The Islamic University Gaza
Higher Education Deanship
Faculty of Engineering
Civil Engineering Department
Infrastructure Program

الجامعة الإسلامية – غزة
عمادة الدراسات العليا
كلية الهندسة
قسم الهندسة المدنية
تخصص البنى التحتية

Effects of Climate Change on Groundwater Resources

(Northern Gaza Strip Case Study)

تأثير التغير المناخي على المياه الجوفية (حالة خاصة: شمال قطاع غزة)

Submitted by:

Salah Basem Ajjur

Supervised by:

Dr. Yunes Khalil Mogheir

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This thesis is dedicated to my parents.

For their endless love, support and encouragement

LIST OF PUBLICATIONS

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This thesis is only a beginning of my journey.

Finally, I would like to leave the remaining space in memory of my university, a brilliant university.

Salah B. Ajjur

August, 2012

ABSTRACT

Gaza Strip water sector management is essential for sustenance of life. The knowledge of the occurrence, replenishment and recovery of groundwater assumes special significance in quantity-deteriorated regions, as Gaza Strip because of scarce presence of surface water. In addition, unfavorable climatic condition on one hand and an unsuitable geological set up on the other, a definite limit on the effectiveness of surface and subsurface reservoirs.

Thus, a research is essential to confirm the relationship between groundwater in Gaza Strip region and the sustainability of such climate conditions. Given the role of natural resources within the current conflict dynamics, climate change has a significant role to play in groundwater management within the region in next years.

Studying the relation between climate change and groundwater resources was carried by estimating the recharge quantities that infiltrate to the aquifer using WetSpass software, then studying its effects on groundwater depth using Modflow software. Finally forecasting the possible scenarios may occur in the future and its effects on groundwater resources were studied.

The research showed a minor decrease in temperature and decreasing trend of the rainfall after 1995 which implied the climate change, and consequently influenced the recharge values. The temporal relation between the most sensitivity parameter (rainfall) and the recharge was studied in three presented locations in Gaza Strip: Beit lahia, Gaza City and Rafah rainfall stations with high correlation between the rainfall and recharge trends ranges between 0.96 to 0.99. It's noticed that after year 1995 rainfall decreased by 63.8% in Beit lahia station that caused deficit in recharge values with 87.64%, and lastly decrease in groundwater storage.

Then, recharge values were input to calibrated transient groundwater model (Modflow software) for the northern part of Gaza Strip. Two scenarios were considered; the recharge of year 2010 was assumed to still remain and recharge rate decreases at the same trend. Output showed a large decreasing in the water table from -3m at the start date to -6, -7.5, -8 and -8.5m at the middle and from 2m to -3.31, -6, -7 and -7.5m for years 2015, 2020, 2025 and 2030 respectively with clear expansion in the deficit region over time. The same trend observed for the second scenario with larger values. Therefore, it is recommended that all water resources management plans in Gaza Strip should consider the impact of climate change.

Keywords: Gaza, climate change, groundwater, management.

ملخص الدراسة

Abstract in Arabic

تأثير التغير المناخي على المياه الجوفية (حالة خاصة: شمال قطاع غزة)

إدارة قطاع المياه في قطاع غزة هو أمر ضروري لاستمرار الحياة. المعرفة الجيدة بوقت حدوث الترشيح إلى الخزان الجوفي يشكل أهمية خاصة في المناطق ذات العجز الواضح من حيث كمية المياه بسبب ندرة المياه السطحية مثل قطاع غزة. بالإضافة إلى ذلك كله، الحالة المناخية غير المواتية من جهة والجيولوجي الغير مناسب من جهة أخرى يحدد كمية معينة من المياه المتوفرة في الخزان الجوفي والخزانات السطحية.

بناءً على ما سبق ، فإن البحث في هذا المجال أمر ضروري لتأكيد العلاقة بين المياه الجوفية في قطاع غزة واستدامة مثل هذه الظروف المناخية أو تغيرها. نظراً لدور الموارد الطبيعية في هذا الصراع الحالي، فإن ظاهرة تغير المناخ سيكون لها دور هام في إدارة المياه الجوفية في المنطقة خلال السنوات القادمة.

تمت دراسة تأثير التغيرات المناخية على المياه الجوفية عن طريق تقدير كمية ترشيح المياه الجوفية باستخدام برنامج WetSpass, ثم دراسة تأثير ذلك على منسوب الخزان الجوفي باستخدام برنامج Modflow, وأخيرا التنبؤ بالسيناريوهات المتوقع حصولها في المستقبل ودراسة تأثيرها المحتمل على هذا القطاع.

تم تقدير كمية ترشح المياه الجوفية خلال السنوات العشرين الماضية. يظهر البحث سلوك متقلب في هطول الأمطار مما يعني تغير المناخ، وبالتالي يؤثر ذلك على قيم الترشيح للخزان الجوفي. تمت دراسة العلاقة الزمنية بين العنصر الأكثر فعالية (الأمطار) وترشيح المياه الجوفية في ثلاثة مواضع في قطاع غزة: محطة رصد بيت لاهيا ومحطة رصد مدينة غزة ومحطة رصد رفح مع وجود الإرتباط الكبير بين هطول الأمطار وإعادة التغذية فتتراوح نسبة الإرتباط بين 0،96 و 0،99.

لوحظ أنه وبعد عام 1995 انخفضت قيم هطول الأمطار بنسبة 8،63٪ في محطة بيت لاهيا مما تسبب في عجز قيم التغذية إلى 87،64٪، وانخفاض في مخزون المياه الجوفية.

قيم الترشيح استخدمت في نمذجة المياه الجوفية بنظام المحاكاة للمنطقة الشمالية من قطاع غزة. تم اعتبار سيناريوهين محتملين : الأول قيم التغذية للعام 2010 لا تزال قائمة وستستمر للأعوام القادمة, والثاني انخفاض قيم التغذية لعام 2015 بنفس معدل انخفاضها للسنين السابقة. بعد ملاحظة المخرجات ظهر تناقص كبير في قيم منسوب المياه الجوفية من -3,3 متر إلى -3,86- ثم -5 ثم -6 ثم -7،5 ثم -8 ثم -8.5 متر في منطقة الوسط ومن 2 متر إلى 2.04 -3,31 -3,31 ثم -6 ثم -7,5 متر للسنوات 2005 و 2010 و التوالي, مع التوسع في المنطقة واضحة العجز على مر الزمن. نفس الاتجاه لوحظ في السيناريو الثاني مع قيم مختلفة. بناء على ذلك

كله, فإنه يوصى بأن تؤخذ التغيرات المناخية بعين الاعتبار في كل تخطيطات إدارة قطاع المياه الجوفية في قطاع غزة.

كلمات البحث: غزة، تغير المناخ، المياه الجوفية، الإدارة.

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LIST OF ABBREVIATIONS

Symbol	**Description**
AR	Artificial Recharge
CGCM	Canadian Global Coupled Model
CMWU	Coastal Municipalities Water Utility
EPA	Environmental Protection Agency
GCM	General Circulation Model
GIS	Geographic Information System
IUG	Islamic university of Gaza
IPCC	Intergovernmental Panel on Climate Change
MCM	Million Cubic Meter
NATCC	North Atlantic Thermohaline Circulation Change
KMNI	Royal Netherlands Meteorological Institute
MOA	Ministry of agriculture
Modflow	Modular Three-Dimensional Finite-Difference Groundwater Flow Model
MOG	Municipality of Gaza
MoI	Ministry of interior
msl	Mean sea level
PCBS	Palestinian Central Bureau of statistics
PWA	Palestinian Water Authority

UNDP	United Nations Development Programme
USGS	United States Geological Survey
WetSpass	Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State
WHO	World health Organization
WWTP	Waste Water Treatment Plant

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CHAPTER 1

INTRODUCTION

CHAPTER 1: INTRODUCTION

Groundwater is a critical source of fresh drinking water for almost half of the world's population and it also supplies irrigated agriculture (Holger et. al., 2012). It is now the most significant source in quantity-deteriorated regions, as Gaza Strip because of scarce presence of surface water, it's important for sustaining streams, lakes, wetlands, and ecosystems in many countries, supplying nearly half of all drinking water in the world and around 43% of all water effectively consumed in irrigation (Holger et. al., 2012).

Water sector management is essential for sustenance of life particularly in rural areas in arid and semi-arid regions. The knowledge of the occurrence, replenishment and recovery of groundwater assumes special significance. Water problem is expected to grow and the deficit in terms of quantity will reach to about 100 Mm^3/y by year 2020, while the water quality will be deteriorated dramatically according to Palestinian Water Authority report (PWA, 2003).

While groundwater is a major source of Gaza's Strip water, relatively little researches has been undertaken to determine the sensitivity of groundwater systems to changes in critical input parameters, such as temperature, precipitation and runoff. Changes in climate are expected to affect the hydrological cycle, altering surface - water levels and groundwater recharge to aquifers with various other associated impacts on natural ecosystems and human activities.

Furthermore, an understanding of the climate processes is essential to make sensible predictions of the possible impact of climate change on groundwater resources.

The main objective of this research is quantifying the present risks of climate change on the groundwater resources of Gaza Strip in terms of quantity under possibly future conditions using a physically distributed water balance model (WetSpass).

1.1 Problem Statement

Gaza Strip is in critical situation that requires immediate efforts to improve the water situation in terms of quantity and quality. Although groundwater is a major source of drinking water in Gaza Strip and plays a vital role in maintaining the ecological value of the area, relatively little research has been undertaken to determine the sensitivity of groundwater systems to changes in critical input parameters, such as temperature, precipitation and runoff.

It is expected that changes in temperature, precipitation and runoff will alter groundwater recharge to aquifers, causing shifts in water table levels in unconfined aquifers as a first response to climate trends.

Furthermore, an understanding of the climate processes is essential to make sensible predictions of the possible impact of climate change on groundwater resources.

1.2 Research Objectives

This research aims to quantifying the present risks of climate change on the groundwater resources of Gaza Strip in terms of quantity under possible future conditions. The specific objectives of this research are to:

a. Investigate and study Gaza Strip hydrogeological cycle properties and geological setting of the area.
b. Construct WetSpass model, to predict values of the recharge that will feed the aquifer.
c. Built up a groundwater model using Visual Modflow, to study water levels extent of the recharge mound.
d. Forecast the possible future climate change scenarios impacts on groundwater resources in the northern part of Gaza Strip.

1.3 Research Importance

Based on a deep knowledge on Gaza Strip area, no research has been studied the climate change effects on groundwater resources till now, hence this study might be considered as one of the unusual contributions in quantitatively modeling of the relation between groundwater resources and climate change in Gaza Strip. This can contribute in management of the groundwater resources.

1.4 Research Limitations

Although the aim of the research was carefully prepared and reached, researchers still aware of its unavoidable limitations and shortcomings.

First of all, since the stage of studying the climate parameters history designed to measure years from 1990 to 2010, the long term study might give useful information about the trends of climate in Gaza Strip; lack of data was the most difficult step the research faces.

Second, because of the time limit, the research was conducted in the Northern area of Gaza Strip in the second part of studying the water level state. Therefore, to generalize the results for larger area, the study should involve all area of Gaza Strip. This will need more and more efforts.

In addition, since the prediction of future scenarios for recharge values might have in next years is limited to two scenarios; it is preferable that further studies suggest other scenarios. In fact, it would have been sort of objective if it had been set by two or three researches.

1.5 Research Structure

The thesis is divided into different chapters that range from chapter 1 to 6 and 2 annexes.

Chapter 1: is a general introduction with an overview of the groundwater condition, water problem statement in Gaza Strip, research aim, objectives and importance and brief research methodology.

Chapter 2: is a pithy review of the history and methods of predicting climate change effects on Groundwater resources at both global and local scale. It also discusses a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada. It's also taking about analyzing the sensitivity of water balance components resulting from climate changes in the Grote-Nete basin, Belgium.

It also discusses the groundwater flow equations and groundwater modeling computational tools (WetSpass model and Modflow) and describes techniques and computing equations used by this tools.

It discusses methods of integration GIS and WetSpass with distributed hydrologic modeling, and highlights about GIS and its use in hydrologic modeling environment in Grote Nete basin and Kleine Nete basin in Belgium. Its finally talk about ARCVIEW Interface for WetSpass and Modflow.

Chapter 3: starts with a brief description of the Gaza Strip: Geography, Geology, Topography, Soil, Landuse, Population, Climate and Coastal Aquifer state. Also in this chapter, a brief description of the Groundwater Quality, and Palestinian Water Resources Policy.

Chapter 4: discusses the Research Methodology parts.

Chapter 5: provides a modeling approach for the Gaza Strip, to derive recharge values and comparing the results behavior with climate parameters behavior. It's also discusses studying the groundwater state with different recharge values and predicting what will happen in groundwater table in future as a result of climate change.

Chapter 6: gives conclusions and recommendations about the research work described in this thesis and outlines of future work in similar research direction.

Annex 1: provides some maps and database files of the Gaza Strip used in WetSpass model and Error maps outputs. In addition provides names abbreviation listed in WetSpass files.

Annex 2: provides observation wells data used in Modflow program and groundwater depth maps used in the research.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

Climate changes have relevant importance on the groundwater resources availability in the world. However, estimating its effect has long been one of the most difficult challenges in hydrological science, the potential international and global impacts have been, and continue to be explored (Folland et. al., 2001).

This chapter will first present climate change effects, then it will explain groundwater modeling equations and how to solve these equations. In addition some programs that deal with groundwater modeling and the studies of the impacts of climate change on groundwater resources will be shown. Also, in order to evaluate these studies at local scales, main downscaling techniques and some applications will be reviewed.

2.1 Climate change effects

2.1.1 Global climate change effects

The main components of hydrology cycle are the precipitation, evapotranspiration, runoff, groundwater, and soil moisture, and it is linked with changes in atmospheric temperature and radiation balance. According to Bates et. al., 2008, precipitation pattern over 20th century has shown important spatial variability; which has decreased in the zones located between 10 ^{o}S to 30 ^{o}N latitude and increased in high northern latitudes since 1970. In addition to this, precipitation increased around 2 % between 0 ^{o}S to 55 ^{o}S and from 7 to 12 % from areas located between 30 ^{o}N to 85 ^{o}N (Folland et. al., 2001).

On the other hand, for the 21st century, simulations with climate models indicate an increase in the globally evaporation, water vapor, and precipitation, indicating that precipitation will decrease in the lower and mid latitudes regions while it increases in high latitudes and part of tropics (Bates et. al., 2008).

Global climate simulations indicate that precipitation will decrease in lower and mid latitudes and increase in high latitudes (Bates et. al., 2008). Results show that rainfall will decrease in Caribbean regions, sub tropical western coasts, part of North American (Mexico), and over the Mediterranean. Evaporation, soils moisture content, groundwater recharge will also affected by climate changes. Drought conditions are projected in summer for sub tropics, low and mid latitudes. Some results show that for warmer climate the drought increases from 1 % to 30 % in 2100. On the other hand, global impacts on the water resources show that freshwater for different uses will be affected.

According to Folland et. al., 2001, a notable reduction of the water resources service is projected where the runoff decrease, and also the projection of water stress for year 2050 indicates an increase in range of 62-76 % of the global land areas.

Important decrease of up 20% will occur on the Caribbean regions, sub tropical western coasts in most countries, and over the Mediterranean. Changes in soil moisture depend basically of the precipitation and evaporation which may be affected by changes in the land use; therefore its Evapotranspiration is projected to increase in almost everywhere due to the water holding capacity of the atmosphere increases with higher temperatures. Climate change also affects the groundwater recharge rate which is the most important source of water in many places of the world.

In global terms, water demand will grow in the next decades due to the population growth and regionally, substantial changes in irrigation water demand are expected as results of climate change. In general, negative effects of climate changes on water resources systems would complicate the impacts on the changing economic activity, water quality, increase population, land use change and urbanization. In the year 2050 “the area of the land subject to increasing water stress due to climate change is projected to be more than double than with decreasing stress”. A clear reduction of the water resources services is shown in zones where the runoff is projected to decrease and the others where the rainfall increases, increased total water supply are projected (Bates et. al., 2008).

2.1.2 Local climate change effects

The changes described above, as it was mentioned, are at global scale. However, at the local scale, several studies about changes in climatic parameters as precipitation, runoff, wind speed, temperature, evapotranspiration, landuse and soil moisture using different emission scenarios have been carried in many basins all over the world in the past decades. Several hydrology and water resources models are used in order to assess the climate changes impacts at local scale which guide us finally to study the present groundwater state and predict the possibly future scenarios.

Assessing climate change impacts on the groundwater resources further complicates a complex process. A method is required that accounts for not only temporal variations in climatic variables and their impact on the hydrologic cycle, but also the spatial variation of surface and subsurface properties throughout the study site.

To appreciate the groundwater state we firstly need to know recharge process and to simulate groundwater recharge, a physically-based approach is needed. This is typically accomplished by modeling the interaction between all of the important processes in the hydrologic cycle such as infiltration, surface runoff, evapotranspiration, snowmelt, and groundwater level variations (Jyrkama et al., 2007).

2.2 Case study examples

2.2.1 Grand Forks aquifer, southern British Colombia, Canada

The study attempted to identify the potential impacts of climate change on groundwater of the Grand Forks aquifer, a surficial, unconfined aquifer located in south-central BC, Canada. The aquifer is a highly productive, alluvial aquifer, consisting predominately of sand and gravel. The region is semiarid; groundwater constitutes approximately 22 % of the drinking water in BC and is used for agriculture in many regions of the province. The main drainage features in the Grand Forks area include two rivers (Allen et al. 2004).

The authors assessed two main parameters potentially affected by climate change impacts to groundwater levels: recharge and river stage/discharge. This was accomplished by calibrating a flow model and conducting sensitivity analysis by varying both recharge and river stage/discharge and calculating the differences in water levels.

The authors developed a three-dimensional groundwater flow model for the Grand Forks aquifer to facilitate a comparison of well captured zones defined using numerical modeling and analytical techniques. The authors used Visual Modflow, a groundwater flow model that solves the groundwater flow equation using block-centered finite-difference method. Visual Modflow can simulate flow in a quasi-3D manner, and both steady-state and transient conditions can be modeled, as well as water-balance calculations (using Zone Budget) and particle tracking (using MODPATH).

To estimate recharge based on available precipitation and temperature records and anticipated changes to these values, the authors utilized the computer code UnSat Suite and its subprogram Visual HELP. Visual HELP, a more user-friendly interface for the program HELP, a program approved by the US Environmental Protection Agency's (EPA) for designing landfills, enables the modeler to generate estimates of recharge using a weather generator and properties of aquifer column.

The authors varied the amount of recharge to the system by varying precipitation and evaporation according to the General Circulation Model (GCM) values for precipitation and temperature. In reality, this increase in precipitation and evaporation is coupled with river-stage elevation. However, to conduct a controlled sensitivity analysis, the authors varied two independent variables: recharge and river-stage elevation.

The authors used the model HELP to conduct the climate sensitivity analysis by using four scenarios generated by various GCMs. The four scenarios include:

1) Low temperature/low precipitation
2) Low temperature/high precipitation
3) High temperature/low precipitation
4) High temperature/high precipitation

The two extreme recharge values (high temperature/low precipitation and low temperature/high precipitation) were then put into Visual Modflow in order to determine the impact on the groundwater system. The results of the climate sensitivity modeling indicate that there is very little difference in either the general appearance of the water-level contours or the hydrogeology of the valley compared to the current recharge model. There is a very small (0.05m) increase in water level under the high-recharge scenario and a very low (-0.025m) decrease in water level under the low-recharge scenario.

Allen's results indicated that changes in river-stage elevation of the Kettle and Granby Rivers, which flow through the valley, have a much larger impact than variations in recharge to the aquifer under different climate-change scenarios, modeled under steady-state conditions.

The model incorporated specified head boundaries relating to projected impacts of climate change. Using this method it was determined that these specified heads play a dominant role on the hydrogeology of the aquifer. Furthermore, their role affects the overall water balance much more than recharge due to changes in precipitation and evaporation. Simulated flows 20 and 50% greater than peak flow levels correlated with 2.72 and 3.45 m increases in water-table levels, respectively.

A new method for linking climate models and groundwater models in a systematic manner was developed by Scibek et. al., 2006. The Grand Forks aquifer in south central British Columbia was used as the study site, and climate change scenarios from the Canadian Global Coupled Model 1 (CGCM1) were downscaled to local conditions using Statistical Downscaling Model. The factors were then extracted and applied in LARS-WG stochastic weather generator. The outputs of this model were inputs for the groundwater recharge model, HELP. Finally, Modflow was used to simulate four climate scenarios - present, 2010 – 2039, 2040 – 2069, and 2070 – 2099. Groundwater levels for the modeled climate scenarios were then compared to present levels.

Results indicated that the effects of spatial distribution of recharge on groundwater levels, was much greater than that of temporal variation in recharge. Predicted future climate scenarios resulted in more recharge to the unconfined Grand Forks aquifer for the spring and summer seasons; however, due to the dominant interactions between river stage and groundwater levels, the overall effect of recharge on the water balance was small.

The authors presented a method to generate spatially distributed and temporally varying recharge zones using a GIS model linked to the one-dimensional U.S. Environmental Protection Agency’s Hydrologic Evaluation of Landfill Performance model, HELP. The approach depends on high resolution GIS maps for defining recharge zones, which the authors then linked to Modflow model grids by developing a specific code to link Visual Modflow 3.1.84 to Arc GIS 8.13. The authors highlighted that their method differs from that of previous distributed recharge methods in that they also estimated the distribution of vertical saturated hydraulic conductivity in the unsaturated zone and the thickness of the unsaturated zone. Sixty-four recharge zones for the study site were determined based on combinations of soil permeability, vertical hydraulic conductivity and water depth.

The authors then evaluated sensitivity of modeled recharge in the HELP model to input parameters. Results indicated that the type of stand grass, wilting point, field capacity and initial moisture content had very little effect on output results (<5%). Soil thickness and porosity of percolation layer had a moderate effect. Recharge was most sensitive to depth to water table (depth of unsaturated zone), soil permeability, and for vertical hydraulic conductivity of the unsaturated zone. These effects were found to be seasonal and most pronounced in early summer.

In the previous study made by Allen et al. 2004, a uniform annual recharge value for the Grand Forks aquifer of 135.5 mm/year (approximately 27% of precipitation) was used. However, according to the results of this study, mean annual recharge varies across the 64 recharge zones, ranging from less than 30 mm/yr to over 120 mm/yr.

Under the predicted climate change scenarios, recharge was predicted to increase in all recharge zones, under all climate-change scenarios. The 2010 – 2039 climate scenario predictions indicated a 2 to 7% increase in historical mean annual recharge. The 2040 – 2069 climate scenario had a predicted 11 to 25% increase from historical mean annual recharge. Recharge values for each climate period were implemented into Visual MODFLOW in order to quantify the effect of changes in recharge on groundwater levels in the aquifer.

The authors investigated the sensitivity of the HELP model by evaluating two scenarios. The first scenario had spatially distributed mean annual recharge as the recharge input, and the second had temporally variable recharge rates with one uniform recharge zone. Results indicate that spatial distribution of recharge representation in the model has more significant impact on the water balance than does the temporal representation of recharge.

Under future climate scenarios, recharge was slightly lower in the late winter and was greatly increased in the late spring and summer. However, in this aquifer, effects of changing recharge due to climate change on groundwater levels was found to be very small compared to changes in timing of snowmelt events in the Kettle River. Because the groundwater system and the Kettle River are so hydraulically connected, shifts in the hydrographs had greater impacts on groundwater levels compared to that of changing recharge. It should be noted that this may not be the case for aquifers where surface water and groundwater are not as highly connected.

2.2.2 Grote-Nete basin, Belgium

The main objective of the study is to analyze the sensitivity of water balance components, especially recharge and groundwater discharge, in the Grote-Nete basin resulting from climate changes, using different climate scenario outputs at a regional scale. Size, rate, and volume of groundwater recharge and discharge are identified using a three-dimensional groundwater flow model, Modflow (Harbaugh et. al., 1996), in conjunction with a physically based distributed water balance model, WetSpass (Batelaan et.al., 2001), integrated in a GIS environment.

Study Area

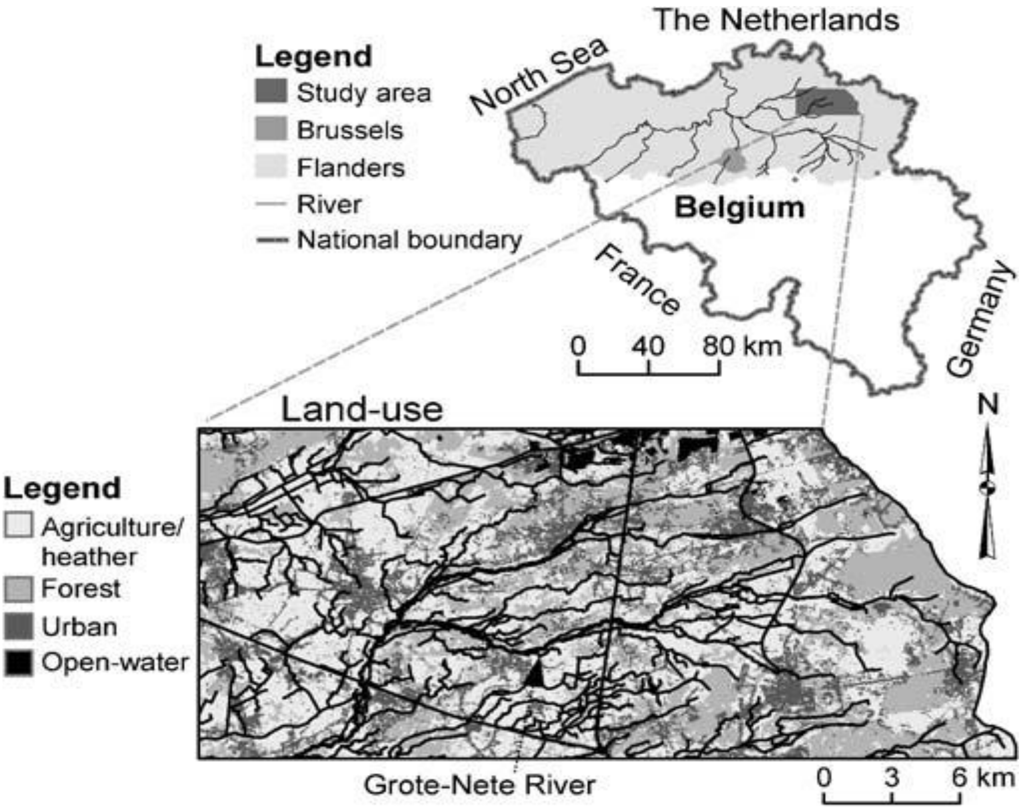


Figure 2.1 Simplified land-use map and location of Grote-Nete study area in the Flanders region of Belgium

The study area is located about 60 km northeast of Brussels and covers about 525 km^2 as shown in Figure 2.1. It is part of the Central Campine region including most parts of the Grote-Nete basin. It is characterized by a moderate rolling landscape cut by the Grote-Nete River and its tributaries, resulting in long stretched hills, very slightly elevated interfluves and broad swampy valleys (Wouters et. al., 1994).

The elevation ranges from 13 to 73 m, with an average of 32 m above sea level, while the mean slope is 0.24%.The soil type is dominated by sandy and loamy sand covering 91% of the basin, while loamy sand, silty loam and clay loam are also found in the valleys. The land-use comprises 28% arable land, 19% of built-up area, 18%deciduous forest, 15% grass lands, 10% coniferous forest,5% heather, 3% mixed forest, and about 2% open-water bodies. A simplified map of land-use types is shown in Figure 2.1. The long-term mean annual precipitation ranges from 743 to 801 mm with an average of 764 mm, while the average summer and winter precipitation are respectively 392 and 372 mm. In this study, winter months refer to October until March while summer months are April until September. The average annual potential evapotranspiration is 670 mm. The area has moderate average winter and summer temperatures of 5 and 14°C respectively.

The methodology consists of three steps. To begin with, climate scenarios are formulated for the years 2050 and 2100. This is done by assigning percentage or value changes of climatic variables on a seasonal and/or annual basis only for the years 2050 and 2100 relative to the present year (2000). Secondly, based on these scenarios and present situation, seasonal and annual recharge, evapotranspiration and runoff are simulated with the WetSpass model. Finally, the annual recharge outputs from WetSpass are used to simulate groundwater system conditions using steady-state MODFLOW model setups for the present condition and for the future years.

Although numerous scenarios for both 2050 and 2100 have been used, only selected scenarios for 2100 that represent the range of responses are discussed hereafter.

A climate scenario is defined as a plausible future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change (Folland et. al., 2001). The climate scenarios used in this study were developed by the Royal Netherlands Meteorological Institute (KNMI), The Netherlands, and have been used in several water management studies, e.g. Korset al., 2000.

The climate scenarios are categorized in three general types, i.e. greenhouse, North Atlantic Thermohaline Circulation Change (NATCC), and dry scenarios, which are assumed to be realistic representations of the controversial views regarding the change in climate for the future. All scenarios are based on an incremental approach where particular climatic elements are changed by realistic but arbitrary amounts, commonly applied to study the sensitivity of an exposure unit to a wide range of variations in climate. In most studies, constant changes throughout the year have been adopted, as for instance Terjung et al., 1984 and Rosenzweig et al., 1996.

The effects of climate change on the water balance and groundwater system of a sandy aquifer under temperate conditions are modeled using a physically distributed water balance model and a finite difference groundwater model. The climate scenarios considered are wet, cold and dry, as they are assumed to represent all controversial but realistic predictions of climate change. Among the proposed scenarios, the ones which are likely to have a significant effect on the water-balance components and groundwater system are either the wet or dry scenarios. Further studies pertaining to climate change impacts for the study region should concentrate mainly on these scenarios. However, planning appropriate mitigation strategies will depend on the likelihood of occurrence of such climate change. In this sense constant observation for the coming years may reveal which scenario is more likely to occur. In addition, in order to study seasonal variation of the groundwater components and the effect of extreme events, studies based on a transient modeling approach should be conducted. Climate change impact studies based on steady-state groundwater simulations have limitations in representing boundary conditions and can only be used for assessing sensitivities before implementing more rigorous and data-intensive transient modeling.

For the wet scenarios, runoff was the most sensitive component showing the highest percent increase. This, combined with the increase in groundwater discharge areas, groundwater level and winter precipitation, might pose more risk of flooding, given the shallow groundwater depth of the area. On the other hand, a greater difference between summer and winter recharge, which implies greater seasonal fluctuation of the groundwater levels, may influence the distribution and species richness of wet meadows, as they are sensitive to fine-scale variations of the water-table depth.

Furthermore, the decrease in summer groundwater recharge is mainly attributed to high evapotranspiration rates from forests. In the case of dry scenarios, recharge is the most sensitive parameter and decreases for all seasons. More water is lost than can be replenished due to low precipitation and high evapotranspiration, especially by forests, throughout the year. This will result in a decrease of the annual groundwater levels by as much as 3 m. The consequences could be drastic, as this could reduce the water availability to crucially low levels for both aquatic life in wetlands and riverine ecosystems, especially in summer when the decline in water level is expected to be greater than the average annual decline. Prolonged dryness can eventually result in complete alteration/ disappearance of short-rooted plant populations. Irrigation requirements for crop production might need to be adjusted to counteract the effects of summer dryness. This would lead to more pumping from the groundwater, which can further lower the groundwater levels. Thus, adding pumping scenarios that consider irrigation requirement and water-supply demands have to be considered in order to appreciate the full extent of the effects of dry scenarios. It has also been shown that land-use plays an important role on the effects of climate change. Therefore, integrated water-management strategies can only feasibly be designed when climate scenario analyses are complimented with land-use scenarios. The results of such work could yield a range of options for making decisions for appropriate land-use development planning to safeguard the water resources in the catchment. In addition, as groundwater and surface water are inseparable components of the hydrologic cycle, concrete conclusions can only be made if their interaction is included in climate change impact studies.

