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قسم الهندسة المدنية
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Modeling & Monitoring the Impact of Storm water Artificial Recharge on Groundwater

Case study: Beit Lahia Municipality Infiltration Basin

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A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Civil/ Water Resources Engineering

1431هـــ - 2010م

بسم الله الرحمن الرحيم

﴿ رب أوزعني أن أشكر نعمتك التي أنعمت علي وعلى والدي وأن أعمل صالحا ترضاه وأدخلني برحمتك في عبادك الصالحين ﴾

(النمل الآية 19)

"O my Lord! So order me that I may be grateful for Thy favours, which Thou has bestowed on me and on my parents, and that I may work the righteousness that will please Thee: and admit me, by Thy Grace, to the ranks of Thy Righteous Servants"

ABSTRACT

The main source of water in Gaza Strip is the shallow aquifer which is part of the coastal aquifer. The quality of the groundwater is extremely deteriorated in terms of salinity and nitrates. Artificial recharge is a way to improve the ground water quality and quantity. This research investigates the impact of storm water that is artificially recharged into the groundwater quantity and quality. The newly constructed Biet Lahia Municipality infiltration Basin is considered as a case study.

Two methods were used: 1) laboratory analysis, where samples were taken from the storm water in different times of winter and from groundwater wells surrounding the basin and 2) groundwater flow and quality models were developed for the basin using MODFLOW and MT3D.

The first method results showed that the quality of storm water in Biet Lahia infiltration basin is acceptable according to World Health Organization (WHO) in many parameters as No_3^-, Cl^-, Mg^{+2}, Ca^{+2}, Na^{+1}, k^+, detergent, turbidity, TSS, TDS, and hardness. However, the Fecal Coliform in storm water is not acceptable. The quality of groundwater in the area surrounding the basin is not acceptable in terms of nitrate. Therefore, the artificial recharge of storm water to the groundwater, will work on reducing the concentration of nitrate in the ground water.

The simulation of the groundwater flow model showed that the groundwater mound beneath the center of the recharge basin can be expected to rise to about 25 cm above the present water table in winter, then drop in the summer and so on. This makes groundwater level oscillatory near the basin. The model simulations indicate that the water level will be increased in the area and the cone of depression will diminish substantially due to the infiltration.

The simulation using MT3D showed that the concentration of nitrate in the groundwater in the study area is reduced since the infiltrated storm water has less nitrate than that in the groundwater It also showed the pathlines for imaginary particles that are infiltrated in the recharge area will spread radially about 100 m after 2 year, 250 m after 10 years, 400 m after 20 years.

A monitoring system was developed to measure the impact of groundwater in the infiltration basin in the future, by using monitoring wells around the basin, where the location of these wells were based on the results of groundwater models

Alternative of recharging treated wastewater in the basin was tested. The simulation of the model showed that the groundwater mound beneath the center of the recharge basin will be about 1.2 m above the present groundwater level after 1 year. The native groundwater downstream of the recharge area will gradually be influenced by the water originating from the infiltrated water and the cone of depression will diminish substantially due to the infiltration. Therefore, it is recommended to increase the number of infiltration basins in Gaza Strip to make use of all available storm water and treated wastewater as a means to reduce the scarcity of water.

الخلاصـــة

المصدر الرئيسي للمياه في قطاع غزة هي المياه الجوفية السطحية و التي هي جزء من الخزان الجوفي الساحلي .جودة المياه الجوفية متدهورة للغاية من حيث الملوحة والنترات. التغذية الاصطناعية هو وسيلة لتحسين المياه الجوفية من حيث الكمية و الجودة وهذا البحث يدرس تأثير مياه الأمطار في حالة استخدام التغذية الاصطناعية على المياه الجوفية من حيث الكمية و الجودة، دراسة الحالة هي حوض ترشيح بلدية بيت لاهيا .

طريقة العمل تتكون من 1)التحليل المخبري ،حيث أخذت عينات من مياه الأمطار في أوقات مختلفة من فصل الشتاء و عينات من المياه الجوفية من الآبار المحيطة بالحوض . 2) عمل نموذج للتدفق و الجودة للمياه الجوفية باستخدام MODFLOW and MT3D .

أظهرت نتائج التحليل المخبري أن جودة مياه الأمطار في حوض ترشيح بيت لاهيا مقبولة حسب منظمة الصحة العالمية في العديد من العناصر مثل النترات، الكلور، و المغنسيوم، الكالسيوم، الصوديوم، المنظفات، والعكارة، العسر، المواد العالقة والذائبة. ولكن فإن الفيكل كلوروفورم غير مقبولة. و كذلك أظهرت النتائج أن جودة المياه الجوفية في بيت لاهيا غير مقبولة بالنسبة لتركيز النترات. وهذا يعني استخدام التغذية الاصطناعية للمياه الأمطار على المياه الجوفية ستعمل على تحسين تركيز النيترات في المياه الجوفية.

أظهرت محاكاة نموذج تدفق الخزان الجوفي أن المياه الجوفية أسفل مركز حوض الترشيح يتوقع أن ترتفع إلى حوالي 25سم فوق الوضع الطبيعي للمياه في فصل الشتاء، ثم تنخفض في فصل الصيف وهكذا تتكرر العملية . وهذا يجعل مستوى المياه الجوفية متذبذب بالقرب من الحوض. هذا الارتفاع في الخزان الجوفي يكون على شكل مخروط مرتفع من الوسط ويقل تدريجاً إذا ابتعدنا عن الوسط.

المحاكاة باستخدام MT3D أظهرت تحسن جودة الخزان الجوفي من حيث تركيز النترات وأظهر أيضا مسار الخطوط الوهمية للجزيئات التي تسللت من بركة الترشيح انتشرت لمسافة 100 متر تقريبا بعد سنتين ،و 250 م بعد 10 سنوات ، و400 م بعد 20 سنة.

تم اقتراح نظام مراقبة لقياس مدى تأثر المياه الجوفية بأحواض الترشيح، من خلال أبار مراقبة حول الحوض، و نحدد مواقع تلك الآبار بناءاً على نتائج نموذج الخزان الجوفي.

إذا إستخدمنا مياة عادمة معالجة في إحواض الترشيح، فإن النموذج يظهر إرتفاع في مستوى المياه الجوفية بحوالي 1.2م أسفل مركز الحوض بعد عام ، ينخفض هذا الإرتفاع كلما إبتعدنا عن الحوض وتكون على شكل مخروط و تقل تدريجاً إذا إبتعدنا عن الوسط وبناء علي ذلك فإن الدراسة توصي بزيادة عدد أحواض الترشيح في قطاع غزة، لاستغلال مياه الأمطار والمياه العادمه المعالجة للحد من مشاكل المياه.

Dedication

I dedicate my thesis to my parents whose prayers have continued to guide me in all aspects of my life. I also dedicate this to my beloved brothers, especially Ahmad, my sisters, friends and colleagues. Last but certainly not least, a special dedication to my wife Bessan and my lovely daughter Sama.

Acknowledgements

First and foremost, I am grateful to my lord who has given me the strength, ability, wisdom, knowledge and required understanding to complete this thesis.

Next, I wish to express my unreserved gratitude to my advisors, Dr. Yunes Mogheir, and Dr. Abd El Majeed Nassar for their tremendous help. Their constructive comments and ideas have made this project worth reading.

I would also like to thank the Islamic University of Gaza, Faculty of Engineering for providing me high standard Education through the duration of a master program in Water Recourses Engineering.

I appreciate the support rendered by the staff of PWA who provided me with the data used in this project available.

Many thanks go in particular to the staff of MOH, MOA for their support in facilitating my work in their laboratories.

My deepest gratitude goes out to my parents and my wife for their unremitting support during preparation of my thesis.

Finally, I would like to thank all those who have assisted, guided and supported me in my studies leading to the successful realization of this thesis.

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Symbols and Abbreviations

Symbol	Item
AR	Artificial Recharge
APHA	American Public Health Agency
CRD	Cumulative Rainfall Departure
CAMP	Coastal Aquifer Management Program
C.G	Certified Geologist
EPA	Environment Protection Agency
EQA	Environment Quality Authority
MOH	Ministry of health
MOA	Ministry of Agriculture
MOPIC	Ministry of Planning and International Corporation
MSL	Mean sea level
PCBS	Palestinian Central Bureau of Statistics
PNA	Palestinian National Authority
PWA	Palestinian Water Authority
FC	Fecal Coliform
TSS	Total Suspended Solid
TDS	Total Dissolved Solids
UNEP	United Nations Environment Programme
USGS	Unit State Geological Survey
WWTP	Wastewater Treatment Plant
WHO	World Health Organization
$\mathbf{No_3^-}$	Nitrate
$\mathbf{Cl^-}$	Chloride
$\mathbf{Ca^{2+}}$	Calcium
$\mathbf{Mg^{2+}}$	Magnesium
$\mathbf{K^+}$	Potassium
$\mathbf{Na^+}$	Sodium
E.C	Electrical Conductivity

Units and Measures

cm	centimeter
km	kilometer
m	meter
m^2	square meter
m^3	cubic meter
m^3/h	cubic meters per hour
Mm^3	Million Cubic Meter
mg/l	milligrams per liter
mm	millimeter
ppm	Part per million
y	year
d	day

Chapter 1
Introduction

1.1 General

Water is essential for sustenance of life. The knowledge of the occurrence, replenishment and recovery of potable groundwater assumes special significance in quality-deteriorated regions, as Gaza Strip because of scarce presence of surface water. The main source of water in Gaza Strip is the shallow aquifer which is part of the coastal aquifer. The quality of the groundwater is extremely deteriorated in terms of salinity and nitrates. This source is currently under serious stress due to mining, pollution from different sources and seawater intrusion. The quantity and quality of groundwater is affected by the quantity and quality of in and out-flowing water from the groundwater system.

The increasing demand for water has increased awareness towards the use of artificial recharge to augment groundwater supplies. Stated simply, artificial recharge is a process by which excess surface water is directed into the ground - either by spreading on the surface, by using recharge wells or by alternating natural conditions to increase infiltration - to replenish an aquifer. It refers to the movement of water through man-made systems from the surface of the earth to underground water bearing strata where it may be stored for future use. Artificial recharge is a way to store water underground in times of water surplus to meet demand in times of shortage. As priority in the Palestinian policy, storm water harvesting is considered as a major part of every large-scale project implemented, e.g. roads, port, industrial estate, etc. (Hamdan, 2007).

This research studied the impact of storm water infiltration on groundwater quality and quantity in Gaza Strip. The research will use the new constructed Biet lahia Municipality as a case study. The basin was designed by (Mogheir, 2005) through a consultancy service prepared by Center for Engineering and Consulting (CEP) and submitted to PWA. The impacts will be tested experimentally and will be predicted using modeling approach.

1.2 Problem Identification

Northern Gaza Strip, in particular, suffers from acute water shortages. Water demand greatly exceeds the available overused supply. This situation has caused a sever drop in the water levels in these areas. Large amounts of rain are lost by escaping into the sewage system , to the sea and through evaporation. Therefore, construction of storm water basin is very essential to collect as much rain as possible and to take advantage of this water (storm water) to be infiltrated into groundwater by wells (artificial recharge). On the other hand, the recharged storm water could increase the pollution of the groundwater aquifer if the storm water quality does not conform to the standards. The artificial recharge using storm water projects in the Gaza Strip aims at breaking the trend of decreasing groundwater table and to improve the quality of the groundwater. Practically, do these basins work so?

1.3 Objectives

The objectives of the current research are:

1. Determine the impacts of artificial recharge of storm water in Biet Lahia Municipality infiltration Basin on groundwater quality and quantity.
2. Development of a monitoring system to measure the impact of storm water in the infiltration basin.

1.4 Methodology

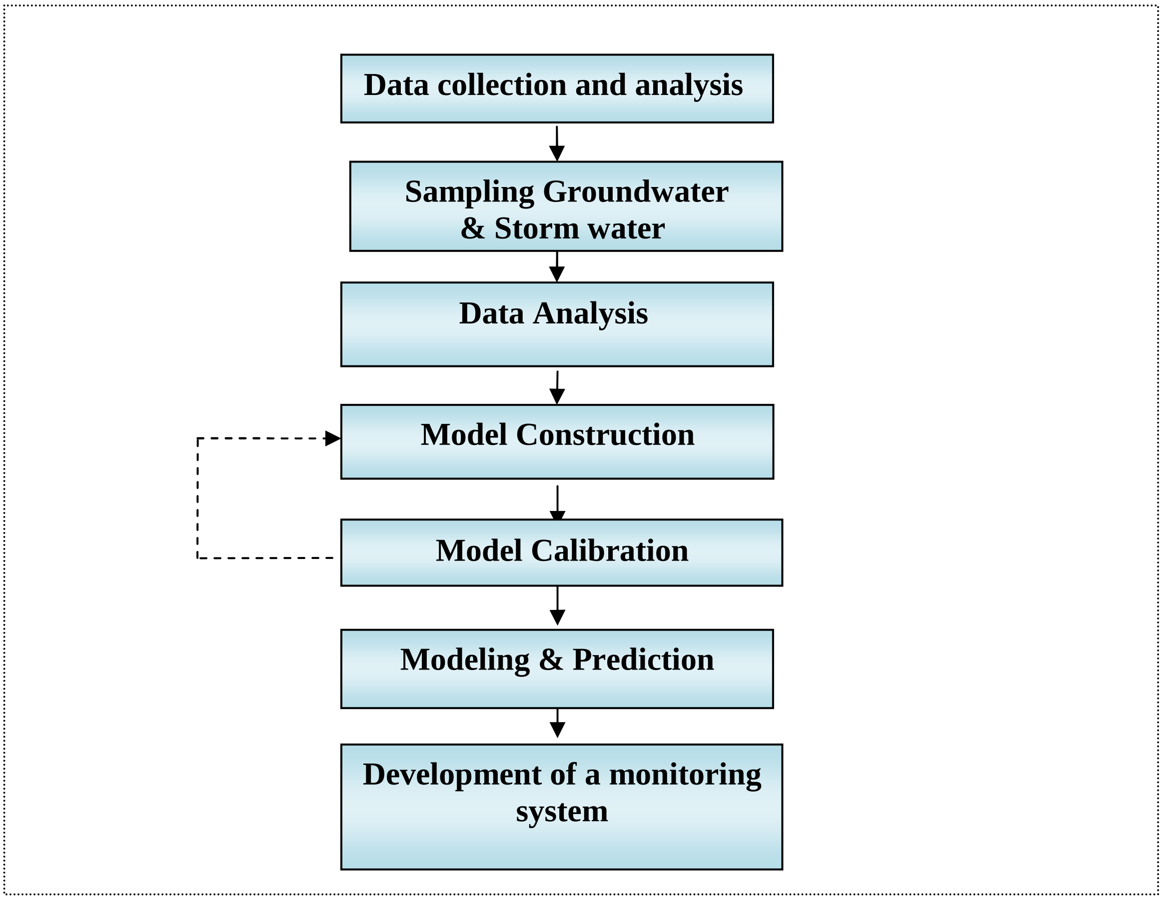
To achieve the objectives of this research, the following methodology was applied:

1. Several data were collected such as description of the Municipality site (area , location , topography , groundwater table , ground water quality , layers of soil , land use about the site , resources of pollutant) and all relevant information about storm water in the site .
2. Sampling of some ground water and storm water as follows:
    - a- Samples were collected from the storm water from the Municipality infiltration basin (winter 2008-2009).
    - b- Samples were collected from ground water wells near the storm water basin in winter and in summer, 2009.

3- Development of a model using MODFLOW software for assessing the effects of storm water infiltration on groundwater aquifer in the area which consists of:

- Ground water flow model to determine the velocity of contamination transport and fluctuation of ground water level (MODFLOW).
- Ground water flow model to describe the path of contamination transport (MOPATH).
- Ground water transport model to determine the concentration of the contamination transport and spatial vertical distributing of pollutants (MT3D).

4- Development of a monitoring system for the storm water basin.



Figure(1.1): Flowchart of the Research Methodology

1.5 Thesis Outline

The dissertation is organized into different chapters that range from chapter 1 to 6 as follows:

Chapter 1 consists of a general introduction with an overview of the groundwater investigations, problem identification, objectives and methodology of the research.

Chapter 2 begins with a brief literature review of the artificial recharge, ground water models, storm water, monitoring wells, and other computational tools.

Chapter 3 consists of a brief description of soil and hydrogeology of the Gaza coastal aquifer and description of Beit Lahia Municipality infiltration basin.

Chapter 4 includes a description of the experimental study, parameters, location, and program test, results and discussion of the laboratory analysis.

Chapter 5 illustrates the modeling approach for the storm water infiltration basin and simulation of artificial recharge in the basin. It also discusses the predicted groundwater level, particles tracking and solute transport in the recharge basin area and management of recharge in the basin. It includes the description of a monitoring system for the basin.

Chapter 6 gives conclusions and recommendations about the research.

Chapter 2
Literature Review

2.1 Artificial Recharge

Water-supply development is challenging. Increasing demands for water joined with concerns for environmental protection require a variety of new water management tools. Such a tool for the conjunctive use of surface water and groundwater supplies is the artificial recharge (AR) of groundwater. AR requires some form of man-made structure. Surface spreading techniques involve keeping water at the surface in areas where the water can percolate down to a shallow, unconfined aquifer (Margaret, 1986).

Artificial recharge is defined as any engineered or designed system that puts water on or in the ground for the purpose of infiltration and subsequent migration into underlying aquifers to augment ground-water resources (Barkmann et al., 2000). Artificial recharge and aquifer storage and recovery are valuable water management tools that effectively help to offset increased demands for water. The variety of techniques, methods, and circumstances for these processes is vast and expanding (Margaret, 1986).

The use of artificial recharge to store surplus surface water underground can be expected to increase as growing populations demand more water, and as the number of good dam sites still available for construction becomes fewer. For example, artificial recharge may be used to store treated sewage effluent and excess storm water runoff for later use (Herman, 1996).

Limited freshwater resources in many parts of the world have led to the development of artificial recharge techniques for conveying surface water and reclaimed wastewater to groundwater reservoirs for later use and for other applications. Other applications include using artificial recharge to create a barrier to saltwater intrusion, reduce land subsidence, raise water levels, and improve water quality by using the natural filtering capabilities of aquifer systems. Subsurface storage of water has many advantages over surface storage, and often is the more physically and economically viable alternative. The worldwide use of artificial recharge likely will increase in the future with continued growth in population and associated competition for finite freshwater resources (Phillips, 2008).

The advantages of groundwater storage compared to surface storage are no losses by evaporation, reduced construction cost in preparing the surface reservoir, and seasonal availability of water, e.g., increasing water in a depleted aquifer, usually accomplished during the off-season (Herman, 1996).

