Water Resources Engineering Program

The Islamic University – Gaza
High Studies Deanery
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Study The Impact of Land Use and Over Pumping on Nitrate Concentration in Groundwater by Using Modeling Approach

Case Study: Khanyounis Governorate- Gaza Strip

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Master of science in water resources engineering.

Supervised by:

Dr. Abdelmajid Nassar,

Dr. Khaled Qahman

By:

Rami J. H. Alghamri

This Thesis is dedicated to

My Mother, Father, Wife and child

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Rami Alghamri

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	Description
H_2o	Water
Kj-N	Total Kendal nitrogen
NH_3	Ammonia
NH_4^+	Ammonium
NO_2^-	Nitrogen Dioxide
N_2	Nitrogen Gas
NH_4^+-N	Ammonia as Nitrogen
N-KjD	Kjeldahl Nitrogen
NO_3^-	Nitrate
NO_3^- -N	Nitrate as Nitrogen
O_2	Oxygen Gas
pH	Acidity
TDS	Total Dissolved Solids
TS	Total Solids
TSS	Total Suspended Solids

LIST OF ABBREVIATIONS

ANN	Artificial Neural Networks
CAMP	Coastal Aquifer Management Program
CEC	Cation- exchange capacity
EQA	Environmental Quality Authority
GIS	Geographic Information System
ha	Hectare
Kg N/ha.yr	Kilo gram nitrogen per hectare per year
l/c/d	Liter per capita per day
M^3/d	Cubic meter per day
MCL	maximum contaminant level
MCM	Million cubic meter
MCM/yr	Million cubic meter per year
mg	Millie gram
Mg/l	Millie gram per liter
MoA	Ministry of Agriculture
MOPIC	Ministry of Planning and International Cooperation
MSL	Mean Sea Level
PCBs	The Palestinian Central Bureau of Statistics
PWA	Palestinian Water Authority
UNEP	United Nations Environment Program
WHO	World Health Organization
WWTP	Wastewater 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 nitrate concentration is one of the most important and widespread of the numerous potential groundwater contaminants. The nitrate sources in the groundwater of Gaza Strip are wastewater septic tanks and cesspits, sewage sludge, animal manure and N-fertilizers. The problem of high nitrate concentrations in drinking water exceeded the WHO standards of 50 mg/l constitutes a major health risk to both humans and stock life. The highest level of nitrate in Gaza Strip is Khanyounis which showed average nitrate concentration more than 190 mg/l. Therefore, this work tried to study the nitrate concentration in groundwater in Khanyounis governorate area. A coupled flow and transport model using a three-dimensional, finite difference simulation model (VMODFLOW Pro.) was applied to simulate the southern part of Gaza coastal aquifer. Model application was carried out in three steps; (a) Application of the flow model under steady state conditions for the year 1935 and quasi- steady state for the year 2004 to estimate the hydraulic parameters and water balance of the system, and applying the transient calibration for the target period (2005-2008) to estimate the storage coefficients, (b) Simulation of nitrate transport in the southern part of Gaza Strip coastal aquifer to estimate transport parameters (i.e., dispersivity), and finally (c) The calibrated flow and transport model was used to study management scenarios. The approach for selecting the management scenarios was carried out depending on the need to reduce the transport of nitrate into the aquifer system during the next 30 years. Seven selected management scenarios were tested; (1) work as usual (zero scenario), (2) Management of the pumping, (3) Implementation and operation of sewerage system at Khanyounis, (4) Reduction of N-fertilizers loadings at agricultural areas, (5) Bringing together all the previous scenarios (2,3,and 4) and (6) Using artificial infiltration of groundwater in addition to the management options in scenario no.5. It was estimated that the implementation of a sewerage system at Khanyounis governorate will reduce the rising of average nitrate concentration in Khanyounis area by 8.5 mg/l annually. This means that the average nitrate concentration in Khanyounis governorate will increase by only 1.5 mg/l annually. While the reduction of usage of N-fertilizers by 50% will not have significant impact on nitrate concentration where it will reduce the rising of average nitrate concentration in Khanyounis area by 3.35 mg/l annually. The best scenario to solve the increasing of nitrate concentration problem in the groundwater is the combination of many options (reduction the pumping from the aquifer by using RO unit, implementation sewerage system at Khanyounis area, reduction the usage of N-fertilizers by 50%, and using artificial infiltration from both stormwater and treated wastewater) in addition to artificial recharge as planned by the concerned authorities.

Keywords: Khanyounis governorate, groundwater, nitrate, VMODFLOW, flow, transport.

الملخص

نمذجة تأثير استخدام الأراضي وزيادة السحب من الخزان الجوفي على تركيز النترات في المياه الجوفية

(حالة الدراسة: محافظة خانيونس- جنوب قطاع غزة)

تعتبر المياه الجوفية أحد أهم المصادر الطبيعية للمياه في قطاع غزة، كما أنها المصدر الوحيد للشرب لغالبية سكان القطاع. النترات واحدة من أهم الملوثات التي يعاني منها الخزان الجوفي في القطاع. يعزى ارتفاع تركيز النترات في الخزان الجوفي إلى استخدام الأراضي في ذات المنطقة ومن أهم مصادر التلوث: تسرب المياه العادمة من الحفر الامتصاصية، أو شبكات الصرف الصحي، وكذلك الأنشطة الزراعية بما تحويه من أسمدة ومبيدات تحتوي على النترات بشكل كبير.

التركيزات المرتفعة للنترات والتي تزيد عن 50 ملليغرام / لتر وفق منظمة الصحة العالمية تؤثر سلباً على صحة الإنسان والحيوان. تعتبر محافظة خانيونس الأكثر تأثراً بمشكلة النترات في الخزان الجوفي حيث يصل لما يزيد عن 190 ملليغرام / لتر، لذلك فإن هذه الدراسة ركزت على مشكلة النترات في محافظة خانيونس وسبل إيجاد الحلول المناسبة لعلاجها مع دراسة أهم المؤثرات عليها.

تم استخدام نموذج المحاكاة ثلاثي الأبعاد (VMODFLOW Pro.) لمحاكاة التدفق والانتقال في المياه الجوفية للمنطقة الجنوبية من قطاع غزة (بما يشمل محافظة خانيونس) مع تطبيق النموذج على ثلاث مراحل: (أ) تطبيق النموذج تحت ظروف التدفق المطرد لعام 1935، وكذلك عام 2004 بهدف تقدير الخواص الهيدرولوجية للخزان الجوفي، وكذلك التوازن المائي للنظام، ثم تطبيق النموذج لتقدير معاملات التخزين للخزان الجوفي تحت ظروف المعايرة في الفترة (2005-2008)، (ب) محاكاة انتقال النترات داخل المياه الجوفية لتحديد معاملات الانتقال الخاصة بالخزان الجوفي، (ج) استخدام النموذج بعد معايرته لدراسة السيناريوهات المختلفة نحو إدارة الخزان الجوفي بما يتعلق بمشكلة النترات، وذلك خلال الثلاثين عام القادمة.

ستة سيناريوهات تم دراستها خلال هذا العمل، وهي: (1) الاستمرار في الوضع القائم، (2) إدارة السحب من الخزان الجوفي بإيجاد البدائل لهذا المصدر، (3) تنفيذ شبكة الصرف الصحي في خانيونس وتشغيلها بكل مكوناتها، (4) تخفيف استخدام الأسمدة المحتوية على النترات أو مشتقات النيتروجين في المناطق الزراعية، (5) الجمع بين السيناريوهات السابقة "2،3،4"، (6) حقن الخزان الجوفي بمياه الأمطار والمياه العادمة بعد معالجتها بالإضافة للسيناريو السابق.

وفق نتائج الدراسة فإن تنفيذ وتشغيل شبكة الصرف الصحي وفق المخطط له من قِبل المؤسسات المختصة سيقلل من تركيز النترات سنوياً بمقدار 1.5 ملليغرام / لتر، أي سيقلل الزيادة في تركيز النترات السنوي بمقدار 8.5 ملليغرام / لتر مقارنةً مع الاستمرار بالوضع القائم.

أما تخفيف استخدام الأسمدة المحتوية على النترات أو مشتقات النيتروجين في المناطق الزراعية سيكون له تأثير بسيط على تركيز النترات حيث سيقلل الزيادة السنوية بما لا يتجاوز 3.35 ملليغرام / لتر مقارنةً مع الاستمرار بالوضع القائم.

أما السيناريو الأفضل فهو الجمع بين جميع السيناريوهات (تشغيل شبكة الصرف الصحي، وإدارة السحب من الخزان الجوفي، وتخفيف استخدام الأسمدة المحتوية على النترات أو مشتقات النيتروجين) مع حقن الخزان الجوفي بمياه الأمطار والمياه العادمة بعد معالجتها، وهذا من المتوقع أن يصل بالنترات إلى تركيز يقارب القيمة التي تنص عليها منظمة الصحة العالمية.

CHAPTER
1

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Background

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 (Shomar et. al., 2005). It is utilized extensively to satisfy agricultural, domestic, and industrial water demands. Groundwater crisis in Gaza includes two major folds: shortage and contamination. The extraction of groundwater currently exceeds the aquifer recharge rate. As a result, the groundwater level is falling continuously and accompanied with it the contamination with many pollutants mainly nitrate and seawater intrusion (UNEP, 2003; Weinthal and Vengosh, 2005; Qahman and Larabi, 2006).

The manmade sources of pollution endanger the water resources supplies in the major municipalities of the Gaza Strip. Many water quality parameters in the Gaza aquifer presently exceed the maximum contaminant level of the WHO drinking water standards, especially for nitrate and chloride. Chloride or salinity of the groundwater increases by time due to seawater intrusion and mobilization of incident deep brackish water, caused by over-abstraction of the groundwater (Rocca et. al., 2005).

Nitrate is one of the most important and widespread of the numerous potential groundwater contaminants (Rocca et. al., 2005). Contamination of the groundwater can occur if input of NO_3^- into soil exceeds the consumption of plants and denitrification (Mcclain et al., 1994). Shomar (2006) proposed that the excess NO_3^- in the groundwater of the Gaza Strip occurred as a result of NO_3^- leaching from irrigation, wastewater septic tanks, sewage sludge, animal manure and synthetic fertilizers.

The problem of high nitrate concentrations in drinking water constitutes a major health risk to both humans and stock life. Nitrite reacts directly with hemoglobin in human blood and other warm-blooded animals to produce methaemoglobin. Methaemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious for babies. It causes a condition known as methaemoglobinemia or “blue baby” disease. The WHO assigned the nitrate of 50 mg/l as a health significant value in drinking water (Khayat et. al., 2006).

1.2 Problem Identification

Almost 90% of the groundwater wells of the Gaza Strip sampled between 2001 and 2007 showed NO_3^- concentrations two to eight times higher than the WHO standards. The highest levels of NO_3^- were in Khanyounis (south) and Jabalia (north). These regions showed average NO_3^- concentrations of 191 and 151 mg/l, respectively (Shomar et. al., 2008). In the worst affected areas (urban centers), NO_3^- concentrations are increasing at rates of up to 10 mg/l per year (Mogheir, 2005). This means that the level of nitrate contamination is rising so rapidly and continuously that most of Gaza's domestic wells are no longer adequate for human consumption due to this very poor quality unless serious solutions and management protections are used to face the present and future challenges (Jaber, 2008).

The main sources of the high nitrate pollution of groundwater in Gaza Strip are infiltration of untreated wastewater in cesspits and excess agricultural fertilizers, where about 40% of the population uses leaky infiltration boreholes, and the rest uses inadequate sewage system (Metcalf and Eddy, 2000). According to personal contacts, about 60% of Khanyounis Governorate is covered by wastewater network collection and distribution system. This included large number of illegal connections to stormwater network . The extensive use of fertilizers in row crops is considered as the main source of nitrate leaching to ground water particularly in sandy soils (UNEP, 2003; Almasri and Kaluarachchi, 2005).

On the other hand, the aquifer is currently being over pumped where pumping largely exceeds the total recharge. According to PWA, since 1967 the Gaza aquifer has been over pumped by a rate of 90-100 MCM/yr in order to meet both Israeli settlers and Palestinian water needs. The consumption from the groundwater resources in the Gaza Strip has been estimated in year 2000 about 131 MCM from groundwater, with a safe yield of only 55 MCM. This implies that there is over-pumping of about 60%, which leads to the deterioration of the groundwater quality (PWA, 2001).

In 2006, Gaza strip's water demand revealed an expected increase estimated 170.6 MCM, and it was divided among agricultural needs (87.5 MCM), domestic, and industrial needs (83.1 MCM) including water purchased from Mekorot (Israeli water company), whereas the total billed water consumption is about 44 MCM from domestic and industrial use, imparting low water delivery efficiency. It is expected that water demand for the agricultural purposes will reach a constant figure ranges from 85 to 90 MCM/yr. While the municipal demand expected to become the major demand in the water sector. This is due to the rapid increase of demand to meet the population growth in addition to improve the living level style associated with high per capita needs. By the year 2020, the domestic and industrial demand is expected to reach 170 MCM/yr (PWA, 2007a).

For all of the previous, this research focused on studying the impact of land use and over pumping on nitrate transport and concentrations in groundwater. Khanyounis governorate was chosen as a case study because it is the most governorates in the Gaza Strip which suffers from high nitrate contamination in drinking water.

1.3 Research Objectives

The overall goal of this research is to study the impact of land use change, and the rapid increasing of water abstraction from the aquifer on nitrate concentration in Gaza's aquifer especially in Khanyounis area.

This may be achieved through the following objectives:

1. Define the main sources of nitrate to the groundwater in Khanyounis governorate.
2. Calculate water demand for all purposes in Khanyounis governorate.
3. Calculate the nitrate loadings leaching from the ground surface to the aquifer.
4. Develop ground water flow and transport models for the study area.
5. Predict the aquifer future and find appropriate solution of the nitrate contamination in Khanyounis governorate by using expected scenarios during the following 30 years.

1.4 Methodology

The objectives of this research will be achieved by implementing the following steps:

1. Identify the problem of the research and define the objectives.
2. Literature review on the nitrate in groundwater, the study area, groundwater modeling, and related previous studies.
3. Collection and analysis of the data needed to build the model.
4. Preparation of detailed calculations of nitrate loads in the model area.
5. Develop the conceptual flow and transport model of the study area. Two-stage finite difference simulation algorithms will be used under steady and transient states for calibrating the flow and transport parameters.
6. Using the "VMODFLOW Pro" software code to evaluate different management options or scenarios to improve water quality.
7. Writing the M.Sc thesis which summarizes and reports the achieved results.

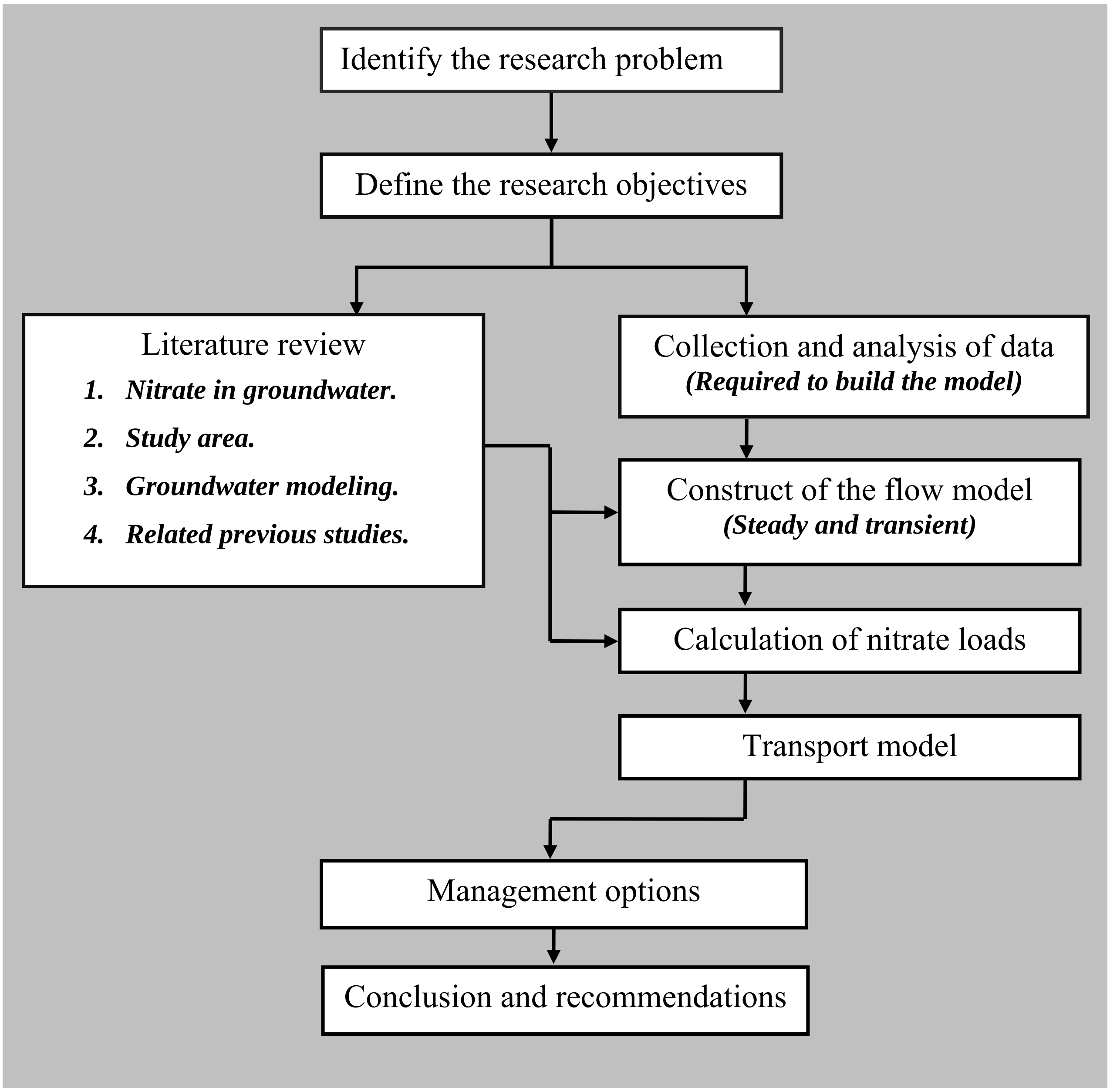


Figure 1.1: Schematic diagram of study methodology

1.5 Thesis Structure

This study consists of six chapters;

1. ***Chapter one*** includes introduction on general information and view about groundwater pollution, problem identification, study objectives and methodology.
2. ***Chapter two*** covers a general literature review on the nitrate pollution including nitrogen cycle, nitrogen balance, nitrogen sources and sinks, the possible ways for nitrate transport mechanisms and leaching, and an overview about groundwater modeling as well as includes a literature review of some studies of nitrate pollution, either related to Gaza Strip or not.

3. ***Chapter three*** describes the study area with respect to geology, hydro-geology, climate, Gaza coastal aquifer and water quality of the study area.
4. ***Chapter four*** discusses the setting up of the flow and transport models in details. It presents the steady and transient states flow calibration steps and results to provide the calibrated parameters.
5. ***Chapter five*** covers some of the suggested management scenarios by taking into consideration the factors affecting the existing and future nitrate contamination of groundwater.
6. ***Chapter six*** contains the conclusion, recommendations, and the limitations of the study.

Note: All calculations of nitrate loads are represented in appendix A.

CHAPTER
2

LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

2.1 Nitrate in Groundwater

Nitrogen is extremely important to living material. Plants, animals and humans could not live without it. The major source of nitrogen is the atmosphere. It exists as a colorless, odorless, nontoxic gas and makes up about 78 % of the atmosphere. Nitrogen is also found in the Earth's crust as part of organic matter and humus.

The nitrogen gas in our atmosphere exists as a molecule composed of two atoms of nitrogen. Plants cannot directly use this form of nitrogen. Nitrogen must be converted into other forms before it can be used by plants. Plant uptake of nitrogen is largely in the form of nitrate (NO_3^-), and to a lesser degree ammonium (NH_4^+). Nitrogen becomes a concern to water quality when nitrogen in the soil is converted to the nitrate (NO_3^-) form. This is because the nitrate is very mobile and easily moves with water. The concern of nitrates and water quality is generally directed at groundwater.

Nitrates in the soil result from natural biological processes associated with the decomposition of plant residues and organic matter. Nitrates can also come from animal manure, nitrogen fertilizers, and sewage discharges (Killpack and Buchholzfile, 1993).

2.1.1 WHO Standards

Nitrate concentrations are usually expressed in different units, generally of milligrams per litre (mg/l). The mass representing either the total mass of nitrate ion in the water (nitrate-NO_3^-) or only the nitrogen (nitrate-N). The World Health organization recommended maximum limit for nitrate concentration in drinking water is 11.3 mg/l nitrate-N which is equivalent to 50 mg/l nitrate-NO_3^- (WHO, 2003). Water analysis in terms of nitrogen usually express nitrite (NO_2^-) and Nitrate (NO_3^-) as the total oxidized nitrogen which is the sum of nitrite and nitrate nitrogen.

2.1.2 The Environmental Health Concerns of Nitrate in Drinking Water

Concentrations of nitrate in groundwater have been known to be a potential human health problem since Comly (1945) reported that nitrate in drinking water could cause methaemoglobinemia (Timothy et. al, 2002). The extent of the worldwide problem has been reviewed by WHO (2003). It has been recommended that water supplies containing high levels of nitrate (more than 10 mg/l NO_3^--N) should not be used for the preparation of infant foods, alternative supplies with low nitrate content such using bottled water have been recommended.

The unsafe levels of nitrate affect the health of people because it associates with gastric cancer and cause “blue baby” syndrome known as methaemoglobinemia, which can lead to brain damage and sometimes death (Cabrera and Blarasin, 1999; Lake, 2003; Ramasamy and Krishnan, 2003).

2.1.3 The Nitrogen Cycle

Nitrogen in the atmosphere or in the soil can go through many complex chemical and biological changes, be combined into living and non-living material, and return back to the soil or air in a continuing cycle. This is called the nitrogen cycle (Killpack and Buchholzfile, 1993) which is shortly overviewed in Figure 2.1.

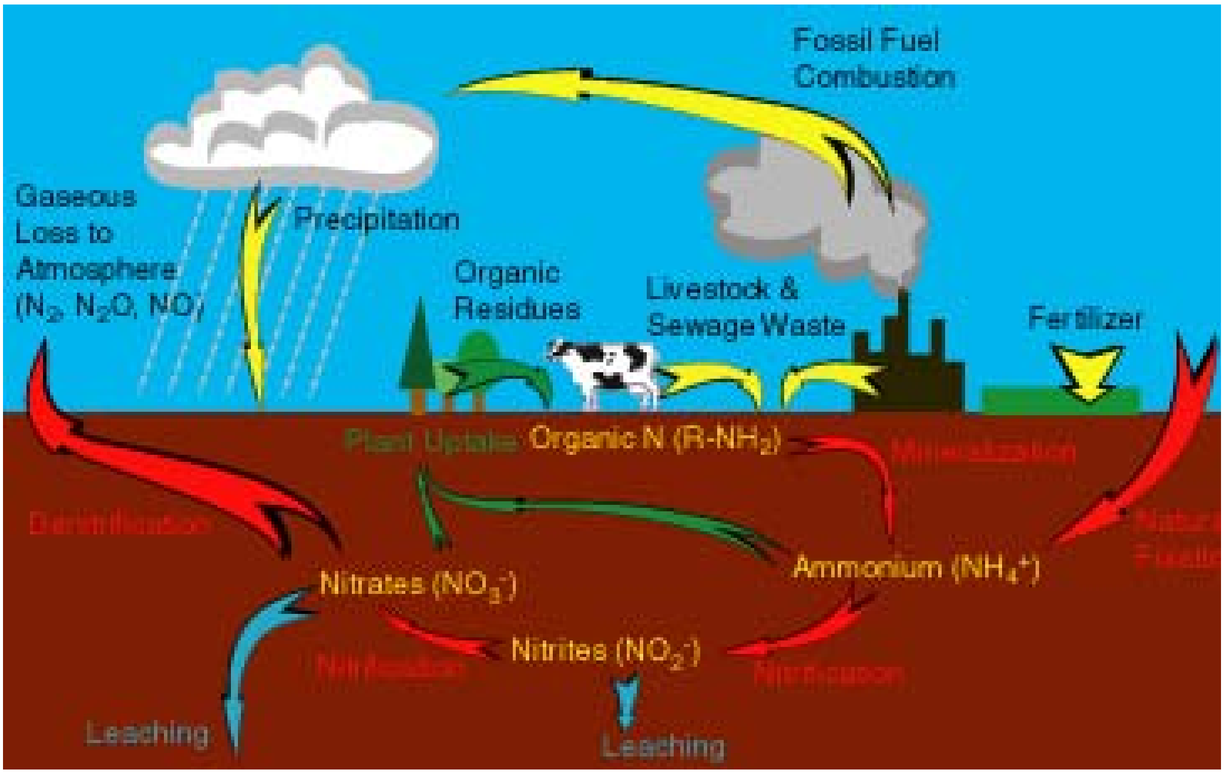


Figure 2.1: The Nitrogen Cycle (Source: Harrison, 2004)

2.1.3.1 Nitrogen Fixation

Nitrogen fixation is the process wherein N_2 is converted to ammonium, essential because it is the only way that organisms can attain nitrogen directly from the atmosphere (Arthur Harrison, 2004).

$$N_2 \xrightarrow{\qquad\qquad} NH_4^+ \qquad \text{Eq. (2.1)}$$

2.1.3.2 Mineralization-Immobilization

The chemical yield of organic nitrogen in soil results in releasing ammonium. Two main opposing processes are occurring continually:

$$\underset{\textbf{Organic Nitrogen}}{N\equiv N} \xrightarrow{\text{Mineralization}} \underset{\textbf{Ammonium (aq)}}{NH_4^+} \qquad \text{Eq. (2.2)}$$

$$\underset{\textbf{ammonium (aq)}}{NH_4^+} \xrightarrow{\text{Immobilization}} \underset{\textbf{Organic Nitrogen}}{N\equiv N} \qquad \text{Eq. (2.3)}$$

Mineralization (ammonification) of organic nitrogen refers to degradation of proteins, amino sugars, and nucleic acids to ammonium. In appropriate conditions, some of the ammonium produced by mineralization step is immobilized by the aid of microbial biomass into the organic pool producing organic nitrogen again. The rate of mineralization is of great importance to estimate the amounts of nitrate leaching to the groundwater (keeney, 1989).

2.1.3.3 Nitrification

Some of the ammonium produced by biodegradation is transformed to nitrate by a process called nitrification:

$$NH_4^+ \longrightarrow NO_3^- \qquad \text{Eq. (2.4)}$$

The bacteria that carry out this reaction gain energy from it. Nitrification requires the presence of oxygen, so it can happen only in oxygen-rich environments like circulating or flowing waters and the very surface layers of soils and sediments (Arthur Harrison, 2004).

Each one mg of ammonium requires 4.33 mg of oxygen to be nitrified (Keeney, 1989). In this process, two groups of micro-organisms are involved in this process: Nitrosomonas and nitrobacter (Aish, 2000).

$$2NH_4^+{}_{(aq)} + 3O_{(aq)} \xrightarrow{\textit{Nitrosomonas}} 2NO_{2(aq)} + 2H_2O_{(aq)} + 4H^+{}_{(aq)} \qquad \text{Eq. (2.5)}$$

$$2NO_2^- + O_2 \xrightarrow{\textit{Nitrobacter}} 2\,NO_3^- \qquad \text{Eq. (2.6)}$$

The process of nitrification has some important consequences. Ammonium ions are positively charged and therefore stick (are sorbed) to negatively charged clay particles and soil organic matter. The positive charge prevents ammonium nitrogen from being washed out of the soil (or leached) by rainfall. In contrast, the negatively charged nitrate ion is not held by soil particles and so can be washed down the soil profile, leading to decreased soil fertility and nitrate enrichment of downstream surface and groundwater. (Arthur Harrison, 2004)

2.1.3.4 Ammonia volatilization

This is important process, mainly in basic soils. Ammonia is volatilized following the dissociation of ammonium to ammonia and hydrogen:

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \qquad \text{Eq. (2.7)}$$

The volatilization of ammonia is determined by the percentage of free ammonia present, which is a direct function of the pH. The ratio of free ammonia (gas) to ammonium (aq) is given as:

$$\frac{[NH_3]}{[NH_4^+]} = \frac{[OH^-]}{K_{eq}} \quad \text{, Where } K_{eq} = 1.74 \times 10^{-5} \qquad \text{Eq. (2.8)}$$

Besides pH, other properties affect ammonia. According to Gasser (1963), the most important factor is the cation exchange, while Ivonove (1963) found that the presence of carbonate is the dominant factor for ammonium losses (Alawneh, 1996). More ammonia volatilization can occur, and then ammonia fertilizers are finely and evenly spread on the soil compared to spreading of granular or large droplets of the same fertilizer. The reason for this could be that in the granular from, part of the ammonia will volatilize (Yoram et. al., 1977).

2.1.3.5 Adsorption

Part of the ammonium ions is adsorbed by the negatively charged clay and organic particles X^-, present in the soil to form a cation -exchange complex.

$$NH_4^+ + X^- \rightleftharpoons NH_4^+ \ldots\ldots X \qquad \text{Eq. (2.9)}$$

The cation – exchange capacity (CEC) of the soil depends upon the amount and type clay and organic matter. The CEC may range from 10 meq to 20 meq/kg of soil for very sandy soils with little clay or organic matter to more than 1000 meq/kg for soils high in clay or organic matter to more than 1000 meq/kg matter, or both (Aish, 2000).

The fraction of the CEC that may be used to adsorb ammonium depends on the concentration of other cations in the water applied because these cations (particularly $Ca^{+2}$and Mg^{+2}) compete with ammonium for exchange site. This fraction, called the exchangeable ammonium proportion, can be estimated if the CEC and the concentration of the principal competing divalent cations are known (Gabriel and Charles, 1990).

The ammonium adsorbed by the soil CEC is only temporarily immobilized because it can be readily remobilize or oxidized to NO_3^- when oxygen is available. However this adsorption is extremely important because it retains nitrogen within the root zone for a time (Aish, 2000).

2.1.3.6 Denitrification

Denitrification is the reduction of nitrites back into the largely inert nitrogen gas (N_2):

$$NO_3^- \longrightarrow N_2 + NO_2^- \qquad \text{Eq. (2.10)}$$

It is an anaerobic process that is carried out by denitrifying bacteria, which convert nitrate to dinitrogen in the following sequence:

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2 \qquad \text{Eq. (2.11)}$$

Denitrification is the only process that could reduce nitrite concentration during downward percolation under cesspits and wastewater pools. However, significant denitrification is unlikely to occur in well aerated sandy subsoil or in carbon-deficient groundwater. Therefore, relatively high nitrate concentration can be expected in groundwater under crusted seepage beds in sands (Alawneh, 1996).

2.1.4 Sources of Nitrogen in Soil

Madison and Brunett (1985) list the following as major anthropogenic sources of nitrate: "fertilizers, septic tank drainage, dairy and poultry farming, land disposal of municipal and industrial wastes, dry cultivation of mineralized soils, and the leaching of soil as the result of the application of irrigation water". Natural sources include: "soil nitrogen, nitrogen-rich geologic deposits and atmospheric deposition".

Generally, the source of contamination is usually classified *in space* as either *a point source or a non-point source***.** A point source is a contaminant released at one specific location, whereas a non-point source is a release over a widespread area. The source of contamination is also classified *in time* as either a *continuous source or an instantaneous source.* A continuous source is a contaminant that is released over a long period of time, whereas an instantaneous source is a contaminant that is released at only one time. The type of contamination source in space and time is important in determining the resulting spatial and temporal distribution of concentrations of contaminant within the ground-water system. The identification of nitrate sources to groundwater is usually difficult. Nitrogen can enter the soil from many sources including anthropogenic sources of nitrate or natural environment processes without human influences (Jaber, 2008).

Nitrate in vadose zones is accumulated over long periods of time in arid zones, its source may include atmospheric nitrate deposition of ammonium and organic N or bacterial nitrification of reduced N. The reduced N may be present as a result of rock weathering, biologic nitrogen fixation. Natural vadose zone accumulations of nitrate may be augmented by anthropogenic nitrate as a result of land use change, and both may enter ground water as a result of climate change, flooding, irrigation, or artificial recharge (BÖHLKE et al., 2004).

2.1.5 Nitrate Leaching

Leaching is one of the two important mechanisms of nitrate losses (leaching and denitrification). NO_3^- in solution is highly mobile in the soil until it is immobilized (assimilated) by micro-organisms or assimilated by plants (Al Mahallawi, 2005).

2.1.5.1 Factors Affecting Leaching

- Infiltration rate, that is related to soil slope, land use, stability of soil aggregates, the moisture content and all factors affecting size and continuity of soil pores.
- Interactions with soil constituents: Sandy, light textured soils generally have a fairly uniform porosity. They retain less water than clayey, heavily textured soils and nitrates can be leached with relatively small amount of rainfall. By contrast, finer textured homogeneous clayey soils favor chemical processes (exchange of anions and cations, absorption of dissolved organic substances, reactions between dissolved materials and those absorbed on the clay-humus complex) and retain more nitrate and water.
- The size of soil pores which is related to the soil texture, structure, cracks, worm holes, old root channels, and any restrictive pans of soil layers. Also the continuity of the pores that is affected by the tillage system plays an important role (Al Mahallawi, 2005).
- Rainfall and amount of nitrogen applied: As a general rule the greater the total winter rainfall, the greater the mount of nitrate being leached though average concentrations of nitrate in the leachate decline as winter progress and rainfall increases. Bergstrom and Brink (1986) found that the leaching of nitrate was moderate up to a rate of application of 100 kg N/ha.yr, but increase rapidly thereafter.

Movement of nitrate is generally considered to be more of a problem in light textured sandy soils, however it should not be understood that nitrate movement is not a serious problem in clay soils (Swoboda, 1977). Thomas and Swoboda (1969) have reported anion movement in clay soils as much as estimated faster than would be predicted if the water moved through the soil as (piston type) flow. Barraclough et. al. (1983) found that the cumulative nitrate leaching over 3 years from isolated 0.4 ha grass land plots were equivalent to 1.5%, 5.4% and 16.7% of the fertilizer applied at 250, 500, and 900 kg/ha rates respectively. Vagstad et al. (1997) found that the major parts of the N lost by leaching apparently derive from soil organic matter rather than from recently applied fertilizers (Al Mahallawi, 2005).