CHAPTER 3

CASE STUDY: GAZA STRIP

CHAPTER 3: STUDY AREA: GAZA STRIP

3.1 Geography

Gaza Strip is a strip of land on the eastern coast of the Mediterranean Sea, located in the Middle East (at latitudes 31°16" and 31°45"N and longitudes 34°20" and 34°25"E) (Aish et. al., 2004) that borders Negev Desert and Egyptian Sinai Peninsula on the southwest (11 km) and Israel on the east and north (51 km). It is 41 kilometers long, and 6 and 12 kilometers wide, with a total area of 365 Km^2 (Figure 3.1).

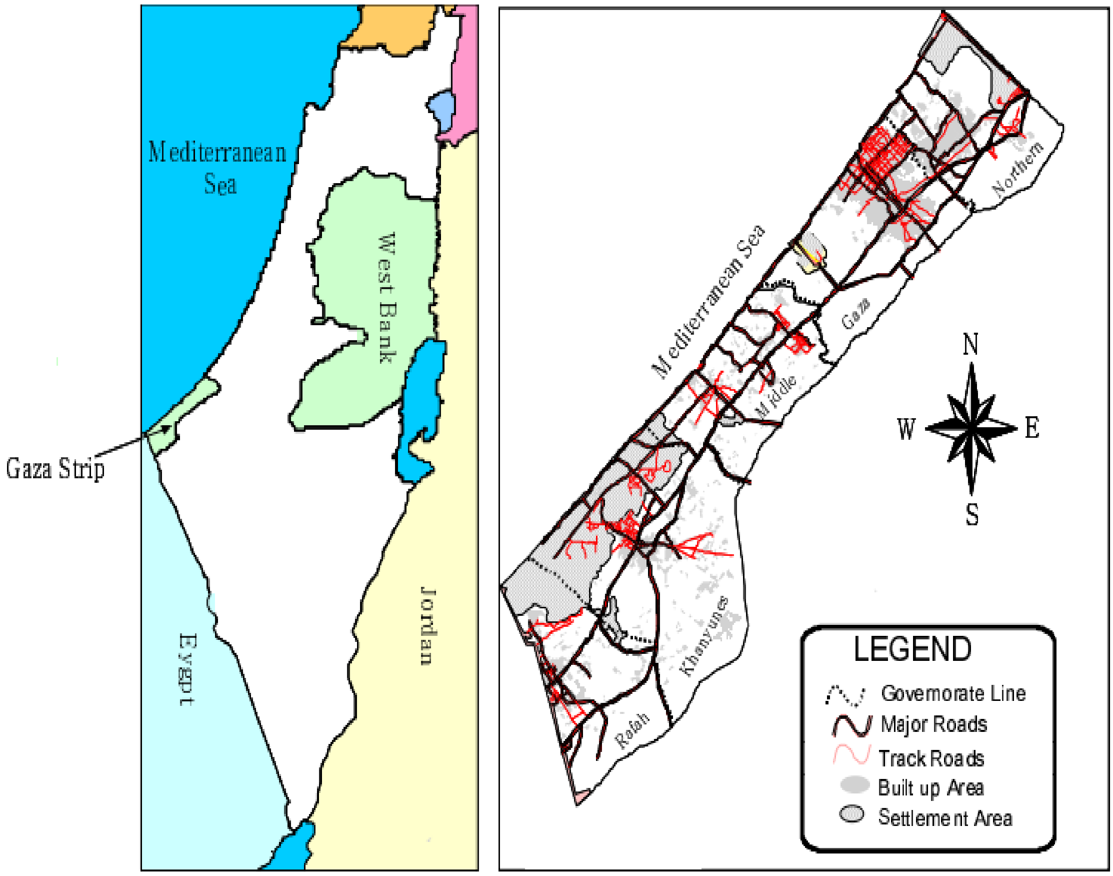


Figure 3.1 Location map of Gaza Strip, Palestine

3.2 Geology

The coastal aquifer of the Gaza Strip consists of the Pleistocene age Kurkar and recent (Holocene age) sand dunes. The Kurkar Group consists of marine and aeolian calcareous sandstone (Kurkar), reddish silty sandstone, silts, clays, unconsolidated sands, and conglomerates.

Regionally, the Kurkar Group is distributed in a belt parallel to the coastline, from north of Haifa to the Sinai in the south. Near the Gaza Strip, the belt extends about 15-20 km inland, where it un-conformably overlies Eocene age chalks and limestone, or the Miocene-Pliocene age Saqiye Group, a 400-1000 m thick sequence of marls, marine shales, and claystones. The transition from the Kurkar Group to the Saqiye Group is sometimes obscured by the presence of a thin, basal conglomerate. Figure 3.2 presents a generalized geological cross-section of the coastal aquifer.

The Kurkar Group consists of a complex sequence of coastal, near-shore and marine sediments. Marine calcareous sandstone forms the base of each transgressive sequence, and marine clays form the end of regressions. Cycles of deposition may be incomplete, depending on location; hence sedimentary sequences may be truncated and rest unconformable on one another. The calcareous sandstone are interbedded with irregular layers and pockets of uncemented sand, thin red-brown sands and silty sands, and especially at greater depth, marine silts and clays.

Within the Gaza Strip, the thickness of the Kurkar Group increases from east to west, and ranges from about 70 m near the Gaza border to approximately 200 m near the coast. Israeli literature suggests that the Kurkar Group becomes more clastic towards the east. The distinct 'layering' of sedimentary cycles becomes less obvious, and the presence of red silty-clayey sandstone becomes more dominant. In addition, alluvial clays and soils become more evident along the courses of major drainage features such as Wadi Gaza.

Clay formations or units within the Gaza Strip, and the coastal aquifer in general, are of two types: marine and fluvial. Marine clays are present along the coast, at various depths within the formation. They pinch out about 5 km from present coastline, and based on existing data, appear to become more important towards the base of the Kurkar Group.

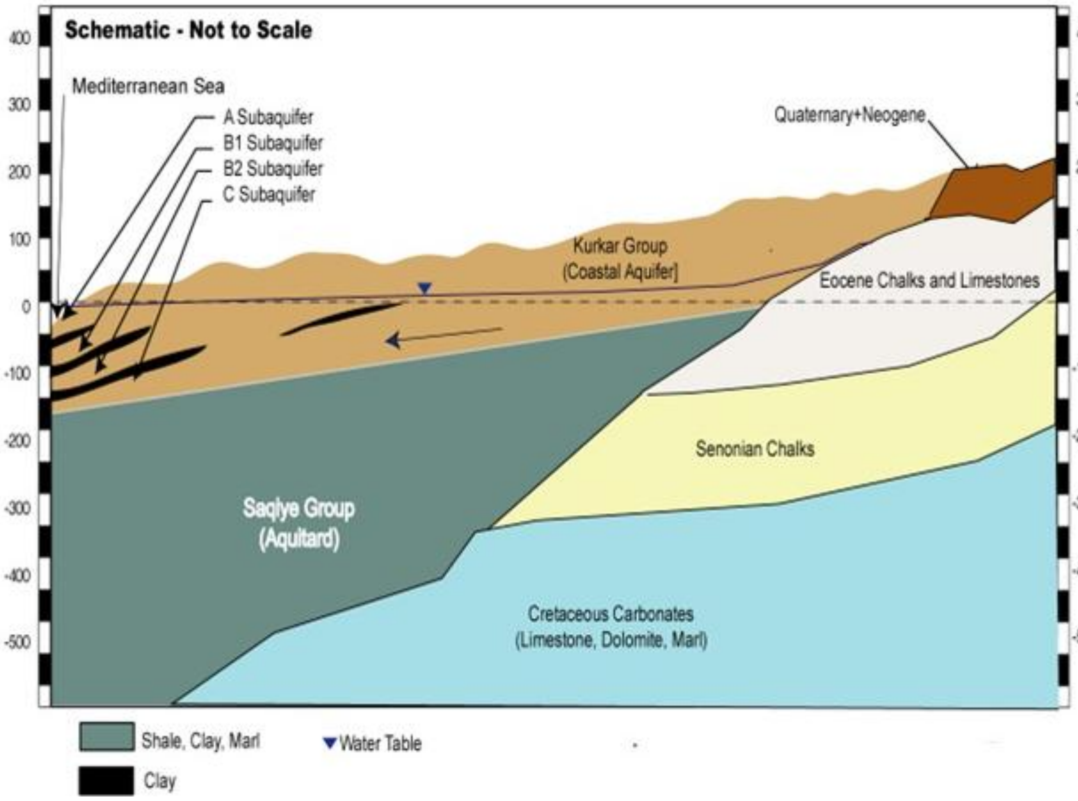


Figure 3.2 Typical hydrogeological cross section of Gaza Strip (PWA, 2003)

Three major clay layers were defined that can be correlated between boreholes from north to south in Gaza. They extend inland about 2 to 5 km, depending on location and depth. Limnic and fluvial clays near ground surface are present along Wadi Gaza, in the middle area along the Gaza border, and in the Beit Hanoun area. Where cemented sandstone is present near the surface, they form distinctive topographic ridges with vertical relief up to 60 m. These “Kurkar” ridges, from which the coastal aquifer has obtained its name, typically extend in a NE-SW direction.

The dune sands (and loess soils) which overlie the Kurkar Formation consist of mostly fine, well-sorted sands of aeolian origin. They are predominantly present in the north and along the Mawasi area in the southwest. Thickness of these sands and loess range from a few meters to 15 m. In addition, alluvial sediments, consisting of sand, loess and gravel beds, are present along wadi courses. In Wadi Gaza, the reported thickness of alluvial sediments is between 30 to 40 m.

3.3 Topography

The topography of Gaza Strip is characterized by elongated ridges and depressions, dry streambeds and shifting sand dunes in coastal area.

Land surface elevations range from mean sea level (msl) to about 110 msl in some places as shown in Figure 3.3.

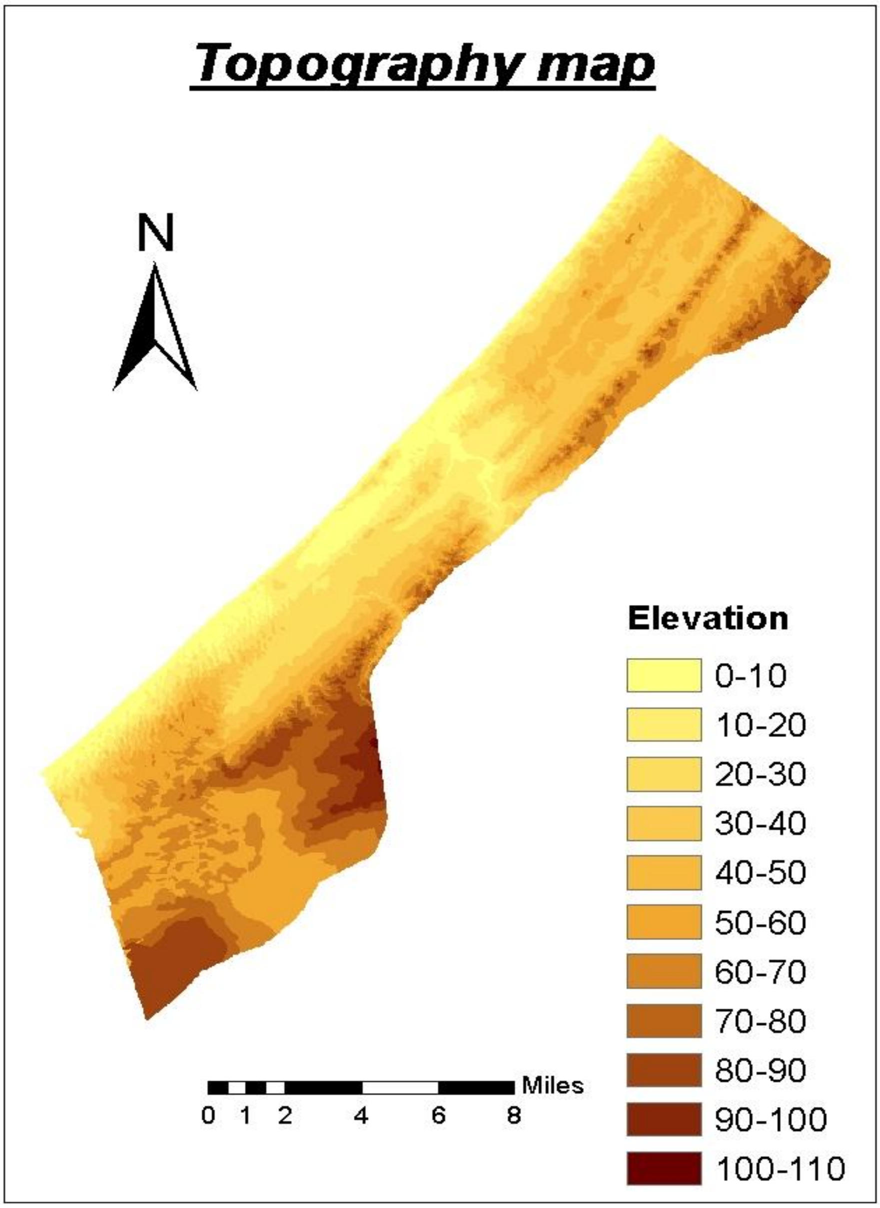


Figure 3.3 Topography of Gaza Strip (MOA, 2012)

The height increase towards the east. There are three valleys through Gaza strip Wadi Gaza, Wadi Alsalqs and Wadi Beit Hanoon. The largest one is Wadi Gaza. It's 8.5 km length and 45 m width but as a result of the dams which were built by Israel to pump the water to the north of El Naqab the wadi rarely flow. The other valleys are dry most of the time and flow only if very strong storms occur.

3.4 Soil

There are three main types of soil in Gaza Strip: sand, clay and loess. The soil map of the Gaza Strip is shown in Figure 3.3.

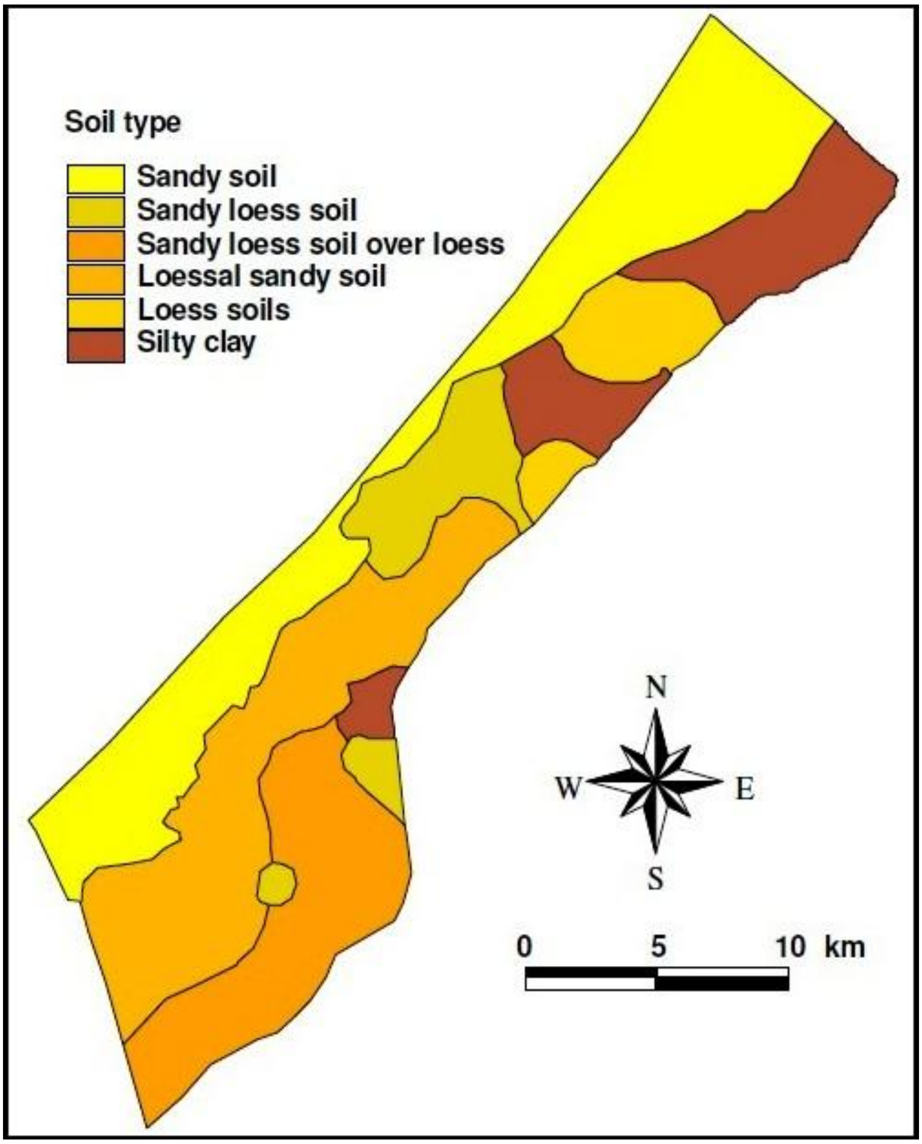


Figure 3.4 Soil map of Gaza Strip (PWA, 2003)

Types of soil in Gaza Strip and its characteristics, contents and concentration are presented below:

- Sandy soil is composed of regosols, its very weak, moderately calcareous (5-8% calcium carbonate), very low in organic matter and chemically poor but physically suitable for intensive horti- culture in greenhouses.

In the top meters textures are usually uniform and consist of medium to coarse quartz sand with a very low water. In the deeper surface (1-3 m below the surface) occasionally loam or clay loam or clay layers of alluvial origin can be found.

- Sandy Loess soil is a transitional soil, characterized by a lighter texture. This soil can be found in the depression between the kurkar ridges of Deir al-Balah. Apparently windblown sands have been mixed with loessial deposits.

- Loessial sandy soils can be found some 5 km in the central and southern part of strip, in zone along Khanyounes towards Rafah, parallel to the coast. This belt forms a transitional zone between the sandy soil and the loess soil usually with a calcareous loamy sand texture and deep uniform pale brown soil profile. There might be some accumulation of calcium carbonate in soil subsoil.

- Loess soil are formed in the area between the Gaza city and wadi Gaza, most soils in Gaza are more or less influenced by deposition of eolian dust, since the Gaza strip is situated at the main deposition zone in north-western Naqab desert.

Typical loess soil is brownish yellow colored, silty to sand clay loam, often with an accumulation of clay and lime concretions in the subsoil and contain 8-12% calcium carbonate.

- Silty clay soil is found in the north eastern part of the Gaza Strip, composed mainly of silt and clay, its less dense than a pure clay soil due to the larger particle size of the silt, holds moisture well, rich in nutrients.

3.5 Landuse

There is land scarcity for all kinds of uses (urban, industrial, and agriculture). Most of the study area is categorized as agricultural and urban but it also includes small industries located on site. The agricultural land is considered the dominant and economic sector. Urban and agriculture expansion is concentrated in the western coastal zones of Gaza Strip. There is overpopulation and related housing problems, especially in the refugee camps areas. Also there are inappropriate designs of wastewater treatment plant (WWTP) and disposing of untreated wastewater in Wadi Gaza. Consequently, there is a huge bad impact on the groundwater quality situation in the study area. Taking into consideration the rate of population growth and the expected economic expansion, groundwater quality problems will rapidly increase.

The period (1994-2004) can be called the urban transformation period, when development legally and illegally has been started. The present and the built up areas per governorates in the study area as estimated and predicted by Table 3.1.

Table 3.1: Present and future built up areas in Gaza strip (Abu Shaaban, et al., 2011)

Area	1997		2005		2015		2025	
	Km	%	Km	%	Km	%	Km	%
North	13.56	10.04	16.72	12.39	21.6	16	25.64	18.99
Gaza	20.23	15	28.93	21.43	44.2	32.74	54.57	40.42
Total	33.79	25.04	45.65	33.82	65.8	48.74	80.21	59.41

3.6 Climate

Gaza Strip is a semi-arid region. It's located in the transitional zone between a temperate Mediterranean climate in the west and north, and an arid desert climate of the Sinai Peninsula in the east and south. In this research, Gaza weather is divided into only two seasons:

- Summer dry season that runs from 1st April till 30th September, and
- Winter wet season that begins in 1st October and ends in 31st March.

Climate parameters that concern the study will be discussed individually below:

3.6.1 Rainfall

There are 12 rain gauge stations in Gaza Strip distributed over the whole area, three stations in the Northern area: Beit Lahia, Beit Hanon and Jabalia stations, four in Gaza city: Shati, Remal, Moghraga and south Gaza stations, two in the middle area: Nussirate and Deir al-Balah stations and three in the Southern area: Khanyounes, Khuzaa and Rafah stations (Figure 3.5).

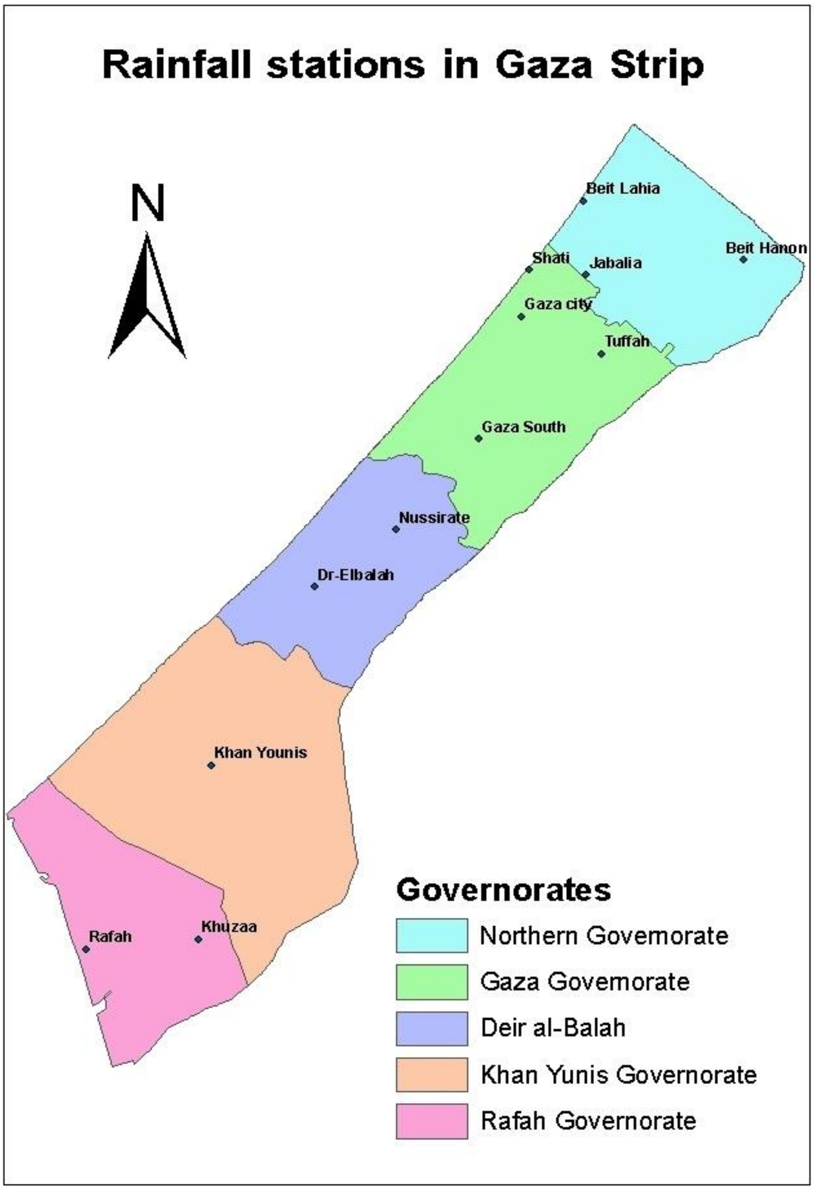


Figure 3.5 Rainfall stations location in Gaza Strip

The major source of renewable groundwater to the aquifer is rainfall. Rainfall is sporadic across Gaza. It's varied from 425 mm/y in the North to about 140 mm/y in the south over the last 20 years. Table 3.1 show rainfall values of Beit Lahia (Northern area), Gaza (Gaza city area) and Rafah (Southern area) stations for years 1990, 1995, 2000, 2005 and 2010.

Table 3.2: Total Rainfall values in mm of Beit Lahia, Gaza and Rafah station for years 1990, 1995, 2000, 2005 and 2010

Year Station	1990	1995	2000	2005	2010
Beit Lahia	533.5	679.5	391.5	320.6	246.0
Gaza	413	601.3	334.8	316.0	272.0
Rafah	268	487.3	198.5	360.2	141.7

3.6.2 Evapotranspiration

Evapotranspiration is equal to the sum of evaporation and transpiration, the monthly average evaporation over a period of 25 years in Gaza varied between maximum 173 mm in July and minimum of 63.4 mm in January with an annual average of 129.9 mm (Aish et. al., 2010). The reference evapotranspiration is a climatic index integrating the effect of air temperature, humidity, wind speed and solar radiation. In Gaza Strip reference evapotranspiration value varies from 2 to 3.03 mm/d in winter, and reaches its maximum value in summer at about 5.11 mm/d.

3.6.3 Temperature

Figure 3.6 presents the maximum, minimum and mean monthly air temperatures as observed in the meteorological station of Gaza city for the period lasting from 1976 until 2006. Temperature gradually changes throughout the year, reaches its maximum in July or August (summer) and its minimum in January or February (winter). The average daily mean temperature ranges from 26.5 C^o in summer to 13.8 C^o in winter, and the average daily maximum temperatures range from 31.9 C^o to 19.7 C^o, while minimum temperature from 21.2 C^o to 7.6 C^o in the summer and winter respectively.

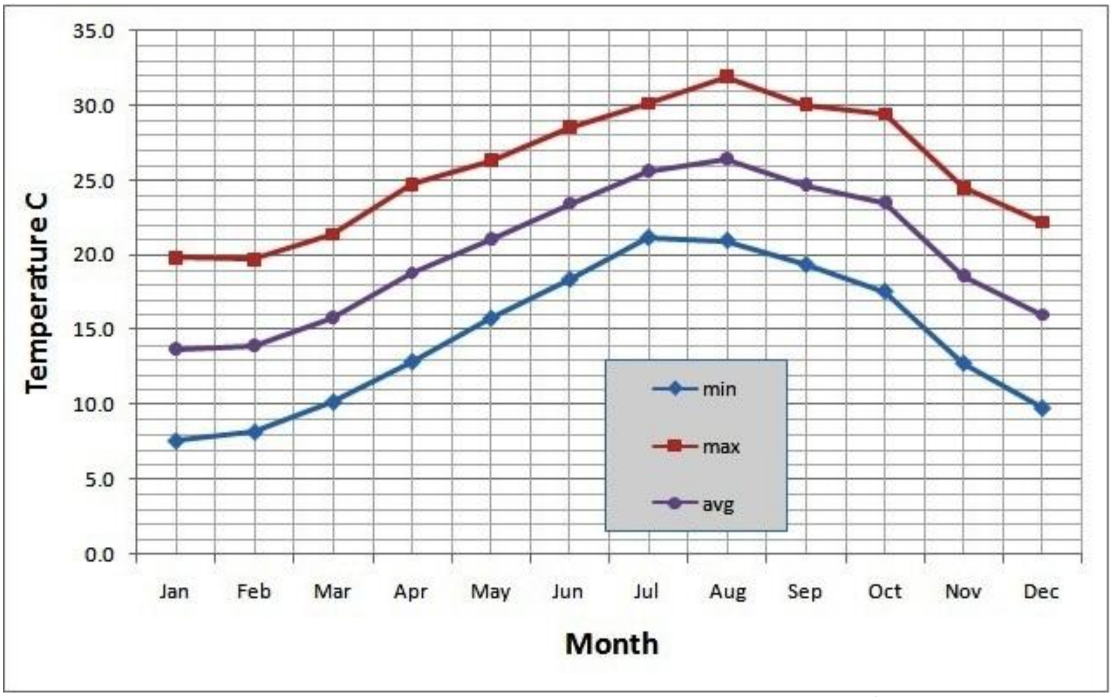


Figure 3.6 Mean monthly maximum, minimum and average temperature (C^o) for the Gaza Strip (period 1976 - 2006)

Figures 3.7 and 3.8 present the maximum and minimum values of temperature during the years 1976 -2006 respectively. Average daily maximum temperature values ranges from 31.9 to 28.1 C^o while average daily minimum values ranges from 12.2 to 7.6 C^o, and there is obvious decreasing trend for average daily maximum and minimum temperature values for years 1976 to 2006, this reflect clearly that there is climate change in temperature parameters.