2.1.1 History of Artificial Recharge

Artificial recharge applications have been documented from the early 19th century, when European countries first attempted to ease the stress on their groundwater supplies. The European Environment Agency (Lallana and Krinner, 2001), shows a growing increase in artificial recharge noted in several countries such as Belgium, Denmark, Finland, Greece, the Netherlands, Poland, Spain and Switzerland. Other countries in which artificial recharge schemes are operating include Australia, Austria, Hungary, Iran, Israel, Jamaica, Morocco and South Africa. The motivation for artificial recharge is highly dependent of the country. While some countries practice recharge to match pre-development levels, others go beyond these levels to create temporary storage for dry seasons. Coastal regions are more concerned about saline water intrusion, and industrialized countries might see artificial recharge as an alternative means for treated wastewater disposal (Aish, 2004).

2.1.2 Purposes of Artificial recharge

Artificial recharge may be defined as the practice of artificially increasing the amount of water that enters a groundwater reservoir. Artificial recharge has application in waste disposal, secondary oil recovery, and land subsidence problems, as well as water supply problems (Herman, 2002).

Specific purposes for which artificial recharge is practiced are, as listed in (Walton, 1970), to:

1. Conserve and dispose of runoff and flood waters
2. Supplement the quantity of groundwater available

3. Reduce or eliminate decline in the water level of groundwater reservoirs
4. Reduce or balance salt water intrusion
5. Store water to reduce costs of pumping and piping
6. Store water in off-seasons for use during the growing seasons
7. Conserve energy in geothermal applications
8. Remove suspended solids by filtration through the ground.

An artificial recharge installation may serve more than one purpose. In certain areas, for example, artificial recharge not only adds water to the available groundwater supply, but also is a mean of disposing of storm water runoff. In another instance, artificial recharge to control salt water intrusion is also increasing the available supply of fresh water and alleviating a ground subsidence condition that has been in progress for years.

2.1.3 Methods for artificial recharge

2.1.3.1 Infiltration basins

Infiltration basins require a substantial amount of land area with a suitable geology, allowing the water to infiltrate into the aquifer and percolate to the groundwater table. It is simple to maintain and regular restoration of infiltration capacity and removal of clogging layers is relatively easy though time consuming. This method also allows for natural, quality improving processes, to take place in the infiltration ponds and subsoil. Construction is normally comparatively simple and of low cost. Impermeable topsoil may, however, rise the costs . The infiltration from a recharge basin produces a groundwater mound above the original water table. The groundwater mound grows over time and once the infiltration stops, it decays gradually. see Figure (2.1) (Herman, 2002).

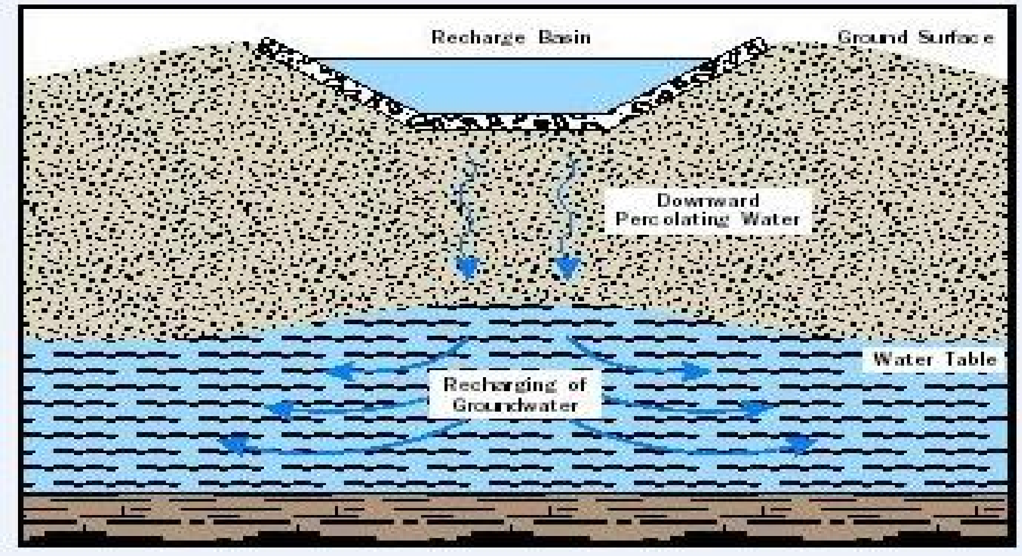


Figure (2.1): Typical Infiltration basin

2.1.3.2 Well infiltration

Infiltration wells or injection wells are used where permeable soils and/or sufficient land area for surface infiltration are not available, See figure (2.2) .Well infiltration calls for very high quality of the infiltration water if clogging of the well screen and the aquifer in the vicinity of the well is to be avoided. The construction is more complicated and costly and restoration of the hydraulic conductivity around the wells may be unfeasible, if not impossible. The best strategy for dealing with clogging of recharge wells is to prevent it by proper treatment of the water before injection. This means removal of suspended solids, organic carbon, nutrients like nitrogen and phosphorous, and microorganisms (Herman, 2002).

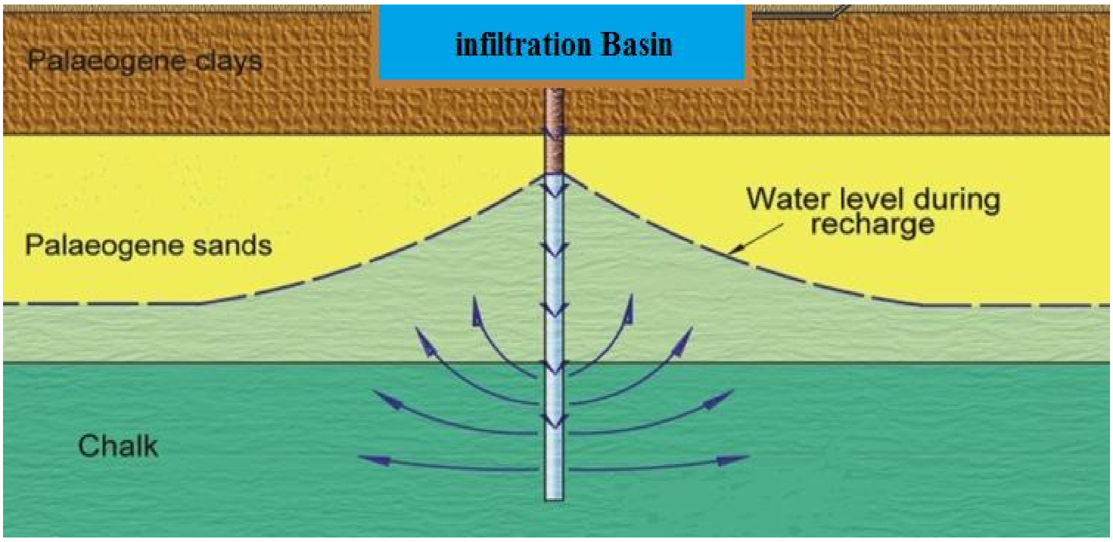


Figure (2.2): Typical of Infiltration using wells

2.2 Storm Water

Storm water is defined as the flow of water that results from precipitation and which occurs immediately following rainfall or as a result of snow melt. When a rainfall event occurs, several things can happen to the precipitation. Some of the precipitation infiltrates into the soil surface, some is taken up by plants, and some is evaporated into the atmosphere. Storm water is the rest of the precipitation that runs off land surfaces and impervious areas (Patchett and Wilhelm, 1999)

Storm water discharges are generated by precipitation and runoff from land, pavements, building rooftops and other surfaces. These hardened surfaces are called 'impervious surfaces' and they do not allow rainfall to infiltrate into the soil surface like natural vegetation, so more of the rainfall becomes storm water runoff. Storm water runoff accumulates pollutants such as oil and grease, chemicals, nutrients, metals, bacteria as it travels across land. Heavy precipitation or snowmelt can also cause sewer overflows that may contaminate water sources with untreated human and industrial waste, toxic materials, and other debris (Patchett and Wilhelm, 1999)

2.2.1 Relationship between Storm water and Land use

The quality and quantity of storm water runoff depend on the types of land use or activities in the drainage area. In general:

- Natural areas with open vegetated spaces result in small amounts of runoff with few pollutants.
- Developed areas may result in larger volumes of runoff, causing accelerated erosion and flooding.
- Industries, businesses and residential areas may result in large amounts of pollutants in the runoff (Arnold et al., 1993).

In general, developed areas with large impervious surfaces do not allow the water to infiltrate, or be absorbed, into the soil, causing increased runoff. The industrial, commercial and residential activities in developed areas bring more pollutants into contact with storm water and these pollutants are then carried into streams and rivers with the runoff. Thus, the type of land use - natural, commercial, industrial or residential - affects both the quantity and quality of storm water runoff as shown in Figure (2.3).

The quantity of storm water that runs off a parcel of land increases when storm water runs off impervious surfaces such as compacted soil, roofs, parking lots and roads that are created as a result of development. These impervious surfaces prevent infiltration of the water into the soil, directly increasing the volume of water flowing over the land and into the streams draining the area (Arnold et al., 1993).

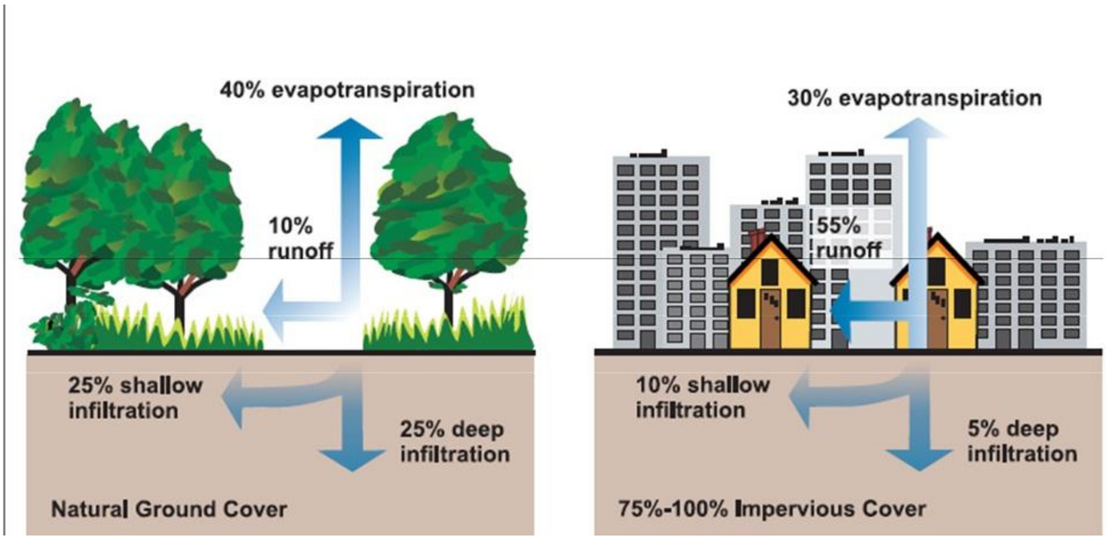


Figure (2.3): Relationship between land use and surface runoff

2.2.2 Storm Water Runoff Pollutants

Polluted storm water runoff generally happens anywhere people use or alter the land. People going about their daily lives are the major source of storm water pollutants see figure (2.4). Most people are unaware of how they impact water quality. Some common examples include over fertilizing lawns, excessive pesticide use, pet waste, using salt or fertilizer to de-ice driveways, letting oil drip out of their vehicles and littering. Developed areas in general, with their increased runoff, concentrated numbers of people and animals, construction and other activities, are a major contributor to NPS pollution, as are agricultural activities. Other contributors include forest harvesting activities, roadways, and malfunctioning septic systems (Schillinger and Gannon, 1985)

Few pollutants ever disappear from the urban landscape. They are merely transferred from one medium to another—from air to land, from land to surface water, or from soil to groundwater (Robert, 1994).

Figure (2.4): Sources of storm water pollutant

Storm water could usually infiltrate to groundwater without increasing the risk of pollution if it is not mixed with wastewater. The storm water could however, carry large amounts of sediments and suspended solids (Chralowicz et al., 2001) . Rainfall in urban areas can be a threat to groundwater by carrying contaminants into the ground water. There are three main types of storm water pollution: (Robert, 1994).

- Litter : such as cans, paper or plastic bags
- Chemical pollution: such as detergents, oil or fertilizers
- Natural' pollution :such as leaves, garden clippings or animal droppings

Our analysis of contaminant removal focuses on four of these categories: nutrients, metals, pathogens, and synthetic organic chemicals, as discussed in Removal of Storm water Contaminants. These contaminants come from a variety of sources, including residential, industrial, and commercial areas; streets and parking lots; and atmospheric deposition, as shown in Table (2.1). (Chralowicz et al, 2001).

Table(2.1):Sources of contamination in Urban Storm water Runoff (EPA, 1999b)

Contaminant	Contaminant Sources
Solids	Streets, lawns, driveways, roads, construction, activates, atmospheric, deposition, drainage channel erosion
Organic Materials	Residential lawns and gardens, commercial landscaping, animal wastes
Nutrients	lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion , animal waste, detergents
Metals	automobiles, bridges, atmospheric deposition, industrial area, soil erosion, corroding metal surfaces, combustion processes
Pathogens	Lawns roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems
Oil, Grease and Hydrocarbons	roads, driveways, parking lots, vehicle maintenance area, gas stations, illicit dumping to storm drains
Synthetic Organic Chemicals	residential lawns and gardens, roadsides, utility right-of -ways, commercial and industrial landscaped area, soil wash-off

2.2.3 Storm water Runoff Computations

This policy describes methods which can be used to determine rates and volumes of storm water runoff. It is important to remember that the physical relationship between precipitation and the rate and amount of runoff is very complex, and that computational methods which have been developed are empirical. When applying any hydrologic technique, the designer must be aware of its basic assumptions and limitations. Experience and good judgment must be used to evaluate the results.

2.2.3.1 Rational Method

The Rational Formula is the most commonly used method of determining peak discharges from small drainage areas. This method is traditionally used to size storm sewers, channels and other storm water structures which handle runoff from drainage areas less than 200 acres (FDER, 1988).

The Rational Formula is expressed as

$$Q = (C)(I)(A)$$

where:

Q = peak rate of runoff in cubic feet per second (cfs)

C = runoff coefficient, a dimensionless unit

i = average intensity of rainfall in inches per hour (in/hr)

A = the watershed area in acres (ac).

Components of the Rational formula

A - The Area

The area, A, draining to any point under consideration in a storm water management system must be determined accurately. Drainage area information should include:

- Land use - present and predicted future - as it affects degree of protection to be provided and percentage of imperviousness.
- Character of soil and ground cover as they may affect the runoff coefficient.
- General magnitude of ground slopes which, with previous items above and shape of drainage area, will affect the time of concentration. This includes information about individual lot grading and the flow pattern of runoff along swales, streets and gutters.

C - The runoff coefficient

The runoff coefficient, C, is expressed as a dimensionless decimal that represents the ratio of runoff to rainfall. Except for precipitation, which is accounted for in the formula by using the average rainfall intensity over some time period, all other portions of the hydrologic cycle are contained in the runoff coefficient. Therefore, C includes interception, infiltration, evaporation, depression storage and groundwater flow. The variables needed to estimate C should include soil type, land use, degree of imperviousness, watershed slope, surface roughness, antecedent moisture condition, duration and intensity of rainfall, recurrence interval of the rainfall, interception and surface storage. The fewer of these variables used to estimate C, the less accurately the rational formula will reflect the actual hydrologic cycle.

The use of average runoff coefficients for various surface types is common. In addition, C is assumed to be constant although the coefficient will increase gradually during a storm as the soil becomes saturated and depressions become filled.

I - Rainfall Intensity

The determination of rainfall intensity, I, for use in the Rational Formula involves consideration of three factors:

- Average frequency of occurrence.
- Intensity-duration characteristics for a selected rainfall frequency.
- The rainfall intensity averaging time, Tc.

The critical storm duration that will produce the peak discharge of runoff is the duration equal to the rainfall intensity averaging time.

The rainfall intensity averaging time, Tc, is usually referred to as the time of concentration. However, rainfall intensity averaging time more accurately defines the reason for and the use of this variable. Tc is not the total duration of a storm, but is a period of time within some total storm duration during which the maximum average rainfall intensity occurs.

2.2.4 Storm water Basin

Storm water basins are permanent structures designed to replace the natural water storage of a site and provide some water quality improvement after the site is completed. Historically, the primary purpose of storm water basins was to reduce on-site and downstream flooding by controlling the rate of storm water discharge. Secondary benefits include water quality improvement such as sediment removal, aesthetics, and recreational opportunities. Many of these secondary benefits are now being incorporated into the design of storm water basins.

2.2.5 Response to rainfall

Groundwater level fluctuations due to rain infiltration depend mainly upon the soil type, land use and rain intensity. In the north (Beit Lahia) one well was selected (A/107) as an indicator to it. Water level of the well showed response to rainfall. Figure (2.5) show the distribution of rainfall in three consecutive years in the north, respectively, while Figure (2.6) shows the response of groundwater levels in monitored water wells that is located in the same areas represented by the measured rain stations.

In November 2004, at the beginning of the rainy season, water level was measured to be-2.581 amsl and increased to-2.001 amsl in March 2005, which is the end of the rainy season giving a total increase of groundwater level of + 0.58 m (Hamdan, 2007).