2.1.5.2 Nitrate Transport Mechanisms

Movement of any dissolved ion such as nitrate through soil is governed by two mechanisms, ***convection*** (or mass flow of the chemical with the moving soil solution) and ***diffusion*** of the chemical within the solution (Jury and Nielsen, 1989).

The extra three dimensional convection which has been averaged out of the mass flow expression is included as a separate solute transport mechanism called hydrodynamic dispersion, which is used to describe the movement of solute around solid obstacles. The simplest representation of mass transport of solute by *convection* is given as $J_{sc} = J_w .C$. Where J_{sc} is the mass of solute per unit area per unit time, J_w is the water or soil solution flux (average over many pores), and, C is the solute concentration in mass per solution volume. The last equation is often used alone to give a rough estimate of solute movement. Solute dissolved in solution spread out under the influence of molecular scale collisions, a process known as molecular diffusion. The diffusive flux of solute J_{SD} in one dimension is described by Fick's Law as: $J_{SD} = -D_{sw}. \partial C/\partial Z$, where D_{sw}: Binary diffusion coefficient (Al Mahallawi, 2005; Jaber 2008).

2.1.6 On-Ground Nitrogen Loadings

Most nitrate-related environmental impacts occur on local or regional scales, rather than on the national scale. The nature of those impacts is usually quite closely related to the nature and spatial distribution of the sources. For example, some point sources of nitrogenous wastewater streams can cause localized but intense pollution. Other inputs such as emissions of nitrogen oxides from combustion, may originate with point sources but can contribute to nitrate problems over large areas, because of the transport and transformation processes typically associated with such emissions. On the other hand, dispersed non-point sources, such as agriculture operations, are often responsible for pollution of groundwater or surface waters and nitrous oxides. The sources of nitrogen to be discussed are the effluents from sewer systems and septage, leachate from landfills, fertilizers and manure inputs, nitrogen fixation, irrigation water and precipitation (Al Mahallawi, 2005).

2.1.6.1 Effluent from sewer systems and septage

Untreated sewage flowing from municipal collection systems typically contains 20-85 mg/l total nitrogen (Scheible, 1994). The total nitrogen in domestic sewage comprises approximately 60% ammonia nitrogen, 40% organic nitrogen and very small quantities of nitrates. The septage from rural areas has a nitrogen content of 100-1600 mg/l TKN (Total Kjeldahl Nitrogen) with 700 mg/l TKN typical value (Metcalf and Eddy, 1990). At least half of the nitrogen that enters sewage treatment facilities is not removed, and is discharged in the environment largely as ammonia or nitrate (National Academy of Science, 1978).

Magdoff and Keeny, (1976) found that the removal of nitrogen in the septage by soil materials is nearly about 22%. This makes septage a major local source of nitrate. Significant denitrification is not likely if seepage for the effluent is built in deep sandy soils (Walker et al., 1973a). In the movement of nitrate through sand soil beneath a septic tank disposal field; nitrate concentration increased, and ammonia concentration decreased with depth. Walker et al. (1973b) reported nitrate concentrations from 2 to 42 mg/L in groundwater around several non-sewered households in a sandy soil area of central Wisconsin; the highest concentrations were just down the flow gradient from the disposal field. As distance from the septic tank field increased, nitrate concentrations declined rapidly because of dilution groundwater. Contamination of groundwater by nitrate from septic tanks and cesspits is of little significance in sparsely population rural areas; however increased population density can produce high nitrate levels in groundwater supplies (Al Mahallawi, 2005).

2.1.6.2 Leachate From landfills

Leachate from municipal solid waste landfills is characterized as a relatively low volume, high-strength wastewater. A survey of leachate characterized for many landfills shows ammonium values of 0–1160 mg/l and nitrate plus nitrite nitrogen of 0.2–10.2 mg/l (Scheible, 1994). Depending on the landfill and the materials placed in it, typical values of nitrogen in the landfill leachate are 200 mg/l organic nitrogen, 200 mg/l ammonia nitrogen and 25 mg/l nitrate nitrogen (Rabah, 1997).

Poul et al.1995, found that the leachate of the Grindsted landfill in Denmark contains lower ammonium concentration closer to the landfill and they related this to the cation exchange process that may attenuate ammonium in the anaerobic part of the plume. The leakage of organic and inorganic pollutants from old landfills without leachate collecting system may influence the groundwater quality and thereby be a risk for drinking water. The composition of leachate from landfills is dependent on the age of the landfill (Al Mahallawi, 2005).

2.1.6.3 Fertilizers

Fertilizer N use is increasing worldwide and it is considered as a major source of nitrogen to the soil. Ludwick et al., (1976) sampled the 0-90 cm depth under a number of irrigated Colorado fields and showed a direct relationship of nitrate profile to fertilizer N use. On average, about 170 kg N/ha was in the upper layer. These levels were the result of build up of excess N over many years of excessive fertilizer use. Fertilizers are applied in different forms and it has different nitrogen concentration. Table (2.4) shows composition of various N fertilizers used (Al Mahallawi, 2005).

Table (2.1): Composition of various common N fertilizers

Fertilizer material	*Percent composition N-P_2O_5*
Anhydrous ammonia	0-82
Urea	0-46
Ammonium nitrate	0-34
Ammonium Sulphate	0-21
Urea – ammonium nitrate (UAN) liquid	0 -28 to 0-32
Di-ammonium phosphate	18-46
Mono-ammonium phosphate	11-55
Aqua ammonia	0-20
Ammonium polyphosphate	10-34

2.1.6.4 Manure N Inputs

Land application of animal wastes, especially concentrated wastes as poultry and cattle wastes as manures can lead to nitrate accumulation in the profile and groundwater pollution. Manure N inputs are very difficult to estimate because of the variability in N composition, the uncertainty in loading rates, the spatial variability of manure application, and the many N losses that manure undergoes after excretion (ammonia volatilization and denitrification).

Nitrogen in excreted waste is mainly in the form of urea, which is hydrolyzed to NH_3, the hydrolysis of urea produces a temporary rise in pH, which favours the formation of ammonia, easily lost to the atmosphere by volatization. Moisture, temperature, and wind speed conditions are influencing the volatilization of NH_3. After these processes, NH_4^+ is converted to NO_3^- in the soil zone and can infiltrate to reach the groundwater (Al Mahallawi, 2005).

2.1.6.5 Irrigation Water Inputs

Nitrates in irrigation water abstracted from the aquifer or reused after wastewater treatment may provide a significant part of the nitrogen needed by a crop. Irrigated agriculture is a primary source of nitrate. The inputs can be readily estimated from the quantity of water applied and its N content (Al Mahallawi, 2005; Jaber, 2008).

2.1.6.6 Nitrogen Fixation Inputs

The N_2 fixation converts atmospheric N_2 gas into plant N through bacteria living in root nodules of certain plants, primarily legumes. The mass of fixed N depends on many environmental factors including plant species, available soil N, crop management, soil water, type of fixing bacteria and soil chemical environment. Nitrogen fixation is an adaptive process that occurs at significant rates only when the supply of fixed nitrogen is low and apparently growth-limiting. Fixation of nitrogen requires a considerable input of energy. The estimates of nitrogen fixation will be rather crude (Al Mahallawi, 2005; Jaber, 2008).

2.1.6.7 Precipitation Inputs

The atmosphere contains ammonia and compounds released from soil and plants as well as from the combustion of coal and petroleum products. The main sources of atmospheric N are combustion of fuels, volatilization of NH_3 from animal wastes and fertilizers, volcanoes, and lightening. The principal forms of N in precipitation are NH_3, N-oxides and organic N. The concentration of nitrogen in precipitation in most cases will contain between 1 and 4 mg/l total N (Al Mahallawi, 2005).

2.1.7 Losses of Nitrogen

The main losses of nitrogen are ammonia volatilization, denitrification, plant uptake, leaching (leaching was discussed before), erosion and runoff.

2.1.7.1 Losses Through Ammonia Volatilization

Ammonia volatilization is a complex process involving chemical and biological reactions within the soil, and physical transport of N out of the soil. The most favourable conditions for ammonia losses to occur are N sources containing urea, fertilizers application in surface, soil pH above 7, and dry weather conditions. The intensity of ammonia volatilization from solution is directly related to the concentration of dissolved ammonia in the water. Ammonia volatilization from acidic solutions is negligible. Ammonia volatilization fellows first order reaction kinetics. The rate of volatilization is severely restricted by limiting the movement of air above the water, enhanced by water turbulence and increased exponentially with temperature. pH of the solution is the dominant factor controlling the extent of ammonia volatilization when the concentration of ammonium in the soil is low. At high pH and high initial ammonium concentrations, the dominant factor controlling the reaction is the buffer capacity of the soil. Losses from unincorporated surface application of NH_4^+ sources on high pH soils or urea-containing sources on any soil can reach as high as 30% to 50%.

2.1.7.2 Losses Through Denitrification

Biological denitrification is the main method of removing nitrogen because it returns nitrogen to the atmosphere as inert N_2 gas and complete the nitrogen cycle. Several intermediates are involved as: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$ (gas).

E. coli is one of the organisms which converts nitrate to nitrite under anaerobic conditions, and does not do the subsequent reaction steps. It utilizes the best available electron acceptor available, i.e. nitrate. Bacteria of facultative anaerobes normally used oxygen of the air as hydrogen acceptor (aerobically) but also possess the ability to use nitrates and nitrites in the place of oxygen anaerobically and predominantly in two genera: Pseudomonas and Bacillus. Many soil bacteria like Thiobacillus also reduce nitrate to nitrogen. The anaerobic conversion of nitrate into molecular of nitrogen is also known as nitrate respiration. It is likely to be found in agricultural land receiving substantial inputs of nitrogenous fertilizers or manure. The common requirements for denitrification are;

- The presence of an electron acceptor which in this case is nitrate,
- Presence of a microbial population that possess the metabolic capacity. Researches has shown that denitrification losses are higher in manured soils than the non-manured soils,
- Presence of suitable electron donors and,
- The presence of anaerobic conditions or restricted oxygen availability.

The main limiting condition for these four conditions is the presence of dissolved oxygen, which is highly observed in shallow depths. So, nitrate is most likely to be denitrified at deep depths due to lack of oxygen (Almasri and Kaluarachchi, 2004). Their study about Whatcom County, Washington, recognized by heavy agricultural activities, shows the relationship between the nitrate concentration and dissolved oxygen concentration. High nitrate concentrations are noticed at high dissolved oxygen concentrations and vice versa (Jaber, 2008).

2.1.7.3 Plant Uptake

The amount of N consumed by plants varies greatly from one species to another and for any given species; the amount varies with the environment. Also considerable variation exists in the relative amount of the N contained in the different plant parts. Substantial variation can occur depending on soil N status, fertilization management, and climate. Nitrogen uptake by plants is very rapid during the period of rapid vegetative growth (Jaber, 2008).

2.1.7.4 Erosion and runoff

Nitrogen losses in surface runoff (that is dissolved in the runoff water) are usually small. Such losses are variable however and depend on degree of soil cover, source of N applied, rainfall intensity immediately after application, and soil properties such as soil crusting. The largest losses (e.g., 10% losses) occur if a soluble N source is surface applied to a bare soil and significant runoff events occur within one day of application. In most cases, runoff N losses are small and may reach 3 kg/ha annually or less (Legg and Meisinger, 1982).

2.2 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 resources (Wang and Anderson, 1982). 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 (Anderson and Woessner, 1992).

2.2.1 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:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)+w=S_s\frac{\partial h}{\partial t} \qquad \textit{Eq. (2.12)}$$

Where K_x, K_y and K_z are the hydraulic conductivity components in the x, y and z direction (LT^{-1}), h is the hydraulic head (L), *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. (2.12) 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. (2.13):

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)+w=0 \qquad \textit{Eq. (2.13)}$$

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 as the volume of water released from storage per volume of soil for a unit decline in hydraulic head (Aish 2004; Jaber 2008).

2.2.2 Numerical Methods of Solving Flow Equations

Groundwater flow equations are usually not easy to solve analytically. This is because either the flow is described by a partial differential equation or usually the medium properties are heterogeneous. In such cases, numerical solution techniques can be used to obtain approximations.

Two major classes of numerical methods have been accepted for solving the groundwater flow equation. These are finite difference methods and finite element methods.

Finite difference method is much easier in programming and application than finite element method in which the heads at the nodes can be computed as an average value of the cells surrounding the node. However, finite element method is suitable for irregular shaped boundaries because the variations of heads within the element can be handled by means of an interpolation function, so it can handle complex geometry and important parameters with high accuracy (Aish 2004; Jaber 2008).

2.2.3 Solute Transport

Advection is the primary transport mechanism by which a pollutant can be transported through a groundwater system, which is the movement of a dissolved chemical along with the groundwater flow. In addition to transport by advection, dissolved particles are also subjected to hydrodynamic dispersion, a process accounting for the seemingly random spreading of solutes. Dispersion causes particles to deviate from the macroscopic advective flow paths that do not take into account the actual geometry of the pore space. Hence, some particles will move faster and some slower due to the difference in size of the pores, while also deviations in direction of the flow will because the particles have to move around the solid material. The resulting dispersion is rather random and as such very similar to diffusive spreading, but generally it has a much wider impact on the transport of dissolved chemicals compared to diffusion. In addition to transport by advection and dispersion, other processes can affect the transport of solutes, as adsorption of chemicals on the solid material of the porous medium. The partial differential equation describing the fate and transport of contaminants of species k in 3-D, transient ground water flow systems can be written as following (Zheng and Wang, 1999):

$$\frac{\partial\left(\theta C^k\right)}{\partial t}=\frac{\partial}{\partial x_i}\left(\theta D_{ij}\frac{\partial C^k}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(\theta v_i C^k\right)+q_s C_s^k+\sum R_n \qquad \textit{Eq. (2.14)}$$

Where,

- θ is porosity of the subsurface medium, dimensionless;
- C^k is dissolved concentration of species k (M L^{-3});
- t is time (T);
- $x_{i,,j}$ is distance along the respective Cartesian coordinate axis (L);
- D_{ij} is hydrodynamic dispersion and diffusion coefficient tensor (L^2 T^{-1});
- v_i is seepage or linear pore water velocity (L T^{-1}); it is related to the specific discharge or Darcy flux through the relationship, $v_i = q_i/\theta$;
- q_s is volumetric flow rate per unit volume of aquifer representing fluid sources (positive) and sinks (negative) (T^{-1});
- C^k_s is concentration of the source or sink flux for species k (M L^{-3});
- ΣR_n is chemical reaction term (M L^{-3} T^{-1}).

2.2.4 Numerical Methods of Solute Transport Equations

The numerical solutions for solute transport are different and rather difficult. This difficulty is essentially due to the advective component of solute transport. Three main methods are used for solving the solute transport equation; method of characteristic (MOC), modified method of characteristics (MMOC) and hybrid method of characteristics (HMOC).

- ***The Method Of Characteristic (MOC)***

The method of characteristic consists of computing the advective term of the transport equation, using moving particles that represent the solute concentrations. A set of particles is assigned; each particle has the concentration of the cell where it is located. Then, if only the advective effect is assumed, the concentrations will travel through the flow paths since the advective term is proportional to the velocity vector. Hence, the concentrations will be estimated by a forward particle tracking method. Then having the advective term, these concentrations are injected into the dispersion, sink/sources and chemical reaction terms and solved by Eulerian method, with finite-difference or finite-elements.

- ***Modified Method Of Characteristics (MMOC)***

The modified method of characteristics was originally developed to approximate the advection term, but the particles are assigned to fixed coordinates that are the grid nodes and the tracking is no more forward, but rather backward. For each particle, that has the node position, the preceding position (corresponding to time step n-1) is calculated from the present time step n. Assigning immobile coordinates for the particles at each time step saves a lot of time processing and computer storage. Hence, the modified method of characteristic reduces dramatically the time consuming in the solute transport equation solution. However, the advantage of saving huge computer memory is balanced by numerical problems in zones where sharp fronts of solute concentration are present.

- ***Hybrid Method of Characteristics (HMOC)***

The two previous methods have shown their limitations when applied to solute transport equations. As a matter of fact, to take advantage of the MOC and MMOC, a concept of combining these two methods was developed, and characterized as HMOC. This method consists of using the method of characteristic when sharp fronts of solute exist, while away from those zones the modified method of characteristic is used. An automatic choice of the method is based on the solute concentration distribution during the time period, and after each time step (Aish 2004; Jaber 2008).

2.3 Related Studies

Many studies were performed on water quality of the Gaza Strip aquifer in related with increase of nitrate pollution, a lot of them focused on the relationship between land use and groundwater contamination by nitrate. This section contains a brief explanation to the findings of the previous studies ordered from oldest to newest.

1. In 1995, a study about nitrate pollution in Gaza groundwater was done by the Environmental Planning Directorate in the Ministry of Planning in Gaza (Maarten Gischler, 1997). They followed an approach of nitrogen balances. *In urban areas* they calculated an N-load per ha based on population density, daily N-production per capita, percentage of population sewered, and assuming a certain removal coefficient to account for volatilization of NH_3, ammonium adsorption and many other factors. Hading calculated this load for each city; the N-load was dissolved to the amount of recharge percolating to the groundwater. They compared this with nitrogen concentration and found a remarkable correlation or good relationship. *In agricultural*

areas, they followed a similar approach and found that nitrogen applied through fertilizers is in some crops more than ten times the potential plant uptake. This explained the great jump of nitrate concentrations over the last years. However, dissolving the N-load in the amount of recharge did not give a very good correlation with nitrate concentrations found in the groundwater.

2. In 1997, a study of title "Quantification of nitrate pollution to groundwater resources of Rafah (Gaza Strip)" was done by Dr. Fahed Rabah as a M.Sc Thesis in IHE, Delft, the Netherlands. This study is devoted for the investigation of the sources of nitrate pollution to groundwater in Rafah and the assessment of the contribution of each source to the pollution load. Through field word investigations it has been found that agricultural and urban activities are the two major nitrate sources in Rafah. Agricultural activity contribution to nitrate pollution is investigated through N-balance for most of the crops cultivated in Rafah. The produced nitrate leachate under different crops is estimated and found to be in the range of 300-1900 mg No3 /L. Urban activity contribution to nitrate pollution is also investigated through N-balance for different locations in Rafah. The produced nitrate leachate under different urban pollution sources (cesspits, solid waste, overflow ponds ….etc) is estimated to be in the range of 250-2000 mg No3 /L. The relation between the nitrate in the leachate of the pollution sources and that in the groundwater is assessed by a set of expected scenarios which confirmed that the nitrate pollution to groundwater of Rafah is a human-made pollution through agricultural and urban activities while natural nitrate sources are of negligible effect.
3. In 2002, Molenat and Gascuel-Odoux developed a two dimensional model to characterize the flow and nitrate transport in the groundwater within a hillslope of the Kervidy catchments in France. The finite-difference code MODFLOW was used to simulate the distribution of hydraulic head within the groundwater. Nitrate transport was described by the convection equation solved using MT3D. MODPATH was also used to analyze flow paths and travel times in the groundwater. Autotrophic and heterotrophic denitrification in the soil was represented. A steady-state average flow was assumed with a spatially uniform groundwater recharge found in the study area. Nitrate recharge rate was fixed at 100 mg/l, equivalent to a nitrogen flux of 165 kg/ha/year. Six scenarios of nitrate leaching changes were analyzed using the model. The first two correspond to spatially uniform decreases of the nitrate recharge rate to 80 and 60 mg/l respectively. In the other four scenarios, nitrate recharge rate was

spatially distributed along the study area while the average nitrogen flux remained equal to 165 kg/ha/year. The transport model reproduced the spatial pattern of nitrate concentrations observed in the groundwater. Scenarios analysis showed that a significant decrease of stream nitrate concentration could be expected following a global decrease in nitrate leaching along the hillslope and the fall could be very gradual in time.

4. In 2004, a study about "Seasonal variations and mechanisms of groundwater nitrate pollution in the Gaza Strip" was performed by Y. Abu Maila, I. El-Nahal and M. R. Al-Agha. This study showed that nitrate is one of the major pollutants of groundwater in the Gaza Strip. Several cases of blue babies disease were reported in the last couple of years. The average concentration of nitrate in domestic wells is 128 mg/L in June-July and 118 mg/L in Jan-Feb, and for the agricultural wells, the average is 100 mg/L in June-July and 96 mg/L for Jan-Feb. The results suggest that the seasonal differences in nitrate concentrations of the domestic wells are slightly more observable than those of the agricultural wells. The environmental factors that control nitrate in groundwater are: a partially-confined aquifer, lack of a sewage system, population density, the presence of refugee camps, the presence of fertilizers and the annual rain. The variations in nitrate concentration of the domestic wells are not of considerable values. It is suggested that concrete policies in pollution control and/or prevention measures could be formulated upon better understanding of the environmental factors.
5. In 2005, Chowdary et al. developed a groundwater flow and solute transport model to assess the impacts of non-point-source pollution from fertilizers on groundwater quality in the aquifers underlying the Godavari Delta Central Canal, India. The model involved five steps or processes combining the variation in weather, crop, soil, water supplies, fertilizers use, and environment interactions; 1) Recharge of groundwater by seepage from water distribution network, 2) Recharge of groundwater by percolation from fields in the study area estimated by soil water balance model constructed by Chowdary et al., accounted the important nitrogen transformations adopted for the study, 3) The concentration of nitrates in the percolated water out of the root zone was governed by the nitrogen balance to determine the nitrate pollutant loads from applied fertilizers. Chowdary et al. modeled the transport and transformations of different N species in the soil, water, plant, and atmosphere system, taking into consideration the main processes including hydrolysis, ammonia volatilization, mineralization and

immobilization, nitrification, denitrification, leaching and plant uptake, 4) Groundwater flow in the aquifer underlying the project area in response to recharge, and 5) Transport of nitrates in the aquifer; Geographic Information System (GIS) tools were used to represent the input data and map the output of the recharge, nitrogen balance and loading. Alternative strategies of resource management were evaluated to minimize the impacts.

6. Al Mahallawi (2005) used a statistical method to model the factors that have effect on nitrate pollution. He applied the nitrogen balance approach in the Gaza Strip. The approach required data and information concerning the sources and sinks of nitrogen which many were not available. He used the Artificial Neural Networks (ANN) modeling to assess distributions of nitrate contamination and analyze the system behavior in order to predict nitrate contamination. He studied the factors that may have significant effects of groundwater contamination. Six explanatory variables for 189 sampled agricultural wells were used and those with significant influence were identified. The input variables were: nitrogen load, housing density surrounding wells, well depth, screen length, well discharge, and infiltration rate. He showed that agriculture activities and wastewater from urban areas were the two major contributors to the nitrogen load in the study area while the added nitrogen load from solid waste leachate, drinking water networks leakage and precipitation were considered minor compared to other sources.
7. In 2006, Abushbak investigated the nitrification and denitrification mechanisms in the Gaza soil types by an experimental study. The main objectives were to evaluate the influence of the composition of the local soil types, the NH_4^+, the NO_3^- and carbon concentration in the applied wastewater on the nitrification and denitrification process at conditions corresponding to Gaza Strip. A laboratory column experiments were implemented to determine the nitrification/denitrification performances under different carbon to nitrogen ratios. He used the same secondary treated wastewater produced by Gaza City wastewater treatment plant. He observed the transformation of the majority of influent nitrogen (mainly as NH_4^+) in the applied wastewater to nitrate, and thus, a peak in NO_3^- concentration in the percolated wastewater was expected. Successful attempts to establish denitrifying conditions is done by manipulating the C: N ratio in a loam sandy soil. Complete denitrification of the applied NO_3^- was achieved when C: N ratio was 1:1 and 3:1 ratio, but it was unsuccessful with C: N ratio of 1:3 after applying the wastewater in a loam sandy soil.

8. In April 2006, Dillon, P. J performed a study with title "Models of nitrate transport at different space and time scales for groundwater quality management". In this study two models were developed and applied in an analysis of regional groundwater nitrate contamination, covering different space and time scales. The first, NITWIT, is a monthly inorganic nitrogen balance for grazed legume-based pastures, to predict nitrate leaching. It takes account of the irregular spatial distribution of livestock urine in determining paddock mean annual recharge and aquifer nitrogen load. Another model, DIVAST, is a diffuse-source vertical slice analytical model of solute transport in an aquifer receiving uniform recharge with nitrate concentrations which vary in space and time. The model typically considers elements several kilometers long and gives vertical resolution for solute concentrations through the aquifer thickness over time periods of the order of hundreds of years. It is useful for preliminary regional assessment of non-point source contamination and in design of monitoring networks with a high information: cost ratio. The models were used to estimate the contribution to nitrate in groundwater by diffuse sources and allow preliminary forecasts of groundwater quality for a 1000 km^2 pastoral area in South Australia. NITWIT output was aggregated and used as input to DIVAST. Based on groundwater sample analyses and model results, it was concluded that diffuse sources were responsible for almost 90% of nitrogen in the aquifer and that the prognosis for portability of groundwater depends on the unknown vertical mixing in the aquifer. Consequently a monitoring program to detect nitrate concentration of recharge has been proposed.
9. In September 2006, ALMADINA-Consultants with the Finland Project Management Unit (PMU) which is one the PWA arms performed a study with title "Khanyounis wastewater treatment plant- Infiltration System- Geotechnical and Hydrological Study". During the winter season, PMU is proposing to infiltrate the treated wastewater into the ground in order to replenish and improve the almost-dry aquifer in the area. To that extent, PMU is performing this geotechnical and hydrogeological investigation in order to locate the candidate locations for the infiltration basins and pinpoint the best sites for constructing those basins. PMU is responsible for following up and managing the design stage of the proposed Khanyounis wastewater treatment plant. Therefore, the PMU/PLANCENTER contracted Al-MAMDINA Consultants to perform the geotechnical and hydrological study to select feasible sites in eastern Khanyounis area for the construction of rapid infiltration basins and preparing the conceptual design of the basins. These basins are expected to accommodate the total

effluent of treated wastewater from the proposed WWTP in Khanyounis of around 50,000 cubic meters per day in the year of 2025. Other infiltration systems such as injection wells are not preferred due to high risks involved such as clogging at depth is costly or impossible to remediate and experience with well infiltration is limited and the water quality demand is higher , in addition to the geological formation of the study area , land availability and the hydraulic properties of the soil indicates that the preferred and cost effective system is rapid infiltration based on available data and the consultant past experience. The study showed - based on the geological features and hydrogeological models conducted for the selected sites- that the best location for rapid infiltration ponds is Khuza site to the north west of the location of the WWTP. The groundwater table is very deep in this locality and the aquifer highly permeable kurkar layer is very close to the surface. However, multiple thin clayey layers have been found sandwiched in the aquifer material at different depths in different locations. It was found that the presence of these layers determines the hydrological behavior of the site underneath the rapid infiltration ponds and the mounding of infiltrated water under the ponds. It has been suggested that according to the specific site selected for the ponds, the detailed study should determine the feasibility of ignoring the effect of such layers if local, removing the first layer (or layers if necessary) if such layers are close to the surface, or reducing the effect of these layers by introducing a determined number of auger boreholes in the layer to be filled with permeable materials. According to the determined design parameters in this study, the required infiltration area of the rapid infiltration ponds at 2018 , is three basins each (19000m^2) including slopes and track roads, and the required infiltration area at 2025 , is nine basins each (19000m^2) including slopes and track roads. The land investigated in this study in the Khuza area is owned by local farmers. Land plots in the area range from small plots of few donums area to larger ones that can be as large as a hundred donums. The land prices and availability in this agricultural area make the possibility of purchasing the required area for the ponds very feasible.

10. Mushtaha et al. (2007) used the finite difference code (MODFLOW) to quantify the impacts of controlled infiltration of the partially treated sewage from the new Beit-Lahia wastewater treatment plant (BL-WWTP) on the aquifer water quality with respect to chloride and nitrate. The untreated effluent from the old BL-WWTP was allowed to accumulate forming huge lake allowing the infiltrated sewage water reaches the groundwater and may contaminate the aquifer. The partially treated

effluents will be transferred to the new infiltration site located at the north eastern borders of Gaza Strip. Water level was calibrated based on steady state simulation for the year 2000 and the transient calibration was for the period 2000 to 2004. Transport model to simulate nitrate was performed using MT3D model, zero concentration was set to the model as initial concentration. The calibrated effective porosity was 0.25 and calibrated dispersivity ranged from 3 to 12 m. The study had showed that the difference in dispersivity did not give any significant changes in results. Also, the study showed that water quantity would be improved slightly but the nitrate concentration around the basins site would increase significantly.

11. In 2007, study about "Analysis of Nitrate Contamination of Gaza Coastal Aquifer, Palestine" was performed by Mohammad N. Almasri and Said M. S. Ghabayen._The study analyzes nitrate concentration distribution for the GCA (Gaza Costal Aquifer) at different levels such as land use classes and sampling depth. Nitrate concentration data from 1990 and from 2000 to 2004 were compiled and assembled into a single composite database. A geographic information system was used to assess the spatial and temporal variability of nitrate occurrences in the aquifer. Results show that the first quartile of nitrate concentration for the years 1990 and 2000–2004 exceeds the MCL. In addition, the analyses demonstrated a generally increasing trend in groundwater nitrate concentration. The areas with the most elevated nitrate concentrations are areas characterized by heavy agricultural activities and urban areas. Elevated nitrate concentrations in the GCA indicate anthropogenic contamination sources.
12. In 2007, "Guiding Information Towards Domestic Groundwater Supply Management in the Gaza Strip Governorates-Palestine" report was prepared by Palestinian Water authority. This report displayed that the wastewater is the main groundwater pollution cause, where only 20% of Khanyounis Governorate is covered by wastewater network collection and distribution system. Therefore it should be given a priority to that issue in order to minimize the aquifer deterioration. Also, the illegal wells should be licensed through the normal PWA’s procedure.
13. In April 2008, Shomar B, Osenbrück K, Yahya A performed a study on: "Elevated nitrate levels in the groundwater of the Gaza Strip: Distribution and sources". The objectives of the research were to study the distribution of NO_3^- in the groundwater of the Gaza Strip and to identify the sources of NO_3^- in the Gaza aquifer system by assessing nitrogen and oxygen isotopes. The study concluded that almost 90% of the

groundwater wells of the Gaza Strip sampled between 2001 and 2007 showed NO_3^- concentrations two to eight times higher than the WHO standards. Manure and septic effluents are the main sources of NO_3^- in the groundwater of Gaza followed by sludge and synthetic fertilizers.

14. In 2008, Al Masri and Ghabayen published a paper with title "Analysis of Nitrate Contamination of Gaza Coastal Aquifer, Palestine". This study analyzed nitrate concentration distribution for the Gaza Costal Aquifer at different levels such as land use classes and sampling depth. Nitrate concentration data from 1990 and from 2000 to 2004 were compiled and assembled into a single composite database. A geographic information system was used to assess the spatial and temporal variability of nitrate occurrences in the aquifer. Results show that the first quartile of nitrate concentration for the years 1990 and 2000–2004 exceeds the MCL. In addition, the analyses demonstrated a generally increasing trend in groundwater nitrate concentration. The areas with the most elevated nitrate concentrations are areas characterized by heavy agricultural activities and urban areas. Elevated nitrate concentrations in the GCA indicate anthropogenic contamination sources.
15. In 2008, R Jaber performed a study with title: "Fate and transport of nitrate in the costal aquifer of Gaza Strip and the feasible management options. A coupled flow and transport model using a three-dimensional, finite difference simulation model (VMODFLOW Pro.) was applied to simulate the Gaza coastal aquifer. Model application was carried out in three stages; (1) Application of the flow model under steady state conditions for the year 2000 to estimate the hydraulic parameters and water balance of the system, and applying the transient calibration for the target period (2000-2004) to estimate the storage coefficients, (2) Simulation of nitrate transport in the Gaza Strip coastal aquifer to estimate transport parameters (i. e., dispersivity), and finally (3) The calibrated flow and transport model was used to study management scenarios. They gave an impression about the situation in Gaza aquifer regarding groundwater contamination by nitrate in the next 30 years. Four selected management scenarios were tested; (a) work as usual, (b) 25% reduction of annually nitrate loading, (c) 50% reduction of annually nitrate loading, (d) 75% reduction of annually nitrate loading. It was estimated that the 25%, 50% and 75% reductions in nitrate loading reaching the aquifer will lower the nitrate concentration by rates of 1.24, 1.56 and 1.82 (mg/l) respectively. So, nitrate was expected to tone with the WHO standards in the years 2051, 2036 and 2026 for the tested management

scenarios of 25%, 50% and 75% reduction of nitrate respectively. The objectives of improving the quality of groundwater with respect to nitrate concentration could be achieved externally by reduction and/or cutting-off only the sources of high on-ground nitrate contributors and lately internal by pump and treat or mixing with desalinated water from the sea.

16. In March 2009, Lubna Hajhamad, Mohammad Almasri performed a study with title "Assessment of nitrate contamination of groundwater using lumped-parameter models". In this paper, lumped-parameter models (LPMs) were developed and utilized to simulate nitrate concentration in the groundwater of Gaza City and Jabalia Camp (GCJC) in the Gaza Coastal Aquifer (GCA) in Palestine. In the GCJC area, nitrate levels exceed the maximum contaminant level (MCL) of 10 mg/L NO_3^--N (45 mg/L NO_3^-) in many wells. Elevated nitrate concentrations in the groundwater of GCJC area are due to the disposal of untreated wastewater, the existence of heavy agriculture in the surrounding areas, and the use of cesspits for wastewater disposal. The developed LPMs utilize monthly time steps and take into consideration all the sources and sinks of water and nitrate in the study area. The main outcomes of the LPMs are the average temporal water table elevation and nitrate concentration. In order to demonstrate LPMs usability, a set of management options to reduce nitrate concentration in the groundwater of the study area were proposed and evaluated using the developed LPMs. Four broad management options were considered where these options tackle the reduction of nitrate concentration in the lateral inflow, rehabilitation of the wastewater collection system, reduction in cesspit usage, and the restriction on the use of nitrogen-based fertilizers. In addition, management options that encompass different combinations of the single management options were taken into account. Different scenarios that correspond to the different management options were investigated. It was found based on the LPMs that individual management options were not effective in meeting the MCL of nitrate. However, the combination of the four single management options with full rehabilitation and coverage of the wastewater collection network along with at least 60% reduction in both nitrate concentration in the lateral inflow and the use of nitrogen-based fertilizers would meet the MCL constraint by the end of the management period.