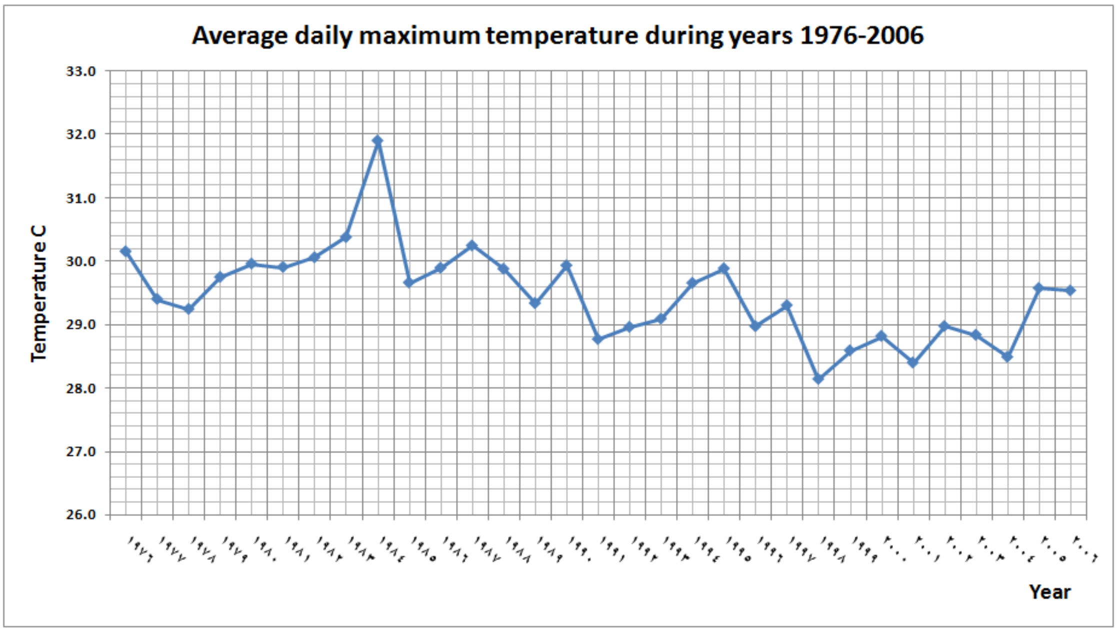


Figure 3.7 Average daily maximum temperatures (C^o) for the Gaza Strip (period 1976 - 2006)

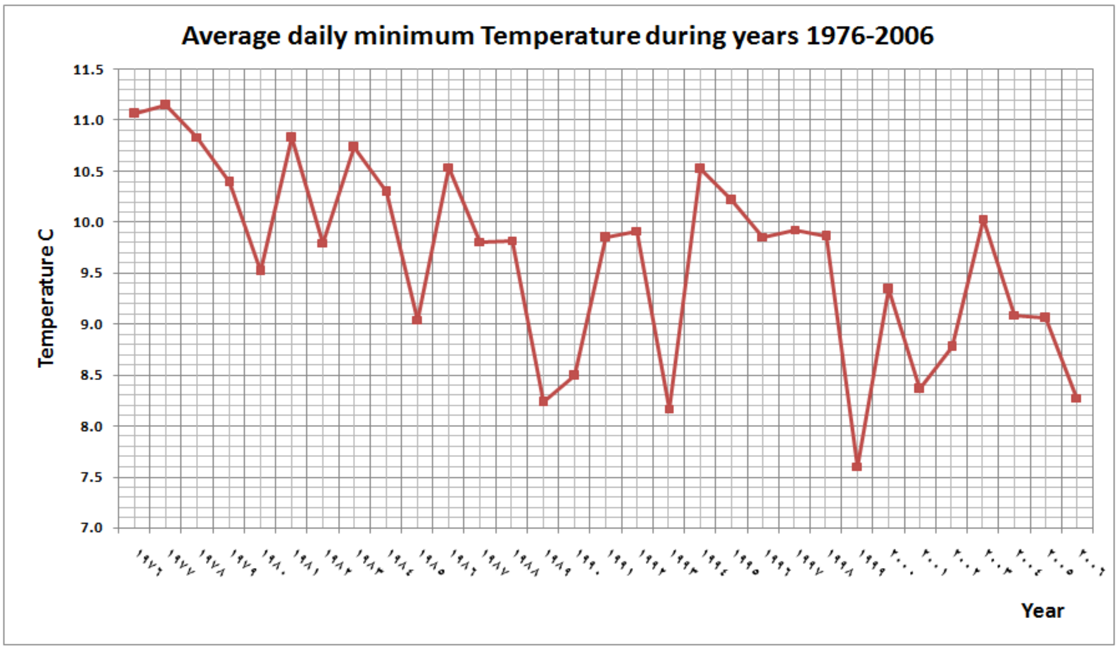


Figure 3.8 Average daily minimum temperatures (C^{o}) for the Gaza Strip (period 1976 - 2006)

3.6.4 Wind

The monthly average wind velocities in the last 16 years were in the range of 28.15 Km/hr. The highest was 38.82 Km/hr in 1992 and the lowest was 28 Km/hr in 1987. Wind directions ranged from 215 and 260 degrees from the north, analysis show that wind with velocities above 48 km/h occurred below 1% of the time (Al-Talmas et. al., 2012).

3.7 Aquifer

Gaza's water resources are essentially limited to that part of the coastal aquifer that underlies its small area (365km^2). The coastal aquifer is the only aquifer in the Gaza Strip and is composed of Pleistocene marine sand and sandstone, intercalated with clayey layers. The maximum thickness of the different bearing horizons occurs in the northwest along the coast (150m) and decreasing gradually toward the east and southeast along the eastern border of Gaza Strip to less than 10m. The base of coastal aquifer system is formed of impervious clay shade rocks of Neogene age (Saqiyah formation).

Depth to water level of the coastal aquifer varies between few meters in the low land area along the shoreline and about 80m along the southern eastern border.

The coastal aquifer holds approximately 5000 Mm^3 of groundwater of different quality. However, only 1400 Mm^3 of this is “freshwater”, with chloride content of less than 500 mg/l. This fresh groundwater typically occurs in the form of lenses that float on the top of the brackish and/or saline ground water. That means that approximately 70% of the aquifer is brackish or saline water and only 30% is fresh water.

The total rainfall recharge to the aquifer is estimated to be approximately $45m^3$/yr. The remaining rainwater evaporates or dissipates as run-off during the short periods of heavy rainstorms.

The layered stratigraphy of the Kurkar Group within the Gaza Strip subdivides the coastal aquifer into 4 separate subaquifers near the coast. Further east, the marine clays pinch out and the coastal aquifer can be regarded as one hydrogeological unit. The upper subaquifer “A” is unconfined, whereas subaquifers “B1, B2, and C” become increasingly confined towards the sea.

The thickness of the entire coastal aquifer sequence at the coastline is on average about 120 m. At the eastern Gaza border, the saturated thickness is about 60m in the north, and only 5-10 m in the south near Rafah. Localized perched conditions may exist in the unsaturated zone throughout the Gaza Strip, due to the presence of shallow fluvial and limnic clays.

The Transmissivity values of the upper 20-30m tested saturated part interval of the aquifer are ranging between 700 and 5,000 m^2/d. The corresponding values of hydraulic conductivity (K) are within a relatively narrow range, 20-80 m/d, with a few outliers greater than 100 m/d. Based on lithology and information from studies carried out in Israel, the specific yield of the unconfined coastal aquifer is in the 0.15-0.3 range.

3.8 Population

Gaza Strip is considered as one of the most densely populated areas all over the world. According to the Ministry of Interior (MoI) records in September 2012 the number of inhabitants of the Gaza Strip in 2012 is 1.8 million people, including more than 200 thousand new baby born during the past four years. In 2011 more than 929019 inhabitants were crowded in the Northern area of about 135 km^2. The natural rate of population growth in the Gaza Strip is estimated at 3.8% per year (MoI, 2011), the population is predominantly Sunni Muslim.

While the majority were born in the Gaza Strip, a large percentage identify as Palestinian refugees, fleeing to Gaza Strip as part of the 1948 Palestinian exodus following the Arab-Israeli War.

3.9 Water wells

There are an estimated 4,000 wells within the Gaza Strip. Almost all of these are privately owned and used for agricultural purposes. Approximately 110 wells are owned and operated by individual municipalities and are used for domestic supply. The average density of wells is about 5 per km^2. In some areas in north of Gaza city, the density of wells is greater than 20 per km^2.

There is significant uncertainty around historical pumping in Gaza; it is believed that large-scale abstraction started in the early 1960s, when agricultural development of the Gaza Strip began. Total groundwater abstraction in the Gaza Strip in recent years is estimated at 140 to 145 Mm3/yr. Agricultural abstraction is estimated to account for about 85 to 90 Mm^3/y, while municipal (55 Mm^3/y) and settlements (5 to 7 Mm^3/y) pump the remainder.

Agricultural wells are mostly drilled and installed as large diameter boreholes (less than 2.5 m) to the water table (using regular excavation techniques and placing caissons in the subsurface), and as drilled holes (less than 10-inch) thereafter to total depth. Most agricultural wells in Gaza are shallow and extend only a few meters (5 to 15) below the groundwater table, tapping almost exclusively Subaquifer “A”.

It is estimated that more than 3,900 agricultural wells are operational today. Agricultural wells have not been metered since 1994, and hence current production totals are not exactly known. About 1,500 wells were metered from about 1980 to 1993 during Israeli occupation. The Israeli Civil Administration recorded abstraction on a monthly, quarterly, and/or semi-annual basis.

The metered data from the Ministry of Agriculture (MOA) indicated that the total average annual abstraction for the 1,500 metered wells over the period of records (1988 to 1993) was approximately 43 Mm^3/y. Prorating this average to the estimated 3,900 wells in operation today yields an estimated total agricultural abstraction of about 85 to 90 Mm^3/y.

Municipal wells are deeper, and may tap Subaquifers A, B1, and B2 depending on location and distance from the coast. Municipal wells are typically screened throughout their lengths from the water table and down, and are not selectively screened across individual subaquifers. Hence, subaquifers are hydraulically connected in places (including near the coast). Detailed abstraction records have not been obtained for years prior to 1996. Based on Israeli reports from the 1970s, basic records on pump capacities, as well as information on typical pumping hours by season, it is estimated that municipal abstraction has increased from about 12 Mm^3/y in 1967 to 35 Mm^3/y in 1990, and 55 Mm^3/y in 2000. The number of municipal supply wells has also increased from about 40 in 1973 to 56 in 1993 to 110 in 2000.

There are about 35-40 or so known Israeli settlement wells within the Gaza Strip. Almost 30 wells were drilled inside Gush Qatif settlement, the largest settlement in the south. The abstraction records that have been obtained from Mekorot (Israeli Water Company) indicated that the annual total abstraction of the Israeli settlement wells is about 5 Mm^3/y.

3.10 Groundwater Flow regime

Regional groundwater flow is toward the Mediterranean Sea. However, natural flow patterns have been disturbed by pumping and artificial recharge. Within the Gaza Strip, large cones of depression have formed over the past 40 years within the Gaza, Khan Younis, and Rafah governorates.

Regional water levels have been lowered by several meters, and flow directions are impacted by major pumping centers in the south and near Gaza City. The total aquifer abstraction in the early-1970s is estimated to be about 100 Mm^3/y. The lowering of regional water tables has continued, and hydraulic gradients have been significantly reversed (from the sea) in the south and around Gaza City. Water levels around Gaza City and in the southern part are more than 2m and 5m below sea level respectively as a function of high total abstraction.

3.11 Water Quality

Ongoing deterioration of the water supply of Gaza poses a major challenge for water planners and sustainable management of the coastal aquifer. The aquifer is presently being overexploited, with total pumping exceeding total recharge. In addition, anthropogenic sources of pollution threaten the water supplies in major urban centers. Many water quality parameters presently exceed World Health Organization (WHO) drinking water standards. The major documented water quality problems are elevated chloride (salinity) and nitrate concentrations in the aquifer

More water was pumped from the aquifer than was recovered. This over extraction has resulted in draw down of the groundwater with resulting intrusion of seawater and up-coning the underlying saline water. The major water quality problems are high salinity and high nitrate concentrations in the aquifer.

3.11.1 Chloride concentration

Less than 10% of the aquifer's yield is water meeting the WHO drinking standard. High levels of chloride in the groundwater cause high salinity in the water supply. Some agricultural wells are currently reporting salinity levels of more than 1200 mg/l. Sources of high chloride content have been determined to be; sea water intrusion, lateral flow of brackish water from east in the middle and southern area and up-coning of the brine water from the base of the aquifer. Seawater intrusion and uplift the deep brine water are the direct consequences of over pumping, and represent the greatest threats to municipal and agricultural water supplies in the Gaza Strip. The lateral inflow of brackish water from the east is believed to be groundwater from the Eocene age rocks that underlie the coastal aquifer in the east and is therefore of natural origin.

Chloride concentrations in the monitored, shallow portions of the coastal aquifer are generally better in the north of the Gaza Strip than in the south. The relatively low values of chloride in the north, and demonstrates the shallow nature of wells that are sampled. This suggests that brackish water from Israel is flowing toward the northern well fields in Gaza city and Jabalya. The increasing chloride trends in the Khan Younis municipal well field are demonstrated by the deeper wells.

3.11.2 Nitrate concentration

Most municipal drinking wells in Gaza show nitrate level in excess of the WHO drinking water standard of 50 mg/l. In urban centers nitrate concentrations are increasing at rates up to 10 mg/l per year. The main sources on are domestic sewage effluent and fertilizers. In contrast to salinity, groundwater flowing from east has relatively low nitrate levels.

The extent to which the aquifer may be impacted by other pollutants such as organic chemicals, metals and pesticides has not been fully defined. A screening of total petroleum hydrocarbons (TPH) and Organo chlorine pesticides from 130 wells was conducted. None of the wells had a TPH level exceeding 1 mg/L, the detection limit for the analytical method used, even though floating oil product has been observed in several agricultural wells. Low levels of Organo chlorine pesticides were found in 5 agricultural wells and 8 municipal wells, primarily in the Khan Younis and Rafah areas.

3.12 Future Water Demand

Mainly the population growth and socio-economic development control water demand for the different uses.

Based on Ministry of Interior (MoI) records in September 2012, Gaza Strip population was recorded at 1,800,000 inhabitants with a growth rate of about 3.8% and assuming an influx of 50,000 returnees by 2010, the estimated population in 2020 will be over 2,425,780 inhabitants and forecast population of 3,522,288 inhabitants by 2030. This means that population is expected to be double after 19 years.

In 1999, it was estimated that a proximately 140 Mm^3/y of water was pumped from about 4000 wells. Of which, about 90 Mm^3/y of water uses was used for irrigation and 50 Mm^3/y were pumped for domestic and industrial from 90 municipal wells.

The World Health Organization (WHO) recommends an average of 100 liters per capita per day (L/c/d) as a minimum standard for individual water use. In 1999, it is estimated that 80 l/c/d were actually made available to consumers. On the other hand, only about 13 L/c/d meet WHO quality standards. As social development occurs, the demand for water will increase to meet the average WHO recommendation of 150 l/c/d in future years.

These facts make it evident that the Gaza Coastal Aquifer is in extreme danger of becoming unusable for drinking water and irrigation. Over exploitation of the aquifer has resulted in salt-water intrusion and continuous decline in groundwater levels has been observed in most of the areas of Gaza Strip since mid-1970s. The ability of the aquifer to sustain life for the increasing population and a basic agriculture industry will be destroyed in twenty years if no action will be taken.

3.12.1 Domestic and Industrial Water Demand (D&I):

Population growth, the changing water needs of households and industry and changing demands of agriculture will shape in the future (D&I) water demand.

The D&I demand include net demand for domestic, industrial, public customers and livestock water supply. Water losses through transmission pipeline and water distribution system are included. Therefore, D&I demand presents quantity of water at water supply source that should be delivered to the D&I customers. It is clear that the total D&I water needs will reach to about 182 Mm^3 by 2020 assuming an overall efficiency of water distribution of 20%.

3.12.2 Agricultural Water Demand:

If the demand for irrigation is calculated on the basis of the food requirements of the growing population, it appears that it will increase from the present usage of about 90 Mm^3/y to 185 Mm^3/y by 2020. However that figure is not realistic projection for Gaza, because neither the water nor the land to support an increase in agricultural activity exists. Fig.3 illustrates the continuing trend in decreasing the agricultural water demand reflecting the decrease use of both irrigated and rain fed agricultural land area in Gaza.

That is occurring as result of the growth of urban areas, which expand onto agricultural land. This encourages farmers to bring what had been marginal land into production. It also means that farmers are turning to more intensive methods of agriculture, which require expensive inputs. In general, there is a trend to select crops of less water needs.

Generally, the overall water demand in Gaza Strip is estimated to increase from present of about 145 Mm^3/y to about 260 Mm^3/y in 2020, as shown in Figure 3.7. This includes D&I demand at water supply source and agricultural demand.

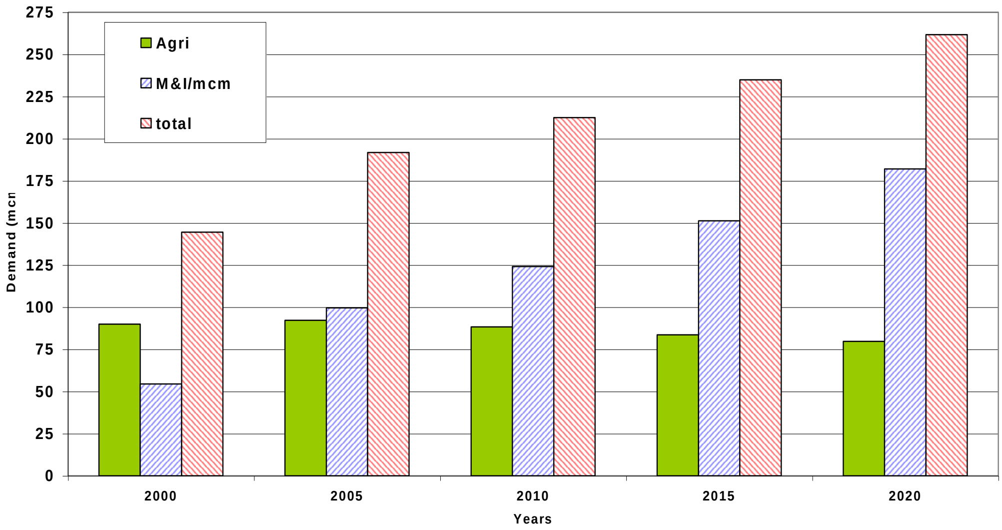


Figure 3.9 Overall Water Demand in Gaza until the Year 2020 (Yaqoubi, 2007)

The effect on the water balance in the aquifer without any water resources management is dramatically illustrated in Figure 3.8. The figure shows that the water deficit will reach to about 100 Mm^3/y by year 2020. The results will be continuing water level decline and water quality deterioration through seawater intrusion and saline water up coning.

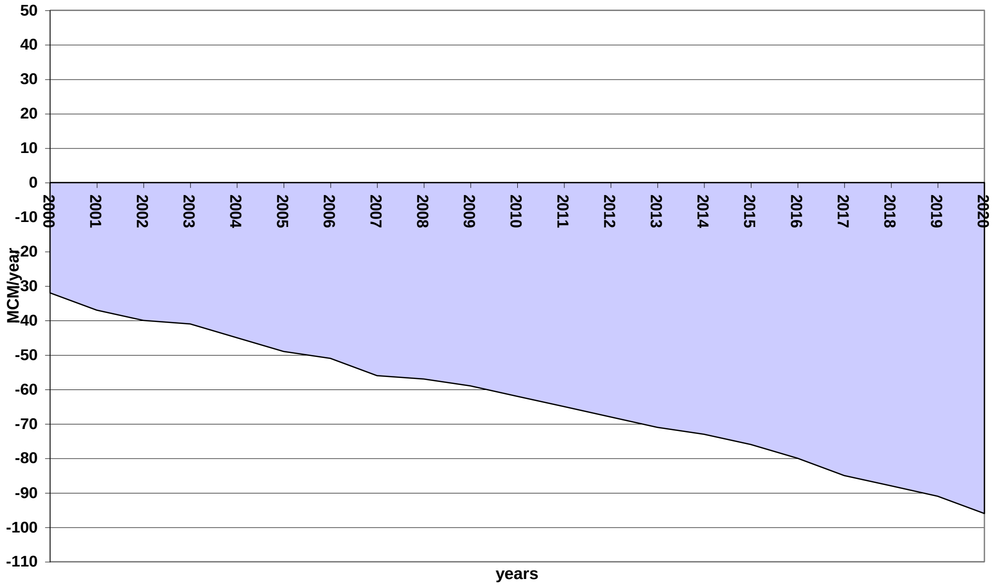


Figure 3.10 Overall Aquifer Balance without water resources management (PWA 2003)

3.13 Palestinian Water Resources Policy:

Water resources must be developed and managed efficiently in order to meet present and future water needs, in an environmentally sustainable way. Wastewater reclamation and reuse, desalination and storm water recharge together with renewable aquifer capacity will provide quantity of the water that would satisfy water demands in the Gaza Strip for the next 20-years. However, comprehensive aquifer protection is necessary to maintain its sustainable capacity. Certain aspects of water demand management and water quality management should be considered to support management of the aquifer at its sustainable capacity (PWA, 2003).

The Palestinian Water Authority (PWA) has considered the following three principal objectives for sustainable water resources management:

a. Provide quantity and quality of water for domestic purpose in compliance with WHO standards.

b. Supply adequate quality and sufficient quantity of water that is required for the planned agricultural production in Gaza Strip.

c. Managing the Gaza Coastal Aquifer at its safe yield and preventing further deterioration of the aquifer water quality.

Accomplishment of those principal objectives is based on the following fundamental promises:

a. Reclamation of wastewater and maximum use of the reclaimed water for agriculture.

b. Introduction of new water resource(s) into the Gaza Strip water sector as soon as possible to meet the projected water demands.

c. Improve pumped groundwater quality needed for domestic use by desalination facilities.

The aquifer must remain the backbone resource for supplying water to the Gaza Strip. Over-drafting has led to a dramatic deterioration in the aquifer's water quality and immediate limits must be placed on extraction. In addition to meet the increased overall water demand and to reverse the process of saltwater intrusion, sustainable quantities must be added to the water cycle and wastewater should be used to the extent feasible.

Successful implementation of those issues will be able to maintain water balance and prevent further deterioration of the aquifer. In parallel, clear and precise legislation and strict water sector implementation policies are must for successful implementation.

CHAPTER 4

RESEARCH METHODOLOGY

CHAPTER 4: RESEARCH METHODOLOGY

Research methodology consists of four parts as shown in Figure 4.1:

4.1 Preparing data:

Understanding climate condition history and prepare climate parameters input data as follows:

1- Collecting data about Gaza climate condition history from relevant institution, ministries, libraries and internet.

2- Revision of accessible references as books, studies and researches relative to the topic of this research.

3- Build up landuse, rainfall, wind-speed, temperature, potential evapotranspiration, and groundwater depth grid maps for summer and winter seasons of years 1990, 1995, 2000, 2005 and 2010.

4- Prepare soil, slope and topography maps in addition to Landuse, Soil, and Runoff Parameters for the above years.

4.2 WetSpass model:

Simulating the seasonal and annual recharge in *Water and Energy Transfer between Soil, Plants and Atmosphere Under quasi Steady State* (WetSpass model) based on present situation as follows:

1- Run WetSpass model and get Recharge for the 5th years.

2- inspect the accuracy of calculating and study Error maps values.

3- Studying the relation between outputs_ (recharge) and the most sensitivity input Rainfall.

4.3 MODFLOW Program:

Studying the groundwater state using *Modular Groundwater Flow Model* (Visual Modflow 4.2) as follows:

1- Setting up a groundwater level model. Calibration of this model with head data and discharge.

2- Simulation of the groundwater head distribution as well as identification of groundwater discharges (location and fluxes).

3- Determining of groundwater fluxes and shallow table conditions.

4- Input the observed head wells data and calibrate the model for years 2005 and 2010.

5- Simulate recharge and studying the groundwater state for years 2015, 2020, 2025 and 2030.

4.4 Prediction of future scenarios:

Assume two scenarios of recharge for the future years 2015, 2020, 2025 and 2030 as a consequence of climate change and study the groundwater table state for each one in order to represent all controversial but realistic predictions of climate change.

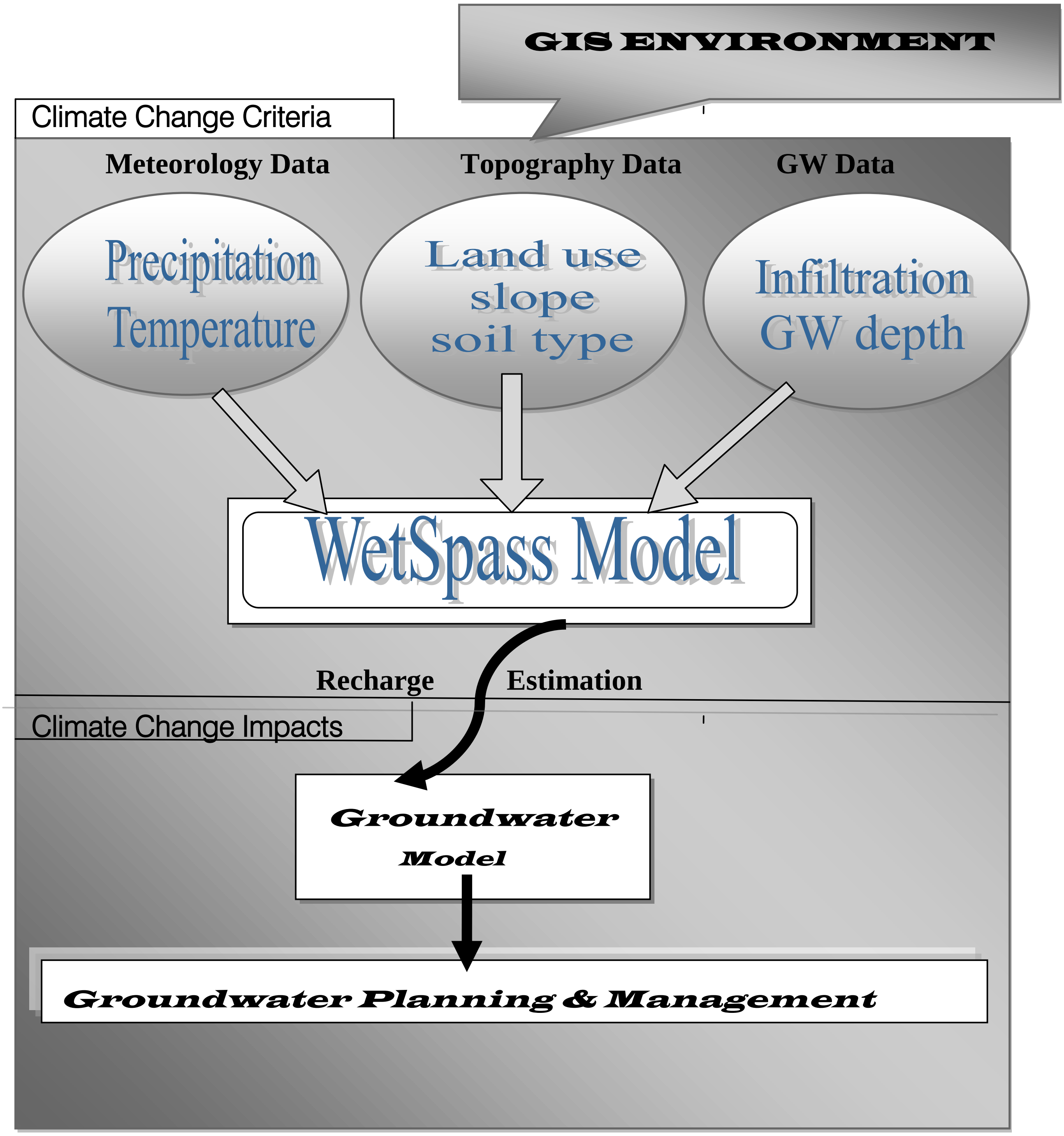


Figure 4.1 Schematic representation of the iteration process in the WetSpass & MODFLOW models

4.5 Groundwater modeling

Groundwater model is a representation of reality and, if accurately constructed, it can be an important predictive tool used for management of groundwater resources. A mathematical model simulates groundwater flow indirectly by means of governing equation that represents the physical processes that occur in the system, together with equations that describe heads or flows along the boundaries of the model. For time-dependent problems, an equation describing the initial distribution of heads in the system is also needed.

4.5.1 General groundwater flow equations

Differential equations that govern the groundwater flow can essentially represent the groundwater flow system derived from the basic principles of groundwater flow hydraulics. The main flow equation for saturated groundwater flow is derived by combining a water balance equation with Darcy's law, which leads to a general form of the 3-D groundwater flow governing equation:

$$\partial \frac{d}{dx}(K_x \frac{\partial h}{\partial x}) + \frac{d}{dy}(K_y \frac{\partial h}{\partial y} + \frac{d}{dz}(K_z \frac{\partial h}{\partial z} + R(x,y,z) = S_s \frac{\partial h}{\partial t} \qquad (2.1)$$

Where K_x ,K_y and K_z, are the hydraulic conductivity components in the x, y and z direction (LT^{-1}), h is the hydraulic head (L), R is the local source or sink of water per unit volume (T^{-1}), S_s is the specific storage coefficient (L^{-1}) and t is the time (T).

Darcy's law

In differential form, Darcy's law is expressed as:

$$q = - K. \text{grad } (h) \qquad (2.2)$$

where q is the groundwater flux (LT^{-1}), K is the conductivity tensor (LT^{-1}) and grad (h) is the gradient operator. This equation clearly shows that the cause of groundwater movement is the difference in the hydraulic potential. The potential is a function of all three space coordinates, that is h = h(x, y, z), the rate of change of head with position giving the gradient, which multiplied by the conductivity yields the groundwater flux (Wang et. al., 1982). The hydraulic conductivity is represented by a second order tensor that takes into account anisotropic conditions. Usually, anisotropy is only considered in the vertical and horizontal direction, hence

$$q_x = -K_x \frac{\partial h}{\partial x} \tag{2.3a}$$

$$q_y = -K_y \frac{\partial h}{\partial y} \tag{2.3b}$$

$$q_z = -K_z \frac{\partial h}{\partial z} \tag{2.3c}$$

Where q_x, q_y, q_z are the three components of the flux, and K_x, K_y, K_z the hydraulic conductivity values in the horizontal (x, y) and vertical (z) direction. In case of isotropic conditions, $K_x = K_y = K_z$ each component of q is the same scalar multiple K of the corresponding component of -grad (h), such that the vectors q and -grad (h) both point in the same direction.

4.6 Groundwater modeling software

Groundwater flow equations are usually not easy to solve analytically. This is because either the flow is described by a partial differential equation or usually the medium properties are heterogeneous. In such cases, numerical solution techniques can be used to obtain approximations. Two major classes of numerical methods have been accepted for solving the groundwater flow equation. These are finite difference methods and finite element methods. Each of these includes a variety of subclasses and implementation alternatives.

4.6.1 Modflow tools

Modflow is a finite-difference groundwater flow modeling program, written by the United States Geological Survey (USGS). Modflow is the name that has been given the USGS Modular Three-Dimensional Groundwater Flow Model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, Modflow has become the worldwide standard groundwater flow model. Modflow is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, Modflow is the recognized standard model used by courts, regulatory agencies, universities, consultants and industry.

Modflow allows you to develop a numerical representation (i.e. a groundwater model) of the hydrogeologic environment at a field site that you are investigating. It uses the finite-difference method to divide the groundwater flow model domain into a series of rows, columns and layers, which defines a unique set of grid blocks (i.e. model cells) to represent the distribution of hydrogeologic properties and hydrologic boundaries within the model domain. When you develop a groundwater model, you assign properties and boundaries to these model cells, and Modflow uses the cell dimensions, property values and boundary values to write a set of finite-difference equations that it solves to calculate the hydraulic head at the center of each model cell (McDonald et. al., 2003).

The main objectives in designing Modflow were to produce a program that can be readily modified, is simple to use and maintain, can be executed on a variety of computers with minimal changes, and has the ability to manage the large data sets required when running large problems. The Modflow report includes detailed explanations of physical and mathematical concepts on which the model is based and explanations of how those concepts were incorporated in the modular structure of the computer program. The modular structure of Modflow consists of a Main Program and a series of highly-independent subroutines called modules. The modules are grouped in packages. Each package deals with a specific feature of the hydrologic system which is to be simulated such as flow from rivers or flow into drains or with a specific method of solving linear equations which describe the flow system such as the Strongly Implicit Procedure or Preconditioned Conjugate Gradient. The division of Modflow into modules permits the user to examine specific hydrologic features of the model independently. This also facilitates development of additional capabilities because new modules or packages can be added to the program without modifying the existing ones. The input/output system of Modflow was designed for optimal flexibility.

Although Modflow was designed to be easily enhanced, the design was oriented toward additions to the ground-water flow equation. Frequently there is a need to solve additional equations; for example, transport equations and equations for estimating parameter values that produce the closest match between model-calculated heads and flows and measured values (McDonald et. al., 2003).

4.6.1.1 Visual MODFLOW

The visual Modflow interface is divided into three modules, the Input Module, the Run Module, and the Output Module. The input Module provides users with the ability to create a graphical three-dimensional representation of the study area. The modeler can assign values directly to the study area and the software creates the appropriate files. The Run Module allows the user to alter the parameters and options that are run specific, such as the solver package, recharge and rewetting applications and the tolerances for convergence. The Output Module provides the user with the ability to display all of the modeling and calibration results. Although Visual Modflow graphically represents the study area, the inputs, and the outputs, the files are translated and processed by the version of Modflow 2000 (Harbaugh et. al., 2000).