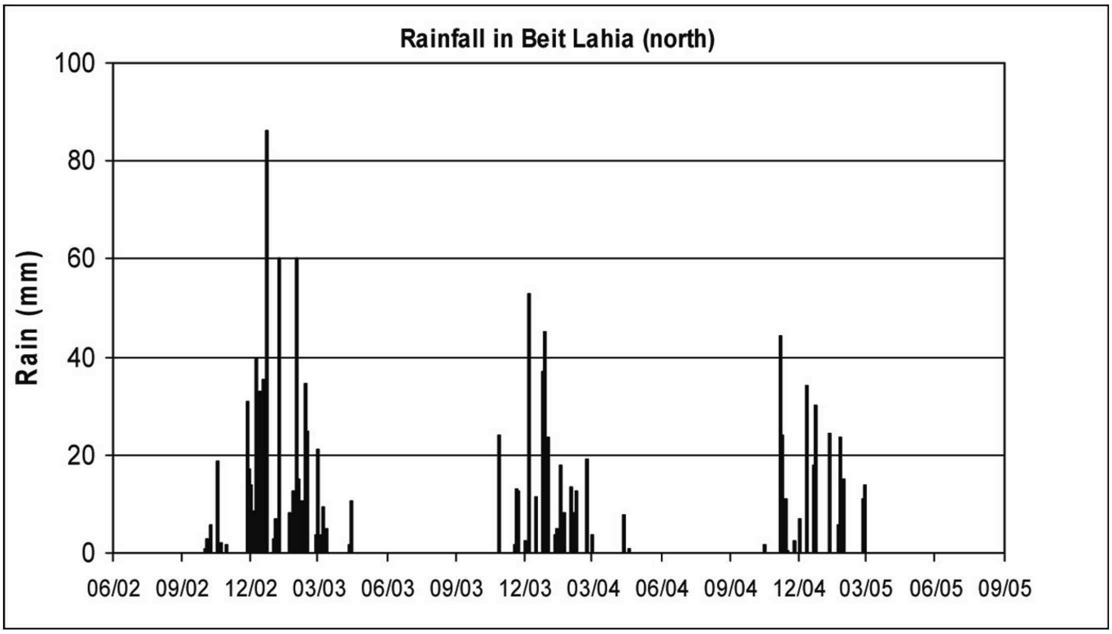


Figure (2.5): Rainfall in north Gaza

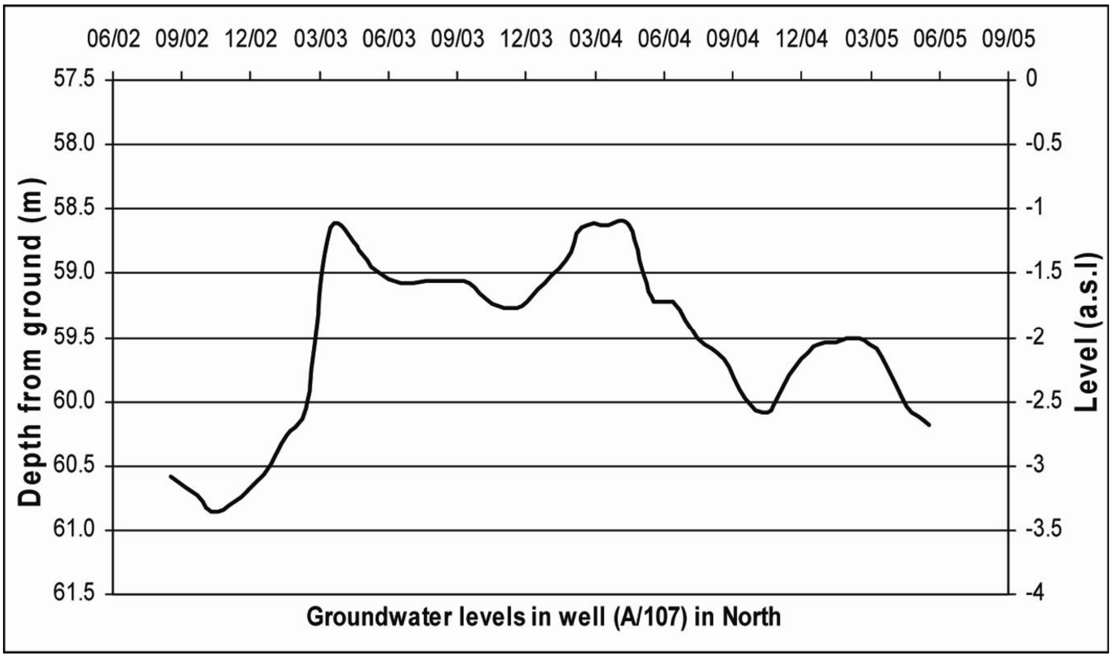


Figure (2.6): Response of groundwater level in well (A/107)

These examples give an indication that the groundwater system responds rapidly to rainfall which encourages harvesting all urban storm water as one of the most important sources in Gaza (Hamdan, 2007).

2.3 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 though to represent 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).

2.3.1 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:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right)+R(x,y,z)=S_s \frac{\partial h}{\partial t}$$

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

2.3.2 Darcy's law

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

q = - K . grad (h)

where q is the groundwater flux (LT^{-1})

K is the conductivity tensor (LT^{-1})
grad (h) is the gradient operator.

This equation clearly shows that the cause of groundwater movement is the difference in the hydraulic potential. The potential is a function of all threespace coordinates, that is h = h(x,y,z), the rate of change of head with position giving the gradient, which multiplied by the conductivity yields the groundwater flux (Wang and Anderson, 1982).

The hydraulic conductivity is represented by a second order tensor that takes into account anisotropic conditions. Usually, anisotropy is only considered in the vertical and horizontal direction, hence

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

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

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

Where qx, qy, qz are the three components of the flux, and Kx, Ky, Kz the hydraulic conductivity values in the horizontal (x,y) and vertical (z) direction. In case of isotropic conditions, Kx = Ky = Kz each component of q is the same scalar multiple K of the corresponding component of -grad (h), such that the vectors q and -grad (h) both point in the same direction (Aish, 2004).

2.4 Monitoring Wells

The monitoring of the storm water infiltration basin includes the measurement of, storm water inflow to the infiltration basin, transfers of water and pollutants through the groundwater, impacts of these transfers on groundwater quality and quantity. (Barraud et al., 2006). The purpose of the monitoring wells is to provide controlled access for sampling ground water near an agricultural waste storage or treatment facility in order to detect seepage and monitor the effects of contaminants in seepage on ground water quality .

2.4.1 Hydrogeologic Investigation.

Prior to the design of a monitoring well, a surface and subsurface investigation shall be conducted to develop a conceptual hydrogeologic model of the site, to identify potential ground water flow paths, and to determine the location of the target monitoring zone.

The hydrogeologic investigation shall include the mapping, identification and description of soil and rock masses that affect the movement and transport of subsurface water occurring within at least 100 feet of the perimeter of the facility of interest. The hydrogeologic investigation shall identify and describe all characteristics and properties of geologic units that can influence subsurface water flow paths or produce preferred flow paths such as Karst development, joint sets, fracture systems, faults, lineaments, and other similar discontinuities. These shall be located on a geologic evaluation map of the site.

2.4.2 Layout of the monitoring wells

Monitoring wells shall be located both up gradient and down gradient of the waste storage facility and at a distance and depth based on the results of the hydrogeologic investigation of the site. The placement of monitoring wells in fracturedrock and karst aquifers shall be based on the location of zones of high-permeability even if they are located offsite.

A minimum of one monitoring well shall be placed on the up gradient side of the waste storage facility and a minimum of three monitoring wells shall be placed down gradient. When seasonal changes in the direction of subsurface water flow are possible, monitoring wells shall be placed in such a manner as to capture both up gradient and down gradient flow during any time of year. The layout of the monitoring wells shall be based on the conceptual hydrogeologic model to intercept representative subsurface water flow path of the target monitoring zone.

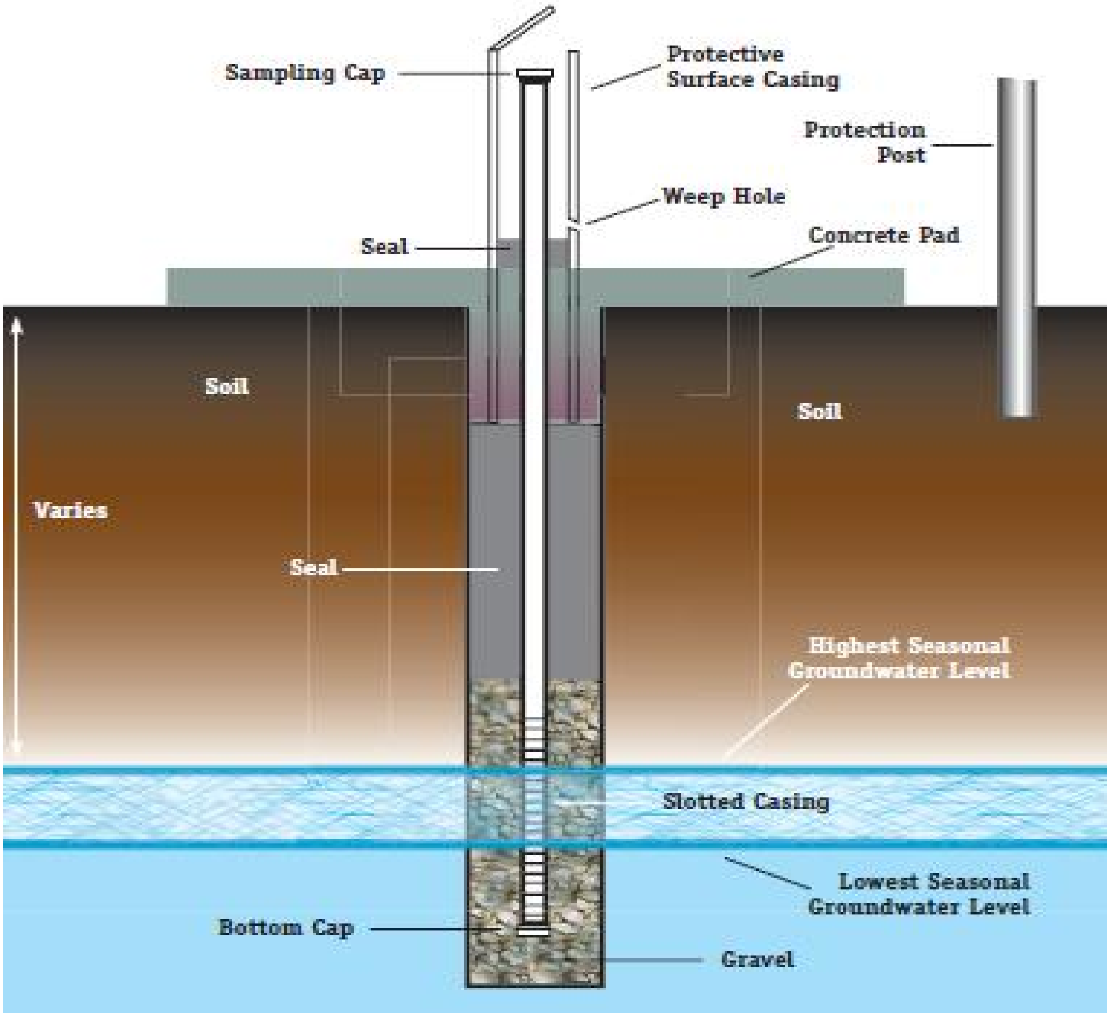


Figure (2.7):Typical Ground water monitoring well

2.4.3 Materials

Materials used for the construction of monitoring wells shall be non-reactive with subsurface water and shall not leach substances into the subsurface water. Materials shall be free of contaminants prior to installation. Well screens shall be made by machine. All joints shall be threaded. Glued or solvent welded joints shall not be used. Materials shall have adequate strength to withstand the forces of installation and development.

2.4.4 Installation

Installation methods shall be selected based on site-specific conditions. The equipment used shall be capable of creating a stable, open, vertical borehole for installation of the monitoring well.

2.4.5 Geologist information

Monitoring well or piezometer locations, depths, and construction details must be determined by a Maine Certified Geologist (C.G.), based on interpretation of the geology and hydrogeologic regime at a project site, in order to provide valid groundwater monitoring data. To adequately interpret information obtained from monitoring wells, the investigating C.G. must provide a properly-endorsed monitoring well installation report to the Department. This report should contain a brief narrative which indicates the date each monitoring point was installed, the method of installation, the purpose/objectives of the monitoring network, and a discussion on the basis for selection of monitoring well locations and depths.

2.4.6 Type of Monitoring wells

The earliest systems designed for sample collection rather than full scale monitoring including sampling, level measurements and permeability testing. Prior to advancements in multilevel instrument design this detailed monitoring was accomplished either by drilling numerous separate boreholes to various depths, often referred to as a cluster type installation, or by installing a series of piezometers at different depths in a single borehole, nested type Figure (2.8). The single hole, nested type piezometers were introduced to limit costs and disturbance to the aquifer. However, uncertain seal placement resulting in possible interconnection between monitoring zones resulted in the (EPA, 1986) stating that "Information obtained on multiple piezometer placement in a single borehole may generate erroneous data". Cluster type installations, subsequently, became the more popular approach. Today’s modular type multilevel monitoring installations are continually increasing in reliability, with improvements in the integrity of seals, and flexibility to become the best option for the majority of projects involving groundwater monitoring. (Cherry and Johnson,1982)

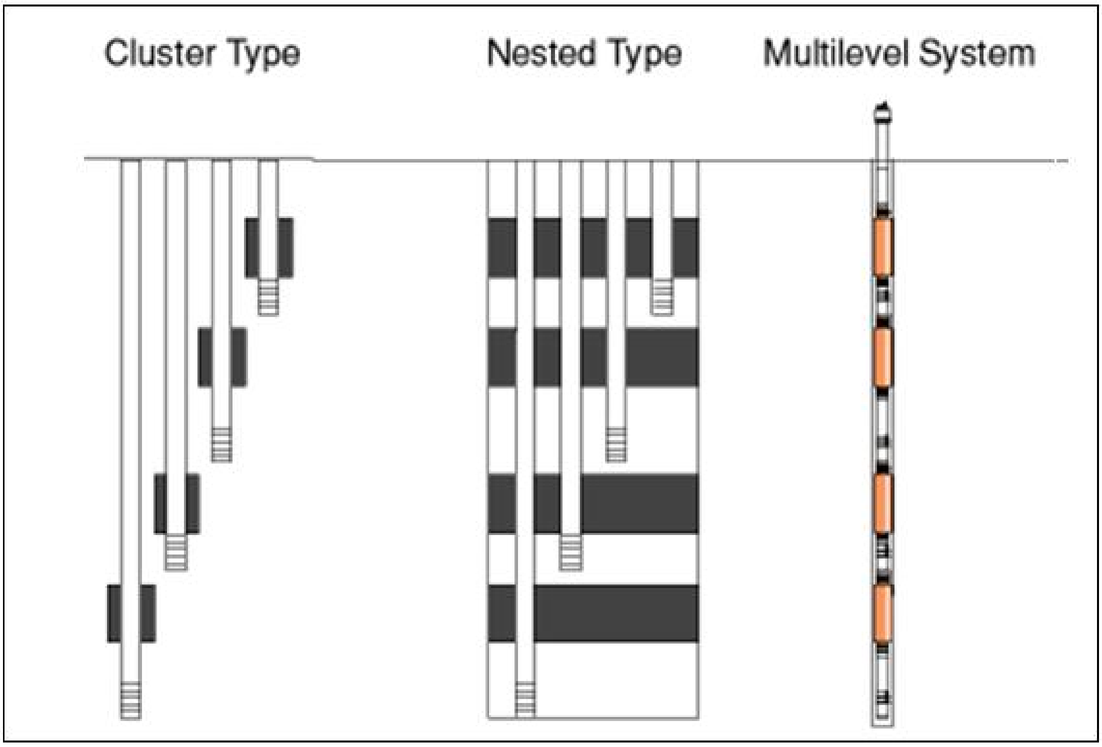


Figure (2.8): type of monitoring wells

2.5 Computational tools

2.5.1 Visual MODFLOW

MODFLOW is a computer program that numerically solves the three-dimensional ground-water flow equation for a porous medium by using a finite-difference method. Although MODFLOW was designed to be easily enhanced, the design was oriented toward additions to the ground-water flow equation. Frequently there is a need to solve additional equations; for example, transport equations and equations for estimating parameter values that produce the closest match between model-calculated heads and flows and measured values (Harbaugh, et al., 2000)

MODFLOW is a computer program that simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method (McDonald and Harbaugh, 1988).

2.5.1.1 MODFLOW

modflow, "a three-dimensional finite-difference groundwater flow model" by Michael G. Mcdonald and Arlen W. Harbaugh, is the most widely-used groundwater model in the world .

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

Groundwater flow within the aquifer is simulated in MODFLOW using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated . (Harbaugh,et al, 2000)

2.5.1.2 Modpath

MODPATH, "A Particle Tracking Post-Processing Package for MODFLOW, the USGS 3-D Finite-Difference Ground-Water Flow Model (MODFLOW)," is the most widely-used particle tracking program in the world MODPATH is a particle tracking post-processing package that was developed to compute three-dimensional flowpaths using output from steady-state or transient ground-water flow simulations by MODFLOW. MODPATH uses a semi-analytic particle tracking scheme that allows an analytical expression of the particle's flow to be obtained within each finite-difference grid cell. Particle paths are computed in MODPATH by tracking particles from one cell to the next until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion. Data input for MODPATH is a combination of data files and interactive keyboard input. Output from steady-state or transient MODFLOW simulations is used in MODPATH to compute paths for imaginary "particles" of water moving through the simulated ground-water system. In addition to computing particle paths, MODPATH keeps track of the time of travel for particles moving through the system. By carefully defining the starting locations of particles, it is possible to perform a wide range of analyses such as delineating capture and recharge areas or drawing flow nets. (Harbaugh,et al, 2000).

2.5.1.3 MT3D

MT3D is a comprehensive three-dimensional numerical model for simulating solute transport in complex hydrogeologic settings. MT3D has a modular design that permits simulation of transport processes independently or jointly. MT3D is capable of modeling advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and nonlinear sorption. (Harbaugh,et al, 2000)

The model was developed by the US Environmental Protection Agency (EPA) as an extension of MODFLOW. Using simulation results of MODFLOW, MT3D will predict the fate of chemicals dissolved in the groundwater in function of advection, dispersion, absorption and decay. Hence, the model uses output files from MODFLOW as input for obtaining the groundwater flows. Boundary conditions for transport can be added together with dispersive and absorptive properties of the ground layers, as well as chemical reaction characteristics (Aish ,2004)

Chapter 3
Study Area Description

3.1 Geography

3.1.1 Location

The study area is 4 km^2 is located in the north of Gaza Strip (in the middle of Beit Lahia) as shown in Figure (3.1) .