CHAPTER
3

STUDY AREA

CHAPTER 3: STUDY AREA

3.1 Introduction

Khanyounis governorate is one of the five governorates of the Gaza Strip. Gaza Strip is located in an arid area with scarce water resources. It is a part of the Palestinian coastal plain in the south west of Palestine as shown in figure 3.1, where it forms a long and narrow rectangular area of about 365 km^2, with 45 km length, and between 5 and 12 km width. Nowadays, its five governorates are: Northern, Gaza, Middle, Khanyounis and Rafah as shown in Figure 3.2. It is located on the south-eastern coast of the Mediterranean Sea, between longitudes 34° 2’’ and 34° 25’’ east, and latitudes 31° 16’’ and 31° 45’’ north. The Gaza Strip is confined between the Mediterranean Sea in the west, Egypt in the south. Before 1948, it was part of Palestine under the British mandate. From 1948 to 1967, it was under the Egyptian administration. From 1967 until 1994, the Gaza Strip was under Israel occupation. According to the peace agreement between Israel and the Palestinian, the Gaza Strip has been under the Palestinian Authority control since May, 1994 (Qahman, 2004).

Figure 3.1: Geographic location of the Gaza Strip (Aish, 2004)

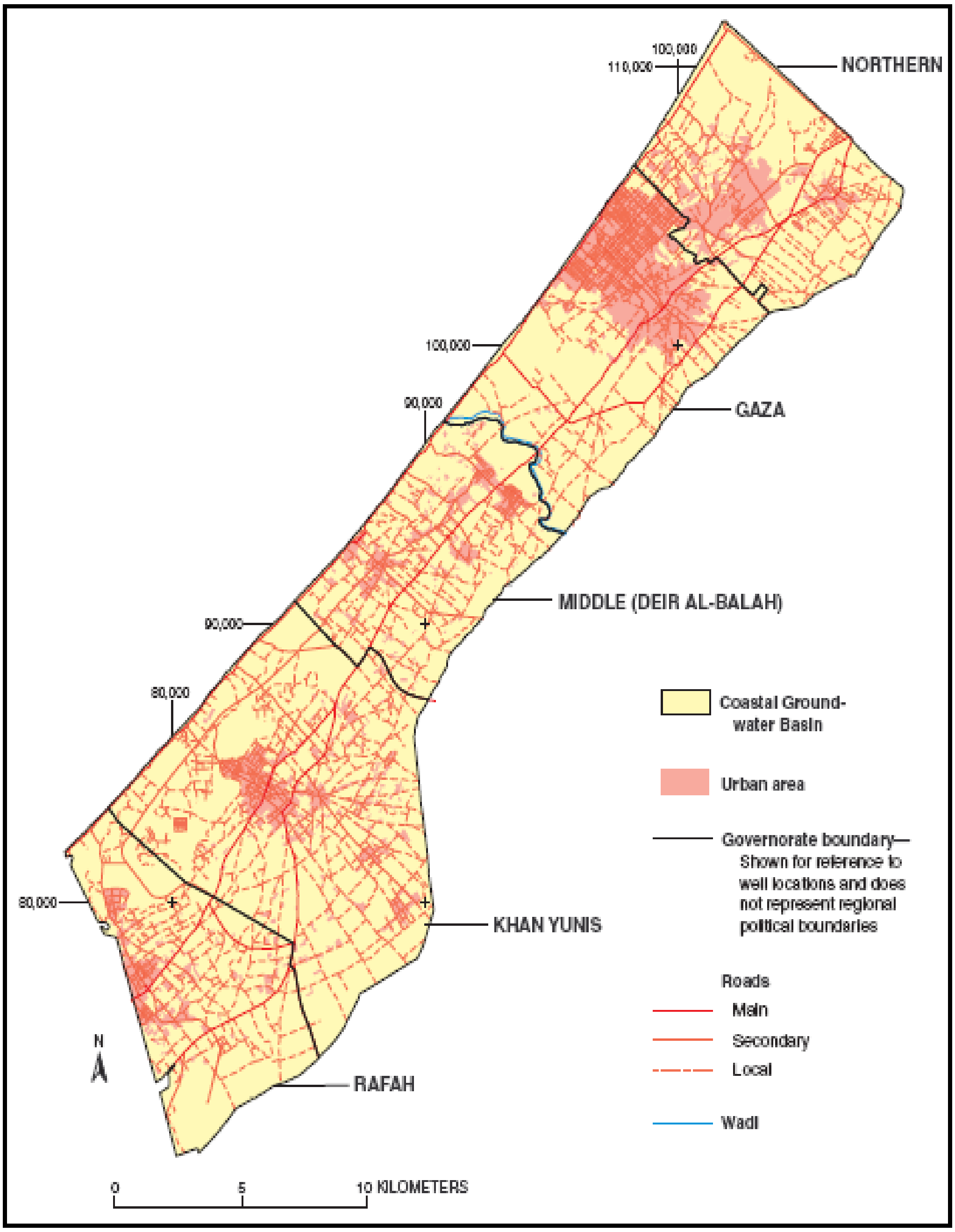


Figure 3.2: Gaza Strip Governorates (PWA, 2000)

The Gaza coastal aquifer is an important source of water to over 1.5 million residents in the Gaza Strip. It is utilized extensively to satisfy agricultural, domestic, and industrial water demands. The extraction of groundwater currently exceeds the aquifer recharge rate. Today, the Gaza Strip is a land under great pressure. It is densely populated, with population of more than one million in the year of 1998 and the population increased rapidly up to approximately 1.5 million in 2007, which means that the environment in Gaza has been under great pressure and as a result most of the people there suffers severely now (Qahman and Zhou, 2001).

Khanyounis Governorate is located in the southern part of Gaza Strip as shown in figure 3.2. Its district capital is Khanyounis City. In 2007, About 280 thousand inhabitants are living in Khanyounis. The Khanyounis governorate consists of six municipalities: Khanyounis, Bani Suhaila, Abasan El-Kabira, Abasan El-Saghira, Quarrara, Al Fakhari and the Khaza'a as shown in figure 3.3.

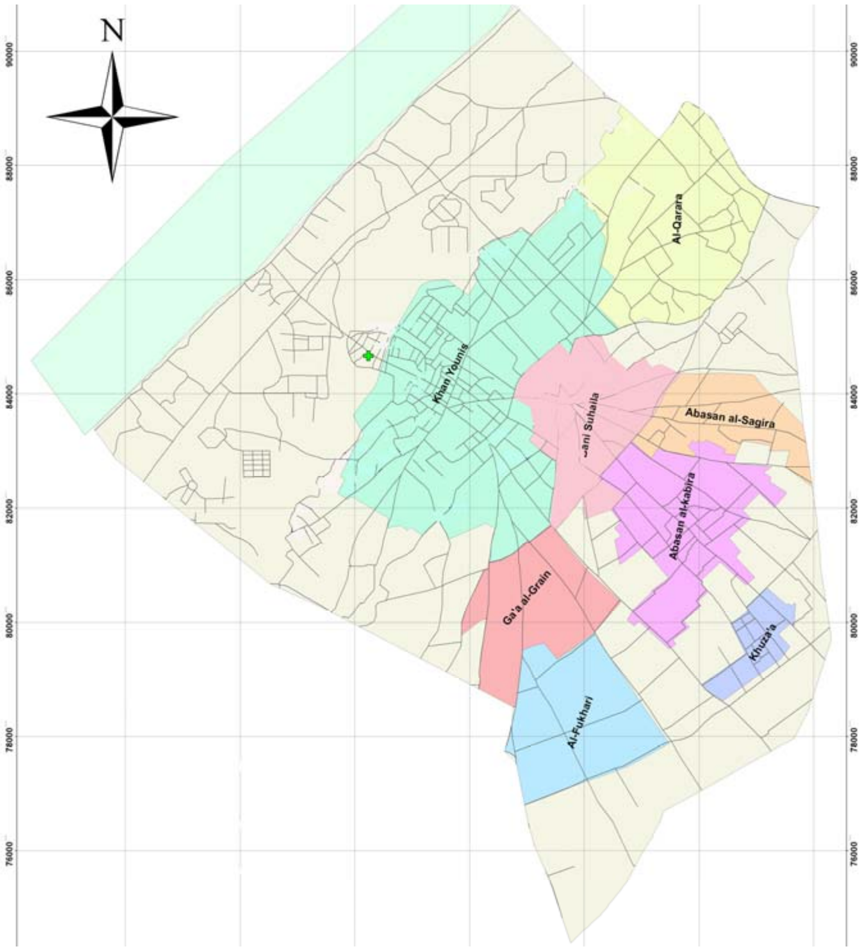


Figure 3.3: Khanyounis map (PWA, 2007b)

3.2 Physical Settings

3.2.1 Climate

Khanyounis as a part of Gaza Strip has a characteristically semi-arid climate and is located in the transitional zone between a temperate Mediterranean climate in the west and north, and an arid desert climate of the Sinai peninsula in the east and south. In this study, the climate parameters are average monthly and annually.

Regarding the rainfall data and measurements of Khanyounis governorate, the wet season starts in October and extends to April while the dry season occurs between May to September.

3.2.1.1 Temperature, Humidity and Solar Radiation

Figure 3.4 presents the maximum, minimum and mean monthly air temperatures as observed in the meteorological station of Gaza city (closed to Khanyounis temperature) for the period lasting from 1999 until 2005. Temperature gradually changes throughout the year, reaches it's maximum in August (summer) and its minimum in January (winter), average of the monthly maximum temperature range from about 15.6 C° for January to 27.84 C° for August. The average of the monthly minimum temperature for January is about 12.85 C° and 27.6 for August.

The daily relative humidity fluctuates between 65% in daytime and 85% at night in summer, and between 60% and 80% respectively in winter. The mean annual solar radiation amounts to 2200 J/cm^2/day (Metcalf & Eddy, 2000).

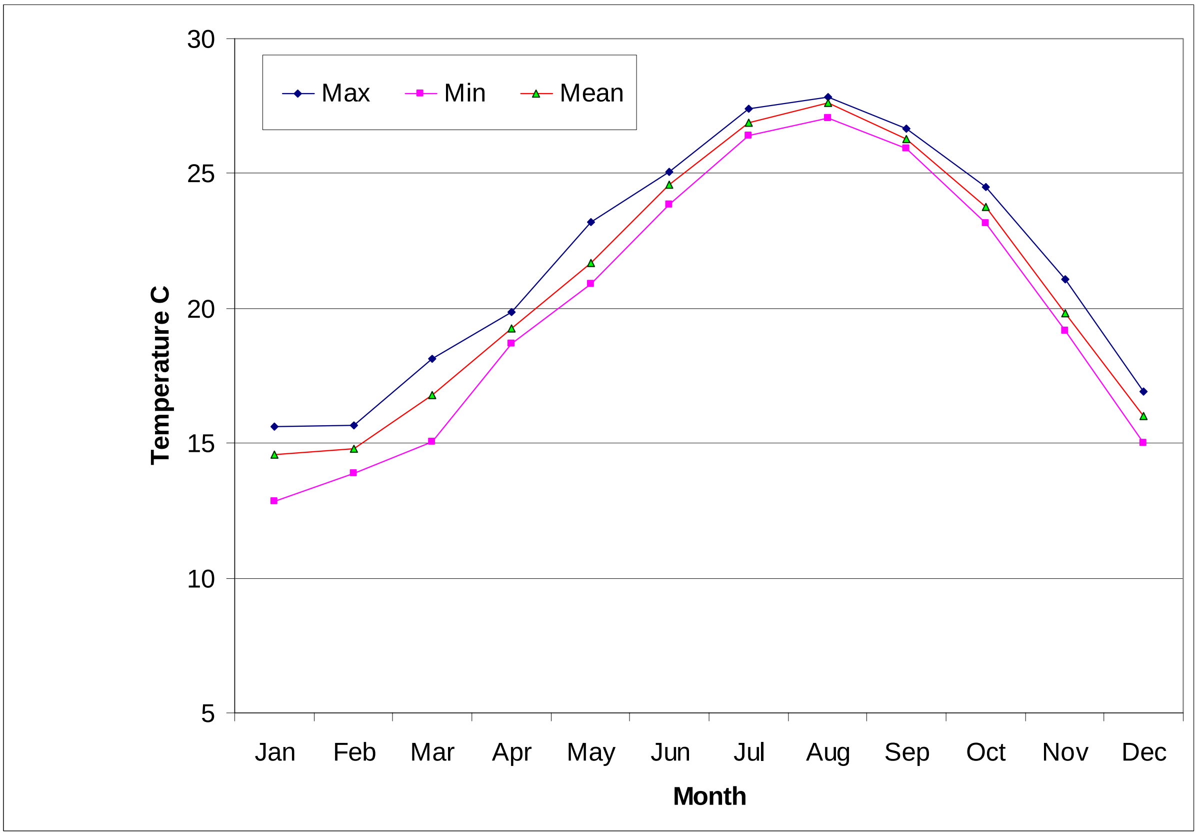


Figure 3.4: Mean monthly maximum, minimum and average temperature (C°)for the Gaza Strip (period 1999 – 2005)

3.2.1.2 Rainfall

The rainfall data of the Khanyounis is based on the data collected from the main two rain stations located in Khanyounis city and Khaza'a as shown in Figure 3.5. Daily rainfall data are available for Khanyounis station since 1985 but for Khaza'a station since 1999.The average rainfall in Khanyounis governorate from 1999 to 2008 was 263.5 (mm/year) as an annual precipitation as shown in table 3.1.

Table 3.1: Average yearly precipitation in Khanyounis governorate from 1999-2009 (source: MoA, 2009)

Year	**Readings of Gauge(1)**[*] (mm/ year)	**Readings of Gauge(2)**[*] (mm/ year)
1999/2000	191.80	142.20
2000/2001	381.00	284.30
2001/2002	311.70	258.50
2002/2003	298.00	261.20
2003/2004	204.40	184.00
2004/2005	373.00	367.70
2005/2006	270.5	214.0
2006/2007	252	256.1
2007/2008	178	137.8
2008/2009	309	261.8
Avg. yearly prec.	**276.94**	**236.69**
Approximated Area	**86.70**	**43.40**
Annual Precipitation (mm/year)	***263.5***	***Approximated from last 10 years(1999-2008)***

[*] **Gauges as shown in figure 3.5**

3.2.1.3 Reference Crop Evapotranspiration (ET_o)

ET_o is small in winter about 1.3 to 1.6 mm/d, and reaches its maximum in summer at about 6 mm/d. The mean monthly evaporation in Khanyounis Governorate varies significantly throughout the year. The monthly average evaporation over 25 years in Khanyounis varies between maximum of 194 mm in July and minimum of 51 mm in January, with an annual average evaporation of 1410 mm.

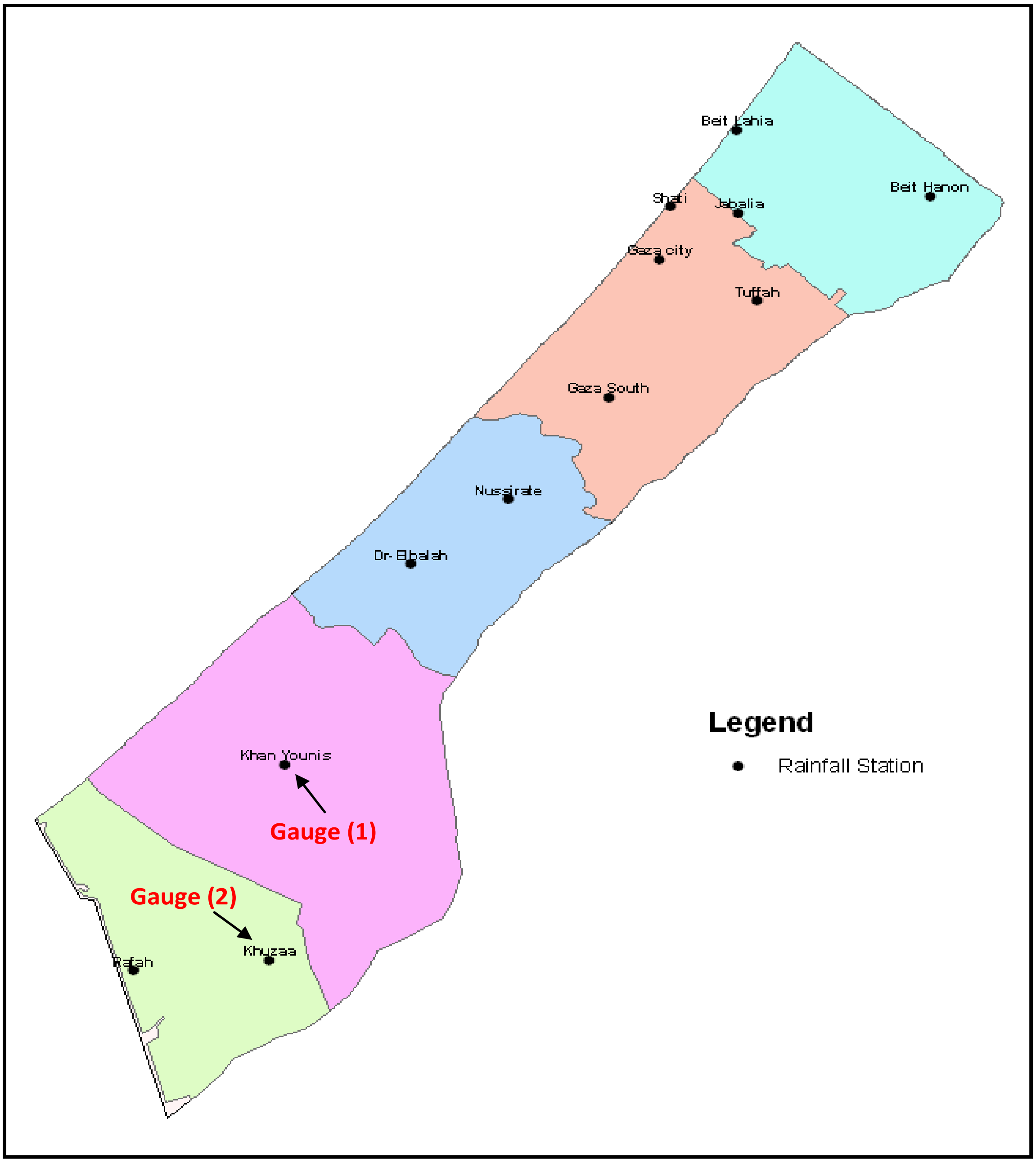


Figure 3.5: Locations of rain stations in the Gaza Strip (PWA, 2000)

3.2.2 Topography and Soil

The Gaza Strip topography is characterized by elongated ridges and depression parallel to the coastline, dry streambeds and shifting sand dunes. They are narrow and consist of "Kurkar" sandstone. The major depressions are filled with alluvial sediments from storm water (Aish, 2004). Land surface elevations range from mean sea level (MSL) to about 100 meters above the mean sea level at the eastern areas as shown in figure 3.6. Figure 3.7 shows the soil map distribution of Gaza Strip.

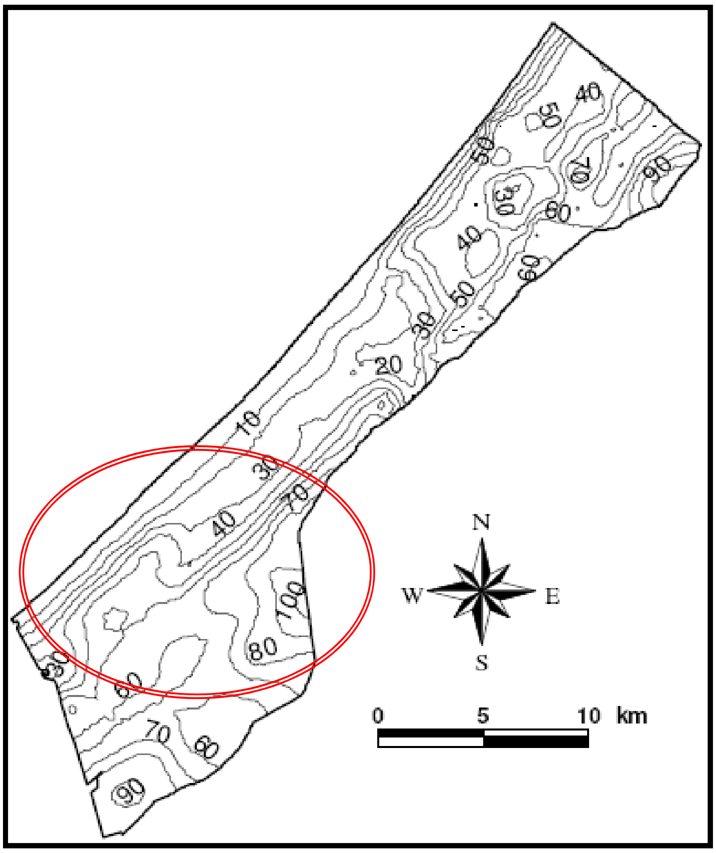


Figure 3.6: Topography of Gaza Strip (MOPIC, 1996)

Figure 3.7: Soil map of Gaza Strip (PWA, 2003)

3.2.3 Land Use

The land use map of Khanyounis as shown in figure 3.8 is based on the regional plan developed by central committee in the Ministry of the local government (MoLG, 2005).

The land as shown in figure 3.8 is scarce and the pressure on it is increasing rapidly for all kinds of uses; urban, industrial, and agricultural uses. Agricultural land occupies about 72 km^2, which is about to 65% of the total area of the Khanyounis governorate. It is expected that future expansion will be for the domestic use only.

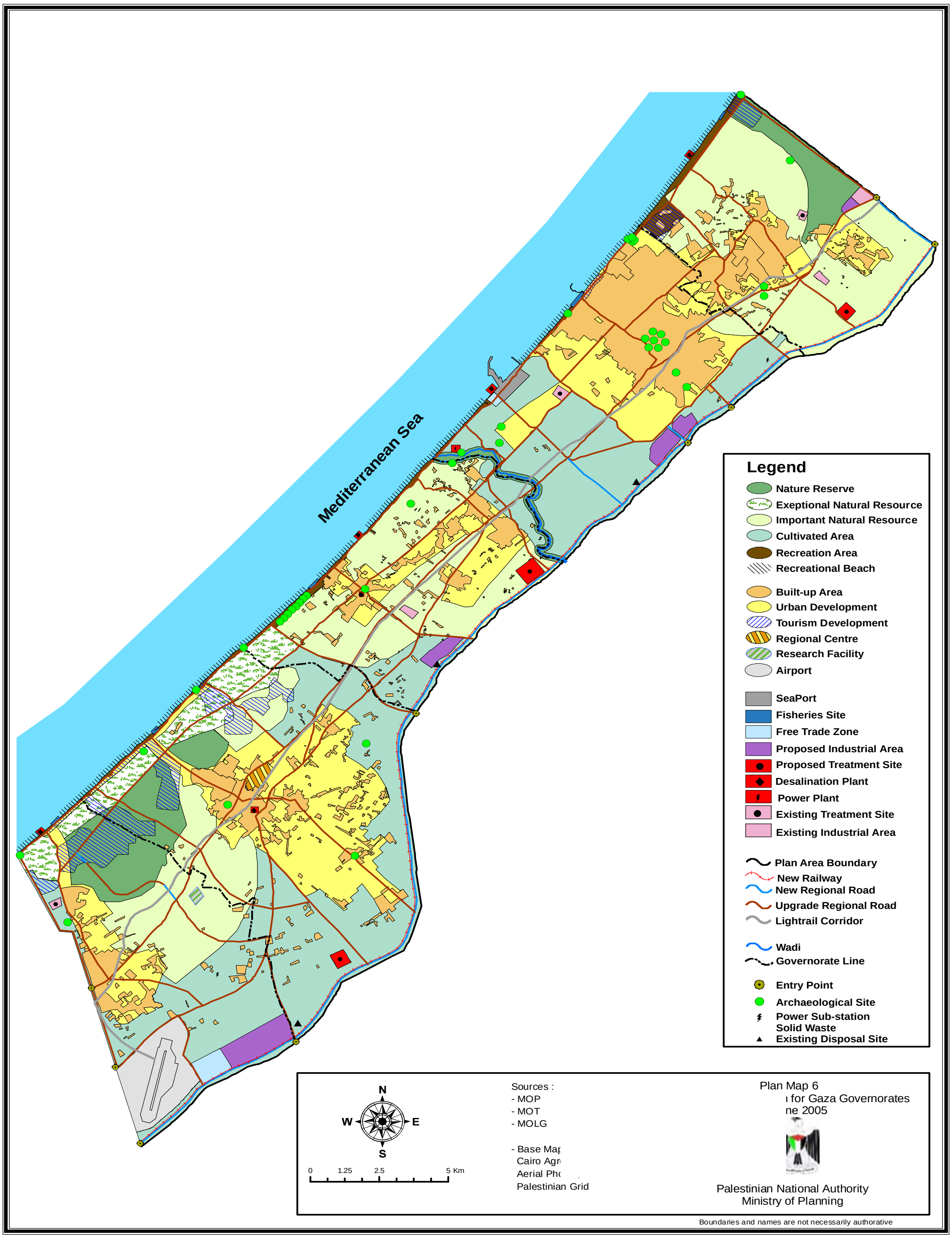


Figure 3.8: Regional plan for Gaza Governorates, (MoP, 2005)

3.3 Hydrogeology

3.3.1 Description of the Coastal Aquifer

The coastal aquifer of the Gaza Strip (included Khanyounis governorate) 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 subaquifers, referred to as subaquifers A, B1, B2, and C. A conceptual geological cross-section of the coastal plain geology is presented in Figure 3.9.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 (Metcalf & Eddy, 2000; Qahman and Zhou, 2001).

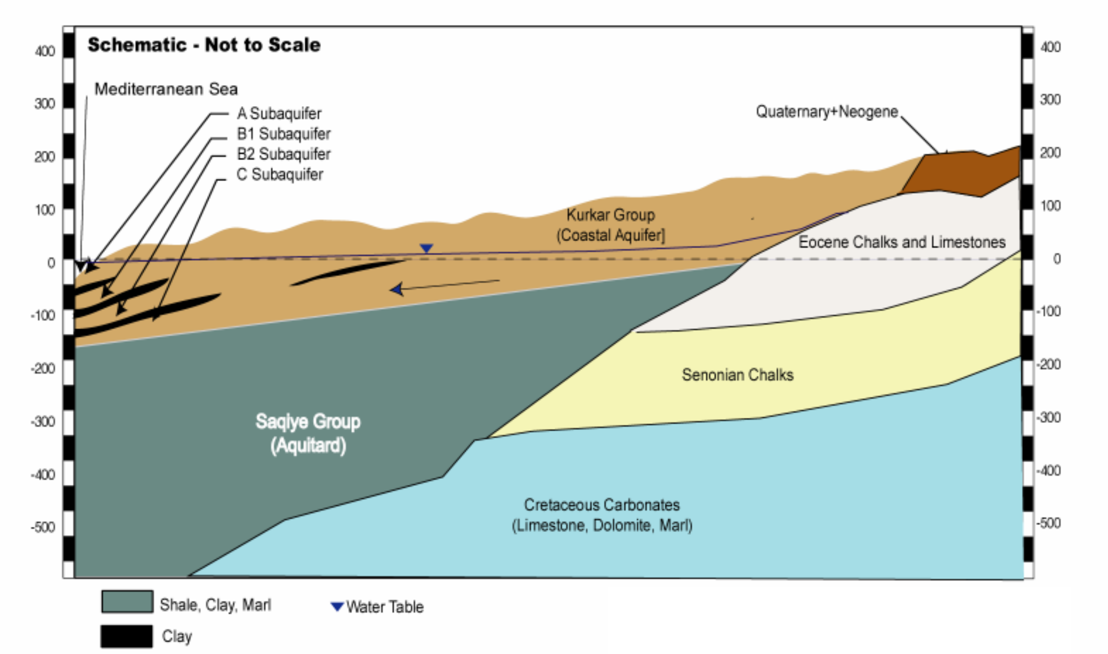


Figure 3.9: Generalized Cross-Section of the Coastal Plain, (Dan. Greitzer,1967)

3.3.2 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 (Metcalf & Eddy, 2000).

Table 3.2: Summary of the available values of hydraulic parameters of the Coastal Aquifer within Gaza Strip

Parameter	Value
Transmissivity (m^2/d)	700 - 5,000
hydraulic conductivity (m/d)	20 - 80
Specific yield (%)	15 - 30
Storativity	10^{-4}

Source: Adapted from (Metcalf & Eddy, 2000; Qahman and Zhou, 2001; Aish, 2004; Qahman, 2004; Qahman and Larabi, 2006).

3.3.3 Groundwater Flow and Water Levels

Under natural conditions, groundwater flow in the Khanyounis governorate is towards the Mediterranean Sea, where fresh groundwater discharges to the sea. However, natural flow patterns have been significantly disturbed by increasing population and over pumping in the past 40 years (Metcalf & Eddy, 2000). Within the southern part of Gaza Strip, large cone of depression has formed over large area. Water levels are presently below mean sea level in many places, inducing a hydraulic gradient from the Mediterranean Sea towards the major pumping centers and municipal supply wells as shown in figure 3.10. In Khanyounis, water levels range from greater than 3 meters above sea level near the eastern border to less than -6 meters in the area of cone of depression.

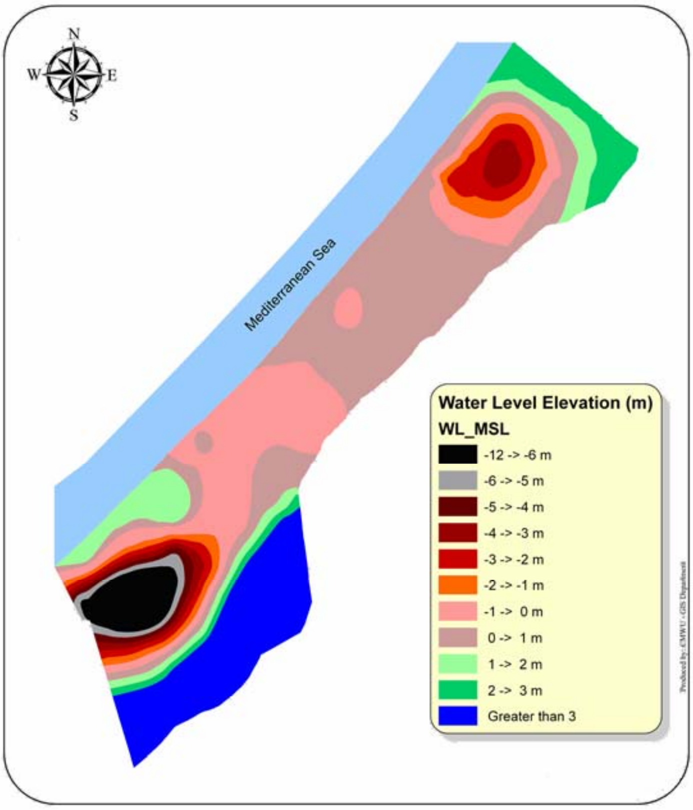


Figure 3.10: Water level elevation map for hydrological year 2007 (CMWU,2008).

3.4 Water Quality

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

The major documented water quality problems are elevated chloride (salinity) and nitrate concentrations in the aquifer (Aish, 2004).

3.4.1 Groundwater Salinity (Chloride)

Salinity in the Gaza coastal aquifer is most often described by the concentration of chloride in groundwater. Sea water intrusion and intensive exploitation of groundwater have resulted in increased salinity in the most areas in Gaza Strip. According to CMWU, a generalized contour map of year 2007 is shown in figure 3.11. Chloride concentrations are the highest along the Gaza border in the middle and south areas with concentrations exceeding 1500 mg/l. The best water quality is founded in the sand dune areas in the north, mainly in the range of 50 – 250 mg/l.

There are three major sources of groundwater salinity; leakage of brackish saline water lowing from adjacent aquifers along the eastern boundary of the coastal aquifer (600-2000 mg/l Chloride), sea water intrusion along the coast from the west and mixing with deeper very saline water from below and the over-exploitation of the coastal aquifer resulting in the creation of water level depressions while preventing the flushing of accumulated salts (Ghazali and Abu Aqleen, 2003; Qahman, 2004). Seawater Intrusion is defined as the migration of saltwater into fresh water aquifers under the influence of groundwater development. Seawater intrusion began in the late-1960s and the wedge continued to migrate inland at high rates due to increasing in municipal pumping and abstractions. Many modern studies indicate that seawater intrusion extends from 1 to 2.5 km along the western boundaries of Gaza Strip along the sea, especially in Gaza city-Jabalia and Khanyounis-Rafah. These areas correspond to the largest pumping quantities where the groundwater levels are 1-6 m below the mean sea level (Metcalf & Eddy, 2000; Qahman, 2004).

Each Municipality in Khanyounis governorate has it own wells, network distribution and operational system therefore the equity of consumption varies from municipality to another either in term of quantity and/or in quality (PWA, 2007b).

Concerning the pumped water quality, the chloride ion concentration of the Khanyounis municipality is in the range of 350-1250 mg/l. Only 2-wells are with chloride of about 350 mg/l and 3-wells are 500-600 mg/l and the remaining 15-wells are 600-1250mg/l. This means that 90% of the wells with chloride exceed the WHO limit (PWA, 2007b).