4.6.1.2 MODPATH

MODPATH is an extension of Modflow to calculate flow paths and travel times of water particles. The model was also developed by USGS. Simulation results obtained with Modflow are used as input to MODPATH. The streamlines and travel times of water particles can be calculated starting from the groundwater flow velocities using Darcy’s law.

4.6.1.3 MT3D

MT3D is a model for the simulation of pollutant transport. MT3D stands for “Mass Transport in 3 Dimensions”. The model was developed by the US Environmental Protection Agency (EPA) as an extension of Modflow. Using simulation results of Modflow, MT3D will predict the fate of chemicals dissolved in the groundwater in function of advection, dispersion, absorption and decay. Hence, the model uses output files from Modflow as input for obtaining the groundwater flows. Boundary conditions for transport can be added together with dispersive and absorptive properties of the ground layers, as well as chemical reaction characteristics. There are several extensions and improvements of MT3D available, as for instance:

RT3D: a pollutant transport model for specific pollutants as hydrocarbons that transform into other chemicals or are subjected to more complicated decay processes as in MT3D.

MT3DMS is an extension of MT3D for the solution of simultaneous transport of different interacting chemicals. The code also allows for kinetic absorption processes, instead of instantaneous equilibrium as described by absorption isotherms (De Smedt, 2003).

4.7 Geographic Information System (GIS) tools

4.7.1 Arc-View

ArcView is the entry level licensing level of ArcGIS Desktop, a geographic information system software product produced by Esri. It is intended by Esri to be the logical migration path from ArcView 3.x. The use of (GIS) provides a powerful and efficient means of data preparation and visualization of simulation results. Arc-View was used for basic spatial data management tasks (data storage, manipulation, preparation, extraction, etc.) and spatial data processing (Batelaan et. al., 2007).

4.7.2 WetSpass Model

Linking GIS and the distributed hydrological model is of rapidly increasing importance in studying the impact of human activities on hydrological behaviours in basins. For the estimation of long-term spatial patterns of the groundwater recharge, that could be used as input in regional groundwater flow models and for the analysis of regional groundwater flow systems, a simplified model "WetSpass" was developed by Batelaan et. al., 2001 based on the time dependent spatially distributed water balance model called "WetSpa" model.

WetSpa is a physically based and distributed hydrological model for predicting the Water and Energy Transfer between Soil, Plants and Atmosphere on regional or basin scale and daily time step developed in the Vrije Universiteit Brussel, Belgium (Wang et al., 1997 and Batelaan et al., 1996).

WetSpass stands for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State (Batelaan et. al., 2001). It is a physically based model for the estimation of long-term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration employing physical and empirical relationships. Regional groundwater models used for analyzing recharge-discharge relations are often quasi-steady and need long-term average recharge input that accounts for the spatial variability of the recharge. Thus, they can use the recharge output from WetSpass for their computations. WetSpass is specially suited for studying long-term effects of land-use changes on the water regime in a watershed. It is handy in that it allows easy new definition of climatic as well as land use types.

4.7.2.1 WetSpass Input Data

WetSpass requires a combination of ArcView/ArcInfo grid files and tables (dbf files) as input, which is listed below:

Table 4.1: WetSpass Input data

ArcView/ArcInfo Grid files	Tables (dbf)
• Soil • Topography • Slope • Land-use (summer and winter) • Temperature (summer and winter) • Precipitation (summer and winter) • PET (summer and winter) • Wind-speed (summer and winter) • Groundwater depth (summer and winter)	• Soil parameter • Runoff Coefficient • Land-use parameter (summer and winter)

Inputs for this model include grids of landuse, groundwater depth, precipitation, potential evapotranspiration, wind-speed, temperature, soil, and slope where by parameters such as land-use and soil types are connected to the model as attribute tables of their respective grids. The spatially distributed recharge output of WetSpass model can improve the prediction of simulated groundwater level and the locations of discharge and recharge areas for a steady-state groundwater model. In this case, WetSpass and the groundwater model perform simulations one after the other, while exchanging inputs of groundwater and recharge values respectively. This results in a stable solution for the groundwater level and discharge areas.

Originally this exchange of data was performed manually, but later on a WetSpass-Modflow interface was developed to facilitate the job (Kassa, 2001),

WetSpass model uses long-term average climatic data together with an elevation, land use and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area. This model is fully integrated or embedded in the GIS ArcView (version 3.x). Parameters, such as land-use and related soil type, are connected to the model as attribute tables of the land-use and soil raster maps. This allows for easy definition of new land-use or soil types, as well as changes to the parameter values. Input files unit are shown in Annex 1 (Table A-7).

4.7.2.2 WetSpass model calculations

Since the model is a distributed one, the water balance computation is performed at a raster cell level. Individual raster water balance is obtained by summing up independent water balances for the vegetated, bare soil, open- water, and impervious fraction of a raster cell Eq. 2.4, 2.5, 2.6). The total water balance of a given area is thus calculated as the summation of the water balance of each raster cell.

Water Balance Calculation

The water balance components of vegetated, bare-soil, open-water, and impervious surfaces are used to calculate the total water balance of a raster cell as briefly mentioned earlier,

$$ET_{raster} = a_v ET_v + a_s E_s + a_o E_o + a_i E_i \qquad (2.4)$$

$$S_{raster} = a_v S_v + a_s S_s + a_o S_o + a_i S \qquad (2.5)$$

$$R_{raster} = a_v R_v + a_s R_s + a_o R_o + a_i R_i \qquad (2.6)$$

Where ET_{raster}, S_{raster}, R_{raster} are the total evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having a vegetated, bare-soil, open-water and impervious area component denoted by a_v, a_s, a_o, and a_i, respectively. The computation of each component's water balance is discussed in the following sections (Batelaan et. al., 2001).

Vegetated Area

The water balance for a vegetated area depends on the average seasonal precipitation (P), interception fraction (I), surface runoff (S_v), actual transpiration (T_v), and groundwater recharge (R_v) all with the unit of [LT^{-1}], with the relation given below

$$P = I + S_v + T_v + R_v \qquad (2.7)$$

Landuse parameters and its abbreviation are shown in Annex 1 (Tables A-6 and A- 2) respectively.

Interception

Depending on the type of vegetation, the interception fraction represents a constant percentage of the annual precipitation value. Thus, the fraction decreases with an increase in an annual total rainfall amount (since the vegetation cover is assumed to be constant throughout the simulation period).

Surface runoff

Surface runoff is calculated in relation to precipitation amount, precipitation intensity, interception and soil infiltration capacity. Initially the potential surface runoff ($S_{v\text{-}pot}$) is calculated as

$$S_{v-pot} = C_{sv} (P - 1) \qquad (2.8)$$

Where, C_{sv} is a surface runoff coefficient for vegetated infiltration areas, and is a function of vegetation, soil type and slope. Saturated surface runoff occurs in groundwater discharge areas giving rise to a very high surface runoff coefficient. This is due to the reduced dependency on soil, vegetation type and the vicinity of the area to the river, the coefficient is here usually assumed to be constant.

In the second step, actual surface runoff is calculated from the Sv-pot by considering the differences in precipitation intensities in relation to soil infiltration capacities.

$$S_v = C_{Hor} \, S_{v-pot} \qquad (2.9)$$

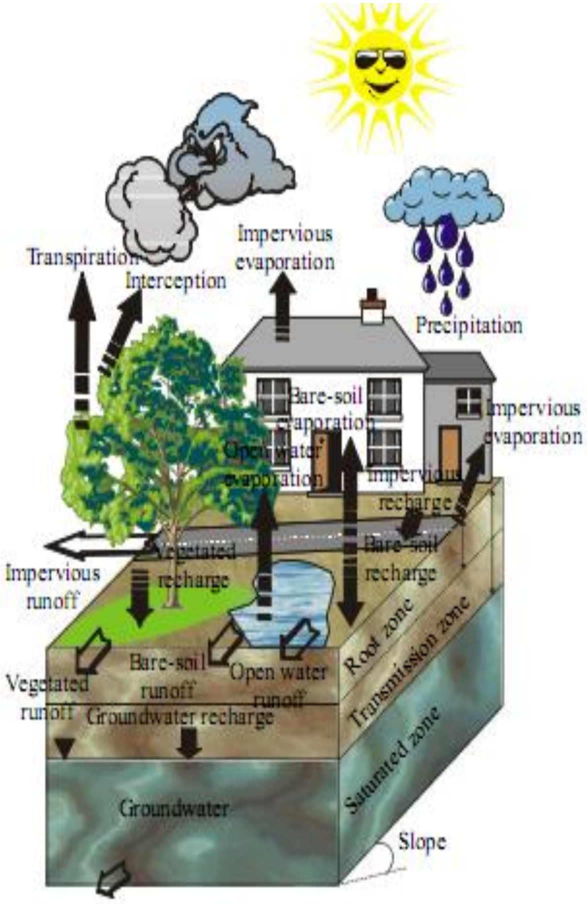


Figure 4.2 Schematic representation of water balance of a hypothetical raster cell after Batelaan and De Smedt (2001)

Where C_{Hor} is a coefficient for parameterizing that part of a seasonal precipitation contributing to the Hortonian overland flow. C_{Hor} for groundwater discharge areas is equal to 1.0 since all intensities of precipitation contribute to surface runoff. Only high intensity storms can generate surface runoff in infiltration areas (Batelaan et. al., 2001).

Surface runoff coefficient parameters files are shown in annex 1 (Table A-5).

Evapotranspiration

For the calculation of seasonal evapotranspiration, a reference value of transpiration is obtained from open-water evaporation and a vegetation coefficient:

$$T_{rv} = c E_o \qquad (2.10)$$

T_{rv} = the reference transpiration of a vegetated surface $[LT^{-1}]$;

E_o = potential evaporation of open water $[LT^{-1}]$ and

c = vegetation coefficient [–], can be calculated from Penman-Monteith equation.

Recharge

The last component, the groundwater recharge, is then calculated as a residual term of the water balance, i.e.

$$R_v = P - S_v - ET_v - I \qquad (2.11)$$

ET_v is the actual evapotranspiration [LT^{-1}] given as the sum of transpiration T_v and E_s (the evaporation from bare soil found in between the vegetation).

The spatially distributed recharge is therefore estimated from the vegetation type, soil type, slope, groundwater depth, and climatic variables of precipitation, potential evapotranspiration, temperature, and wind-speed. In addition, there will be some recharge associated with discharge areas owing to the concept that there is a thin unsaturated zone present even in discharge areas. In the summer season, however, there is high potential transpiration due to vegetation and this result in negative recharge values in discharge areas. In some cases, high winter recharge will compensate the negative recharge values.

There are two ways of incorporating change in storage to the model on a seasonal basis. The first instance is that the plant available soil moisture reservoir in the winter is assumed to be filled up while it can be depleted in the model in the summer; the second case is that in the model a different groundwater depth can be used for winter and summer (Batelaan et. al., 2001).

Bare-soil, Open-water, and Impervious surfaces

A similar procedure as that for the vegetated surfaces is followed for the calculation of the water balance for bare-soil, open-water, and impervious surfaces. The only difference is that there is no vegetation in these cases and thus there is no interception and transpiration term. The ET_v in this case becomes E_s. Abbreviation soil parameters names and soil parameters are shown in Annex 1 (Tables A-3 and A-4) respectively.

4.7.2.3 WetSpass model Applications

WetSpass was used for the analysis of the effect of landuse changes on the groundwater discharge areas for Grote Nete basin, Belgium (Batelaan et al, 2001, Batelaan et al., 2007). WetSpass recharge outputs for the Dijle, Demer and Nete river basins were used as an input for the groundwater model. Total discharge and surface runoff and base-flow, were used for the calibration of the WetSpass water balance components. The associated groundwater model was also calibrated along with the WetSpass calibration. Lastly, the resulting groundwater discharge areas were verified by mapped phreatophytes.

WetSpass was also used in the analysis of the hydrological characteristics of the Kikbeek sub-basin of the Border Meuse River, Belgium (Van Rossum et al., 2001). In the study, fast and slow discharge coefficients were calculated from WetSpass output data as these discharge coefficients are related to the total surface runoff and groundwater recharge respectively. By using the WetSpass model of the actual hydrological situation in the Kikbeek sub-basin as a starting point, the sensitivity of the discharge coefficients of the Kikbeek sub-basin towards climate and landuse changes was analyzed. Numerous climate and landuse scenarios were used and the geographical input data of the present situation was adjusted for their simulations by WetSpass.

WetSpass model also applied to a land-use planning project in the Grote-Nete basin, Belgium (Batelaan et. al., 2003). Discharge regions are delineated on the basis of their spatial discharge contiguity, position in the landscape and alkalinity of the plants habitat. The simulated discharge areas are verified by field mapping of phreatophytic vegetation. Particle tracking is used to delineate the recharge area associated with each discharge area, and to characterize each recharge–discharge groundwater system. Three groundwater flow and two vegetation parameters are used in a cluster analysis to obtain four different clusters of groundwater discharge systems.

The spatial variation in the recharge due to distributed land-use, soil type, slope, groundwater level, meteorological conditions, etc. should be accounted for. Hence, WetSpass model was used for estimation of the long-term average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge was developed; this methodology was WetSpass model (Batelaan et. al., 2001).

The surface runoff S is calculated from the slope, soil type, land-use and precipitation intensity ratio, while ET is calculated from potential evapotranspiration, soil moisture storage capacity and soil cover. The model has been integrated with Arc/Info (Asefa et al., 2000) and ArcView (Batelaan et al., 2001).

The calibration of the Modflow and WetSpass models is based on comparison of observed and calculated groundwater levels as well as on the surface and groundwater balance of the basin.

The results indicate the sensitivity and impact of the changes on the recharge and discharge areas, and groundwater discharge fluxes. The impact of the changes for the different areas for both the predevelopment and the future situation appears to differ from large decrease to large increase in total groundwater discharge.

Dams et. al., 2008 used WetSpass model to assess the impact of land-use changes, from 2000 until 2020, on the hydrological balance and in particular on groundwater quantity, as results from a case study in the Kleine Nete basin, Belgium. New is that this study tests a methodology, which couples a land-use change model with a water balance and a steady-state groundwater model. Four future land-use scenarios (A1, A2, B1 and B2) based on the Special Report on Emission Scenarios (SRES) were modeled with the CLUE-S model. Water balance components, groundwater level and baseflow were simulated using the WetSpass model in conjunction with a steady-state MODFLOW groundwater flow model. Results show that the average recharge decreases with 2.9, 1.6, 1.8 and 0.8% for scenario A1, A2, B1 and B2, respectively, over the 20 covered years. The predicted reduction in recharge results in a small decrease of the average groundwater level in the basin, ranging from 2.5 cm for scenario A1 to 0.9 cm for scenario B2, and a reduction of the baseflow with maximum 2.3% and minimum 0.7% for scenario A1 and B2, respectively. Although these averages appear to indicate small changes in the groundwater system, spatial analysis shows that much larger changes are located near the major cities in the study area. Hence, spatial planning should take better account of effects of land-use change on the groundwater system and define mitigating actions for reducing the negative impacts of land-use change.

4.7.3 ARCVIEW Interface for WetSpass and Modflow

The hydrological cycle is so complex that it is practically impossible to devise one system that can describe all its processes to a satisfying degree of detail. Therefore, the components of the cycle are treated separately to achieve a reliable representation of the components. But decisions related to water management cannot be made solely based on the result of one component and thus the need arises for the integration of the different components. Taking this into consideration an attempt has been made to loosely couple WetSpass (Batelaan et. al., 2001) and MODFLOW (McDonald et. al., 1988) models through the use of ArcView (GIS software) for an accurate representation of regional groundwater systems. The results of such integration can help in the better understanding of groundwater flow systems.

For the ease of inputting data and facilitating integration processes, dialogs have been developed in the ArcView interface. To have access to these dialogs, the WetSpass_MODseasonal extension has to be loaded first through the usual File/Extension menu of the ArcView interface. The Spatial Analyst and Dialog designer extensions need to be loaded for the proper functioning of the Model.

Integrating WetSpass and Modflow plays an important role in understanding the groundwater flow characteristics that will be used as a decision support system (DSS) for water resource management. For example, the result of such integrated model can be easily used in identifying recharge (infiltration) areas of wetlands for restoring the wetland ecosystem (Batelaan et al., 2001).

Asefa (1998) integrated WetSpass with the GIS ARC/INFO in an Open Development Environment (ODE) on UNIX Working Station. To facilitate the models pre- and post-processing, a menu driven graphical user interface has been developed using OSF/Motif and C. The interface allows model input, and output to be created, stored and displayed with in ARC/INFO-ODE.

Gebremeskel (1999) extended the WetSpass interface by adding Modflow in the GIS ARC/INFO ODE. In addition to facilitating the models pre-and post-processing, the interface facilitate linkage between the two models by allowing usage of groundwater discharge of WetSpass as an input to the groundwater simulation model Modflow. The interface also converts the ASCII output of MODFLOW into grid using ASCIIGRID function of ARC/INFO, and display the result graphically.

Later, an improved WetSpass version and Modflow were loosely coupled in ArcView (Kassa, 2001). Using AVENUE, programming language of ArcView, the GIS software ArcView (ESRI 1994) was customized to serve as an interface for the two models. The interface was developed specifically for facilitating and automating the integration processes in addition to building model input data sets as well as viewing and manipulating model results.). The integration is done by running the models one after the other with continuous communication of input data. Thus, the output of MODFLOW run, groundwater depth, is used as an input for WetSpass and the recharge output of WetSpass is used as an input for Modflow for the calculation of new groundwater depth. The model has three principal components: WetSpass embedded in GIS ArcView, Modflow linked to GIS ArcView, and loose link between WetSpass and Modflow. The governing water balance equation is embedded into GIS as intrinsic function. In addition, all model inputs and outputs are in GIS grid format. Thus, there is no need for data conversion. Parameters such as land-use and related soil type are connected to the model as attribute tables of the land use and soil raster maps allowing for an easy change of parameter values and definition of new land-use or soil types.

CHAPTER 5

RESULTS AND DISCUSSIONS

CHAPTER 5: RESULTS AND DISCUSSIONS

The output of our research is divided into two parts:

First part is to simulate the recharge values that infiltrate the aquifer by WetSpass model, and the second part is to use recharge values in Groundwater program (VISUAL Modflow 4.2) in order to get head values, that's will lead to study climate change effects on groundwater resources (our research aim).

5.1 WetSpass Model

The first part that concerned WetSpass model was prepared for all Gaza strip area, climatic parameters data like precipitation, potential evapotranspiration, soil, topography, slope, landuse, temperature and groundwater depth was prepared as a GRID files, otherwise soil parameter, runoff coefficient and landuse parameters was prepared as a DATABASE files. All of above was set for summer and winter seasons and for sample years 1990, 1995, 2000, 2005 and 2010.

The model was run for these five years, and the model output grids include 3 sets of results where each set includes seven grids. The first set is the winter output while the second and third sets are for the summer and yearly cases. The output grids are Runoff, Evapotranspiration, Interception, Transpiration, Soil evaporation, Recharge and Error.

Figures 5.1, 5.2, 5.3, 5.4 and 5.5 show rainfall values at the right side and recharge values obtained from WetSpass model at the left side for years 1990, 1995, 2000, 2005 and 2010 respectively. These figures show that maximum rainfall in year 1990 was 572.9mm; it increases to 679.5mm in year 1995, then its decreases to values 426.69, 404.9, and 272.3mm in years 2000, 2005 and 2010 respectively.

The recharge was calculated using the WetSpass model for the same year; the recharge maps for 1990, 1995, 2000, 2005 and 2010 presented below in Figures 5.1, 5.2, 5.3, 5.4 and 5.5 respectively. It's worthy to say that the trend rainfall values take is similar to that recharge values obtained from the model. The maximum value of recharge in 1990 was 275.03mm, it increases to 389.4mm in year 1995, and then it decreases to values 195.97, 144.45, 62.67mm in years 2000, 2005 and 2010 respectively. This reflects the change of the climate which led to the change of the rainfall and consequently changes in the recharge quantities.

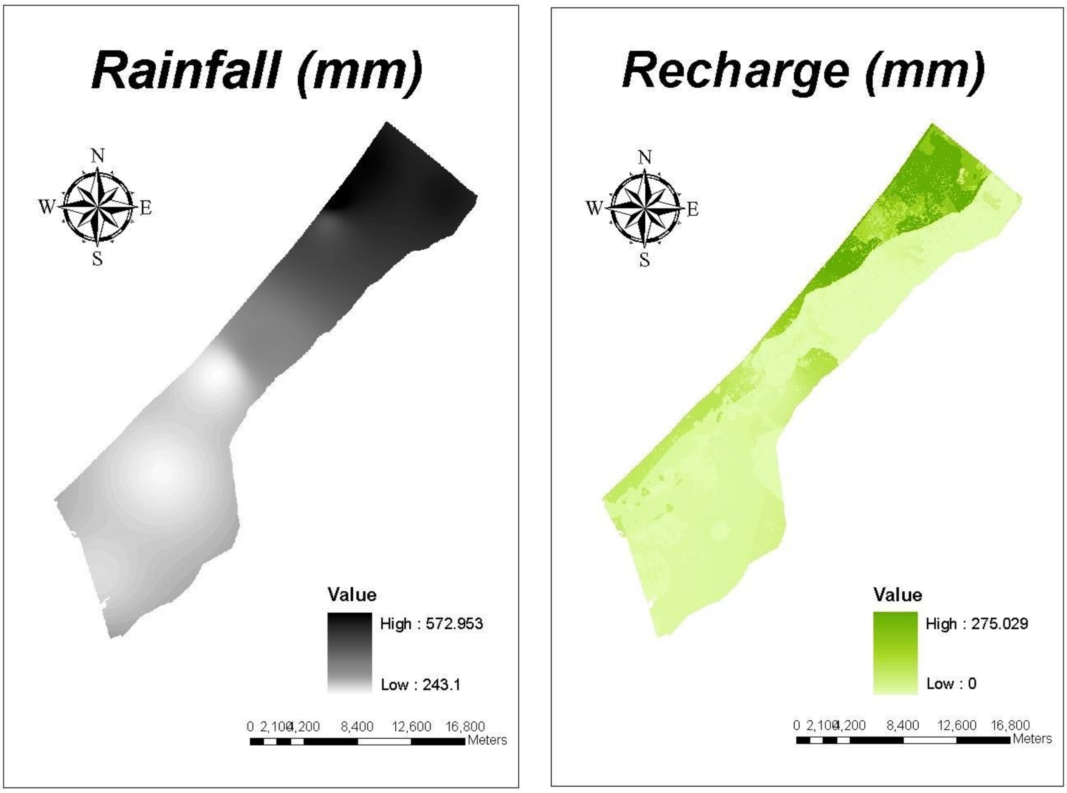


Figure 5.1 Annual groundwater recharge, calculated by the WetSpass model for year 1990

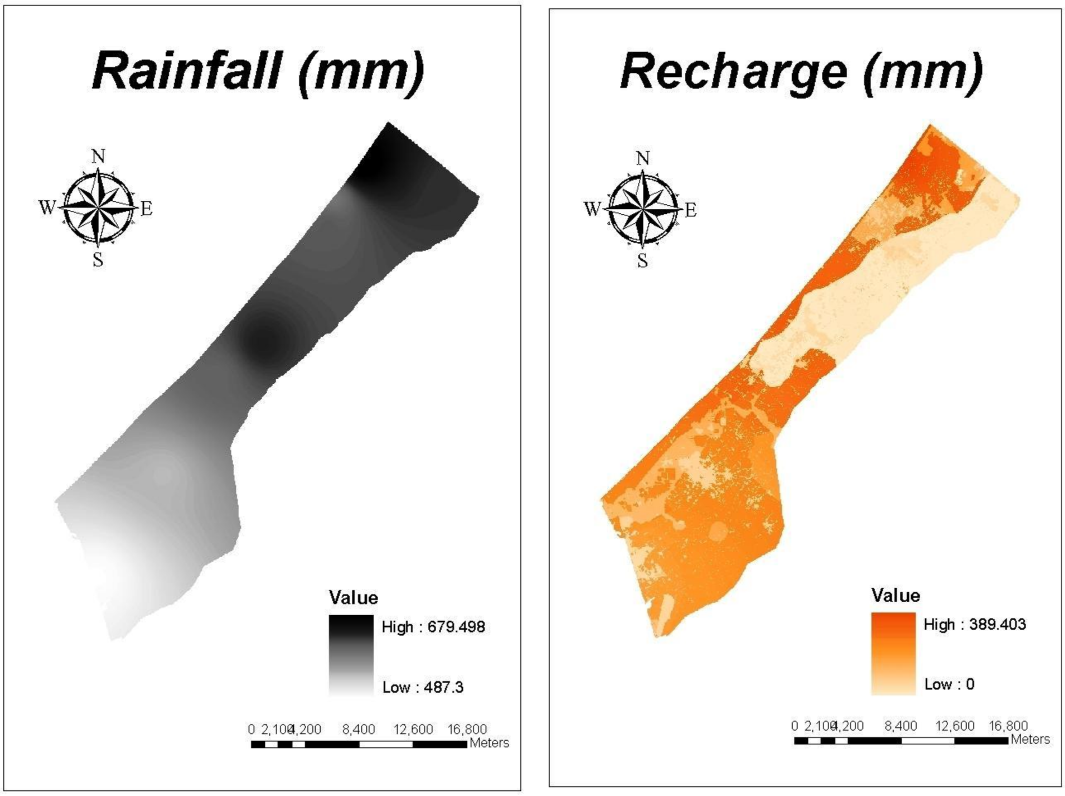


Figure 5.2 Annual groundwater recharge, calculated by the WetSpass model for year 1995

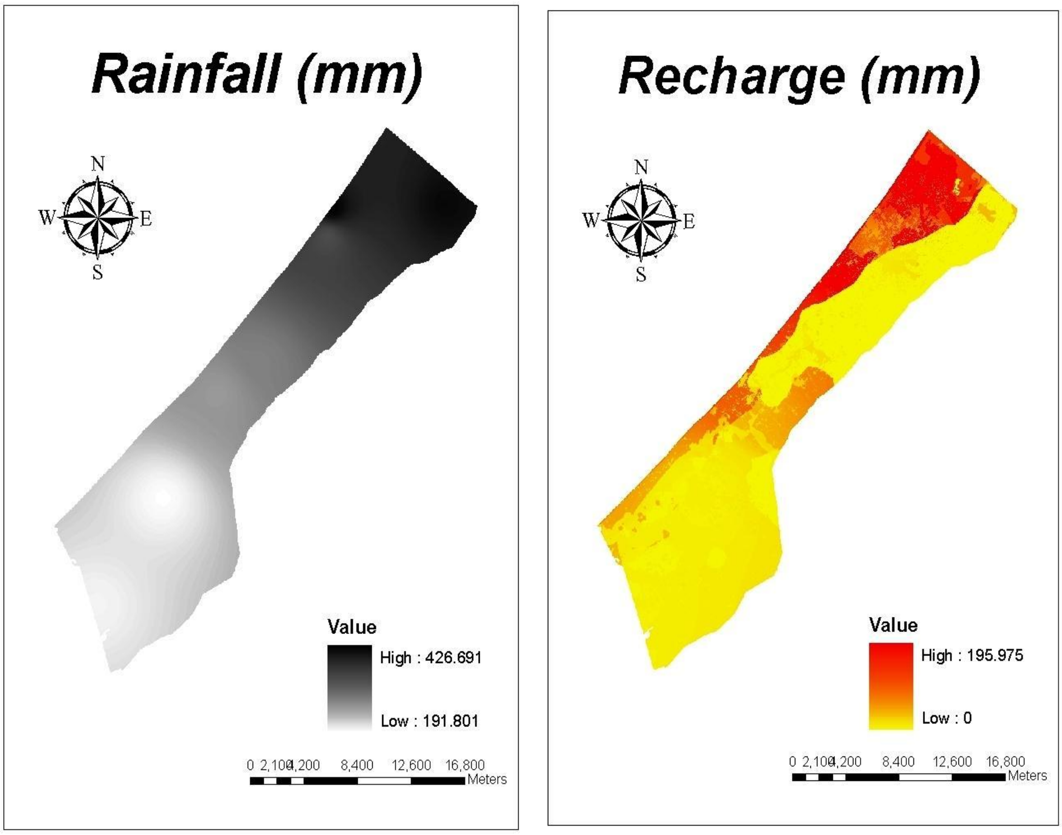


Figure 5.3 Annual groundwater recharge, calculated by the WetSpass model for year 2000

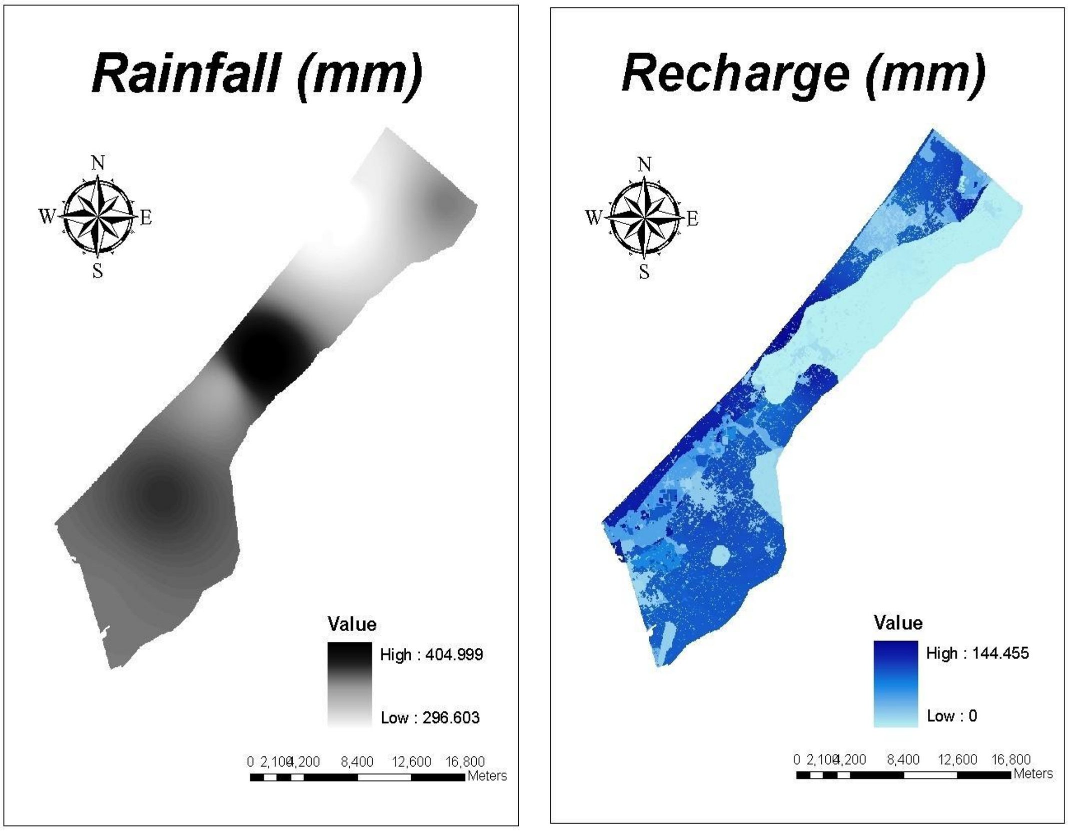


Figure 5.4 Annual groundwater recharge, calculated by the WetSpass model for year 2005

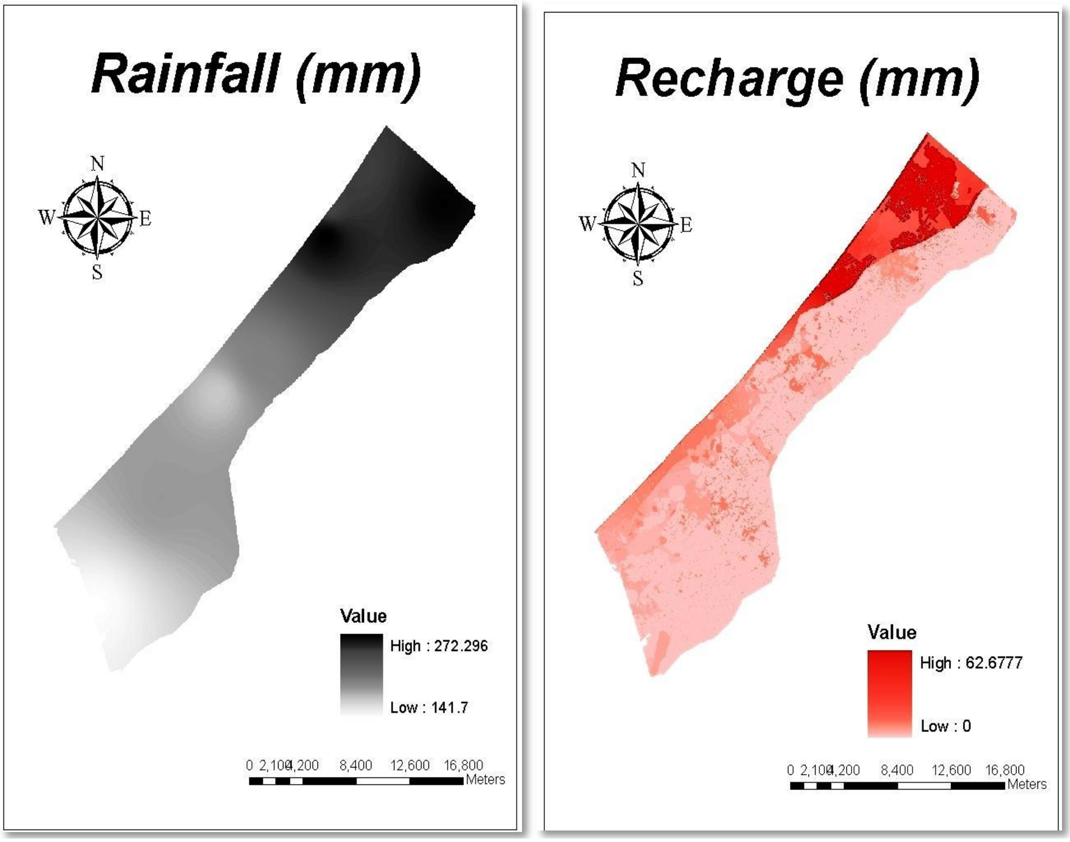


Figure 5.5 Annual groundwater recharge, calculated by the WetSpass model for year 2010

In order to compare between rainfall and recharge values the temporal frequency of the relation between the rainfall and the recharge were studied in three locations in Gaza Strip: Beit lahia, Gaza City and Rafah stations. The period from 1990 to 2010 using 5 years interval was considered. It was noticed that the recharge values for Gaza city and Rafah stations are less than Beit Lahia station values. This implies to the soil classification and runoff coefficient of the station which considered as a main input criteria in the point of view of the model. Beit Lahia station is sandy soil region while Gaza and Rafah are clayey soils.