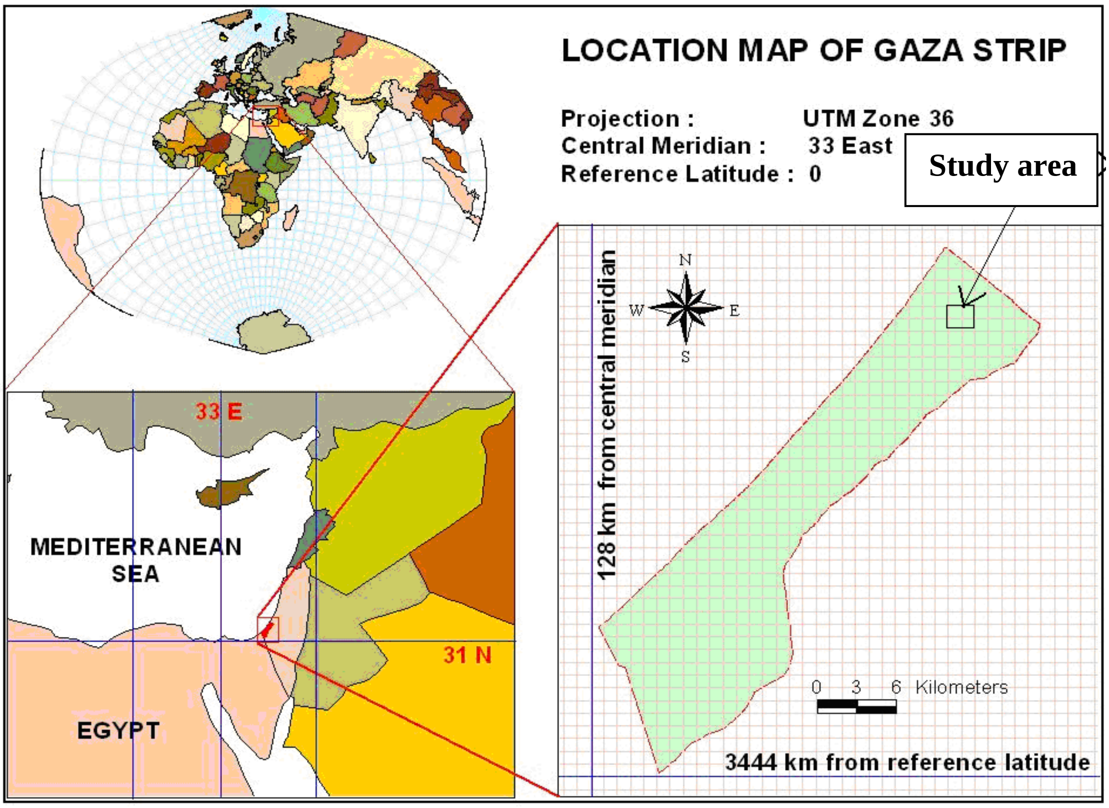


Figure (3.1): Location map of Gaza strip

3.1.2 Topography

The study area is a depressed area surrounded by Tel EL Zater mountain (+60m) from east and Beit lahia Tilet (+40m) from west while the site level is ranging between +19 m to +25m above mean sea level (MSL). The site is surrounded by unpaved roads from the east and neighbors from other sides . see Figure (3.2)

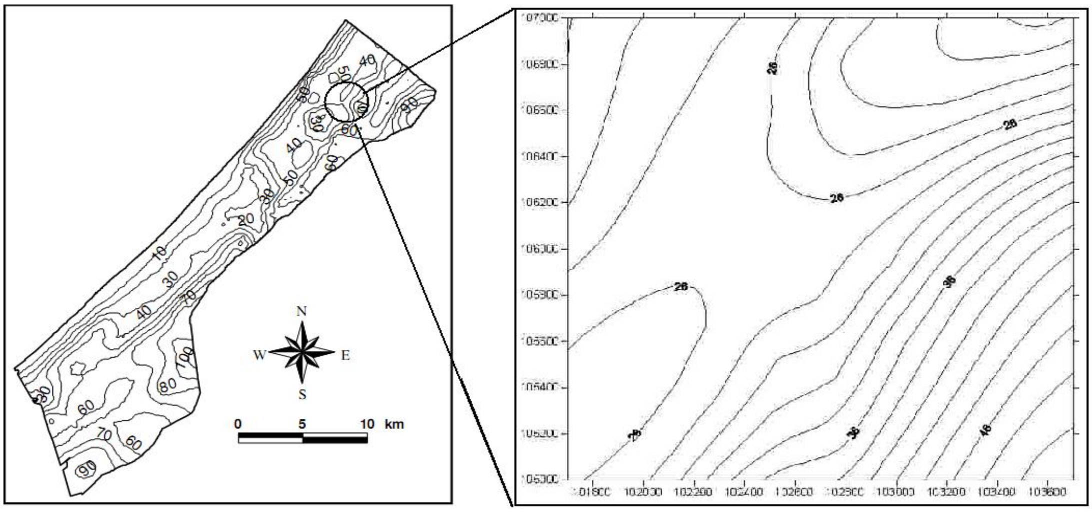


Figure (3.2): Topography of Gaza strip and the study area (m)

3.1.3 Population

The northern part of Gaza Strip is considered as one of the most densely populated areas all over the world. In 2004, more than 780,000 inhabitants were crowded in to an area of about 135 km^2. The natural rate of population growth in the Gaza Strip is estimated at 4% per year. (PCBS, 2004)

3.1.4 Climate

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.

3.1.5 Rainfall

Rainfall is measured in the Gaza Strip at 12 rain gauge stations distributed spatially at the whole area and representing all zones from north to south as shown Figure (3. 3) . The average rain head fluctuates from 200 mm /y in the south of Gaza Strip to about 450 mm /y in the north. (Hamdan, el at. ,2007). On average, rainfall over Gaza Strip as a bulk quantity is estimated to be about 114.1 Mm^3/y. Rainfall replenishes the aquifer with an average amount of 40.8 Mm^3/y . as a part of the total supply to the aquifer 107.9 Mm^3/y (PWA, 2005).

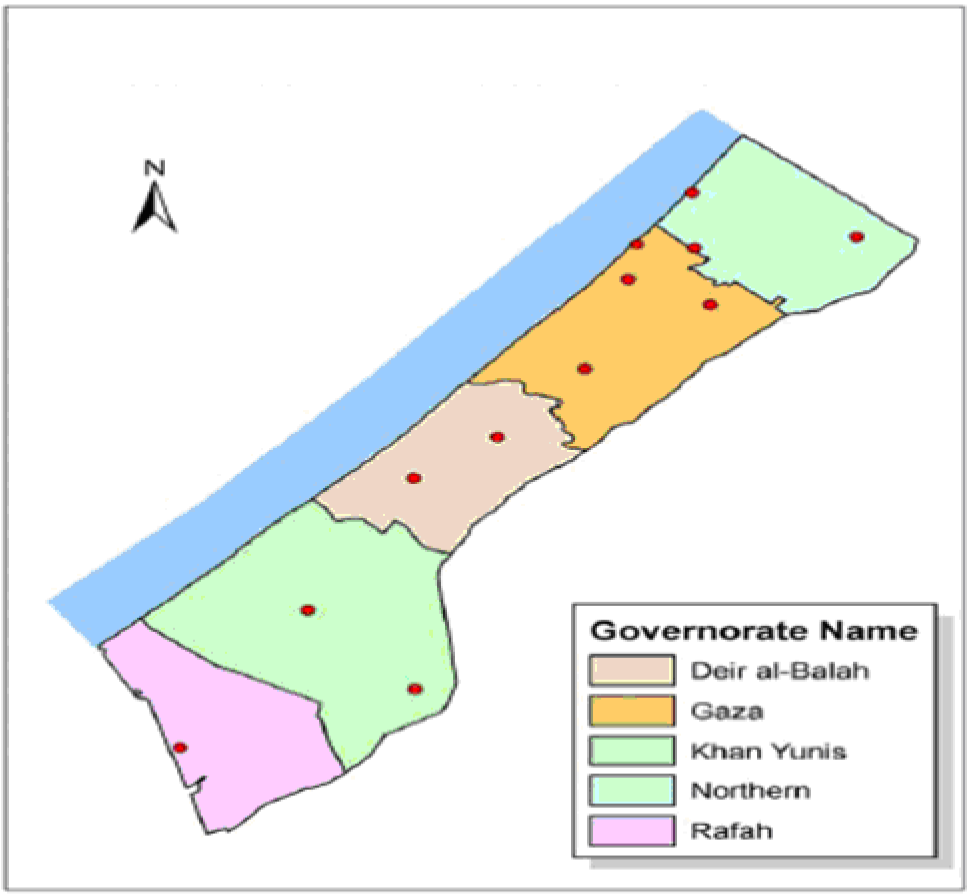


Figure (3.3): Location of rainfall stations in Gaza Strip.

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

For year 2007, it was observed that the total accumulated rainfall, exceeded the normal seasonal rainfall at all station sites as shown in Figure (3.4) Furthermore, about 20 percent of Gaza strip area received rainfall between 500-550 mm, 50% received between 300 – 500 mm and 30 percent of the area received less than 300 mm as shown in Figure (3.5). Monthly rainfall was also calculated for all Gaza strip station sites (to more information see annex 1). In 2006-2007 rainy season extended from September 2006 to May 2007 where the maximum rainfall is in January 2007, and maximum of non rainy days is in February 2007. (PWA, 2007)

Table (3.1): Average rainfall depth in Gaza Strip

station name	Accumulated observed rainfall /station(mm)	Normal Rainfall / station(mm)	Governorate	Accumulated observed rainfall (mm) / governorate	Total rainfall quantity (Mm^3)
Beit Hanon	509.9	418	North	521.9	30.7
Beit Lahia	530.3	433			
Jabalia	536.7	432			
shati	469	392	Gaza	460.4	33.8
Gaza city	501.2	370			
Tuffah	545.5	434			
Gaza South	388.2	400			
Nussirate	403	354	Middle	411.5	28
Dr-Elbalah	418	324			
khan Younis	252	290	khan Younis	253.4	31.9
khuzaa	256.1	250			
Rafah	225	236	Rafah	225	8.7
Average rainfall depthy(Gaza strip)			**364.7mm**		**133.1Mm^3**

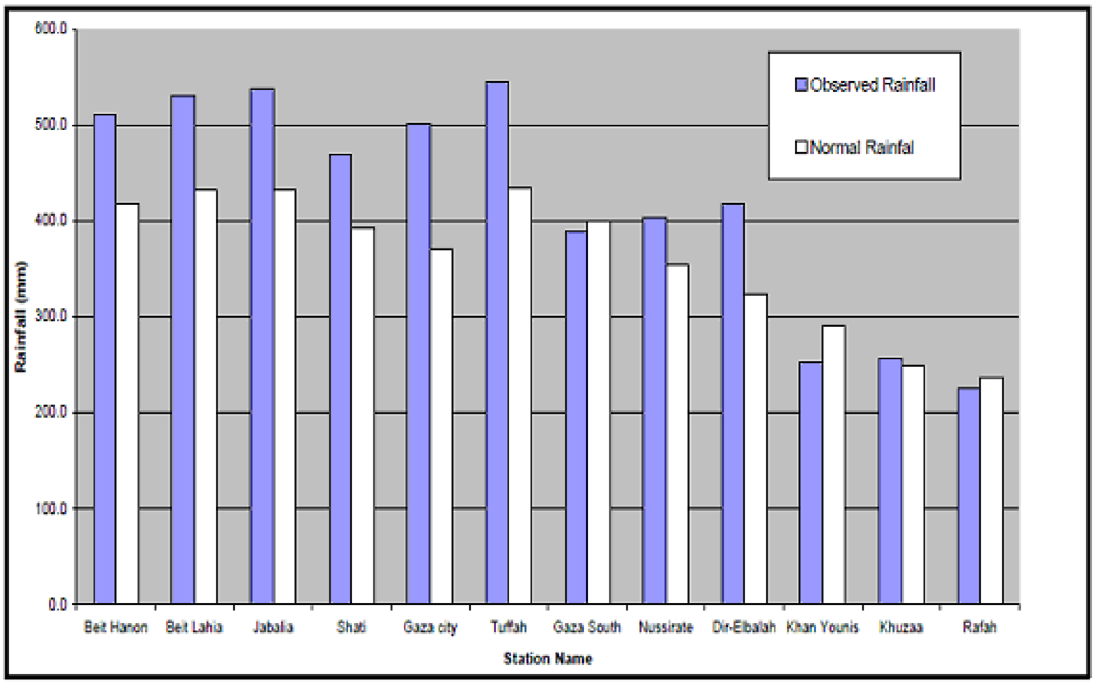


Figure (3.4): 2006-2007accumulated recorded rainfall depth & normal rainfall depth

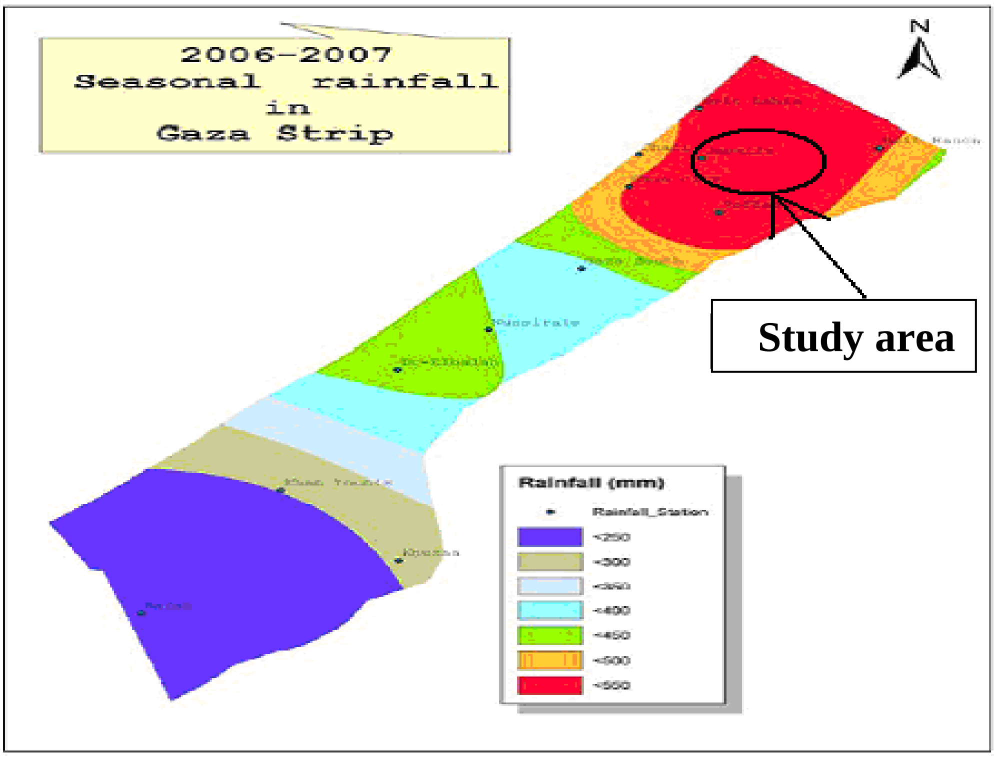


Figure (3.5): Rainfall depth contour map in year 2007

3.1.5.1 Storm Water Run Off

The Palestinian Water Authority (PWA) has identified of storm water harvesting as an important resource to bridge the gap between water resources demand and supply. Its strategy was to maximize rainwater recharge as far as practical by recharging runoff from large surface areas and introduction of flood alleviation measures at the source (PWA, 2000). Storm water will be increased due to urbanization and runoff water will increase. So, some storm water facilities were proposed by the storm water master plan to mitigate floods and harvest the collected storm water. The initial amounts of artificial storm water recharge are estimated to be 4.25 Mm^3/y at 2005 and will increase to reach only 7.1 Mm^3/y in the year 2020 (Metcalf and Eddy, 2000), where this forms only 30% of storm water coming from urban areas 22.2 Mm^3/y (hamdan ,2007). The runoff waters of about 27.8 Mm^3/y and this will increase to about 42.6 Mm^3/y when the planned land use is implemented in the coming decade. Until now, this runoff is still used partially in different projects of rainwater harvesting in Gaza Strip, and some projects faced difficulties in implementation. There are projects for storm water collection, but they serve flood mitigation measures only, without harvesting it for recharging the aquifer. Most of this water is pumped to the sea. Storm water harvesting became a priority issue firstly to mitigate flooding and secondly, to add to the existing limited water resources. (Hamdan ,2007)

Urban storm water harvesting is an important water resource that plays a significant role in enhancement of water resources management in Palestine, in general and in Gaza Strip in particular (Hamdan, 2007)

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

These amounts of storm water in Gaza Strip will reach about 37 Mm^3/y from planned urban areas. The amount of runoff of the completely planned area is calculated to be about 43 Mm^3. When urban expansion is implemented as planned, the natural infiltration of rainfall to the aquifer will decrease, and these amounts of runoff are good resources to be utilized (Hamdan , 2007).

3.1.6 Soil

Soil media refers to upper of the phreatic zone. Soil media is an important factor in terms of movement of pollutants. All the infiltration processes take place in the upper soil . The soil varies in the study area. It is composed mainly of three types : sand , clay and loess as shown in the soil map (Figure 3.6). The thickness of sand fluctuates from 2 meters to about 50 meters due to the hilly shape of the dunes. Clay soil is found in the north eastern part of Gaza Strip. Loess soil is found around Wadis, where the approximate thickness reaches about 25 to 30 m. (Jury and Gardner, 1991).

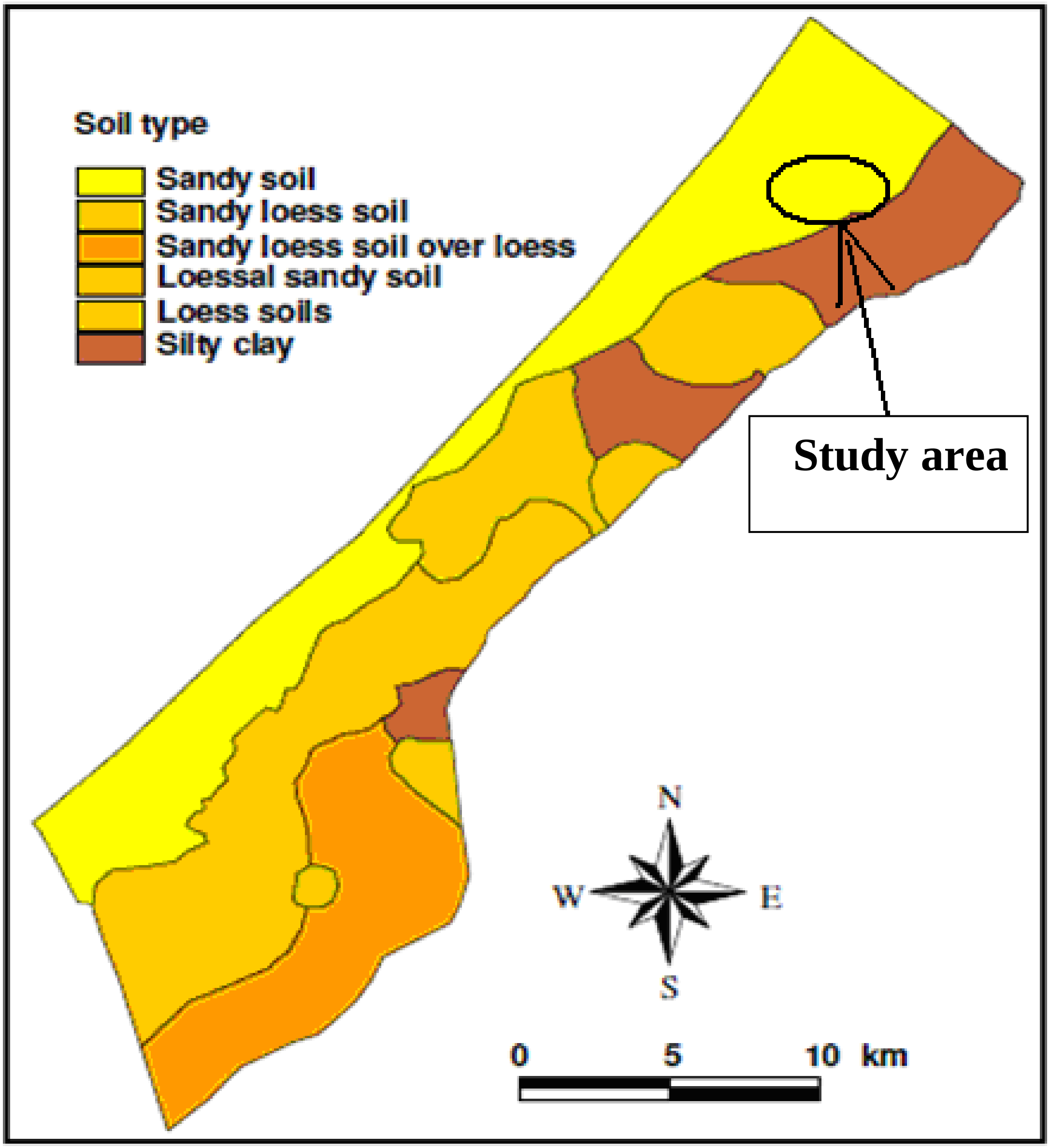
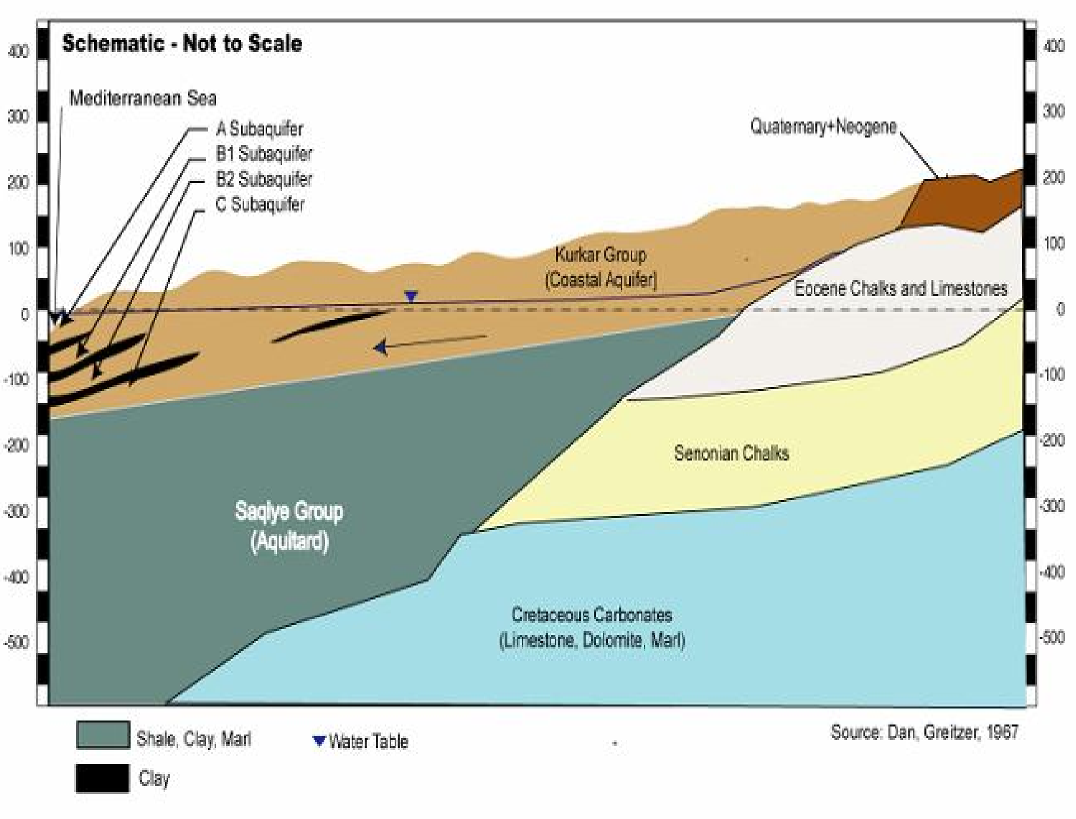


