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Risk Assessment and Mitigation of the Seawater Intrusion Using Modeling Approach

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Infrastructure engineering

1433هـ - 2012م

ACKNOWLEDGMENTS

First of all, thanks God for his care and grace.

I would like to extend my deepest and humble gratitude to my promoters Dr. Yunes Mogheir for his invaluable supervision, helpful suggestions and priceless support during the period of my study. Thank you very much.

Also, I send my deepest thanks to the whole staff of civil engineering department in the Islamic University of Gaza, especially those who taught me.

I wish to express my deepest thanks to Eng. Jamal Al-Dadah , Ahmed Al-Yaqobey and Mohammed Abu Shamala from Palestinian Water Authority for there great help..

Additionally, thanks go to my colleagues in the Infra structure engineering program.

My ultimate respect and appreciation to all my family members, especially my father and mother for their moral support and their faithful prayers.

Mohammed Altalmas

August ,2012

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Symbol	Description
AR	Artificial Recharge
BLWWTP	Biet Lahia Waste Water Treatment Plant
CM	Cubic Meter
CMWU	Coastal Muncipalities Water Authority
GWWTP	Gaza Waste Water Treatment Plant
IAMP	Integrated Aquifer Management Plan
IUG	Islamic university of Gaza
MCM	Million Cubic Meter
MOA	Ministry of agriculture
MOG	Municipality of Gaza
MOI	Ministry of interior
PCBS	palestinian Central Bureau of statistics
PPM	Part Per Million
PWA	Palestinian Water Authority
UNDP	Unaited Nations Development Programme
WHO	World health Organization
WWTP	Waste Water Treatment Plant

Abstract

Groundwater is one of the most precious natural resources in the Gaza Strip as it is the only source of drinking water for the majority of the population. The increasing of salinity problem and the dropping in water level are two of the most important and widespread of the numerous potential groundwater problems. The salinity sources in the groundwater of Gaza Strip are from the intrusion of the seawater which caused by increased abstraction from the wells. The problem of high salinity concentrations in drinking water exceeded the WHO standards of 250 mg/l constitutes a major health risk to both humans and stock life. The chloride concentration reached to 1500 mg/l in some wells. The water level will drop to -10 M.S.L in some area in north of Gaza strip within 10 years if the levels of abstraction continues in this regime.

Therefore, this work tried to study the increase of chloride concentration and the drop of level of groundwater in North of Gaza Strip area as a result of seawater intrusion. A coupled flow and transport model using a three-dimensional, finite difference simulation model (VMODFLOW Pro.) was applied to simulate the Northern part of Gaza coastal aquifer. Model application was carried out in two steps; (a) The calibrated flow and transport model was used to study management scenarios for the Seawater intrusion problem, (b) Simulation of chloride concentration and water level transport in the Northern part of Gaza Strip coastal aquifer to estimate transport parameters. The approach for selecting the management scenarios was carried out depending on the need to reduce the transport of chloride concentration and improving the water level into the aquifer system during the next 10 years. Six selected management scenarios were tested; (1) work as usual (zero scenario), (2) Management of the pumping to 50%, (3) Injection of treated wastewater to the aquifer, (4) combining the previous two scenarios together, (5) Reduction the abstraction to 20% and injection of treated wastewater (6) Injection of treated wastewater and stopping the abstraction from the aquifer. The best scenario to solve the increasing of chloride concentration and dropping in water level problems in the groundwater is the implementation of the sixth scenario from 2012 to 2020 which cause rising of water level and reversing the seawater toward west.

Abstract in Arabic

الملخص

تقييم ودرء أخطار تداخل مياه البحر باستخدام نظام المحاكاة حالة الدراسة : شمال قطاع غزة

تعتبر المياه الجوفية من أهم الموارد الطبيعية في قطاع غزة وهي مصدر مياه الشرب الرئيسي بالنسبة لغالبية السكان في قطاع غزة . ان تزايد مشكلة الملوحة وانخفاض منسوب المياه هما أهم مشكلتين متعلقتين بالمياه في قطاع غزة. إن سبب الملوحة للمياه الجوفية في قطاع غزة هي تقدم مياه البحر نتيجة الازدياد المضطرد في السحب من الآبار. لقد تجاوزت مشكلة الملوحة العالية المعايير التي تضعها منظمة الصحة العالمية وهي 250 ملغم /لتر وهذا يشكل خطر على حياة البشر. لقد بلغ تركيز الكلورايد في بعض الآبار في قطاع غزة 1500 ملغم /لتر ، و كذلك سينخفض مستوى المياه الجوفية الى -10 متر تحت مستوى سطح البحر خلال عشر سنوات اذا استمرت معدلات السحب بهذا النمط.

هذه الدراسة سوف تعمل على دراسة تزايد تركيز الكلورايد و هبوط مستوى المياه في المنطقة الشمالية من قطاع غزة كنتيجة لمشكلة تداخل مياه البحر باستخدام نموذج رياضي . تم استخدام نظام المحاكاة (ModFlow) ثلاثي الأبعاد لمحاكاة التدفق والانتقال للمياه الجوفية في المنطقة الشمالية من قطاع غزة وتمت منهجية الدراسة على مرحلتين (أ) استخدام النموذج بعد معايرته لدراسة السيناريوهات المختلفة لإدارة الخزان الجوفي بما يتعلق بمشكلة تداخل مياه البحر . (ب) محاكاة انتقال الكلورايد داخل المياه الجوفية لتحديد معاملات الانتقال الخاصة بالخزان الجوفي .

تم دراسة ستة سيناريوهات مختلفة للعوامل التي تؤثر في الخزان الجوفي وهي كالتالي، (1) الاستمرار في الوضع القائم، (2) إنقاص معدلات السحب الى النصف، (3) حقن المياه العادمة المعالجة إلى الخزان الجوفي، (4) الجمع بين السيناريوهين السابقين، (5) إنقاص معدلات السحب إلى 20% مع حقن المياه العادمة المعالجة و (6) إيقاف السحب من الخزان الجوفي بالإضافة إلى حقن المياه العادمة المعالجة .

إن أفضل سيناريو تم للحد من تداخل مياه البحر هو السيناريو السادس والذي ينصح بإيقاف السحب من الخزان الجوفي من سنة 2012 بالإضافة إلى حقن المياه العادمة المعالجة وهذا يسبب تراجع مياه البحر وارتفاع مستوى المياه في الخزان الجوفي.

Chapter One

Introduction

1.1 Introduction

Water is an extremely important issue in every community in the world. Without water, there is no life. Water can create wars or be the key to regional cooperation. The effective management of water resources is essential to the development of medical, social, agricultural and industrial development in all countries, especially the developing ones.

In Gaza Strip , it was noticed that drinking water problems are increasing in terms of quality and quantity. Gaza Strip suffers from several problems related to water. The most common problem is the sea water intrusion gradually as sea water intrusion reached about 2 km towards east and salination averages reached about 1500 mg/l (R-299 well) (PWA, 2009).

The sea water Intrusion is the phenomena of the movement of the sea water into the coastal freshwater aquifers, due to natural processes or human activities. Sea water intrusion is caused by the decreases in groundwater levels, or by rising in the sea water level. Sea Water Intrusion lead to different environmental consequences like increase the chloride concentration , drop in groundwater level, increase soil salinity and increase in health problems.

The Gaza coastal aquifer is the only natural source of water supply in the Gaza strip for drinking water. Groundwater is intensely overused due to the continuous growth of the population. The water supply for Gaza strip is provided from the shallow sandy coastal aquifer. Over-pumping has been causing seawater intrusion (Hussien et al., 2010). In the coastal margins of the Gaza strip, seawater intrusion is still expanding and the salinity of many wells has increased (MOA records, 2009). The aquifer is unconfined in many places in the strip, thus the infiltration of the contaminants is easy through the surface soil layer (Hussien et al., 2010).

Many water quality parameters presently exceed World Health Organization (WHO) and the Palestinian Water Authority (PWA) drinking water standards. The increasing salinity, which is often described by the concentration of chloride in groundwater, is one of the important problems that affect the usability of water for drinking, usage, irrigation and water supply. PWA said that "there are a serious deterioration in water quality, mainly in wells that are located at the shoreline proximity (Hussien, et al , 2010).

Moreover; high nitrates may have carcinogenic effects for adults. While the presence of chlorides may not be as harmful as that of nitrates, the salinity it causes makes the water unacceptable for drinking. Therefore, low level of chlorides is critical for customer satisfaction. In most areas, salinity rates are increasing with time.

In Gaza city, 60 artesian wells are operating to produce bout 80000 cubic meter of drinkable water, related to drinking water quality, daily tests results assure that the microbiological side is safe, but from chemical side about 80 % of drinking water denote that the chloride and nitrates averages are over allowed average for WHO (Aldameer Institution for Human Rights Report, 2010).

Gaza municipality mixes the most sweetness water which comes from north Gaza and Jabalia with salty water to dilute this problem to gain acceptable to some extent for water (Aldameer Institution for Human Rights, 2010).

CMWU explained that , the solution of water crisis in Gaza strip will not finish by some projects and small desalination plants and digging new wells since solve the crisis of drinking water that reaches citizen houses. CMWU registered that in 2010 the produced amount of water reached 91 MCM due to the increasing population (Aldameer Institution for Human Rights , 2010).

The average rainfall in Gaza Strip did not exceed 250 mm in 2010 where it exceeded 400 mm in the last years. PWA predicts that in 2015 Gaza Strip will suffer from huge water crisis. In this time gaining drinking water will be a crucial and big challenge. Therefore, it advisable to search for new water resources before that period .There are several methods for controlling and reducing sea water intrusion in coastal aquifer these methods are modification of pumping pattern , inducing artificial recharge , installation of subsurface impermeable barrier , developing an abstraction barrier and developing an injection barrier .

1.2 Problem identification

Gaza strip suffers from several problems related to water (Quality and quantity), one of these problems is the sea water intrusion, sea water intrusion causes high salinity averages, the high salinity averages causes high chloride concentration above PWA and WHO levels which lead to several health problem like kidney failure .

In Gaza strip there were four treatment plants and huge quantity of waste water is produced, not all of these amounts of waste water is treated in these treatment plants, but huge amounts of produced waste water is going to the sea which lead to pollution of sea water in Gaza strip , Figure (1.1) illustrates the chloride concentration distribution in Gaza strip in 2009.

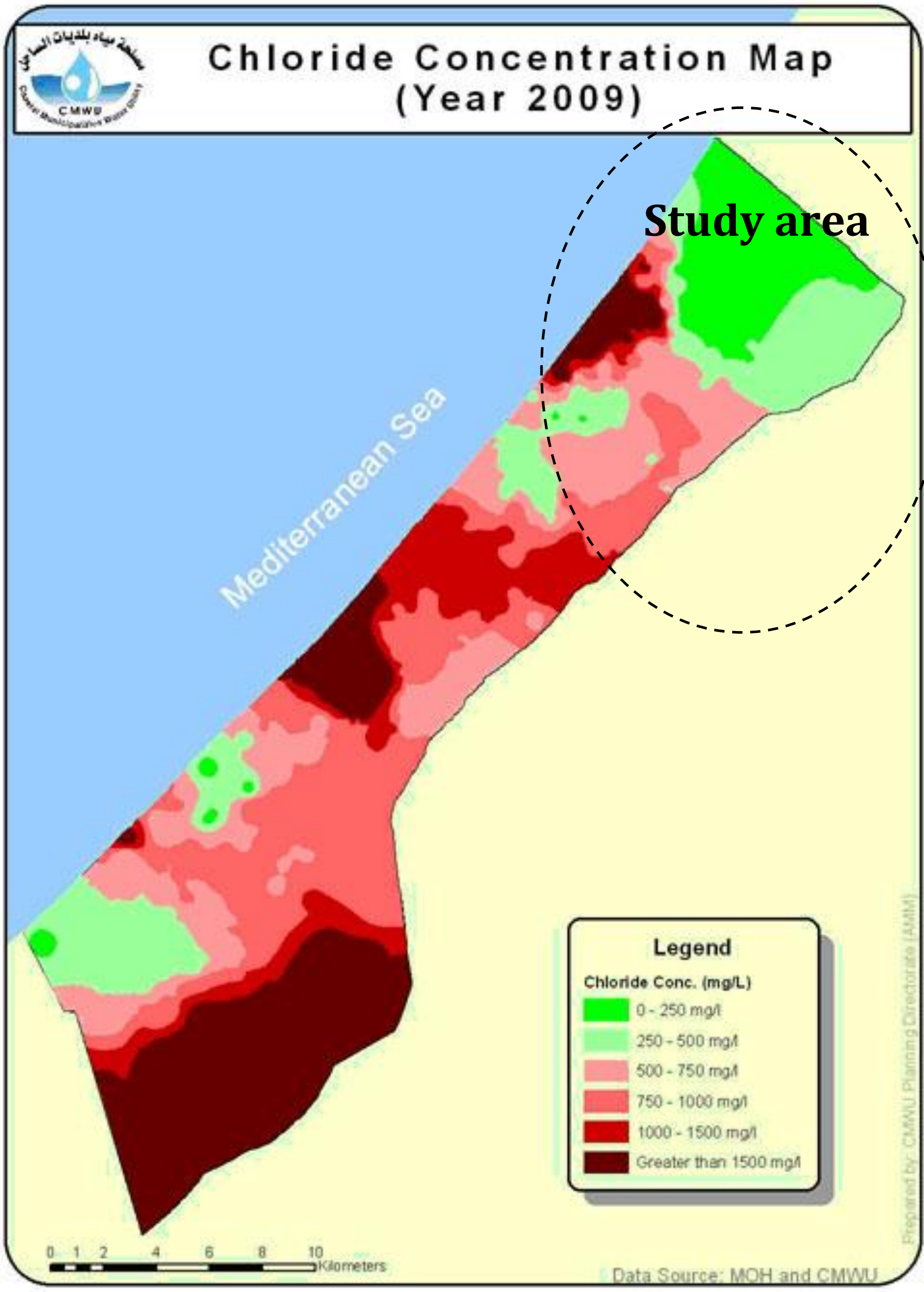

Figure 1.1: Chloride concentration in Gaza strip in 2009**.**

1.3 Objective of the research:

The objective of this research is to test by modeling approach the groundwater behavior in Northern Gaza strip using injection the treated waste water to groundwater and managing the quantities of abstracted water from the wells in the study area

1.4 Methodology

To achieve the objectives of this research, the following methodology will be applied:

- Reading of previous books, studies, papers and researches relative to the thesis title.
- Data collection from different institution and ministries.
- Building up the modflow model to identifying and quantifying the problem by analyzing the model .

Chapter Two

Literature Review

Chapter 2: Literature Review

2.1 Groundwater Modeling

A groundwater model is a representation of reality and, if properly constructed, it can be a valuable predictive tool used for management of groundwater resource. 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 .

2.1.1 General Groundwater Flow Equations

Differential equations that govern the flow of 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:

$$\frac{\partial}{\partial x}(K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(K_z \frac{\partial h}{\partial z}) + w = S_s \frac{\partial h}{\partial t} \quad \text{Eq:2.1}$$

Where Kx, Ky and Kz are the hydraulic conductivity components in the x, y and z direction (LT-1), h is the hydraulic head (L), w is the local source or sink of water per unit volume (T-1), Ss is the specific storage coefficient (L-1) and t is the time (T). Under steady state conditions, Eq. (2.1) is equal to zero as continuity requires that the amount of water flowing in to a representative elemental volume is equal to the amount flowing out, this leads to Eq. (2.2):

$$\frac{\partial}{\partial x}(K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(K_z \frac{\partial h}{\partial z}) + w = 0 \quad \text{Eq2.2}$$

In transient conditions the general flow equation is formulated by applying the law of conservation of mass over an elemental volume of an aquifer situated in the flow field in function of time. Continuity requires that the net inflow into the elemental control volume must be equal to the rate at which water is accumulating within the volume under investigation, which is outflow minus inflow equals change in storage. The change in storage is represented by the specific storage, or specific storage coefficient, Ss, which is defined asthe volume of water released from storage per volume of soil for a unit decline in hydraulic head (Alghamri, 2009).

Darcy's law

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

q = - K . grad (h)

where q is the groundwater flux (LT-1)

K is the conductivity tensor (LT-1)

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 .

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.

Where:

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

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

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

Where qx, qy, qz are the three components of the flux, and Kx, Ky, Kz the hydraulic conductivity values in the horizontal (x,y) and vertical (z) direction. In case of isotropic conditions, Kx = Ky = Kz 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 (Alramlawi,2010).

2.1.2 Ground water modeling program

2.1.2.1 Visual MODFLOW

MODFLOW is a computer program that numerically solves the three-dimensional ground-water flow equation for a porous medium by using a finite-difference method.

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 .

MODFLOW is a computer program that simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method.

2.1.2.2 Modflow

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.

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 an explanation 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 .

2.1.2.3 MT3D

is a comprehensive three-dimensional numerical model for simulating solute transport in complex hydrogeological settings. MT3D has a modular design that permits simulation of transport processes independently or jointly. MT3D is capable of modeling advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and nonlinear sorption. The new MT3D99 can also handle bio plume-type reactions, monad reactions, and daughter products. This enables MT3D99 to do multi-species reactions and simulate or assess natural attenuation within a contaminant plume. MT3D99 is linked with the USGS groundwater flow simulator, MODFLOW, and is designed specifically to handle advectively-dominated transport problems without the need to construct refined models specifically for solute transport .

2.1.2.4 MODPATH

Is a particle tracking post-processing package that was developed to compute three-dimensional flow paths using output from steady-state or transient ground-water flow simulations by MODFLOW. MODPATH uses a semi-analytic particle tracking scheme that allows an analytical expression of the particle's flow to be obtained within each finite-difference grid cell. Particle paths are computed in MODPATH by tracking particles from one cell to the next until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion. Data input for MODPATH is a combination of data files and interactive keyboard input.

Output from steady-state or transient MODFLOW simulations is used in MODPATH to compute paths for imaginary "particles" of water moving through the simulated ground-water system. In addition to computing particle paths, MODPATH keeps track of the time of travel for particles moving through the system. By carefully defining the starting locations of particles, it is possible to perform a wide range of analyses such as delineating capture and recharge areas or drawing flow nets (Alramlawi, 2010).

2.2 Groundwater Quality Modeling

Groundwater models are computer models of groundwater flow systems, and are used by hydrogeologists. Groundwater models are used to simulate and predict aquifer conditions.

"A groundwater model may be a scale model or an electric model of a groundwater situation or aquifer. Groundwater models are used to represent the natural groundwater flow in environments. Some groundwater models include (chemical) quality aspects of the groundwater. Such groundwater models try to predict the fate and movement of the chemical in natural, urban or hypothetical scenario.

Groundwater models may be used to predict the effects of hydrological changes (like groundwater abstraction or irrigation developments) on the behavior of the aquifer and are often named groundwater simulation models. Also nowadays the groundwater models are used in various water management plans for urban areas." *(http://zomobo.net/Groundwater_model).*

Groundwater models and modeling software are the focus of our software products. Products related to the following topics can be found using the search tools above: Groundwater flow modeling, groundwater transport modeling, contaminant transport modeling, particle tracking, multi-species transport modeling, reactive transport modeling, multi-phase modeling, unsaturated zone modeling, vadose zone modeling, soil vapor extraction modeling, bioremediation, natural attenuation, site remediation, pump and treat, site characterization, geostatistics, geostatistical analysis, stochastic modeling, groundwater-surface water interaction, parameter estimation, inverse modeling, calibration, salinity intrusion, density dependent flow, unconfined aquifer modeling, confined aquifer modeling, landfill design, risk assessment, and numerous other hydrogeological modeling applications.

Specific groundwater models available through Scientific Software Group for groundwater modeling include: MODFLOW, MODPATH, MT3D, MT3DMS, RT3D, SEAM3D, UTCHEM, SEEP2D, FEMWATER, MODFLOW-SURFACT, PEST ASP, UCODE, MODFLOW2000, Groundwater Modeling System - GMS, Visual MODFLOW, Groundwater Vistas, PMWin, Processing MODLFOW, FEFLOW, Argus One, ChemFLux, SVFlux, Svheat, Aqua3D, MOFAT, BioSVE, SVE_3D, Bioslurp, SWIFT2000, Flowpath II, WHI Unsat Suite Plus, SESOIL, VLEACH, GFLOW, WinFlow WinTran, TWODAN, MLAEM, AT123D, Visual Groundwater , Visual HELP, RISC WorkBench and many more *(http://www.ground-water-models.com HYPERLINK "http://www.ground-water-models.com/"/).*

2.2.1 Limitation

The water must have a constant density, dynamic viscosity (and consequently temperature) throughout the modelling domain (SEAWAT is a modified version of MODFLOW which is designed for density-dependent groundwater flow and transport). (*http://gwmodel.blogspot.com/2010/06/modflow.html).*

2.2.2 Risk in Groundwater Contamination

Both quality and quantity of the groundwater are of essential importance for the diversity of ecosystems. Lower groundwater levels and changes in groundwater quality due to man induced contamination cause loss of diversity of ecosystems and deterioration of natural reserves.(Ganoulis, 2007).

Groundwater is in danger of losing its potential functions due to the deterioration of quantity and quality. While aiming at sustainability of the use. the vital functions of groundwater reservoirs are threatened by pollution and over pumping.

One very important problem of deterioration of groundwater quality is the increasing Stalinization near the soil surface.

As groundwater moves upward, salinity is increased by dissolving of salts in the soil. When the water table rises to a depth less than two meters below soil surface, salt concentrations are further increased by evaporation and damage to vegetation and soils is then likely.

The protection of groundwater resources is based on different strategies involving either empirical or sophisticated methods. Various traditional strategies for groundwater protection range from the construction of groundwater vulnerability maps and the definition of protection perimeters around pumping wells, to the use of sophisticated optimization multi-criterion decision-making techniques under risk conditions. A very characteristic example is the definition of adequate waste disposal sites in relation to the risk of groundwater contamination. The main difficulty in designing groundwater development plans is that groundwater pollution is subject to several types of uncertainties. These are related to the high variability in space and time of the hydro geological, chemical and biological processes involved. The principal task of the engineering risk analysis is to assess the probability or risk to comply with the groundwater quality standards in the areas to be developed. For example, according to the environmental quality standards, in groundwater used for irrigation the salinity concentration may not exceed 1.000 ppm.

2.2.3 Groundwater Modeling Around the World

The simulation of ground water was used in several areas around the world The simulation of Ground water was done in the famous High Plains aquifer system, the California Central Valley aquifer system and, among others, the Florida and Great Basin aquifer systems. Computer models used in most cases were the USGS 3D finite difference model and the USGS MODLFOW. In China, several regional groundwater models have been constructed in recent years. Among them, a transient groundwater flow model was constructed for the North China Plain in order to assess its groundwater development potential.

2.2.4 Groundwater Modeling in Palestine

In Palestine there are many uses for modflow application , one of these uses is to use ModFlow applications as a predictive tool for rehabilitation and conservation of Israeli coastal aquifer in ShafDan area . This study is part of a large-scale project aimed at rehabilitation of the Israeli Coastal Aquifer. Development of a regional 3-D, transient flow and transport model of the hydrological system in the vicinity of the Dan Region Sewage Reclamation Project (SHAFDAN) is presented.

The SHAFDAN facilities include five infiltration ponds to which high-quality treated effluent is sent for soil aquifer treatment (SAT). The ponds are surrounded by recovery wells that abstract the treated water and prevent it from spread to fresh water pumping zones.

The model is used for estimating the spread of SHAFDAN water and testing operational scenarios. A 30-year forecast run showed that significant spread in the aquifer from the southern ponds is expected. The model examined two possible solutions for reducing spread: (1) increased pumpage in existing recovery wells; (2) additional wells on the eastern side of the ponds (Abbo and Gev, 2007).

Since its establishment in 1995, Palestinian Water Authority (PWA) has forced to use this modern technique in water resources management program in order to simplify the complex hydro geologic situation of groundwater aquifers and tries to understand the water regime within the entire aquifers. The ultimate goals of the (PWA) is to produce a long-term management plan that will provide rational and practical tools for management of groundwater extraction in Gaza Strip and West Bank aquifers and to identify the most potential zones that are suitable for future development (PWA, 2005).

In recognition the worsening situation of the water in Gaza Strip, PWA and United State Agency for International Development (USAID) have jointly developed the implementation of an Integrated Aquifer Management Plan (IAMP). The IAMP presented overall planning guidelines for water supply and usage through year 2020. As a result to this jointly, new model depending on Coupled Flow-Transport Modeling Code (DYNCFT) was conducted to simulate the effect of IAMP.

Some researchers attempted to model the ground water in Gaza Strip. Aish research work investigated the feasibility study on the impact of artificial recharge from a planned wastewater treatment plant on the groundwater quantity and quality of the coastal aquifer in the Gaza Strip, Palestine (Seyam .M and Moghier ,2011) .

Aish made an extensive program of hydrogeological investigation and laboratory analysis of soil samples were undertaken to assist in the design and implementation of a pilot artificial recharge system for treated wastewater to groundwater. The main concerns of the hydrogeological study was to determine the hydrological parameters, lithological description, and geological setting.

The studya area is located in the North east of Gaza city in Jabalia town.