Figures 5.6, 5.7 and 5.8 show the temporal relation between rainfall data records and recharge values obtained from WetSpass model for Beit Lahia, Gaza City and Deir Balah Stations respectively. The figures show high correlation between the rainfall and recharge trends range between 0.96 to 0.99. The figures also show unsteady trend of the rainfall which implies the climate change between year 1990 to year 2010. That climate change is illustrated in the three areas: where in year 1995 there is increase in the rainfall while after this year and up to year 2010 the rainfall decrease with 63.8 % in

Beit lahia stations. The same unsteady trend is found in recharge values where according to the WetSpass model results there is a decrease in the recharge quantities in Beit lahia station with 87.64 %. This will adversely influence the groundwater storage and mainly the groundwater level will decrease due to the decrease in the recharge values. The trends of the rainfall and recharges in other locations (Gaza and Rafah stations) are the same as Beit lahia with different decrease percentages.

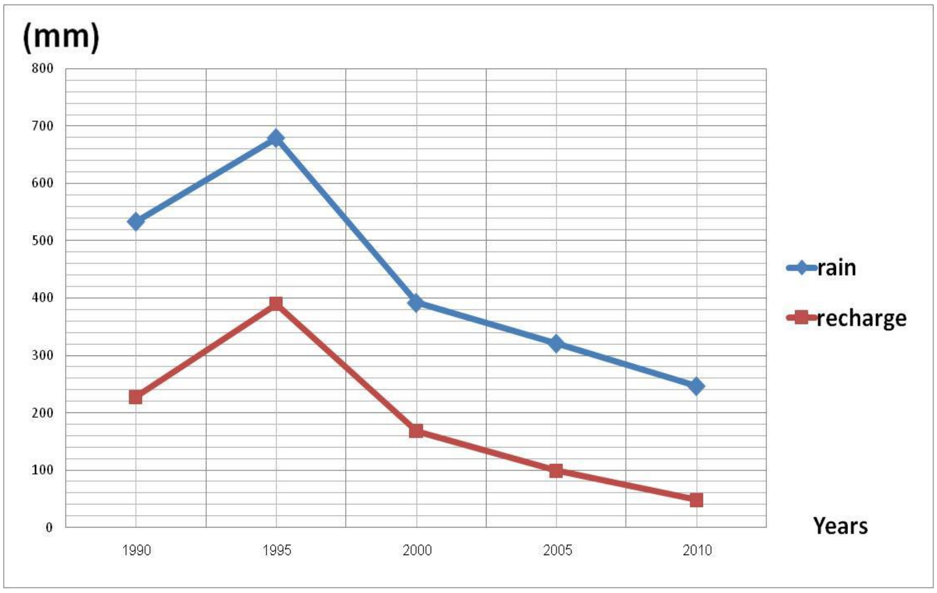


Figure 5.6 Relation between Rainfall and Recharge for Beit Lahia Station

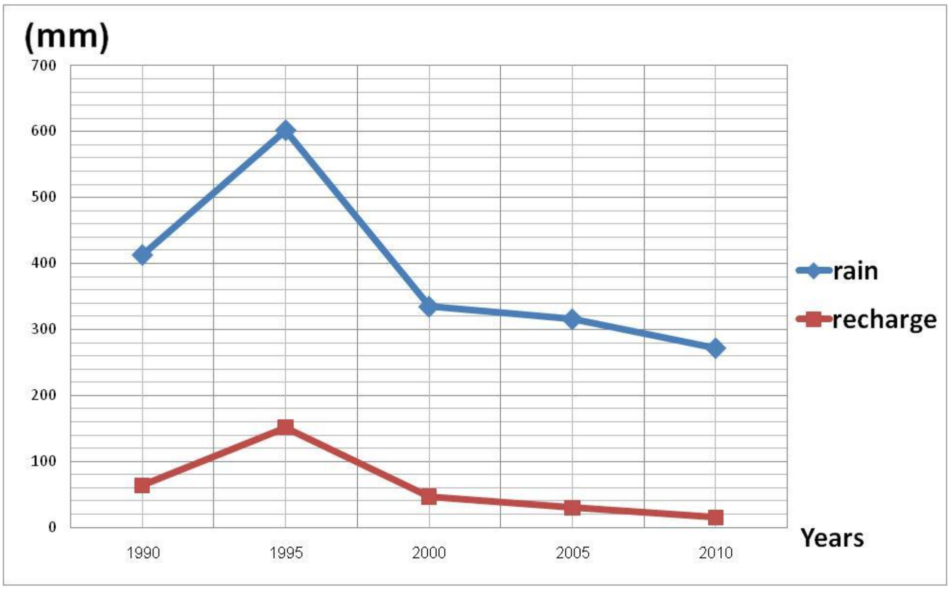


Figure 5.7 Relation between Rainfall and Recharge for Gaza City Station

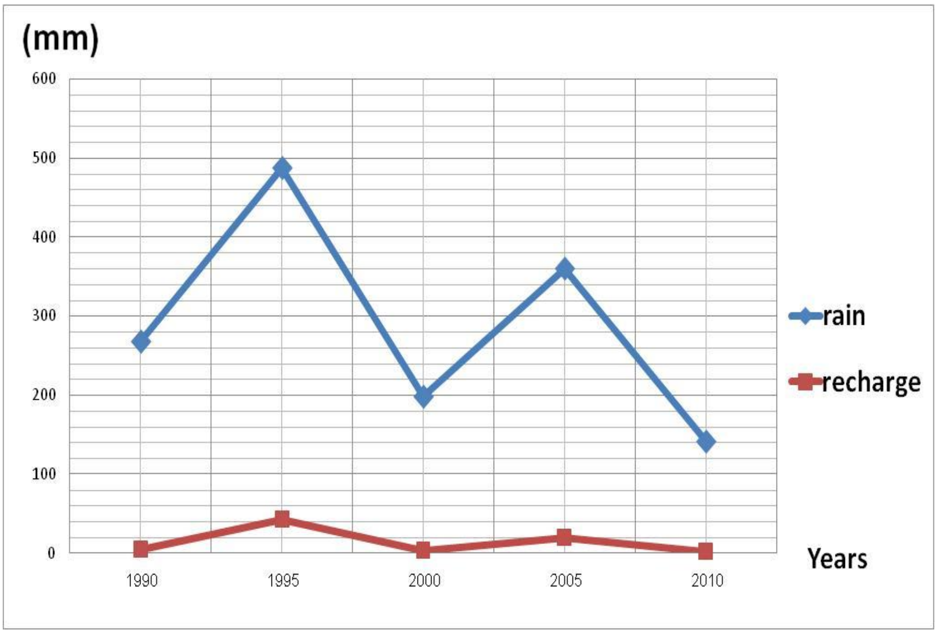


Figure 5.8 Relation between Rainfall and Recharge for Rafah Station

To distinguish the accuracy of the WetSpass model, error maps in years 1990, 1995, 2000, 2005 and 2010 running were observed, very low values are appeared. Figure 5.9 show error map for year 1990.

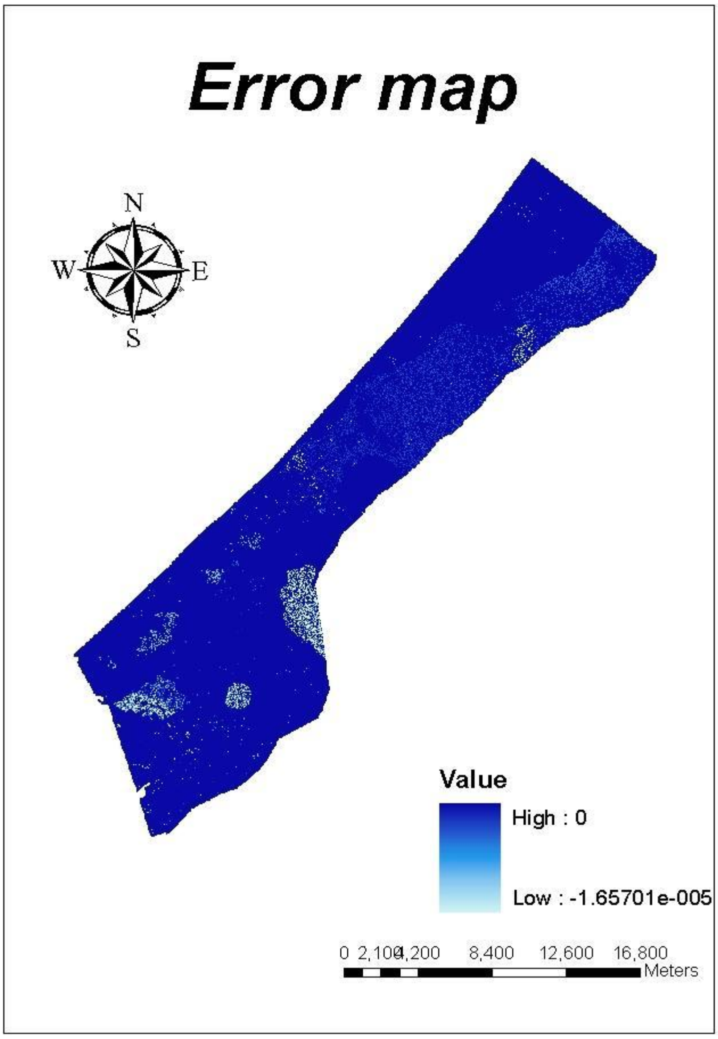


Figure 5.9 Error map percentage obtained from WetSpass model for year 1990

Other years and their error values are described in Table 5.1 and shown in Annex 1 (Figures A-1 to A-4).

Table 5.1: Error values in years 1990, 1995, 2000, 2005 and 2010

Year	Error	
	High value	Low value
1990	0	-1.65701e-005
1995	0	-7.62939e-006
2000	0	-1.49012e-005
2005	0	-2.28938e-005
2010	0	-1.51550e-005

5.2 Groundwater Flow Modeling

After computing the values of recharge using WetSpass Model, these values were used as input to the groundwater model _VISUAL Modflow 4.2_ software was used. The output of the groundwater model will give a good indicator of how will the climate change parameters affect the aquifer. The groundwater flow model used the northern part as a case study (Figure 5.10).

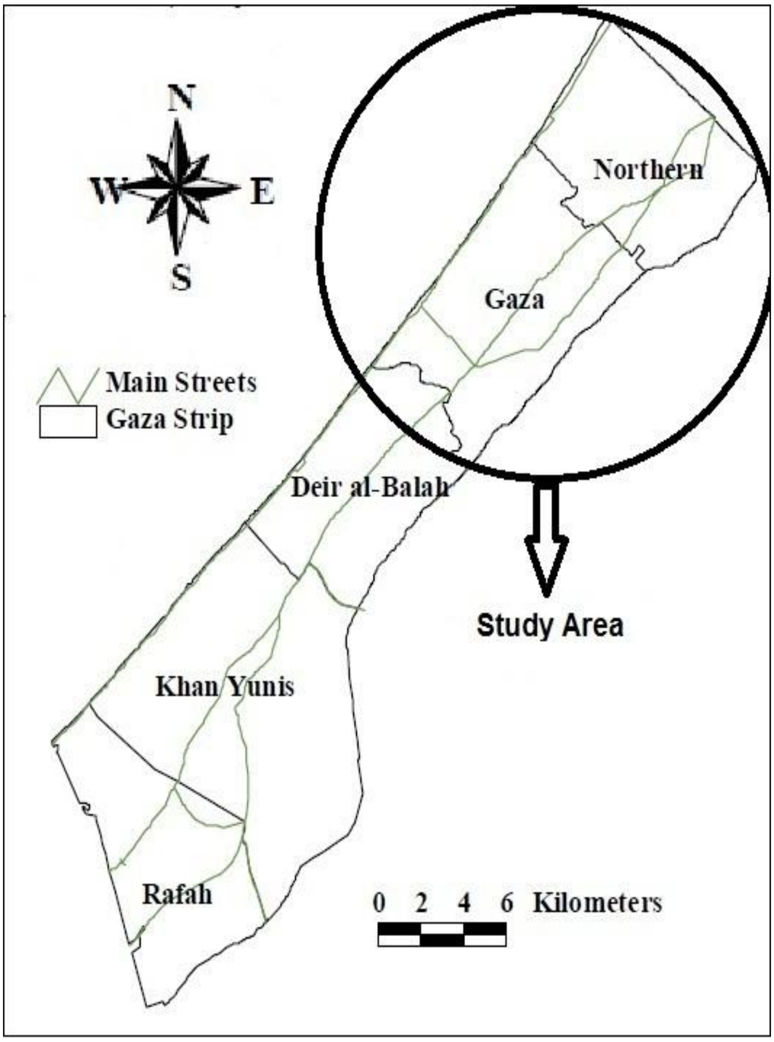


Figure 5.10 Location map of North area, Gaza.

5.2.1 Model setting up

The groundwater model domain encloses an area of 17 x15 km in the north part of Gaza Strip. The model domain is a uniform square grid comprising with a grid spacing of 200x200m as shown in Figure 5.11. A constant head boundary was assigned in west, the north, south, and east boundary was assigned as no flow boundary.

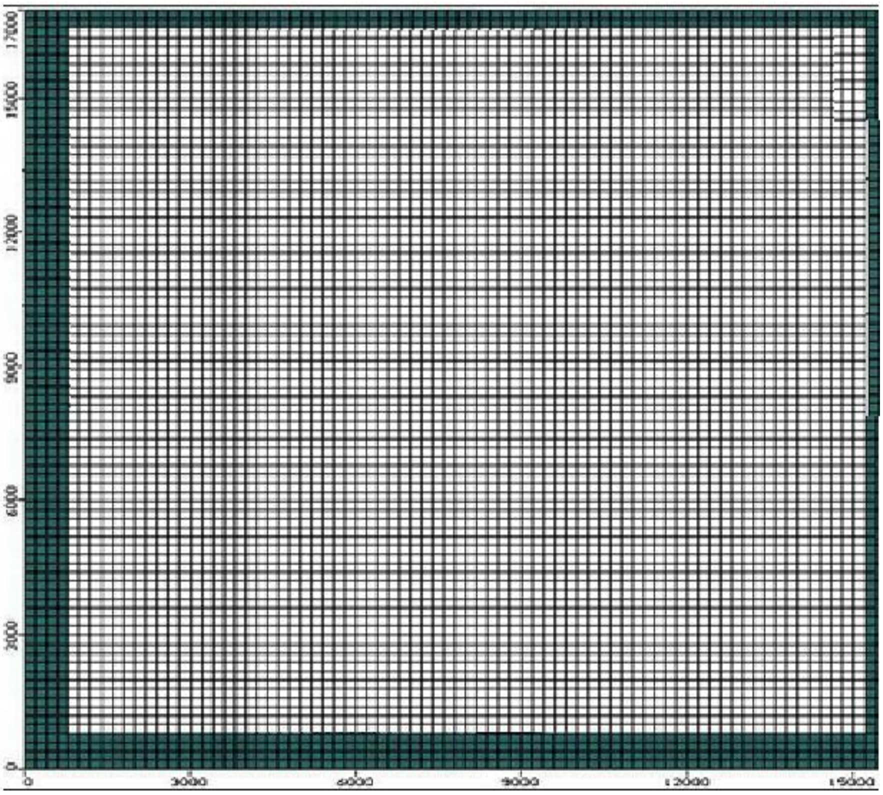


Figure 5.11 The model domain with the grid.

Recharge zones in the study area are shown in Figure 2.12.

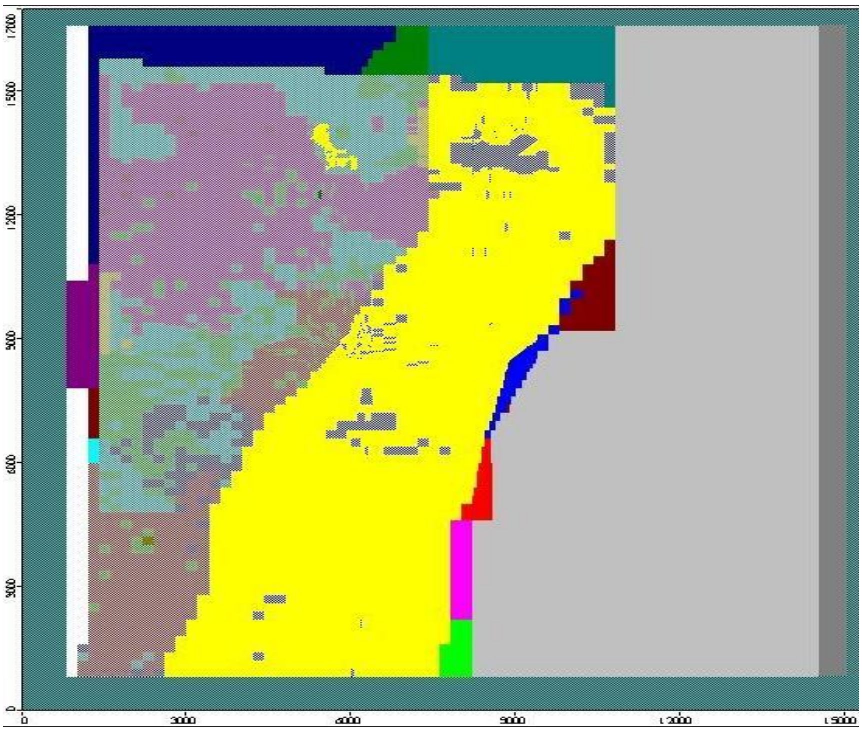


Figure 5.12 Recharge zones in the study area.

5.2.2 Observation wells

The Observation wells in the model are 34 wells were selected as head observation well as shown in Figure 5.13.

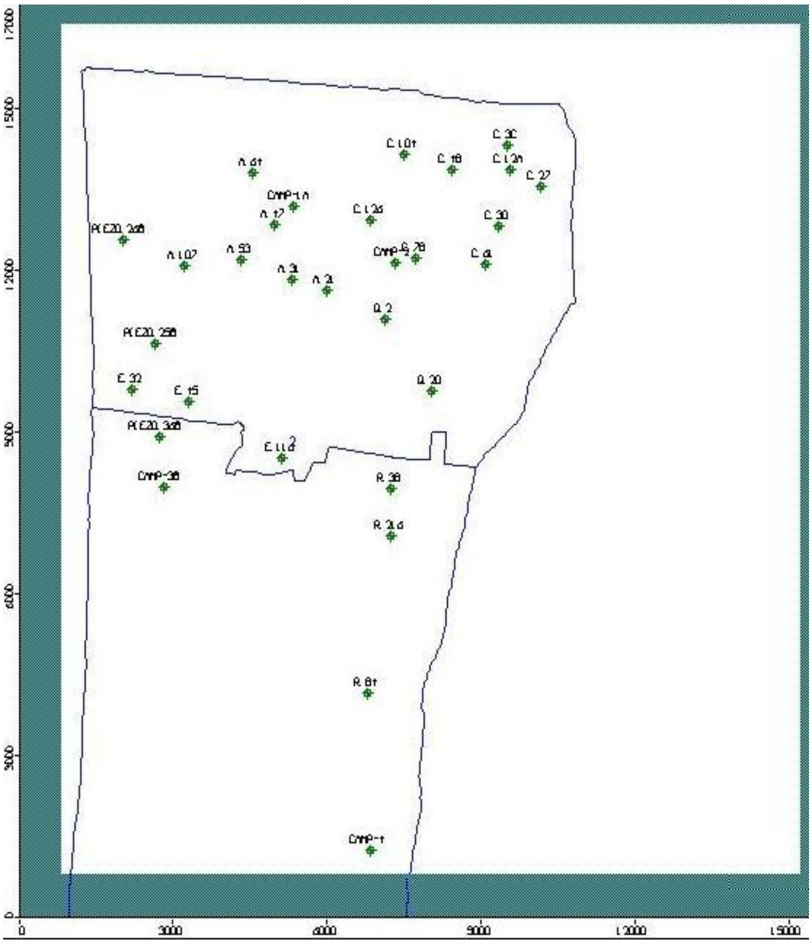


Figure 5.13 Head observation wells in the study area.

5.2.3 Pumping wells

Ground water is the main source of Palestinian agriculture, municipal, and industrial demands in north Gaza Governorate. The collected data contained partial data of all known wells in the period between 2004 and 2010, including the location of wells, coordinates, screens depths, abstractions. There is limited information about the well construction and pumping readings for illegally-dug wells which are were discovered through a survey conducted lately by PWA and agricultural wells.

In the study area there were 73 municipal wells in year (2008) and about 1213 registered agricultural well (PWA), The municipal wells were inserted to the model by their abstraction schedule, But the agricultural wells were inserted to the model by estimating their abstraction, these wells is shown in the Figure 5.12.

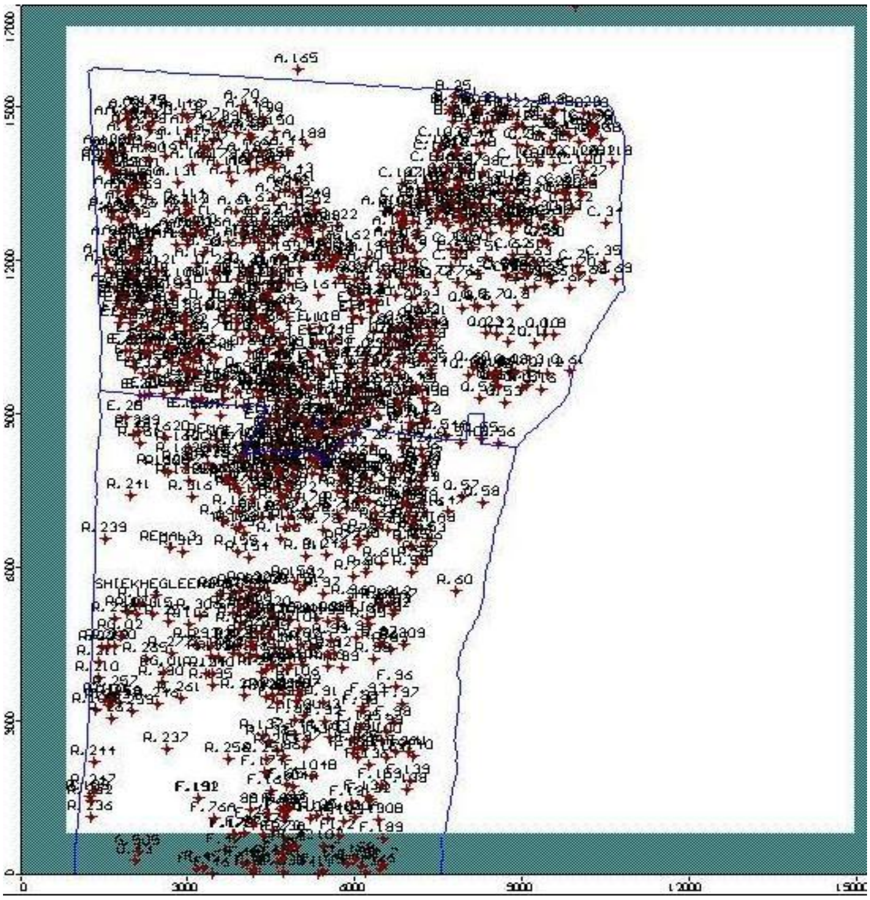


Figure 5.14 Municipal and agricultural wells in the study area

Hydraulic conductivity values used in the model are presented in the Table 5.2.

Table 5.2: Conductivity values (CAMP, 2000)

Zone	K_x (m/day)	K_y (m/day)	K_z (m/day)
1	60	60	6
2	40	40	4
3	55	55	5.5

5.2.4 Groundwater Modeling

Modflow model was calibrated from 1 October 2004 ,start date, and run to show results for years 2005, 2010, 2015, 2020, 2025 and 2030. The recharge of year 2000 was used. Head values at start date ranges from -3m at the middle area to 2m at the boundaries (Figure 5.15). initial groundwater level data are shown in Annex 2 (Table B-1).

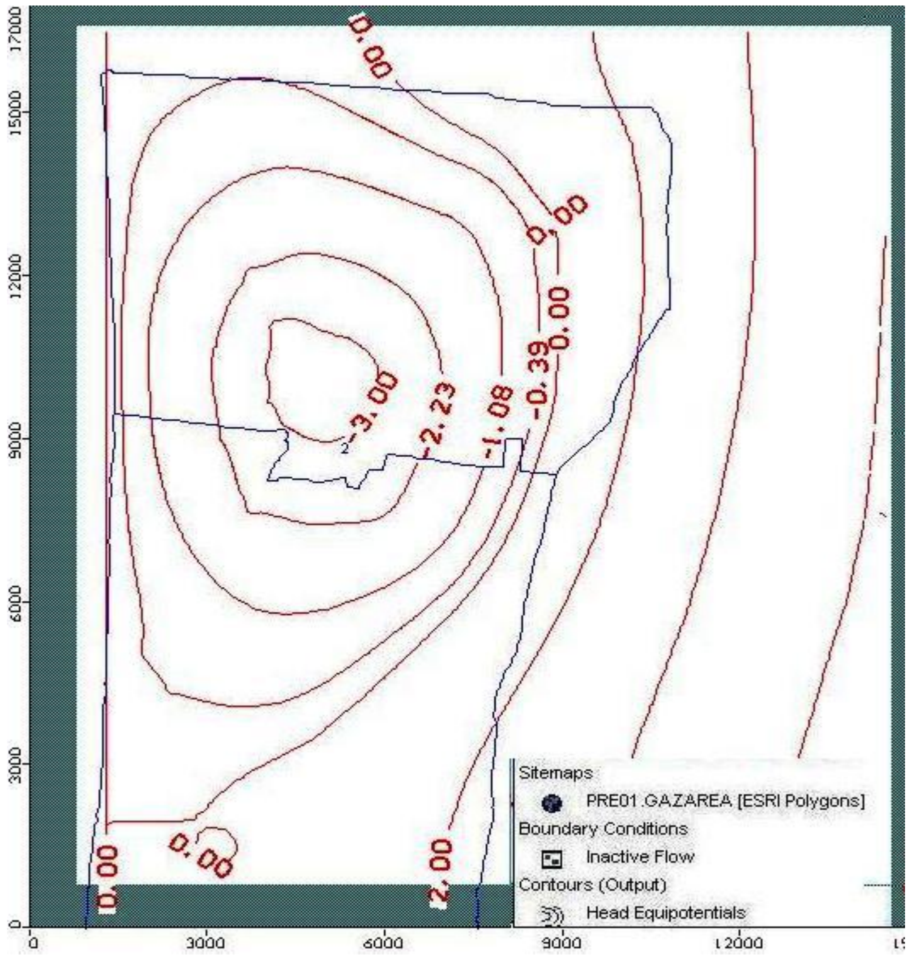


Figure 5.15 Initial head of the MODFLOW model at 1 October 2004

The model run to 1 January 2005, then the calculated Head map as it appears in figure 5.16. Head values range from -3.86m at the middle of the northern area to 2.04m at the eastern boundary. That's because of the middle area wells abstract larger than the boundaries wells. As it appeared in Figure 5.16 the deficit in aquifer storage is small, that is due to the proximity of the start and the end date running the model through. To distinguish the model results accuracy, observed head wells data were used in order to get comparison between calculated values and observed values, with 95% confidence interval. The obtained Correlation Coefficient was 0.94 which was considered as a good result.

