

IMPACT OF CLIMATE CHANGE ON GROUNDWATER IN NORTH EAST SINAI

Submitted By

Muna Hussein Ahmed Dahabiyeh

B.Sc. of Science (Soil Sciences & its Administration), Faculty of Science,

Yarmouk University, 1998

Master in Environmental Sciences, Institute of Environmental Studies and Research,

Ain Shams University, 2001

A thesis submitted in Partial Fulfillment
Of
The Requirement for the Doctor of Philosophy Degree
In
Environmental Sciences

Department of Environmental Basic Sciences
Institute of Environmental Studies and Research
Ain Shams University

2018

APPROVAL SHEET
IMPACT OF CLIMATE CHANGE ON GROUNDWATER IN
NORTH EAST SINAI

Submitted By
Muna Hussein Ahmed Dahabiyeh

B.Sc. of Science (Soil Sciences & its Administration), Faculty of Science,
Yarmouk University, 1998
Master in Environmental Sciences, Institute of Environmental Studies and Research,
Ain Shams University, 2001

A thesis submitted in Partial Fulfillment
Of

The Requirement for the Doctor of Philosophy Degree
In

Environmental Sciences

Department of Environmental Basic Sciences

This Thesis Towards a Doctor of Philosophy Degree in
Environmental Sciences Has been Approved by:

Name

Signature

1-Prof. Dr. Ayman Farid Abo Hadid

Prof. of Vegetables

Faculty of Agriculture

Ain Shams University

Ex- Chairman of Climate Laboratory – Ministry of Agriculture

2-Dr. Eng. Eman Sayed Ahmed Soliman

Chairman of Planning Sector

Ministry of Water Resources and Irrigation

3-Prof. Dr. Sameh A. Sakr

Prof. of Hydraulics & Hydrology

National Water Research Center

Ministry of Water Resources & Irrigation

4-Prof. Dr. Mohamed Gharib El Malky

Prof. of Environmental Geophysics, Department of Environmental

Basic Sciences - Institute of Environmental Studies & Research

Ain Shams University

2018

IMPACT OF CLIMATE CHANGE ON GROUNDWATER IN NORTH EAST SINAI

Submitted By

Muna Hussein Ahmed Dahabiyeh

B.Sc. of Science (Soil Sciences & its Administration), Faculty of Science,
Yarmouk University, 1998
Master in Environmental Sciences, Institute of Environmental Studies and Research,
Ain Shams University, 2001

A thesis submitted in Partial Fulfillment
Of
The Requirement for the Doctor of Philosophy Degree
In
Environmental Sciences
Department of Environmental Basic Sciences

Under The Supervision of:

1-Prof. Dr. Mohamed Gharib El Malky

Prof. of Environmental Geophysics, Department of Environmental
Basic Sciences - Institute of Environmental Studies & Research
Ain Shams University

2-Prof. Dr. Sameh A. Sakr

Prof. of Hydraulics & Hydrology
Head of Groundwater Sector
National Water Research Center
Ministry of Water Resources & Irrigation

2018

TO

My Father, Mother,

Brother; Ali, Sisters; Dalia and

Huda, and My Friend;

Raneem

Acknowledgment

First of all praise be to Allah, the Lord of the creations who thought us what we didn't know, and peace and blessings be upon our beloved teacher Muhammad, who brought us out of the darkness of ignorance to the light of guidance

I would like to express my sincere gratitude to my advisors Prof. Mohamed El-Malky for his continuous support, patience, motivation, and immense knowledge. I appreciate all his contributions of time, ideas, and funding to make my Ph.D. experience productive and stimulating.

My appreciation to Prof. Dr. Sameh Sakr head of the groundwater sector in ministry of water resources and irrigation for his academic support and the facilities provided to carry out the research work despite the tremendous pressure in his work that coincides with the research period.

I am grateful to Dr. Ezz El-Din El-Tablawi, who provided me an opportunity to join his team as intern, and who gave access to the numerical laboratory and research facilities. Without his precious support it would not be possible to conduct this research.

ABSTRACT

Identifying and quantifying future climate impacts on water resources has major economic and societal importance for water planners. This research has integrated the outputs of the three general global models (CNRM-CM5, GFDL-ESM2M and EC-EARTH) downscaled by regional climate model (RCA4) under representative concentration pathways RCPs scenarios 4.5 and 8.5, into two hydrological models to provide approximations of climate change impacts on water quantity and quality in El Sheikh Zuwaid-Rafah quaternary aquifer system which is the main source of water in the area.