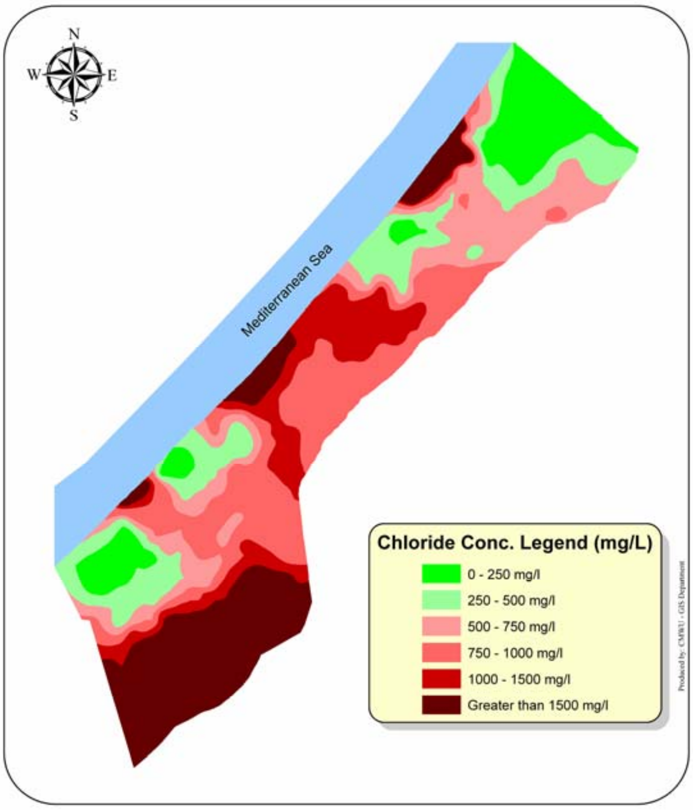


Figure 3.11: Chloride concentration map for the year 2007 (CMWU, 2008)

3.4.2 Nitrate Pollution

Increasing of nitrate is one of the most important and widespread of the numerous potential groundwater contaminants. The main causes of nitrate pollution are the excessive use of fertilizers in intensive agriculture, the irrigation with domestic wastewater and livestock farming (Rocca et. al., 2005).

The problem of high nitrate concentrations in drinking water constitutes a major health risk to both humans and stock life. Nitrite reacts directly with hemoglobin in human blood and other warm-blooded animals to produce methaemoglobin. Methaemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious for babies under three months of age. It causes a condition known as methaemoglobinemia or “blue baby” disease. The WHO assigned the nitrate of 50 mg/L as a health significant value in drinking water (Khayat et. al., 2006).

Most municipal wells in Gaza Strip especially those are located in Khanyounis governorate show nitrate levels in excess of the WHO drinking water standard of 50 mg/l. In the worst affected areas (urban centers), NO_3^- concentrations are increasing at rates of up to 10 mg/l per year. The main sources of NO_3^- are fertilizers and domestic sewage effluents. The quantities of sewage that infiltrate to the water table on an annual basis through cesspits and septic tanks are significant, about $12*10^6$ m^3/y. In contrast to salinity, groundwater flowing from the east has relatively low NO_3^- levels (Mogheir, 2005). Figure 3.12 shows nitrate concentration in the Gaza Governorates for the year 2007.

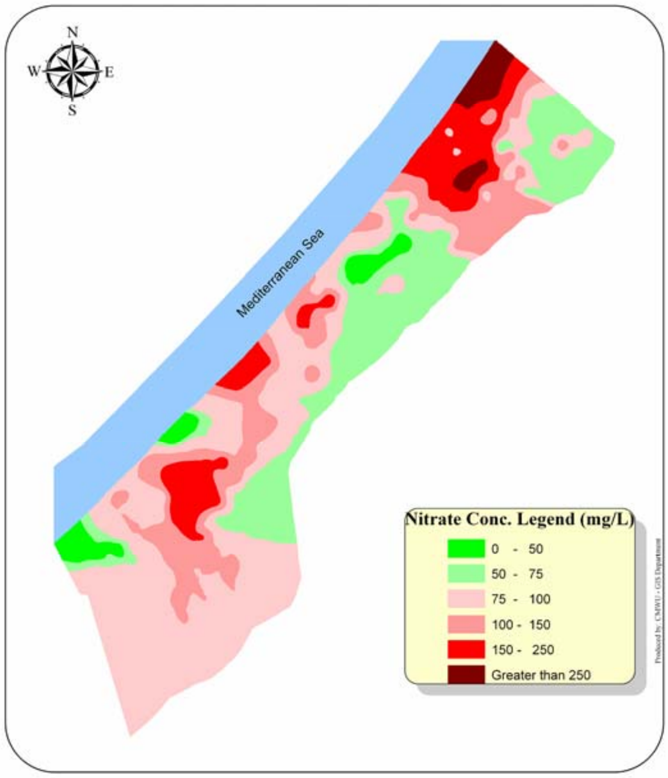


Figure 3.12: Nitrate concentration map for the year 2007 (CMWU, 2008)

3.5 Description of Existing Sewerage Situation

Despite its big size as the second city in Gaza Strip, Khanyounis city and the surrounding villages are still suffering from the lack of conventional wastewater collection system. The sources contributing to the wastewater are primarily households, since little industry exists. The residents in Khanyounis depend on the cesspits and or septic tanks for wastewater disposal. More than 30,000 units (cesspits) exist in Khanyounis Governorate according to the municipalities' estimates. Table 3.3 below depicts the detailed distribution of these cesspits among the municipalities

Table 3.3: No. of Cesspits in Khanyounis Governorate in year 1997

No.	Area	No. of Cesspits
1.	Khanyounis City	20,000
2.	Bani Suhaila	2,500
3.	Abasan Al Kabira	3,500
4.	Abasan Al Jadida	500
5.	Al Qarara	2,850
6.	Khuza'a	950
	Total	**30,300**

Part of the wastewater is left to percolate to the underground water table especially during the initial stage of the cesspits use, however a big portion of the collected wastewater is evacuated by suction trucks and disposed off finally to Wastewater Lagoons located in the Eastern Area without any treatment. The lagoons are not protected with lining layers. This contributes to several health and environmental impacts.

Recently, a sewerage collection and pumping system has been implemented that covered a large area of Khanyounis city. The designed system comprises (80Km) main collection networks, three main pumping stations and conveyance lines (pressure / gravity). According to the Finland project in cooperation with PWA the Khanyounis governorate waste water network is shown in figure 3.13. All components of the network were implemented unless WWTP and reuse systems which have been suspended as a result of the political conditions of the Gaza Strip.

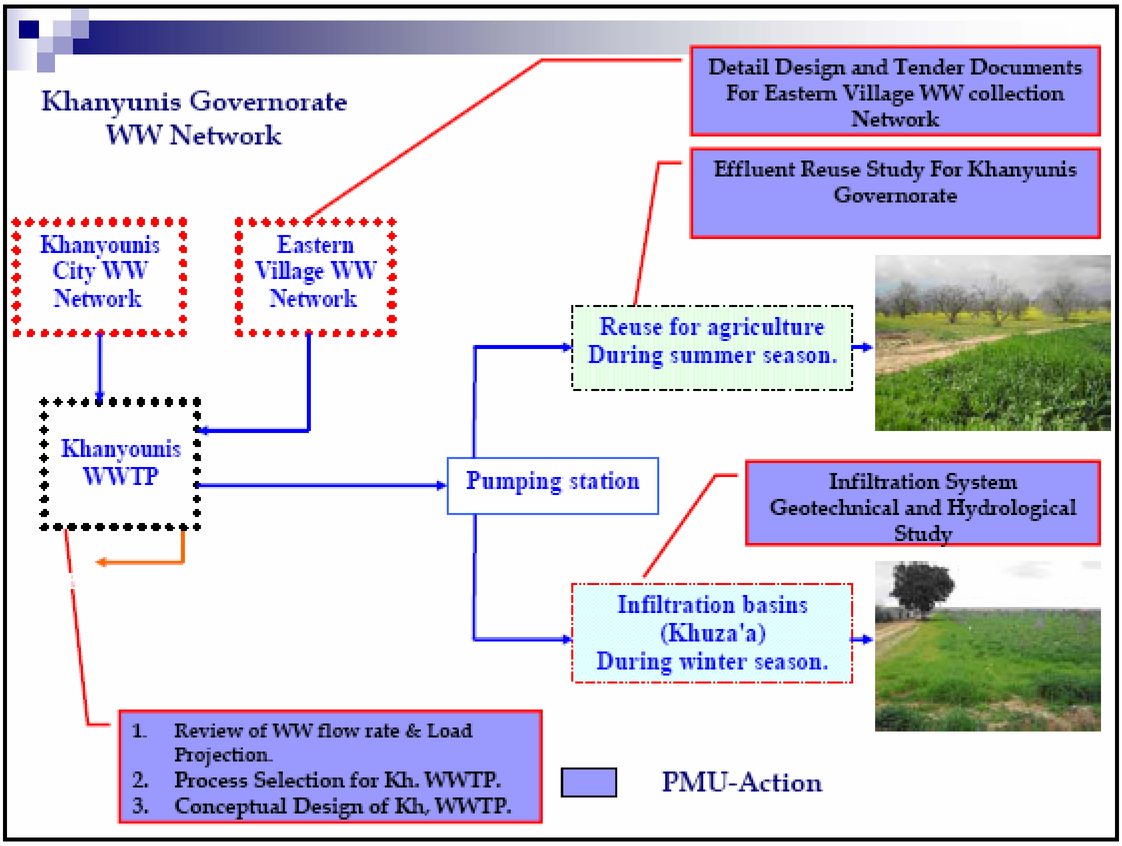


Figure 3.13: ***Scheme for Khanyounis governorate waste water network (PWA, 2007)***

After 2006, Khanyounis residents initiated to connect their house connections to the waste water network or mostly to the storm water network. There are 2 pumping stations, collecting wastewater and discharged to the existing storm water ponds at El Amal area located in the west of Khanyounis as shown in figure 3.14. These ponds with an approximately area equals 100 dunam, and 3 meters depth. The current flow rate is about 5,000 m^3/day. A new project was completed to pump the partially treated wastewater to the sea.

Figure3.14: Waste water discharged to the existing storm water ponds at Al Amal Area-Khanyounis.

CHAPTER
4

GROUNDWATER MODELING

CHAPTER 4: GROUNDWATER MODELING

4.1 Introduction

A fully three-dimensional, coupled flow and transport model was used to simulate the southern part of Gaza coastal aquifer system. Most importantly, the model should ultimately serve as an aquifer management tool so it can be used to examine and monitor specific aquifer management actions, and to track the response of the aquifer in conjunction with aquifer monitoring data.

A conceptual model was first developed to depict the hydrogeology of the aquifer system, and on its basis, a finite difference model (VMODFLOW Pro.) was applied in three consecutive steps; (a) the flow model calibration step in which the estimation of hydraulic conductivity field was conducted and water balances over the aquifer were calculated under steady state conditions, and storage coefficients and the specific yields were calibrated under transient conditions, (b) the model transport calibration step in which the estimation of dispersivity for the movement and fate of nitrate was made, and (c) the simulation step in which the calibrated flow and transport model was applied to test various management scenarios of reducing nitrate concentrations in the aquifer system.

In this chapter, the setting up of the flow and transport models will be discussed in details. The steady and transient states flow calibration steps and results will be discussed in the next sections in this chapter providing the calibrated parameters. Also, calibration under transient conditions is reported.

Figure 4.1 is a flow chart of the modeling process in general as applied to the southern part of Gaza coastal aquifer system.

4.2 Modeling Code and Principles

The VMODFLOW Pro. Computer code was applied for simulation of three dimensional coupled flows and transport of nitrate in Gaza coastal aquifer. It is a numerical engine based on finite difference grid. The flow processes and the transport process require specific information about the finite-difference grid such as column widths, row heights, and the top and bottom of each layer or layer thicknesses.

The full version of VMODFLOW Pro is an integrated package combines MODFLOW, MODPATH, Zone Budget, MT3D/RT3D, and WinPEST with a powerful available graphical interface. The linkage used MODFLOW-2000 v.4.2 (Harbaugh and McDonald, 1996) and MT3DMS (Zheng and Wang, 1999).

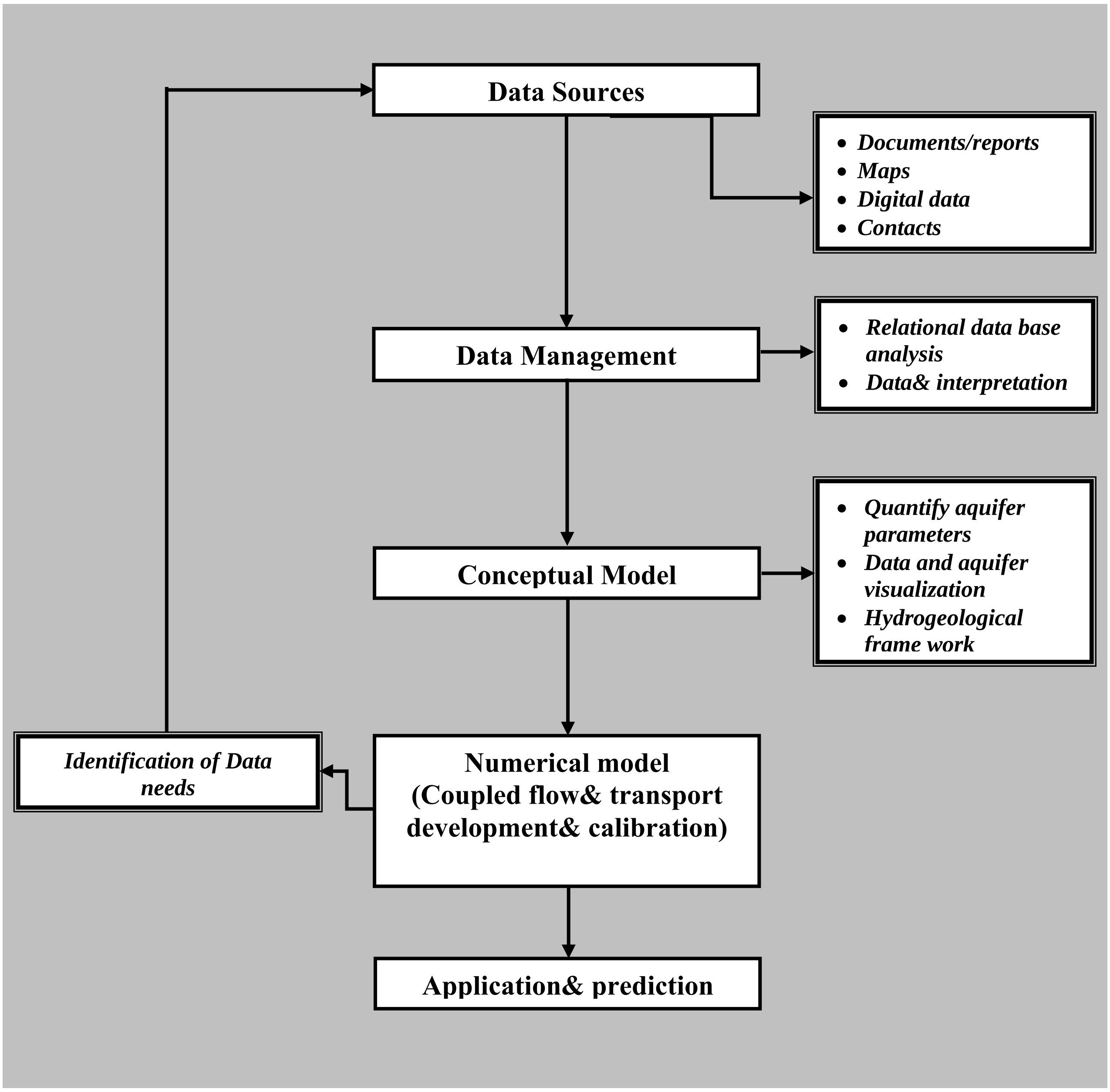


Figure 4.1:Chart of the modeling process

4.2.1 MODFLOW

MODFLOW is a fully distributed model that calculates ground water flow from aquifer characteristics, the model was developed by USGS. It solves the three-dimensional ground water flow equation using finite-difference approximations. The finite-difference procedure requires that the aquifer be divided into cells, where the aquifer properties are assumed to be uniform. The unknown head in each cell is calculated at a point or node at the center of the cell. MODFLOW is designed to simulate aquifer systems in which saturated-flow conditions exist, Darcy's Law is applied, the density of ground water is constant, and the principal directions of horizontal hydraulic conductivity do not vary within the system.

4.2.2 MODPATH

MODPATH is an extension of MODFLOW to calculate flow paths and travel times of water particles. The model was also developed by USGS. Simulation results obtained with MODFLOW are used as input to MODPATH. The streamlines and travel times of water particles can be calculated starting from the groundwater flow velocities using Darcy's law (De Smedt, 2003).

4.2.3 MT3DMS

MT3DMS is a three-dimensional groundwater contaminant and solute transport model that can simulate advection, dispersion, mass transfer, and chemical reactions of dissolved constituents in ground water. MT3DMS uses the output head and cell-by-cell flow data computed by MODFLOW to establish the ground water flow field.

4.3 Data Management

To develop the flow and transport models, all available data collected for Gaza costal aquifer -especially southern part of it- should be added to the modeling data base. This applies to historical and future new data. Specific data items that needed to enter into modeling data base are:

1. Geological maps and cross sections showing the vertical and horizontal extend and the boundaries of the aquifer.
2. Topographic maps depicting the ground surface elevations, the bases and the thickness of the aquifer, and surface water bodies.
3. Water level measurements for the selected years of study.
4. Historical rainfall data from all rainfall gauges.
5. Spatial and temporal distribution of groundwater recharge including rainfall data and return flow estimates.
6. Collection of wells properties within the model domain of the study area enclosing the numbers of different types of wells.
7. Collection of water quality data (nitrate data) and land use maps.
8. Available data outside the Gaza Strip, for the area within the model domain, especially the data related to the groundwater quality.

The collected data was obtained from many local sources in different formats. The main source was the Palestinian Water Authority (PWA) and the ministry of agriculture (MOA). The data are presented below in more details to give an understanding of the level of accuracy that the model based on. In addition to the next listed data, an extensive literature review of almost conducted studies was read, as well as online published papers and related researches. Many reports and drawings were revised before the development of the model. Much of the available data required checking and modifications, and even assumption of large number of missing data especially related to wells construction, abstractions and water quality data in the transport model.

4.3.1 The Aquifer Hydrogeology

Many geological cross-sections were drawn by Israelis in 1979 especially for the Gaza Strip area. They contained longitudinal and transverse sections of the coastal aquifer starting at Rafah (Strip 81) and ending at (Strip 101) north of Gaza Strip as shown in figure 4.2 and figure 4.3 (Sorek, et al., 1997). Initial values of hydraulic conductivity and storage coefficients were taken based on pumping tests carried out through the CAMP project (Metcalf and Eddy, 2000).

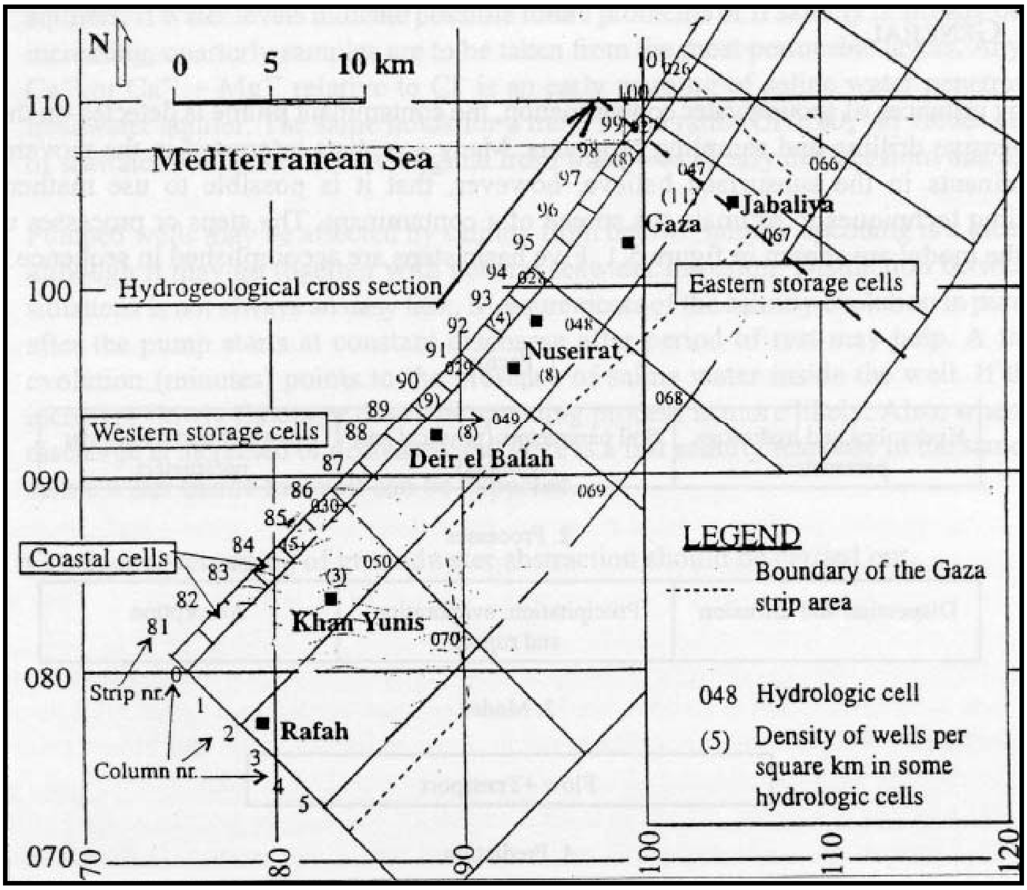


Figure 4.2: Gaza Strip with geological cross-sections drawn by Israelis in 1979, (Sorek, et al., 1997)

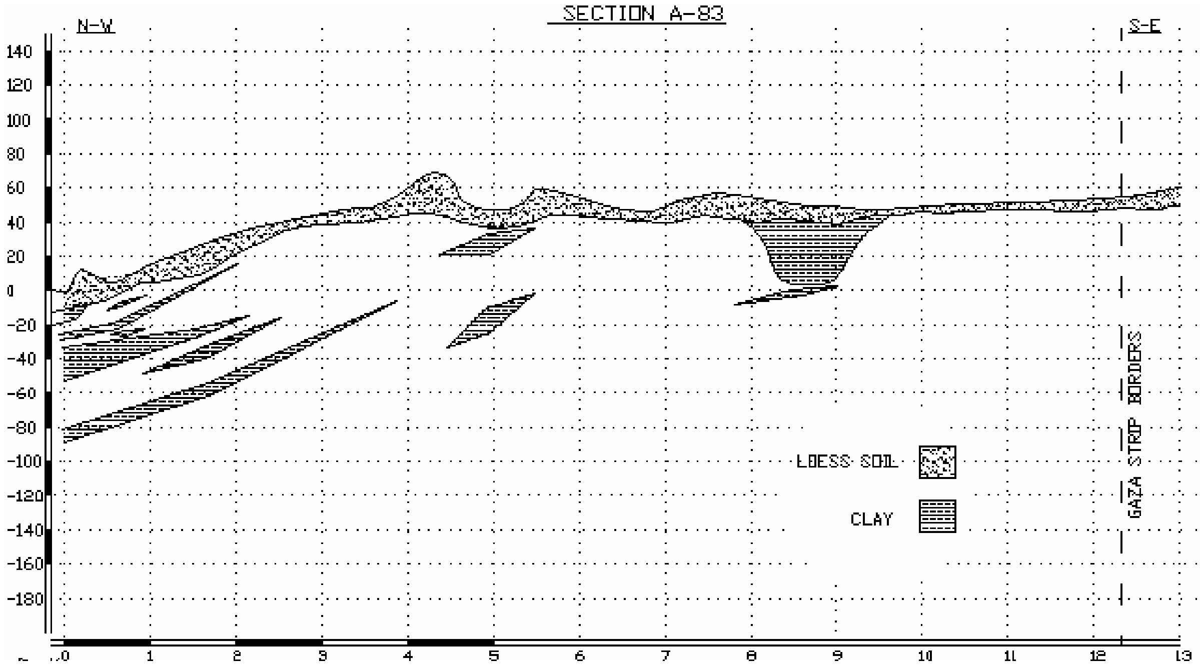


Figure 4.3: Geological cross-section sample, along strip 83, (Sorek, et al., 1997).

4.3.2 Water Quality Data

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

4.3.3 Water Level Data

Excel sheets from PWA including the monthly recordings of water levels for about 30 observation wells were available. However, most observation wells details were missing or incomplete. This leads to more assumption depending on the interpolation, or exclude the well with large lack of data.

4.4 Conceptual Model

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.

4.5 Model Construction

Ideally and when model domains are determined no flow boundaries are searched. Therefore to determine the boundaries of the model domain, groundwater levels contour map for the year 2004 for the entire Gaza Strip is prepared as seen below in figure 4.4.

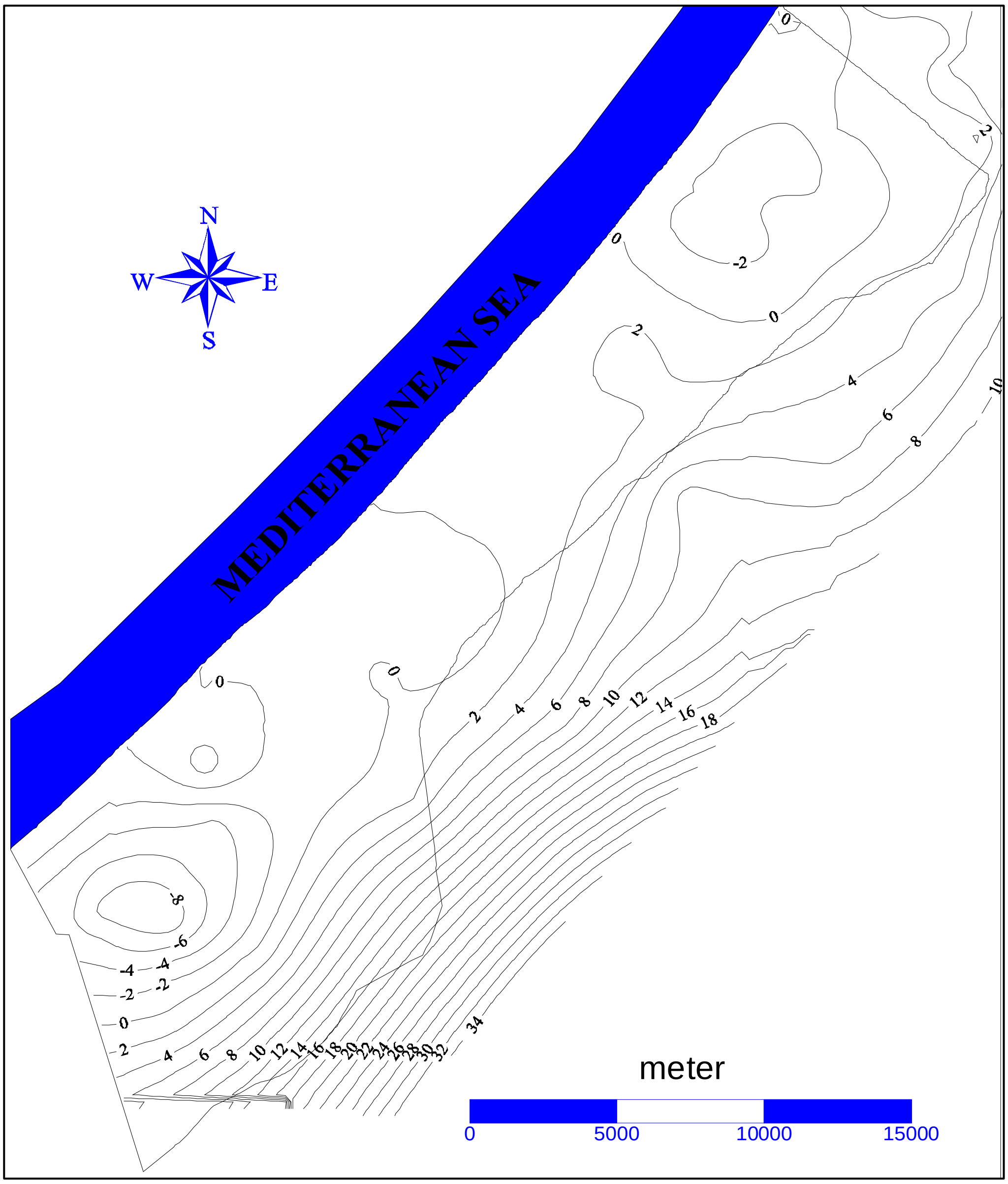


Figure 4.4: Groundwater levels of the coastal aquifer in Gaza Strip from the mean sea level for the year 2004, (PWA)

Based on the groundwater level contour map the model domain was selected as shown in figure 4.5. Regarding the eastern boundary it is selected to be far enough from the eastern boundary of Gaza area (green line) where the aquifer thickness is negligible. The model domain is about 17.8 km by 20.6 km. It consists of a finite difference mesh of 103 rows and 87 columns, discretized horizontally to cells of 200 m x 200 m as shown in figure 4.2 and vertically to nine layers consistent in with the stratification of the Gaza coastal aquifer system hydrogeology as shown in figure 4.3. A vertical cross section depicting the vertical discretization of the flow domain is shown in figure 4.4. It shows that the nine layers are actually four sub-aquifers belonging to Kurkar group and three aquitards representing the three clay layers in between.

The boundary conditions imposed on the developed three dimensional numerical groundwater flow model are defined as constant head boundary along the Mediterranean Sea, and no flow boundary in the north, east and south.

The north and south boundaries are defined as no flow boundaries based on the groundwater level contour maps where groundwater flow is perpendicular to the sea shore line. For the eastern boundary and since the aquifer thickness is negligible (0-10 meters), the boundary is assumed as no flow boundary.

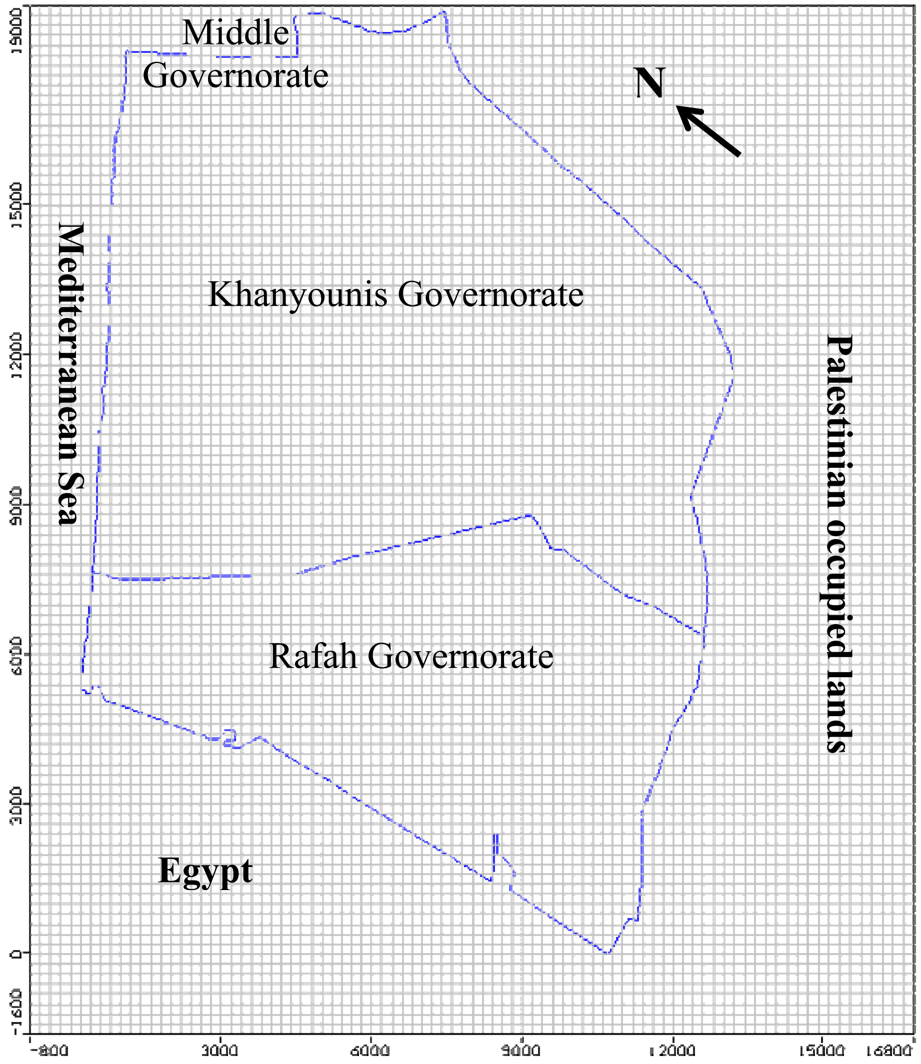


Figure 4.5: The model domain with the grid origin, orientation and boundaries.

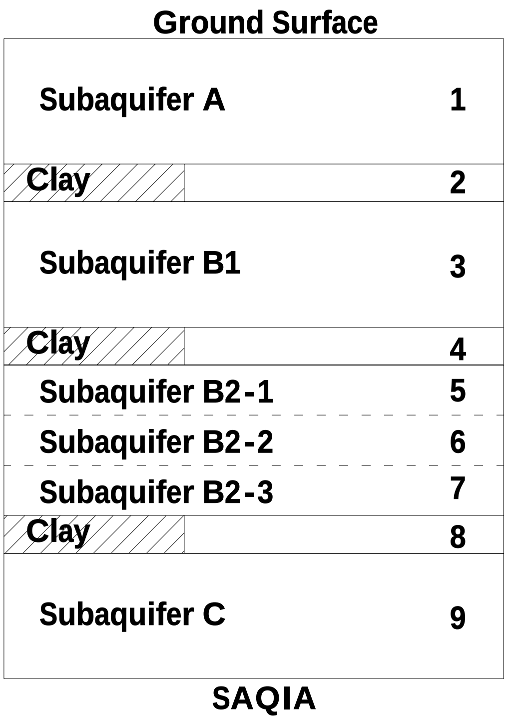


Figure 4.6: A vertical representation of the discretization of the model. Clay layers do not extend the full length of layer to signify their limited pinch out inland.