Figure (3.6): soil map of the Gaza strip (PWA, 2003)

3.2 Geology

Geology of the Gaza strip was obtained from oil and Gas exploitation logs up to depth of about 2000 m drilled by Israelis and from Wells drilled during the Costal Aquifer Management Project (CAMP)

The coastal aquifer of the Gaza strip consists of the Pleistocene age Kurkar group (Gvirtzman, 1984) and recent (Holocene age) sand dunes. The Kurkar group consists of marine and Aeolian calcareous sandstone (Kurkar), reddish silty sandstone (Hamra), silts, clays, unconsolidated sands and conglomerates. Regionally, the Kurkar group is distributed in a belt parallel to the coastline, from Haifa in the north to the Sinai in the south. Near Gaza Strip, the belt extends about 15-20 km inland, where it unconformable overlies Eocene age chalks and limestones (the Eocene), or the Miocene-Pliocene age Saqiye group, a 400-1000 m thick aquitard beneath the Gaza Strip, consisting of a sequence of marls, marine shale’s and claystones. (Aish , 2004) Figure 3.7 presents a generalized geological cross-section of the coastal aquifer.



Source: Dan, Greitzer, 1967

Figure (3.7): Typical cross section of Gaza Strip Aquifer (PWA, 2000a)

3.2.1 Geology of Study Area

The site is a depressed area and part of Al wadi area filled by 17m depth of alluvium clay/clayey silt deposits over deep calcareous sand and sandstone and covered at the top by a 4.0 m thin layer of dune sand . The top layers were previously excavated inside the old infiltration basin which was surrounded by gabion and concrete wall. The subsoil in the site can be generally classified into the following layers as shown in boring logs and soil profile. The layers encountered and their engineering characteristics are described below in Figure (3.8). (IUG, 2007)

The First Layer

The top layer under the basin consists of yellowish fine to medium clean non-plastic dune sand of high permeability, wet, medium dense. The fines percentage is 1 % while the gravel is 0.0 % and there mains is sand. The natural water content is 2.6 %. This layer is covered at the surface by sandy clay fill of 0.6m thick. The layer almost extends from surface up to 4m depth. This layer is high permeable where the hydraulic conductivity is 1×10^{-2} cm / sec.

The Second Layer

The second layer is brown /dark brown, stiff, medium to high plasticity clay/clayey silt with fine kurkar gravel. The fines percentage is 67 to 87% while the gravel is 1-2% and the remains are sand. The natural water content is 13-30 %. The liquid limit is 29-63 % and the plasticity index is 13-29%. The layer is of very low permeability. This layer extends from 4.0 m up to 23 m depth below existing ground surface.

The Third Layer (KURKAR)

The third layer is composed of yellowish calcareous non-plastic fine to coarse sand with fragments and layers of cemented coarse sand stone (KURKAR) (dense and wet). The fines percentage is (3-9) % while the gravel is 1-60 % and the remains are sand. The natural water content is 1to 3%. The coefficient of permeability of Kurkar layer is in the range of 0.1 to 3.5×10^{-3} cm/sec. This layer appeared from depth of 17m to 23 m up to the end of boring 25m .

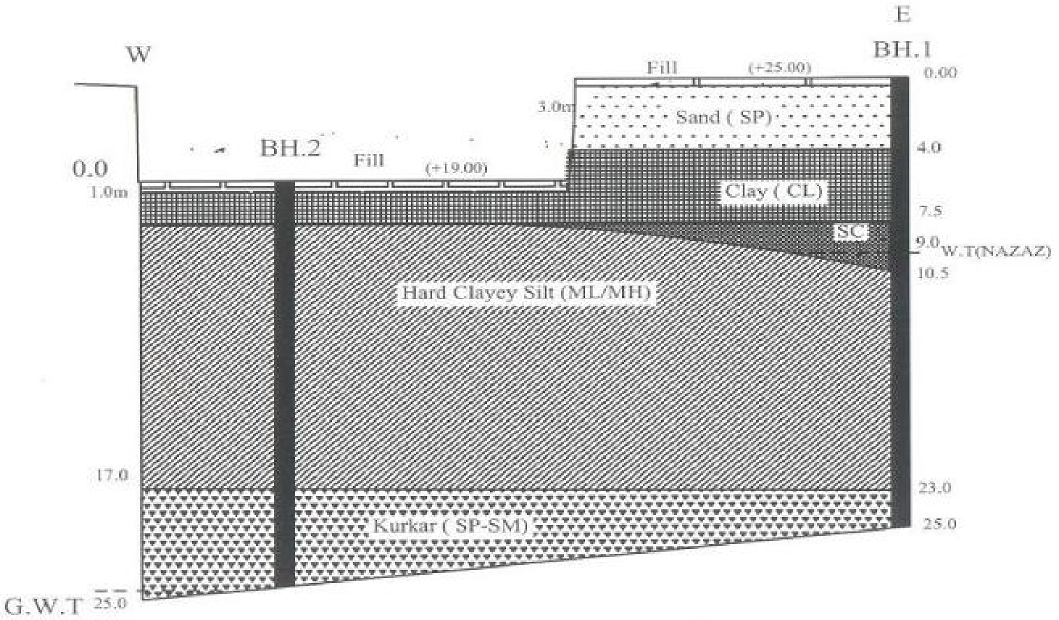


Figure (3.8): Soil profile under Biet Lahia Municipality infiltration Basin

3.3 Hydrology

The coastal aquifer consists of interfering continental and marine units composed of sandstone, calcareous sands, siltstone, and red loamy stone. The bottom formation consists of thick compact marine clay (Saqyieh formation), This layer is dipping toward the sea at an average slope of 10m per kilometer (MOPIC,1998).

The hydrogeology of the coastal aquifer consists of one sedimentary basin, the post-Eocene marine clay (Saqyieh) which fills the bottom of the aquifer, Pleistocene sedimentary deposits of alluvial sands, graded gravel, conglomerates, pebbles and mixed soils which constitute the regional hydrological system. Intercalated clay deposits of marine origin separate these deposits. these clay lenses are randomly distributed in the area. Their thickness is decreasing to the east and basically, they can be classified as aquitards. In the eastern plains the aquifer is semi-confined with an average thickness of 10 m clay, becoming phreatic 4 km from the sea (MOPIC,1998).

3.3.1 Water Table

The groundwater level ranges between 5m below mean sea level (MSL) to about 6m above mean sea level as shown in Figure (3.9). The groundwater level corresponds to depth below the soil surface between 0 and 95 m.

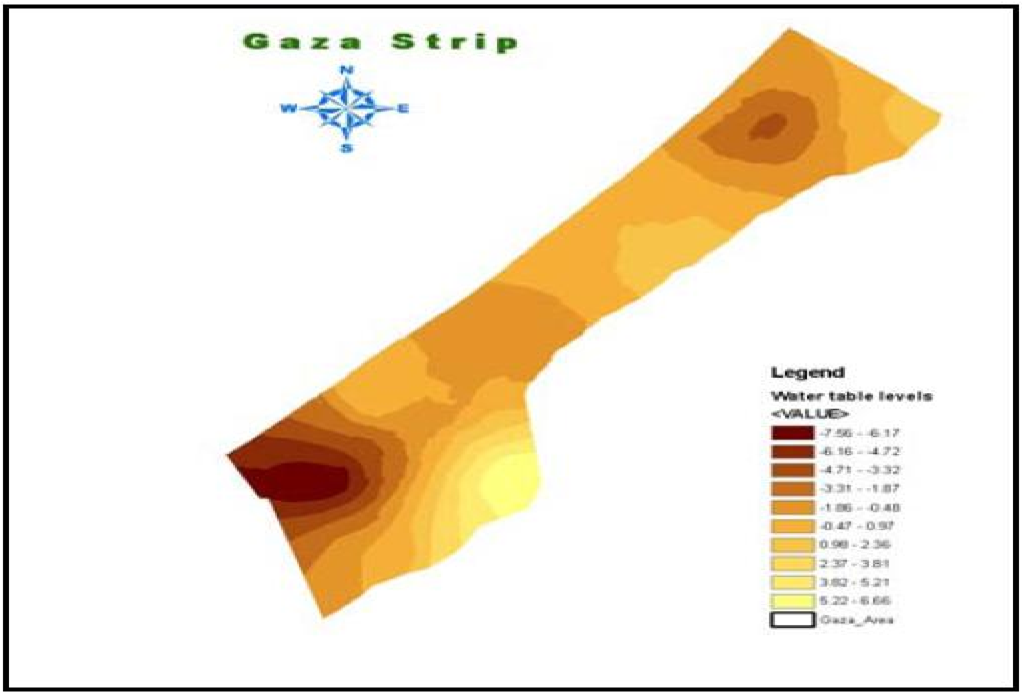


Figure (3.9): Water level Contour Map (PWA-databank,2007)

3.3.2 Groundwater flow

During the 1930's, before intensive exploitation of the aquifer began, the predominant direction of water flow was from east to west, with groundwater draining ultimately into the sea. Gradient levels varied between 0.1 - 0.3%. Since the 1930's, water exploitation has come to exceed natural replenishment, resulting in a steady lowering of the water table as well as accompanying alterations in direction of groundwater flow. Over-pumpage of the Coastal aquifer has led in certain areas to the development of hydrological depressions, preventing outflow of contaminants from these areas to the sea, and leading to a deterioration of groundwater quality of the more inland zones of the Coastal aquifer (Melloul et al., 2006).

3.3.3 Recharge

Recharge from the rainfall is the most important line in the water budget of Gaza coastal aquifer were it can be considered as a renewable resources. Using the WetSpass - Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State (Batelaan and DeSmedt, 2001), the average annual recharge was estimated to be about 41 Mm^3/y ; the recharge map is presented in Figure (3.10).

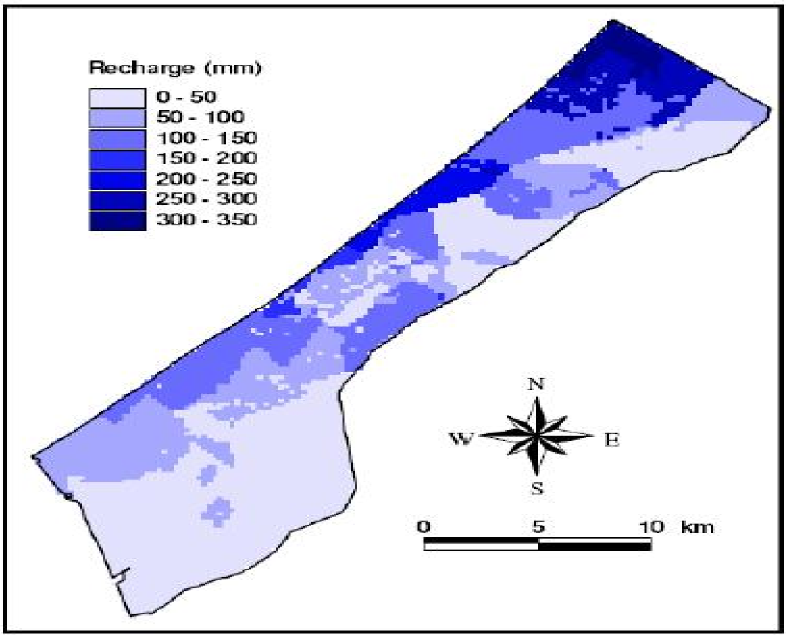


Figure (3.10): Annual groundwater recharge

The inputs for WetSpass model are: physical and hydrological parameters of the area; namely, the topography, the soil type, wind speed and potential evapotranspiration. Using Cumulative Rainfall Departure method (CRD) (Baalousha, 2005), the estimated annual amount of groundwater recharge from rainfall in the Gaza Strip is about 43 Mm^3. The input data for CRD method are: rainfall, measured groundwater level, storativity, lateral flow, and pumping.

Based on CAMP study, 2000, the average annual recharge was estimated 40-45 Mm^3/y, using groundwater modeling of Gaza coastal aquifer, and estimated 37 Mm^3/y using the land use recharges coefficient (Metcalf and Eddy, 2000). The net annual recharge was estimated to be 46 Mm^3/y and it was also 62 and 65 Mm^3 in the seasons 2001/2002 and 2002/2003 consecutively (Hamdan and Muhaisen, 2003). Table (3.2) summarizes the results of recharge estimation according to different methods (Baalousha, 2005).

Table (3.2): Summary of estimated recharge in Gaza based on different methods

#	Source	Method	Mm^3/y
1	Fink 1970	Change in aquifer storage	33-37
2	Melloul and Bachmat 1975	Recharge coefficients	41
3	IWACO and WRAP 1995	Chloride mass balance	46
4	CAMP 2000	Land use and recharge coefficients	37
5	CAMP 2000	Groundwater modeling	40-45

The spatial distribution of recharge is summarized in Table (3.3). The average groundwater recharge as a percentage of rainfall in the entire area of Gaza Strip is calculated at 36.74% (Baalousha, 2005). Since the average annual rainfall for year 2006-2007 is 364.7 mm/Area (PWA, 2007), and the total area of Gaza Strip is 365 km^2, the calculated recharge value from rainfall amounts to 48.91 Mm^3/y.

Table (3.3): Recharge Amount for year 2006-2007

Location	Area (km^2)	Rainfall(2006-2007)		Recharge(2006-2007)		
		Depth (mm)	QTY (Mm^3)	CRD (%)	Depth (mm)	QTY (Mm^3)
North	61	521.9	30.7	37.4	195.02	11.9
Gaza	74	460.4	33.8	34.8	160.22	11.86
Middle	58	411.5	28	33.5	137.73	7.99
KH/Younis	108	253.4	31.9	33.6	85.14	9.2
Rafah	64	225	8.7	41.1	92.48	5.92
	365	133.1	133.1	133.99	670.59	46.87

3.3.4 Return flows

There are three primary sources of return flow in Gaza Strip: leakage from municipal water distribution system, wastewater return flows and irrigation return flow (Aish, 2004). According to the Palestinian Water Authority, the return flow in Gaza strip can be summarized in Table (3.4).

Total amount of return flow of Gaza Strip for year 2000 is about 41.79 million cubic meters (Mtcalf and Eddy, 2000). Based on water balance in Table (3.4) below, the value of return flow for year 2006 ranges from 44.5 to 50 Mm^3.

Table (3.4): Return flow components in Gaza strip for year 2006

#	**Return Flow sources**	**Percent (%)**	**Total amount (Mm^3/y)**	**Return flow amount (Mm^3/y)**
1	Leakge from water distribution system out of total domestic abstration	29	70-80	20-23.2
2	Waste water (Jabalia WWTP-north) and (Gaza WWTP-Gaza city out of total disposal	25	18-22	4.5-5.5
3	Irrigation out of total agricultural abstration	25	80-85	20-21.3
1	Total	**26.28**	**159**	**44.5-50**

3.3.5 Hydraulic conductivity

Pumping tests were used to determine the hydraulic properties of the Gaza strip aquifer system; where transmissivity values range between 700 and 5,000 m^2/day. Corresponding values of hydraulic conductivity (K) are mostly within a relatively narrow range, 20-80 m/day. Specific yield values are estimated to be about 15–30% while specific storativity is about 10−4 m^{-1} (PWA, 2007). Figure (3.11) conducted by (Metcalf and Eddy, 2000), shows the distribution of hydraulic conductivity values for Gaza strip.