The projected changes in precipitation of the rising scenario between the periods 1980-2005 and 2050-2075 have showed increasing by 28% by RCA4-CNRM-CM5 while both other models were estimated to decrease. A Simple Bias correction (SBC) technique was implemented to correct the simulated monthly precipitation series. A three dimensional finite difference flow model (Processing MODFLOW -PM5), and the implemented solute transport model (MT3D) were used to predict the groundwater and the total dissolved solids storage. Results from running the rising scenario RCP 8.5 estimated that by the hydrological year 2074 groundwater recharge would be decreased from year 1996 by 2.73 M.m³, leading with the yearly exploitation to decrease groundwater storage to 11.83 M.m³ and decrease in dissolve salt storage 33.1 M. Kg.

Table of Contents

TABLE OF FIGURES	9
1. CHAPTER ONE: INTRODUCTION	18
1.1. General outline	18
1.1. Problem statement and objectives	19
1.2. Plan of work (Methodology)	23
1.3. Description of the Study Area	26
1.3.1. Location	26
1.3.2. Climate	27
1.3.3. Geomorphology	29
1.4.4. Geological settings and structure	30
1.3.5. Groundwater aquifers.....	31
2. CHAPTER TWO: LITERATURE REVIEW	34
2.1 Previous Studies upon presentation and evaluation of regional climate models	34
2.2 Previous Studies upon Climate change effect on groundwater,	36
2.3 Previous Studies upon the study region	41
3. CHAPTER THREE: CLIMATE PROCESS AND MODELING	46
3.1. Climate System	46
3.2. Climate Change	48
3.2.1. Observed Changes in the Climate System	48
3.2.2. Drivers of Climate Change	51

3.3.	Global Climate Models	52
3.3.1.	Types of Global Climate Models	53
3.3.2.	Representative Concentration Pathways (RCPs)	57
3.3.3.	Spatial and time discretization	59
3.4.	Coupled Model Inter-comparison project - CMIP	61
3.5.	Reliability of Climate Models GCMs to Reproduce Observational patterns and Make Projections of Future Climate Change	61
3.6.	Regional Climate Models.....	62
3.7.	CORDEX – An international climate downscaling initiative	64
3.7.1.	Model Domain and Resolutions:	65
3.7.2.	Model evaluation framework	67
3.7.3.	Climate projection framework	70
4.	CHAPTER FOUR: ANALYZING CLIMATE CHARACTERISTICS OF THE SINAI PENINSULA	74
4.1.	Datasets characteristics	75
4.1.1.	CRU	76
4.1.2.	CPC PREC/L	77
4.1.3.	UDeI Air Temperature and Precipitation.....	77
4.1.4.	E-OBS	78
4.1.5.	ERA-Interim.....	79
4.2.	Background of Statistical Characteristics	80
4.2.1.	Measures of location	80
4.2.2.	Measures of Spread/Dispersion	80
4.2.3.	Cumulative Frequency Distributions	81
4.2.4.	Measures of correlation.....	82
4.2.5.	Measures of trend.....	82
4.3.	Data Analysis of Climatological Observed and ECMWF (ERA Interim) Data Sets	82

4.3.1. Results of Temporal Analysis	82
4.3.1.1. Descriptive Statistic of Observed Datasets Variables	84
4.3.1.2. Descriptive Statistic of Averaged Series Variable	89
4.3.1.3. Descriptive Statistic of ECMWF ERA-Interim reanalysis dataset Variables	92
4.3.1.4. Correlation coefficient.....	101
4.3.1.5. Trend regression.....	106
4.3.2. Results of Spatial Analysis.....	115
 5. CHAPTER FIVE: THE CLIMATE CHARACTERISTICS OF THE SINAI PENINSULA BASED ON THE DOWNSCALING OF GCM VIA RCA4	 123
5.1. The Rossby Centre regional climate model, RCA4	124
5.2. Short Description of Selected GCMs	127
5.3. CORDEX simulations for MENA with RCA4	129
5.4. Output analysis of Sinai Peninsula.....	131
5.4.1. Recent past climate from the RCA4-ERA-Interim (evaluation output)	131
5.4.1.1. Descriptive statistic comparison.....	132
5.4.1.2. Correlation.....	150
5.4.1.3. Distribution.....	151
5.4.1.4. Linear Regression test	152
5.4.2. Recent past climate from RCA4-GCMs (historical output)	156
5.4.2.1. Descriptive statistics.....	156
5.4.2.2. Correlation coefficient.....	171
5.4.2.3. Linear regression.....	172
5.5. Results of Spatial Analysis.....	175