The study area extends over 336,000 m^2, of which 212,000 m^2 is used for a treatment plant and artificial recharge basin .Three sets of boreholes have been drilled. The first set consists of 19 shallow boreholes that penetrate the silty clay layer and the underlying sandstone (kurkar). The second setconsists of five boreholes that penetrate the unsaturated zone to at least 5 mbelow the groundwater level. The last set consists of three deep boreholesand one pumping well. The deep boreholes were drilled at 100 m to 120 m depth going through the kurkar and clay formations. The pumping well was drilled at 156 m. The hydraulic conductivity of the unsaturated zone were determined by packer. Also, 5 infiltration tests were conducted to assess the infiltration capacity at the location of the proposed artificial recharge. In addition, a pumping test was also carried out to determine the hydraulic properties of the aquifer.

In the local model of the artificial recharge simulation, an analytical and numerical solution of the transient groundwater flow is used to predict the time-dependency of the groundwater response in case of the planned artificial infiltration pond of the wastewater treatment plant. The maximum rise of the groundwater mound after 100 days would be 14 m in the center of the infiltration pond and about 12 m at the edges. Regional groundwater flow simulations are made using the three-dimensional numerical model MODFLOW. The groundwater mounding has been simulated with a constant recharge of 60000 m^3/d, and an infiltration rate of 0.75 m/d, while all other hydrogeological conditions are assumed as present conditions. The simulation shows that the groundwater mound beneath the center of the recharge basin can be expected to rise to about 15 m above the present water table, and after about 2 years will be a slight increment in the groundwater mound. The native groundwater downstream of the recharge area will gradually be influenced by the water originating from the infiltrated water and the cone of depression will diminish substantially due to the infiltration.

In the solute transport model MT3D we assumed the infiltration water is at hypothetic conservative concentration of 100 mg/l that no absorption or adsorption solute is present, and that the initial concentration in the aquifer is 0 mg/l. In the analysis of the results, the 100 mg/l of solute will be considered as the reference concentration (100% injected water) and the simulated concentration in the aquifer will be expressed relative to this value. The results indicate that 90% of the infiltrated water will be mixed with the aquifer water after 1 year beneath the recharge area with decreasing percentages inthe surrounding area.

Ghabayen et al., 2010 developed a model using Bayesian belief networks (BBNs), for Identification of salinity origin. The BBN model incorporates the theoretical background of salinity sources, area specific monitoring data that are characteristically incomplete in their coverage, expert judgment, and common sense reasoning to produce a geographic distribution for the most probable sources of salinization. The model showed areas where additional data on chemical and isotopic parameters are needed to understand the contribution of each of these sources to the problem. The model has successfully identified areas where seawater intrusion, deep brines, wastewater leakage, agricultural return flows, and Eocene waters exist with high probability. It has also identified areas where there is missing information or incomplete data especially in the eastern part of the coastal aquifer outside Gaza Strip.

Barakat developed a model to find optimal values of water quantities from different resources in in the southern Gaza Strip. Visual Modflow (VMF) and its integrated modules, was developed to quantify, and analyze the raw input data. Many scenarios for domestic supply and demand reconfiguration are introduced. Genetic algorithm (GA) is used as a global optimization method, to find optimal values of water quantities from different resources. The resulted optimal values for water quantities were introduced into the groundwater model to predict water level contour maps in the next years (Seyam .M and Moghier ,2011) .

The use of ANN in groundwater quality modeling in Gaza Strip doesn't found in large scale. Al Mahalawi used ANN in Modeling Groundwater Nitrate Concentration of the Gaza Strip and Seyam and Moghier study the salinity problems in Gaza strip using artificial neural network.

Qahman study presents a trial for establishment of sustainable development and management policies for utilization of coastal aquifers represented in this study by the

Gaza Strip aquifer. Two approaches were used in this study for developing the management policies .

In the first approach, hydrochemistry and groundwater piezometry of the Gaza aquifer were studied and a numerical assessment of seawater intrusion has been achieved applying a 3-D variable density groundwater flow model. SEAWAT computer code was used for simulating the spatial and temporal evolution of hydraulic heads and solute concentration of groundwater along a cross-section in the southern part of the Gaza strip near Khan-Younis. Accordingly, 3D simulation using SEAWAT code was done for the Gaza aquifer. Two pumpage schemes were designed to use the calibrated model for prediction of future changes in water levels and solute concentration in the groundwater for planning period of 17 years. The results show that seawater intrusion would worsen in the aquifer if the current rates of groundwater pumpage continue. The alternative is, to eliminate pumpage in the intruded area, to moderate pumpage rates from water supply wells far from the seashore and to increase the aquifer replenishment by encouraging artificial recharge.

In the second approach, four management (optimization) models for sustainable use of a coastal aquifer hindered by seawater intrusion are developed and solved under steady state conditions. The objective of the first management model is to maximize the total amount of water pumped from the aquifer for beneficial use. The objective of the second management model is to maximize the economic value of selling the pumped water from the aquifer. Salt concentration of the pumped water from each pumping well was considered as a constraint in the two models. The third model is a multi-objective model and the objective of it is to maximize the total amount of water pumped for beneficial use and to minimize the total amount of salt extracted with the water. The fourth model is like the model 3, but with a constraint on hydraulic head of each pumping well. Solutions of the management models are based on a linkage between a 3D simulation model (CODESA-3D) and genetic algorithm optimization model using simulation-optimization approach. The heads and concentrations (state variables), calculated by the simulation model based on pumping rates (decision variables), are used in a Genetic Algorithm optimization procedure to achieve an optimum solution. The management models are solved for hypothetical confined aquifer. The solution results demonstrate basically the feasibility of the developed optimization models for managing extraction from coastal aquifers.

For the real world case, the two multi-objective management models, model 3 and model 4, were applied on a local-area selected from the Gaza coastal regional aquifer. The results show that using optimization/simulation approach in the Gaza Strip can improve planning and management policies and can give better decision for aquifer utilization. It confirms that the use of the concept of safe yield alone is not enough for sustainable development of the coastal aquifer. The results of application on this part of the Gaza aquifer show that the optimum pumping rate according to the results of model 4 is in the range 26%-34% of the total natural replenishment.

Aish and Qahman works where considering local application of artificial recharge, while the intended specially the Northern part of Gaza strip will consider the regional aquifer .

2.3 Artificial recharge for the groundwater:

Water-supply development is challenging. Increasing demands for water joined with concerns for environmental protection require a variety of new water management tools. Such a tool for the conjunctive use of treated wastewater and groundwater supplies is the artificial recharge (AR) of groundwater.

Artificial recharge is defined as is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Recharge occurs both naturally and anthropologically, where rainwater and or reclaimed water is routed to the subsurface (Alramlawi, 2010) .

The use of artificial recharge to store surplus surface water underground can be expected to increase as growing populations demand more water, and as the number of good dam sites still available for construction becomes fewer. For example, artificial recharge may be used to store treated sewage effluent and excess storm water runoff for later use. Groundwater recharge may also be used to mitigate or control saltwater intrusion into coastal aquifers. *(http://www.oas.org/dsd/publications/unit/oea59e/ch18.htm).*

A variety of methods have been developed and applied to artificially recharge groundwater reservoirs in various parts of the world. Details of these methods, as well as related topics, can be found in the literature .The methods may be generally classified in the following four categories:Direct Surface Recharge Technique , Direct Subsurface Recharge Technique, Combination surface-subsurface methods, including subsurface drainage and basins with pits, shafts, and wells and Indirect Recharge Techniques.

The advantages of groundwater storage compared to surface storage are no losses by evaporation, reduced construction cost in preparing the surface reservoir, and seasonal availability of water, e.g., increasing water in a depleted aquifer, usually accomplished during the off-season (Alramlawi, 2010).

2.3.1 Purposes and Principles of Artificial Recharge:

Artificial recharge of groundwater is a means of augmenting the natural infiltration of surface water into a groundwater reservoir at a rate that vastly exceeds that which would occur naturally .

Artificial recharge of groundwater has been used throughout the world for a variety of general purposes as like purification and equalization of water quality, storage of water, transportation of water, maintenance of groundwater levels and disposal of unwanted water .

The detailed purposes of the artificial recharge techniques include the followings:

1. Groundwater (well field) management.
2. Reduction of land subsidence.
3. Renovation of wastewater.
4. Improvement of groundwater quality.
5. Storage of stream waters during periods of high or excessive flow.
6. Reduction of flood flows.
7. Increase well yield.
8. Decrease the size of areas needed for water supply systems.
9. Reduction of salt water intrusion or leakage of mineralized water.

10. Increase stream flow.

11. Store fresh water, derived from rain and snowmelt.

(http/water.re.kr/files/research_data/).

2.3.2 Methods of artificial recharge

2.3.2.1 Infiltration basins

Infiltration basins require a substantial amount of land area with a suitable geology, allowing the water to infiltrate into the aquifer and percolate to the groundwater table. It is simple to maintain and regular restoration of infiltration capacity and removal of clogging layers is relatively easy though time consuming. This method also allows for natural, quality improving processes to take place in the infiltration ponds and subsoil. Construction is normally comparatively simple and low cost. Impermeable topsoil may, however, rise the costs . The infiltration from a recharge basin produces a groundwater mound above the original water table. The groundwater mound grows over time and once the infiltration stops, it decays gradually (Aish,2004), Figure 2.1 shows the scenery of infiltration basins.

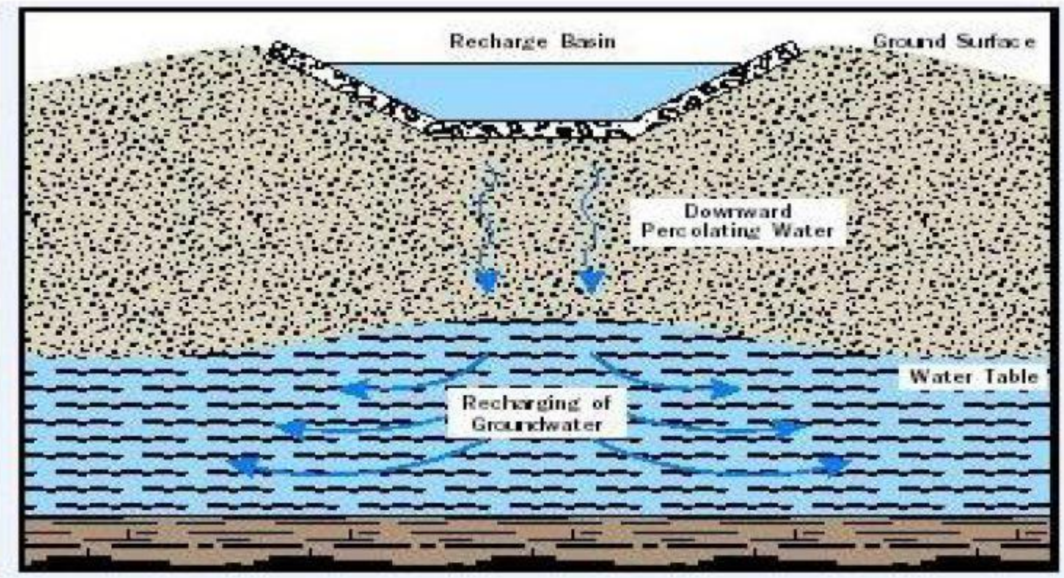

Figure 2.1 : The scenery of infiltration basins (Alghamri, 2009)**.**

2.3.2.2 Ditches

A ditch could be described as a long narrow trench, with its bottom width less than its depth. A ditch system can be designed to suit the topographic and geologic conditions that exist at a given site. A layout for a ditch and a flooding recharge project could include a series of ditches trending down the topographic slope. The ditches could terminate in a collection ditch designed to carry away the water that does not infiltrate in order to avoid ponding and to reduce the accumulation of fine material .

(http://www.cee.vt.edu/ewr/environmental/teach/gwprimer/recharge/recharge.html)

2.3.2.3 Recharge Wells

Infiltration wells or injection wells are used where permeable soils and/or sufficient land area for surface infiltration are not available. Well infiltration calls for very high quality of the infiltration water if clogging of the well screen and the aquifer in the vicinity of the well is to be avoided. The construction is more complicated and costly and restoration of the hydraulic conductivity around the wells may be unfeasible if not impossible. The best strategy for dealing with clogging of recharge wells is to prevent it by proper treatment of the water before injection. This means removal of suspended solids, assailable organic carbon, nutrients like nitrogen and phosphorous, and microorganisms (Aish ,2004) Figure 2.2 shows the scenery of recharge well .

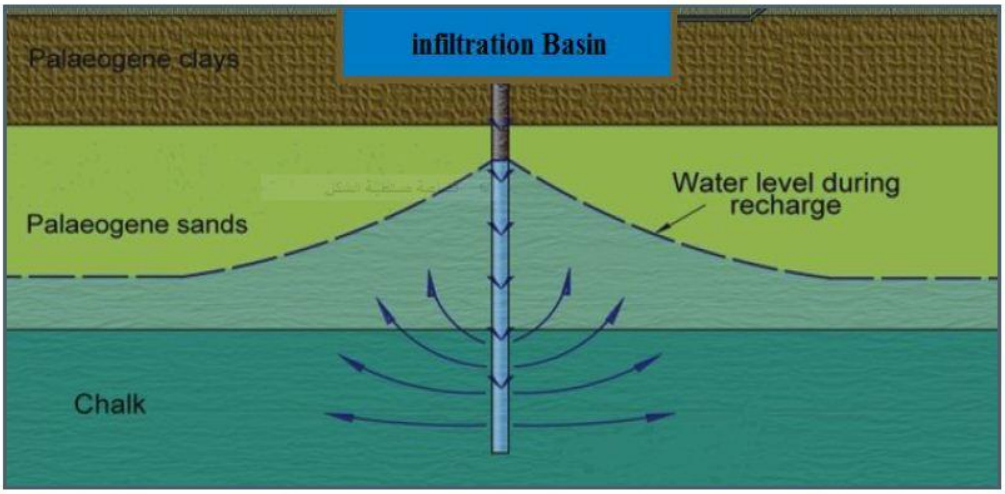

Figure 2.2 : The scenery of recharge well (Alramlawi, 2010)**.**

2.4 Saltwater intrusion

Saltwater intrusion is the movement of saline water into freshwater aquifers. Most often, it is caused by ground-water pumping from coastal wells, or from construction of navigation channels or oil field canals. The channels and canals provide conduits for salt water to be brought into fresh water marshes. Salt water intrusion can also occur as the result of a natural process like a storm surge from a hurricane. Saltwater intrusion occurs in virtually all coastal aquifers, where they are in hydraulic continuity with seawater.*(http://www.amyhremleyfoundation.org/php/education/features/Aquifers/SaltwaterIntrusion.php).*

2.4.1 Effect on drinking water

When fresh water is withdrawn at a faster rate than it can be replenished, the water table is drawn down as a result. This draw-down also reduces the hydrostatic pressure. When this happens near an ocean coastal area, salt water from the ocean is pulled into the fresh water aquifer. The result is that the aquifer becomes contaminated with salt water. This is happening to many coastal communities *http://www.elmhurst.edu/~chm/vchembook/301groundwater.html.*

2.4.2 Hydrology:

Saltwater intrusion occurs when saltwater is drawn-in from the sea into freshwater aquifers. As it carries more solutes, sea water has a higher density than freshwater. This difference in density causes the pressure under a column of saltwater to be greater than the pressure under a column of the same height of freshwater. If these two columns are connected at the bottom, the pressure difference causes a flow of saltwater column to the freshwater column until the pressure equalizes.

The flow of saltwater inland is limited to coastal areas. Further inland, the freshwater column is higher due to the increasing altitude of the land, and is able equalize the pressure from the salt water, preventing saltwater intrusion. The higher water levels inland also cause the freshwater to flow seaward. Therefore at the sea-land boundary, freshwater flows out from the highest point of the aquifer, and at the lowest point, saltwater flows in. The saltwater intrusion then forms a wedge.

Pumping of fresh water from an aquifer reduces the water pressure and intensifies the effect, drawing salt water into new areas. When freshwater levels drop, saltwater intrusion can proceed inland, reaching the pumped well. Then saltwater, unfit for drinking or irrigation, is produced by the pump. To prevent this, more and more countries adopt extensive monitoring schemes and numerical models to assess how much water can be pumped without causing such effects.

Ghyben-Herzberg relation

The first physical formulations of saltwater intrusion were made by W. Badon-Ghijben (1888, 1889) and A. Herzberg (1901), thus called the Ghyben-Herzberg relation. They derived analytical solutions to approximate the intrusion behavior, which are based on a number of assumptions that do not hold in all field cases. Figure 2.2 shows the The Ghyben-Herzberg relation. In the equation

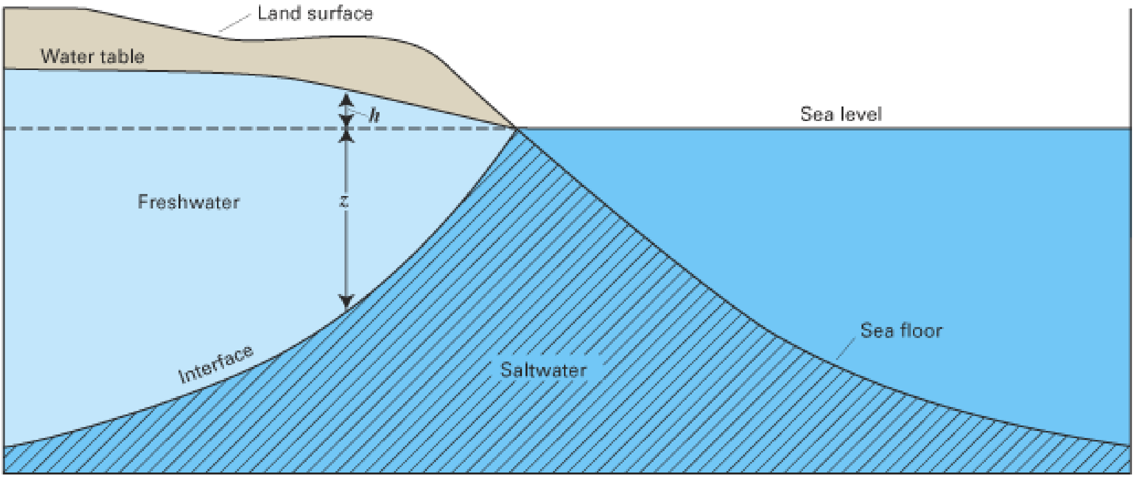

Figure 2.3: The Ghyben-Herzberg relation. In the equation.

$$z = \frac{\rho_f}{(\rho_s - \rho_f)} h$$

The thickness of the freshwater zone above sea level is represented as $h$and that below sea level is represented as z. The two thicknesses $h$and z, are related by $\rho_f$and $\rho_s$where $\rho_f$is the density of freshwater and $\rho_s$is the density of saltwater. Freshwater has a density of about 1.000 grams per cubic centimeter (g/cm^3) at 20 °C, whereas that of seawater is about 1.025 g/cm^3. The equation can be simplified to

$$z \ = 40h.$$

The Ghyben-Herzberg ratio states, for every foot of fresh water in an unconfined aquifer above sea level, there will be forty feet of fresh water in the aquifer below sea level.

In the 20th century the higher computing power allowed the use of numerical methods (usually finite differences or finite elements) that need fewer assumptions and can be applied more generally.

(http://www.amyhremleyfoundation.org/php/education/features/Aquifers/SaltwaterIntrusion.php.)

2.5 Wastewater Situation in Gaza strip

2.5.1 Wastewater Collection

The percentage of population connected to sewer networks in Palestine counts for approximately 52% distributed as 84% in Gaza Strip and 36% in West Bank while cesspits and septic tanks receive the rest as shown in Table 3.1. In the West Bank, sewage collection has low coverage compared to the Gaza Strip. Only ten towns in the West Bank are served by sewerage systems, of which four towns have treatment plants and none has a reuse scheme, table 2.1 shows the coverage of wastewater network in Gaza strip areas.

Table 2.1: The coverage of wastewater network in 2009, SOURCE: PWA,APRIL,2011.

Region	Population	Coverage %
North Gaza	286,246	80
Gaza City	519,027	90
Middle Area	215,808	65
Khan Younis	283,286	40
Rafah	182,449	65
Total (Gaza Strip)	1,486,816	84

2.5.2 Existing Wastewater Treatment Plants

There are four wastewater treatment plants operating in the Gaza Strip: Beit Lahia WWTP in the north, Gaza WWTP in the Gaza City, Khan Younis and Rafah WWTP in the south. The existing three WWTPs are heavily overloaded as the actual flow far exceeds the design flow. Blocked pipes and flooded manholes are daily events in Gaza Strip. The total effluent of the existing three WWTPs is approximately 41 MCM/year. The Mediterranean Sea represents the final disposal of most treated or partially treated wastewater in Gaza strip.

The type of treatment, quantity and final disposal of each wastewater treatment plant is summarized in Table 2.2.

Table 2.2: General Characteristics of Municipal Wastewater Treatment Plants, Source: PWA, April, 2011.

	Municipalities WWTP	Type of Treatment	Construction date	Effluent Quantity m^3/d	Effluent Disposal Method
Gaza Strip	Beit Lahia	Stabilization ponds and aerated lagoons	1976	25,000	100% Infiltration basins East & North of Gaza Strip
	Gaza	Anaerobic ponds followed with bio-towers	1977	60,000	100% to sea (50,000 partially 10,000 Raw)
	Middle Area	without treatment	1998	More than 10,000	100% Wadi Gaza and to the Sea 10,000 Raw
	Khan Younis	Anaerobic lagoon followed by aerobic lagoon	2007	8,000	100% to sea (partially treated)
	Rafah	Anaerobic ponds followed with bio-towers	1983	More than 10,000	100% to sea 10.000 partially
	Total effluent of Gaza (MCM/year)	41 MCM (38 MCM discharged to the Sea)			

In the following a summary description of most existing WWTPs in operation:

2.5.2.1 Beit Lahia WWTP

Beit Lahia wastewater treatment plant (BLWWTP) was built in 1976 and designed to serve a population of 50,000 with a load capacity to treat 5,000 cubic meters per day (CM/day) of wastewater to secondary treatment level. However the plant currently receives more than 23,000 CM/d to the design capacity. The sewage is delivered from the main manholes and is processed though a number of lagoons shown in the schematic diagram of Beit Lahia wastewater treatment plant below. The treatment consists of: Primary sedimentation lagoons (1 and 2) with area of 7,660 and 8000m^2; Aerobic lagoons with surface aerators (3 and 4) with areas 7,514 and 7915m^2;

Facultative Lagoons (5 and 6) with areas of 15,584 and 15,604m^2; Finally the wastewater flows to a maturation pond (7) and is disposed by siphoning to the newly constructed Emergency lagoon. Finally the treated wastewater is conveyed through two pump station to the Eastern infiltration basins and to the temporary infiltration basins at the Northerner boarder. Due to the huge overload on the system, the wastewater is only partially treated, and the effluent is considered a low quality, Figure 2.4 illustrate the components of BLWWTP.

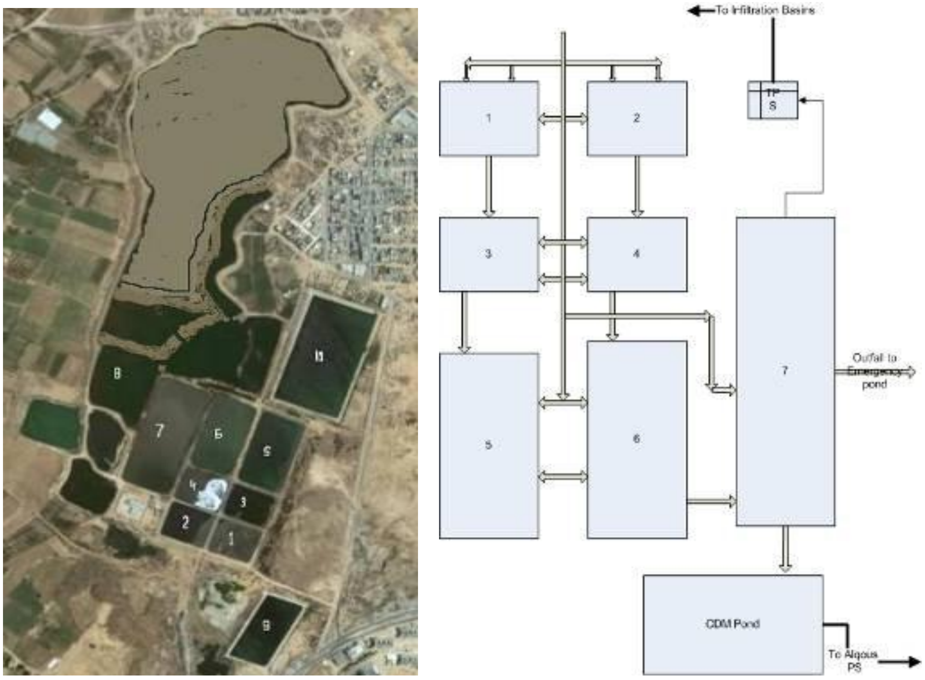

Figure 2.4: Beit Lahia WWTP & its Process Schematic Diagram

2.5.2.2 Gaza WWTP

The Gaza Wastewater Treatment Plant (GWWTP) serves the municipality of Gaza and part of the North Gaza Governorate, although this area is expected eventually to be diverted to the Northern WWTP. The GWWTP plant is located on an elevated position to the south of the city (in the area of Sheikh Ejleen). The plant covers an area of 130,000 m^2. Originally the plant was constructed in 1977 as a two-pond treatment system. It was expanded in 1986 by UNDP when two additional ponds were constructed. Part of this expansion included reuse facilities, consisting of three large recharge basins, a booster pumping stations, a 5,000 m^3 storage tank, a distribution piping system and an overflow pipeline to the Wadi Gaza. Modifications were made in

1996 and funded by USAID, including the addition of two “bio-tower” trickling filters. In 2006, the Gaza Municipality commenced construction of an additional fourth anaerobic pond. Currently, CMWU and the Municipality of Gaza are upgrading the plant for improving the effluent quality on the medium term.