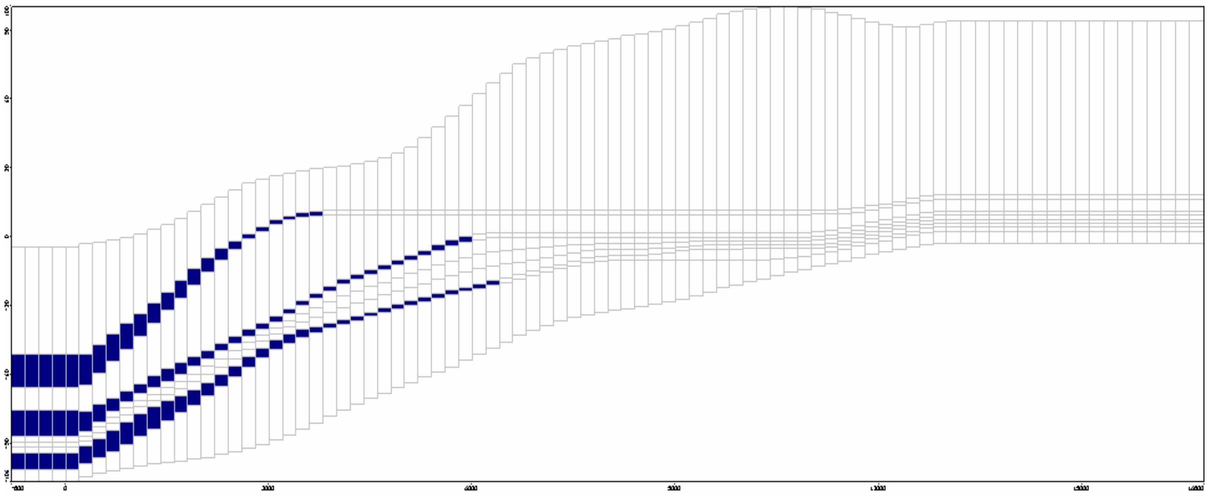


Figure 4.7: Vertical cross section through model, (row 22)

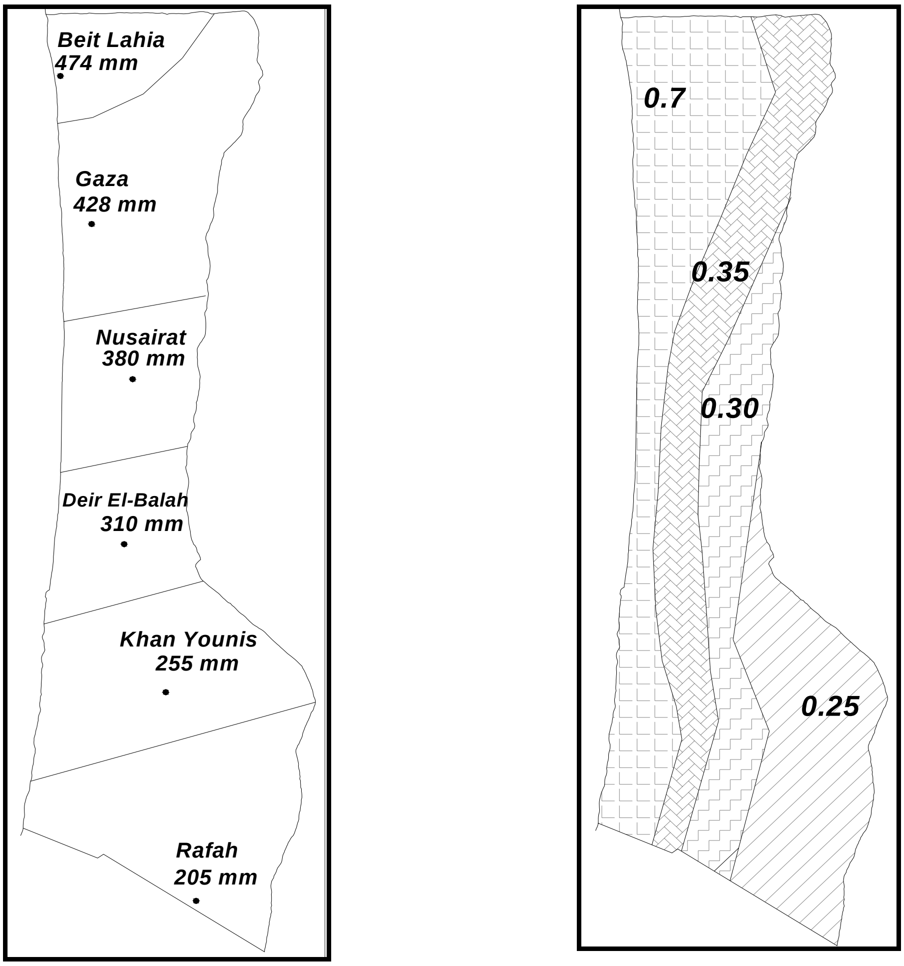
4.6 Internal Hydrologic Stresses

4.6.1 Recharge from Precipitation

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 reminder is lost to evapotranspiration and runoff (Metcalf and Eddy, 2000).

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. The total area of Gaza Strip was divided into six representative sub-areas as shown in figure 4.8(a) in accordance with available readings of rainfall stations located in that area. Those readings were taken from the year of steady state study in 2000. 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 (Metcalf and Eddy, 2000). Those coefficients are presented in figure 4.8(b). The highest recharge coefficient value is 0.7; it is in sand dunes area parallel to the shore.



(a) (b)

Figure 4.8: (a) Distribution of rainfall stations and zones, (b) Recharge coefficients (Jaber, 2008)

4.6.2 Pumping Wells

In 2004, according to the Palestinian Water Authority (PWA), there are around 47 municipal wells within the southern part of Gaza Strip. The estimated municipal abstraction totals about 18.4 MCM/yr. Agricultural wells have not been metered since 1994. In 2000, MoA reported a total average annual abstraction for the 1293 legal and illegal agricultural wells in Khanyounis and Rafah governorates –southern part of Gaza Strip- was approximately 30 MCM/yr.

The collected data contained partial data set of all known wells in the period between 2000 and 2008, including wells location, coordinates, screens depths, abstractions and water quality parameters. Limited information of well construction and pumping readings are available for illegal wells, they are known mostly from a survey conducted lately by PWA. There are suspected to be additional existing illegal wells after the year 2000, expecting to have no data even the location. A summary of an approximate number and total abstraction of wells in the model domain is presented in table 4.1 and they are located in the model as shown in figure 4.7.

Table 4.1: Summary of pumping wells according to their type within the model domain in year 2004

Well classification	**Number of wells**	**Total Abstraction** (MCM) **Year 2004**
Agricultural (legal and illegal)	1293	30
Municipal	47	18.4
Total	**1340**	**48.4**

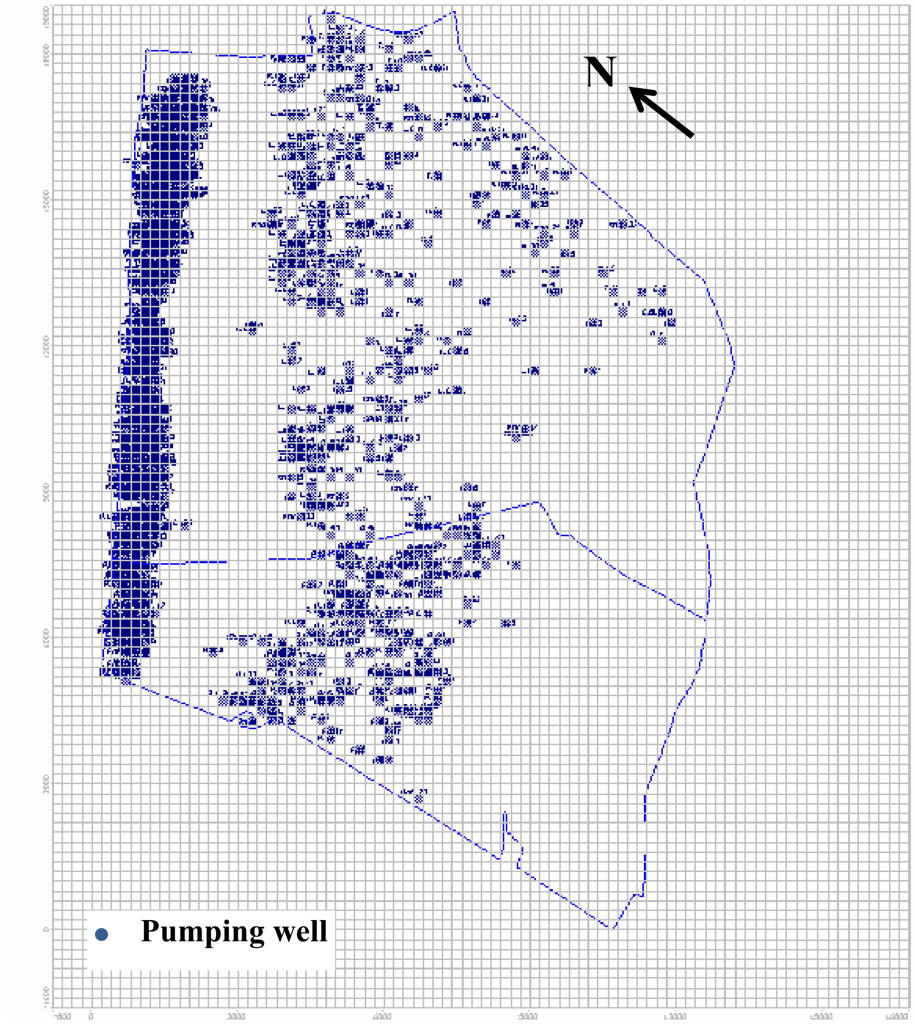


Figure 4.9: Wells distribution in southern Gaza Strip within model domain in year 2004 (Pumping wells)

4.6.3 Return Flows

There are three primary sources of return flow in the Gaza Strip: leakage from municipal water distribution system, wastewater return flows and irrigation return flow.

According to the Palestinian Water authority, the leakage from municipal water distribution system was estimated from 10%-50% of the total abstraction. This is related with the network system efficiency in each municipality. For example the total losses from municipal water in Rafah approximately equals 11% where equals 49% in Khanyounis city.

The only wastewater treatment plant (WWTP) operating in the southern part of Gaza Strip is Rafah Waste Water Treatment Plant. Wastewater returns flows Rafah WWTP has been estimated to about 25%. While the wastewater recharge from unsewered areas where septic system exists is significant, especially in Khanyounis city. The total quantity of recharge from this wastewater was inserted in the model in the corresponding areas.

Irrigation return flow has been estimated to be about 25 % of the total agricultural abstraction (Metcalf and Eddy, 2000).

4.7 Water Balance

According to the inflow and outflow components in the model domain a water balance for the year 2004 is estimated as shown in the Table 4.2 below. From the table it is obvious that there is water deficit in the water balance as 19.15 MCM. This deficit is reflected as lowering in the water table and inland seawater encroachment.

Table 4.2: Water balance for the southern part of Gaza Strip for the year 2004

INFLOW (2004)	*VALUES* (MCM)	*OUTFLOW* (2004)	*VALUES* (MCM)
Rainfall recharge	**12.35**	***Agricultural abstraction***	**30**
Water supply leakage	**2**	***Municipal abstraction***	**18.4**
Wastewater leakage	**3.4**	***Discharge to Sea***	**1.5**
Agricultural return	**7.5**		
Lateral flow from east	**3**		
Lateral flow from Egypt	**2.5**		
Total	**30.75**		**49.9**
Deficit	**19.15**		

4.8 Initial Conditions

The initial heads or concentrations are set at the beginning time of the simulation. Here, within the model of southern Gaza Strip, the initial water level was the water level map of year 2004 as surfer map was set to the model.

4.9 Model Calibration

Model calibration consists of successive refinement of model input parameters from the initial estimates to improve the fit between observed and model-predicted results. The purpose of calibration is to tune up successively aquifer parameters so that the model produces groundwater levels that match field observations (e. g., observed heads at observation wells, flow behavior, and head changes). All calibration steps in this model was done annually by trial and error.

The numerical model was calibrated and tested against both steady state and transient state. Three sets of target conditions were selected for calibration purposes, steady state conditions in year 1935, quisi-steady state conditions in year 2004 and time varying conditions within 2005-2008.

4.9.1 Steady State Calibration

Calibrated groundwater levels for year 1935 conditions are shown in figure 4.10. Average water levels of year 1935 for 7 wells within the model domain were used as calibration targets. The calculated residual mean error and absolute mean error are about -1.042 (m) and 1.845 (m), respectively, with a correlation coefficient for the model domain of 0.925. In general, the residual values range from -3.003 m to 0.42 m, as shown in figure 4.11.

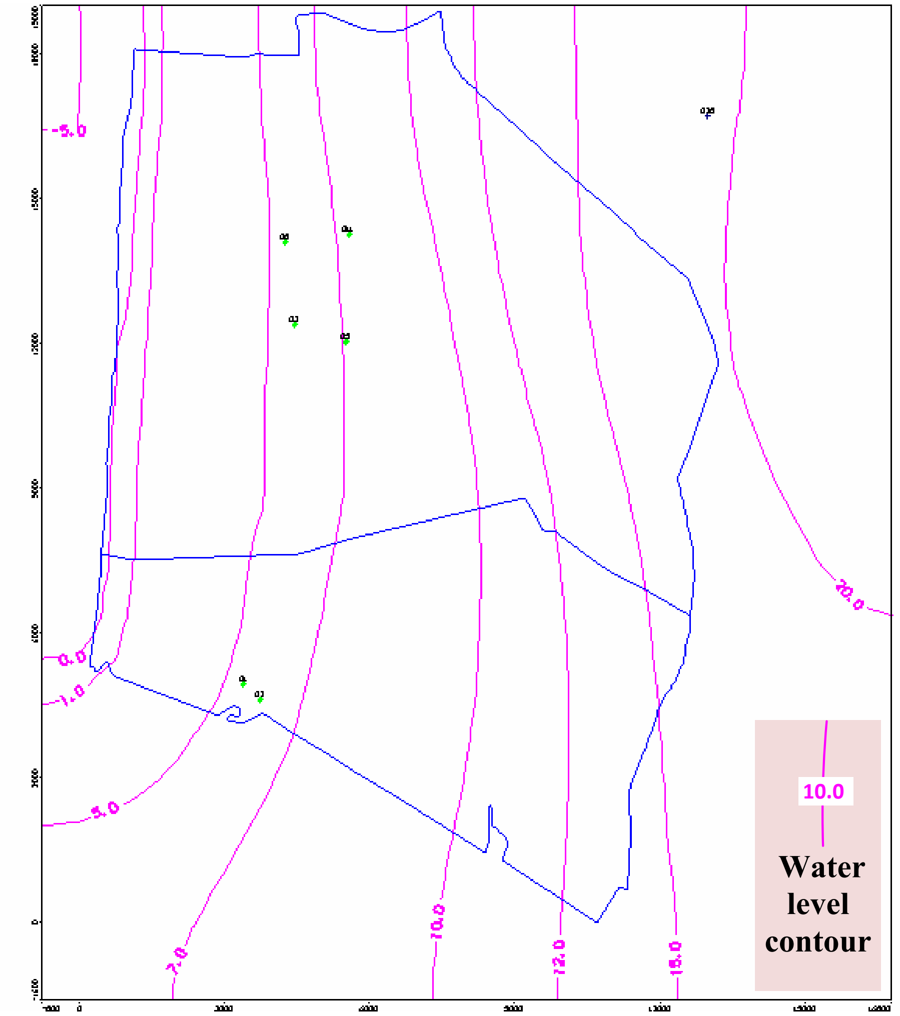
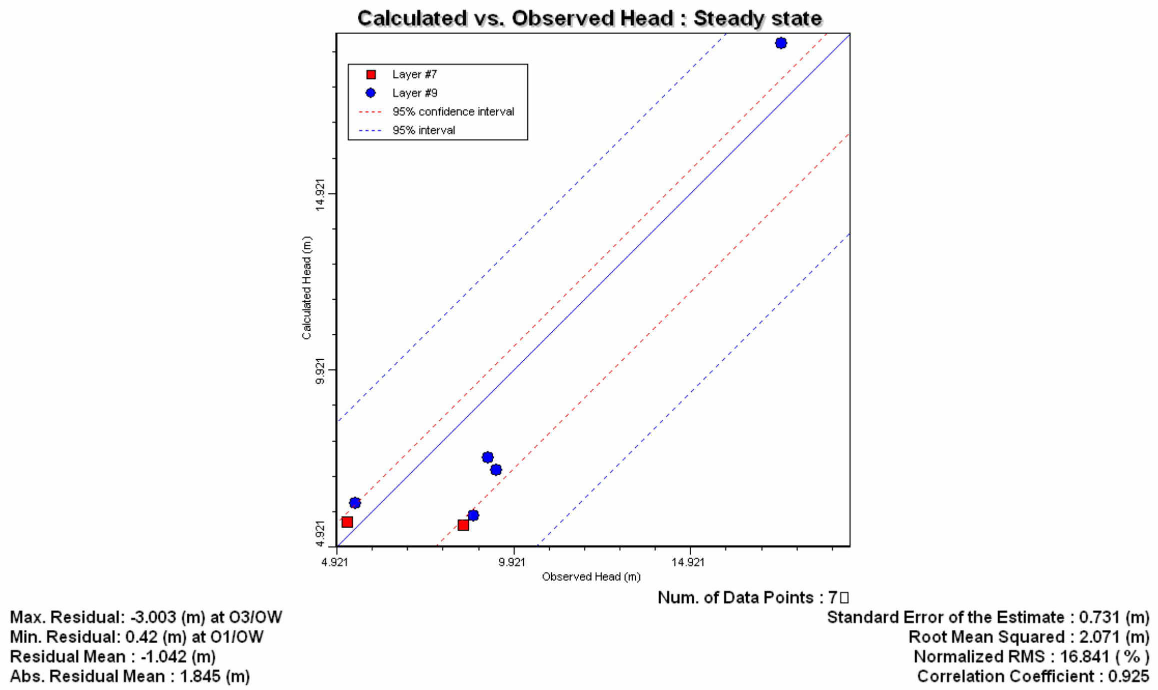


Figure 4.10: Simulated groundwater table for year 1935-calculated by VMODFLOW



Num. of Data Points : 7□

Max. Residual: -3.003 (m) at O3/OW
Min. Residual: 0.42 (m) at O1/OW
Residual Mean : -1.042 (m)
Abs. Residual Mean : 1.845 (m)

Standard Error of the Estimate : 0.731 (m)
Root Mean Squared : 2.071 (m)
Normalized RMS : 16.841 (%)
Correlation Coefficient : 0.925

Figure 4.11: Calibrated versus measured groundwater levels at the end of year 1935

Also the steady state model was simulated for the year 2004. This year was selected because it represents a year when rainfall records were close to the long-term average. Rainfall readings after year 1998 shows clearly that year 2004 precipitation depth on southern Gaza Strip reached long term average rainfall, which as a result has produced an appreciable recharge and groundwater recovery to the coastal aquifer system. Though it is not truly steady-state, the quisi-steady state conditions could be assumed as a result of the high recovery of groundwater in this year.

4.9.1.1 Calibrated Mass Balance

Table 4.3 summarizes the mass balance calculated by the model for steady state taking into consideration that 25% is deducted from the total agricultural abstraction to represent the return flow which comes from irrigation. This means that the amount assigned for the wells item in the table represent the net abstraction after deducting the return flow from the total abstraction. This was done to simplify the modification of recharge zones assigned for the model and also it decreases uncertainty coming from assigning the location of return flow from irrigation which is not known very well. The steady-state water balance for year 1935 shows that a large quantity of groundwater is discharged to the sea (about 18 Mm^3/yr) which is enough to counteract seawater intrusion. In year 2004, the seawater intrusion quantity reaches about 14 Mm^3/yr.

Table 4.3: Summary of the Calibrated water fluxes for Gaza part and entire model domain- steady state (1935 and 2004)

In/Out	***1935***		***2004***		**Remarks**
	All Domain	**Gaza part**	**All Domain**	**Gaza part**	
Constant head	**-18.79**	**-18.00**	**14.42**	**13.50**	***To or from the sea***
Recharge	**28.09**	**18.50**	**25.7**	**14.80**	***Including all leakage components***
Lateral Flow	**0.00**	**8.80**	**0.00**	**11.83**	
Wells	**-9.30**	**-9.30**	**-40.12**	**-40.12**	***Return flow was deducted***
Total	**0.00**	**0.00**	**0.00**	**0.00**	

The calibrated water fluxes shown in the table 4.3 were compared with the calculated data shown in section 4.6. This is for year 2004, while the calibrated water fluxes for year 1935 were compared with (Qahman, 2000) calculated mass balance of Gaza Strip.

4.9.1.2 Calibrated Parameters

The field measurements of groundwater levels in 2004 were taken as targets of steady-state calibration. Observed heads of about 30 observation wells shown in figure 4.12 were used as target points for steady state calibration. The model steady-state calibration was also checked for the transient situation extending from 2005 through 2008.

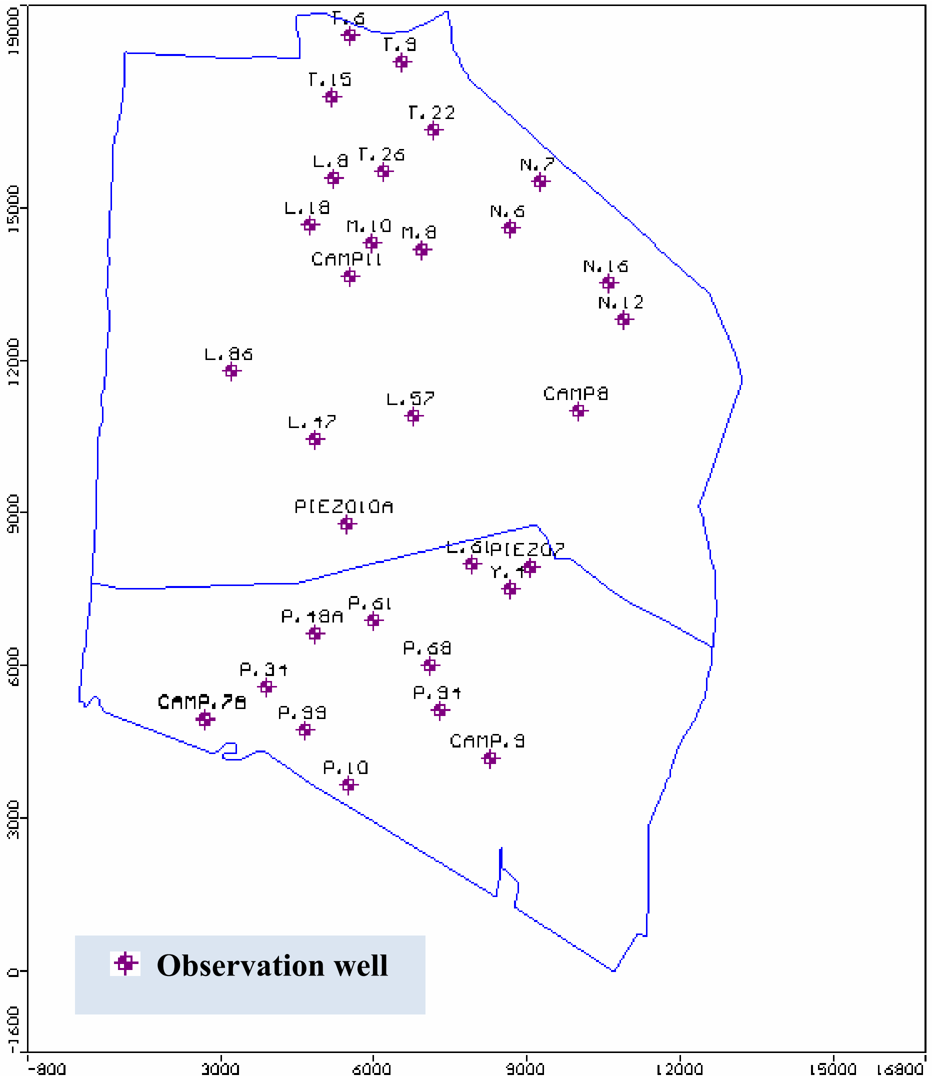


Figure 4.12: Distribution of head observation wells within the model area

The model was run a number of times for various values of hydraulic conductivity distributed over the domain. Those values were varied according to the stratification in the conceptual model above, the results of pumping well tests mentioned in the literature, and the calculated values in the previous studies. The horizontal hydraulic conductivity was adjusted during many sequential model runs until accepted match between the observed and calculated heads were obtained. Best fit of simulated water table including the heads for the 30 observation wells is shown in figure 4.13.

Table 4.4 summarizes the results and statistics of steady state calibration for many selected hydraulic conductivities within the range values indicated in the literature, the result show no significant changes of convergence between observed and simulated heads.

The calibrated hydraulic conductivity in sandstone layers(subaquifers) was found to be 22 m/d in all areas, while it was 0.02 m/d for the three aquitards (clay layers). The vertical hydraulic conductivity was 10% of the corresponding horizontal values. The calculated versus observed heads and the summary of steady state calibration statistics for year 2004 are graphed in figure 4.14. The calculated residual mean error and absolute mean error were about-0.002 and 0.328m, respectively, with a correlation coefficient of 0.939.

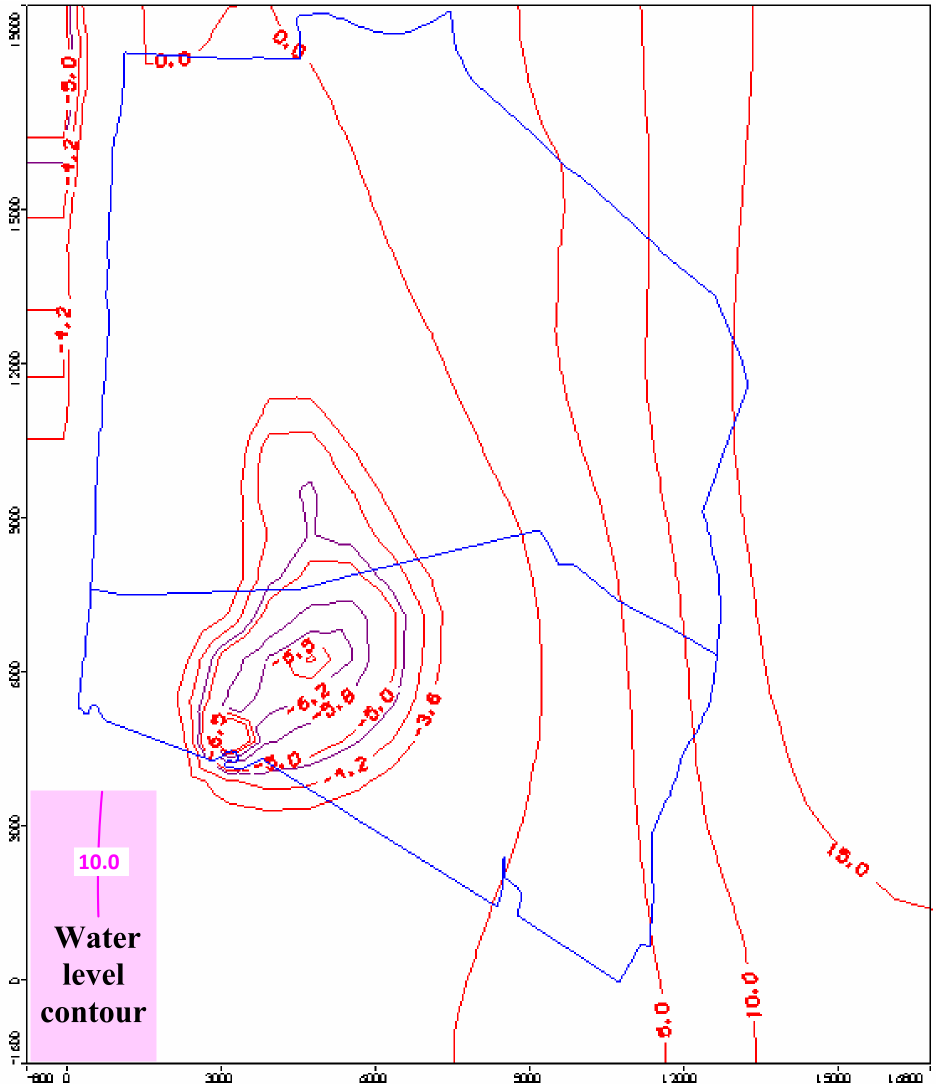
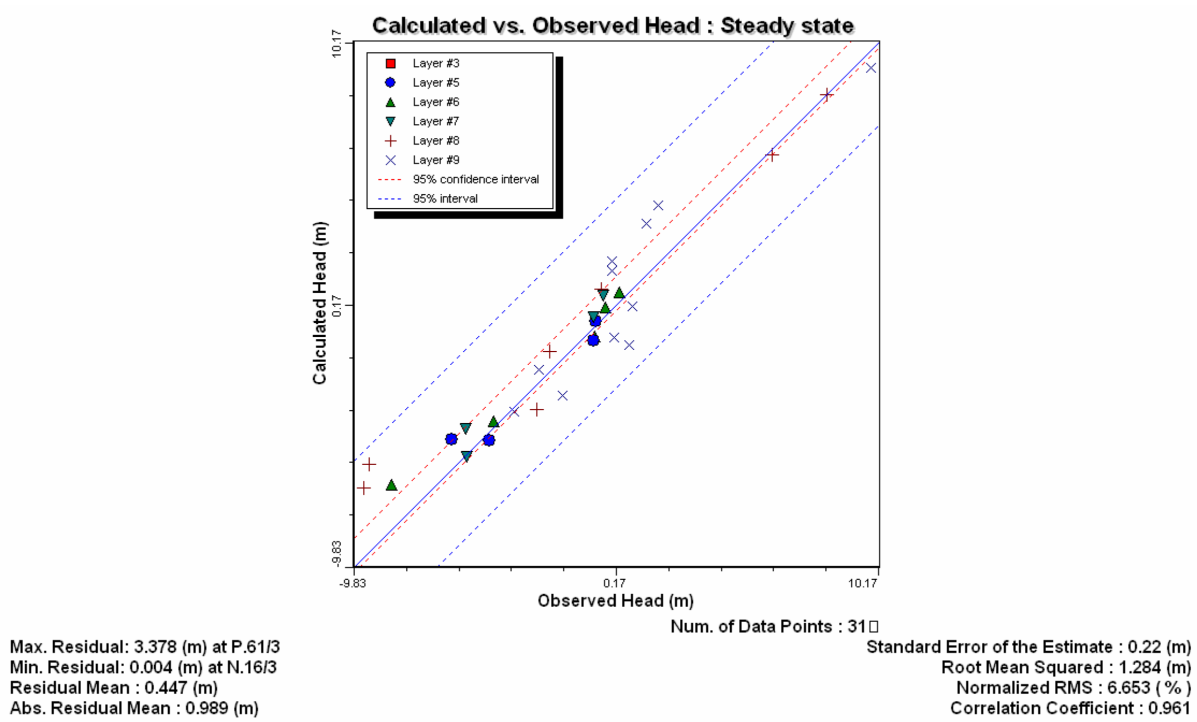


Figure 4.13: Simulated water table for year 2004-calculated by VMODFLOW

Table4.4: Summary of the results and statistics of steady state calibration in 2004 based on the different values of hydraulic conductivity

Parameter/Trial	1	2	3	4	5	6
K (sandstone), (m/d)	20	22	30	35	40	50
K (clay) (m/d)	0.2	0.2	0.2	0.2	0.2	0.2
Max. residual(m)	2.83	3.378	4.832	5.352	5.716	6.456
Min. residual (m)	0.113	0.004	-0.061	-0.001	0.039	0.111
Residual mean (m)	0.424	0.447	0.643	0.71	0.778	0.932
Absolute residual mean (m)	1.12	0.989	1.383	1.571	1.717	1.978
Standard error of the estimate (m)	0.254	0.22	0.307	0.36	0.401	0.468
Root mean squared (m)	1.34	1.284	1.798	2.094	2.331	2.728
Correlation coefficient	0.959	0.961	0.957	0.955	0.954	0.951



Num. of Data Points : 31

Max. Residual: 3.378 (m) at P.61/3
Min. Residual: 0.004 (m) at N.16/3
Residual Mean : 0.447 (m)
Abs. Residual Mean : 0.989 (m)

Standard Error of the Estimate : 0.22 (m)
Root Mean Squared : 1.284 (m)
Normalized RMS : 6.653 (%)
Correlation Coefficient : 0.961

Figure 4.14: Calculated vs. observed heads and summary of steady state calibration statistics (year 2004)

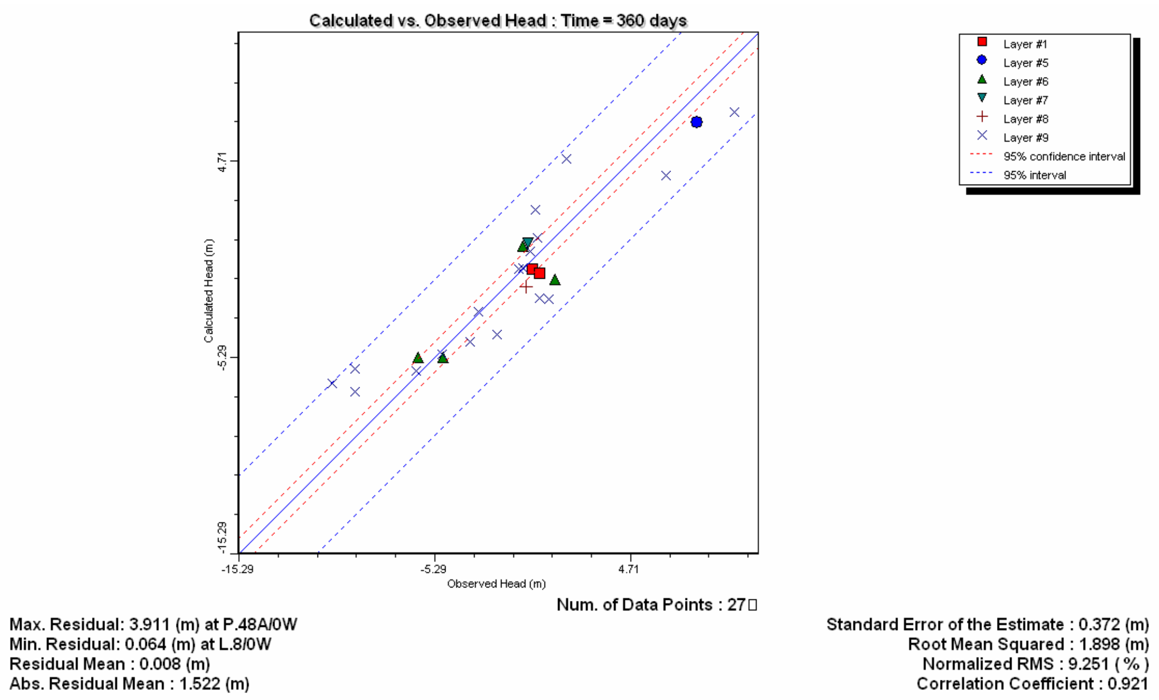
4.9.2 Transient Calibration

The simulation period was conducted over 4 years, starting in 2005 and ending in 2008 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 2005 to 2008. The agricultural abstraction data could be used without any modifications. Moreover, the real data of municipal wells were available, they included measured monthly abstractions for all municipal wells for the entire simulation period. Also, yearly precipitation and recharge data were available and distributed. The initial conditions or heads of the transient period were taken from the steady-state output of the year 2004 to ensure the setting of calibrated hydraulic parameters. Model parameters were adjusted by trial-and-error to reduce the differences between simulated and measured values. Calibration under transient conditions included adjustment of specific yield. Calibrated values are summarized in Table 4.5. All theses calibrated values are within the range of literature values given for Gaza aquifer.