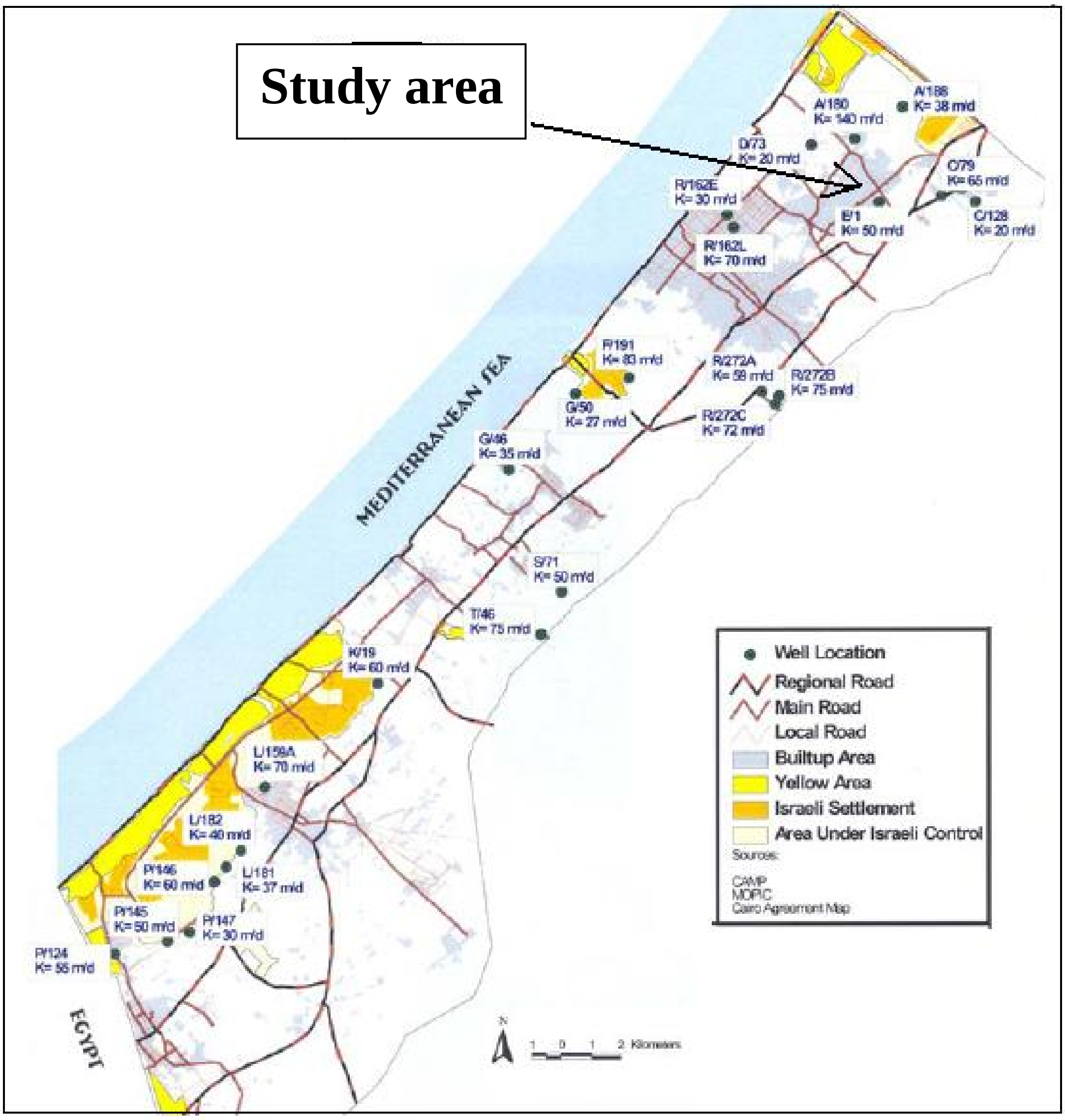


Figure (3.11): Distribution of Estimated Hydraulic Conductivity Values

3.3.6 Hydraulic budget

Lowering of water levels, reduction in availability of fresh groundwater and seawater intrusion, and potentially upcoming of deep brines are considered as indicators for water deficit in aquifer balance in Gaza strip. It should be indicated that the Gaza coastal aquifer is a dynamic system, with continuously changing inflows and outflows. Lateral inflow is an important parameter in the overall water balance of the Gaza Strip; however, this is subject to considerable variation from one year to another depending on the hydraulic regime in Israel (Aish, 2004). In order to assess the water budget of Gaza hydraulic system, the inflow and outflow water has to be estimated. Comparing amount passed to the system with that taken out, the deficit in water balance will be clearly assigned. Depending on the quality of estimation, the closer figure we can achieve for water management level. Table (3.5) summarizes most budget lines of Gaza aquifer for the year 2006 (PWA, 2007)

Table (3.5): Summary of Water balance of Gaza Strip in year 2006.

Parameters	**Budget lines**		**Min**	**Max**
INFLOW			**Mm^3/y**	**Mm^3/y**
Recharge	1	Effective recharge form precipitation	40	45
	2	Wadi Gaza	1	1.5
	3	Lateral flow east	20	35
	4	Sea water intrusion	10	15
	5	Mekarot water supply	4	5
Return flow	6	Municipal distribution system	20	23.2
	7	Waste water (treatment plant in Gaza, jabalia, and Rafah)	4.5	5.5
		Waste water (pipes)	1.5	2
		Waste water (septic systems)	9	9.5
	8	Agriculture irrigation	20	21.3
		Subtotal of inflow =	**130**	**163**
OUTFLOW				
Exploiting	1	Municipal abstraction	70	80
	2	Agriculture abstraction	80	85
	3	Mecorot abstraction	4	5
	4	Lateral flow to the sea	3	4
		Subtotal of inflow =	**157**	**174**
Net balance (deficit) =			**-27**	**-44**

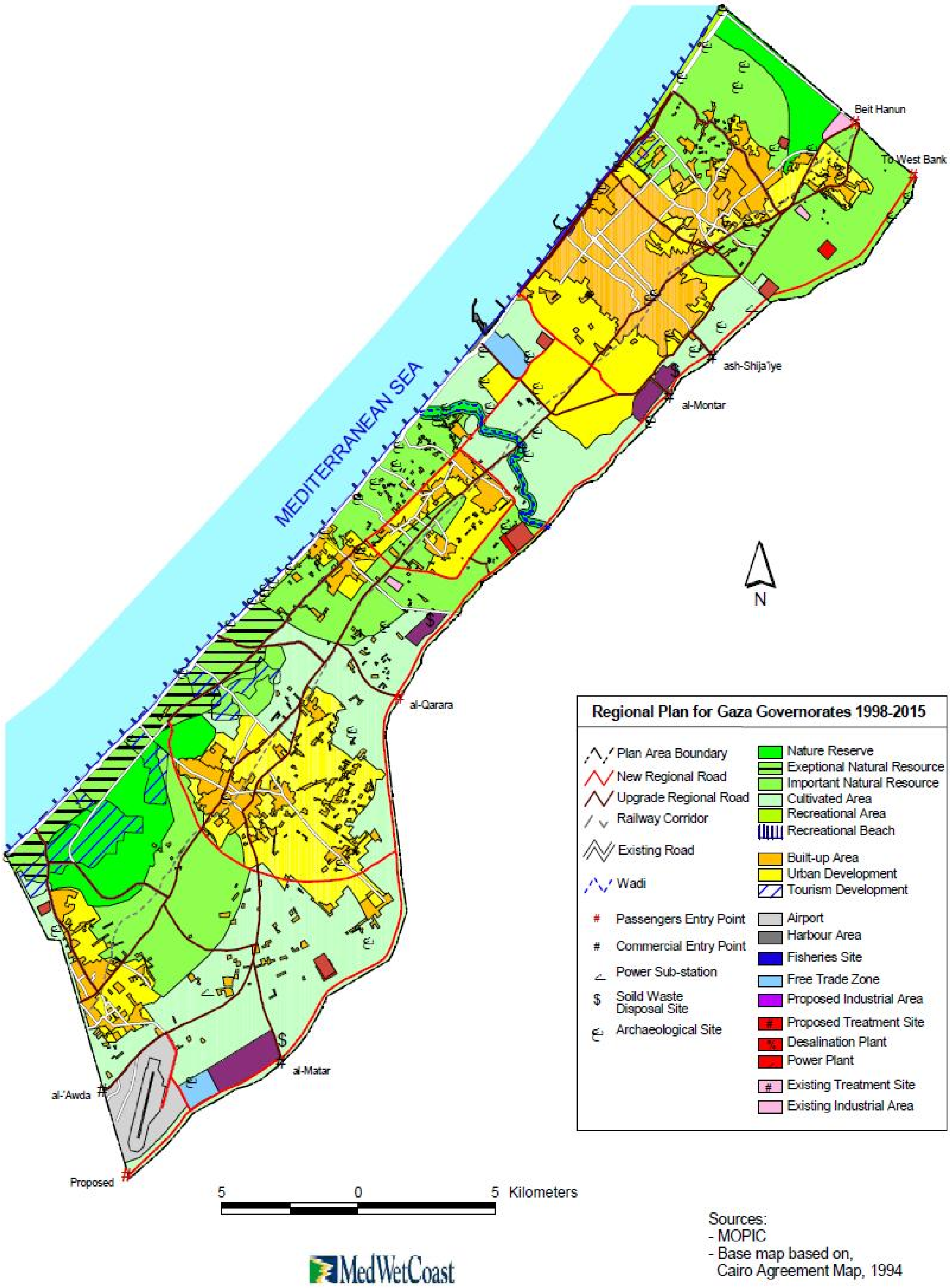
3.4 Land use

There is land scarcity for all kinds of uses (urban, industrial, and agriculture). Most of the study area is categorized as agricultural and urban but it also includes small industries located on site. The agricultural land is considered the dominant and economic sector. Urban and agriculture expansion is concentrated in the western coastal zones of Gaza Strip. There is overpopulation and related housing problems, especially in the refugee camps areas. Also there are inappropriate designs of wastewater treatment plant (WWTP) and disposing of untreated wastewater in Wadi Gaza. Consequently, there is a huge bad impact on the groundwater quality situation in the study area. Taking into consideration the rate of population growth and the expected economic expansion, groundwater quality problems will rapidly increase (MOPIC, 1998).

The period (1994–2004) can be called the urban transformation period, when development legally and illegally has been started. The present and the built up areas per governorates in the study area as estimated and predicted By (MOPIC,1998) Shown in Table (3.6) and in Figure (3.12) land use.

Table (3.6): Built up area per Governorate

Area	1997		2005		2015		2025	
	km^2	%	km^2	%	km^2	%	km^2	%
North	13.56	10.04	16.72	12.39	21.6	16	25.64	18.99
Gaza	20.23	15	28.93	21.43	44.2	32.74	54.57	40.42
Total	33.79	25.04	45.65	33.82	65.8	48.74	80.21	59.41



Sources:
- MOPIC
- Base map based on, Cairo Agreement Map, 1994

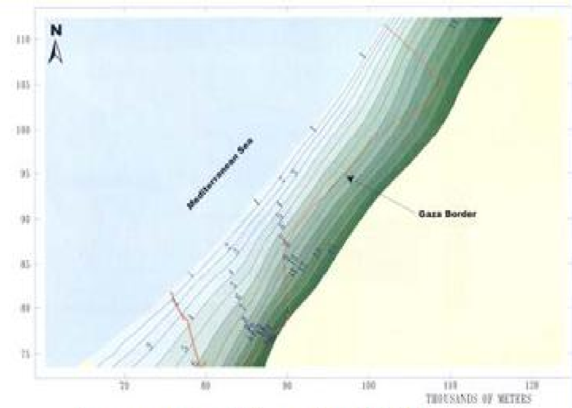
Figure (3.12): The present land use and future industrial land use distribution (1998-2015)

3.5 Groundwater Situation in the Study Area

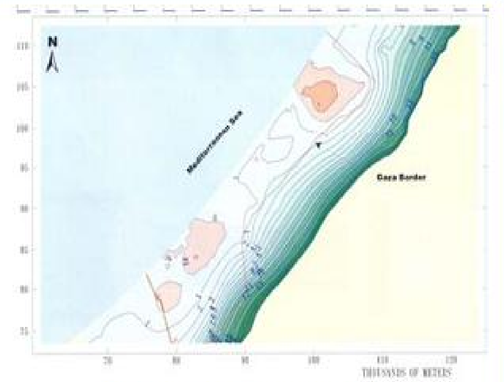
Groundwater from the coastal aquifer is the only source of water for the people of Gaza Strip and they rely mainly on it to fulfill all needs. Other minor sources are surface water occurrences and collected rainwater. Depletion of the fresh groundwater resources is already a severe problem in Gaza (EQA, 2004). The aquifer is presently being overexploited, with total outflow exceeding total inflow (PWA, 2004). This deficit in the water balance leads to steady lowering of the groundwater level. This continuous declination led to formation of depression cones, mostly in the heavily populated areas. Consequently, the hydraulic gradients have been significantly reversed from the sea in these areas and the resultant washing of salts into the sea has been reduced.

The groundwater contours maps had been conducted to measure variation in groundwater levels over years; from 1935 up to 2007 Figure (3.13) illustrates , that the groundwater levels dropped by more than 14 meters between year 1935 and 2006. The groundwater level ranges were between 7.6 m below mean sea level (MSL) to about 6.9 m above mean sea level (Zidan, 2009).

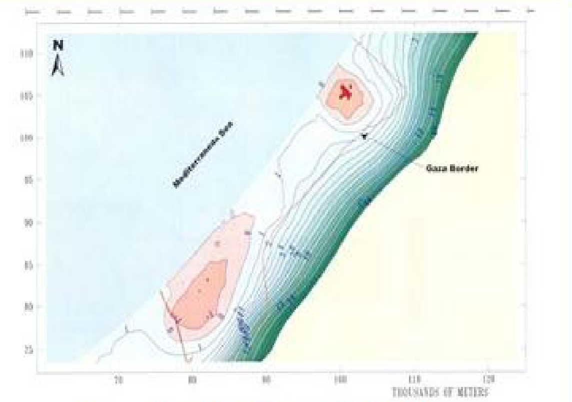
Other significant causes of depletion of groundwater resource are high losses in the water supply systems and inefficient water use, particularly in the agricultural sector (EQA, 2004). Also, due to normal population growth, water demand for different purposes is expected to rise from the current level of 145 Mm^3/y to about 260 Mm^3/y by the year 2020 (PWA, 2000a). The freshwater resources will be completely exhausted as groundwater pumping will increase at the same rate, while the brackish water resources will become increasingly saline (PWA, 2000a). Israeli wells around the border of Gaza Strip and the over-pumping of Israel wells within the settlements disengagement in 2005 have accelerated the increase of salinity of groundwater. Israel has also retained and changed the course of the two main Wadis in the study area as sources of freshwater that recharge the aquifer which has renderd them dried up Wadis since the early seventies (MWCP, 2001).



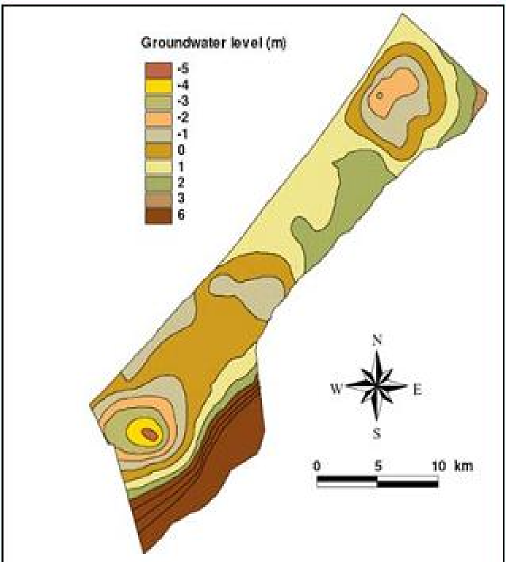
Average water table contour (1935)



Average water table contour (1989)



Average water table contour (1998)



Average water table contour (2000)

Figure 3.22.e: Average water table contour (2007)

Figure (3.13): Water level contour maps since 1395 to 2006

3.5.1 Salinity Problem

Since the beginning of the 1970s, many studies have described the hydrological situation of Gaza Strip. Parallel to the long term water shortage, saline water has replaced freshwater in many parts of the Gaza Strip (Weinthal et al., 2005). The existing network of wells is only adequate to identify shallow water quality situations (PWA, 2000a).

Generally, most of the pumped water from wells comes from the upper 30-40m of the aquifer (PWA, 2004b). Chloride concentrations for the shallow portion of the coastal aquifer in the north of Gaza Strip are generally better than those in the south. (Al-Jamal, and Al-Yaqubi, 2001). Few boreholes have penetrated the deeper parts of the Gaza Strip coastal aquifer. Trapped water with higher salinity than sea water was found in the deeper aquifer, mainly in its western portion up to (2 km) from the sea. The deepest sample showed brine with a chloride concentration with approximately of 2 times of seawater. (60,300 mg/L) (PWA, 2004b). However due to the low exploitation of the deep subaquifers in the west, this trapped saline water is still inactive and does not appear to affect the quality of the aquifer as far as its chlorides content is concerned (Melloul and Collin, 1994).

Groundwater salinity increases with water depth and away from the sand dunes area, where ground surface is covered by clay and silt. Salinity increased from 500 to 10,000 mg/L with depth. Wells of the major pumping center in Gaza City and Jabalia display a gradual increase in chloride with time. This suggests that brackish water from eastward is flowing toward the northern well fields in Gaza City and Jabalia. For the year 2004, the chloride content in most of the wells in Gaza Strip fluctuated from 300 to 600 mg/L which is double the recommended value of the WHO as shown in Figure (3.14). In the deepest sub-aquifers, high levels of chloride may be related to different sources of salinity e.g. seawater of possibly poor quality fossil water (PWA, 2004 b).

The high concentration of chloride in the groundwater in Gaza aquifer comes from many different water sources. Those sources include inflow of groundwater from occupied areas, soil water interaction in the unsaturated zone due to recharge and return flows, mobilization of deep brines, sea water intrusion or up-coning of brines. The seawater intrusion and up-coning of brines in some areas may be due to water imbalance in the aquifer, since the rate of water extraction exceeds the rate of groundwater replenishment (PWA, 200l).