2.5.2.3 Khan Younis WWTP

It is temporary partially wastewater treatment plant with anaerobic, aerobic, and settling ponds. The plant was constructed in 2007 as a temporarily solution. The current flow rate is about 7000 m3/day, and it is currently discharging to the sea.

The existing treatment process designed to treat the influent to be suitable for disposal in the sea. The influent BOD, COD, Total suspended solids (TSS) and TKN are accounted for 380, 820, 400 and 71 mg/l respectively. The BOD removal efficiency accounts for less than 70%. It is noticeable that the effluent is not fulfilling the criteria for sea disposal or even reuse in irrigation purposes according to the Palestinian standards.

2.5.2.4 Rafah WWTP

This RWWTP plant serves a population of 112,500 of Rafah inhabitants. Measures showed that in 2007 the total volume of water production was 5.6 MCM with average daily flow 8000-8500 m^3/d. Raw sewage is very heavy and the pollutant's concentration is very high. The raw wastewater characteristics are BOD = 740 mg/l, COD = 1200 mg/l and TSS = 635 mg/l.

This plant consists of two anaerobic ponds, a grit removal and inlet structures. Another old lagoon still exists and will be used as polishing pond in the future. Currently, development is ongoing at Rafah Wastewater treatment plant to add the following facilities:

*Two bio-filters, piping, BTFPS, and Distribution chamber.

*Polishing Pond.

*Pumping assembly.

*Drying beds.

*A constructed wetland of reeds for additional filtering and nutrient (nitrogen) removal

*Infiltration basin.

Ref; Assessment of Wastewater Treatment Reuse and Practices, PWA,2011.

2.6 Measures to restore Disturbed fresh Ground water system in coastal aquifers

When dealing with the restoration of disturbed groundwater systems in coastal areas it is necessary to asses:

1-The present state in terms of groundwater table, piezometric levels and salinity distribution and in terms of exploitation , i.e. location and rates of abstraction,

2-The desired state after restoration , in terms of sustainable rates of abstraction and the means and location thereof , groundwater tables and piezometric levels and the volume of fresh groundwater that should be permanently present in the aquifers as a strategic reserve for emergencies and to cope with fluctuations in the rates of recharge and abstraction .For considerations and criteria to define the desired state.

Once the present state is sufficiently known and the desired state has been defined, within the natural, technical and economic limits posed by the aquifer system and its exploitation , the necessary actions can be taken for restoration where needed . The same actions can and must be taken in those cases which need not to be restored , yet where continuity for a controlled exploitation must be assured .

The following measures can or must be taken to achieve goals:

- Reduction of the rates of abstraction . in order not to be exceed the sustainable yield,
- Relocation of abstraction works , this measures aims at reduction of the looses of fresh groundwater by outflow .
- Increase of natural recharge ,this measures is to increase recharge and therewith the sustainable yield .
- Artificial recharge , this measures is also to increase the recharge and therewith the sustainable yield.

This study will study the influence of groundwater in terms of quantity and quantity by applying several scenarios , these scenarios include the reduction of abstraction from the wells (agricultural and municipal) and to test the effect of injection of treated waste water to the aquifer .

Chapter Three

Study Area

Chapter 3: Study Area

3.1 Study area:

3.1.1 Geography

The study area is 135 km^2 is located in the north of Gaza Strip as shown in the Figure 3.1 .

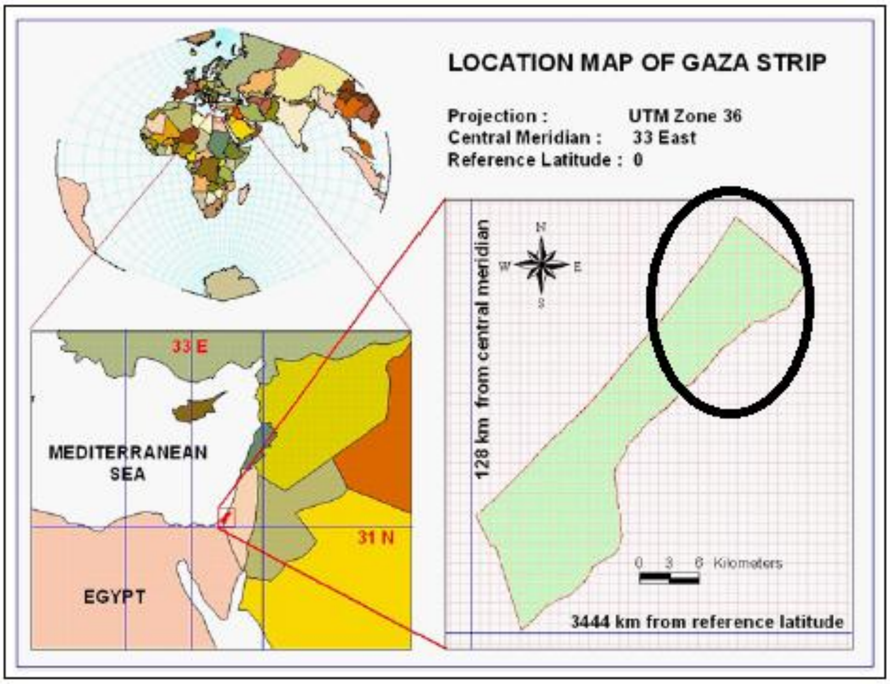

Figure 3.1 : The study area

3.1.2 Population

The northern part of Gaza Strip is considered as one of the most densely populated areas all over the world. In 2011, more than 929019 inhabitants were crowded in to an 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).

3.1.3 Climate

Gaza Strip climate is semi-arid with mild winters, dry and hot summers which are subjected to drought. The arid desert climate of Egypt and the Sinai Peninsula along with the Mediterranean sea, have an imposing influence in the patterns of Gaza weather.

Gaza weather is divided into only two seasons: there is a dry season that runs from April till October, and a wet season that commences in November and ends in March.

3.1.3.1 Temperature:

The average daily mean temperature ranges from 25 C^0 in summer to 13 C^0 in winter, and the average daily maximum temperatures range from 29 C^0 to 17 C^0 and minimum temperature from 21 C^0 to 9 C^0 in the summer and winter respectively.

3.1.3.2 Rainfall

Rainfall is measured in the Gaza Strip at 12 rain gauge stations distributed spatially at the whole area and representing all zones from north to south as shown in Figure 3.2 .

The average rain head fluctuates from 200 mm /y in the south of Gaza Strip to about 450 mm/y in the north. On average, rainfall over Gaza Strip as a bulk quantity is estimated to be about 114.1 Mm^3/y. Rainfall replenishes the aquifer with an average amount of 40.8 Mm^3/y. as a part of the total supply to the aquifer 107.9 Mm^3/y.

In year 2007 the average rainfall depth over Gaza Strip area was estimated about 364.7 mm with total amount 133.1 Mm^3 received through 46 rainy days as shown in Table 3.1. Despite the small land area of Gaza Strip (365km^2), the level of rainfall varies significantly from one area to another with an average seasonal rainfall of 521.9 mm in the north (north governorate), to 225 mm in the south (Rafah) as shown in Table 3.2.

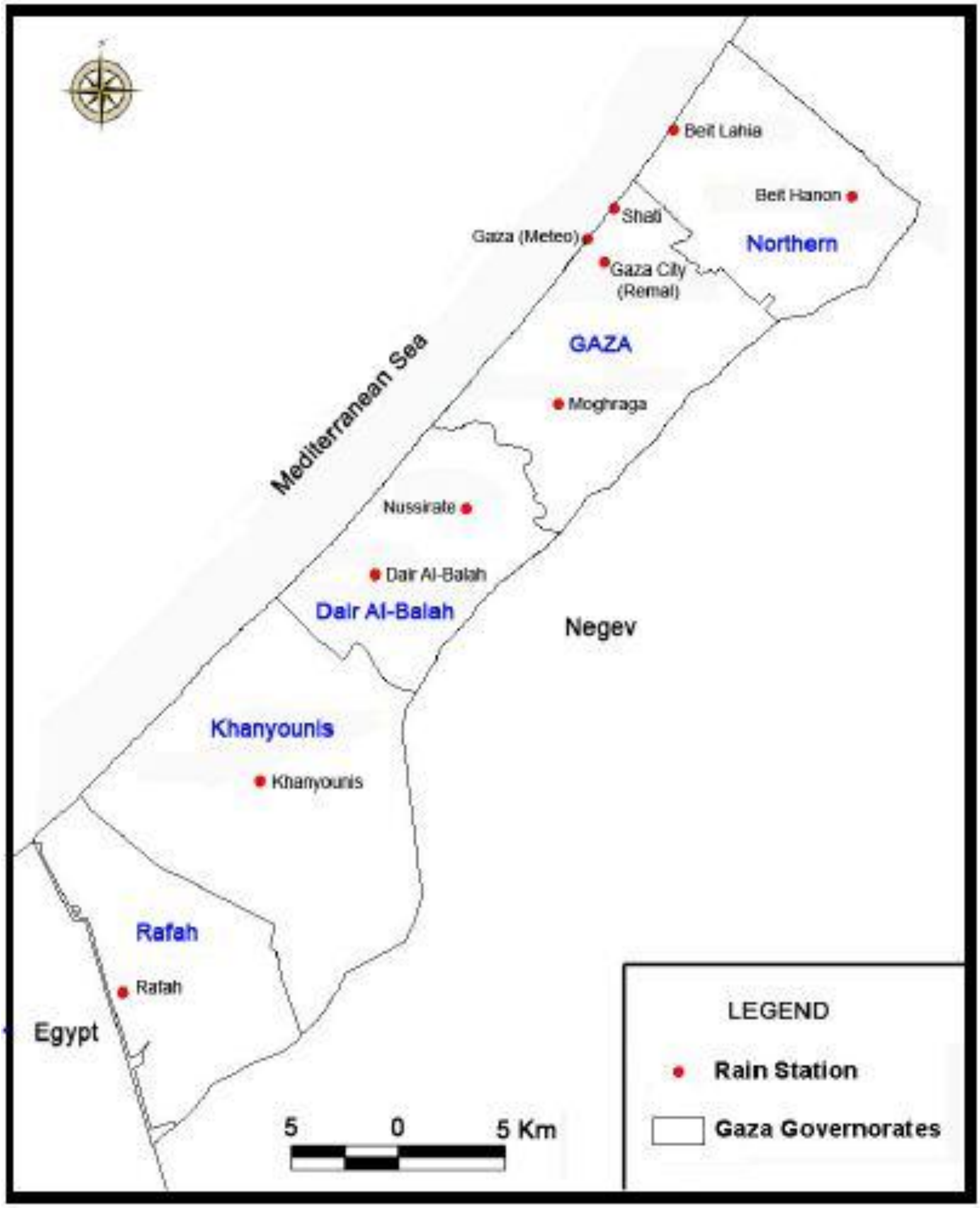

Figure 3.2: Location of rainfall stations in Gaza Strip

Table 3.1: Rainfall in Gaza Strip in 2007 ,(PWA).

Station Name	Accumulated observed rainfall /station (mm)	Normal rainfall /station (mm)	Governorate	Accumulated observed rainfall (mm)/station	Total rainfall quantity (Mm^3)
Beit Hanoon	509.9	418	North	521.9	30.7
Beit Hanoon	530.3	433			
Jabalia	536.7	432			
Shati	469	392	Gaza	460	33.8
Gaza City	501.2	370			
Tuffah	545.5	434			
Gaza South	388.2	400			
Nussirate	403	354	middle	411.5	28
Dr Elbalah	418	324			
Khan Younis	252	290	Khan Younis	253.4	31.9
Khuzaa	256.1	250			
Rafah	225	236	Rafah	225	8.7

Furthermore, about 20 percent of Gaza strip area received rainfall between 500-550 mm, 50% received between 300 and 500 mm and 30 percent of the area received less than 300 mm as shown in Figure 3.3. Monthly rainfall was also calculated for all Gaza strip station sites . In 2006-2007 rainy season extended from September 2006 to May 2007 where the maximum rainfall is in January 2007, and maximum of non-rainy days is in February 2007.

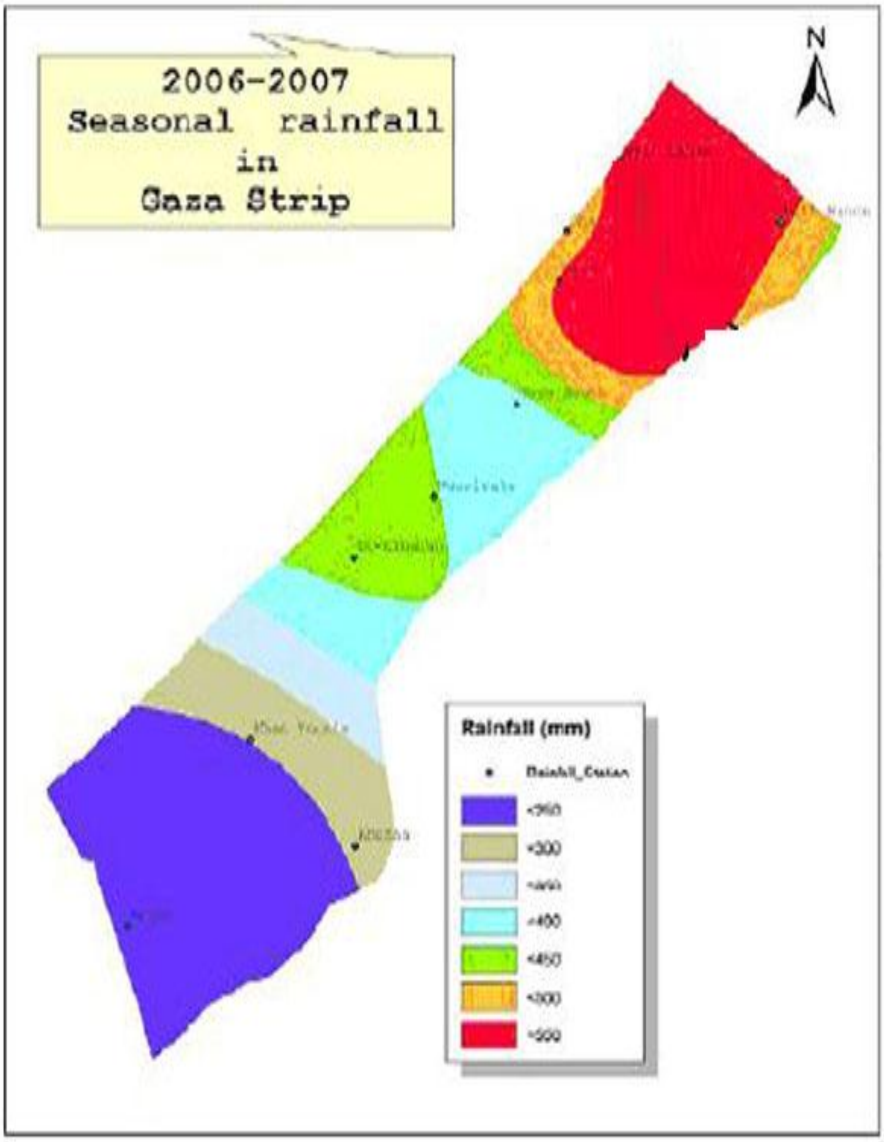

Figure 3.3: Rainfall depths in Gaza Strip

Table 3.2 : Average rainfall and rainfall quantity in Gaza strip.

Season	Gaza strip average seasonal rainfall	
	Average seasonal rainfall depth (mm)	Average seasonal rainfall quantity (Mm^3//y)
1998-1999	108.5	39.6
1999-2000	267.7	97.7
2000-2001	447	163.1
2001-2002	425.6	155.3
2002-2003	461.4	168.4
2003-2004	295.6	107.9
2004-2005	357.4	130.4
2005-2006	280.4	102.3
2006-2007	364.7	133.1
2007-2008	264.6	96.54
2008-2009 until Nov 2008	132.1	48.2

Storm Water Run Off

The Palestinian Water Authority (PWA) has identified of storm water harvesting as an important resource to bridge the gap between water resources demand and supply. Its strategy was to maximize rainwater recharge as far as practical by recharging runoff from large surface areas and introduction of flood alleviation measures at the source . Storm water will be increased due to urbanization and runoff water will increase. So, some storm water facilities were proposed by the storm water master plan to mitigate floods and harvest the collected storm water. The initial amounts of artificial storm water recharge are estimated to be 4.25 Mm^3/y at 2005 and will increase to reach only 7.1 Mm^3/y in the year 2020 , where this forms only 30% of storm water coming from urban areas 22.2 Mm^3/y. The runoff waters of about 27.8 Mm^3/y and this will increase to about 42.6 Mm^3/y when the planned land use is implemented in the coming decade.

Until now, this runoff is still used partially in different projects of rainwater harvesting in Gaza Strip, and some projects faced difficulties in implementation.

There are projects for storm water collection, but they serve flood mitigation measures only, without harvesting it for recharging the aquifer. Most of this water is pumped to the sea. Storm water harvesting became a priority issue firstly to mitigate flooding and secondly, to add to the existing limited water resources. Urban storm water harvesting is an important water resource that plays a significant role in enhancement of water resources management in Palestine, in general and in Gaza Strip in particular.

The natural recharge of rainfall is about 40% of the total bulk rain quantities fallen over Gaza Strip with an average of 117 Mm^3/y. The rest of water that flows into the sea or evaporates can be harvested through the constructed infiltration basins.

These amounts of storm water in Gaza Strip will reach about 37 Mm^3/y from planned urban areas. The amount of runoff of the completely planned area is calculated to be about 43 Mm^3. When urban expansion is implemented as planned, the natural infiltration of rainfall to the aquifer will decrease, and these amounts of runoff are good resources to be utilized (Alramlawi, 2010).

3.1.3.3 Evaporation:

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.

3.1.3.4 Winds:

Winds direction and velocities varied according the season. The monthly average wind velocities in the last 16 years were in the range of 15.20 knots. The highest was 20.96 knots in 1992 and the lowest was 15.12 knots in 1987. Wind directions ranged from 215 &260 degrees from the north, analysis show that wind with velocities above 48 km/h occurred below 1% of the time.

3.1.3.5 Air humidity:

In summer, the daily relative humidity varies between 66% in the night to 86% at the daytime. However, in winter it is between 53% to 81% respectively.

3.1.3.6 Evapotranspiration:

Evapotranspiration is the primary mechanism by which water is removed From a watershed. In Gaza Strip the Evapotranspiration is about 54 Mm^3/y.
(Ref: Group Work,2011,Evaluation the Land use Effect on Hydrological Cycle Parameters Using GIS Based Model (AGWA-SAT),Civil Engineering Dep,IUG).

3.1.3.7 Percolation:

The rainfall intensity plays an important role in the recharge quantity to the aquifer. The long-term average recharge is considered 40% of the whole rainfall quantity that is about 45 Mm^3/y (PWA, 2005), the recharge rate is varying in accordance to the soil porosity and the thickness of the unsaturated zone that overlaying the groundwater aquifer.

3.1.4 Geology

Gaza water resources are essentially limited to that part of the costal aquifer.

While the groundwater underneath the Gaza Strip is limited to the Gaza Strip area, the coastal aquifer is extended from Haifa in the north to Sinai desert in the south, Hebron Mountain in the east and the Mediterranean Sea in the west, this costal aquifer is the only one in Gaza Strip. It is composed of Pleistocene marine sand and sand stone, intercalated with clay layers. The maximum thickness of the different bearing horizons occurs in the North West along the cost (150 m) and decreasing gradually towards the east and southeast along the eastern border of Gaza strip to less than 10 m. The base of the costal aquifer consist of impervious clay shade rocks of Neogene age.

Depth to water level of the coastal aquifer various between few meters in the low land area along the shoreline to about 70 m in the eastern areas. The regional ground water flow is mainly westwards toward the Mediterranean Sea. Most of the recharge of this aquifer is at the adjacent uphill eastern aquifer boundary and from dune areas near the cost overlaying the coastal aquifer itself and from the adjacent uphill area near the east zone.

3.1.5 Topography

There is no appearance of special topography of the Gaza Strip except that the surface in general is .at with sand dunes in coastal area. In addition, there is a series of hills in the eastern part, which rise of the overall level of the surface.

The altitude of the Gaza strip land surface ranges between zero meters at the shorelines to about 100 meters above the mean sea level in some places as shown in Figure 3.4. 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 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 after very strong storms.

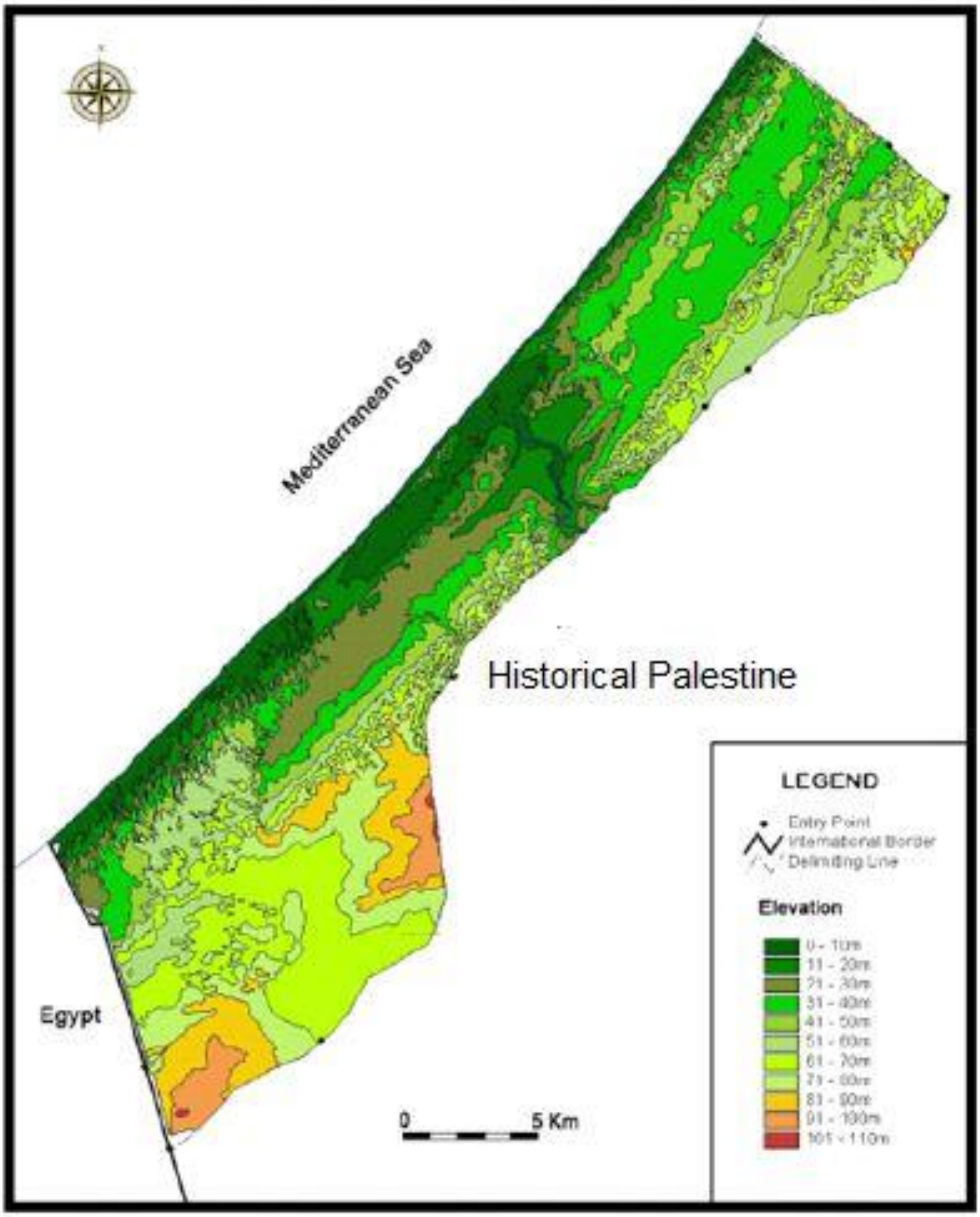

Figure 3.4: Topography of Gaza strip.

3.1.6 Soil

The types of soil in Gaza Strip are sandy soils, loessial sandy soils, loess soil, sandy loess soil, dark brown/reddish brown soils which is represented in Figure 3.5 , while Table 3.1 illustrate the soils , its contents and concentration rate for each one.

- Sandy soil ,Sandy soils of dune accumulations are regosols, which means it is very weakly developed mineral soil in unconsolidated materials without a marked profile.