Calibrated groundwater levels versus measured groundwater levels for the years 2005, 2006, 2007 and 2008 are shown in figure 4.14 through figure 4.17, respectively.

Table 4.5: Summary of the final calibrated parameters- transient calibration for target period (2004-2008).

Parameter		**Sandstone sub-aquifers**	**Clay aquitards**
***Hydraulic conductivity* (m/d)**	K_x	*22*	*0.2*
	K_y	*22*	*0.2*
	K_z	*2.2*	*0.02*
***Specific yield* [Sy]**		*0.2*	*0.1*
***Specific storage* [Ss] (1/m)**		10^{-4}	10^{-4}
***Porosity* [Tot. Por]**		*0.3*	*0.4*
***Effective Porosity* [Eff. Por]**		*0.3*	*0.4*

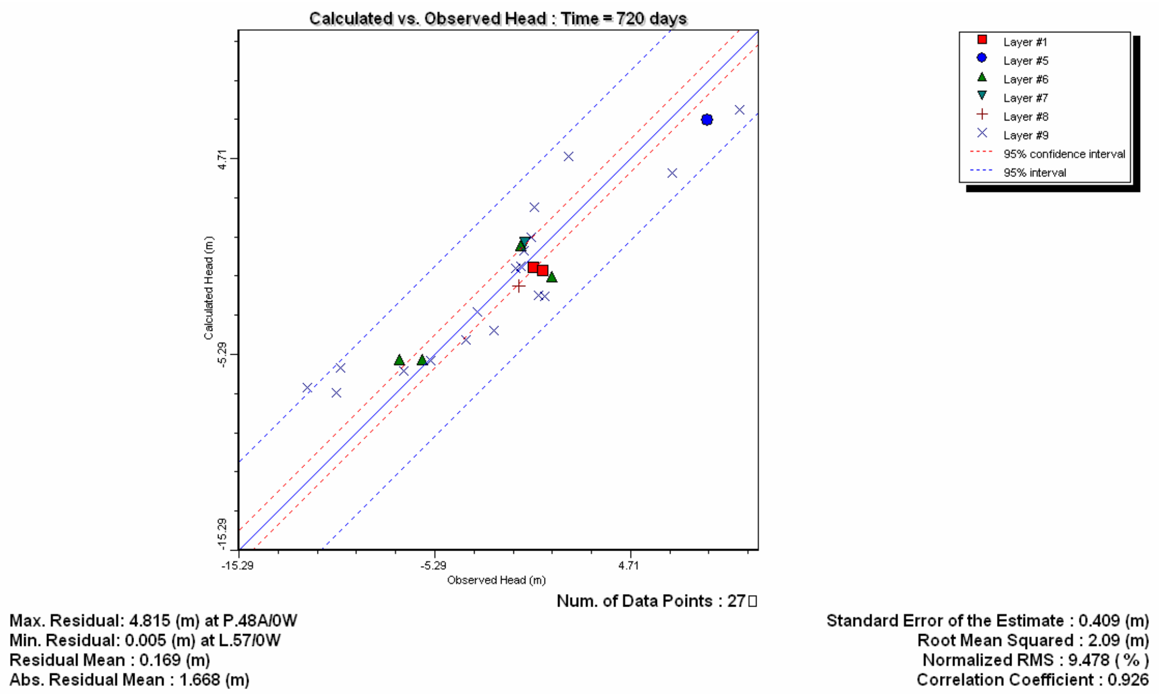


Num. of Data Points : 27□

Max. Residual: 3.911 (m) at P.48A/0W
Min. Residual: 0.064 (m) at L.8/0W
Residual Mean : 0.008 (m)
Abs. Residual Mean : 1.522 (m)

Standard Error of the Estimate : 0.372 (m)
Root Mean Squared : 1.898 (m)
Normalized RMS : 9.251 (%)
Correlation Coefficient : 0.921

Figure 4.15: Calibrated versus measured groundwater levels at the end of year 2005

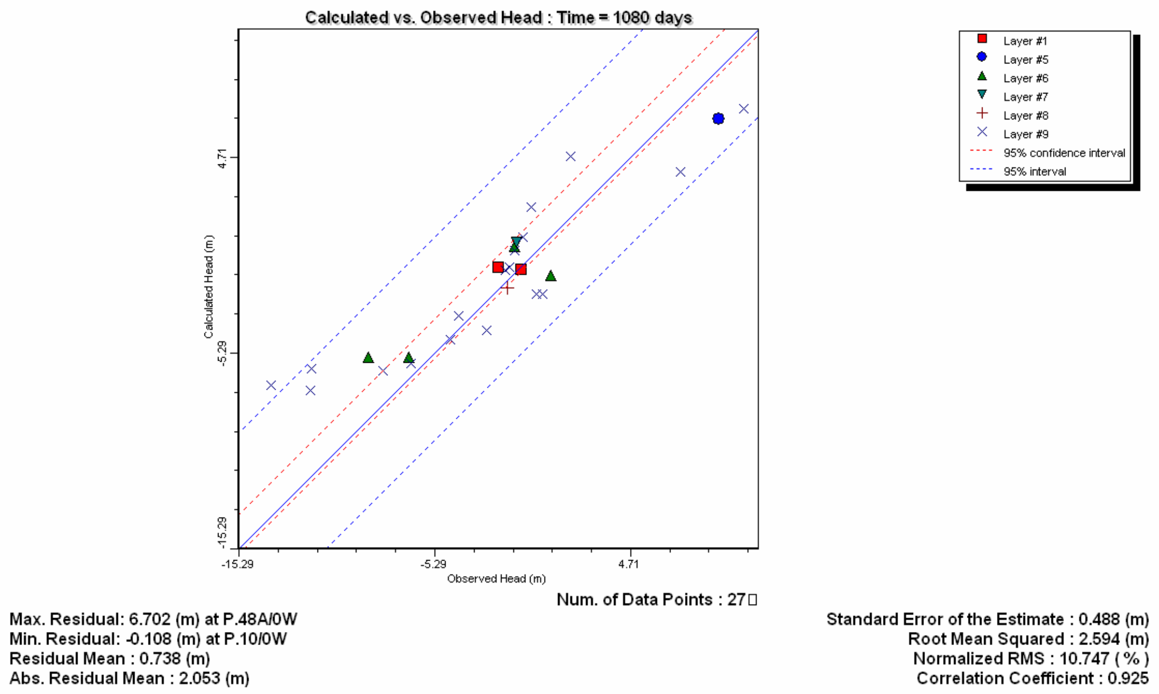


Num. of Data Points : 27□

Max. Residual: 4.815 (m) at P.48A/0W
Min. Residual: 0.005 (m) at L.57/0W
Residual Mean : 0.169 (m)
Abs. Residual Mean : 1.668 (m)

Standard Error of the Estimate : 0.409 (m)
Root Mean Squared : 2.09 (m)
Normalized RMS : 9.478 (%)
Correlation Coefficient : 0.926

Figure 4.16: Calibrated versus measured groundwater levels at the end of year 2006

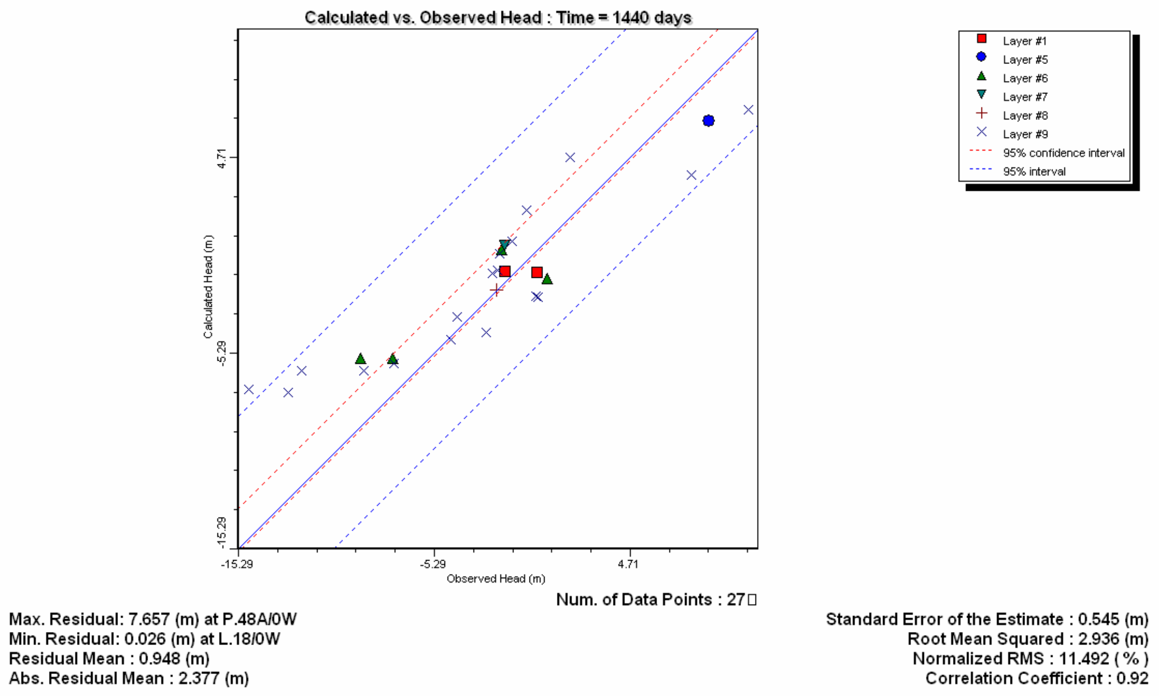


Num. of Data Points : 27□

Max. Residual: 6.702 (m) at P.48A/0W
Min. Residual: -0.108 (m) at P.10/0W
Residual Mean : 0.738 (m)
Abs. Residual Mean : 2.053 (m)

Standard Error of the Estimate : 0.488 (m)
Root Mean Squared : 2.594 (m)
Normalized RMS : 10.747 (%)
Correlation Coefficient : 0.925

Figure 4.17: Calibrated versus measured groundwater levels at the end of year 2007



Num. of Data Points : 27□

Max. Residual: 7.657 (m) at P.48A/0W
Min. Residual: 0.026 (m) at L.18/0W
Residual Mean : 0.948 (m)
Abs. Residual Mean : 2.377 (m)

Standard Error of the Estimate : 0.545 (m)
Root Mean Squared : 2.936 (m)
Normalized RMS : 11.492 (%)
Correlation Coefficient : 0.92

Figure 4.18: Calibrated versus measured groundwater levels at the end of year 2008

Figure 4.19 through figure 4.21 show calculated heads versus time for the selected observation wells (Y4, L.94, L.18, and N.16). From these figures it is very clear that the model can simulate the aquifer system relatively good.

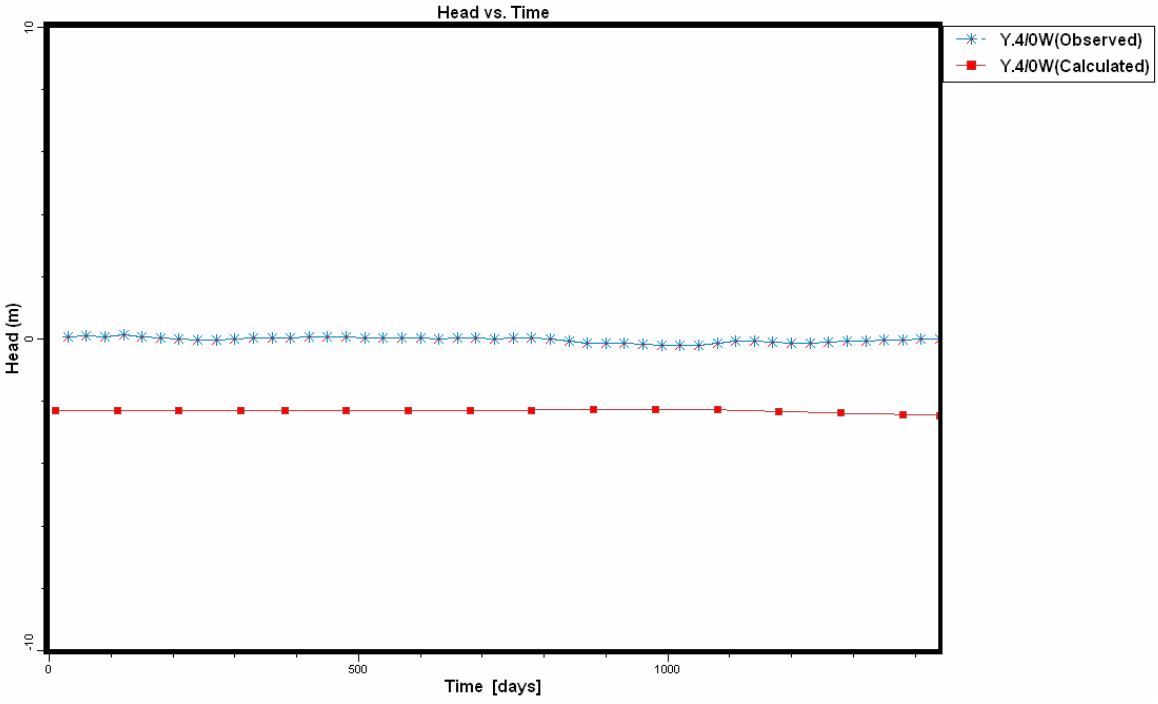


***Figure 4.19**: Observed and calculated heads versus time for well Y4.*

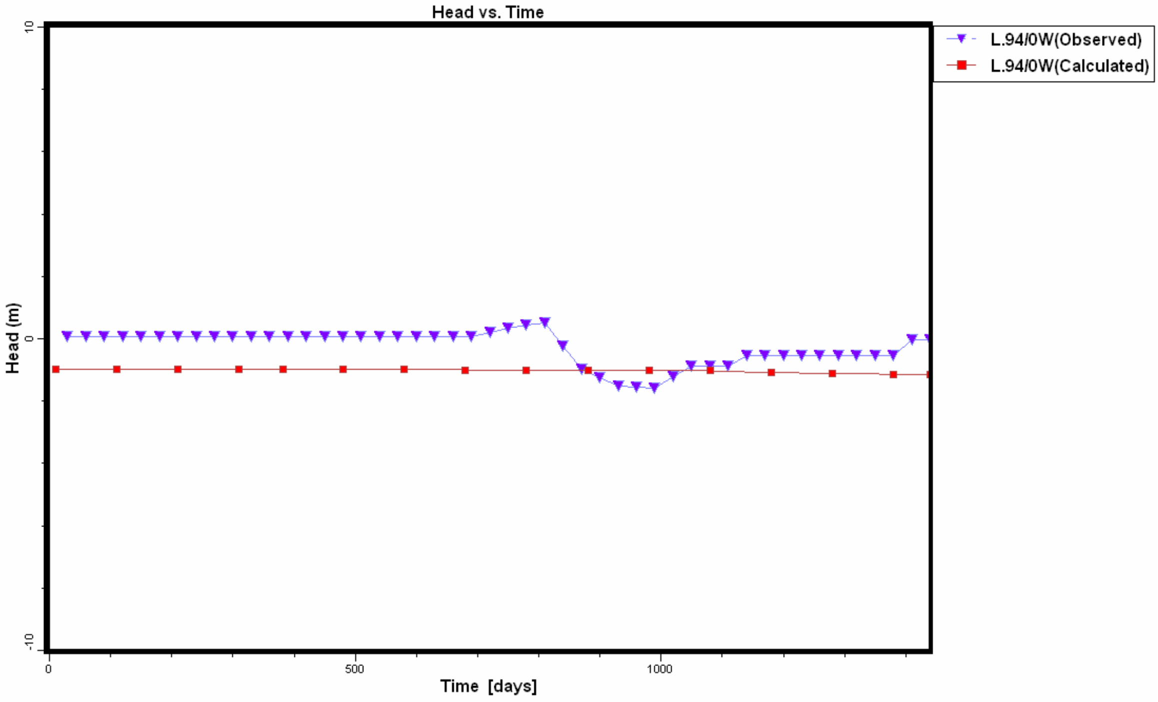


Figure 4.20: Observed and calculated heads versus time for well L.94.

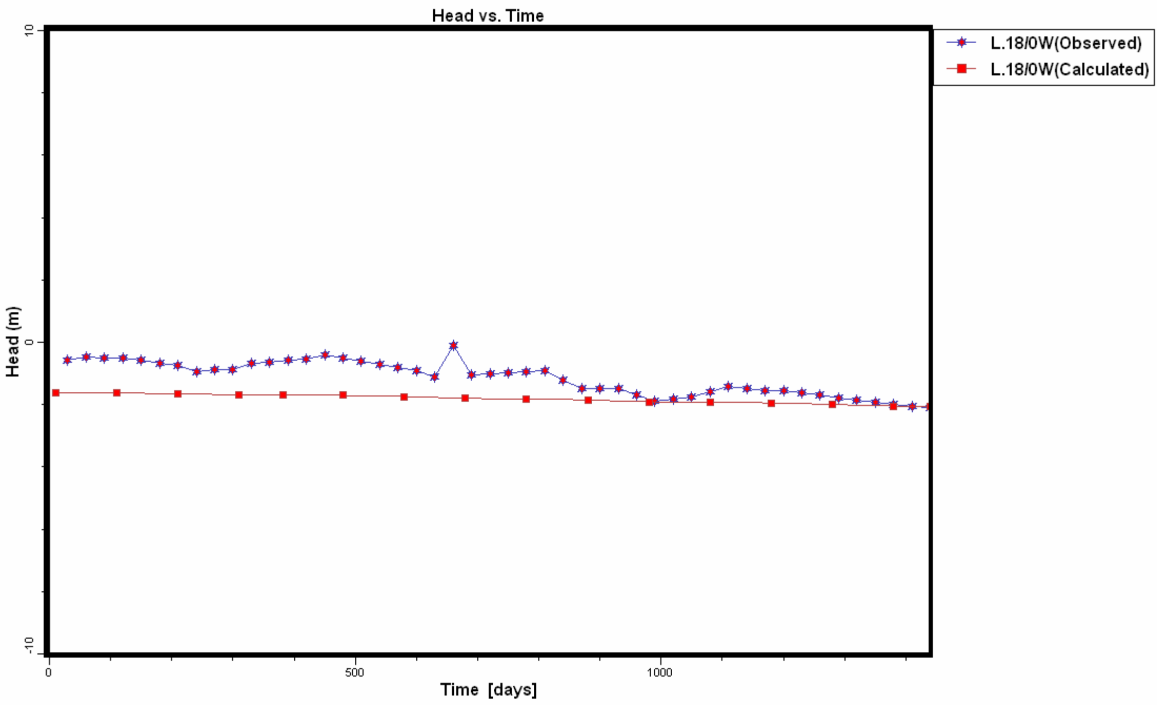


Figure 4.21: Observed and calculated heads versus time for well L.18.

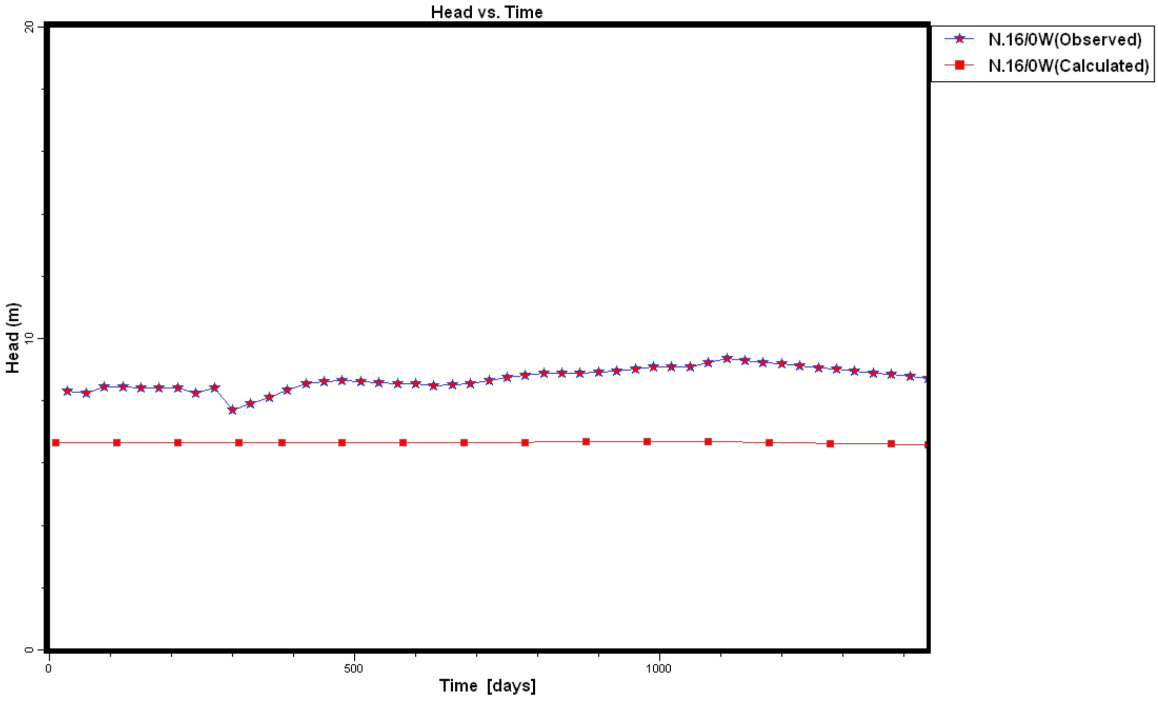


Figure 4.22: Observed and calculated heads versus time for well N.16.

4.10 Comparison of Results Between This Study and Some Related Studies

The flow model was compared with numerous conducted models related to Gaza Strip coastal aquifer. The comparison was summarized in Table 4.6 with respect to many items such as the simulation code, calibration period, and calibrated parameters.

Table 4.6: Comparison between this study and some related studies

Item	This study	Jaber,2008	Metcalf and Eddy, 2000	Qahman and Larabi, 2006	Aish, 2004	Shaheen, 2007	Mushtaha et al., 2007
Simulation Code							
Model	VMODFLOW Pro.	VMODFLOW Pro.	DYNCFT	SEAWAT	MODFLOW	VMODFLOW	MODFLOW
Study area	Southern Gaza Strip	Total Gaza Strip	Total Gaza Strip	Total Gaza Strip	Total Gaza Strip	Rafah area	Northern area of Gaza Strip
Modeling code	Finite difference	Finite difference	Finite element	Finite difference	Finite difference	Finite difference	Finite difference
Cells size (m)	200 x 200	300 x 300	—	400 x 400	250 x 250	200 x 200	200 x 200
No. of Layers	9	9	11	12	7	7	10
Calibration Periods							
Steady state calibration year/s	1935, 2004	2000	1989, 1998	1935	2000	2003	2000
Transient calibration period	2005-2008	2000-2004	1989-1993	1935-1969	—	—	2000-2004
Calibrated Aquifer Parameter Values (sandstone)							
K_h (m/day)	22	40, 30, and 15	30	30	32	30	-
K_v (m/day)	2.2	4, 3, and 1.5	3	3	3.2	3	-
Specific yield	0.2	0.2	0.25	0.2	0.24	0.21	-
Porosity	0.3	0.25	0.35	0.35	0.3	0.35	-
Calibrated Aquifer Parameter Values (three aquitards)							
K_h (m/day)	0.2	0.2	0.2	0.2	0.3	0.2	-
K_v (m/day)	0. 2	0.2	0.2	0.1	0.3	0.02	-
Specific yield	0.1	0.05	0.1	0.1	0.1	0.02	-
Total porosity	0.4	0.35	0.4	0.4	0.45	0.45	-

4.11 Transport Model

The solute transport model describes the process of advection, dispersion-diffusion and chemical reactions. The model set-up was conducted based on the results of the flow model. Transport model was checked for both steady state flow and transient flow conditions. The main transport calibrated parameter was dispersivity.

4.11.1 Assumptions for the Transport Model

- All the calibrated physical and hydro-geological parameters of the aquifer were kept the same as in the baseline model in the previous (flow model).
- The same nitrate load was kept during all simulation transport periods (as calculated in Appendix A). Therefore, it was expected to see increasing of nitrate concentration year after year in all areas where the nitrate load exists. Actually, this is not the situation in Gaza because the previous studies showed that there were three trend types of groundwater quality ranging from decreasing (2%), constant (67%) to increasing (31%) of observation points in the period between 1980 and 2002, (Al Mahallawi, 2005).
- Zero nitrate concentration of the lateral inflow from the eastern borders of southern Gaza Strip as explained before. Of course, the groundwater flowing from east and entering the system contains nitrate, but we assumed low concentration so it can be neglected.
- Natural precipitation & atmospheric deposition were ignored.
- Transformation of nitrogen forms in the unsaturated zone above water table is not considered in details in this research, because there is a wide variability in the conditions that control the mechanisms of each process, i.e. nitrification, denitrification…..etc. Accurate determination of the contribution of each process in the mass of nitrate reaching the water table is very difficult and many parameters are needed, which are not available in Gaza due to the lack of data specially laboratory measurements.
- Initial concentrations of the transport model under transient state groundwater flow conditions (2005-2008) were set as the observed concentrations of nitrate in the model area at the end of year 2004.

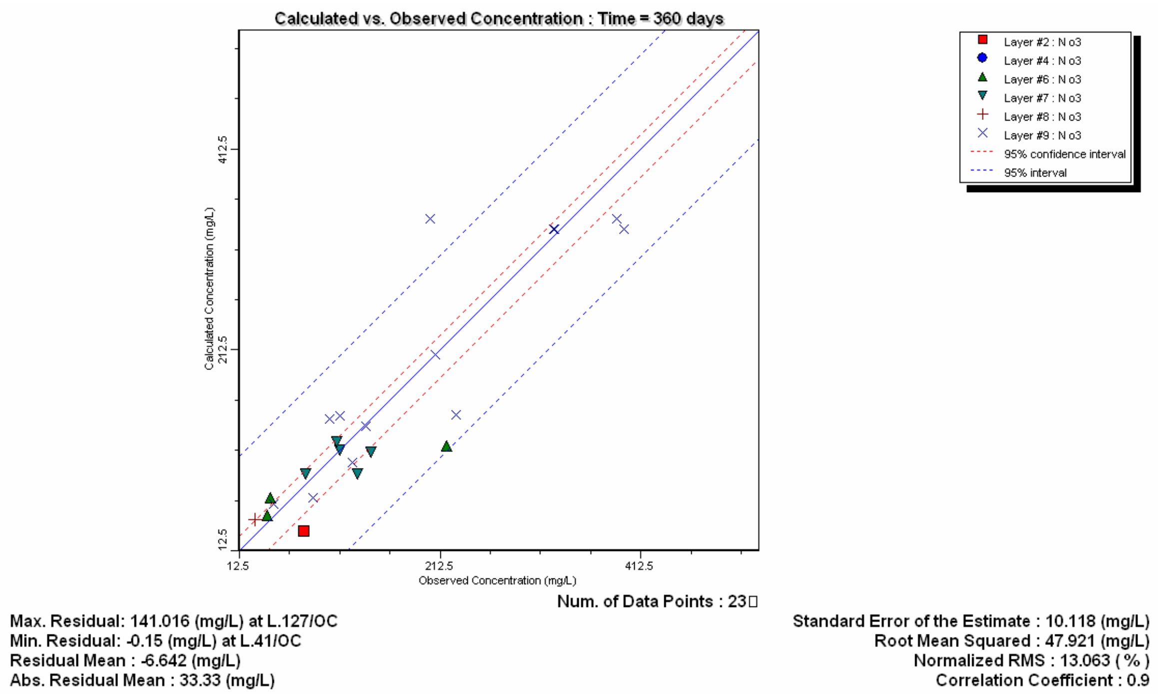
4.11.2 Calibration of Transport Model

The process of calibration requires adjustments of the model input parameters that influence the output in MT3D are specially the recharge concentration value and the characteristics of soil parameters like; Longitudinal dispersivity, horizontal dispersivity and vertical transverse dispersivity. Those values were adjusted and refined throughout the trial and error calibration process until an improved conformity between simulated and observed values was attained. Nitrate concentration values were obtained from analysis of agricultural, observation, domestic wells and wastewater plant as explained in Appendix A. The final results of nitrate load for each area was shown in Appendix A, the nitrate load was assumed dissolved within the amount of recharge percolating to the groundwater.

The calibration procedure is performed under transient state groundwater flow conditions. Transport calibration for the transient flow was conducted for the target period (2005-2008) using the calibrated hydro-geological parameters of conductivity and storage.

The transport model was subsequently tested for various values of dispersivities, the resulting simulated concentrations were compared against the observed ones. The calibrated dispersivity (Longitudinal dispersivity) was found to be 10 m, horizontal dispersivity equals 1m and the vertical transverse dispersivity equals 0.1 m. The calculated residual mean error and absolute mean error were -22.874 (mg/l) and 39.987 (mg/l), respectively, with a correlation coefficient of 0.915.