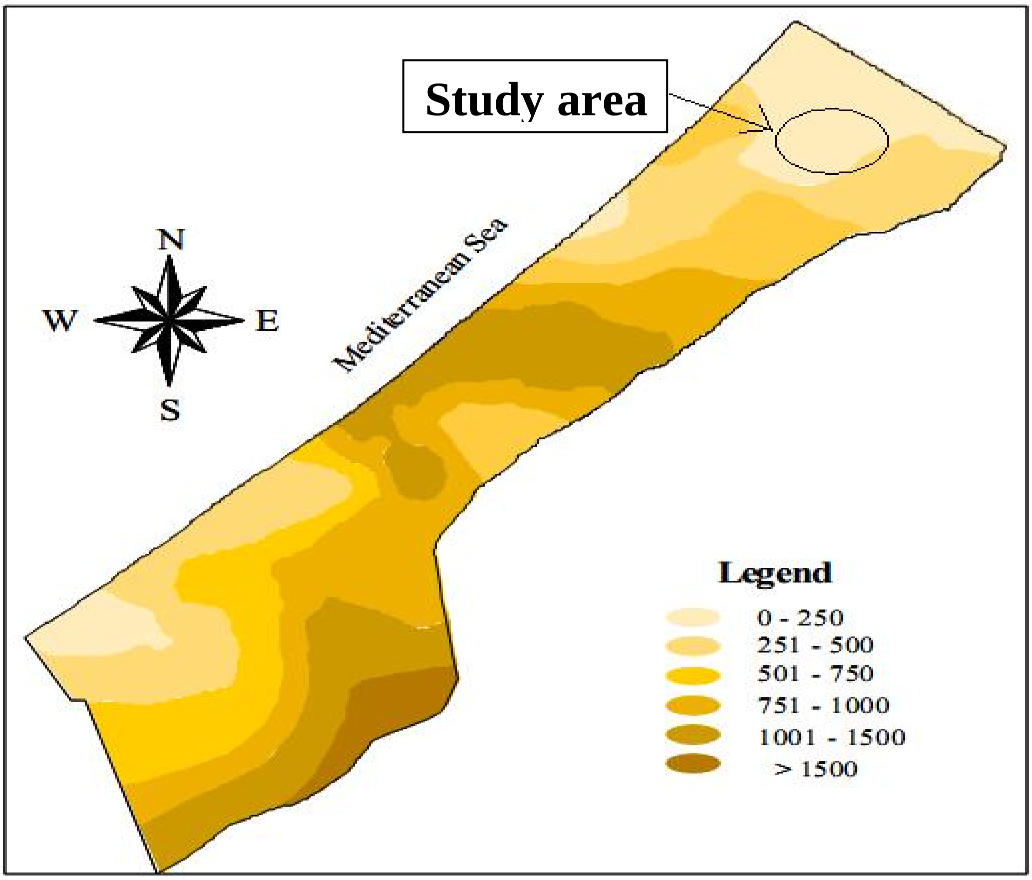


Figure (3.14 : Chloride concentration in the Gaza Strip (EQA, 2005).

Additional sources of groundwater salinity in this area are: (1) the flux of saline water coming from the Eocene aquifer in the east; and (2) pollution sources on the ground surface, such as effluent irrigation, domestic land-use effluents, solid waste, etc. Chloride concentrations up to 2,000 mg/l have been measured in wells that tap the Eocene system (Vengosh et al., 1996). The chemical and isotopic data show that most of the salinity phenomena in Gaza Strip are derived from the natural flow of saline groundwater from the eastern part of the aquifer towards the Gaza Strip (Weinthal et al., 2005).

Saltwater intrusion varies with depth and different sub-aquifers exhibit varying degrees of seawater penetration. Salty water intrusion presently poses the greatest threat to municipal supply and continued urban and industrial growth is expected to impact water quality (Qahaman, 2004). Seawater intrusion has resulted in salinization of groundwater in the western part of the aquifer, but the geochemical and isotopic data indicate that the extent of seawater intrusion is limited (Weinthal et al., 2005). Seawater intrusion occurs along several kilometers of coastline in the Gaza Strip Modeling results, combined with surface geophysical surveys, indicating that seawater intrusion extends 1-2 km inland in areas of heavy pumping, and may extend up to 2-3 km inland in the deepest part of the aquifer within Gaza City (PWA, 2004b).

3.5.2 Nitrate Problem

An additional source of water quality deterioration in the Gaza Strip is the nitrate which is used as an indicator of pollution, especially when salinity is low. Nitrate pollution of groundwater in Gaza, has particular concern due to the environmental sensitivity of the area and the large number of people in city and rural areas relying on groundwater for drinking. Large amounts of N-fertilizer and poorly managed irrigated systems may lead to nitrate leaching and pollution of groundwater.

The groundwater quality in the Gaza Strip with respect to the nitrate pollution is not constant depending on many factors, like the pollution sources, the intensity of pollutant, soil type and sensitivity of the aquifer. Increasing trends may be caused either by the accumulation of nitrates in the groundwater from continued land use practices, or by changes in land use to more intensive agricultural activities or increased rates of wastewater effluent application. Decreasing trends may also be caused by changes in land use to less intensive agriculture or reduced waste disposal rates. In the case of a deep aquifer, decreasing trends could also be caused by increased abstraction rates, which would increase the hydraulic gradients around the well and could cause more water to be drawn from areas with lower nitrate concentrations (Almahallawi, 2004).

The level of nitrate contamination has been rising so rapidly that most of Gaza's drinking water wells are no longer adequate for human consumption. Few wells in Gaza remain unaffected by high nitrate levels , and only about 10% of the municipal water supply remains below the WHO drinking water standard (PWA, 2000a). In most wells and urban areas, nitrate concentrations are increasing at rates up to 10 mg/l/y . Presently, nitrate level in most of the wells is between 100 and 150 mg/L as shown in Figure (3.15). This value exceeds the recommended value by WHO which only 50 mg/L (PWA, 2004b). More than 50% of the domestic municipal wells in Gaza Strip have nitrate concentrations that exceed WHO guidelines of 45 mg/L (Vengosh et al., 2005).

There are numerous sources of nitrate contamination, including agriculture fertilizers, waste dumping, and especially direct discharge of raw sewage to valleys and soil. This contamination is believed to be primarily related to wastewater return flows in urban areas through leakage from septic tanks and municipal pipe systems. Contamination of the water of wells is caused by sewage and the abundant use of agricultural fertilizers and pesticides which contributes to rise in the nitrate level especially in and around areas of arable land. The contribution of fertilizers in agricultural areas cannot be ruled out, although this has never been quantified (i.e., quantities applied vs. levels in groundwater) (PWA, 2000). The threat of groundwater contamination increases under irrigation on sandy soils which have lower adsorption capacity, where nitrate is more easily leached with the irrigation return flow.

Almahallawi (2004) showed that in the northern area, the nitrate concentrations decrease in a north-eastward direction. The water flow direction is from north-eastward to south-westward. This means that water comes from outside of Gaza Strip, especially in the northern part which has almost nitrate concentration less than 50 mg/l. Since this water mixes with the local aquifer, the quality of water regarding nitrate contamination decreases. Two reasons are believed to explain the phenomena of the nitrate concentration which is less than 50 mg/l compared to the high concentration in the rest of the areas of the Gaza Strip. First, parts of these areas are kept low by dilution; second, large parts of this aquifer are far in depth in the range of 50-120 meter.

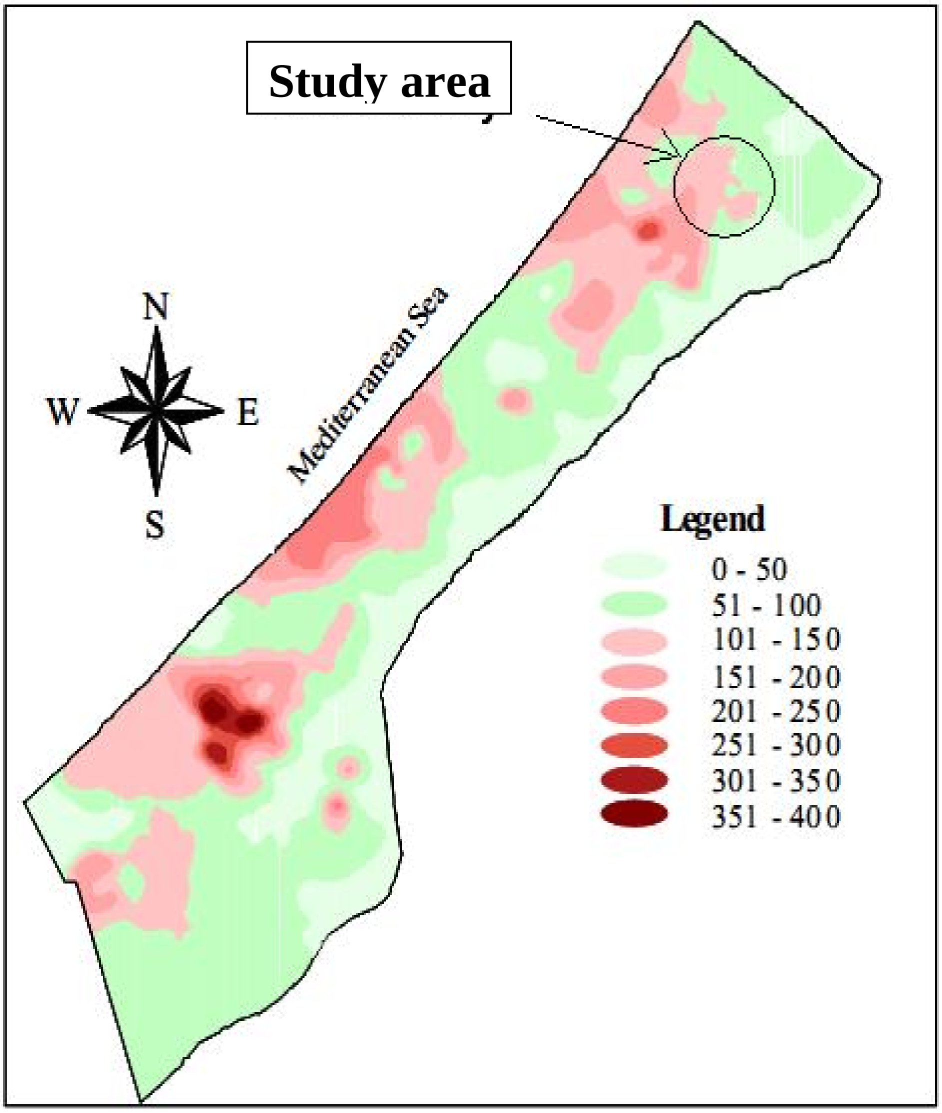


Figure (3.15): Nitrate concentration in the Gaza Strip (EQA, 2005).

3.6 Wastewater treatment

Wastewater treatment has been considered in Gaza Strip since 1970. Stabilization ponds were the technology proposed solution at that time. Greater attention has been paid to improve this sector following the coming of the Palestinian National Authority (PNA) in 1993. The PNA intends to draw a Palestinian policy regarding wastewater treatment and reuse. This policy needs to determine the proper treatment technology using local experience technology.

There are three wastewater treatment plants (WWTP) operating in Gaza Strip: Beit-Lahia WWTP in the north, Gaza WWTP in the Gaza City and Rafah WWTP in the south. The type of treatment, quantity and final disposal of each plant is summarized in Table (3.7). The wastewater quality parameters of the wastewater treatment plants in Gaza Strip are shown in Table (3.8)

Table (3.7): Treatment plant in the Gaza Strip (Zubiller, 2002)

Location	Treatment method	Quantity (m^3/d)	Final disposal
Beit Lahia	Stabilization ponds and aerated lagoons	8,000 - 10,000	surrounding sand dunes
Gaza	Anaerobic ponds followed with bio-towers	40,000 - 45,000	75% to the sea and 25% infiltrated to the ground aquifer
Rafah	one aerated lagoon	3,000 - 4,000	To the sea

Table (3.8): quality of influent & effluent of wastewater in Gaza (Zubiller, 2002).

Parameter	Jabalia			Gaza			Rafah		
	No. of test	Influent	Effluent	No. of test	Influent	Effluent	No. of test	Influent	Effluent
pH	2	7.8	7.2	50	7.4-7.8	7.6-7.8	2	7.4	7.5
T C^0	2	16.1	15	50	14-20.7	16-19	2	23.5	22.2
TS (mg/L)	2	1888	1480	28	1472-3960	1024-1536	2	2140	1610
TDS (mg/L)	2	1471	1445	28	1049-2267	905-1503	2	1518	1484
TSS (mg/L)	2	417	35	40	244-1693	31-79	2	622	126
TVSS (mg/L)	2	370	30	40	212-1397	24-57	2	550	110
NH3-N (mg/L)	2	61.6	54.6	4	51-70	41-47.6	2	88	63.6
N-KjD (mg/L)	2	102.7	75.6	2	74	57	2	128.8	88.2
Cl (mg/L)	2		310-340	2		340-400	2	--	--
BOD (mgO3/L)	2	420	40	10	360-1600	35-41	2	760	240
COD (mgO3/L)	2	1078	120	15	608-3100	114-162	2	1298	556
F.Coliform CFU/100cm	2	4E+08	830000	10	2.5E8-5E9	3.4E6-5E7	2	2E+09	8E+07

3.7 The design of Beit Lahia Municipality infiltration Basin

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

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

- From the intensity duration curve, the volume of rainfall in one day and for 5 years return period is 69.29 mm/m^2.
- By considering the total catchment area of 700 dunums, then the catchment runoff volume is 48,500 m^3.
- The volume of storm water which will reach the basin is 23,280 m^3 by taking in account an average runoff coefficient equals 0.48.
- The infiltrated volume during the rain in one day is computed as 11,738 m^3 (infiltration rate is 3 m/d).
- Then the net volume of the stored storm water is 11,541 m^3. According to this value, the total area which is required for the basins is 4,500 m^2 which includes 3 to 4 m space around the basin for fencing and planting with suitable trees.
- The total depth of the basin is 5.6 (including the depth of the inlet of the basin, which is 2 m below the ground surface) with side slope of the basin is 2v: 1h.
- It should be noted that, the existing basin which has an area of 1,000 m^2 is included in the total area where 3,500 m^2 is requested as an extension.

It is important for the purification of the infiltrated water, as well as to avoid clogging, that the boreholes through clay layer be covered by at least 2 m of dune sand. For a design period for evacuation the basin is 12 days, the amount of water to be infiltrated is 1,940 m^3/d. The volume of storm water which can be stored in the 2 sand layers is 1,539 m^3/d (the porosity of sand is taken as 0.25). Therefore the net daily volume of water to be infiltrated 401 m^3 through a number of boreholes filled with crushed stone with sizes of 10 to 20 mm (hydraulic conductivity is about 2.3 $x10^{-4}$ m/s), then the cross-section area needed to transmit the water through the clay is 18 m^2. Drill holes diameter of 0.6 m which have a cross-section area of 0.310 m^2 are to be used. This means that 65 of such boreholes need to be drilled at a rate of 1 borehole per 48 m^2. Each borehole must be drilled around 3 m inside the permeable layer (Kurkar) which is expected to reach 25 m below the bottom of the basin. Before, the construction of the basin in the Municipality site it is necessary to check the extent of the clay layer and the depth of Kurkar layer by further soil investigations. Figure (3.16a), (3.16b) shows the basin plan and cross section (Mogheir, 2005).

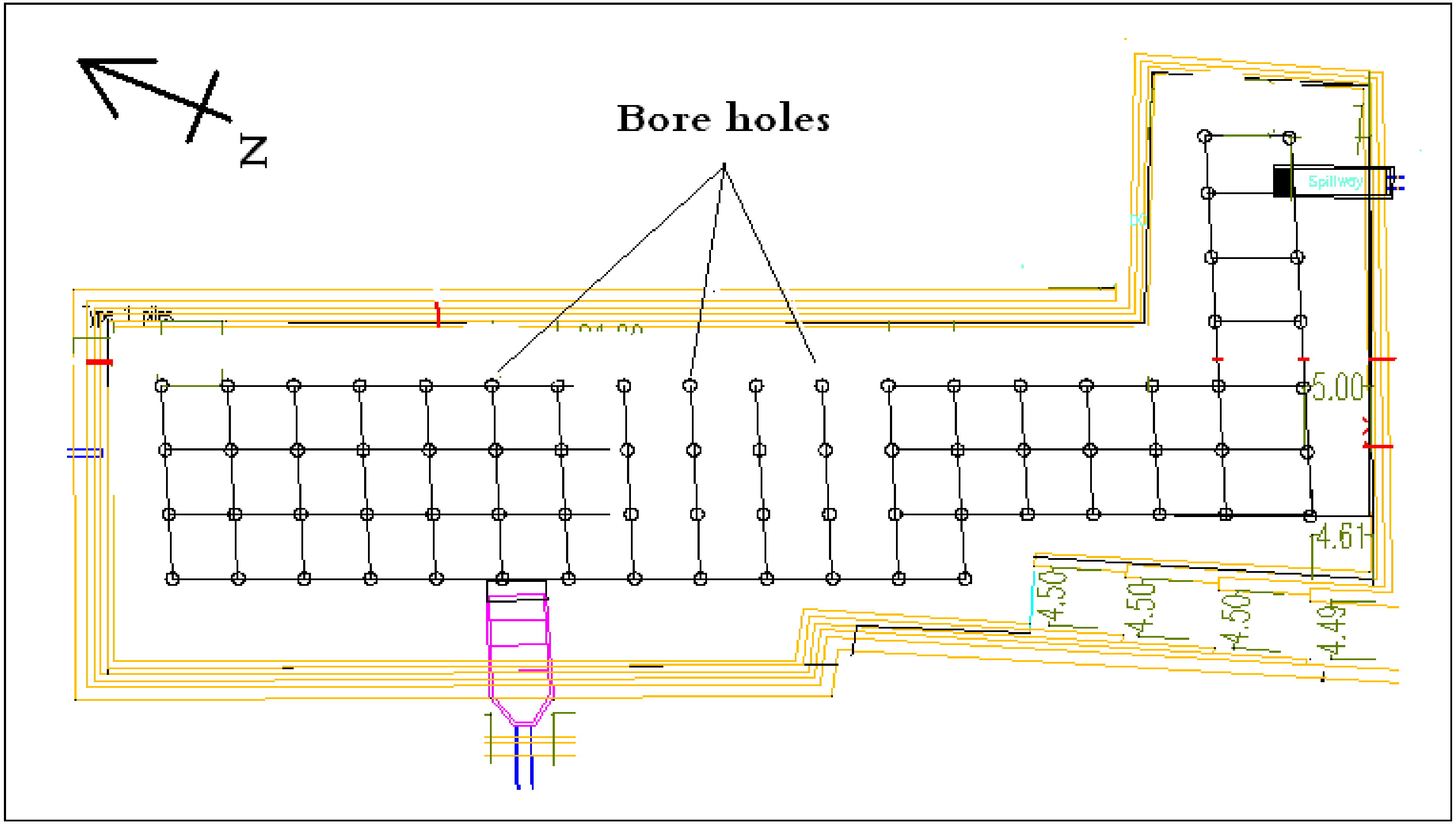


Figure (3.16a): layout of Beit Lahia municipality infiltration Basin (Mogheir, 2005)