Textures in the top meters are usually uniform and consist of medium to coarse quartz sand with a very low water. Holding capacity. The soils are moderately calcareous (5-8% calcium carbonate), very low in organic matter, chemically poor but physically suitable for intensive horti- culture in greenhouses.

In the deeper surface (1-3 m below the surface) occasionally loam or clay loam or clay layers of alluvial origin can be found.

- Loessial sandy soil

Loessial sandy soils can be found some 5 km in the central and southern part of strip, in zone along KhanYounis 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 pro.le. There might be some accumulation of calcium carbonate in soil subsoil.

- Loess soil

Typical 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 .ank of the main deposition zone in north-western Neqab 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.

- Sandy loess soil

It 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.

- Sandy soil over loess

This loess or loessial soil (sandy clay loam) has been covered by a layer (0.2- 0.5 m) of dunes sand. This soil can be found east of Rafah and KhanYounis. Table 3.3 illustrate the infiltration rate for each soil type.

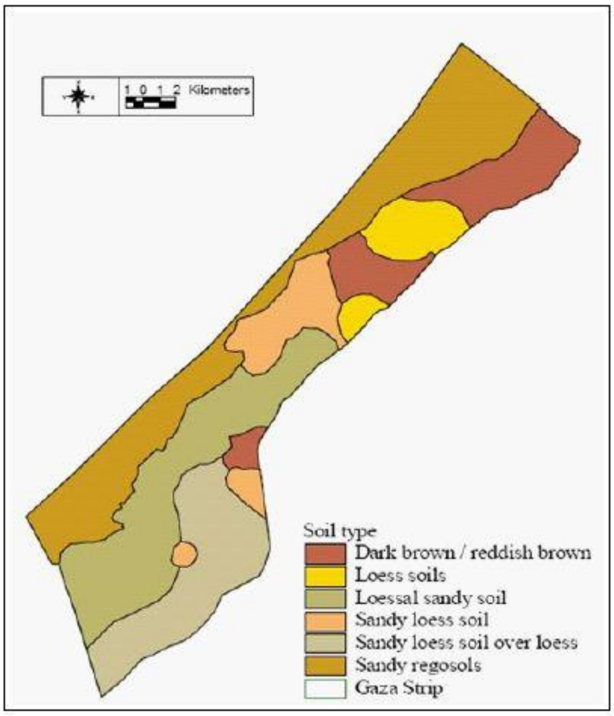

Figure 3.5: Soil distribution in Gaza Strip (Abu Shaaban et al., 2011).

Table 3.3: Gaza soils, its contents and infiltration rate (Abu Shaaban et al., 2011).

Local classification	Texture	Infiltration (mm/hr)
Losses soil	Sandy loam (sand 58%, 34%silt,caly 6%)	404.5
Dark brown / Red dish brown	Sandy clay loam (25%clay, 13% silt ,62% sand	963.42
sandy losses soil	sandy clay loam (23% clay , 21% silt ,56% sand)	258.66
Losssial sandy soil	sandy loam (14% clay, 20%silt , 66% sand)	471.48
sandy losses soil over losses	sandy loam (17.5%clay , 16.5% silt , 66% sand)	337.6
sandy regosol	loamy sand (9% clay, 4% silt , 87% sand)	1079

3.1.7 Description of the Coastal Aquifer

The coastal aquifer of the Gaza Strip is part of a regional groundwater aquifer system that extends north up to Haifa, and south into Sinai coast of Egypt. The coastal aquifer consists primarily of Pleistocene age Kurkar group deposits including calcareous and silty sandstones, silts, clays, unconsolidated sands, and conglomerates. The coastal aquifer is generally 10-15 kilometers wide; the Kurkar group forms a seaward sloping plain, which ranges in thickness from 0 m in the east, and about 100 m at the shore in the south, and about 200 m near Gaza City. At the eastern Gaza border, the saturated thickness is about 60-70 m in the north, and only a few meters in the south near Rafah. Near the coast, coastal clay layers extend about 2-5 km inland, and divide the main aquifer into three sub aquifers, referred to as sub aquifers A, B1, B2, and C. A conceptual geological cross-section of the coastal plain geology is presented in Figure 3.6.The base of the aquifer is marked by the top of Saqiya formation (Tertiary age), it is a thick sequence of marls, clay stones and shale that slopes towards the sea, with low permeability and approximately 400-1000 m thick wedge beneath the Gaza Strip (Ghamri, 2009).

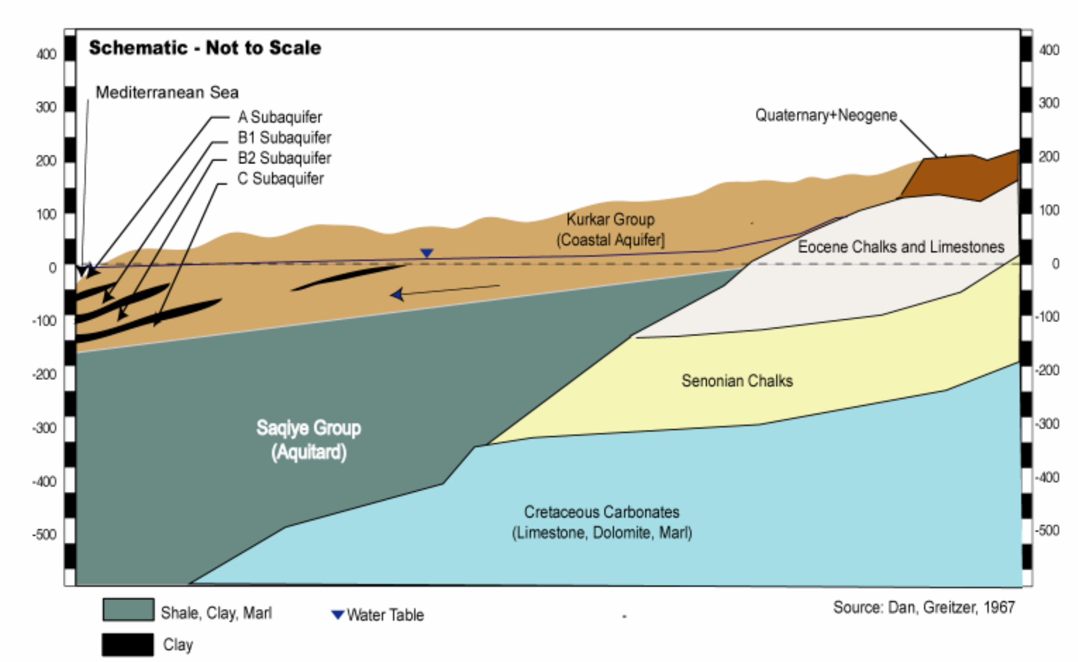

Figure 3.6: Gaza Coastal aquifer (Al-Yaqubi et al., 2011).

Aquifer Hydraulic Properties

Few municipal wells screened across more than one sub aquifer have been tested to determine hydraulic parameters. From results of pump tests carried out, aquifer transmissivity values range between 700 and 5000 (m^2/d). Corresponding values of hydraulic conductivity (K) are mostly within a relatively narrow range, 20-80 meters per day (m/d). Little is known about any differences in hydraulic properties with depth or between the different sub aquifers.

Specific yield values are estimated to be about 15-30 percent while the storativity is about 10-4 from tests conducted in Gaza (Alghamri, 2009), Table 3.4 illustrate the specification of Gaza coastal aquifer.

Table 3.4 : Properties of Gaza coastal aquifer (Abu Shaaban, et al., 2011).

Parameter	Value
Transmitivity(m^2/d)	700-5000
hydraulic conductivity (m/d)	20-80
specific yield %	15-30
Storativity	0.0004

3.1.8 Land use

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 3.5 and Figure 3.7 show the percentage of built up areas in Gaza strip .

Table 3.5: 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

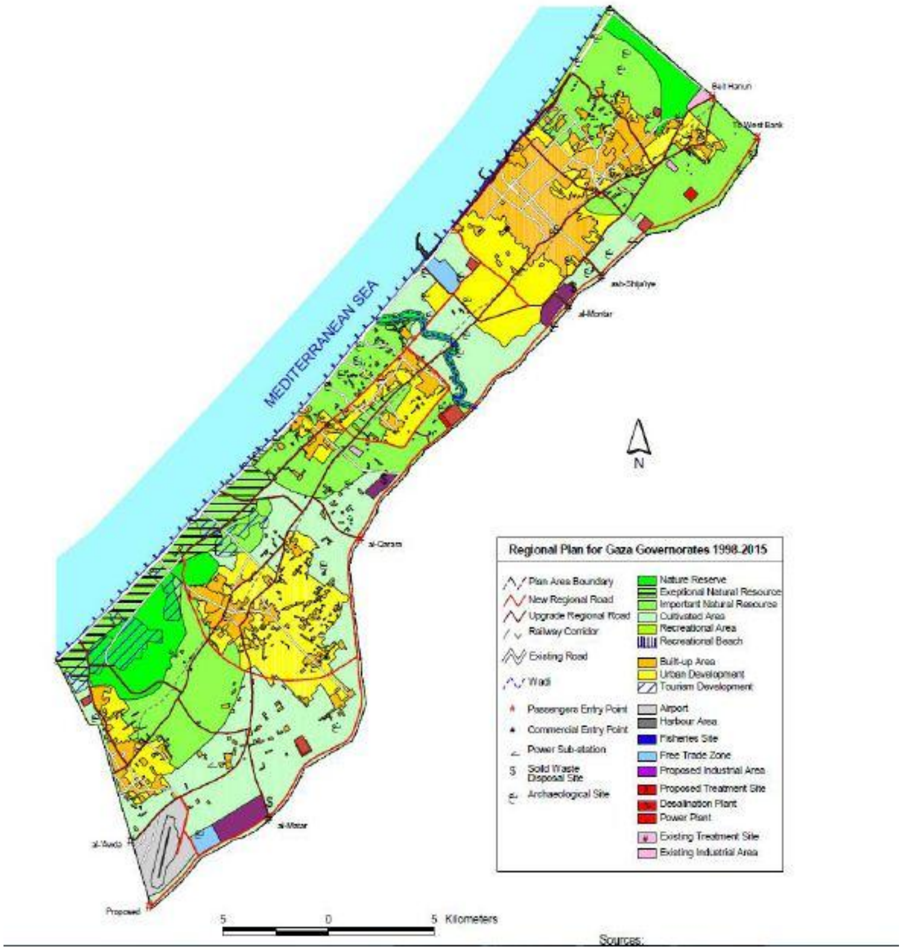

Figure 3.7: The present land use and future industrial land use distribution (1998-2015) (Abu Shaaban et al., 2011).

3.1.9 Bait Lahia Municipality infiltration Basin

The Beit Lahia Municipality basin will be fully operated as infiltration basin due to the location of the basin in a residential area. It was seen that this basin will be constructed adjacent to an existing infiltration basin with an area of 1,000 m^2 and a depth of 6 m. Therefore, the catchment area which will feed the Municipality basins (the new and the existing basins) is determined according to the information obtained from the topographical survey.

The basin was designed by Mogheir, 2005, as a consultancy service through the Center for Engineering and Planning for a project submitted to PWA. The following design criteria were used:

- From the intensity duration curve, the volume of rainfall in one day and for 5 years return period is 69.29 mm/m^2.

- By considering the total catchment area of 700 dunums, then the catchment runoff volume is 48,500 m^3.
- The volume of storm water which will reach the basin is 23,280 m^3 by taking in account an average runoff coefficient equals 0.48.
- The infiltrated volume during the rain in one day is computed as 11,738 m3(infiltration rate is 3 m/d).
- Then the net volume of the stored storm water is 11,541 m^3. According to this value, the total area which is required for the basins is 4,500 m^2 which includes 3 to 4 m space around the basin for fencing and planting with suitable trees.
- The total depth of the basin is 5.6 (including the depth of the inlet of the basin, which is 2 m below the ground surface) with side slope of the basin is 2v: 1h.
- It should be noted that, the existing basin which has an area of 1,000 m^2 is included in the total area where 3,500 m^2 is requested as an extension.

It is important for the purification of the infiltrated water, as well as to avoid clogging, that the boreholes through clay layer be covered by at least 2 m of dune sand. For a design period for evacuation the basin is 12 days, the amount of water to be infiltrated1,940 m^3/d. The volume of storm water which can be stored in the 2 sand layers is 1,539 m^3/d (the porosity of sand is taken as 0.25). Therefore the net daily volume of water to be infiltrated 401 m^3 through a number of boreholes filled with crushed stone with sizes of 10 to 20 mm (hydraulic conductivity is about 2.3 x10-4 m/s), then the cross-section area needed to transmit the water through the clay is 18 m^2. Drill holes diameter of 0.6 m which have a cross-section area of 0.310 m^2 are to be used. This means that 65 of such boreholes need to be drilled at a rate of 1 borehole per 48 m2. Each borehole must be drilled around 3 m inside the permeable layer (Kurkar) which is expected to reach 25 m below the bottom of the basin. Before, the construction of the basin in the Municipality site it is necessary to check the extent of the clay layer and the depth of Kurkar layer by further soil investigations. Figure (3.8a), (3.8b) shows the basin plan and cross section (Alramlawi, 2010).

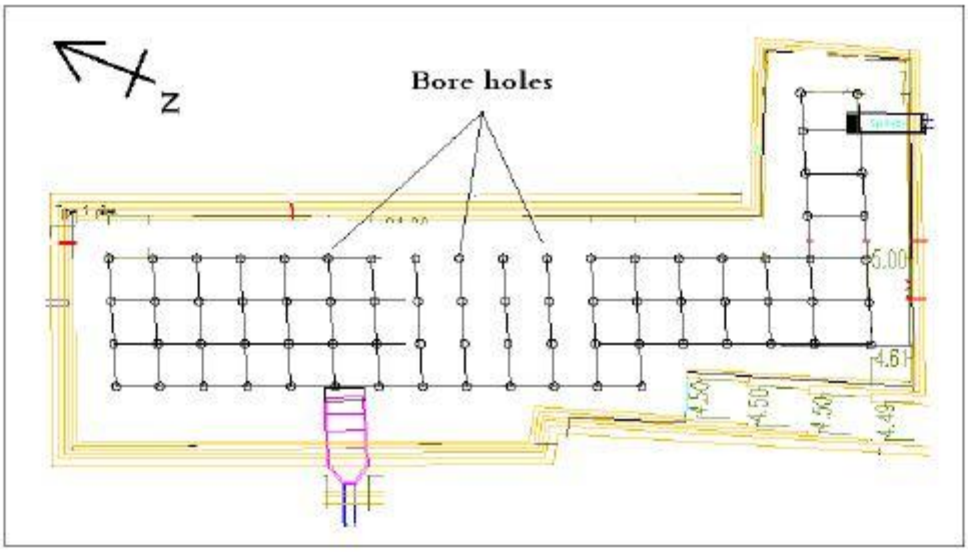

Figure (3.8a): Layout of Biet Lahia municipality infiltration basin (Mogheir, 2005) **.**

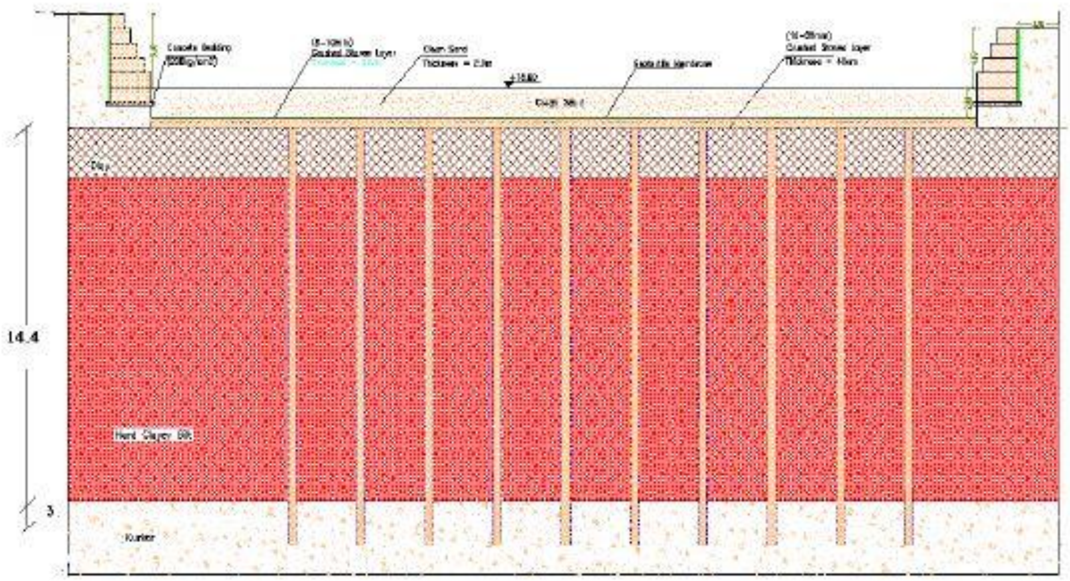

Figure (3.8b): Cross Section of Biet Lahia municipality infiltration basin (Mogheir, 2005) .

Chapter Four

Seawater Intrusion Modeling

Chapter 4: Seawater Intrusion Modeling

4.1 Introduction

A fully three-dimensional, coupled flow and transport model was used to simulate the transport of storm water through the infiltration basin. Most importantly, the model should ultimately serve as an aquifer management tool so it can be used to examine and monitor the storm water infiltration in the surrounding areas, and to track the response of the aquifer in conjunction with aquifer monitoring data.

The V-MODFLOW (4.2) Computer code was applied for simulation of three dimensional coupled flows and transport in the Gaza coastal aquifer. It is a numerical engine based on finite difference grid.

The purpose of the local groundwater modeling is to study the influence of treated wastewater on the groundwater artificial recharge in the north of Gaza strip and to get a more comprehensive view of the effect of the groundwater on the local scale of quantity and quality of groundwater . In this chapter, the flow and transport models will be set up and discussed in details.

Developing of a conceptual model provides better understanding of the current site conditions and the physical behavior of the groundwater flow system. It simplifies and defines the hydrogeological problem and organizes the data to easily develop the mathematical model and selection of the most suitable numerical model. The mathematical model is based on many differential equations for calculating hydraulic heads accompanied with specifications of system geometry, boundary and initial conditions. Dimensions of the numerical model and the design of grids are based on available data regarding the study area, mainly inflows, outflows and system hydrogeology. The conceptual model must be as much as representative of real system as possible, in which constructing the numerical model depends on the conceptual model.

4.2 Data Collection

To develop the flow and transport models, all available data were collected for the northern part of Gaza coastal aquifer and were added to the modeling data base. This applies to historical and future data. Specific data items that needed to enter into modeling data base are:

1. Water level measurements for the selected years of study.

2. Historical rainfall data from the agriculture ministry.

3. Spatial and temporal distribution of groundwater recharge including rainfall data and return flow estimates.

4. Collection of wells properties within the model domain of the study area enclosing the numbers of different types of wells.

5. Collection of water quality data (Chloride concentration) and land use maps.

The collected data were obtained from many local sources in different formats. The source of this data is the Palestinian Water Authority (PWA) the Ministry of Agriculture (MOA) , and coastal municipalities water utility (CMWU) .

4.3 Ground water Model

4.3.1 Model Boundaries

The Model Domain encloses an area of 17.6x16 km in the north part of Gaza Strip as shown in Figure 4.1. A constant head boundary was assigned in west, the groundwater levels along the boundary are assigned according to the data from PWA of groundwater level for the year 2004. The upper boundary is defined by water table which rise and fall according to hydrologic changes. The lower boundary corresponds to the top of the Saqiya Group which is clay layer defined the bottom of the aquifer.

4.3.2 Grid Size

The model domain is divided into a uniform square grid comprising with a grid spacing of 200x200 m, excluding the area lies from 800 to 5000 in east west direction which was gridded by 50x200 as shown in Figure 4.1.

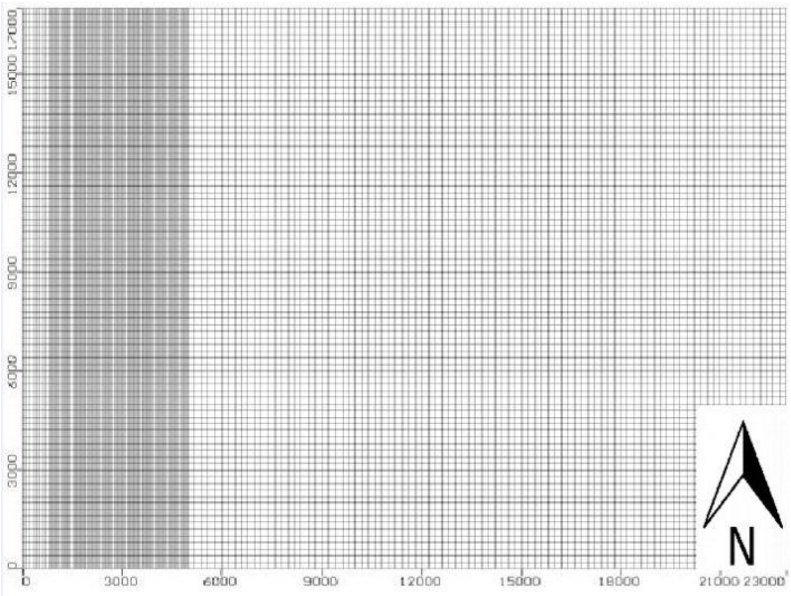

Figure 4.1: The model domain with the grid**.**

4.3.3 Recharge

Recharge from rainfall accounts for most of the renewable resources of the Gaza costal aquifer. A fraction of rainfall infiltrates and replenishes the aquifer system (effective recharge), and the remainder is lost to evapotranspiration and runoff Recharge from precipitation is not a directly measured value, but is estimated by various empirical methods that often involve variables that contain degree of uncertainty. Factors that ultimately influence recharge are precipitation amount (including rainfall duration and frequency), evapotranspiration, land use, soil type, and irrigation practices.

The monthly total rainfall for nine stations in the Gaza strip was utilized to estimate the total rainfall recharge. Values of total precipitation were simply multiplied by certain coefficients reflecting mainly the effect of soil type, land uses, rainfall intensity and irrigation activities to calculate the amount of infiltrated precipitation. The highest recharge coefficient value is 0.7; it is in sand dunes area parallel to the shore (Alghamri, 2009).

In the study area we specify 28 recharge zone as shown in Figure 4.2 , these recharge zones were specify depending on precipitation amount, land use and soil type excluding zone 28 which representing the Mediterranean sea, this zone is defined with chloride concentration 33000 ppm.

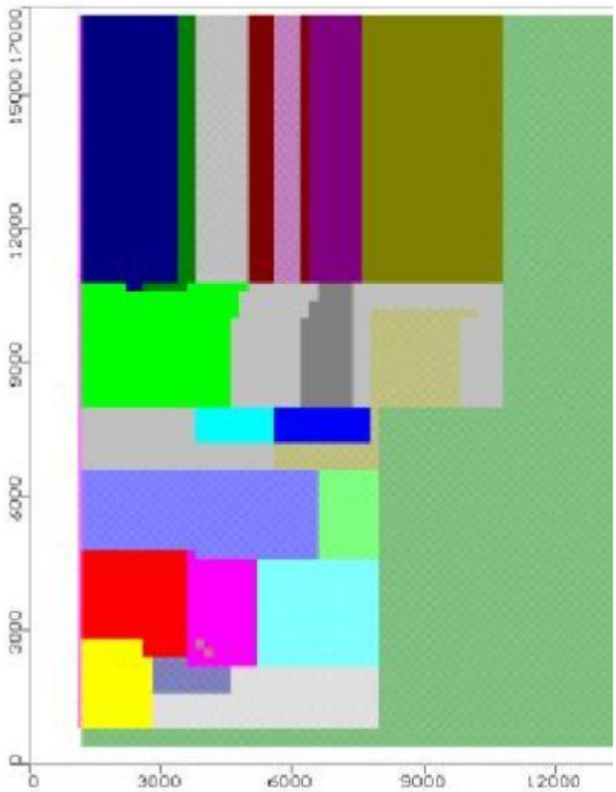

Figure 4.2: Recharge zones in the study area.

The amounts of recharge which is depending on rainfall were entered to the model every 6 months starting from 1/10/2004 to 30/9/2010 as shown in Table 4.1 .

Table 4.1: Rainfall records in the stations located in the study area, Source: PWA

From	To	Biet Hanoon	Biet Hanoon	Shati	Gaza City
01/10/2004	31/03/2005	358.7	320.6	296.6	316
01/04/2005	30/09/2005	167.5	177	141.5	135.8
01/10/2005	31/03/2006	338.4	330.6	279	282.1
01/04/2006	30/09/2006	30.5	33.2	38.2	40.3
01/10/2006	31/03/2007	459.9	440.5	417.5	443.9
01/04/2007	30/09/2007	3	1.8	1	3.2
01/10/2007	31/03/2008	253.2	322.1	286.5	336.5
01/04/2008	30/09/2008	0	0	0	0
01/10/2008	31/03/2009	347	320.5	390.8	413.6
01/04/2009	30/09/2009	0	0	0.5	0
01/10/2009	31/03/2010	250.2	223	270.1	252.3
01/04/2010	30/09/2010	0	0	0	0

4.3.4 Observation wells

The Observation wells in the model is divided into two types (concentration observation wells and head observation wells) 18 well were selected as head observation wells and 14 wells were selected as concentration observation wells for the model local calibration as shown in Figure 4.3.