Results of the correlation between the observed nitrate concentration and the calibrated nitrate concentration within southern Gaza Strip are shown in figure 4.22 through figure 4.25 at the end of the years 2005, 2006, 2007 and 2008 respectively as drawn by VMODFLOW.



```
Num. of Data Points : 23□
Max. Residual: 141.016 (mg/L) at L.127/OC                    Standard Error of the Estimate : 10.118 (mg/L)
Min. Residual: -0.15 (mg/L) at L.41/OC                                 Root Mean Squared : 47.921 (mg/L)
Residual Mean : -6.642 (mg/L)                                             Normalized RMS : 13.063 ( % )
Abs. Residual Mean : 33.33 (mg/L)                                     Correlation Coefficient : 0.9
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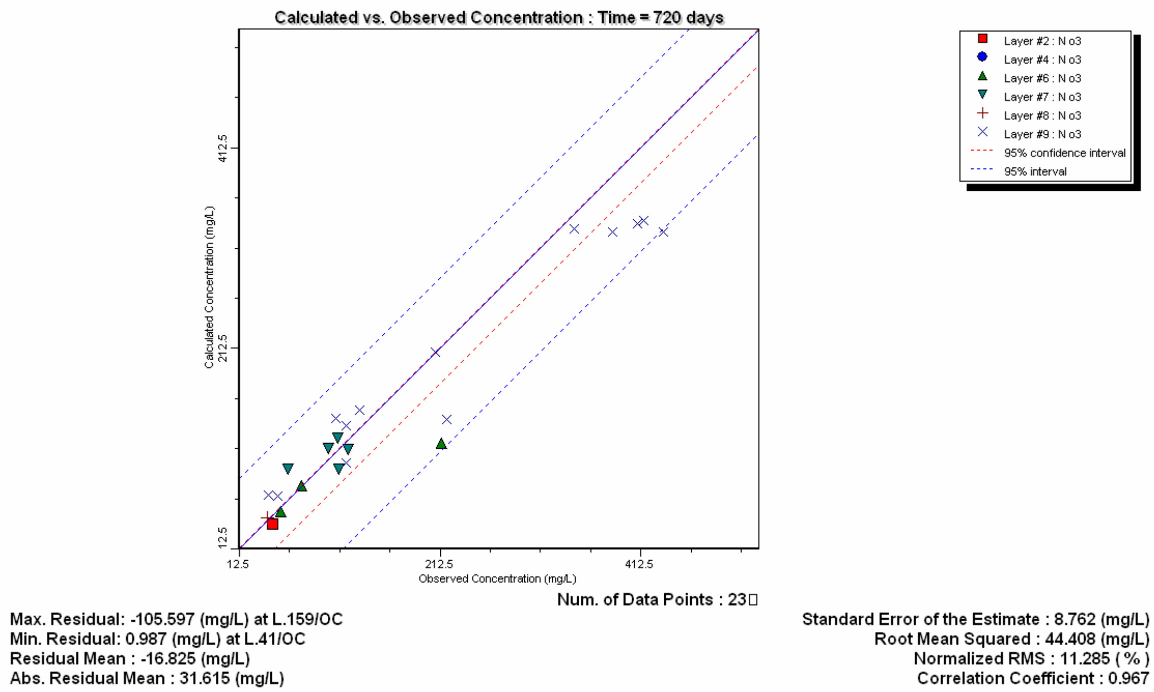
Figure4.23: Calculated versus observed NO_3^- concentration at the end of 2005.

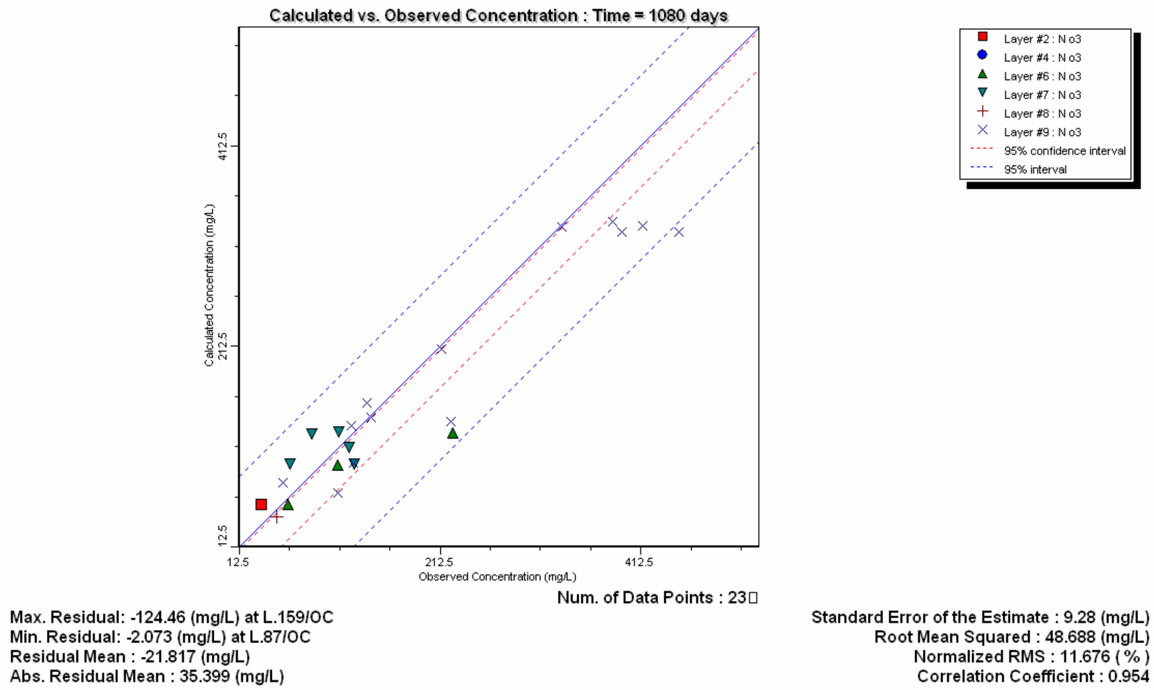


Num. of Data Points : 23

Max. Residual: -105.597 (mg/L) at L.159/OC
Min. Residual: 0.987 (mg/L) at L.41/OC
Residual Mean : -16.825 (mg/L)
Abs. Residual Mean : 31.615 (mg/L)

Standard Error of the Estimate : 8.762 (mg/L)
Root Mean Squared : 44.408 (mg/L)
Normalized RMS : 11.285 (%)
Correlation Coefficient : 0.967

***Figure 4.24:** Calculated versus observed NO_3^- concentration at the end of 2006.*



Num. of Data Points : 23

Max. Residual: -124.46 (mg/L) at L.159/OC
Min. Residual: -2.073 (mg/L) at L.87/OC
Residual Mean : -21.817 (mg/L)
Abs. Residual Mean : 35.399 (mg/L)

Standard Error of the Estimate : 9.28 (mg/L)
Root Mean Squared : 48.688 (mg/L)
Normalized RMS : 11.676 (%)
Correlation Coefficient : 0.954

***Figure 4.25:** Calculated versus observed NO_3^- concentration at the end of 2007.*

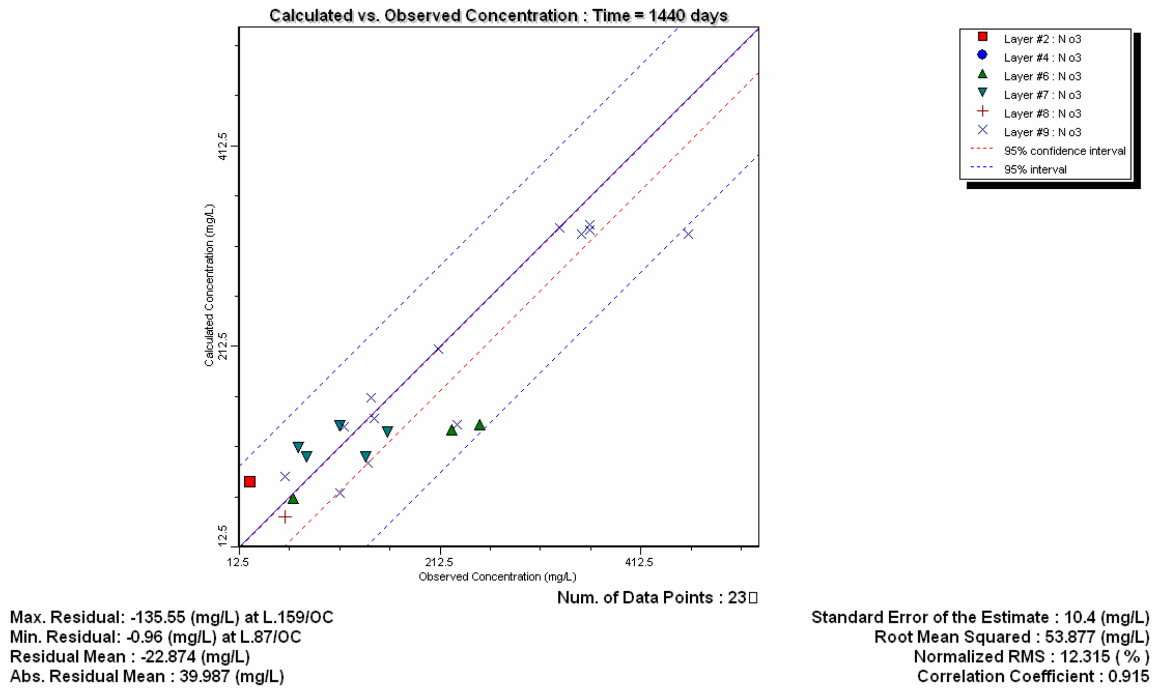


Figure 4.26: Calculated versus observed NO_3^- concentration at the end of 2008.

Figure 4.27 shows the calculated nitrate concentrations within model area for the end of year 2008 in (mg/l), where the highest nitrate concentrations are located in urbanized areas. Khanyounis city centre has nitrate concentration ranging from 300 to 400 (mg/l), while the surrounding agricultural areas have nitrate concentration ranging from 100 to 250 (mg/l). While Rafah city specially where high population density has nitrate concentration ranging from 100 (mg/l) and 150 (mg/l).

Generally, It was observed that nitrate concentration have high values in the areas with high population density. This explained by the variety of recharge and human activities.

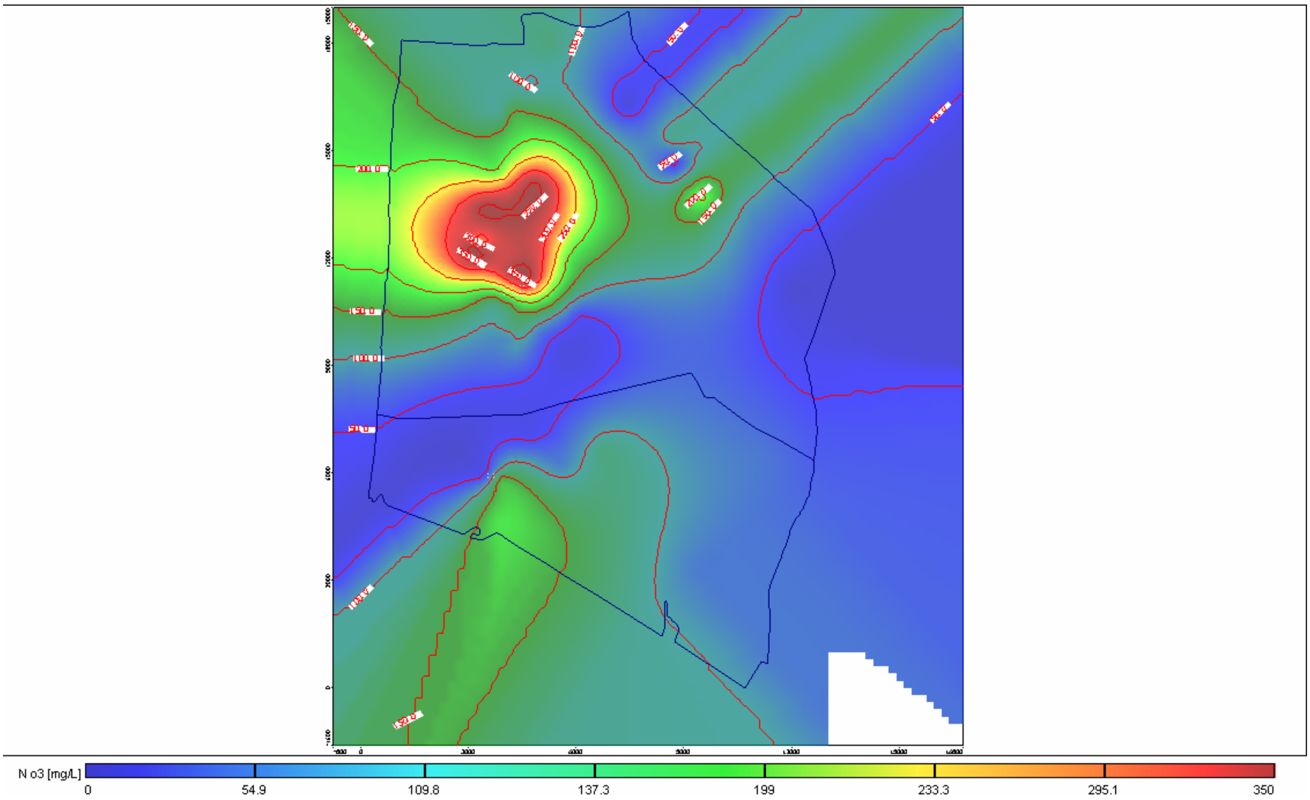


Figure 4.27:Caculated NO_3^- concentrations within southern Gaza Strip for the end of year 2008(mg/l)

4.11.3 Sensitivity Analysis of The Model

Model sensitivity analysis is a process to know the model response to the variations in input parameters. It is typically performed by changing the value of a parameter at a time. In general, the uncertainty in results of the calibration process is due to the inaccurate estimation of aquifer parameters, stresses, and boundary conditions. The importance of the sensitivity analysis is to provide sufficient data to rank the input parameters in terms of their influence on the predicted results.

In this study six predicting scenarios were used to test the sensitivity of the flow and transport models instead of measuring the sensitivity index. These scenarios were studied for the coming 5, 10, 15, 30 years as shown in chapter 5.

CHAPTER
5

MANAGEMENT SCENARIOS

CHAPTER 5: MANAGEMENT SCENARIOS

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 (Metcalf and Eddy, 2000). The management options or scenarios may be regional-scale approaches or local- scale scenarios. In this study only the local- 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 Khanyounis area within the model domain, whereby the research aimed in all to find a reliable solution of the nitrate contamination in Khanyounis. The approach for selecting the management scenarios was carried out depending on the need to reduce the migration of nitrate 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 management the land use especially which effects on nitrate concentration. It is difficult to enumerate all available and feasible alternatives to protect the aquifer against deterioration of water quality with respect to nitrate. Six selected management scenarios were tested; (1) work as usual (zero scenario), (2) Management of the pumping, (3) Implementation of sewerage system at Khanyounis, (4) Reduction of N-fertilizers loadings at agricultural areas, (5) Bringing together all the previous scenarios (2,3,and 4) and (6) Using artificial infiltration of groundwater in addition to the management options in scenario no. (5). All scenarios were studied for the coming 5, 10, 15, 30 years.

5.2 Management Scenarios

This section aims to identify the future extent and the long-term trends in groundwater concentrations for the target period (2009-2038) 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 nitrate load presented in the previous chapter was kept the same as the baseline to predict the future nitrate. As shown in the previous section the six management scenarios were tested in this study were:

(1) Work as usual (zero scenario),

(2) Management the pumping,

(3) Implementation sewerage system at Khanyounis,

(4) Reduction of N-fertilizers loadings at agricultural areas,

(5) Bringing together all the previous scenarios (2, 3, and 4) and

(6)Using artificial infiltration of groundwater in addition to the management options in scenario no. (5) and,

Table (5.1) shows the properties of each scenario.

5.2.1 Assumptions for All Scenarios

- Target period for prediction is from 2009-2039.
- All calibrated physical and hydro-geological parameters from the flow model were used. Also, the calibrated yearly nitrate load presented in the previous chapter was kept the same as the baseline to predict the future nitrate.
- For the period 2009–2038, rainfall and recharge was set to the flow model as an average annual for simplicity. Also, recharge coefficients were kept the same as being used in the baseline flow model.
- According to the Palestinian Central Bureau of Statistics (PCBS) report which published in 2006, the growth population rate of 3.8% was assumed in these years to estimate the future municipal well abstractions. The average abstraction rates for agricultural wells remained the same as in basic flow model.
- Land use distribution was set as in the previous years without any change.

Table 5.1: The properties of all scenarios.

No.	Scenario	Properties
1	Work as usual (zero scenario)	• *Annually increasing of pumping from the aquifer according to the growth of population.* • *No sewerage system at Khanyounis.* • *Bad and random using of fertilizers at agricultural areas.*
2	Management the pumping.	• *Reduction of the pumping from the aquifer by 50% (using Ro unit to serve only Khanyounis and Rafah governorates).* • *The reduction will be by closing the wells in any of the two areas:* • *Cone of depression area.* • *The area of high nitrate concentration (more than 300*

		mg/l). - *Concentrate the reduction in the municipal wells.* o *Total number of municipal wells= 43 well.* o *Number of closed= 21 well*
3	Implementation sewerage system at Khanyounis.	- *Implement sewerage system at the residential areas at Khanyounis governorate.* - *Implement the WWTP (as preplanned from related authorities) to serve Khanyounis governorate.* - *The effluent of WWTP will be used for irrigation in the near agricultural areas (after treated).*
4	Reduction of N-fertilizers loadings at agricultural areas.	- *50% reduction of chemical (N-fertilizers) at agricultural areas, where the present fertilizers loadings are more than the required for the plants and more than the permitted from ministry of agriculture, this will be achieved* ***by:*** o *Launch an awareness campaign among farmers on the optimum use of fertilizers.* o *Cooperation with the Ministry of Agriculture about feeding the market of fertilizers does not contain large amounts of nitrates.*
5	Bringing together all the previous scenarios (2, 3, and 4).	*All properties of (2, 3, and 4) scenarios.*
6	Using artificial infiltration of groundwater in addition to the management options in scenario no. (5)	*Use the surplus stormwater and treated wastewater in addition of all properties of (2, 3, and 4) scenarios.*

5.3 Results and Discussion

Measurements of nitrate concentration in (mg/l) for ten observation wells as shown in figure 5.1 were recorded for years (2013, 2018, 2023 and 2038). Then the average value of all readings was obtained, and the change of nitrate concentration with time was graphed. Comparison between all scenarios was made to evaluate the management scenarios.

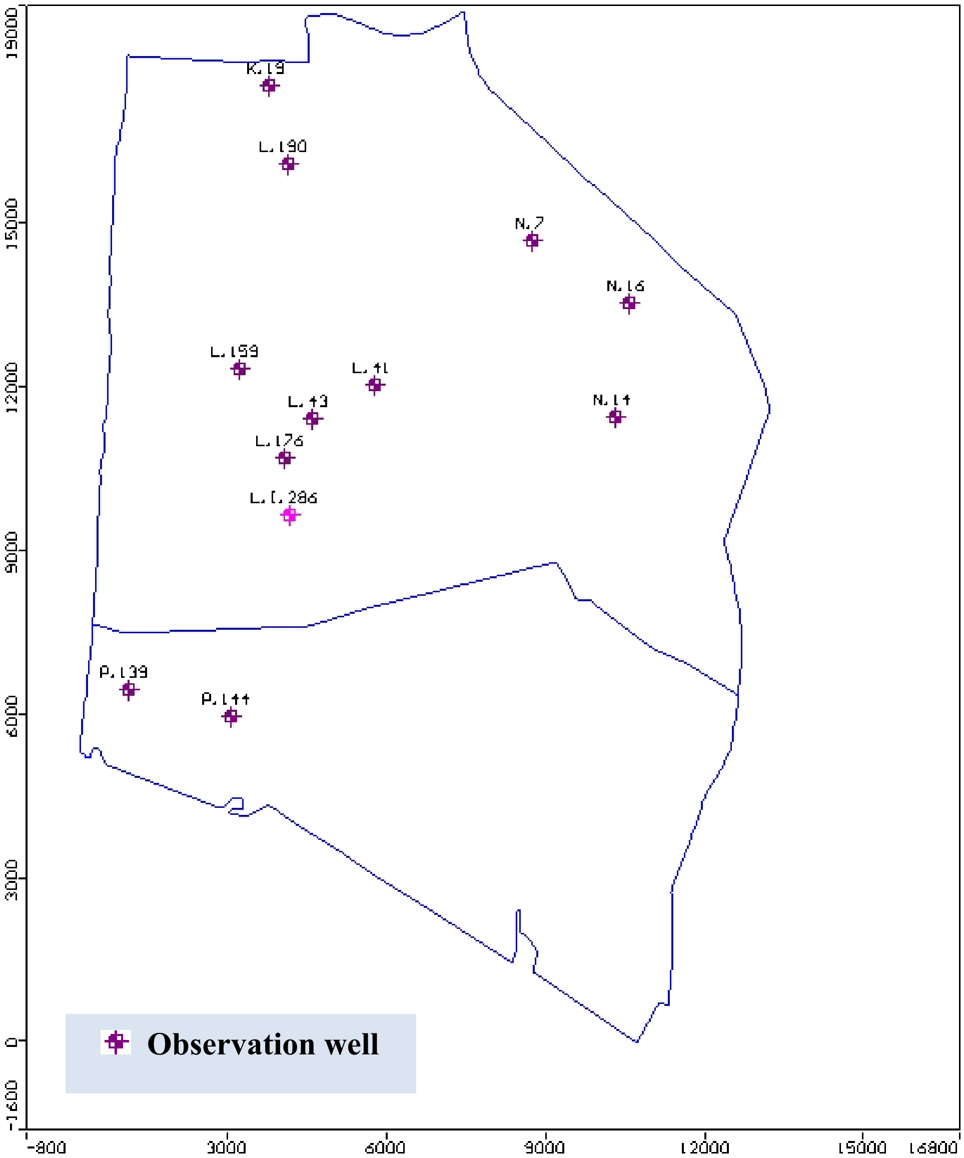


Figure 5.1: Selected observation wells distribution in southern Gaza Strip within model domain for management scenarios.

Depending on the assumptions and properties of all scenarios, this section shows the impact of each scenario on the nitrate contamination. Then analysis the results of the selected management scenarios was indicted.

1. *Work as usual (zero scenario):*

Table 5.2: ***NO_3^- concentration readings for the scenario "work as usual" (2008, 2013, 2018, 2023 and 2038) years.***

Well ID	***NO_3^- concentration (mg/l)***				
	2008	**2013**	**2018**	**2023**	**2038**
K.19	108.01	113.02	117.55	125.13	163.34
L.159	442.00	445.43	522.93	581.32	696.26
L.176	133.00	174.61	210.41	248.98	355.92
L.190	124.18	159.48	188.12	219.29	309.65
L.41	206.30	220.66	256.36	297.75	439
L.43	398.03	393.37	447.48	499.53	639.02
N.14	97.00	117.74	263.91	434.74	897.05
N.7	50.00	77.26	124.18	181.56	374.94
N.16	142.90	112.73	180.4	293.93	670.28
L.I.286	117.90	111.82	146.73	183.23	293.61
P.139	53.24	104.38	183.21	231.03	281.05
P.144	50.04	42.36	41.6	41.88	46.25
Average 1 (a)	**160.22**	**172.74**	**223.57**	**278.20**	**430.53**
Average 2 (b)	**181.93**	**192.61**	**245.81**	**306.55**	**483.91**

(a) Average of readings for the wells located in Khanyounis and Rafah governorates.

(b) Average of readings for the wells located in Khanyounis governorate.

Table 5.2 shows a gradual increasing of nitrate concentration in all areas. The readings of concentration observation wells in the agricultural areas reached nearly 900 mg/l after 30 years, where reached nearly 700 mg/l in residential areas. The continuity of work as usual in dealing with aquifer means full deterioration of the aquifer quality. The approximated annual increasing of nitrate concentration equals on average 10.1 mg/l in Khanyounis governorate.

2. Management the pumping:

Table 5.3: ***NO_3^- concentration readings for the scenario "management the pumping" (2008, 2013, 2018, 2023 and 2038) years.***

Well ID	**NO_3^- concentration (mg/l)**				
	2008	**2013**	**2018**	**2023**	**2038**
K.19	108.01	111.27	113.39	118.48	162.92
L.159	442.00	440.09	552.9	664.75	973.27
L.176	133.00	197.27	240.64	277.69	362.53
L.190	124.18	157.1	177.93	201.75	272.92
L.41	206.30	198.61	205.67	226.7	340.79
L.43	398.03	325.68	308.9	314.79	454.36
N.14	97.00	76.46	118.39	204.91	541.64
N.7	50.00	66.71	92.33	123.71	267.74
N.16	142.90	100.25	125.47	189.21	489.44
L.I.286	117.90	102.39	118.47	138.25	208.15
P.139	53.24	33.5	41	53.95	143.98
P.144	50.04	46.51	56.17	70.39	126.83
Average 1(a)	**160.22**	**154.65**	**179.27**	**215.38**	**362.05**
Average 2(b)	**181.93**	**177.58**	**205.41**	**246.02**	**407.38**

(a) Average of readings for the wells located in Khanyounis and Rafah governorates.

(b) Average of readings for the wells located in Khanyounis governorate.

Table 5.3 shows that the change of nitrate concentration will not be significant in all when management the pumping. But the annual increasing of nitrate concentration will decrease by 2.5 mg/l on average. This means that the annual increasing equals 7.5 mg/l in Khanyounis governorate.

3. *Implementation sewerage system at Khanyounis:*

***Table 5.4:** NO_3^- concentration readings for the scenario "Implementation of sewerage system at Khanyounis" (2008, 2013, 2018, 2023 and 2038) years.*

Well ID	NO_3^- concentration (mg/l)				
	2008	**2013**	**2018**	**2023**	**2038**
K.19	108.01	112.62	115.94	121.39	132.99
L.159	442.00	313.86	309.88	309.96	309.77
L.176	133.00	168.79	186.76	203.21	215.74
L.190	124.18	154.42	175.44	197.26	145.27
L.41	206.30	206.5	203.8	198.61	185.76
L.43	398.03	312.31	291.24	276.29	267.25
N.14	97.00	73.01	91.39	164.07	398.44
N.7	50.00	70.99	92.64	110.98	159.31
N.16	142.90	101.88	131.85	207.15	377.17
L.I.286	117.90	94.96	104.88	116.34	106.11
P.139	53.24	60.09	89.25	104.35	91.46
P.144	50.04	41.92	40.35	39.49	44.34
***Average 1**(a)*	**160.22**	**142.61**	**152.79**	**170.76**	**202.80**
***Average 2**(b)*	**181.93**	**160.93**	**170.38**	**190.53**	**229.78**

(a) Average of readings for the wells located in Khanyounis and Rafah governorates.

(b) Average of readings for the wells located in Khanyounis governorate.

Table 5.4 shows significant improvement of nitrate concentration especially in residential areas. For example the reading of well (L.159) decreases by approximately 400 mg/l in 30 years compared with work as usual scenario as shown in figure 5.2. As well as the wells in agricultural areas have seen significant improvement in the concentration of nitrate, but it was lower than in the residential areas. The decreasing of nitrate concentration in agricultural areas when comparing with readings in work as usual scenario reach 100 mg/l in 30 years. As a whole, After 30 years the average of nitrate concentration in Khanyounis governorate may be changed by not more than 50 mg/l, which means that the annual increasing equals 1.6 mg/l.

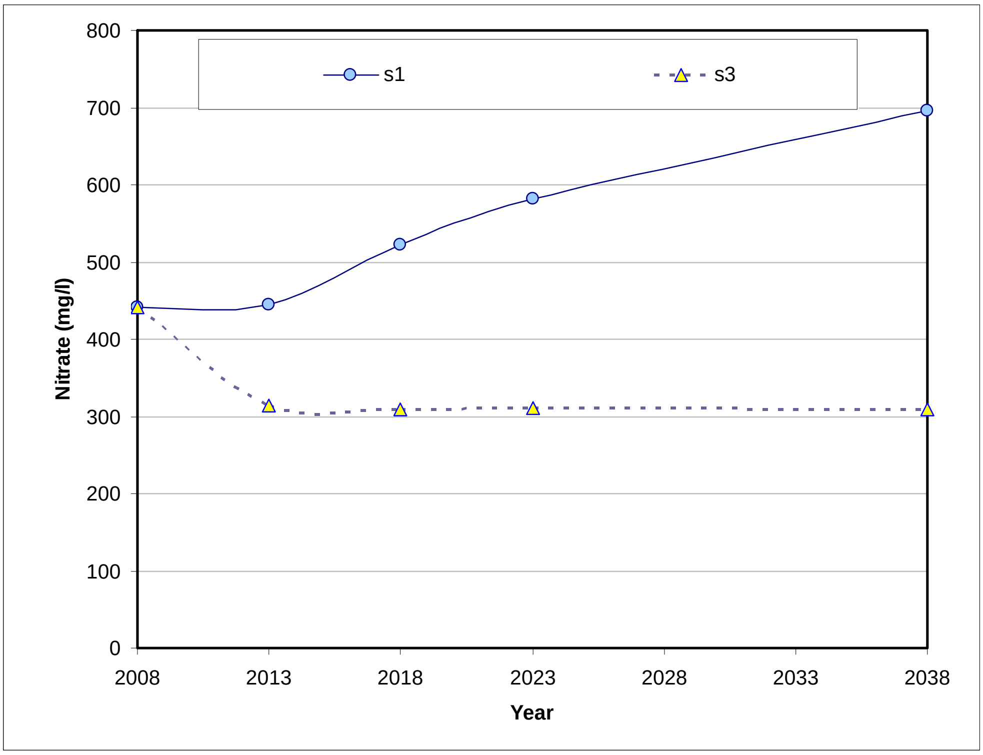


Figure 5.2: Nitrate concentrations versus scenarios 1 and 3 (2008-2038) for well L.159

4. *Reduction of N-fertilizers loadings at agricultural areas:*

Table 5.5: NO_3^- concentration readings for the scenario "Reduction of N-fertilizers loadings at agricultural areas" (2008, 2013, 2018, 2023 and 2038) years.

Well ID	NO_3^- concentration (mg/l)				
	2008	**2013**	**2018**	**2023**	**2038**
K.19	108.01	112.24	114.48	118.24	136.86
L.159	442.00	429.24	476.98	504.32	536.89
L.176	133.00	168.88	187.88	206.9	258.75
L.190	124.18	149.08	162.38	181.72	254.52
L.41	206.30	220.66	256.36	297.75	439.01
L.43	398.03	393.37	447.47	499.52	638.88
N.14	97.00	117.57	256.01	394.39	664.07
N.7	50.00	77.26	124.28	181.94	345.68
N.16	142.90	111.73	160.53	223.9	411.2
L.l.286	117.90	95.05	105.47	117.63	158.09
P.139	53.24	60.42	89.21	104.56	117.88
P.144	50.04	42.22	40.77	39.97	40.08
Average 1 (a)	**160.22**	**164.81**	**201.82**	**239.24**	**333.49**
Average 2 (b)	**181.93**	**187.51**	**229.18**	**272.63**	**384.40**

(a) Average of readings for the wells located in Khanyounis and Rafah governorates.

(b) Average of readings for the wells located in Khanyounis governorate.

Also, table 5.5 shows significant improvement of nitrate concentration but mainly in agricultural areas. For example the reading of well (N.16) decreases by approximately 260 mg/l in 30 years compared with work as usual scenario as shown in figure 5.3. As well as the wells in residential areas have seen significant improvement in the concentration of nitrate, but it was lower than in the agricultural areas. The decreasing of nitrate concentration in well (L.159) which located in residential area comparing with readings in work as usual scenario reach 160 mg/l in 30 years as shown in figure 5.4. As a whole, after 30 years the average of nitrate concentration in Khanyounis governorate will reach 384.4 mg/l that means the annual increasing equals 6.7 mg/l.

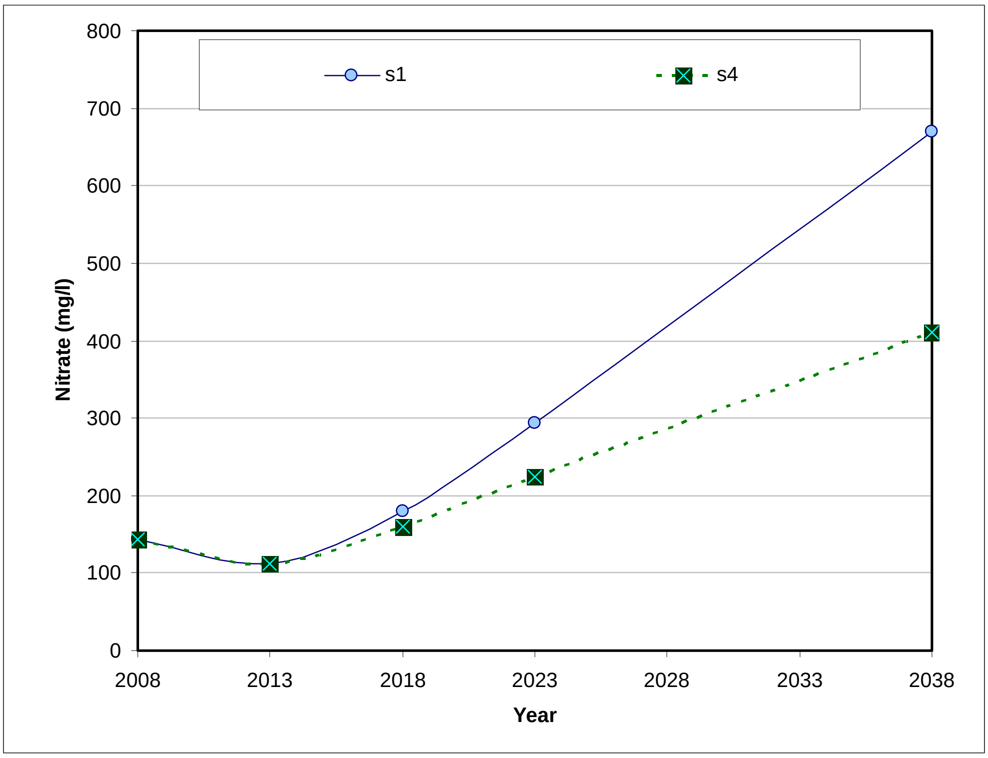


Figure 5.3: Nitrate concentrations versus scenarios 1 and 4 (2008-2038) for well N.16

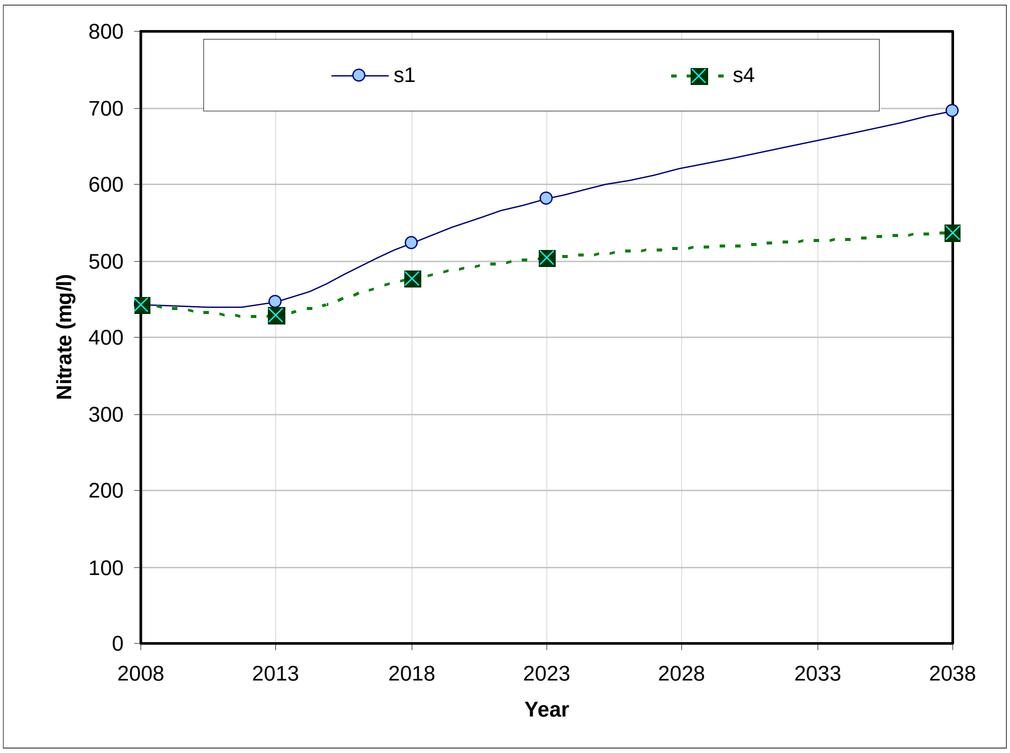


Figure 5.4: Nitrate concentrations versus scenarios 1 and 4 (2008-2038) for well L.159

5. Bringing together all the previous scenarios (2,3,and 4):

Table 5.6: NO_3^- concentration readings for the scenario "Bringing together all the previous scenarios (2, 3, and 4)" (2008, 2013, 2018, 2023 and 2038) years.

Well ID	NO_3^- concentration (mg/l)				
	2008	**2013**	**2018**	**2023**	**2038**
K.19	108.01	110.71	111.13	112.23	116.46
L.159	442.00	305.57	282.39	262.58	206.94
L.176	133.00	193.04	221.49	236.74	231.76
L.190	124.18	146.16	145.87	143.87	126.67
L.41	206.30	195.35	183.75	172.03	137.2
L.43	398.03	324.39	294.98	264.51	192.17
N.14	97.00	68.25	53.1	46.23	72.69
N.7	50.00	66.25	86.7	100.17	128.52
N.16	142.90	96.73	90.4	90.48	121.17
L.I.286	117.90	110.71	111.13	112.23	108.06
P.139	53.24	31.47	33.79	38.22	71.21
P.144	50.04	46.5	56.07	69.8	119.07
***Average 1*(a)**	**160.22**	**141.26**	**139.23**	**137.42**	**135.99**
***Average 2*(b)**	**181.93**	**161.72**	**158.09**	**154.11**	**144.16**

(a) Average of readings for the wells located in Khanyounis and Rafah governorates.

(b) Average of readings for the wells located in Khanyounis governorate.

Table 5.6 shows how the nitrate concentration changed between 2008-2038 when bringing together all the previous scenarios (2, 3, and 4). This means reduction the pumping from the aquifer, implementation sewerage system at Khanyounis area and reduction the usage of N-fertilizers by 50%. The table shows good results when comparing with previous scenarios. Some of the wells recorded a decrease of more than 50% than it was in 2008 like well (L.159) and well (L.43). The decreasing of nitrate concentration in well (L.159) which located in residential area comparing with readings in work as usual scenario reach 490 mg/l in 30 years as shown in figure 5.5. Where the decreasing of nitrate concentration in well (N.16) which located in agricultural area comparing with readings in work as usual scenario reach 549 mg/l in 30 years as shown in figure 5.6. In general, after 30 years the average of nitrate concentration in Khanyounis governorate will reach 144.16 mg/l that means the annual decreasing equals 1.26 mg/l.

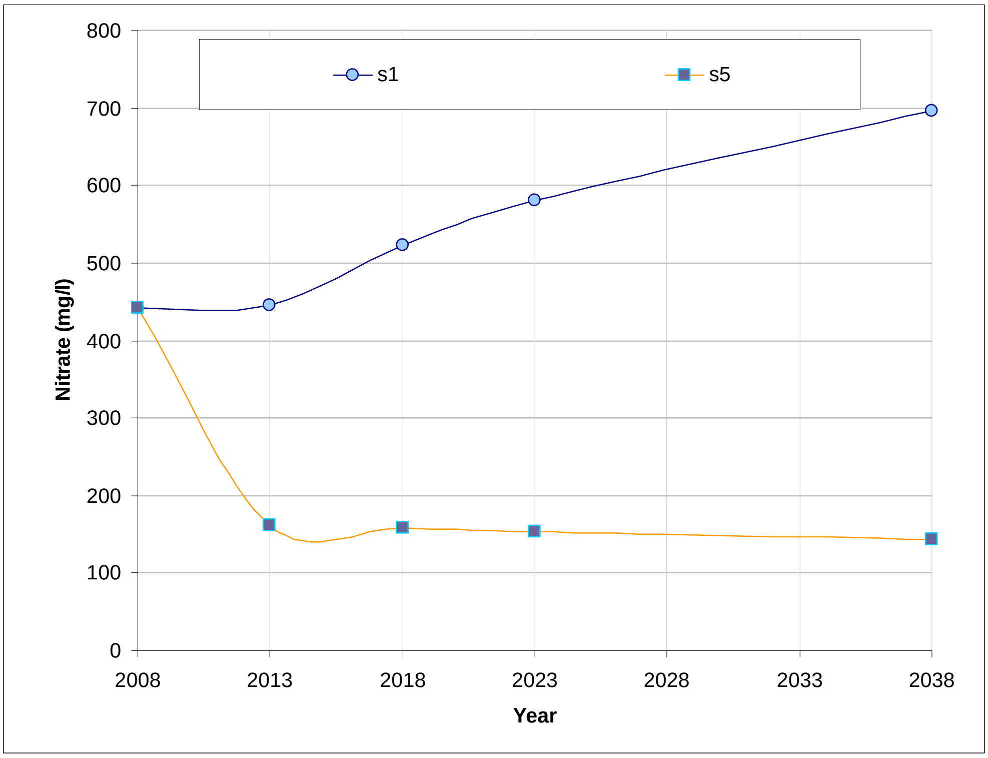


Figure 5.5: Nitrate concentrations versus scenarios 1 and 5 (2008-2038) for well L.159

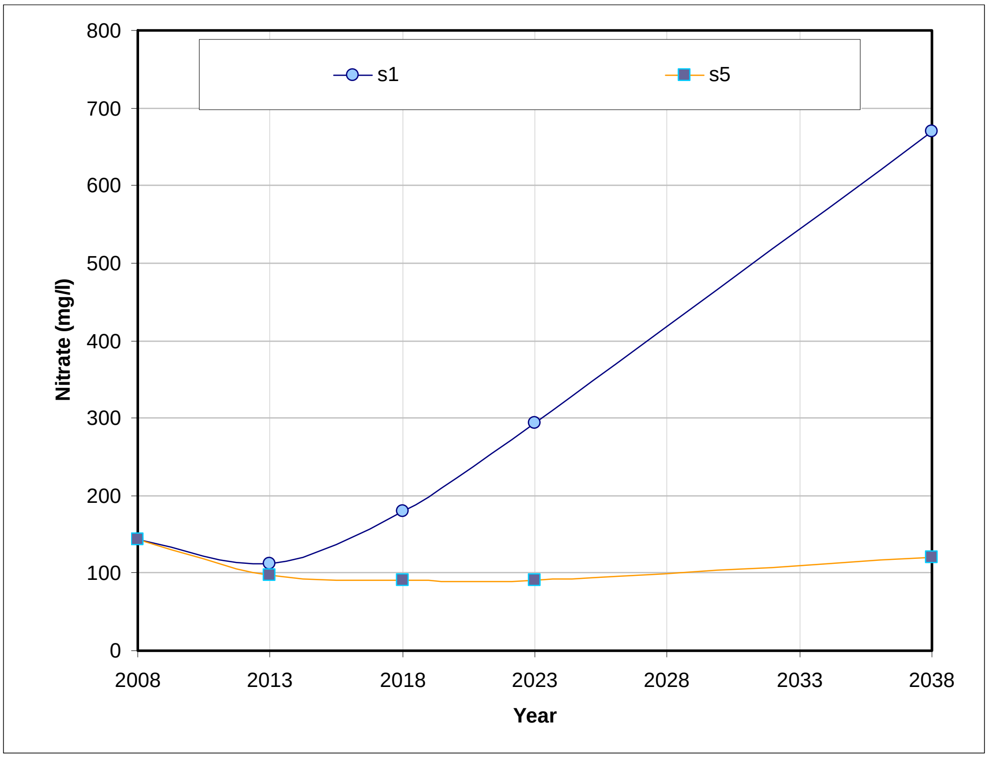


