium ion.
Ca^{++}	=	Calcium ion.
Mg^+	=	Magnesium
HCo_3^+	=	Bicarbonate.
Cl^-	=	Chloride ion.
So_4^-	=	Sulphate.
F^-	=	Fluoride ion.
No_2^-	=	Nitrite.
No_3	=	Nitrate.
NW	=	Nubian sandstone aquifer west Blue Nile area.
NE	=	Nubian sandstone aquifer east Blue Nile area.
G	=	Gezira aquifer.
PHWN	=	Hydrogen ion concentration Nubian west Blue Nile.
PHG	=	Hydrogen ion concentration Gezira aquifer.
PHNE	=	Hydrogen ion concentration Nubian east Blue Nile.
Std. Dev.	=	Standard deviation.

ECNW	= Electrical conductivity of Nubian Sandstone aquifer west Blue Nile Area.
ECNE	= Electrical conductivity of Nubian Sandstone aquifer east Blue Nile Area.
ECG	= Electrical conductivity of Gezira aquifer.
TDSNW	= Total dissolved solids Nubian west Blue Nile area.
TDSNE	= Total dissolved solids east Blue Nile area.
TDSG	= Total dissolved solids Gezira aquifer.
TALKNE	= Total alkalinity Nubian aquifer east Blue Nile area.
TALKG	= Total alkalinity Nubian aquifer east Blue Nile.
THNW	= Total hardness Nubian west Blue Nile area.
THNE	= Total hardness Nubian east Blue Nile area.
THG	= Total hardness Gezira aquifer.
CANW	= Calcium ion Nubian aquifer west Blue Nile area.
CANE	= Calcium Nubian aquifer east Blue Nile area.
CAG	= Calcium ion Gezira aquifer.
MGNW	= Mg Nubian aquifer west Blue Nile area.
MGNE	= Mg Nubian aquifer east Blue Nile area.
MGG	= Mg Gezira aquifer.
NANW	= Na Nubian aquifer Gezira area.
NANE	= Na Nubian aquifer Butana area.
NAG	= Na Gezira aquifer.
KNE	= K Nubian aquifer east Blue Nile area.
KNW	= K Nubian aquifer west Blue Nile area.
KG	= K Gezira aquifer.
HCO3NW	= Bicarbonate Nubian aquifer west Blue Nile area.
HCO3NE	= Bicarbonate Nubian aquifer east Blue Nile area.
HCO3G	= Bicarbonate Gezira aquifer.
SO4NW	= Sulphate Nubian west Blue Nile area.
SO4G	= Sulphate Gezira aquifer.
CLNW	= Chloride Nubian west Blue Nile area.

CLNE	= Chloride Nubian east Blue Nile area.
CLG	= Chloride Gezira aquifer.
FNE	= Fluoride Nubian aquifer east Blue Nile area.
FG	= Fluoride Gezira aquifer.
S ₁	= Low sodium (alkali) hazard.
S ₂	= Medium sodium (alkali) hazard.
S ₃	= High sodium (alkali) hazard.
S ₄	= Very high sodium (alkali) hazard.
C ₁	= Low salinity hazard.
C ₂	= Medium salinity hazard.
C ₃	= high salinity hazard.
C ₄	= Very high salinity hazard.