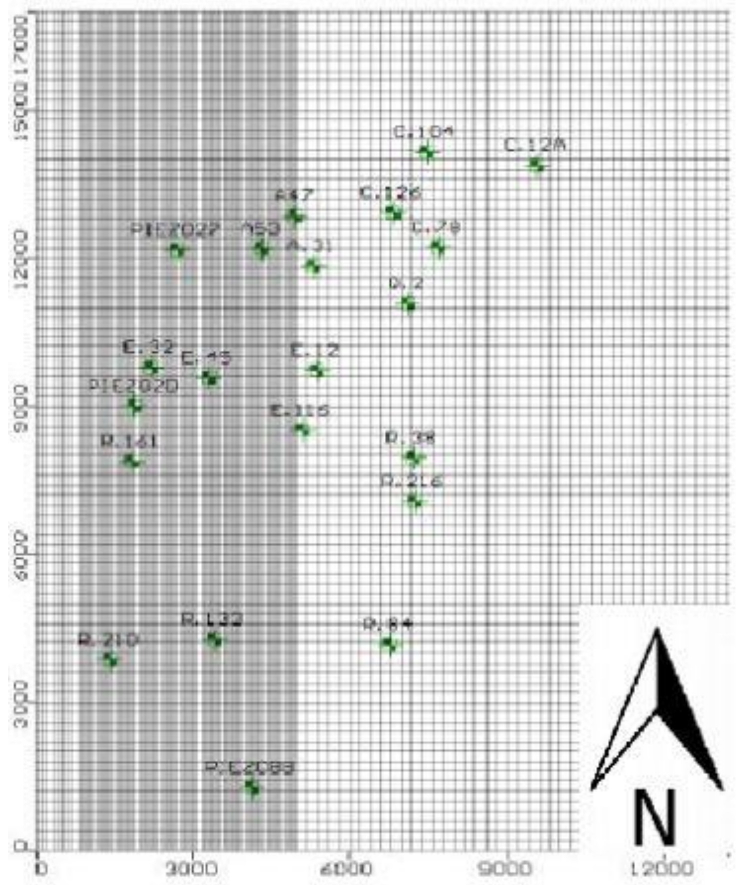

Figure 4.3: Head observation wells in the study area.

4.3.5 Return Flows

There are three primary sources of return flow in Gaza Strip: leakage from municipal water distribution systems, wastewater return flows and irrigation return flow. In the CAMP model report, 2000, it was assumed that 25% of water pumped for irrigation returned to the aquifer in the Gaza Area. According to the Palestinian Water Authority, the leakage from municipal water distribution systems was estimated at 29 % of the total abstraction in 2004 (CMWU). Wastewater return flows from Jabalia WWTP in the north and Gaza WWTP in the Gaza City has been estimated at about 25% of the total disposal (Alramlawi,2010).

4.3.6 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 and water quality parameters. 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 our 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 the their abstraction, These wells is shown in the Figure4.4.

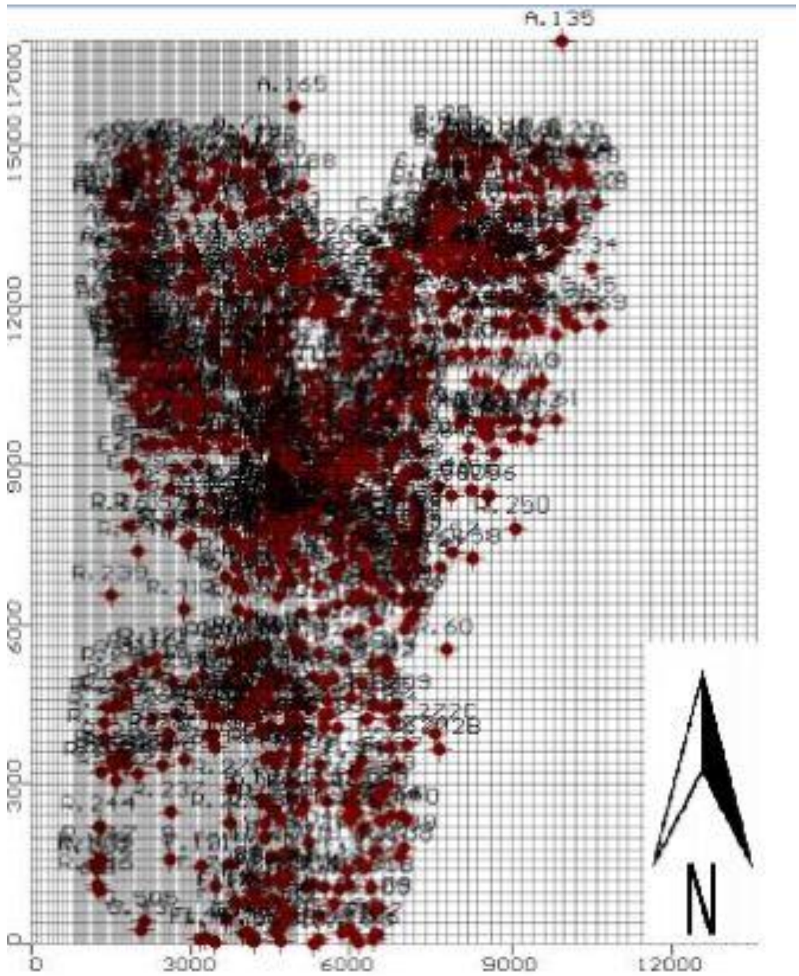

Figure 4.4: Municipal and agricultural wells in the study area.

4.3.7 Water Quality Data

Electronic files from PWA including two recordings of chloride concentrations per year for almost of the quality observation wells were available after the year 2004. Also, graphic map for chloride concentration were available.

47 well with complete data were entered to the model. Figure 4.5: shows the initial chloride concentration (mg/l) used in the model.

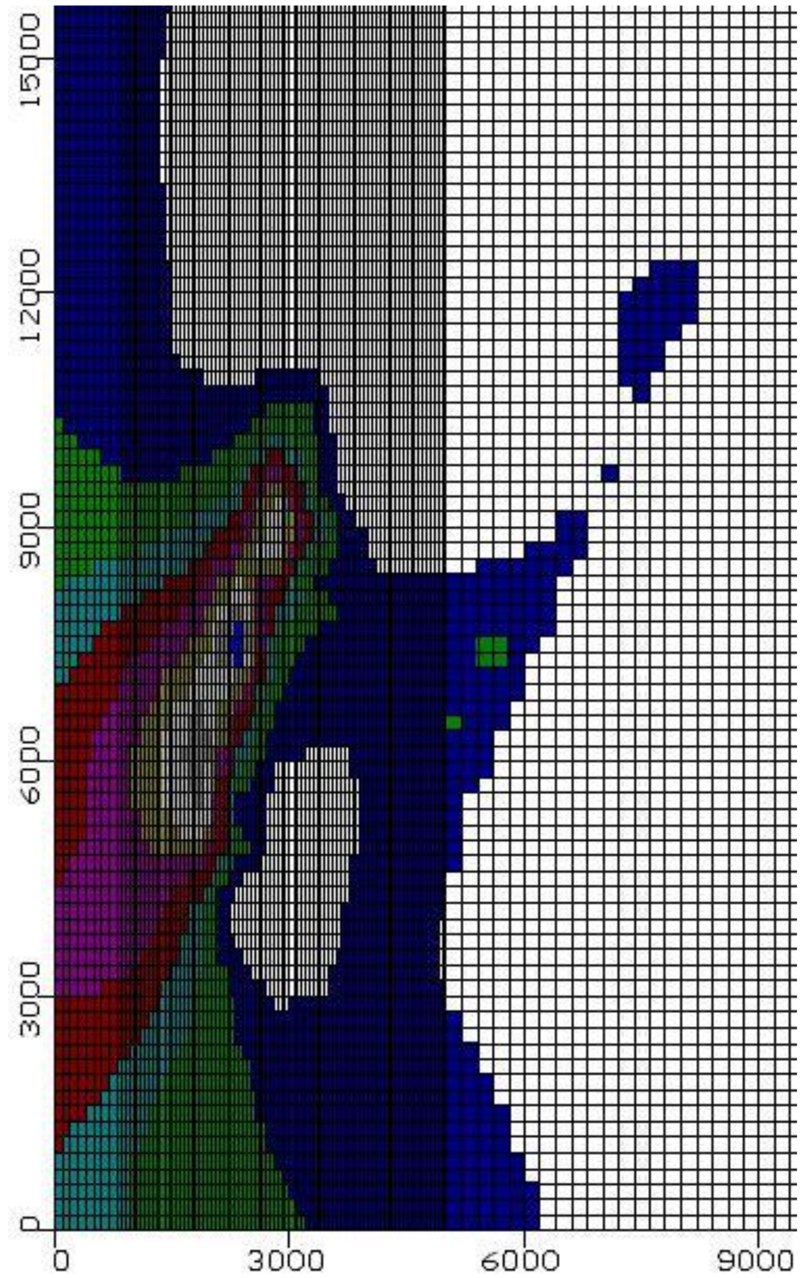

Figure 4.5: The initial chloride concentration used in the model.

4.3.8 Water Level Data

Electronic files from PWA including two recordings of water level data per year for almost of the water level observation wells were available after the year 2004. 57 well with complete data were entered to the model. Figure 4.6: shows the initial water level used in the model.

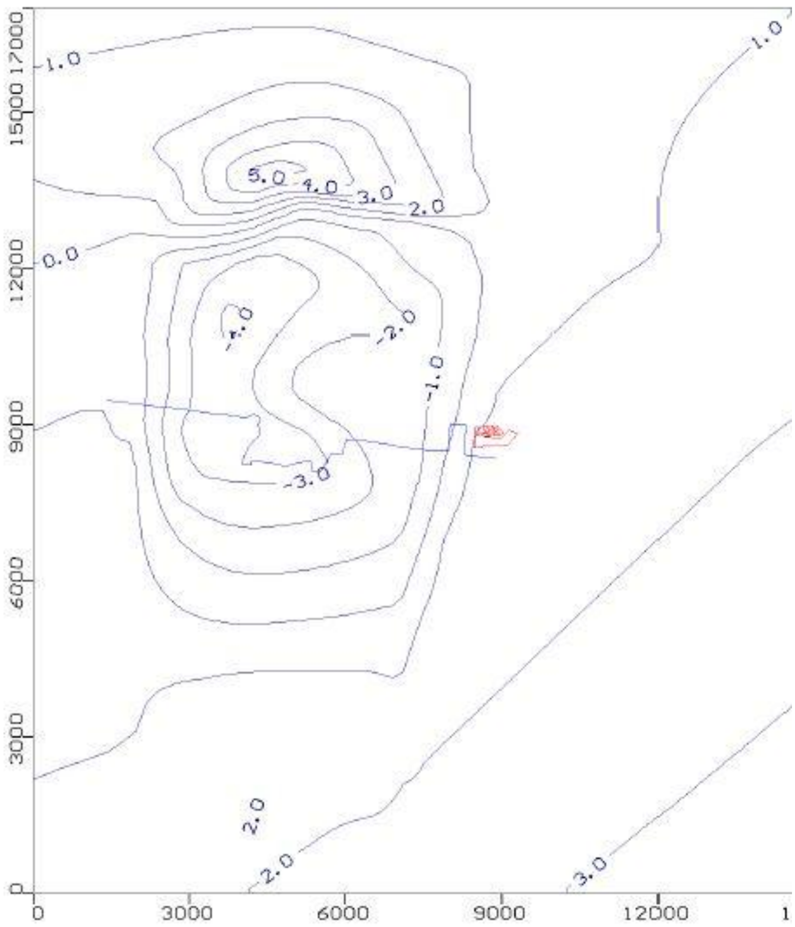

Figure 4.6: Initial Groundwater levels of the coastal aquifer in study area in October 2004 (PWA, 2004).

4.3.9 Model Calibration

Calibration is the iterative process of adjusting the parameters in the model, such as hydraulic conductivity, transmissivity, recharge and dispersivity, so the model adequately represents the real ground water system. Every model must be calibrated before it can be used as a tool for predicting the behavior of a considered system .This is accomplished by comparing the model results to a set of field observations. The calibration data set should include measurements over the lateral and vertical extent of the model area. For a flow model this data will often consist of water level and chloride concentration measurements from monitoring wells and piezometers.

Calibration is evaluated by analyzing the residuals, or differences between observed and simulated values, at specific locations. Calibration may be conducted by trial and error, changing the values of parameters until a good correlation is obtained between observed behavior of the ground water regime and the model results.

Calibration should proceed by first changing those parameters with the lowest level of accuracy, and then fine-tuning the simulation by adjusting other parameters. It must focus on parameters that are not measurable like recharge which is of regional significance .

Calibration is the process where hydraulic properties and boundary conditions are modified so that the simulated values of groundwater heads and concentration approximately meet the observed ones.

The numerical model was calibrated and tested against transient state. The simulation period was conducted over6 years, starting in October 2004 and ending at the end of September 2010 for transient calibration. The transient calibration aimed to calibrate the specific yield of the aquifer. Therefore, transient simulation was set to simulate the groundwater levels for the period from 2004 to 2010.Figure 4.7 compares between the simulated water level (Left Figure) and the observed water level (Right Figure).

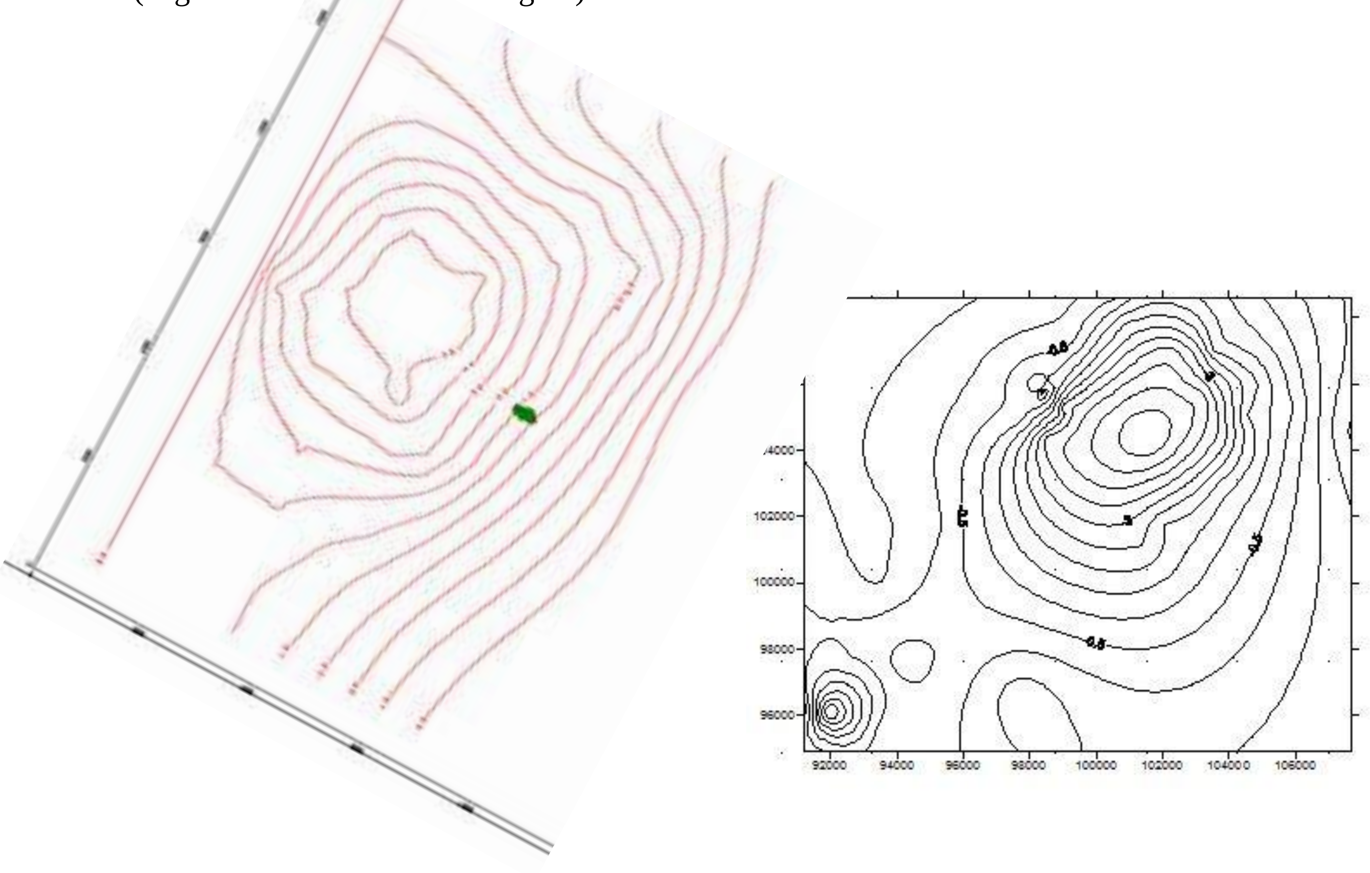

Figure 4.7: Comparison between the simulated water level in 2010 and the observed water level in 2010.

For the 18 wells within the model domain were used as calibration targets. The calculate mean error is 0.12m , mean absolute is 0.491m, standard error of the estimate is 0.092m , root mean squared 0.507 m, normalized RMS 7.71%.Calibrated groundwater levels versus measured groundwater levels for the years 2010 ,correlation is 0.961 are shown in Figure 4.8, while the Figures 4.9 ,4.10 ,4.11, 4.12 illustrate the trend of calculated versus observed water level for representing observation wells in the model.

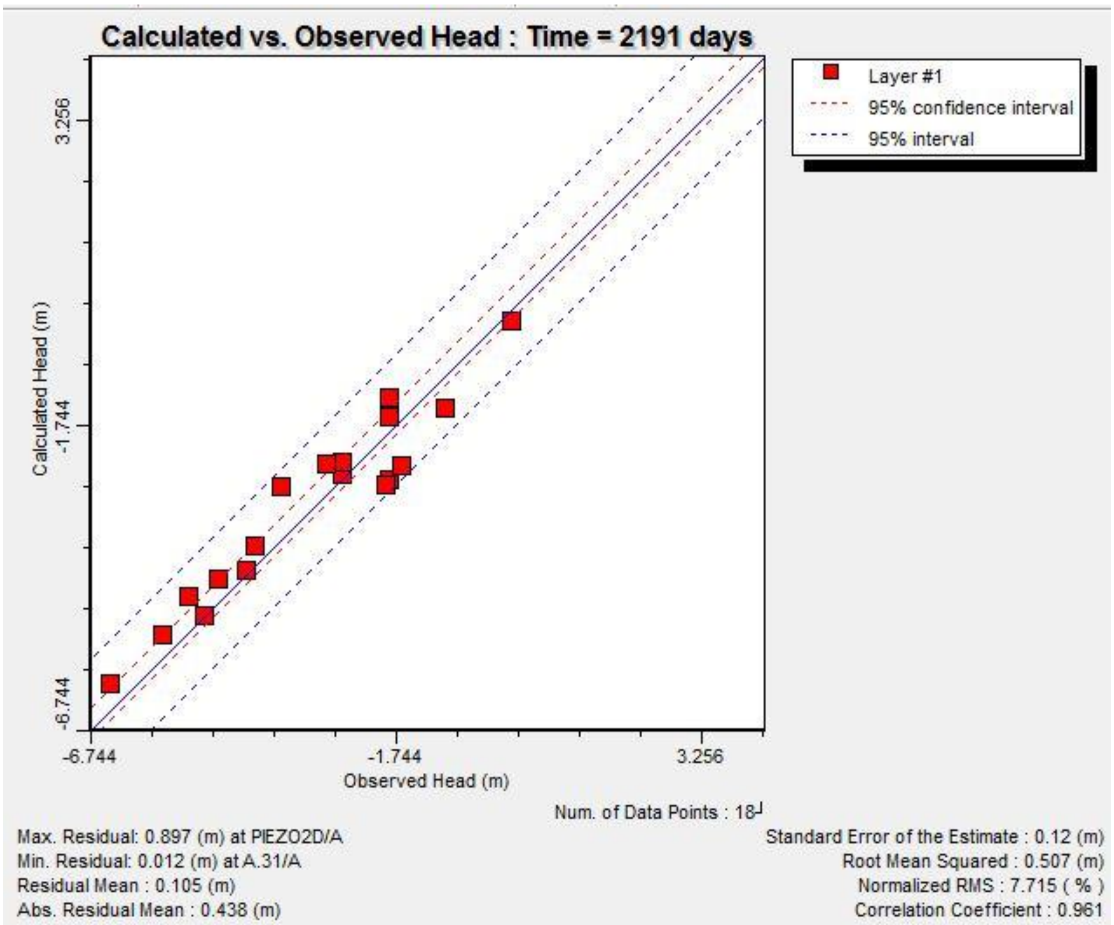

Figure 4.8: Calibrated versus measured groundwater levels at the year 2010.

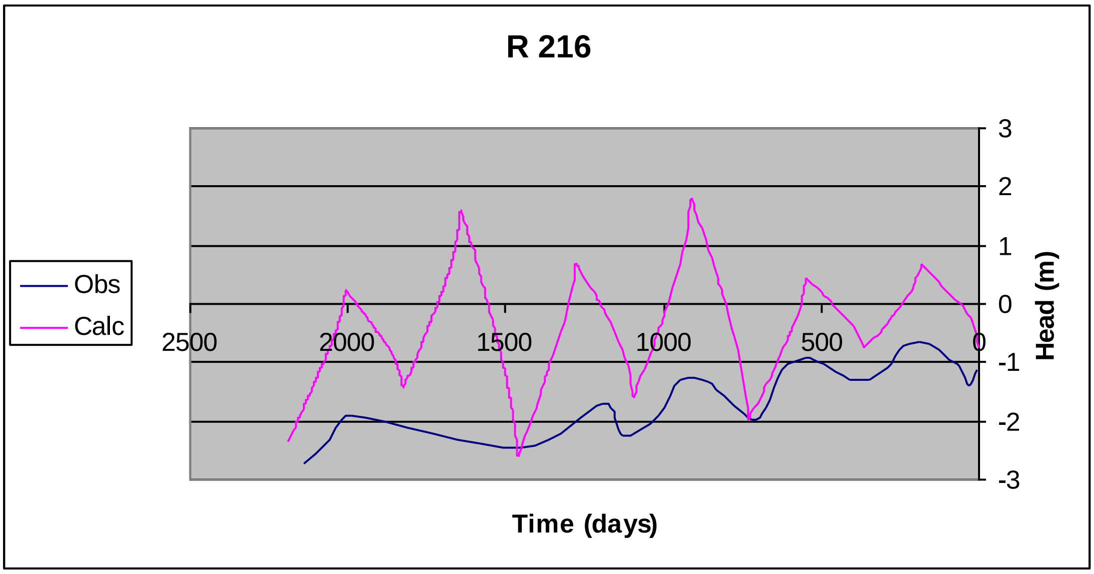

Figure 4.9: Observed and calculated heads versus time for well R 216.

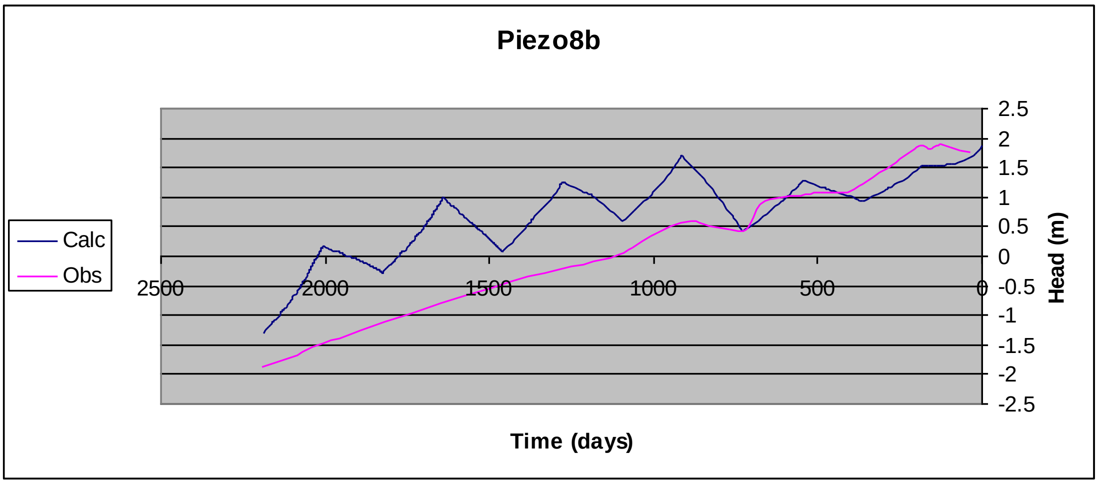

Figure 4.10: Observed and calculated heads versus time for well Piezo 8B.