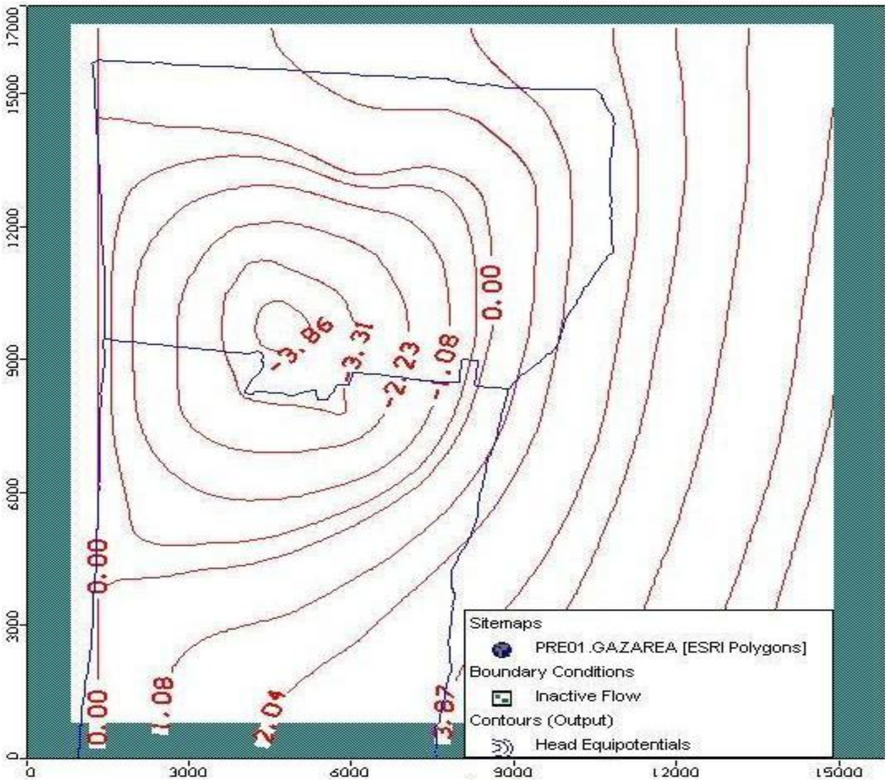
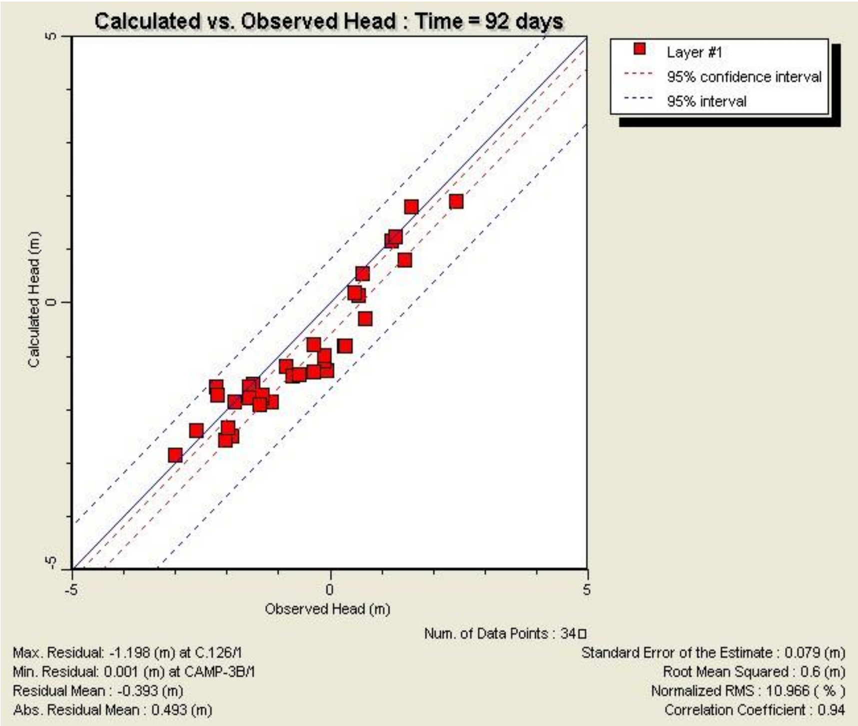


Figure 5.16 Head calculated by the MODFLOW model for year 2005



Num. of Data Points : 34

Max. Residual: -1.198 (m) at C.126/1
Min. Residual: 0.001 (m) at CAMP-3B/1
Residual Mean : -0.393 (m)
Abs. Residual Mean : 0.493 (m)

Standard Error of the Estimate : 0.079 (m)
Root Mean Squared : 0.6 (m)
Normalized RMS : 10.966 (%)
Correlation Coefficient : 0.94

Figure 5.17 Calibration Head for year 2005

After that the recharge value for year 2005 was used as initial value and the model was run for 5 years (up to year 2010) in order to get aquifer state at year 2010. Figure 5.18 shows that the head values drop from -3.86m at the middle to -5m with an obvious expansion at this area, and from 2.04m at the boundaries to -3.31m.

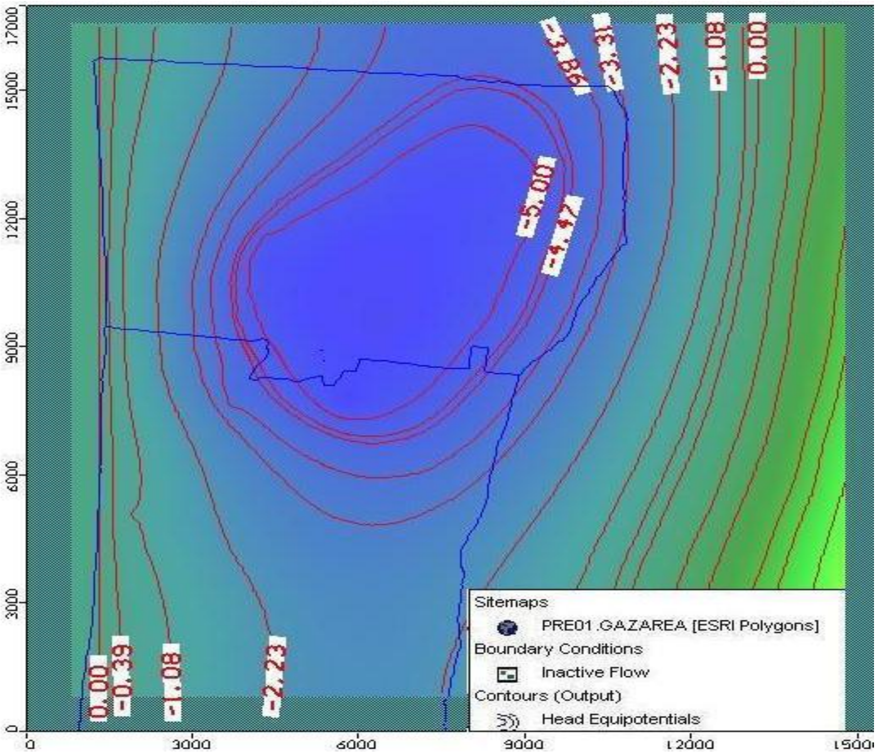


Figure 5.18 Head calculated by the MODFLOW model for year 2010

The Correlation Coefficient was 0.917 between the observed and calculated water level which also enhance model results accuracy. That's appears clearly in (Fig. 5.19).

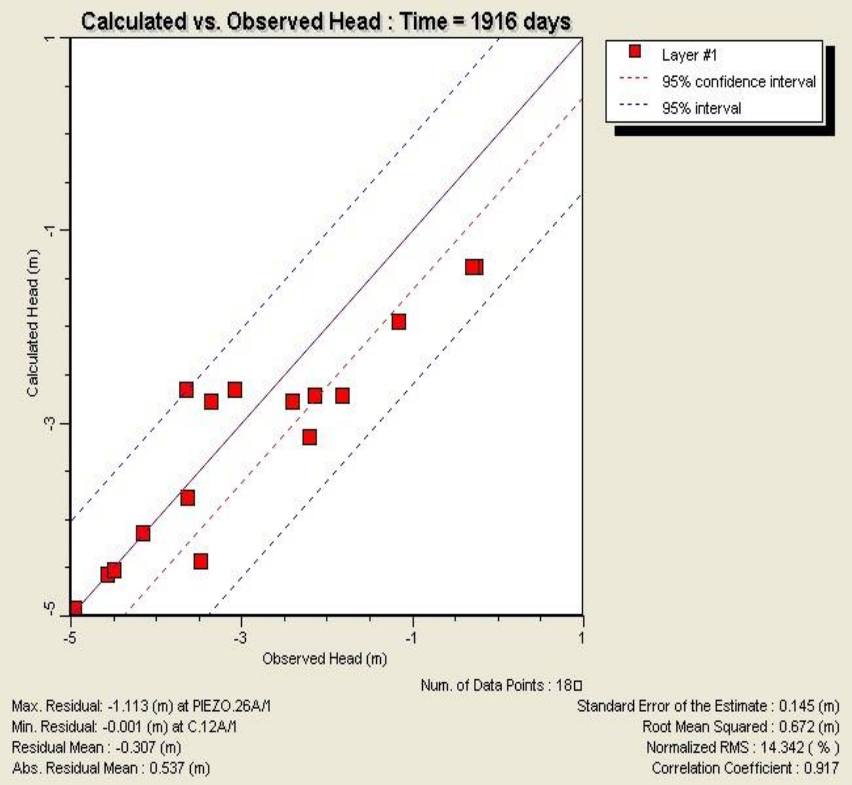


Figure 5.19 Calibration Head for year 2010

5.3 Prediction of Climate Change Impacts

After calibration and verification of the model, as it appeared from previous calibration graphs, the model is used in the stage of future prediction of what will be the aquifer state in the next years, if the same climate conditions continued? In addition, if the decreasing trend continues as a result of climate change, what will be the impacts of such conditions?

5.3.1 First Scenario: the recharge of year 2010 still remains.

The 2010 year recharge values were used as initial value for the calibrated model, and the model was for 20 years. Then the results were explored for each 5 years interval, for 2015, 2020, 2025 and 2030.

The figures 5.20, 5.21, 5.22 and 5.23 show the expected calculated head in the north Gaza area in years 2015, 2020, 2025 and 2030 respectively. It is noticed that the head values decreases from -5m at the middle at 2010 year to -6, -7.5, -8, -8.5m at years 2015, 2020, 2025 and 2030 respectively. Even though the same value of -3.31m last for year 2015, Decrease index last for the boundary regions, that's clearly appeared from value of -3.31m at year 2010 to the values -6, -7 and -7.5m for years 2020, 2025 and 2030 respectively.

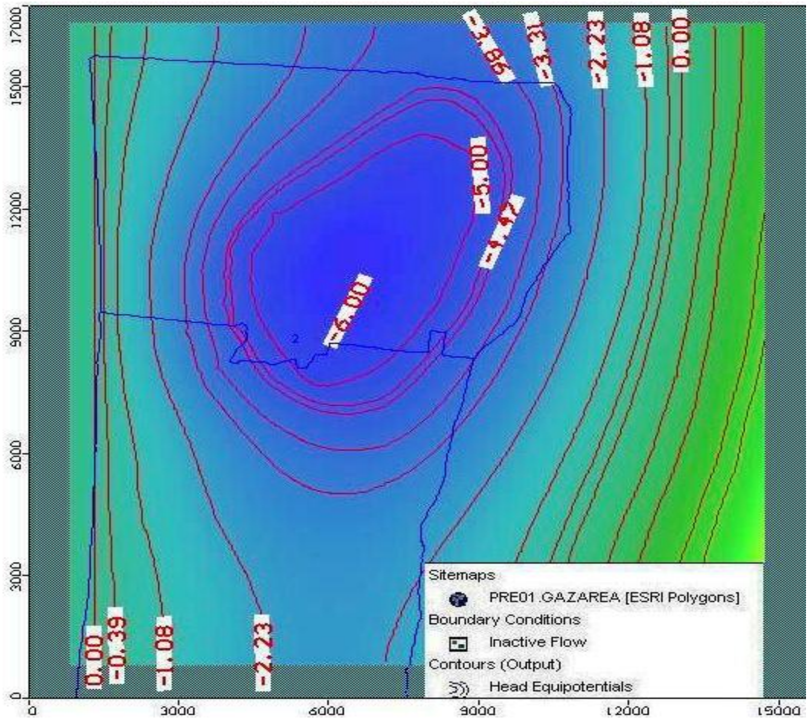


Figure 5.20 Head calculated by the MODFLOW model for year 2015

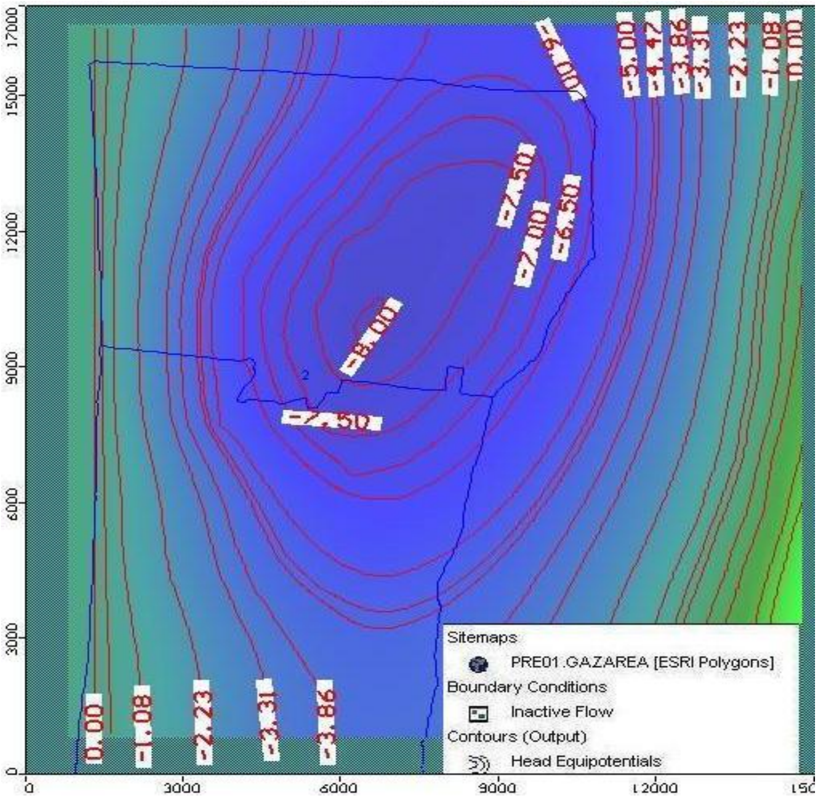


Figure 5.21 Head calculated by the MODFLOW model for year 2020

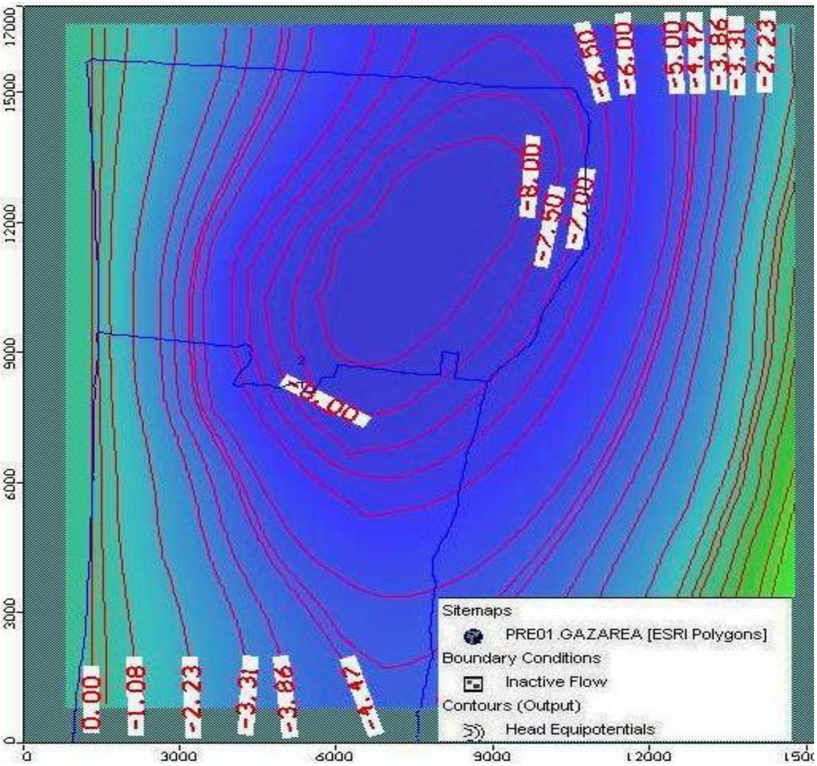


Figure 5.22 Head calculated by the MODFLOW model for year 2025

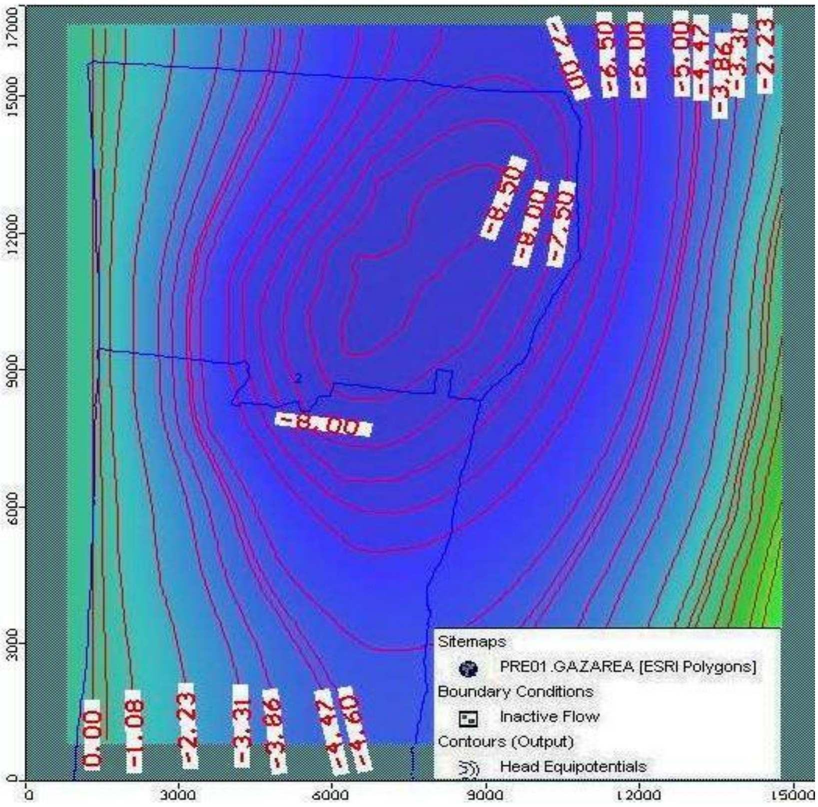


Figure 5.23 Head calculated by the MODFLOW model for year 2030

5.3.2 Second Scenario: recharge rate decreases.

The trend line of recharge values for Beit Lahia station that lies in the north area was developed. As it is shown in Figure 5.24, a linear equation with a value of R^2 = 96.2%, can be considered as model for the recharge trend line as follows:

$$Y = -47.10X + 292 \qquad \text{(eq. 5.1)}$$

Figure 5.24 Expected Recharge rate for year 2015, Beit Lahia Station

Using equation 5.1 the estimated recharge value in year 2015 will be 9.4mm/y. This value need to redefine to Modflow program input as recharge rate with a start date of 1 January 2015 and the calculated head of 2015 will be as initial head value. Results of 1825 days will present the aquifer state for year 2020, as well as 3650 and 5475 days will present years 2025 and 2030 respectively.

Figures 5.25, 5.26 and 5.27 show the calculated head values obtained from Modflow program for years 2020, 2025 and 2030 respectively. As it appeared the expected head in the middle area will decreases to the value -8.5m with increasing expansion of this region over time. In the eastern boundary head value will reach -7.5m in year 2030. This breadth in the deficit area clearly shows the magnitude of the aquifer problem in the next years as effect of the climate change.

Also, it is noticed that the head values decreases in the second scenario more than as it in the first scenario. This is because that the second scenario used the recharge value of year 2015 which is lower than recharge value of 2010 that used in the first scenario.

In term of quality, it expected that groundwater will be deteriorated rapidly as a sequence of the deficit in groundwater table due to climate change effects, therefore this will lead to sea water intrusion and that calls every effort to help and save the unique source of water in that area.

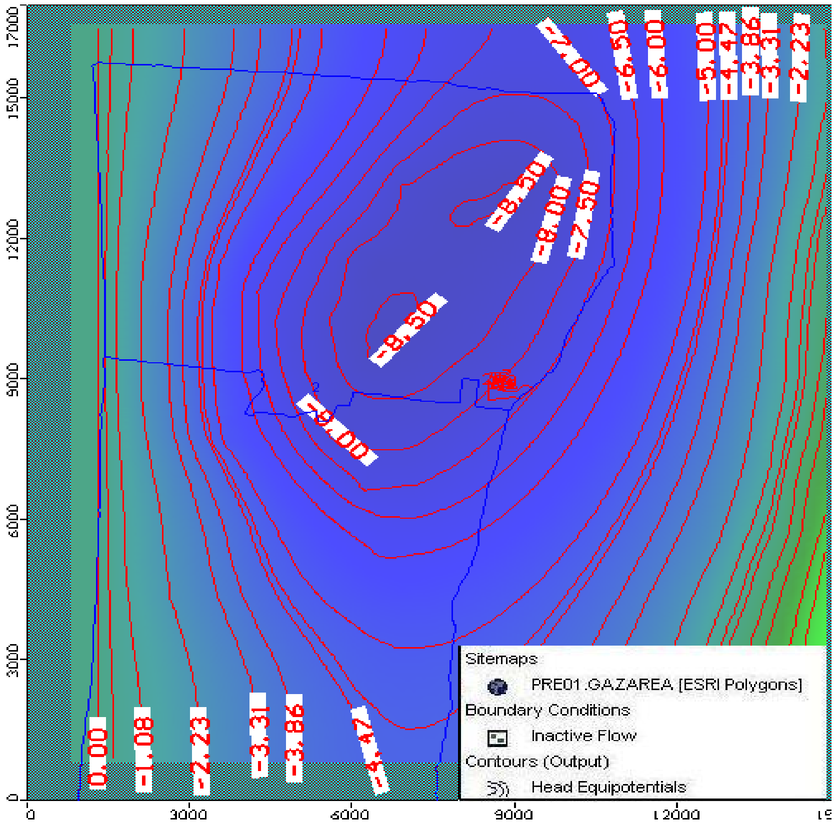


Figure 5.25 Head calculated by the MODFLOW model for year 2020

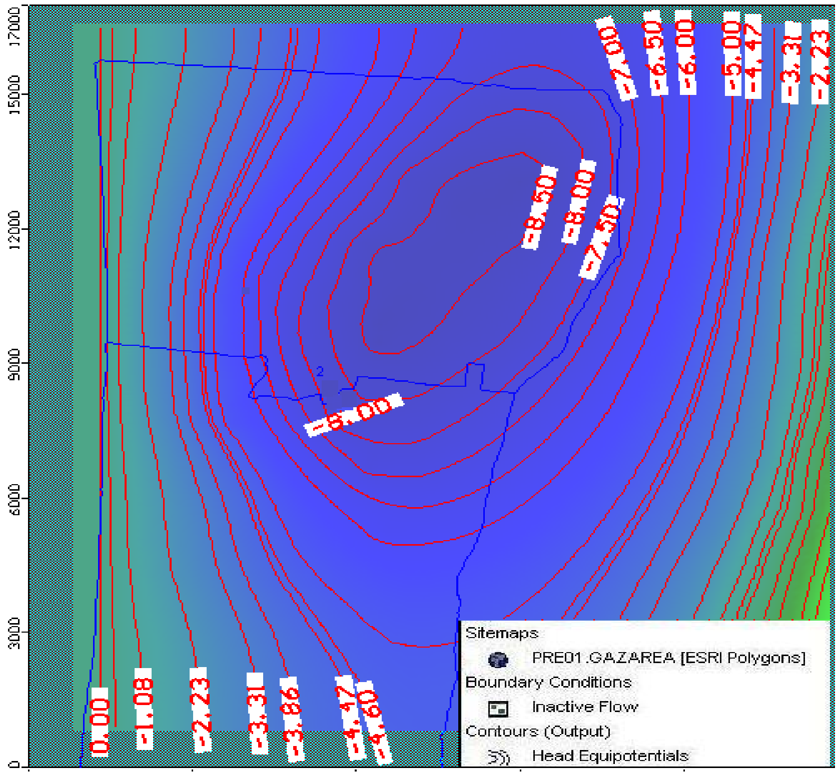


Figure 5.26 Head calculated by the MODFLOW model for year 2025

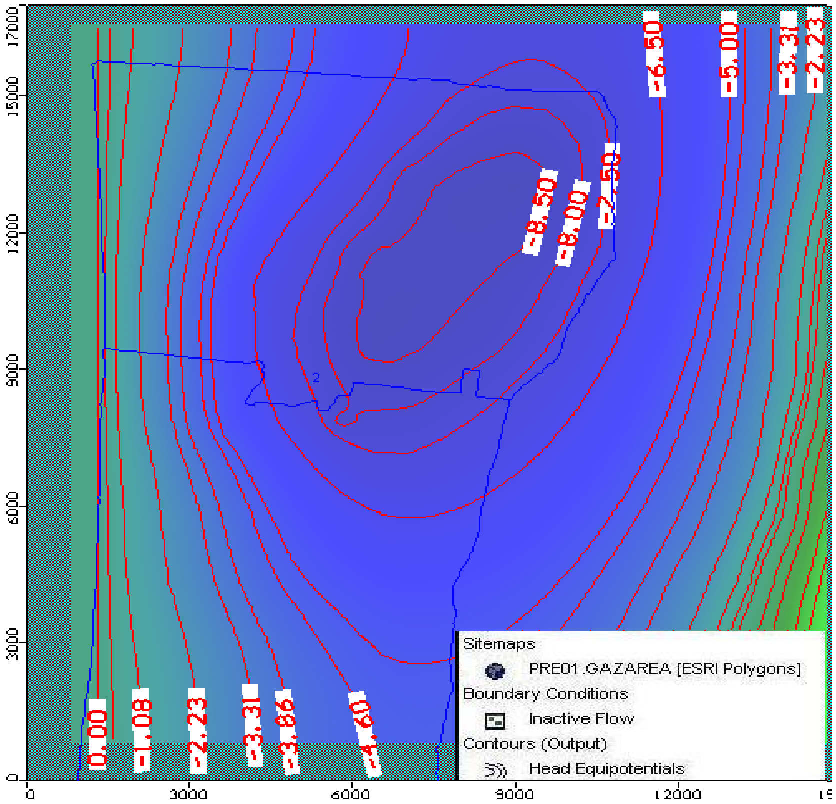


Figure 5.27 Head calculated by the MODFLOW model for year 2030

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

1. Studying the effects of climate changes on groundwater resources is considered as a main point in groundwater management system. Recently understanding the influence of climate change can contribute in an integration of water resources management.
2. Effects of climate change in Gaza strip may include minor decrease of temperatures.
3. This research presented that there is a considered effect of climate changes on rainfall values which has an impact on recharge values. The research illustrated that in the last 20 years there is decreasing trends in rainfall values. This decreasing occurs after year 1995, that caused deficit in recharge values and lastly caused a decrease in groundwater storage.
4. Estimating groundwater recharge is critical for developing an effective management strategy that will ensure the protection of the fresh water resources of Gaza Strip. The physically based hydrologic model WetSpass was integrated with ArcView GIS to estimate spatially distributed groundwater recharge rates for the Northern part of Gaza Strip over a period of 25 years, from October 2004 to December 2030. The use of the GIS was essential and helpful due to the large volume of data required for numerical modeling of area processes at the regional scale.
5. The case study of the Northern area illustrate that the middle and southern areas would be worsen, it's have not as much rainfall quantity as Northern part have, and no clear differentiation abstraction between those areas, hence recharge quantities infiltrate aquifer will reduce and the deficit will be larger.
6. If groundwater is not managed properly in Gaza Strip, there is a high probability that it would be depleted in the next years, depending on the anticipated climate change scenario.
7. Constructing hydrologic models, through which we can realize the behavior of the Gaza Strip coastal aquifer, is reached and provides a complete insight of the groundwater flow in the coastal aquifer. Groundwater program (Modflow) and hydrologic model (WetSpass) as well as all automated data (such as rainfall,

landuse, temperature, wind, evapotranspiration, depth and level of water table and slope of the topography, etc,) will be very valuable for the responsible for further researches and development.

6.2 Recommendations

1. This study can be used as a guide to the concerned authorities and in charge of the follow-up to the quality and quantity of groundwater behavior. It showed clearly the effects of many predicted scenarios on climate change and water level in the Northern part of Gaza strip.
2. The continuous careless abstraction of Gaza Strip aquifer should be stopped. Management integration can help to stop the deterioration of the aquifer. It is the first step in management the groundwater quantity. The second step is to search for other sources of water from the aquifer. Alternative sources can be reducing the massive deficit in the future.
3. The study will be more efficient if it take in account the extends aquifers beyond the area.
4. Considering the results of this study, the concerned authorities should closely monitor groundwater levels, especially at the end of the summer, both in groundwater recharge and discharge zones.
5. The monitoring program for groundwater quality should be designed with a selection of parameters and frequency that allows the effect of the climate change on the groundwater resources to be observed.
6. The best way to solve the deterioration problem in the groundwater resources due to climate change effects is the combination of many options:
    a. Reduction the extreme rates of abstraction from the aquifer by using alternate resources, in order not to be exceed the sustainable yield.
    b. Rearrangement of abstraction works, based on a deep study in the deficit and deteriorated areas.
    c. Implementation artificial recharge system in order to compensate the present deficit. Increasing groundwater recharge could counteract the projected effects of climate changes on the groundwater system.
    d. Construction new management system help in monitoring the groundwater system in terms of quantity and quality .
7. As a general recommendation, PWA, MoA, CMWU, and other related authorities has to construct an integrated database for hydrological data of Gaza Strip.

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1) http://www.ground-water-models.com HYPERLINK "http://www.ground-water-models.com/"/

2) http://www.elmhurst.edu/~chm/vchembook/301groundwater.html.