Figure 5.6: Nitrate concentrations versus scenarios 1 and 5 (2008-2038) for well N.16

6. Using artificial infiltration of groundwater in addition to the management options in scenario no. (5):

Sources of infiltrated water:

The sources of water to be infiltrated are mainly from both stormwater and treated wastewater.

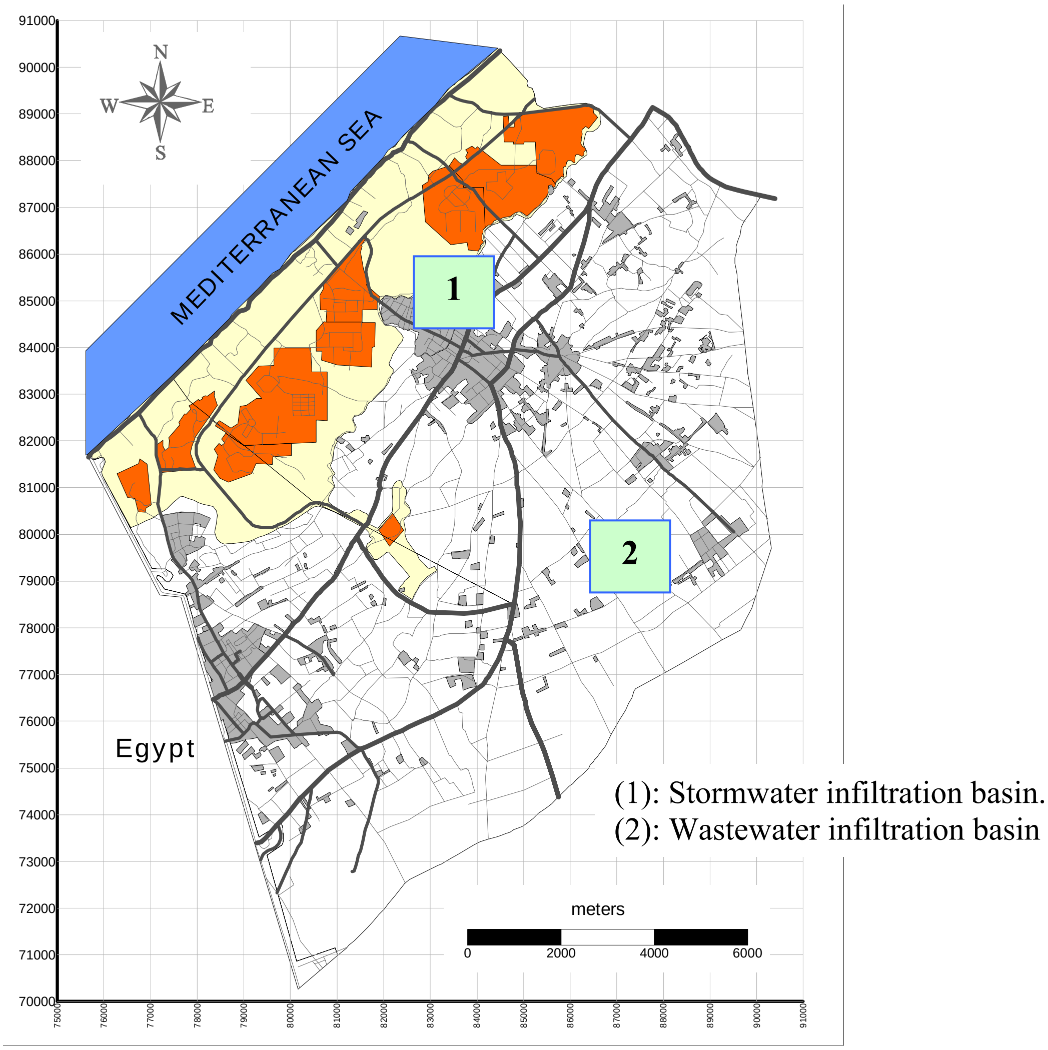
1. Stormwater:

The potential collected stormwater in the rainy season 1991/1992 reached about four million m^3 according to the calculations based on Khanyounis master plan (Hamdan and Jaber, 2001).

The collected stormwater from all areas in Khanyounis supposed to pump to a large infiltration basin in the west of Khanyounis city as shown in figure 5.7 . Processing this pond to work is not over yet, but was suspended because of the conditions of the siege imposed on Gaza Strip. The basin was designed for infiltration of stormwater and is funded by donation from Japan through UNDP.

2. Wastewater:

According the Finland project the wastewater infiltration basins located in Khuza'a village in the east of Khanyounis governorate as shown in figure 5.7. The infiltration basins will receive treated waste water from Khanyounis wastewater treatment plant (WWTP) during the winter season only, during the summer season the effluent from the WWTP will be used for irrigation.



(1): Stormwater infiltration basin.
(2): Wastewater infiltration basin

Figure 5.7: Infiltration sites at Khanyounis governorate

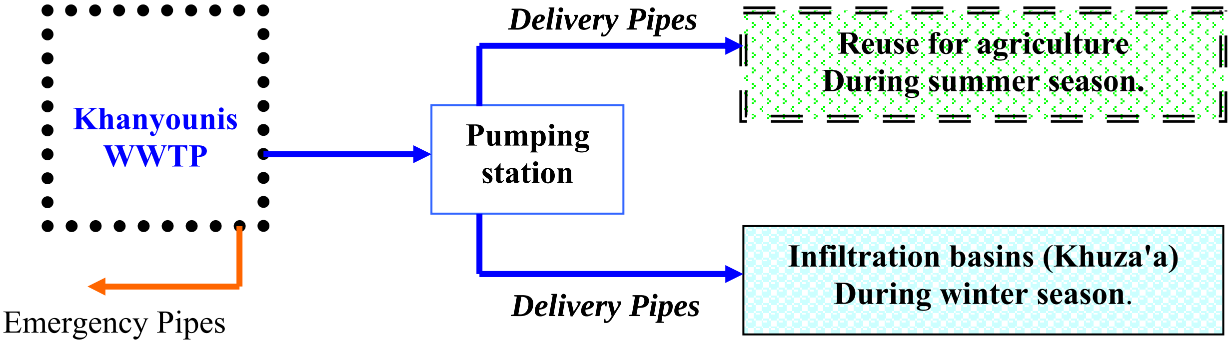


Figure 5.8: Schematic drawing of the component of the wastewater reuse system proposed to implement in Khanyounis.

Table 5.7: NO_3^- concentration readings for the scenario "Using artificial infiltration of groundwater in addition to the management options in scenario no. (5)" (2008, 2013, 2018, 2023 and 2038) years.

Well ID	NO_3^- concentration (mg/l)				
	2008	2013	2018	2023	2038
K.19	108.01	106.64	107.12	97	62.64
L.159	442.00	282.15	147.62	56.86	25.49
L.176	133.00	255.41	221.61	191	100.66
L.190	124.18	69.05	26.98	21.74	20.94
L.41	206.30	193.86	168.45	137.35	75.26
L.43	398.03	248.84	208.25	163.07	69.08
N.14	97.00	30.16	30.14	30.14	30.14
N.7	50.00	97.38	122.67	115.01	76.5
N.16	142.90	45.81	37.39	37.3	37.3
L.I.286	117.90	89.7	100.34	110.27	113.86
P.139	53.24	31.31	36.83	47.48	93.87
P.144	50.04	69.93	107.08	119.9	129.69
Average 1(a)	**160.22**	**126.69**	**109.54**	**93.93**	**69.62**
Average 2(b)	**181.93**	**141.90**	**117.06**	**95.97**	**61.19**

(a) Average of readings for the wells located in Khanyounis and Rafah governorates.

(b) Average of readings for the wells located in Khanyounis governorate.

Table 5.7 shows how the nitrate concentration changed from 2008-2038 when using artificial infiltration of groundwater in addition to the management options in previous scenario no. (5). This means reduction the pumping from the aquifer by using RO unit, implementation sewerage system at Khanyounis area, reduction the usage of N-fertilizers by 50%, and using artificial infiltration from both stormwater and treated wastewater. The total amount of recharged water estimated at 19 MCM/yr at 2038 according to roughly calculations and the study of infiltration system for Khanyounis wastewater treatment plant that preformed by ALMADINA-Consultants at year 2006.

The table shows the best results when comparing with all previous scenarios. Some of the wells recorded a decrease of more than 90% than it was in 2008 like well (L.159) and well (L.43). In general, after 30 years the average of nitrate concentration in Khanyounis governorate will reach 61.19 mg/l that means the annual decreasing equals 4.02 mg/l, and the average will be closest to WHO standard (50 mg/l).

5.4 Comparison between all scenarios

Analysis of the previous management scenarios indicated that as percent of reduction in nitrate loadings increase or the percent of abstraction from the aquifer decrease, the average simulated nitrate concentrations of all target points decrease. Table 5.9 and graph 5.9 show the comparison between the results of all management scenarios. Results in Table 5.9 show that the yearly change in nitrate concentration in all scenarios ranges between -4.02 mg/l to 10.1 mg/l. This means that the deterioration of the Gaza aquifer is fast, while the remedial scenarios lead the aquifer to better, but slowly.

Note that the artificial recharge scenario gives reasonable and acceptable values compared to the time. The average nitrate concentration in this scenario is expected to reach value closest to the WHO standard.

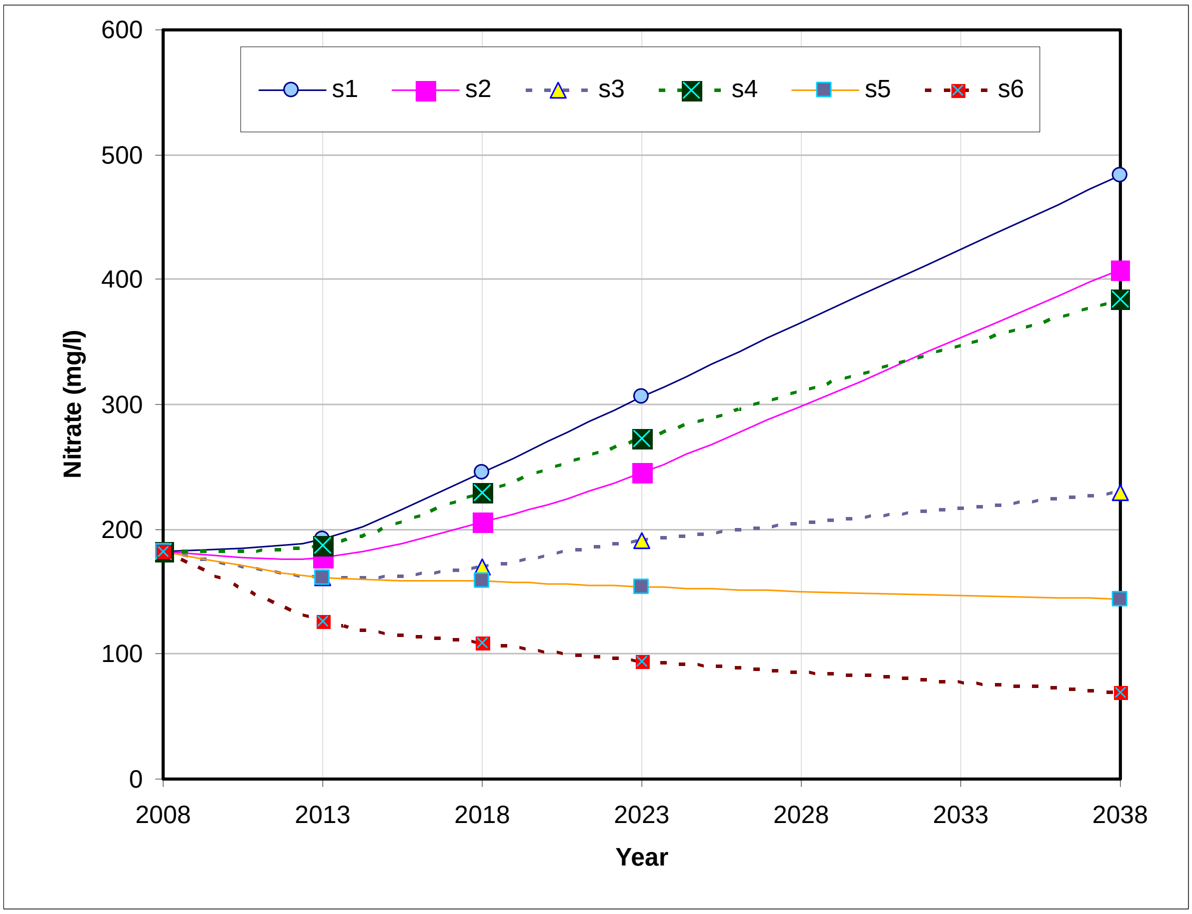


Figure 5.9: Average simulated nitrate concentrations versus management scenarios (2008-2038)

Table 5.8: Average simulated nitrate concentrations versus management scenarios (2008-2038)

No.	**Scenario**	**Initial conc. (mg/l) (2008)**	**Average predicted conc. After 30 years (mg/l)**	**Total change in 30 years (mg/l)**	**Average yearly change (mg/l)**
1	*Work as usual.*	181.93	483.91	+301.98	+10.1
2	*Management the pumping.*	181.93	407.38	+225.45	+7.52
3	*Implementation sewerage system at Khanyounis.*	181.93	229.78	+47.85	+1.595
4	*Reduction of N-fertilizers loadings at agricultural areas.*	181.93	384.40	+202.47	+6.749
5	*Bringing together all the previous scenarios (2, 3, and 4).*	181.93	144.16	-37.77	-1.259
6	*Using artificial infiltration of groundwater in addition to the management options in scenario no. (5)*	181.93	61.19	-120.74	-4.02

CHAPTER
6

CONCLUSION AND RECOMMENDATIONS

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

- The used finite-difference code MODFLOW to simulate the hydraulic head within the groundwater and the MT3D to simulate the nitrate transport are good tools, meanwhile other modeling tools may introduces better results than VMODFLOW.
- According to the management scenarios explained in chapter 5, Septic effluents are the main sources of nitrate in the groundwater of Khanyounis governorate followed by chemical fertilizers and manure.
- The abstraction from the aquifer affects on the nitrate concentration in groundwater. Whenever the pumping from the aquifer increased the nitrate concentration increased, the change is effective but not significant in comparing with annual increasing of nitrate concentration. This relation may be due to change in direction and velocity of the flow of groundwater, especially in the areas of cones of depression. Other factor may enhance this relation is the significant change of aquifer storage.
- In the event of work as usual, the average nitrate concentration in Khanyounis governorate will increases by more than 10 mg/l annually.
- The implementation a sewerage system at Khanyounis governorate will reduce the rising of average nitrate concentration in Khanyounis area by 8.5 mg/l annually. This means that the average nitrate concentration in Khanyounis governorate will increases by only 1.5 mg/l annually.
- Reduction of usage N-fertilizers by 50% will have somewhat effect on nitrate concentration where it will reduce the rising of average nitrate concentration in Khanyounis area by 3.35 mg/l annually.
- Combination of all management scenarios in addition to artificial recharge i.e. (reduction the pumping from the aquifer by using RO unit, implementation sewerage system at Khanyounis area, reduction the usage of N-fertilizers by 50%, and using artificial infiltration from both stormwater and treated wastewater) will lead to acceptable nitrate of concentration in groundwater after 30 years of applying these options.
- The analysis of the impact of projects planned to be implemented in the future by the concerned authorities showed that these projects will have a positive impact in solving the problem of nitrate in Khanyounis governorate. These projects include the implementation of stormwater infiltration basin and wastewater infiltration basins.

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 of groundwater. It introduced in numbers the effect of many management options on nitrate concentration in Khanyounis governorate area.
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, imported water from water companies as Mekorot, or other sources.
3. The implementation of Khanyounis WWTP and operation of its sewerage system will help significantly in reducing the average nitrate concentration in this area.
4. Artificial infiltration from both stormwater and treated wastewater will have dramatic effect on reducing nitrate concentration in groundwater.
5. The best scenario to solve the increasing of nitrate concentration problem in the groundwater is the combination of many options (reduction the pumping from the aquifer by using RO unit, implementation sewerage system at Khanyounis area, reduction the usage of N-fertilizers by 50%, and using artificial infiltration from both stormwater and treated wastewater) in addition to artificial recharge as planned by the concerned authorities.
6. As a general recommendation, PWA, MoA, CMWU, and other related authorities has to construct an integrated data base for hydrological data of Gaza Strip.

6.3 Suggested complementary studies

1. Studying the nitrate transport in the unsaturated zone, and finding empirical equations or model to simplify the calculation of nitrate loads leaching to saturated zone.
2. Studying carefully the impact of artificial recharge on nitrate concentration in groundwater in Khanyounis area.
3. Searching for another software to model the nitrate transport in groundwater.

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APPENDIX A

CALCULATION OF NITRATE LOADINGS

APPENDIX A: CALCULATION OF NITRATE LOADINGS

Table (A-1): Sources of nitrate in groundwater and there classification in southern Gaza Strip

Source	Source No.	Classification
WWTP	1	*Point source*
Leakage from sewer system	2	*Non point source*
Un-sewered areas (cesspits)	3	*Point source*
Drinking water Distribution networks	4	*Non point source*
Agriculture activates	5	*Non point source*

Table (A-2): Area and total recharge volume of each area

Sub-area No.	Area (m^2)	Total Recharge Volume (MCM)
1	13,939,216	2.5369
2	44,385,802	5.2375
3a	20,188,360	3.1494
3b	7,144,339	0.6501
3c	12,496,000	0.9747
4	161,104	0.0227
5	14,695,228	1.6018
6	48,490,595	3.1519
7	225,736	0.0260
8	7,672,955	0.1995
9	5,593,842	0.1454

***Figure (A-1):** Land use map of southern Gaza Strip*

(1) Waste Water Treatment Plant (WWTP)

Table (A-3): Calculation of nitrate loadings from WWTP

Location: Rafah
Sub area No. (4)

			Source of Data
Kj-N(effluent)	*152.7*	*mg/l*	
Flow rate	*10000*	*m3/d*	(Al Mahallawi, 2005)
Discharge to the land	*4200*	*m3/d*	
Area of WWTP	*161104*	*m2*	
Total N	*0.1527*	*kg/m3*	
N input	*234089*	*kg/yr*	
% of losses due to denitrification	*20*	*%*	Massri, 2009
Total losses of nitrogen	*46817.82*	*kg/yr*	
N-leaching	*187271*	*kg/yr*	
No_3-leaching	*829350*	*kg/yr*	
Total recharge	*0.022715664*	*MCM/yr*	
$C(No_3)$	***36510.03073***	***mg/l***	

(2) Leakage from sewer system

Table (A-4): Calculation of nitrate loadings from the leakage from sewer system

Location: Rafah
Sub area No. (5)

			Source of Data
Kj-N(influent)	*238*	*mg/l*	(Al Mahallawi, 2005)
Rafah population	*174000*	*inhab.*	
Total consumption	*7*	*MCM/yr*	(PWA, 2007)
Network efficiency	*63*	*%*	
Water per capita	*69.43788*	*l/c/d*	
Total used water	*4.41*	*MCM/yr*	
Total losses from network	*2.59*	*MCM/yr*	
% of connected to sewer system	*50*	*%*	(PWA, 2007)
% converted to waste water	*80*	*%*	(Massri, 2009)
Fraction of leakage from total flow	*20*	*%*	(Rabah,1996)
Total leakage from sewer system	*0.3528*	*MCM/yr*	
Total area	*14695228*	*m2*	
Average nitrogen concentration	*0.238*	*kg/m3*	
N input	*83966*	*kg/yr*	
% of losses due to denitrification	*20*	*%*	(Massri, 2009)
Losses	*16793.28*	*kg/yr*	
N-leaching	*67173*	*kg/yr*	
No3-leaching	*297483*	*kg/yr*	
Total recharge in this area	*1.60178*	*MCM/yr*	
Concentration (No3)	***185.7202***	***mg/l***	

(3) Un-sewered Areas (cesspits)

Table (A-5): Calculation of nitrate loadings from cesspits in Rafah

Location: Rafah

Sub area No. (5)

			Source of Data
Average conc. of nitrogen in cesspits	*238*	*mg/l*	(Al Mahallawi, 2005)
Rafah population	*174000*	*Capita.*	
Total consumption	*7*	*MCM/yr*	
Network efficiency	*63*	*%*	(PWA, 2007)
Water per capita	*69.43788*	*l/c/d*	
Total used water	*4.41*	*MCM/yr*	
Total losses from network	*2.59*	*MCM/yr*	
% of connected to un-sewered area	*50*	*%*	(PWA, 2007)
% converted to waste water	*80*	*%*	Massri, 2009
Total leakage from cesspits	*1.764*	*MCM/yr*	
Total area	*14695228*	*m2*	
Average conc. of nitrogen in cesspits	*0.238*	*kg/m3*	
N input	*419832*	*kg/yr*	
% of losses due to denitrification	*20*	*%*	Massri, 2009
Losses	*83966.4*	*kg/yr*	
N-leaching	*335866*	*kg/yr*	
No3-leaching	*1487414*	*kg/yr*	
Total recharge	*1.60178*	*MCM/yr*	
Concentration (No3)	***928.601***	***mg/l***	

Table (A-6): Calculation of nitrate loadings from cesspits in Khanyounis

Location: Khanyounis

Sub area No. (2)

			Source of Data
Average conc. of nitrogen in cesspits	370	mg/l	(Al Mahallawi, 2005)
Rafah population	285000	Capita.	
Total consumption	13.77	MCM/yr	
Network efficiency	48	%	(PWA, 2007)
Water per capita	63.53857	l/c/d	
Total used water	6.6096	MCM/yr	
Total losses from network	7.1604	MCM/yr	
% of connected to un-sewered arera	100	%	(PWA, 2007)
% converted to waste water	80	%	Massri, 2009
Total leakage from cesspits	5.28768	MCM/yr	
Total area	44385802	m2	
Average conc. of nitrogen in cesspits	0.37	kg/m3	
N input	1956442	kg/yr	
% of losses due to denitrification	20	%	Massri, 2009
Losses	391288.3	kg/yr	
N-leaching	1565153	kg/yr	
No3-leaching	6931438	kg/yr	
Total recharge	5.237525	MCM/yr	
Concentration (No3)	**1323.419**	**mg/l**	

(4) Drinking water Distribution networks

Table (A-7): Calculation of nitrate loadings from drinking water distribution networks in Rafah

Location: Rafah
Sub area No. (5)

			Source of Data
Average conc. of No3 in Rafah area	*100*	*mg/l*	(PWA, 2007)
Rafah population	*174000*	*Capita.*	
Total consumption	*7*	*MCM/yr*	
Network efficiency	*63*	*%*	
Water per capita	*69.44*	*l/c/d*	
Total used water	*4.41*	*MCM/yr*	
Total losses from network	*2.59*	*MCM/yr*	
% of leakage from total losses	*25*	*%*	(Al Mahallawi, 2005)
Total leakage from network	*0.6475*	*MCM/yr*	
Total area	*14695228*	*m2*	
Average conc. of No3	*0.1*	*kg/m3*	
No3-leaching	*64750*	*kg/yr*	
Total recharge	*1.602*	*MCM/yr*	
Concentration (No3)	***40.42***	***mg/l***	

Table (A-8): Calculation of nitrate loadings from drinking water distribution networks in Khanyounis

Location: Khanyounis
Sub area No. (2)

			Source of Data
Average conc. of No3 in Khanyounis area	*250*	*mg/l*	(PWA, 2007)
Rafah population	*285000*	*Capita*	
Total consumption	*13.77*	*MCM/yr*	
Network efficiency	*48*	*%*	
Water per capita	*63.54*	*l/c/d*	
Total used water	*6.61*	*MCM/yr*	
Total losses from network	*7.16*	*MCM/yr*	
% of leakage from total losses	*25*	*%*	(Al Mahallawi, 2005)
Total leakage from network	*1.79*	*MCM/yr*	
Total area	*14695228*	*m2*	
Average conc. of No3	*0.25*	*kg/m^3*	
No3-leaching	*447525*	*kg/yr*	
Total recharge	*5.24*	*MCM/yr*	
Concentration (No3)	***85.45***	***mg/l***	

(5) Agriculture activates

Sources of nitrate:

1. ***Chemical fertilizers.***

Table (A-9): Amounts and types of nitrogen fertilizers applied for different types of crops in Gaza Strip-average values, (Ministry of agriculture, 2001)

Crop	Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Vegetables	*Compound fertilizer 20-20-20 Nitrate-Ammonia-Amide*	500	20	100
	Potassium Nitrate	400	13	52
	Ammonium sulphate	500	21	105
	Total applied N(kg N/ha.yr)	**1400**		**257**
Citrus	*Ammonium sulphate*	600	21	126
Fruits	*Ammonium sulphate*	500	21	105
Field crops	*Ammonium sulphate*	500	21	105

Table (A-10): Calculation of nitrogen leaching to the aquifer from each crop

Crop	Area (ha)	N.added (kg/ha)	Total N (kg/yr)	N leaching (kg/yr)	N leaching (kg/ha/yr)	Source
Vegetables	3503.9	257	900502.3	585326.495	**167.05**	(Al Mahallawi, 2005)
Field crops	2774	105	291270	189325.5	**68.25**	
Citrus	235.55	126	29679.3	19291.545	**81.9**	
Fruits	1933.2	105	202986	131940.9	**68.25**	
	8446.65		**1424437.6**	**925884.44**		

Note: **Total losses equals 25% of applied fertilizers (Denitrification)+10% plant uptake (Al Mahallawi, 2005)**

2. Organic (Manure additions).

Table (A-11): Nitrogen additions from manure

Type	N (kg/yr)	Source
livestock Gaza	1671485	(Al Mahallawi, 2005
imported from Israel	1087985	
Total Manure	**2759470**	

Note: **Total quantity in the table for only Khanyounis and Rafah.**

Table (A-12): Calculation of nitrogen leaching from manure for each crop area

Crop	Area (ha)	manure (ton/ha)	N.added (kg/ha)	Total N (kg/yr)	N leaching (kg/yr)	N leaching (kg/ha/yr)
Vegetables	3503.9	25	437.5	1532956.25	873785.0625	**249.375**
Field crops	2774	15	262.5	728175	415059.75	**149.625**
Citrus	235.55	15	262.5	61831.875	35244.16875	**149.625**
Fruits	1933.2	15	262.5	507465	289255.05	**149.625**
	8446.65			**1613344.031**	**1613344.031**	

Note: **Total losses equals 33% of applied fertilizers (Denitrification)+10% plant uptake**

Table (A-13): Total N leaching from chemical fertilizers and manure

Source	N leaching (kg/yr)
Chemical fertilizers	925884.44
Manure	1613344.03
Total N leaching	**2539228.47**

Table (A-14): Calculation of nitrate concentrations for all agricultural areas

Sub-area	Area (m2)	N leaching (kg/ha/yr)	Total N leaching (Kg/yr)	No3 leaching (kg/yr)	Total Recharge (MCM/yr)2004	C (mg/L)
1	13,939,216	210	292723.536	1296179.817	2.536937312	510.9230769
3b	7,144,339	210	150031.119	664337.7949	0.650134849	1021.846154
3c	12,496,000	210	262416	1161978.048	0.974688	1192.153846
6	48,490,595	390	1891133.205	8373937.832	3.151888675	2656.8
	82,070,150		**2,596,303.86**	**11,496,433.49**		

SUMMATION OF ALL LOADS

Table (A-15):* *Total nitrate loadings distributed on all areas

Sub-area	**Area** (m^2)	**Land use**	**Total No$_3^-$** (kg/yr)
1	13939216	*Mawasi*	1296179.817
2	44385802	*Built-up*	9559821.616
3a	20188360	*Reserve*	3486368.265
3b	7144339	*Reserve*	664337.7949
3c	12496000	*Reserve*	1161978.048
4	161104	*WWTP*	207337.3977
5	14695228	*Built-up*	2286250.874
6	48490595	*cultivated*	8373937.832
7	225736	*WWTP*	38982.80131
8	7672955	*Airport*	0
9	5593842	*Industrial*	0
Total			**27075194.45**