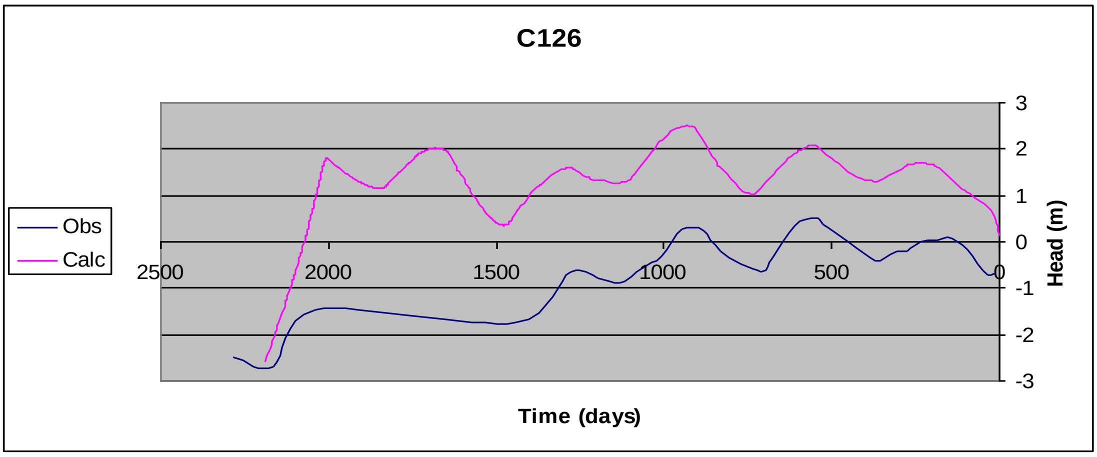

Figure 4.11: Observed and calculated heads versus time for well C 126.

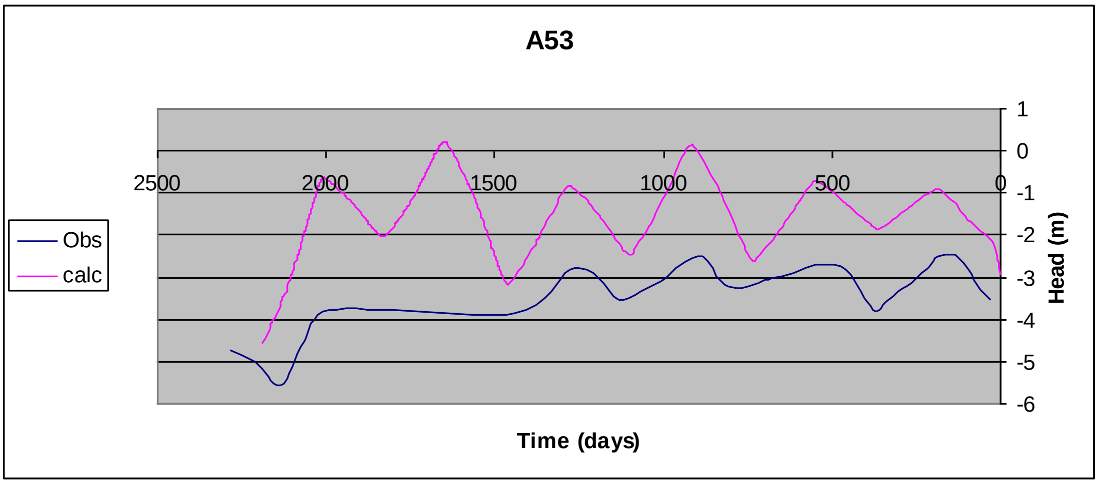

Figure 4.12: Observed and calculated heads versus time for well A 53.

It's observed that the wells of A and R symbols have higher calculated water level than observed water level , this refer to the existence of illegal wells in this area and this wells are not modeled in the study.

For water quality, Average chloride concentration of year 2008 for the 14 wells within the model domain were used as calibration targets. The calculate mean error 17.054mg/l, mean absolute is 102.51mg/l, standard error of the estimate 32.455mg/l , root mean squared 123.821 mg/l, normalized RMS 20.9%.Calibrated chloride concentration versus measured chloride concentration for the years 2008 ,correlation is 0.807as shown in Figure 4.13, while Figure 4.14 compares between the simulated chloride concentration(left Figure) and the observed chloride concentration by PWA (Right figure) and Left.

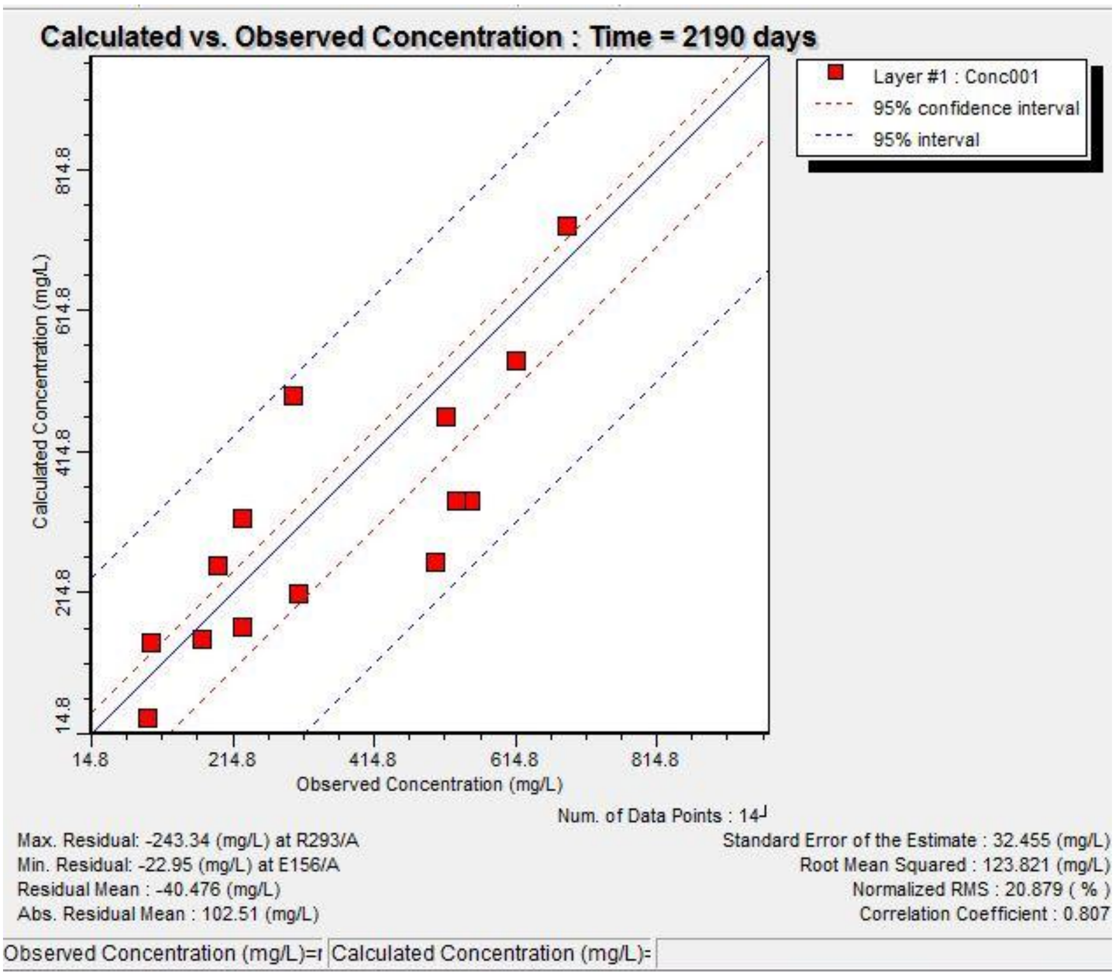

Figure 4.13: Calibrated versus measured chloride concentration at the year 2008.

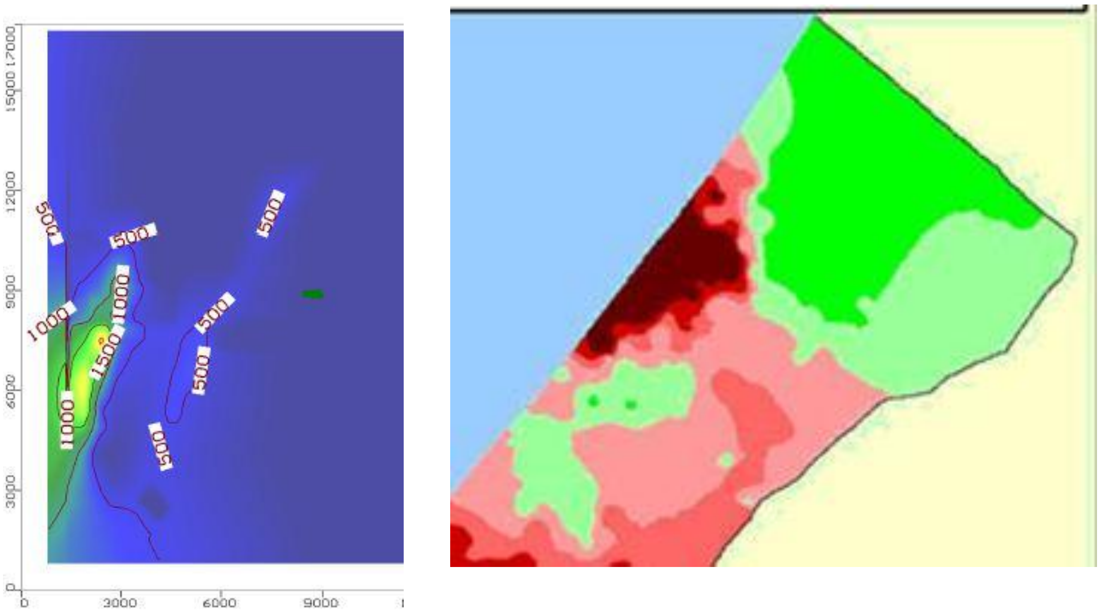

Figure 4.14: Comparison between the simulated chloride concentration in 2008 and the observed chloride concentration in 2008.

Chapter Five

Seawater Intrusion Management and Control

Chapter 5: Seawater Intrusion Management and Control

5.1 Introduction

The advantage of a calibrated ground water model is that it can be applied to investigate 'what -if' scenarios and answer planning questions and predict impact of aquifer management decisions (Alghamri, 2009). The management options or scenarios may be regional scale approaches or local- scale scenarios. In this study only the regional- scale scenarios were studied.

There are many localized and specific management techniques can be investigated. The management options were tested with the calibrated, coupled flow and transport model. It should be noticed that all scenarios focused on North of Gaza valley area within the model domain, whereby the research aimed in all to find a reliable solution of the seawater intrusion in North of Gaza valley area. The approach for selecting the management scenarios was carried out depending on the need to reduce the migration of seawater into the aquifer system, and, according to the results of transport model. All alternatives of scenarios based on management the pumping from the aquifer and injection of treated waste water to the aquifer. six selected management scenarios were tested; where all scenarios were studied to the year 2020.

5.2 Management Scenarios

This section aims to identify the future extent and the long-term trends in groundwater concentrations for the target period (2012-2020) when applying the suggested management scenarios. For the scenario analysis, all calibrated physical and hydro-geological parameters from the flow model were used. Also, the calibrated yearly chloride concentration presented in the previous chapter was kept the same as the baseline to predict the future chloride concentration. As shown in the previous section the six management scenarios were tested in this study were:

1. No action and investigate the expected aquifer status in 2020 with no action,
2. Management the pumping with reduction to 50%,
3. Injection of treated wastewater to the aquifer,
4. Bringing together Scenario2 and Scenario3,
5. Management the pumping with reduction to 80% and injection of treated wastewater,
6. Injection of treated wastewater in addition to stopping the abstraction from 2012.

Scenarios Assumptions

1. Target period for prediction is from 20010 to 2020.
2. All calibrated physical and hydro-geological parameters from the flow model were used.
3. The initial water level and chloride concentration for the management scenarios is that outputted from the calibrated model.
4. For the period 2010–2020, recharge was set to the flow model as set in the calibrated model from 2004 to 2010 and repeated another time.
5. Land use distribution was set as in the previous years without any change.
6. The contour line of 500 mg/l chloride concentration is considered as a reference. The movement of this line will indicate the status of sea water intrusion in spatially.

Table 5.1 shows the properties for all scenarios. The average abstraction rates for agricultural wells remained the same as in basic flow model

Table 5.1: Management scenarios properties**.**

No	Scenario	Properties
1	Expected 2020	*Annually increasing of pumping from the aquifer according to the growth of population and targeted capita consumption at 2020 =150 litre. *The abstraction from Agricultural wells will stay as it now.
2	Management the pumping with reduction of 50%.	*The half of abstraction for scenario 1 will be used.
3	Injection of treated wastewater to the aquifer.	*Artificial recharge for treated wastewater will infiltrated to the aquifer.
4	*Bringing together scenario 2 with scenario 3.	*Applying scenario 2 with scenario3.
5	*Reduction of abstraction to 0.2 of abstraction and injection of treated wastewater.	*1/5 of scenario 1 and injection of treated wastewater.
6	Injection of treated wastewater and stopping the abstraction from October 2012	

According to the Palestinian Central Bureau of Statistics (PCBS), the growth population rate of 3.8 % was assumed in these years to estimate the future municipal well abstractions.

5.3 Results

Measurements of water level for 20 wells and chloride concentration in (mg/l) for 14 observation wells were recorded for years (2013, 2014, 2016, 2018 and 2020) and are shown in Figure 5.1. Depending on the assumptions and properties of all scenarios, this section shows the impact of each scenario on the chloride contamination and water level.

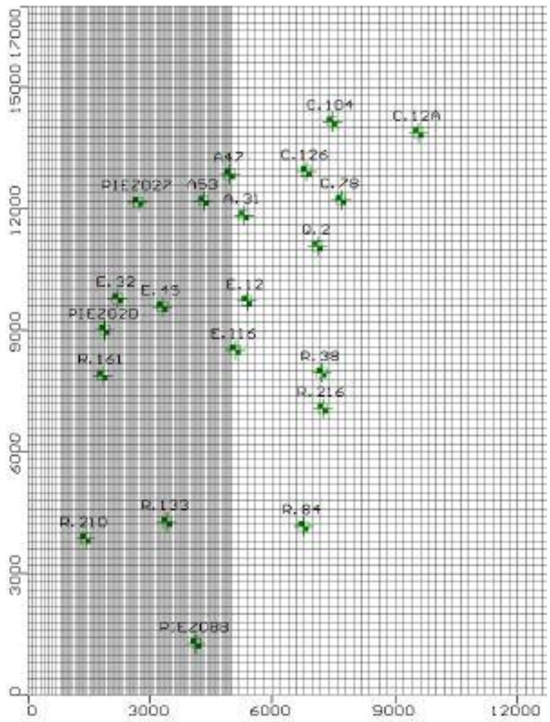

Figure 5.1: Selected head observation wells

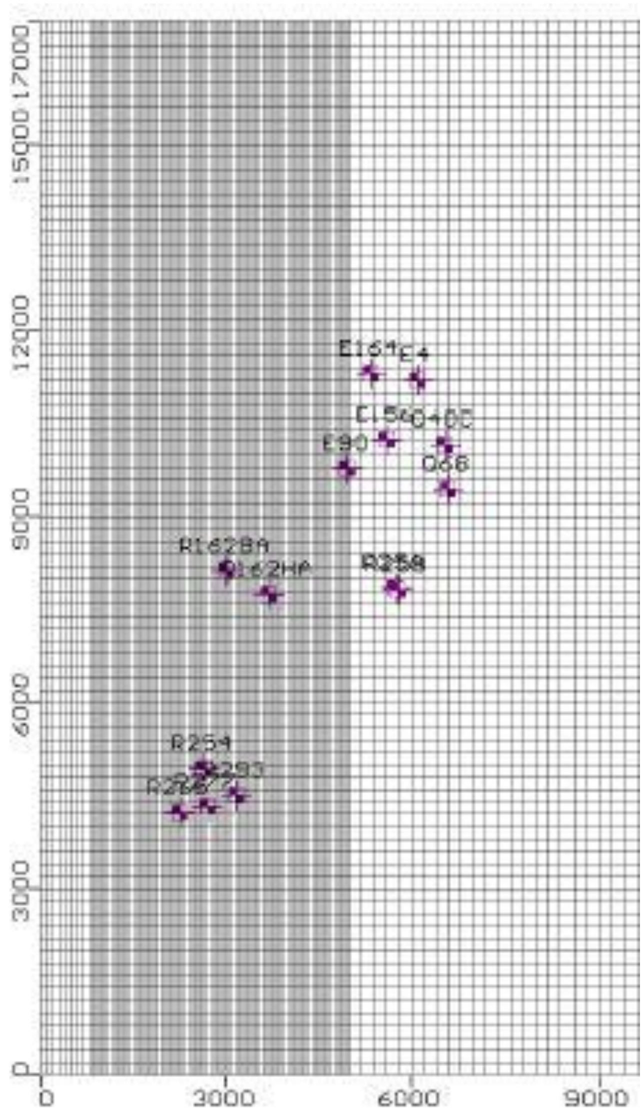

Figure 5.2: Selected Concentration observation wells

5.3.1 Scenario 1 and scenario 2

For scenario 1, it is observed that in year 2020 the expected seawater intrusion will reach to about 4 km from the sea which considered the movement of the contour of 500 mg/l in the aquifer (Figure 5.2). This means the seawater will influence R and some of E wells in the area.

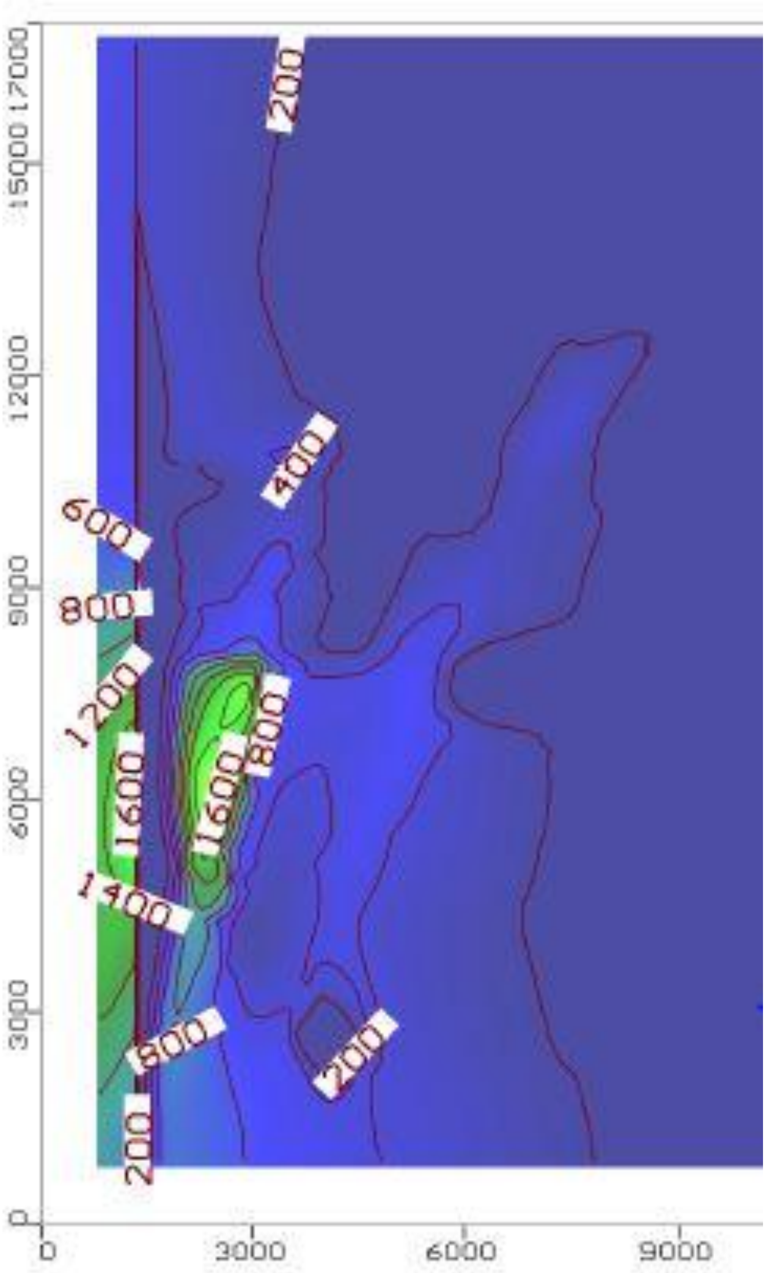

Figure 5.3: Chloride concentration in 2020 for scenario 1.

For scenario 2 , the reduction of abstraction will be half, therefore, as it shown in Figure 5.3 the seawater intrusion will be reduced and the in-aquifer extension will be 2.8 km. The influence wells by the seawater intrusion will be decreased by 30 %. This reduction is not significant.

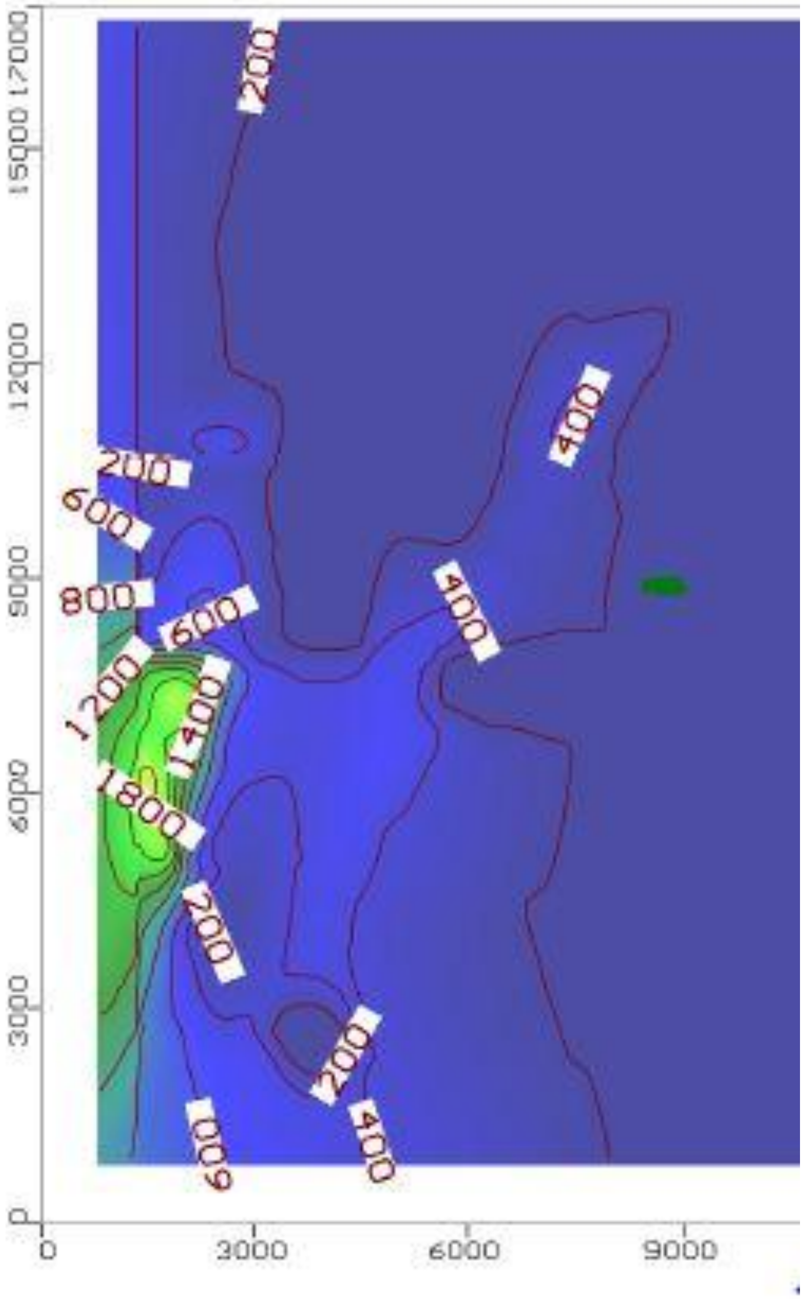

Figure 5.4: Chloride concentration to the year 2020 for scenario 2.

To investigate the local behavior of the aquifer, the chloride concentration and groundwater level were simulated in selected wells in the study area. Figure 5.1 shows the wells that selected for that purpose.

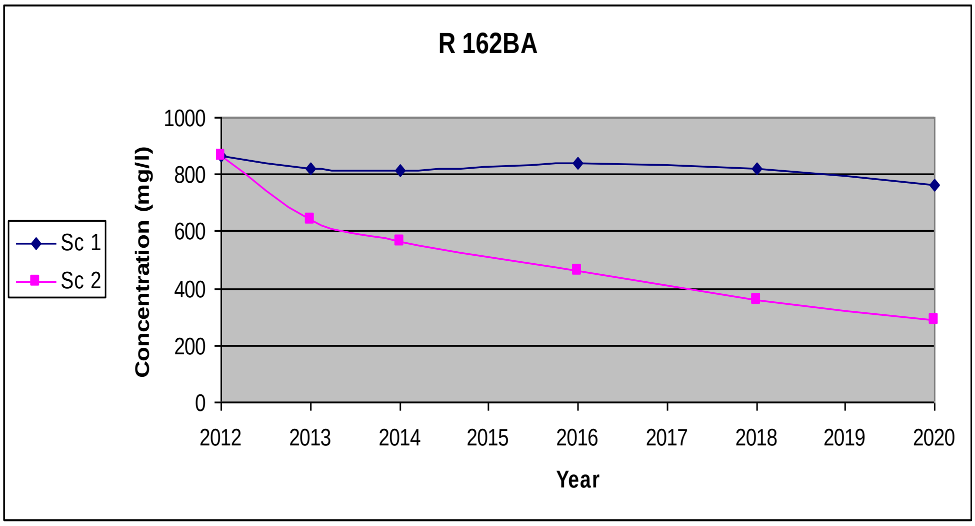

Figure 5.5: Chloride concentration in R-162BA well for year 2020 under scenario 1 and scenario 2.