3) http://www.moi.gov.ps/news/29346/Interior-Ministry-Number-of-population-in-Gaza-Strip-1713505

4) http://www.indexmundi.com/gaza_strip/demographics_profile.html

ANNEX 1

Table A-1: WetSpass grid output names abbreviation

Abbreviation	Full name
er	a measure of error in the water balance (should be 0, or very close to 0)
re	Recharge
ro	Runoff
se	soil evaporation
tr	(vegetation) transpiration
in	interception
et	total evapotranspiration

Table A-2: Abbreviation in WetSpass landuse parameters

Parameter	Full name	Unit
Veg_area	Vegetation area fraction	-
Bare_area	Bare area fraction	-
Imp_area	Impervious area fraction	-
Openw_area	Open water area fraction	-
Root depth	Rooting depth	M
Lai	Leaf Area Index	- area fraction
Min_stom	Minimal stomatal resistance	s/m
Interc_per	Interception percentage	%
Veg_height	Vegetation height	M

Table A-3: Abbreviation in WetSpass soil parameters

Parameter	**Full name**	**Unit**
Porosity	Porosity	- (volume fraction)
Wilting point	Wilting point	- (volume fraction)
Field capacity	Field capacity	- (volume fraction)
Residual wc	Residual water content	- (volume fraction)
a_1	a1 soil empirical parameter for ET calculation	-
PAW	Plant Available Water	- (volume fraction)
tensionhht	Tension saturated height	M
evapodepth	Soil evaporation depth	M
P_frac_winter	Precipitation fraction in winter which has an intensity higher than the soil infiltration rate	- (volume fraction)
P_frac_summer	Precipitation fraction in summer which has an intensity higher than the soil infiltration rate	- (volume fraction)

Table A-4: WetSpass Soil parameters

SOIL	FIELDCAPAC	WILTINGPNT	PAW	RESIDUALWC	A1	EVAPODEPTH	TENSIONHHT	P_FRAC_SUM	P_FRAC_WIN
sand	0.12	0.05	0.07	0.020	0.51	0.05	0.07	0.09	0.01
loamy sand	0.15	0.07	0.08	0.035	0.47	0.05	0.09	0.09	0.01
sandy loam	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01
silty loam	0.29	0.10	0.19	0.015	0.40	0.05	0.21	0.26	0.07
loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02
silt	0.30	0.10	0.20	0.040	0.35	0.05	0.61	0.09	0.01
sandy clayl	0.26	0.16	0.10	0.068	0.32	0.05	0.28	0.54	0.30
silty clayl	0.36	0.19	0.17	0.040	0.29	0.05	0.33	0.62	0.41
clayloam	0.33	0.19	0.14	0.075	0.27	0.05	0.26	0.62	0.41
sandy clay	0.32	0.23	0.09	0.109	0.25	0.05	0.29	0.80	0.68
silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75
clay	0.46	0.33	0.13	0.090	0.21	0.05	0.37	0.95	0.85

Table A-5: Runoff coefficient parameters for vegetated, bare soil and open water raster cells

LANDUSERO	LANDUSENUM	SLOPE_____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
crop	1	<0.5	1	sand	1	0.3500	111	1
crop	1	0.5-5	2	sand	1	0.4000	112	1
crop	1	5-10	3	sand	1	0.4500	113	1
crop	1	>10	4	sand	1	0.5000	114	1
grass	2	<0.5	1	sand	1	0.1500	121	2
grass	2	0.5-5	2	sand	1	0.2000	122	2
grass	2	5-10	3	sand	1	0.2500	123	2
grass	2	>10	4	sand	1	0.3000	124	2
forest	3	<0.5	1	sand	1	0.0500	131	3
forest	3	0.5-5	2	sand	1	0.1000	132	3
forest	3	5-10	3	sand	1	0.1500	133	3
forest	3	>10	4	sand	1	0.2000	134	3
bare soil	4	<0.5	1	sand	1	0.4500	141	4
bare soil	4	0.5-5	2	sand	1	0.4800	142	4
bare soil	4	5-10	3	sand	1	0.5300	143	4
bare soil	4	>10	4	sand	1	0.5800	144	4
open water	5	<0.5	1	sand	1	1.0000	151	5
open water	5	0.5-5	2	sand	1	1.0000	152	5
open water	5	5-10	3	sand	1	1.0000	153	5
open water	5	>10	4	sand	1	1.0000	154	5
crop	1	<0.5	1	loamy-sand	2	0.3800	211	6
crop	1	0.5-5	2	loamy-sand	2	0.4300	212	6
crop	1	5-10	3	loamy-sand	2	0.4800	213	6
crop	1	>10	4	loamy-sand	2	0.5300	214	6
grass	2	<0.5	1	loamy-sand	2	0.1800	221	7
grass	2	0.5-5	2	loamy-sand	2	0.2300	222	7
grass	2	5-10	3	loamy-sand	2	0.2800	223	7
grass	2	>10	4	loamy-sand	2	0.3300	224	7
forest	3	<0.5	1	loamy-sand	2	0.0800	231	8
forest	3	0.5-5	2	loamy-sand	2	0.1300	232	8
forest	3	5-10	3	loamy-sand	2	0.1800	233	8
forest	3	>10	4	loamy-sand	2	0.2300	234	8

LANDUSERO	LANDUSENUM	SLOPE_____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
bare soil	4	<0.5	1	loamy-sand	2	0.4800	241	9
bare soil	4	0.5-5	2	loamy-sand	2	0.5300	242	9
bare soil	4	5-10	3	loamy-sand	2	0.5800	243	9
bare soil	4	>10	4	loamy-sand	2	0.6300	244	9
open water	5	<0.5	1	loamy-sand	2	1.0000	251	10
open water	5	0.5-5	2	loamy-sand	2	1.0000	252	10
open water	5	5-10	3	loamy-sand	2	1.0000	253	10
open water	5	>10	4	loamy-sand	2	1.0000	254	10
crop	1	<0.5	1	sandy-loam	3	0.4000	311	11
crop	1	0.5-5	2	sandy-loam	3	0.4500	312	11
crop	1	5-10	3	sandy-loam	3	0.5000	313	11
crop	1	>10	4	sandy-loam	3	0.5500	314	11
grass	2	<0.5	1	sandy-loam	3	0.2000	321	12
grass	2	0.5-5	2	sandy-loam	3	0.2500	322	12
grass	2	5-10	3	sandy-loam	3	0.3000	323	12
grass	2	>10	4	sandy-loam	3	0.3500	324	12
forest	3	<0.5	1	sandy-loam	3	0.1000	331	0
forest	3	0.5-5	2	sandy-loam	3	0.1500	332	0
forest	3	5-10	3	sandy-loam	3	0.2000	333	0
forest	3	>10	4	sandy-loam	3	0.2500	334	0
bare soil	4	<0.5	1	sandy-loam	3	0.5000	341	0
bare soil	4	0.5-5	2	sandy-loam	3	0.5500	342	0
bare soil	4	5-10	3	sandy-loam	3	0.6000	343	0
bare soil	4	>10	4	sandy-loam	3	0.6500	344	0
open water	5	<0.5	1	sandy-loam	3	1.0000	351	0
open water	5	0.5-5	2	sandy-loam	3	1.0000	352	0

LANDUSE RO	LANDUSE NUM	SLOPE____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
open water	5	5-10	3	sandy-loam	3	1.0000	353	0
open water	5	>10	4	sandy-loam	3	1.0000	354	0
crop	1	<0.5	1	silty-loam	4	0.4300	411	0
crop	1	0.5-5	2	silty-loam	4	0.4800	412	0
crop	1	5-10	3	silty-loam	4	0.5300	413	0
crop	1	>10	4	silty-loam	4	0.5800	414	0
grass	2	<0.5	1	silty-loam	4	0.2300	421	0
grass	2	0.5-5	2	silty-loam	4	0.2800	422	0
grass	2	5-10	3	silty-loam	4	0.3300	423	0
grass	2	>10	4	silty-loam	4	0.3800	424	0
forest	3	<0.5	1	silty-loam	4	0.1300	431	0
forest	3	0.5-5	2	silty-loam	4	0.1800	432	0
forest	3	5-10	3	silty-loam	4	0.2300	433	0
forest	3	>10	4	silty-loam	4	0.2800	434	0
bare soil	4	<0.5	1	silty-loam	4	0.5300	441	0
bare soil	4	0.5-5	2	silty-loam	4	0.5800	442	0
bare soil	4	5-10	3	silty-loam	4	0.6300	443	0
bare soil	4	>10	4	silty-loam	4	0.6800	444	0
open water	5	<0.5	1	silty-loam	4	1.0000	451	0
open water	5	0.5-5	2	silty-loam	4	1.0000	452	0
open water	5	5-10	3	silty-loam	4	1.0000	453	0
open water	5	>10	4	silty-loam	4	1.0000	454	0
crop	1	<0.5	1	loam	5	0.4000	511	0
crop	1	0.5-5	2	loam	5	0.4500	512	0
crop	1	5-10	3	loam	5	0.5000	513	0
crop	1	>10	4	loam	5	0.5500	514	0
grass	2	<0.5	1	loam	5	0.2000	521	0
grass	2	0.5-5	2	loam	5	0.2500	522	0
grass	2	5-10	3	loam	5	0.3000	523	0
grass	2	>10	4	loam	5	0.3500	524	0

forest	3	<0.5	1	loam	5	0.1000	531	0
forest	3	0.5-5	2	loam	5	0.1500	532	0
forest	3	5-10	3	loam	5	0.2000	533	0
forest	3	>10	4	loam	5	0.2500	534	0
bare soil	4	<0.5	1	loam	5	0.5000	541	0
bare soil	4	0.5-5	2	loam	5	0.5500	542	0
bare soil	4	5-10	3	loam	5	0.6000	543	0
bare soil	4	>10	4	loam	5	0.6500	544	0
open water	5	<0.5	1	loam	5	1.0000	551	0
open water	5	0.5-5	2	loam	5	1.0000	552	0
LANDUSERO	LANDUSENUM	SLOPE_____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
open water	5	5-10	3	loam	5	1.0000	553	0
open water	5	>10	4	loam	5	1.0000	554	0
crop	1	<0.5	1	silt	6	0.3800	611	0
crop	1	0.5-5	2	silt	6	0.4200	612	0
crop	1	5-10	3	silt	6	0.4800	613	0
crop	1	>10	4	silt	6	0.5300	614	0
grass	2	<0.5	1	silt	6	0.1700	621	0
grass	2	0.5-5	2	silt	6	0.2200	622	0
grass	2	5-10	3	silt	6	0.2700	623	0
grass	2	>10	4	silt	6	0.3200	624	0
forest	3	<0.5	1	silt	6	0.0700	631	0
forest	3	0.5-5	2	silt	6	0.1200	632	0
forest	3	5-10	3	silt	6	0.1700	633	0
forest	3	>10	4	silt	6	0.2200	634	0
bare soil	4	<0.5	1	silt	6	0.4800	641	0
bare soil	4	0.5-5	2	silt	6	0.5300	642	0
bare soil	4	5-10	3	silt	6	0.5800	643	0
bare soil	4	>10	4	silt	6	0.6300	644	0
open water	5	<0.5	1	silt	6	1.0000	651	0
open water	5	0.5-5	2	silt	6	1.0000	652	0
open water	5	5-10	3	silt	6	1.0000	653	0
open water	5	>10	4	silt	6	1.0000	654	0
crop	1	<0.5	1	sandy claylo	7	0.4300	711	0
crop	1	0.5-5	2	sandy claylo	7	0.4800	712	0
crop	1	5-10	3	sandy claylo	7	0.5300	713	0
crop	1	>10	4	sandy claylo	7	0.5800	714	0
grass	2	<0.5	1	sandy claylo	7	0.2300	721	0
grass	2	0.5-5	2	sandy claylo	7	0.2800	722	0
grass	2	5-10	3	sandy claylo	7	0.3300	723	0

grass	2	>10	4	sandy claylo	7	0.3800	724	0
forest	3	<0.5	1	sandy claylo	7	0.1300	731	0
forest	3	0.5-5	2	sandy claylo	7	0.1800	732	0
forest	3	5-10	3	sandy claylo	7	0.2300	733	0
forest	3	>10	4	sandy claylo	7	0.2800	734	0
LANDUSERO	LANDUSENUM	SLOPE_ ____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
bare soil	4	<0.5	1	sandy claylo	7	0.5300	741	0
bare soil	4	0.5-5	2	sandy claylo	7	0.5800	742	0
bare soil	4	5-10	3	sandy claylo	7	0.6300	743	0
bare soil	4	>10	4	sandy claylo	7	0.6800	744	0
open water	5	<0.5	1	sandy claylo	7	1.0000	751	0
open water	5	0.5-5	2	sandy claylo	7	1.0000	752	0
open water	5	5-10	3	sandy claylo	7	1.0000	753	0
open water	5	>10	4	sandy claylo	7	1.0000	754	0
crop	1	<0.5	1	silty claylo	8	0.4500	811	0
crop	1	0.5-5	2	silty claylo	8	0.5000	812	0
crop	1	5-10	3	silty claylo	8	0.5500	813	0
crop	1	>10	4	silty claylo	8	0.6000	814	0
grass	2	<0.5	1	silty claylo	8	0.2500	821	0
grass	2	0.5-5	2	silty claylo	8	0.3000	822	0
grass	2	5-10	3	silty claylo	8	0.3500	823	0
grass	2	>10	4	silty claylo	8	0.4000	824	0
forest	3	<0.5	1	silty claylo	8	0.1500	831	0
forest	3	0.5-5	2	silty claylo	8	0.2000	832	0
forest	3	5-10	3	silty claylo	8	0.2500	833	0
forest	3	>10	4	silty claylo	8	0.3000	834	0
bare soil	4	<0.5	1	silty claylo	8	0.5500	841	0
bare soil	4	0.5-5	2	silty claylo	8	0.5800	842	0

bare soil	4	5-10	3	silty claylo	8	0.6300	843	0
bare soil	4	>10	4	silty claylo	8	0.6800	844	0
open water	5	<0.5	1	silty claylo	8	1.0000	851	0
open water	5	0.5-5	2	silty claylo	8	1.0000	852	0
LANDUSERO	LANDUSENUM	SLOPE_____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
open water	5	5-10	3	silty claylo	8	1.0000	853	0
open water	5	>10	4	silty claylo	8	1.0000	854	0
crop	1	<0.5	1	clayloam	9	0.4800	911	0
crop	1	0.5-5	2	clayloam	9	0.5300	912	0
crop	1	5-10	3	clayloam	9	0.5800	913	0
crop	1	>10	4	clayloam	9	0.6300	914	0
grass	2	<0.5	1	clayloam	9	0.2800	921	0
grass	2	0.5-5	2	clayloam	9	0.3300	922	0
grass	2	5-10	3	clayloam	9	0.3800	923	0
grass	2	>10	4	clayloam	9	0.4300	924	0
forest	3	<0.5	1	clayloam	9	0.1800	931	0
forest	3	0.5-5	2	clayloam	9	0.2300	932	0
forest	3	5-10	3	clayloam	9	0.2800	933	0
forest	3	>10	4	clayloam	9	0.3300	934	0
bare soil	4	<0.5	1	clayloam	9	0.5800	941	0
bare soil	4	0.5-5	2	clayloam	9	0.6300	942	0
bare soil	4	5-10	3	clayloam	9	0.6800	943	0
bare soil	4	>10	4	clayloam	9	0.7300	944	0
open water	5	<0.5	1	clayloam	9	1.0000	951	0
open water	5	0.5-5	2	clayloam	9	1.0000	952	0
open water	5	5-10	3	clayloam	9	1.0000	953	0
open water	5	>10	4	clayloam	9	1.0000	954	0
crop	1	<0.5	1	sandy clay	10	0.5000	1011	0
crop	1	0.5-5	2	sandy clay	10	0.5500	1012	0
crop	1	5-10	3	sandy clay	10	0.6000	1013	0
crop	1	>10	4	sandy clay	10	0.6500	1014	0
grass	2	<0.5	1	sandy clay	10	0.3000	1021	0
grass	2	0.5-5	2	sandy clay	10	0.3500	1022	0
grass	2	5-10	3	sandy clay	10	0.4000	1023	0
grass	2	>10	4	sandy clay	10	0.4500	1024	0

forest	3	<0.5	1	sandy clay	10	0.2000	1031	0
forest	3	0.5-5	2	sandy clay	10	0.2500	1032	0
forest	3	5-10	3	sandy clay	10	0.3000	1033	0
LANDUSERO	LANDUSE NUM	SLOPE_____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
forest	3	>10	4	sandy clay	10	0.3500	1034	0
bare soil	4	<0.5	1	sandy clay	10	0.6000	1041	0
bare soil	4	0.5-5	2	sandy clay	10	0.6500	1042	0
bare soil	4	5-10	3	sandy clay	10	0.7000	1043	0
bare soil	4	>10	4	sandy clay	10	0.7500	1044	0
open water	5	<0.5	1	sandy clay	10	1.0000	1051	0
open water	5	0.5-5	2	sandy clay	10	1.0000	1052	0
open water	5	5-10	3	sandy clay	10	1.0000	1053	0
open water	5	>10	4	sandy clay	10	1.0000	1054	0
crop	1	<0.5	1	siltyclay	11	0.5300	1111	0
crop	1	0.5-5	2	siltyclay	11	0.5800	1112	0
crop	1	5-10	3	siltyclay	11	0.6300	1113	0
crop	1	>10	4	siltyclay	11	0.6800	1114	0
grass	2	<0.5	1	siltyclay	11	0.3300	1121	0
grass	2	0.5-5	2	siltyclay	11	0.3800	1122	0
grass	2	5-10	3	siltyclay	11	0.4300	1123	0
grass	2	>10	4	siltyclay	11	0.4800	1124	0
forest	3	<0.5	1	siltyclay	11	0.2300	1131	0
forest	3	0.5-5	2	siltyclay	11	0.2800	1132	0
forest	3	5-10	3	siltyclay	11	0.3300	1133	0
forest	3	>10	4	siltyclay	11	0.3800	1134	0
bare soil	4	<0.5	1	siltyclay	11	0.6300	1141	0
bare soil	4	0.5-5	2	siltyclay	11	0.6800	1142	0
bare soil	4	5-10	3	siltyclay	11	0.7300	1143	0
bare soil	4	>10	4	siltyclay	11	0.7800	1144	0
open water	5	<0.5	1	siltyclay	11	1.0000	1151	0
open water	5	0.5-5	2	siltyclay	11	1.0000	1152	0
open water	5	5-10	3	siltyclay	11	1.0000	1153	0
open water	5	>10	4	siltyclay	11	1.0000	1154	0
crop	1	<0.5	1	clay	12	0.5500	1211	0
crop	1	0.5-5	2	clay	12	0.6000	1212	0
crop	1	5-10	3	clay	12	0.6500	1213	0

crop	1	>10	4	clay	12	0.7000	1214	0
grass	2	<0.5	1	clay	12	0.3500	1221	0
grass	2	0.5-5	2	clay	12	0.4000	1222	0
grass	2	5-10	3	clay	12	0.4500	1223	0
LANDUSERO	LANDUSENUM	SLOPE_____	SLOPENUM	SOILTYPE	SOILNUM	RUNOFFCOEF	UNIQUE_NUM	SOIL_BARE
grass	2	>10	4	clay	12	0.5000	1224	0
forest	3	<0.5	1	clay	12	0.2500	1231	0
forest	3	0.5-5	2	clay	12	0.3000	1232	0
forest	3	5-10	3	clay	12	0.3500	1233	0
forest	3	>10	4	clay	12	0.4000	1234	0
bare soil	4	<0.5	1	clay	12	0.6500	1241	0
bare soil	4	0.5-5	2	clay	12	0.7000	1242	0
bare soil	4	5-10	3	clay	12	0.7500	1243	0
bare soil	4	>10	4	clay	12	0.8000	1244	0
open water	5	<0.5	1	clay	12	1.0000	1251	0
open water	5	0.5-5	2	clay	12	1.0000	1252	0
open water	5	5-10	3	clay	12	1.0000	1253	0
open water	5	>10	4	clay	12	1.0000	1254	0

SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
1	0.4500	11	city center	1	1	0.50	11
2	0.4800	12	city center	1	2	0.60	12
3	0.5300	13	city center	1	3	0.70	13
4	0.5800	14	city center	1	4	0.80	14
1	0.4800	21	build up	2	1	0.40	21
2	0.5300	22	build up	2	2	0.50	22
3	0.5800	23	build up	2	3	0.60	23
4	0.6300	24	build up	2	4	0.70	24
1	0.5000	31	open buildu	3	1	0.30	31
2	0.5500	32	open buildu	3	2	0.40	32
3	0.6000	33	open buildu	3	3	0.50	33
4	0.6500	34	open buildu	3	4	0.60	34
1	0.5300	41	infrastructu	4	1	0.30	41
2	0.5800	42	infrastructu	4	2	0.40	42
3	0.6300	43	infrastructu	4	3	0.50	43
4	0.6800	44	infrastructu	4	4	0.60	44
1	0.5000	51	highway	5	1	0.30	51
2	0.5500	52	highway	5	2	0.40	52
3	0.6000	53	highway	5	3	0.50	53

4	0.6500	54	highway	5	4	0.60	54
1	0.4800	61	district roa	6	1	0.30	61
2	0.5300	62	district roa	6	2	0.40	62
SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
3	0.5800	63	district roa	6	3	0.50	63
4	0.6300	64	district roa	6	4	0.60	64
1	0.5300	71	sea harbour	7	1	0.30	71
2	0.5800	72	sea harbour	7	2	0.40	72
3	0.6300	73	sea harbour	7	3	0.50	73
4	0.6800	74	sea harbour	7	4	0.60	74
1	0.5500	81	airport	8	1	0.50	81
2	0.5800	82	airport	8	2	0.60	82
3	0.6300	83	airport	8	3	0.70	83
4	0.6800	84	airport	8	4	0.80	84
1	0.5800	91	industry	9	1	0.30	91
2	0.6300	92	industry	9	2	0.40	92
3	0.6800	93	industry	9	3	0.50	93
4	0.7300	94	industry	9	4	0.60	94
1	0.6000	101		0	0	0.00	0
2	0.6500	102		0	0	0.00	0
3	0.7000	103		0	0	0.00	0
4	0.7500	104		0	0	0.00	0
1	0.6300	111		0	0	0.00	0
2	0.6800	112		0	0	0.00	0
3	0.7300	113		0	0	0.00	0
4	0.7800	114		0	0	0.00	0
1	0.6500	121		0	0	0.00	0
2	0.7000	122		0	0	0.00	0
3	0.7500	123		0	0	0.00	0
4	0.8000	124		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0

0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0

SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0

SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0

SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0

SLOPE_BARE	BAREROCOEF	UNIQUEBARE	IMPLUSERO	NUM_IMP_RO	SLOPE_IMP	IMPROCOEF	UNIQUEIMP
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
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0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0
0	0.0000	0		0	0	0.00	0

Table A-6: WetSpass landuse parameters

NUMBER	LUSE_TYPE	RUNOFF_VEG	NUM_VEG_RO	NUM_IMP_RO	VEG_AREA	BARE_AREA
1	city center build up	grass	2	1	0.2000	0.0000
2	build up	grass	2	2	0.5000	0.0000
10	open build up	grass	2	3	0.6000	0.1000
4	infrastructure	grass	2	4	0.6000	0.1000
201	highway	grass	2	5	0.6000	0.1000
202	district road	grass	2	6	0.6000	0.1000
5	sea harbour	grass	2	7	0.6000	0.1000
6	airport	grass	2	8	0.2000	0.0000
3	industry	grass	2	9	0.4000	0.0000
7	excavation	bare soil	4	0	0.0000	1.0000
21	agriculture	crop	1	0	0.8000	0.2000
27	maize and tuberous p	crop	1	0	0.8000	0.2000
23	meadow	grass	2	0	1.0000	0.0000
28	wet meadow	grass	2	0	1.0000	0.0000
29	orchard	forest	3	0	0.8000	0.2000
31	deciduous forest	forest	3	0	1.0000	0.0000
32	coniferous forest	forest	3	0	1.0000	0.0000
33	mixed forest	forest	3	0	1.0000	0.0000
36	shrub	grass	2	0	1.0000	0.0000
35	heather	grass	2	0	1.0000	0.0000
54	sea	open water	5	0	0.0000	0.0000
53	estuary	open water	5	0	0.0000	0.0000
44	mud flat/salt marsh	open water	5	0	0.4000	0.2000
37	beach/dune	bare soil	4	0	0.3000	0.7000
51	navigable river	open water	5	0	0.0000	0.0000
55	unnavigable river	open water	5	0	0.0000	0.0000
52	lake	open water	5	0	0.0000	0.0000
301	spruce	forest	3	0	1.0000	0.0000
302	pine	forest	3	0	1.0000	0.0000
303	beech	forest	3	0	1.0000	0.0000
304	birch	forest	3	0	1.0000	0.0000
305	oak	forest	3	0	1.0000	0.0000
306	poplar	forest	3	0	1.0000	0.0000
307	reference grass	grass	2	0	1.0000	0.0000

IMP_AREA	OPENW_AREA	ROOT_DEPTH	LAI	MIN_STOM	INTERC_PER	VEG_HEIGHT
0.8000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.5000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.3000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.3000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.3000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.3000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.3000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.8000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.6000	0.0000	0.3000	2.00	100.00	10.00	0.1200
0.0000	0.0000	0.0500	0.00	110.00	0.00	0.0010
0.0000	0.0000	0.4000	4.00	180.00	15.00	0.6000
0.0000	0.0000	0.3000	4.00	180.00	15.00	1.5000
0.0000	0.0000	0.3000	2.00	100.00	10.00	0.2000
0.0000	0.0000	0.3000	2.00	100.00	10.00	0.3000
0.0000	0.0000	0.8000	6.00	150.00	25.00	3.0000
0.0000	0.0000	2.0000	5.00	250.00	25.00	18.0000
0.0000	0.0000	2.0000	6.00	500.00	45.00	15.0000
0.0000	0.0000	2.0000	5.00	375.00	35.00	16.0000
0.0000	0.0000	0.6000	6.00	110.00	15.00	2.0000
0.0000	0.0000	0.2000	6.00	110.00	15.00	0.7500
0.0000	1.0000	0.0500	0.00	110.00	0.00	0.0000
0.0000	1.0000	0.0500	0.00	110.00	0.00	0.0000
0.0000	0.4000	0.3000	2.00	110.00	10.00	0.5000
0.0000	0.0000	0.5000	2.00	110.00	15.00	1.0000
0.0000	1.0000	0.0500	0.00	110.00	0.00	0.0000
0.0000	1.0000	0.0500	0.00	110.00	0.00	0.0000
0.0000	1.0000	0.0500	0.00	110.00	0.00	0.0000
0.0000	0.0000	2.0000	12.00	320.00	55.00	13.0000
0.0000	0.0000	2.0000	6.00	550.00	40.00	15.0000
0.0000	0.0000	2.0000	6.00	320.00	25.00	20.0000
0.0000	0.0000	2.0000	5.00	320.00	25.00	16.0000
0.0000	0.0000	2.0000	4.00	150.00	25.00	17.0000
0.0000	0.0000	2.0000	5.00	250.00	30.00	18.0000
0.0000	0.0000	0.3000	2.00	140.00	10.00	0.1200

Table A-7: WetSpass Input files units

Parameter	**Unit**
Groundwater depth	m
precipitation	mm/y
Openwater evaporation	mm/y
Temperature	^{o}C
Wind speed	m/s
Topography	m
Slope	%

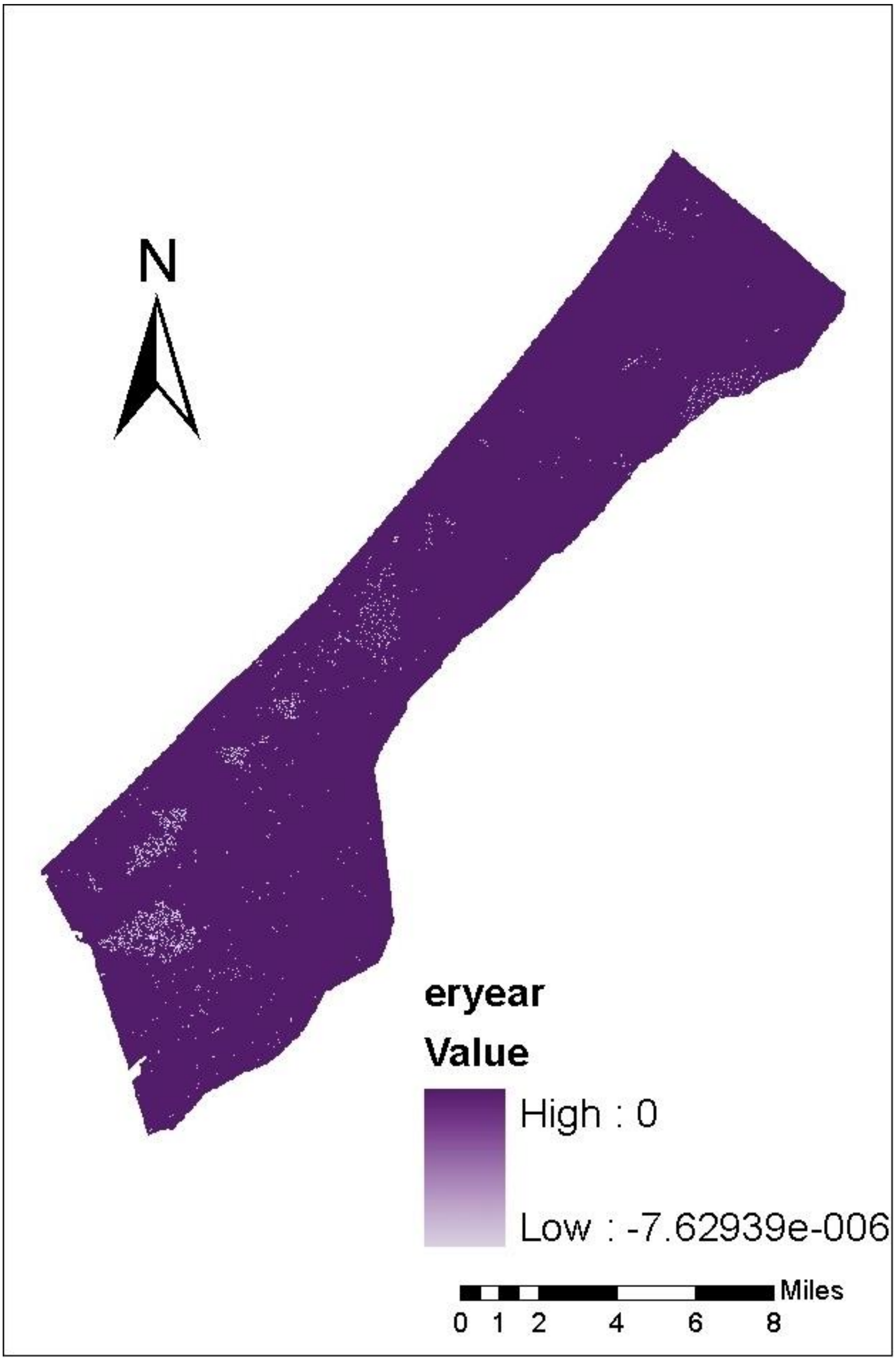

Figure A-1 Error map percentage in WetSpass model (year 1995)

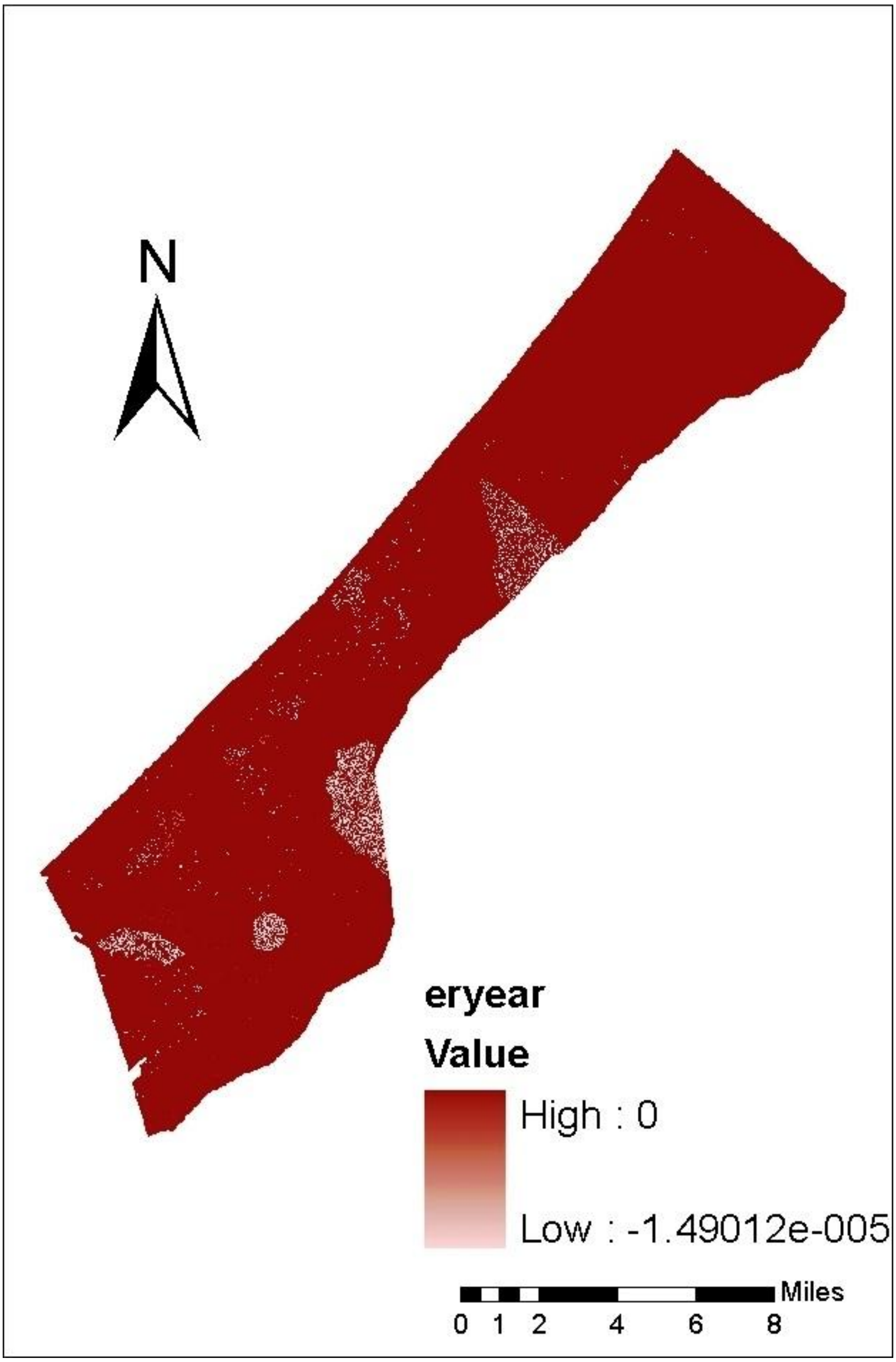

Figure A-2 Error map percentage in WetSpass model (year 2000)