6. CHAPTER SIX: CLIMATE CHARACTERISTIC OF THE FUTURE SIMULATIONS SCENARIOS	182
6.1. Air Temperature	182
6.1.1. Statistical description of monthly data	182
6.1.2. Mann-Kendall trend test.....	190
6.2. Precipitation	199
6.2.1. Statistical description	199
6.2.2. Future Monthly Precipitation characteristic	203
6.2.3. Future variability of precipitation	211
6.2.4. Testing Trend	217
6.3. Results of Spatial Analysis.....	221
7. CHAPTER SEVEN: SALTS AND GROUNDWATER STORAGE UNDER THE EFFECT OF CLIMATE CHANGE	226
7.1. Hydraulic flow model Background	233
7.2. Salts Transport Model Background.....	235
7.3. Results and Conclusions.....	238
7.3.1. The stabile GCM for Sinai Peninsula	238
7.3.2. Bias Correction	238
7.4. Water and salt budgets	238
7.4.1. Results of Running Models by RCA4-GDFL-ESM2M / RCP4.5 Output	240
7.4.2. Results of Running Models by RCA4-GDFL- ESM2M / RCP8.5 Output	244
7.4.3. Results of Running Models by RCA4-CNRM-CM5 / RCP4.5 Output	248
7.4.4. Results of Running Models by RCA4-CNRM-CM5 / RCP8.5 Output	252

7.4.5. Results of Running Models by RCA4-EC-EARTH / RCP4.5	
Output	256
7.4.6. Results of Running Models by RCA4-EC-EARTH / RCP8.5	
Output	260

8. CHAPTER EIGHT: RESULTS AND CONCLUSIONS 264

8.1	Results of analyzing observed datasets	267
8.2	Results of analyzing average of observed datasets and ERA-Interim:	269
8.3	Results of verifying RCA4 (ERA-Interim) historical period	270
8.4	Results of verifying RCA4 (GCMs) historical period	271
8.5	Results of predicted RCA4 (GCMs) for the period 2071-2100 ..	273
8.6	Results of the hydraulic flow and salt transport models	276

SUMMARY 287

REFERENCE 299

الملخص

المستخلص

Table of Tables

Table 4-1 Observational and re-analysis data sets	75
Table 4-2 Statistical descriptive of averaged and ECMWF air temperature series.....	93
Table 4-3 Statistical descriptive of averaged and ECMWF total precipitation.....	94
Table 4-4 January air temperature Normal distribution test	97
Table 4-5 July air temperature Normal distribution test	97
Table 4-6 Normal distribution test of January and July air temperature for averaged and ECMWF of the period 1980-2005	100
Table 4-7 probability values of log normal distribution test of averaged and ECMWF datasets	101
Table 4-8 Matrix of correlation coefficient: left table of precipitation and right table of temperature	102
Table 4-9 Matrix of Air temperature correlation coefficient between averaged and ECMWF	103
Table 4-10 Matrix of precipitation correlation coefficient between averaged and ECMWF	104
Table 4-11 January and July air temperature linear regression.....	107
Table 4-12 Total Precipitation linear regression.....	108
Table 4-13 January and July linear regression for averaged and ERA-Interim datasets	110
Table 4-14 Total precipitation linear regression for averaged and ERA-Interim datasets	113
Table 0-1 List of CMIP5 GCMs that have been used to provide boundary conditions for the RCA4 runs presented in this study.....	127
Table 5-2 Descriptive statistic of monthly long term precipitation (mm/month) for the period 1980-2005.....	142
Table 5-3 Correlation coefficient between ERAINT and RCA4 ERAINT air mean temperature	150
Table 5-4 Correlation coefficient between ERAINT and RCA4-ERA-Interim precipitation.....	151
Table 5-5 Differences percentage; the left table is differences between the mean of RCA4-GCMs and the averaged, ERAINT and RCA4 (ERAINT),	