Figure 5.4 the simulated chloride concentration for year 2020 in well R162BA 3015m from the shoreline) under scenario 1 and 2 was. It can be seen that the chloride concentration in the well will be 300 mg/l in year 2020 where the concentration is reduced by around 500 mg/l in 8 years and using scenario 2.

Figure 5.5 shows that the water level will be deteriorated , and will reach to -10 MSL in the populated areas under scenario 1 which indicates an indirect increase and enlargement of the seaware intrusion in the aquifer as presented in Figure 5.2. The groundwater level will be enhanced if a reduction of abstraction is consider (scenario 2) as shown in Figure 5.6. The groundwater level will rise to -6 MSL instated of -10 in the populated. The groundwater level simulation in well R210 under scenario 1 and 2 is shown in Figure 5.7. The GW level will be increased by 20 cm in 8 years.

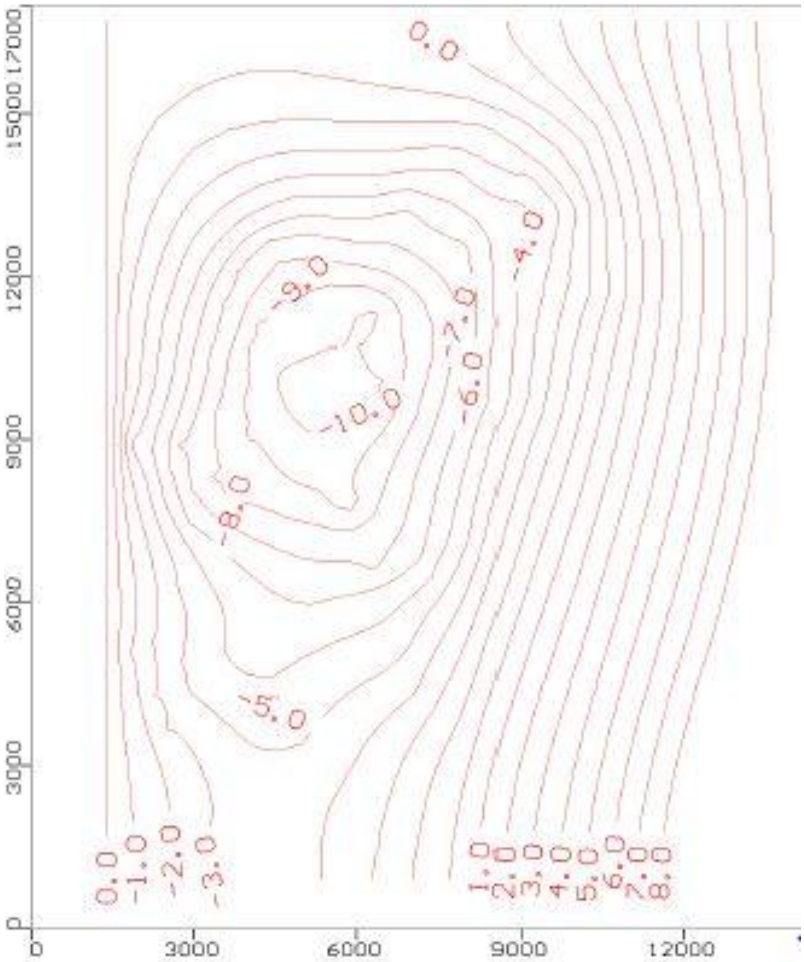

Figure 5.6: Water level to the year 2020 for scenario 1.

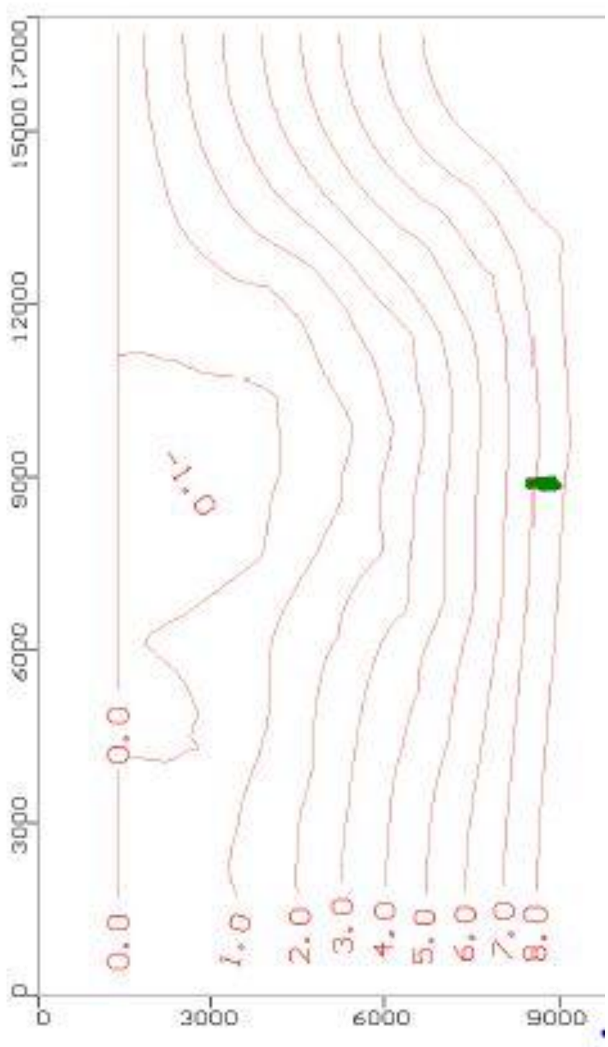

Figure 5.7: Water level to the year 2020 for scenario 2.

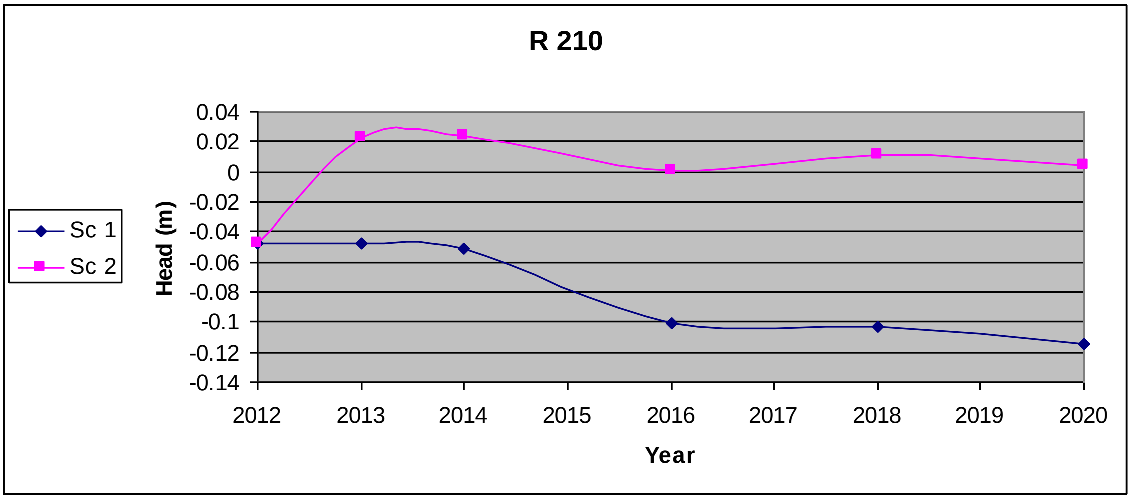

Figure 5.8: Groundwater level in R-210 well for year 2020 for scenario 1 and scenario.

5.3.2 Scenario 3

The third scenario (Injection of treated wastewater to the aquifer) is tested to investigate how much the seawater intrusion problem can be minimized. This scenario assumed that all treated wastewater from the northern area will be artificially recharged into the aquifer. The amounted of current treated wastewater water in the northern area is 94000 MCM/yr. It can be seen from Figure 5.8 that the application of injection of treated waste water to the aquifer will not be valuable to the chloride concentration since the chloride concentration by 200 mg/l in year 2020 and it will be 800 mg/l in well R-254 (2640 m from the shoreline), for example. Figure 5.9 indicates also that the difference between groundwater level in scenario 1 and scenario 3 will not be very high. This is due to that the amounts of treated wastewater are small compared to the abstracted water from the aquifer.

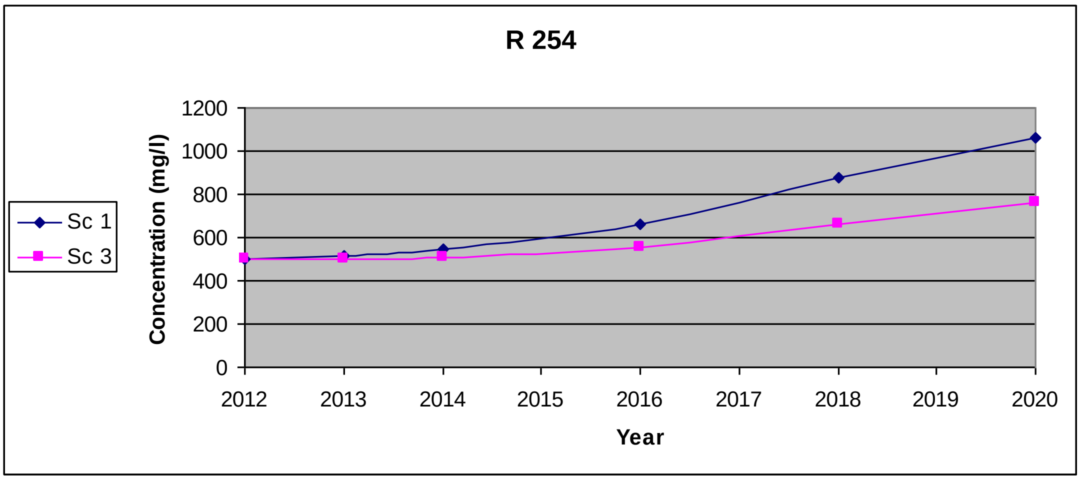

Figure 5.9: Chloride concentration for the well R 254 to the year 2020 for scenario 1 and scenario 3**.**

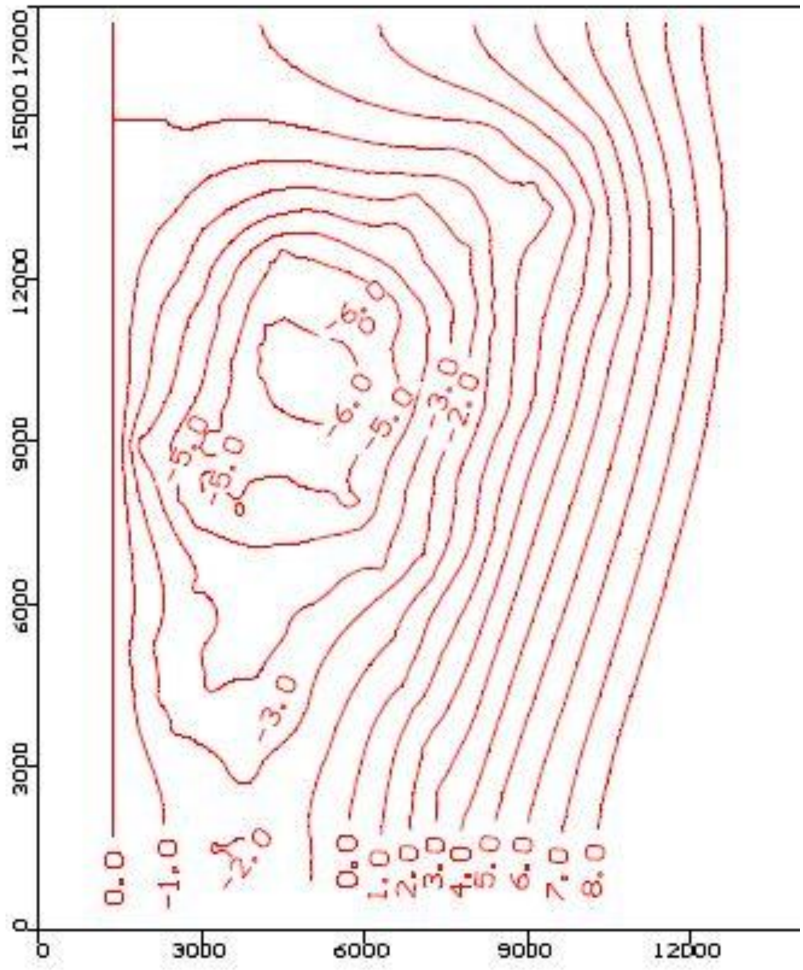

Figure 5.10: Groundwater level in year 2020 for scenario 3 .

5.3.3 Scenario 4

If scenario 2 **(**The half of abstraction for scenario 1 will be used) and scenario 3 are combined and applied at the same time under scenario 4, the global chloride concentration will be enhanced as shown in Figures 10 and 11. It can be seen that the chloride concentration will be close to the chloride concentration in scenario 2. This indicates the reduction of pumping is a dominant factor for seawater intrusion control more than the artificial recharge of the aquifer. Figures 5.12 and 13 shows the groundwater level rise under scenario 4 where the groundwater level will rise by 2 m in year 2020 in well R161.

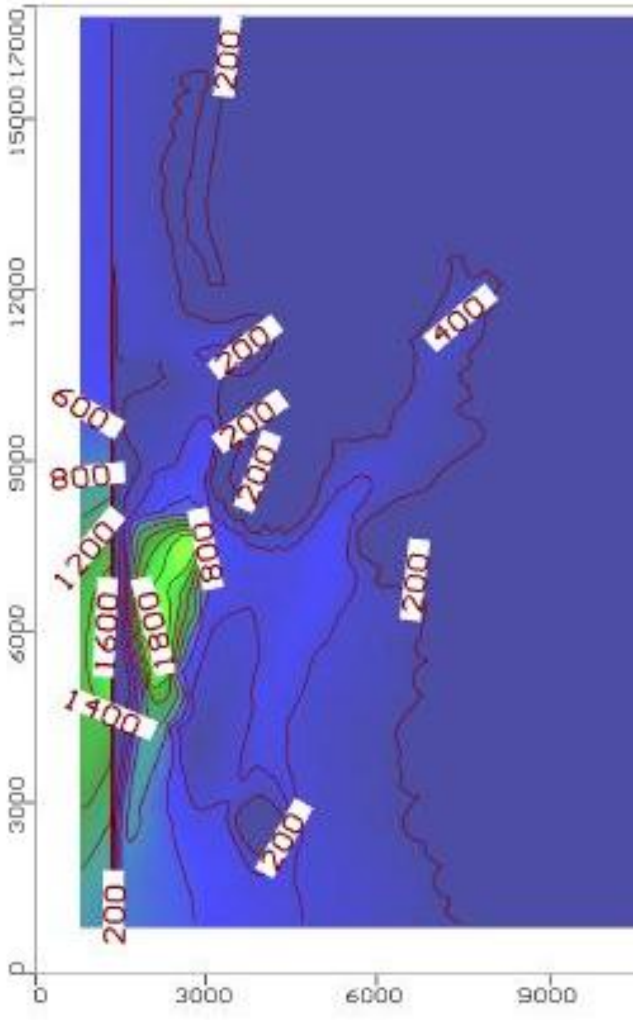

Figure 5.11: Chloride concentration to the year 2020 for scenario 4.

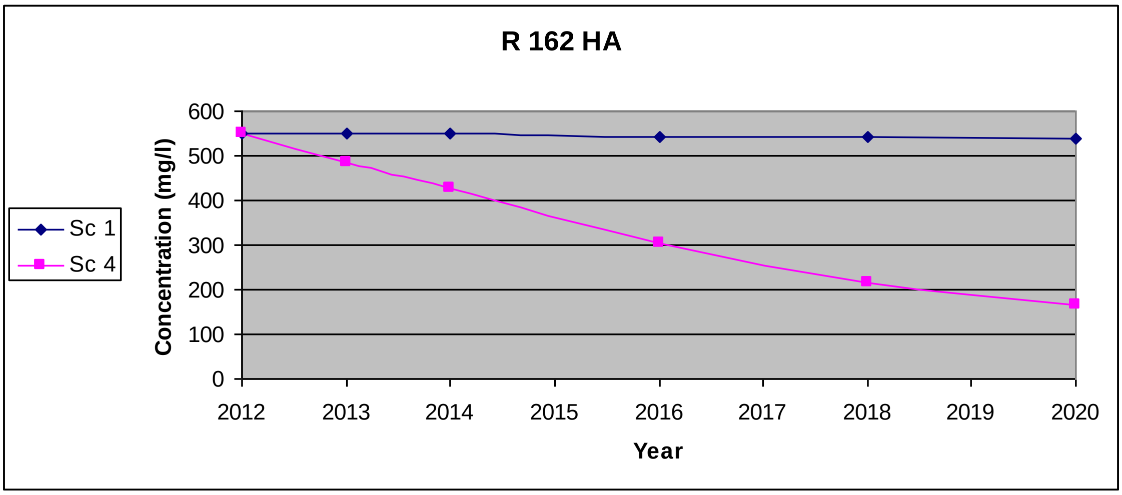

Figure 5.12: Chloride concentration in well R-162HA for year2020 for scenarios 1 and 4.

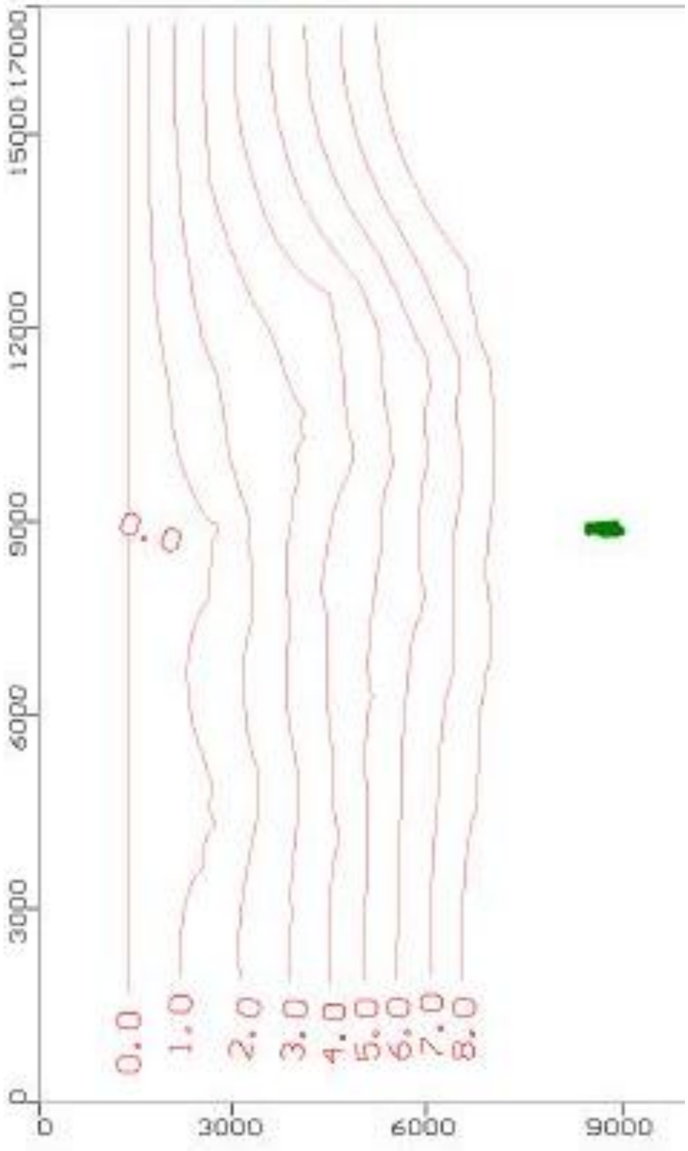

Figure 5.13: Water level to the year 2020 for scenario 4.

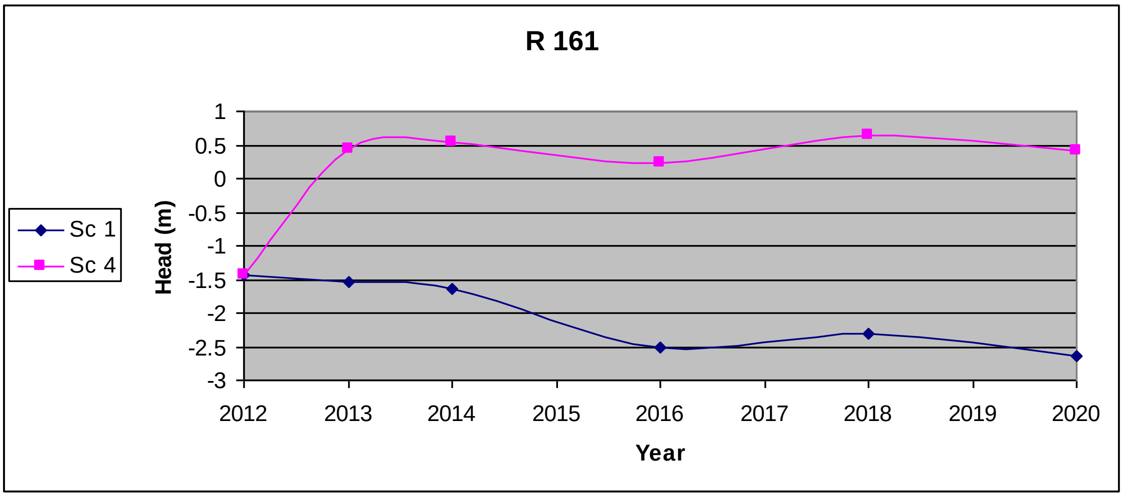

Figure 5.14: Groundwater level in well R-161 for year 2020 for scenarios 1 and 4.

5.3.4 Scenario 5 and Scenario 6

If scenario 5 is considered where the abstraction from the wells will be 0.2 of the original abstraction and injection of all treated wastewater. The seawater intrusion will be diminished in this scenario 5 applied and only the seawater will reach to 0.5 km from the seashore line (Figure 5.14). The seawater intrusion in the northern area will be completely minimized if scenario 6 is considered where injection of treated wastewater and stopping the abstraction starting from October 2012 and up to year 2020 as shown in Figure (5.15).

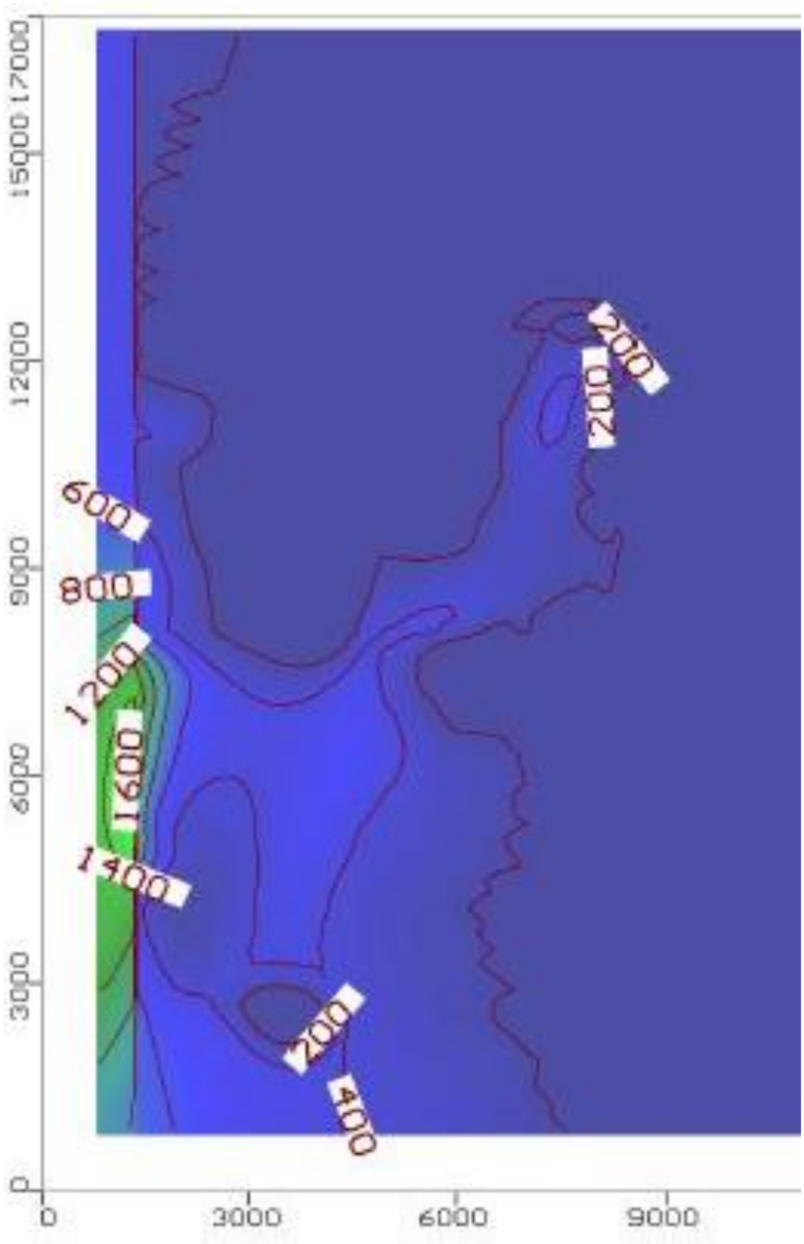

Figure 5.15: Chloride concentration to the year 2020 for scenario 5.