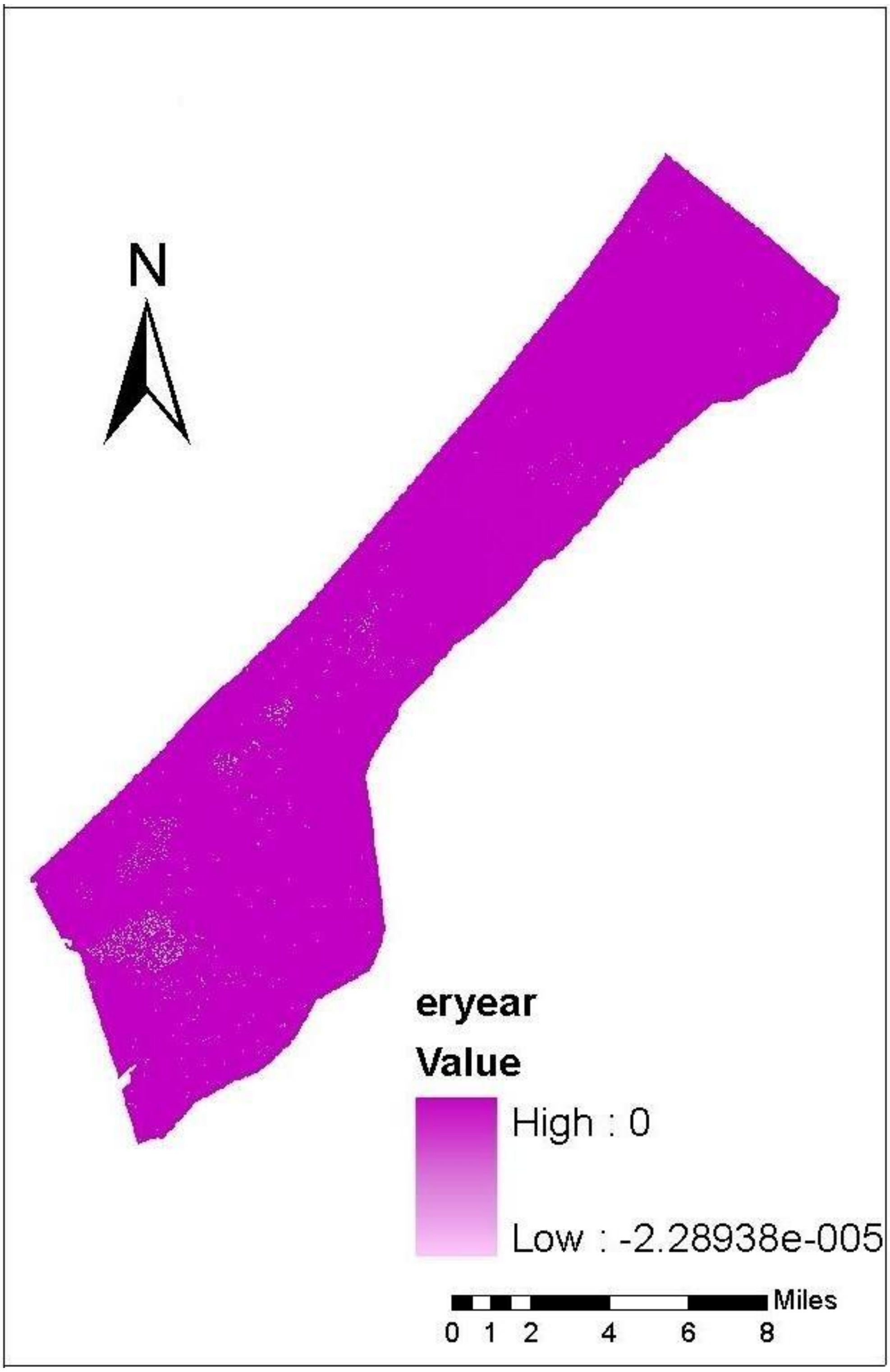

Figure A-3 Error map percentage in WetSpass model (year 2005)

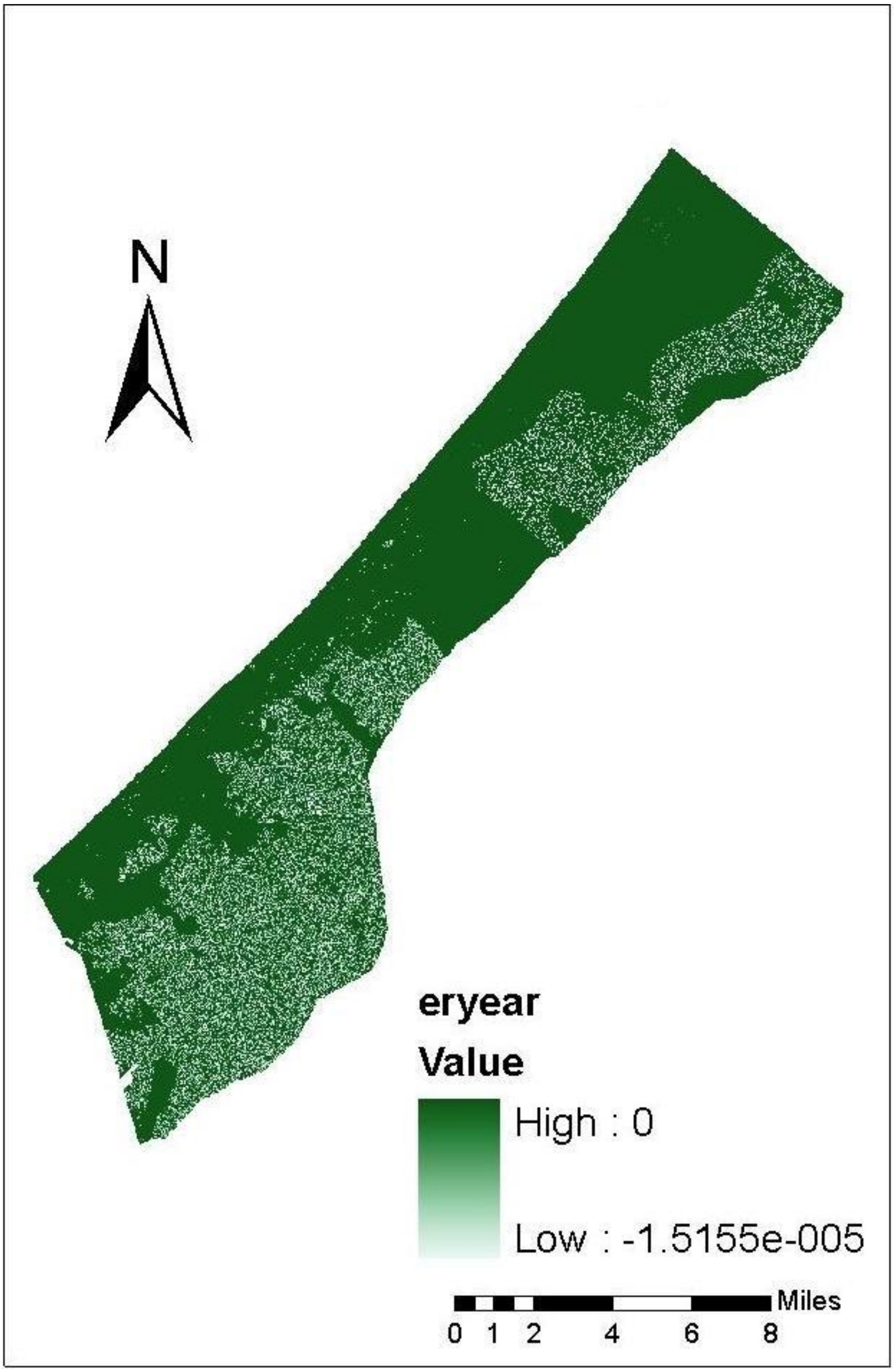

Figure A-4 Error map percentage in WetSpass model (year 2010)

ANNEX 2

Table B-1: Initial Groundwater Level inserted to the MODFLOW model in 1st October 2004

Well Name	X Coordinate	Y coordinate	WL /MSL
A/31	102773	106052	-3.33
A/47	103102	107074	-1.85
A/53	102191	106917	-3.51
A/64	103330	108097	5.95
A/107	101218	107482	-2.47
C/126	104656	106018	-0.69
C/30	106604	104471	0.54
C/49	1060028	105245	0.20
C/61	105984	104040	0.50
C/78	104931	104934	-0.50
CAMP - 12	96338	100535	1.65
CAMP - 13	92594	97658	1.20
CAMP - 1A	103594	107123	-0.56
CAMP - 1B	103596	107124	-0.55
CAMP - 2	104578	105088	-0.73
CAMP - 3A	98491	104403	-2.68
CAMP - 3B	98493	104400	-2.99
CAMP - 4	97738	96579	2.11
D/34	100921	106288	-4.49
E/116	100647	103487	-3.88
E/12	101589	104298	-1.18
E/32	99053	106225	-0.93
E/45	99823	105405	-3.55

Well Name	X Coordinate	Y coordinate	WL /MSL
F/121	96218	95435	1.52
F/21	94056	95964	0.37
F/43	94145	97594	1.43
F/68B	94998	96627	0.68
F/84	96192	97994	1.89
G/10	91189	96149	-0.53
G/24B	92377	98909	0.21
G/26	91922	94939	0.86
Piezo. 24	99269	107327	-0.19
Piezo. 25A	99920	106651	-2.43
Piezo. 25B	99920	106651	-2.16
Piezo. 26A	100549	108580	-0.31
Piezo. 26B	100549	108580	-0.29
Piezo. 27	100870	107858	-1.78
Piezo. 2A	98330	105800	-1.30
Piezo. 2B	98330	105800	-0.27
Piezo. 2C	98330	105799	-0.38
Piezo. 2D	98329	105798	-3.09
Piezo. 2E	98329	105798	-1.70
Piezo. 2F	98329	105798	-0.02
Piezo. 36A	98979	105215	-1.97
Piezo. 36B	98979	105215	-2.96
Piezo. 3A	93621	95544	0.67
Piezo. 3B	93621	95544	0.67
Piezo. 8A	95579	98226	2.06
Piezo. 8B	95575	98224	1.82
Q/2	103785	104376	-2.13

Well Name	X Coordinate	Y coordinate	WL /MSL
R/133	96773	101064	0.88
R/161	97637	104909	0.52
R/210	94911	101914	0.71
R/216	101523	101059	-1.12
R/38	102027	101783	-1.28
R/84	99419	98988	1.07
R/I/69	96681	100107	2.05

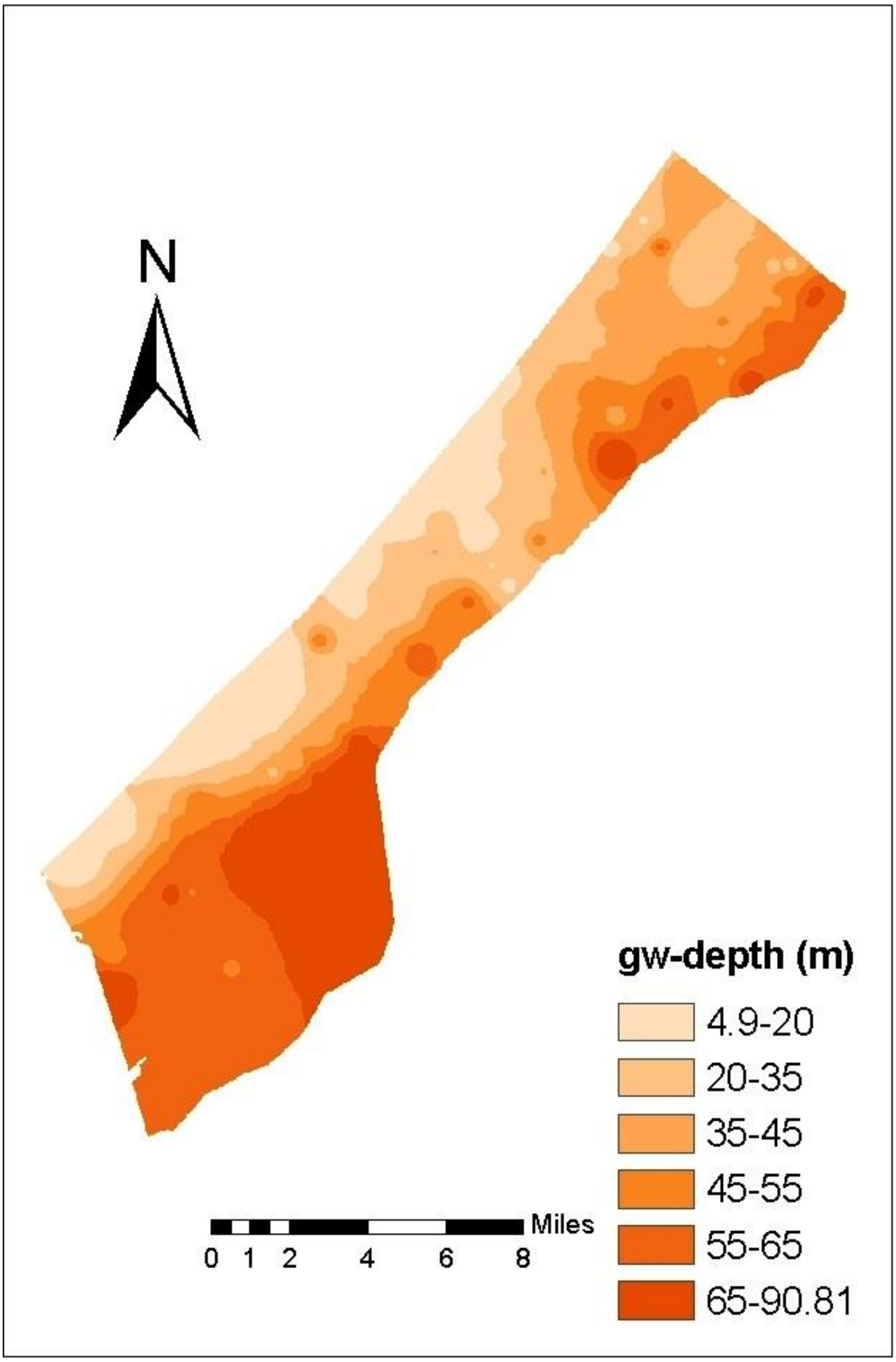

Figure B-1 Groundwater depth in the Gaza Strip (year 1990)

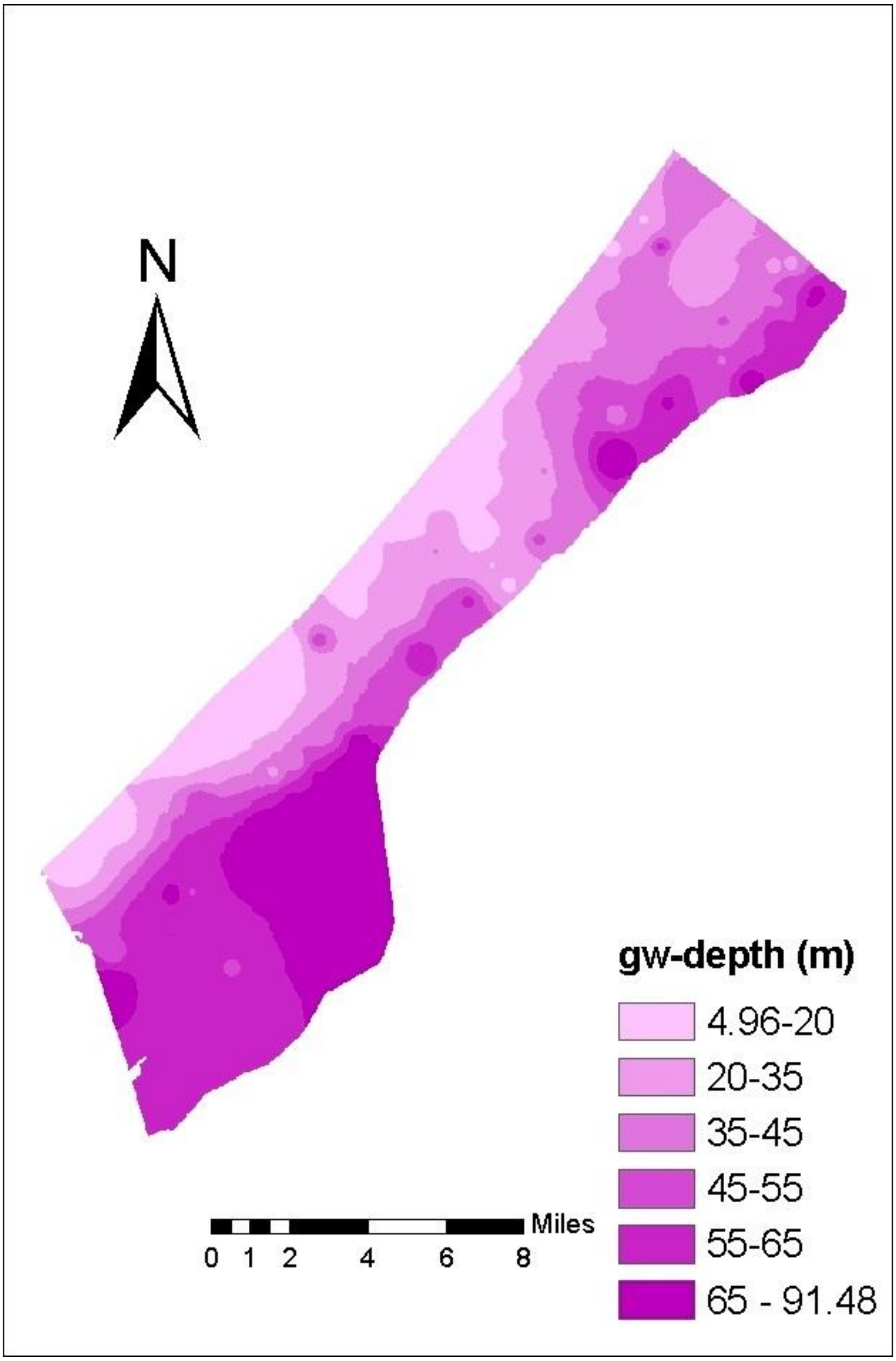

Figure B-2 Groundwater depth in the Gaza Strip (year 1995)

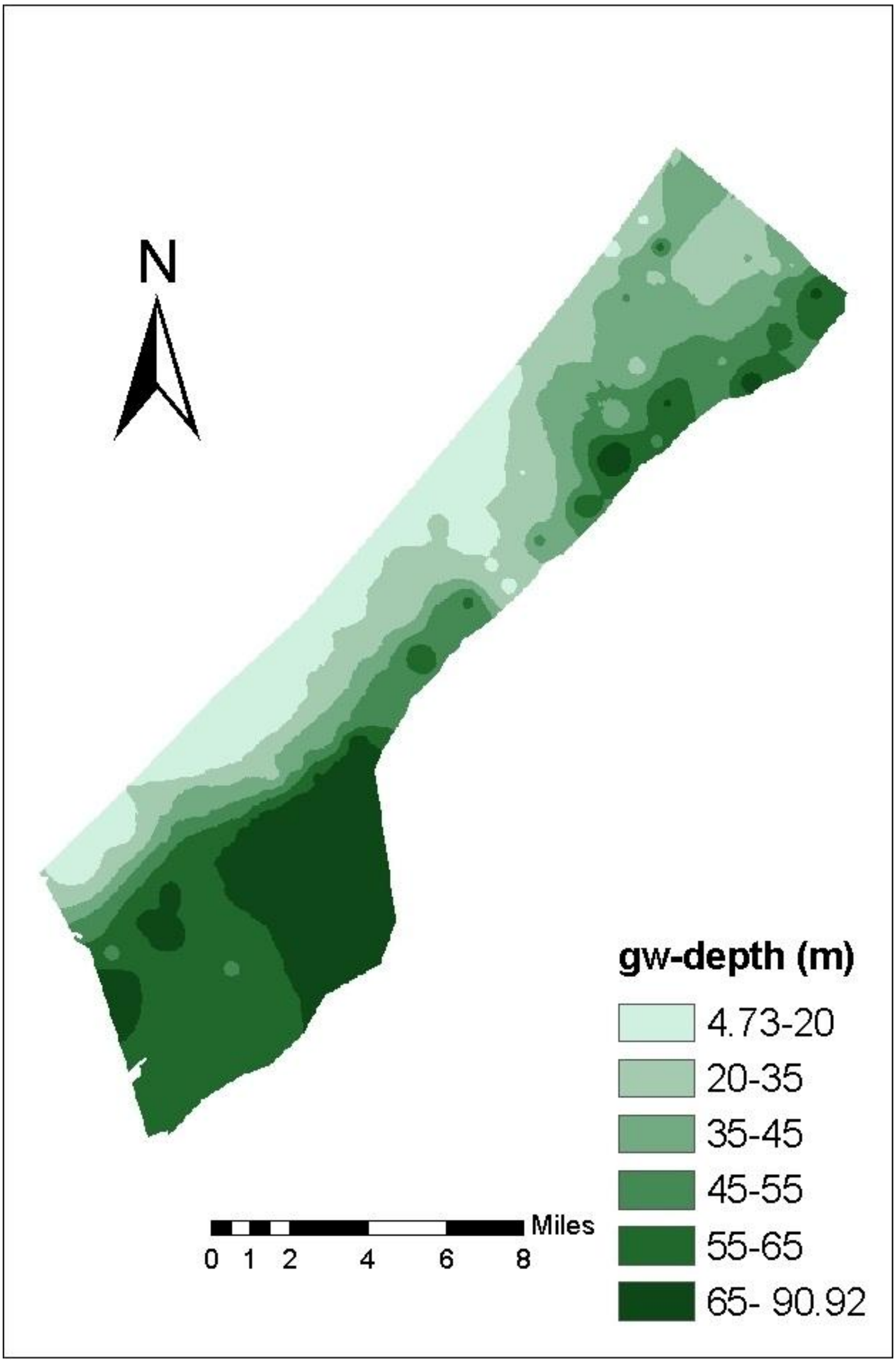

Figure B-3 Groundwater depth in the Gaza Strip (year 2000)

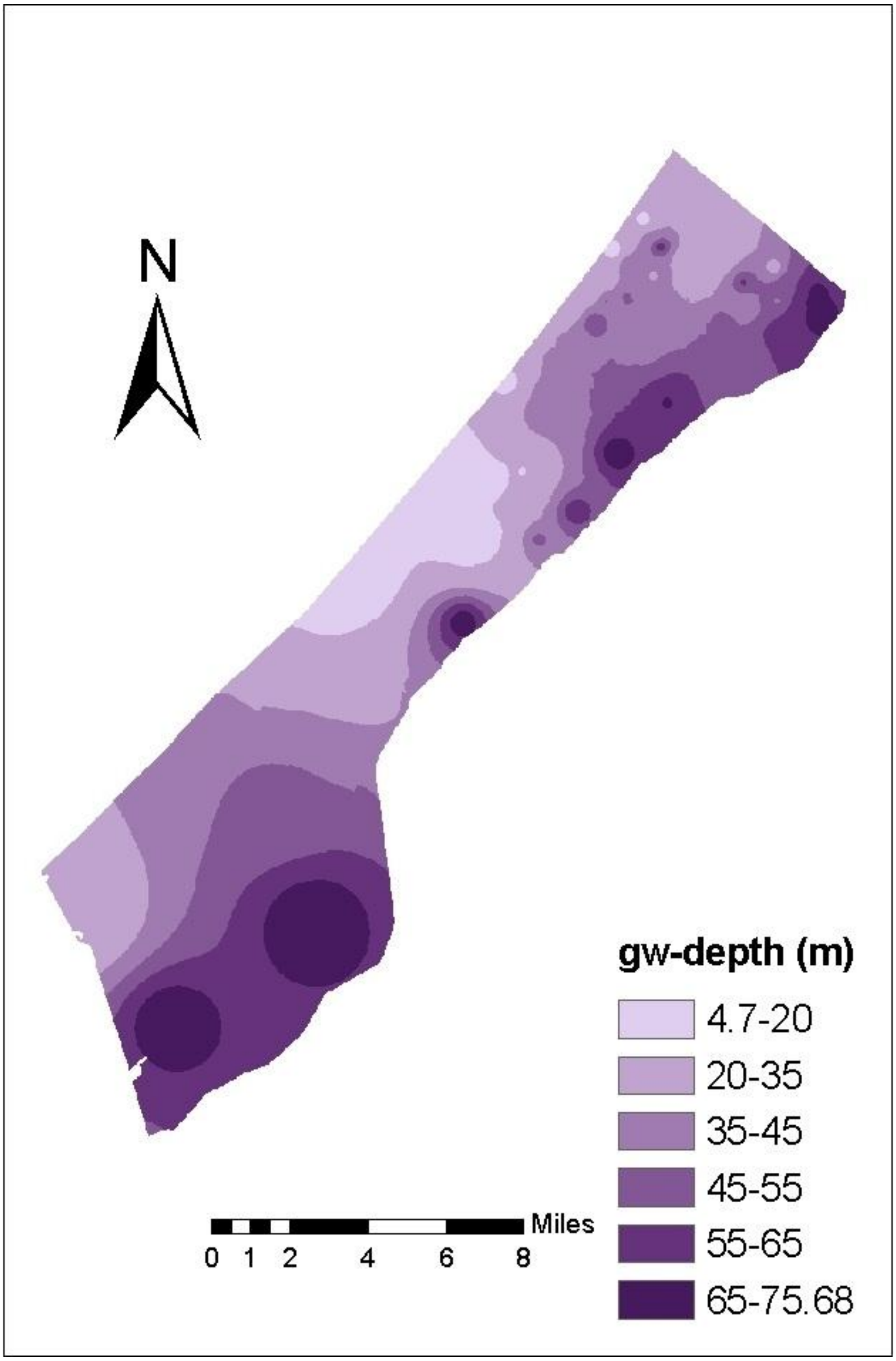

Figure B-4 Groundwater depth in the Gaza Strip (year 2005)

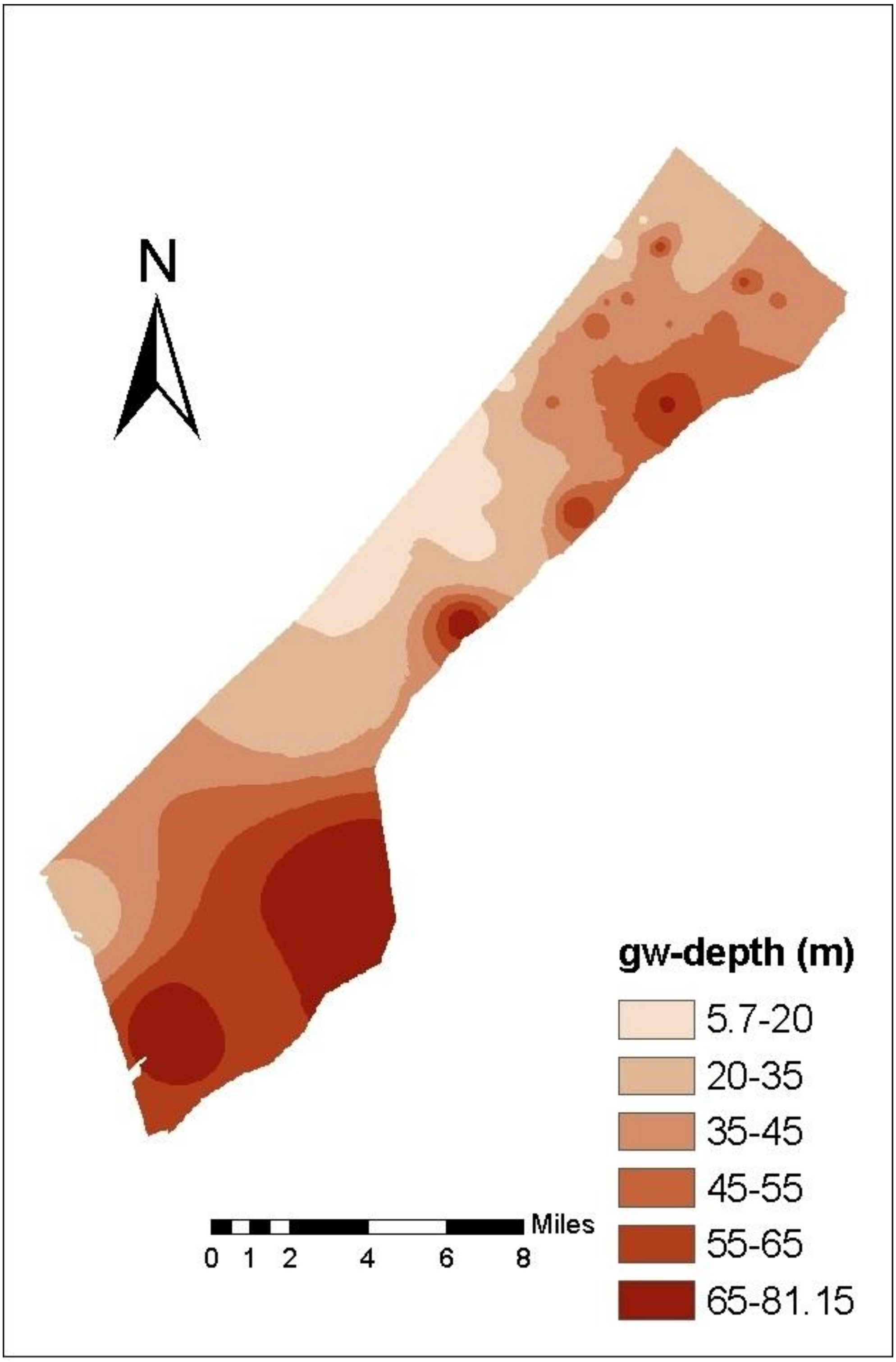

Figure B-5 Groundwater depth in the Gaza Strip (year 2010)