the right table; the differences percentage between each RCA4-GCMs and the averaged	159
Table 5-6 January air temperature statistical descriptive	160
Table 5-7 July air temperature statistical descriptive	161
Table 5-8 Mean square error of RCA4-GCMs air temperature comparing to the three estimator; averaged, reanalysis and evaluated series	165
Table 5-9 Precipitation coefficient of variation	168
Table 5-10 Simulated Precipitation Ratios to the averaged, reanalysis (ERAINT) and RCA4-ERAINT	170
Table 5-11 Air temperature correlation coefficient	171
Table 5-12 Monthly precipitation correlation coefficient	172
Table 5-13 Linear regression air temperature equations of the three RCA4 GCMs; left column for January and the right column for July series	173
Table 5-14 Linear regression equations of the RCA4-GCMs	174
Table 6-1 Statistical description of January air temperature	183
Table 6-2 Statistical description July air temperature	185
Table 6-3 Mann-Kendall trend test of January projection series/ Two tailed test at alpha 0.05	192
Table 6-4 Mann-Kendall trend test of July projection series/ Two tailed test at alpha 0.05	193
Table 6-5 Difference between simulated and historical January air temperature means	194
Table 6-6 Difference between simulated and historical July air temperature means	196
Table 6-7 Statistical description of the total precipitation (mm/year) ...	200
Table 6-8 RCA4 (GCMs) yearly total precipitation ratios; right table to the historical RCA4 (GCMs) P^* and left table to the averaged of observation P^{**}	211
Table 6-9 Ratios of mean monthly precipitation from future RCA4 (GCMs) 2071-2100 to the historical RCA4 (GCMs) 1980-2005	212
Table 6-10 Ratios of maximum monthly precipitation from future RCA4 (GCMs) 2071-2100 to the historical RCA4 (GCMs) 1980-2005	214

Table 6-11 Mann-Kendall trend test and Sen's slope estimator of the total precipitation series (historical :1980-2005 followed by future: 2071-2100).....	220
Table 7-2 precipitation means zonation of RCA4-GFDL-ESM2M under stabilizing scenario RCP 4.5	241
Table 7-3 Water and Salt balance accumulated variation over the 78 year	242
Table 7-4 precipitation means zonation of RCA4-GFDL-ESM2M under raising scenario.....	244
Table 7-5 Water and Salt balance accumulated variation over the 78 year	246
Table 7-6 precipitation means zonation of RCA4-CNRM-CM5 under stabilizing scenario	248
Table 7-7 Water and Salt balance accumulated variation over the 78 year	250
Table 7-8 Precipitation means zonation of RCA4-CNRM-CM5 under raising scenario.....	252
Table 7-9 Water and Salt balance accumulated variation over the 78 year	254
Table 7-10 Precipitation means zonation of RCA4-CNRM-CM5 under stabilizing scenario	256
Table 7-11 Precipitation means zonation of RCA4-EC-EARTH under stabilizing scenario	258
Table 7-12 precipitation means zonation of RCA4-CNRM-CM5 under stabilizing scenario	260
Table 7-13 Water and Salt balance accumulated variation over the 78 year.....	262

Table of Figures

Figure 1-1 Location map of the studied area (after ASCAD & DRC, 1998).....	27
Figure 1-2 Rafah long term annual cycle of temperature (°C) and rainfall (mm) The data for charts above are taken from year 2000 to 2012. Source: world weather web site	28
Figure 1-3 Geological map of the study area (after EGPC, 1987).....	30
Figure 1-4 Major structural elements on the study area (after RIWR, 1988).....	31
Figure 3-1 Estimate of the Earth's annual and global mean energy balance, Source: Kiehl and Trenberth(1997). Kiehl, J., and K. Trenberth, 1997: Earth's annual global mean energy budget. Bull. Am. Meteorol. Soc., 78, 197–206.....	46
Figure 3-2 An idealized model of the natural greenhouse effect. IPCC, 2007.....	47
Figure 3-3 Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one data set (IPCC, 2013).....	49
Figure 3-4 Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets (orange, blue, black). Top panel: annual mean values. Bottom panel: decadal mean values including the estimation of uncertainty for one (IPCC, 2013).....	50
Figure 3-5 Main drivers of climate change, the radiative balance between incoming solar shortwave radiation (SWR) and outgoing long wave radiation (LWR) is influenced by global (IPCC, 2013).....	51
Figure 3-6 Schematic representation of the development	52
Figure 3-7 Types of climate model (Goosse et al., 2010).	54
Figure 3-8 The development of climate models over the 35 years showing how different components were coupled into comprehensive climate model over time (IPCC, AR5).....	55
Figure 0-9 The Whole Earth Climate System: a platform for climate modelling and scenarios	56
Figure 3-10 Representative concentration pathways and anthropogenic radiative forcing	59