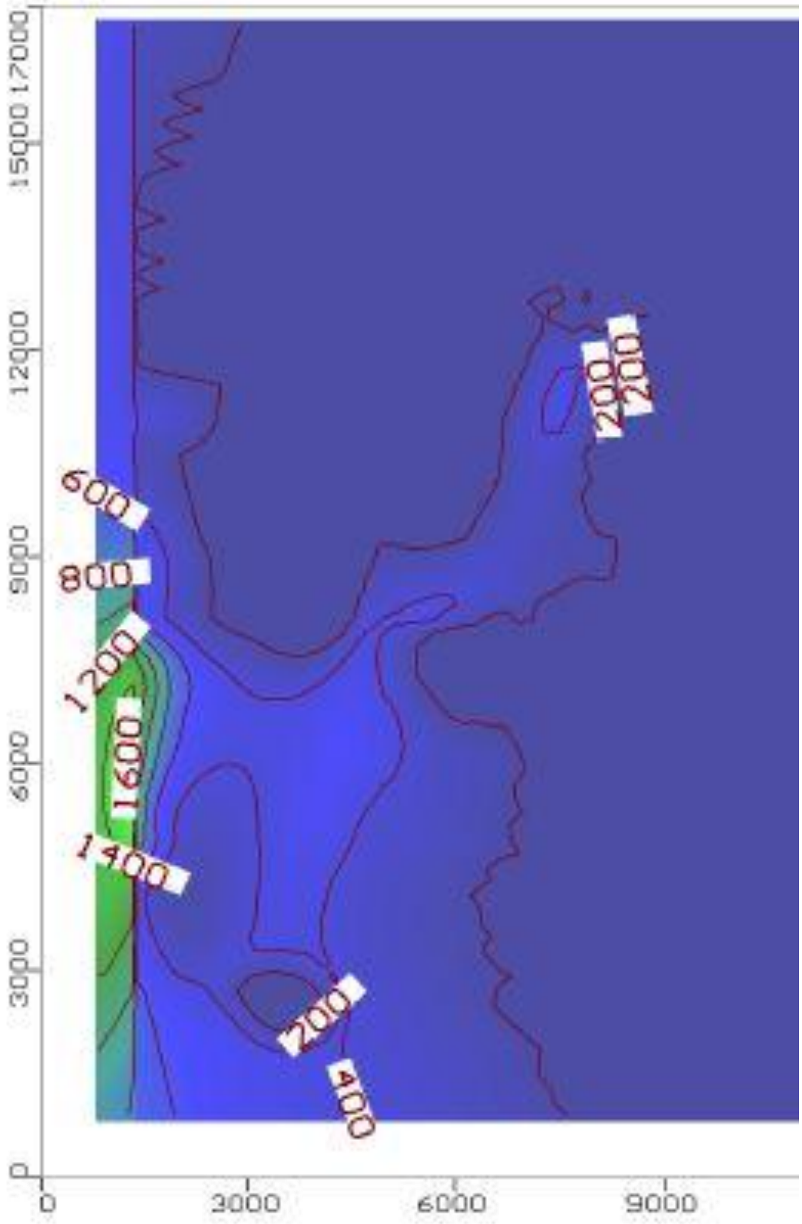

Figure 5.16: Chloride concentration to the year 2020 for scenario 6.

Figure 5.16 shows the change of chloride concentration under the six scenario in well R254 . Figure 5.17 presents the groundwater level simulation for all scenarios in well E32. Figures 5.16 and 5.17 show that the sixth scenario is the best alternative for controlling minimizing the seawater intrusion in terms of groundwater level enhancement and reduction of chlorides concentration. However, scenarios 4, 5 and 6 is very close together in terms of chloride concentration.

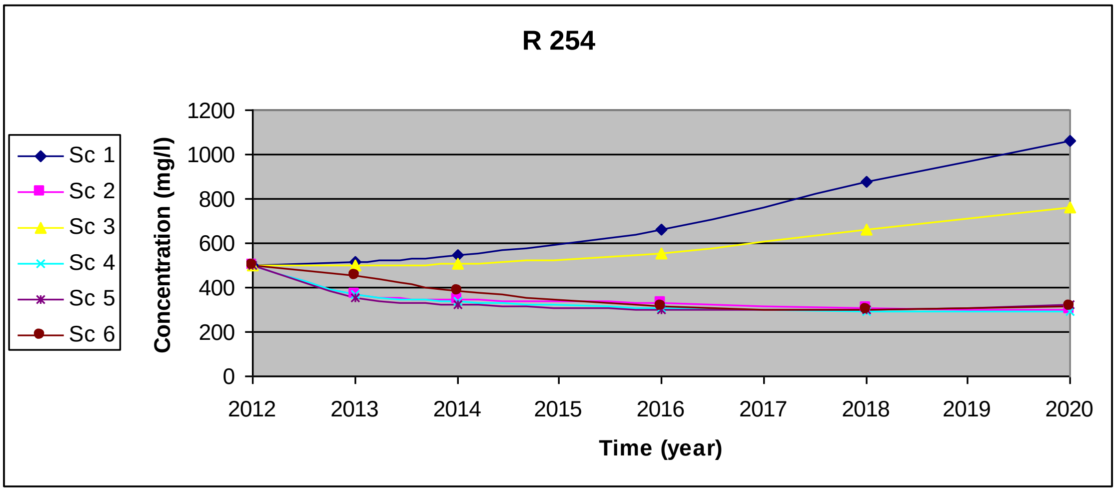

Figure 5.17: Chloride concentration for the well R254to the year 2020 for all scenarios.

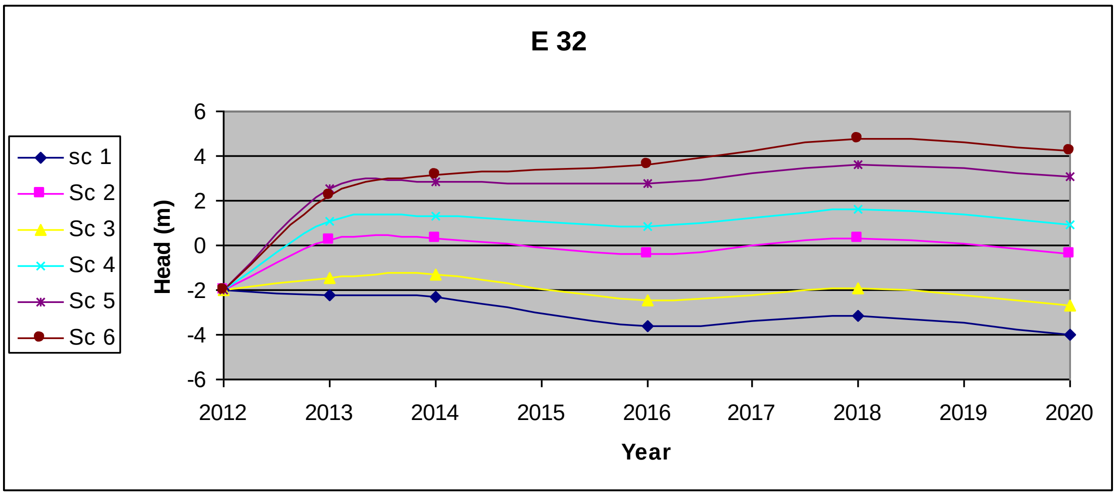

Figure 5.18: Groundwater level in well E 32 for year 2020 for all scenarios

Shows the chloride concentration and groundwater levels in the selected monitoring wells for all scenarios and for years 2016 and 2020.

5.4 The cost of executing the best scenario

Figures 5.13 and 5.14 also show that the best fit scenario for the seawater intrusion in the North of Gaza Strip is injection of all treated wastewater and stopping the abstraction from the aquifer. Applying this scenario requires construction centralized or decentralized infiltration basins to inject the treated wastewater and recovery wells. The sixth scenario also requires stopping the abstraction from the aquifer, which obligate searching for new water resources substituting the abstraction from the aquifer. According to PWA and CMWU the most feasible option is seawater desalination plant. In addition to make the sixth scenario feasible a network and distribution system for irrigation are also required. The cost of these requirements includes:

1. Construction of Desalination plant.
2. Construction of Infiltration Basins.
3. Recovery Wells.
4. Network and distribution System for irrigation.

1- Construction of Desalination Plant for the Northern area

The cost of construction is computed as follows:

- # of People in 2008= 825,895 capita
- # of People in 2020= 825,895 * $(1.038)^{12}$=1,322,285 capita
- The required daily consumption in North of Gaza strip =1322285*0.15=198,343 m^3 take 200,000 m^3/d
- To cover 200,000 m^3/d, it is required to construct large scale desalination plant.
- The cost of desalination plant = 0.8M$/ m^3/d (according to PWA).
- The cost of desalination plant with capacity of 200,000 m^3/d=200,000*0.8M $=160M$.
- The Operation and Maintenance cost =0.5 $/ m^3.
- The O&M cost of 200,000 m^3/d = 0.5*200,000=100,000 $/d.

2- Construction of Infiltration Basins:

In North of Gaza strip there is ongoing project consists of the construction of nine infiltration ponds with a total amount $ 5,714,705.91 and area of 8.0 hectare and an ultimate infiltration capacity of 35,600 m^3/day. These basins are planned to receive the sewage effluent that will be pumped from the BLWWTP effluent lake in part A of the NGEST and to receive the NGWWTP treated effluent upon the construction and commissioning of Part B of the NGEST. The cost to construct Infiltration Basins to infiltrate 94,000 m^3/d will be 14,921,729 M$ and required 20.8 hectare. The recovery schemes that includes the recovery wells, irrigation network and distribution System for irrigation to recover 39,000 m^3/d and to construct network for irrigation 15,000 donums will around 30,000,000 $. In addition the cost of construction the wastewater treatment plant in the northern area which is around 80 M$.

Therefore, the total cost to minimize the seawater intrusion in the northern area will be around 300 M$. This alternative will provide sustainable resources for crop irrigation.

Chapter Six

Conclusion and Recommendations

6.1 Conclusion

1-The used finite-difference code MODFLOW to simulate the hydraulic head within the groundwater and the MT3D to simulate the chloride transport are good tools.

2-The abstraction from the aquifer affects on the chloride concentration in groundwater.

3-In the event of work as usual, the seawater intrusion reaches to 4 Km toward east .

4-Reduction of abstraction to 50% will reduce the seawater intrusion, and the seawater intrusion will reverse to west by 1.2 km and will enhance the water level by 7 meter.

5-The implementation of artificial recharge will not largely enhance the quality of chloride concentration and the water level in the Study area, this is due to that the amount of abstracted water from the aquifer is larger than the amounts of injected treated wastewater.

6-The injection of treated wastewater in addition to reduction of abstraction to the half , the injection of treated wastewater in addition to reduction of abstraction to 0.2 from the demand and finally the stopping the abstraction and injection of treated wastewater scenarios are close together in enhancing the quality of chloride concentration and water level .

7-The best fit scenario is to stop the abstraction from the aquifer and to inject treated wastewater to the aquifer which requires to search for another solution as building up desalination plants, treatment plant, infiltration basins and network for irrigation.

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. It introduced in numbers the effect of many management options on Chloride concentration and water level in North of Gaza strip governorate.

2-The continuous deterioration of Gaza aquifer should be stopped. The management options in this study help to stop the deterioration. It is the first step in management the groundwater quality. The second step is to search for other sources of water from the aquifer. Alternative sources can be plants for seawater desalination, injection of treated waste water to the aquifer.

3-The implementation of desalination plant and injection of treated wastewater will help significantly in reducing the average chloride concentration and will rise the water level in the area.

4-The best scenario to solve the increasing of chloride concentration problem in the groundwater is the combination of many options (reduction the pumping from the aquifer by using RO unit, implementation artificial recharge system at North of Gaza strip area.

5-As a general recommendation, PWA, MoA, CMWU, and other related authorities has to construct an integrated data base for hydrological data of Gaza Strip.

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3. http://www.cee.vt.edu/ewr/environmental/teach/gwprimer/recharge/recharge.html.
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Appendix

Table A-1 : Initial Groundwater Level inserted to the model in 2004

Well Name	X Coordinate	Y coordinate	Wl /MSL
A/107	101218	107482	-2.47
A/31	102773	106052	-3.33
A/47	103102	107074	-1.85
A/53	102191	106917	-3.51
A/64	103330	108097	5.95
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
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

Well Name	X Coordinate	Y coordinate	Wl /MSL
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
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

Table A-2: Initial chloride concentration inserted to the model in 2004

Well Name	X Coordinates	Y Coordinate	concentration (mg/l)
A/180	102459	107033	126.7
A/185	102530	106252	134.6
C/127A	104785	106155	87.07
C/137	104988	106486	31.86
C/20	106737	104857	205.79
C/76	104667	104337	705.36
D/2	101379	105028	162.64
D/60/1	101286	105111	161.11
D/67	101716	107218	43.26
D/68	100514	105179	148.48
D/69	100835	105466	113.39
D/70	101440	105833	107.2
D/71	101458	106193	95.69
D/72	101739	106462	76.45
D/73	101036	106827	69.52
E/1	103274	104898	121.3
E/11A	101845	104415	135.24
E/11B	102165	105095	118.93
E/11C	101971	105190	117.8
E/142A	99984	105270	126.7
E/154	99330	105052	1482.9
E/156	102067	104589	120.43
E/157	100156	104670	199.94
E/4	103034	105064	70.96
E/6	103013	105334	99.36
E/90	101278	104583	210.6
Q/68	102391	103356	179.17

Well Name	X Coordinates	Y Coordinate	concentration (mg/l)
R/112	96061	102650	1836.9
R/113	96558	102589	335.6
R/162BA	98727	104413	951
R/162CA	98867	104589	328.6
R/162D	98638	104990	2462.1
R/162EA	98248	104479	1075.82
R/162G	99166	103952	600.8
R/162H	99055	103668	483.45
R/162HA	99050	103699	521.9
R/162L	98442	104037	680.79
R/162LA	98481	104045	1029
R/254	96542	102055	343.6
R/25A	100758	102581	518.6
R/25B	100779	102527	524.8
R/25D	100820	102496	751.4
R/265	95809	101708	211.2
R/270	96230	99750	490.6
R/277	96237	101529	204.8
R/280	95761	101155	86.65
R/293	96713	101395	234.2

Table A-3: Location and screen levels for injection wells inserted to model

Well name	X coordinate	Y Coordinate	Screen Bottom	Screen top
inj1	3000	15657.1	-23	-22
inj2	2885.7	15257.1	-23	-22
inj3	2771.4	14885.7	-23	-22
inj4	2714.3	14571.4	-15	-5
inj5	2685.7	14342.9	-39	-14
inj6	2600	14057.1	-19	-9
inj7	2514.3	13714.3	-27	-17
inj8	2514.3	13428.6	-27	-17
inj9	2542.9	13142.9	-19	-9
inj10	2600	12800	-15	-5
inj11	2628.6	12571.4	-22	-2
inj12	2628.6	12257.1	-12	-5
inj13	2685.7	11971.4	-15	-5
inj14	2828.6	11828.6	-21	-11
inj15	3000	11771.4	-15	-5
inj16	3200	11657.1	-15	-5
inj17	3428.6	11457.1	-51	-41
inj18	3428.6	11142.9	-51	-41
inj19	3428.6	10885.7	-24	-14
inj20	3342.9	10600	-51	-41
inj21	3285.7	10400	-51	-41
inj22	3228.6	10200	-26	-16
inj23	3228.6	9971.4	-15	-5
inj24	3257.1	9714.3	-18	-8
inj25	3257.1	9600	-18	-3
inj26	3314.3	9314.3	-15	-5

Well name	X coordinate	Y Coordinate	Screen Bottom	Screen top
inj27	3400	9171.4	-15	-5
inj28	3400	8857.1	-58	-45
inj29	3248.6	8657.1	-7	1
inj30	3428.6	8485.7	-25	-14
inj31	3428.6	8257.1	-25	-14
inj32	3542.9	8114.3	-15	-5
inj33	3714.3	8028.6	-64	54
inj34	3885.7	8000	-36	-6
inj35	4000	8000	-36	-6
inj36	4171.4	7971.4	-15	0
inj37	4371.4	7971.4	-15	0
inj38	4514.3	8114.3	-15	0
inj39	4571.4	8257.1	-15	-5
inj40	4657.1	8514.3	-6	4
inj41	4714.3	8771.4	-15	-5
inj42	4771.4	8971.4	-15	-5
inj43	4828.6	9171.4	-9	1
inj44	5000	9428.6	-8	2
inj45	5200	9571.4	-10	0
inj46	5514.3	9457.1	-8	2
inj47	5800	9457.1	-15	-5
inj48	6028.6	9600	-8	2
inj49	6171.4	9800	-15	-5
inj50	6342.9	10057.1	-33	-12
inj51	6457.1	10342.9	-15	-5
inj52	6542.9	10657.1	-15	0
inj53	6600	10914.3	-15	-5
inj54	6685.7	11457.1	-10	-2
inj55	6914.3	11942.9	-16	-6
inj56	7142.9	12400	-15	-5
inj57	7714.3	12542.9	-28	-1
inj58	8028.6	12600	-15	-5
inj59	8542.9	12742.9	-15	-5
inj60	8828.6	12628.6	-15	0
inj61	8800	12228.6	-10	0
inj62	8628.6	11828.6	-20	-10
inj63	8400	11428.6	-16	-6
inj64	8228.6	11000	-15	-5
inj65	8142.9	10542.9	-11	-2
inj66	8142.9	10000	-15	-5
inj67	7971.4	8600	-15	-5
inj68	7914.3	8285.7	-15	-5
inj69	7428.6	8285.7	-46	-26
inj70	6685.7	8085.7	-25	-15
inj71	6171.4	7971.4	-15	-5
inj72	5771.4	7771.4	-25	-15
inj73	6200	6971.4	-10	0
inj74	6600	6857.1	-15	-1.5
inj75	7057.1	6771.4	-15	-5
inj76	7514.3	6542.9	-47	-7
inj77	7485.7	6114.3	-15	0

Well name	X coordinate	Y Coordinate	Screen Bottom	Screen top
inj78	7400	5685.7	-10	7
inj79	7285.7	5142.9	-15	0
inj80	7114.3	4600	-15	-5
inj81	6971.4	4200	-15	-5
inj82	7085.7	3742.9	-28	0
inj83	7171.4	3285.7	-20	-2
inj84	7314.3	2800	-13	-3
inj85	7400	2428.6	-13	-3
inj86	7657.1	2142.9	-8	0
inj87	7828.6	1771.4	-8	0
inj88	7971.4	1428.6	-15	-5
inj89	8028.6	1057.1	-15	-5

Table A-4: Chloride concentration in observation wells for all scenarios in 2016.

Well ID	2012	Concentration in the observation wells in 2016 for all scenarios					
		Sc 1	Sc2	Sc 3	Sc 4	Sc5	Sc 6
R.293	260.6	249.25	297.22	262.59	310.36	330.49	303.78
R.277	226.45	228.89	223.48	221.87	232.71	249.53	232.71
R.265	537.99	800.59	297.41	714.85	262.08	241.78	261.25
R.25B	466.31	391.36	326.43	317.31	279.31	307.26	305.2
R.25A	466.31	391.36	326.43	317.31	279.31	307.26	305.2
R.254	502.76	663.91	327.77	554.12	307.51	300.29	311.93
R.162HA	550.55	540.78	441.76	470.28	303.34	292.92	303.67
R.162BA	868.46	837.2	462.73	669.8	346.32	296.56	326.72
Q.68	266.6	314.1	263.55	308.72	251.53	226.23	241.02
Q.40C	224.96	247.21	227.85	187.9	172.75	186.75	160.36
E.90	202.88	168.34	192.05	163.24	172.37	186.75	194.92
E.4	102.59	27.7483	30.4672	29.0905	34.0615	38.2406	33.0029
E.164	192.85	149.45	116.04	140.74	109.74	97.0606	102.76
E.156	193.8	148.62	154.22	155.92	164.19	169.39	170.62

Table A-5 : Chloride concentration in observation wells for all scenarios in 2020 **:**

Well ID	2012	Concentration in the observation wells in 2020 for all scenarios					
		Sc 1	Sc 2	Sc 3	Sc4	Sc5	Sc 6
R.293	260.6	243.92	332.55	260.11	368.18	412.15	401.08
R.277	226.45	401.68	240.48	259.64	270.91	322.63	311.44
R.265	537.99	925.13	264.04	903.54	224.17	243.85	241.88
R.25B	466.31	338.76	229.01	242.67	178.01	201.82	187.7
R.25A	466.31	338.76	229.01	242.67	178.01	201.67	187.7
R.254	502.76	1061	296.85	763.86	294.33	325.05	318.88
R.162HA	550.55	538.3	346.84	379.43	167.07	152.96	154.45
R.162BA	868.46	764.29	286.69	541.71	146.09	135.11	147.56
Q.68	266.6	298.12	291.32	299.5	283.46	258.3	248.89
Q.40C	224.96	260.1	252.13	201.55	187.75	165.16	153.7
E.90	202.88	111.53	182.04	121.05	136.25	165.16	183.11
E.4	102.59	16.1868	25.5005	29.4101	47.2404	60.6409	52.569
E.164	192.85	109.68	53.0045	90.1557	44.7397	34.0813	31.9527
E.156	193.8	104.66	99.0015	113.11	123.1	132.73	134.75

Table A-6: Water level in the observation wells in 2016.

Well ID	Water Level in Observation wells for the year 2016					
	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
R.84	-2.48	3.52	0.53	6.46	9.92	10.60
R.38	-5.57	3.29	-1.88	6.84	11.83	13.25
R.216	-5.19	3.20	-1.63	6.62	11.36	12.66
R.210	-0.10	0.00	-0.08	0.03	0.09	0.11
R.161	-2.50	-0.43	-1.84	0.24	1.45	2.03
R.133	-3.77	0.39	-2.55	1.61	4.05	4.99
Q.2	-5.91	4.63	-2.25	8.08	13.96	15.39
Piezo 8B	-2.70	1.49	-1.35	2.85	5.31	6.08
Piezo 2D	-3.75	-0.94	-2.97	-0.15	1.51	2.35
Piezo 27	-2.94	0.99	-1.28	2.64	4.94	5.86
E.45	-6.97	-0.52	-4.37	2.00	5.73	7.37
E.32	-3.63	-0.36	-2.45	0.82	2.74	3.61
E.12	-9.03	1.03	-5.34	4.56	10.19	12.39
E.116	-8.59	0.44	-5.02	3.90	8.97	10.96
C.78	-4.05	6.15	-0.61	9.39	15.09	16.71
C.126	-2.43	7.10	0.39	9.80	15.19	16.86
C.104	-0.34	8.37	1.99	10.64	15.36	16.83
A.53	-5.23	2.55	-2.92	4.79	9.25	11.04
A.47	-2.97	4.96	-0.71	7.16	11.71	13.40
A.31	-5.11	4.19	-2.34	6.85	12.13	14.16

Table A-7: Water level in the observation wells in 2020**.**

Well ID	Water Level in Observation wells for the year 2020					
	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
R.84	-3.11	4.65	0.64	8.24	12.62	14.74
R.38	-6.51	4.33	-2.05	8.52	14.49	17.48
R.216	-5.98	4.38	-1.64	8.46	14.17	17.03
R.210	-0.12	0.00	-0.08	0.04	0.11	0.15
R.161	-2.64	-0.33	-1.90	0.42	1.76	2.54
R.133	-4.32	0.62	-2.80	2.11	4.97	6.55
Q.2	-8.55	4.07	-4.11	8.17	15.04	18.58
Piezo 8B	-3.61	1.57	-1.86	3.30	6.31	7.90
Piezo 2D	-3.94	-0.87	-3.08	-0.01	1.78	2.84
Piezo 27	-3.92	0.55	-2.08	2.36	4.95	6.33
E.45	-7.71	-0.48	-4.84	2.31	6.40	8.68
E.32	-3.99	-0.35	-2.68	0.95	3.06	4.26
E.12	-10.67	0.91	-6.42	4.90	11.28	14.66
E.116	-9.55	0.88	-5.46	74.76	10.53	13.61
C.78	-6.73	5.68	-2.47	9.61	16.38	19.78
C.126	-6.50	5.05	-2.95	8.38	14.77	18.06
C.104	-3.69	7.11	-0.60	10.03	16.06	19.06
A.53	-7.80	1.12	-5.10	3.70	8.75	11.48
A.47	-6.75	2.57	-4.01	5.19	10.46	13.28
A.31	-8.96	1.92	-5.64	5.05	11.11	14.35