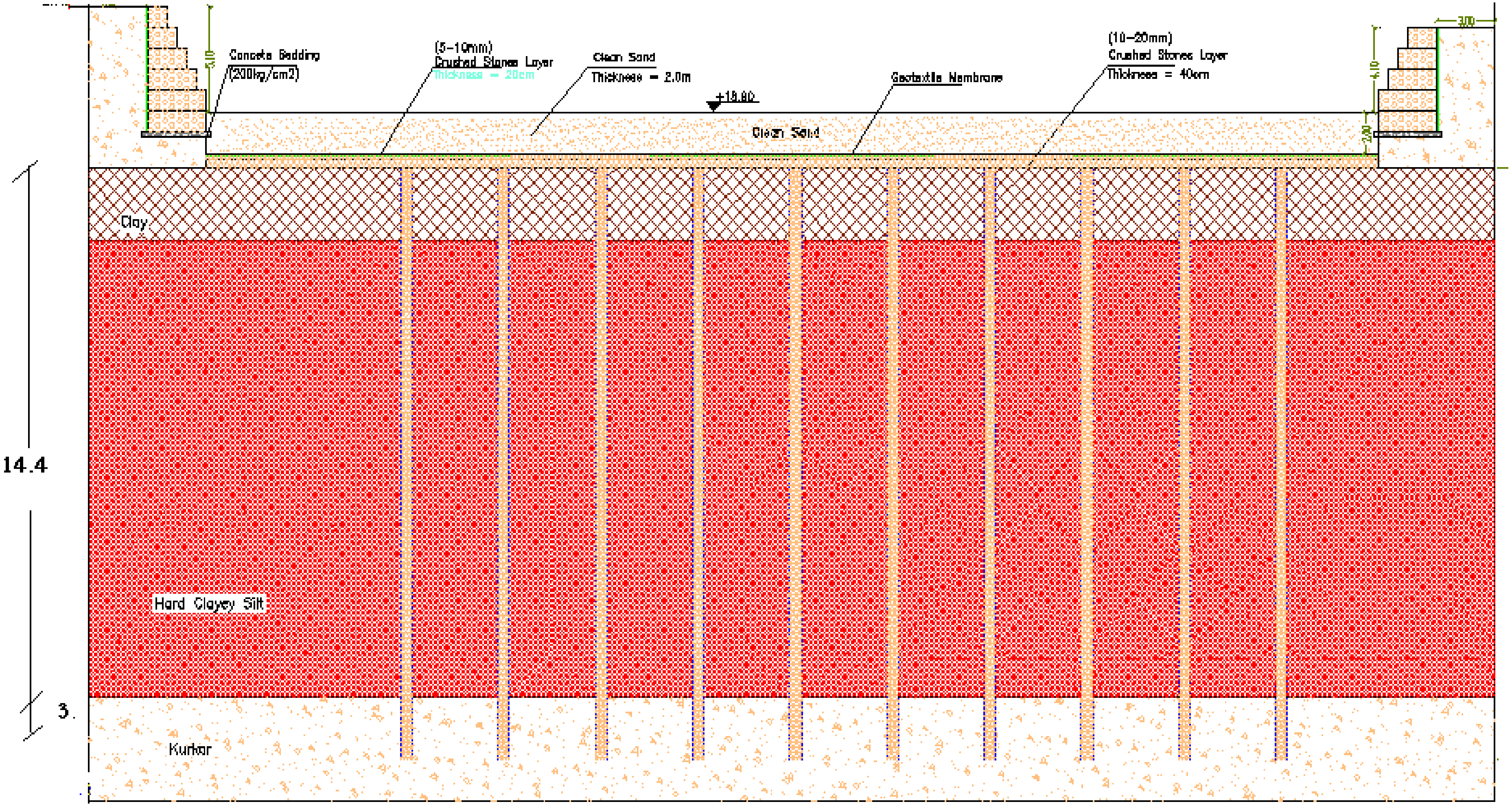


Figure (3.16b): cross section of Beit Lahia municipality infiltration Basin(Mogheir, 2005)

Chapter 4
Laboratory Analysis

4.1 Introduction

The purposes of the experiments included this chapter are to investigate the quality of collected storm water in Beit Lahia infiltration basin before infiltration and to check the quality of groundwater in the area nearby the basin. In addition to the laboratory analysis of collected storm water, in situ experiment was carried out to study the effect of sand filter in the studied infiltration basin.

4.2 Location of samples

Samples were collected from the infiltration Basin, and from four wells surrounding the basin as shown in Figure (4.1).The distances between the wells and the basin are in the range of between 130 to 400 m.

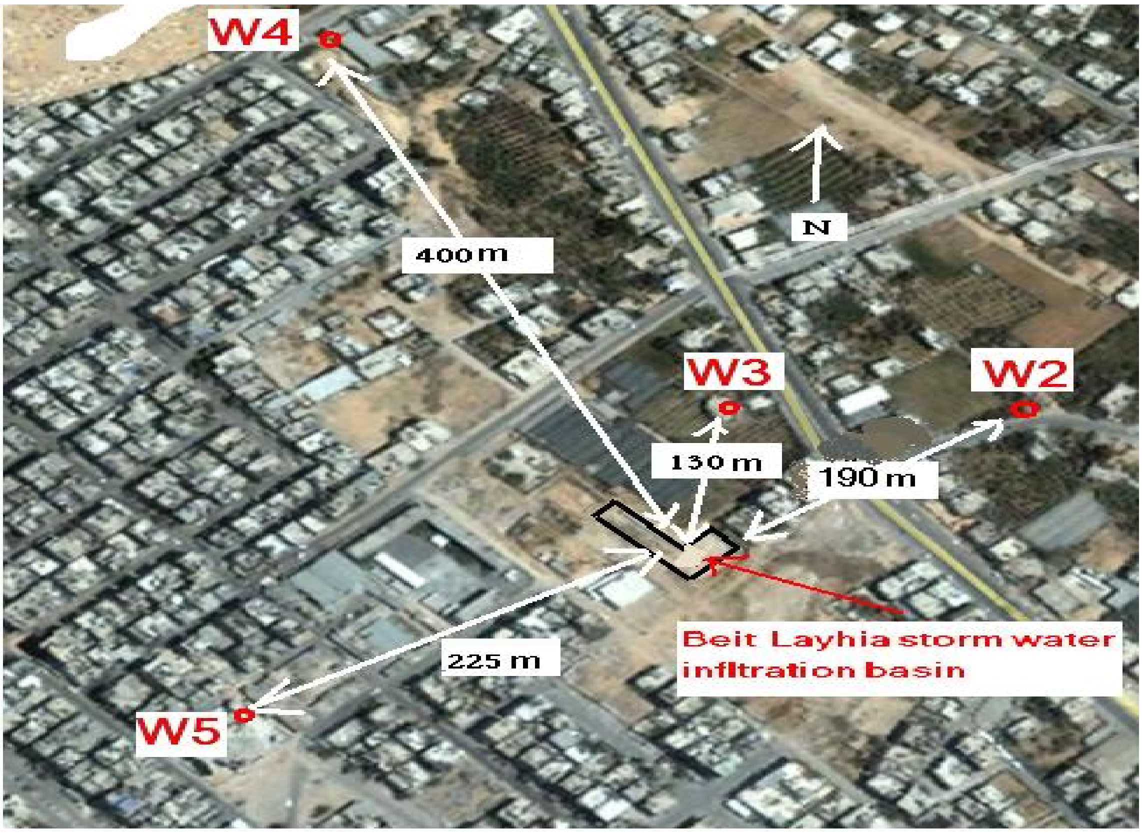


Figure (4.1): location of the wells around the basin (Google earth, 2009).

4.3 Types of Samples

4.3.1 Storm Water Samples

Two types of storm water samples were considered in this section :

- Samples which were collected from the infiltration basin
- Samples which were collected from the infiltration basin after it penetrated 2 meters of sand. As shown in Figure (4.2)

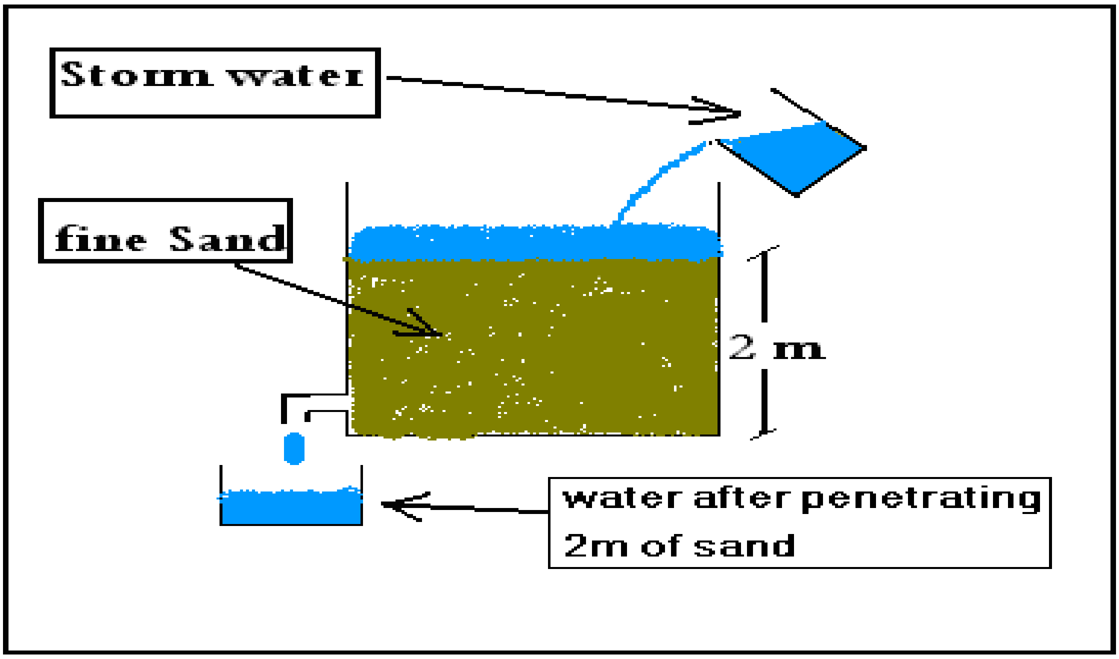


Figure (4.2): Schematic diagram of storm water after penetrated 2 meters of sand

4.3.2 Ground Water Samples

Samples which were collected from wells surrounding the infiltration basin located in several directions and at different distances as shown in Figure (4.1).

4.4 Sampling Parameters

The following parameters were tested in the aforementioned samples:

1- Physical parameters (Turbidity, TSS, TDS).
2- Chemical parameters (No_3^-, Cl^-, Na^+, Ca^{2+}, Mg^{2+}, k^+, hardness, detergent).
3- Biological Parameter (Fecal Coliform) .

These parameters were chosen because of their presence in the storm water and because they can be measured in Gaza strip.

Table (4.1): Parameters examined through the testing program

	physical parameter	Chemical parameters										Biological
	turbidity	TSS	TDS	No_3^-	Cl^-	Na^+	Ca^{2+}	Mg^{2+}	k^+	Hardness	detergent	Fecal Coliform
Storm water samples	X	X	X	X	X	X	X	X	X	X	X	X
Ground water samples	X	—	X	X	X	X	X	X	X	X	—	X

As shown in Table (4.1) the physical, chemical and biological parameters of storm water and groundwater samples were tested. Since the measurement of detergent is hazardous and rare in Gaza strip, it will not tested in the groundwater.

4.5 Test Program

4.5.1 Time of samples collection

The study was carried out for six months that include the wet and dry seasons (February to May 2009), the Storm water samples collected in winter (Februarys to April 2009) and the groundwater samples collected in winter (Feb 2009) and in end of winter in month (Aug 2009) as shown in Table (4.2).

Table(4.2): schedule of sample collection

	2009						
	Feb	Mar	Apr	May	Jun	Jul	Aug
Storm water samples	X	X	X	—	—	—	—
Ground water samples	X	—	—	—	—	—	X

4.5.2 Number of samples

- six samples of groundwater water were collected from each well surrounding infiltration basin. (three sample before winter, three sample after winter).
- Six samples of storm water were collected from the infiltration basin at different times in winter.

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4.6 Laboratories

Two laboratories were used to perform the analysis :

- The public health laboratory of the Ministry of Health (MOH) , where turbidity, TSS, TDS, No_3^-, Cl^-, Na^+, Ca^{2+}, Mg^{2+}, k^+, hardness, and fecal coliform were measured
- Ministry of Agriculture (MOA) laboratory, where TSS and detergent were measured.

4.7 Sampling procedures

4.7.1 Sample bottle

Samples were collected for physical and chemical analyses in clean 1 liter plastic bottles. But for biological analyses (fecal coliform) in 250 mL glass sterile container. The samples were transported to the laboratory in an icebox of 4 ^{0}C. and labeled with necessary information like date, location, sampling hour.

4.7.2 Sample collection

4.7.2.1 Sample Collection for Biological Analysis

The following steps were taken during sampling:

1- The sterile bottle supplied by the lab for bacteriological analyses was used.

2- The hands were carefully washed with soap and water before collecting the sample.

3- Samples were collected directly from the water outlet .

4- The end of the faucet was disinfected with fire .

5- The water was allowed to run for five minutes, before adjusting the flow to a stream about the width of a pencil.

6- The cap was removed off the bottle and held in one hand and the bottle in the other. The bottle was never rinsed and contained a tablet to neutralize any chlorine.

7- The bottle carefully filled within 6-7 mm (¼ inch) of the top.

8- The cap was returned to the bottle without touching the inside of the cap or the mouth of the bottle.

9- The necessary information of the sample such as sample name, date, time and exact location was recorded and labeled. (USGS, 1998)

4.7.2.2 Sample Collection for chemical & physical Analysis

The following points were taken in to consideration during sampling :

1- Samples were collected from the wells after sufficient pumping of at least five minutes to ensure that the sample represents the ground water .

2- All sample bottles were transported to the lab in icebox of 4 ^{0}C .

3- Nitrate tests were performed within 2 hours after reaching the laboratory, detergents were analyzed after 24 hours .

4- Necessary information such as sample name, date, time and exact location was recorded and labeled. (USGS, 1998)

4.7.3 Sample preservation

Most parameters being analyzed are subject to varying degrees of change between sample collection and analysis. Since biological and chemical activity continue after collection, it is recommended that, in the field, samples be stored on ice in a closed cooler. Decreased temperature and light intensity will reduce the level of activity. In the laboratory, samples can be transferred to a refrigerator while awaiting analysis. For some parameters, refrigeration at 4 ^{0}C is adequate for preservation if processing occurs within 24 hours.

4.7.4 Sample-Holding Times

Sample-holding time is the time period from sample collection to sample analysis, during which the testing results will not change. Testing results of some parameters are more time sensitive than others. Samples should always be tested within the sample holding time. Therefore, for best testing results, it is recommended that the sample be submitted to the lab in a cooler immediately after collection.

4.8 Samples Analysis

Water analyzed according to American Public Health Agency (APHA, 1998).

4.8.1 Nitrate (No_3^-)

Nitrate is measured by a spectro-photometric method at wavelength 410nm (using chromo tropic acid). Chromotropic acid spectrophotometrically method is quite rapid, used originally for water .

4.8.2 Chloride (Cl^-)

10ml of water sample or a suitable portion diluted to 100ml is placed into an Erlenmeyer flask and 1ml potassium chromate solution added. The mixture is then titrated against a white back ground with silver nitrate solution until the color changes from greenish yellow to reddish brown. Blank sample with distilled water is treated in the same way as the sample.

4.8.3 Fecal Coliform

The reference method of the APHA 1998 , NO 9222 D. For estimation of FC bacterial populations. The Membrane Filtration (MF) technique is performed. In the initial step, several dilutions of the sample volume are passed through a membrane filter with a pore size small enough (0.45 microns) to retain the bacteria present. The filter is placed on an absorbent pad saturated with a culture medium that is selective for coliform growth (CFU). The pad dish containing the filter and pad is incubated, upside down, for 24 hours at the appropriate temperature (44.5 ±0.2 ^{0}C) After incubation, the colonies that have blue color are identified and counted using a low-power microscope. Few colonies from each plate were picked and biochemical tests were performed to confirm the identity.

4.8.4 Total Dissolve Solid (TDS)

Measuring TDS is done by using EC meter (El-Hanna, TH-2400).

4.8.5 Sodium (Na^+), Potassium (k^+), Calcium (Ca^{2+}), and Magnesium (Mg^{2+})

Na^+ was determined by aflame photometer, Potassium, Ca, and Mg were determined after wet digestion of sub samples in H_2SO_4 salisilic acid mixture with three addition of H_2O_2 .

4.8.6 Turbidity

A turbidimeter is an optical device that measures the scattering of light, and provides a relative measure of turbidity in nephelometer turbidity units (NTUs).

4.8.7 Total Suspended Solid (TSS)

The reference method of the APHA 1998, No. 2540-D by using membrane filter (Total Suspended Solids Dried at 103–105°C).

4.8.8 Detergent

The reference method of the APHA, 1998, No .5540-C depends upon determination by spectrophotometer at wave length 562 nm visible light using chloroform in the extraction of anionic surfactant , and methylene blue as an indicator for all samples .

4.9 Results of Analysis

4.9.1 Storm Water

Results obtained from the analysis of storm water in the laboratory are shown in Table (4.3) for storm water in the infiltration basin, and Table (4.4) for storm water after it penetrated 2 meters of sand.

Table (4.3): Results of Lab. Analysis of Storm water of the infiltration Basin.

parameters	**name of sample**	**storm water in basin**	**storm water in basin**	**storm water in basin**
	Symbol of samples	**B1**	**B2**	**B3**
	Date **Unit**	**Feb**	**Mar**	**Apr**
Turbidity	NTU	39.8	36	30.8
TDS	ppm	220	200	170
TSS	ppm	296	460	595
$No_3{}^-$	ppm as No_3^-	13	12	7
Cl^-	ppm as Cl^-	50	39	20
Hardness	ppm as $CaCO_3^{2-}$	119	130	125
Ca^{+2}	ppm as Ca^{2+}	28	28	24
Mg^{+2}	ppm as Mg^{2+}	16	13	21
K^+	ppm as K^+	3.6	4	2.7
Na^+	ppm as Na^+	23	18	16
fecal coliform	Colony / 100 ml	150	190	135
detergent	ml /L	0.27	0.21	0.18

Table (4.4): Results of Lab. Analysis of Storm water after penetrating 2 meters of sand.

parameters	name of sample	storm water in basin	storm water in basin	storm water in basin
	Symbol of samples	B1	B2	B3
	Date Unit	Feb	Mar	Apr
Turbidity	NTU	3.6	3.1	2.8
TDS	ppm	222	206	195
TSS	ppm	45	53	63
No_3^-	ppm as No_3^-	12	11	7
Cl^-	ppm as Cl^-	43	35	28
Hardness	ppm as $CaCO_3^{2-}$	125	130	130
Ca^{+2}	ppm as Ca^{2+}	34	26	26
Mg^{+2}	ppm as Mg^{2+}	20	12	21
K^+	ppm as K^+	3.2	3.5	2.9
Na^+	ppm as Na^+	23	16	15
fecal coliform	Colony / 100 ml	100	120	130
detergent	ml /L	0.25	0.2	0.18

4.9.2 Ground water

Results obtained from the analysis of wells around the infiltration basin in the laboratory are shown in Table (4.5) in winter ,Table (4.6) in summer .

Table (4.5): Results of Lab. analysis of ground water samples (in winter)

parameters	name of sample	well # 2	well # 3	well # 4	well # 5
	Symbol of samples	W2	W3	W4	W5
	Date Unit	Feb	Feb	Feb	Feb
Turbidity	NTU	0.32	0.23	0.85	0.4
TDS	ppm	590	672	750	530
No_3^-	ppm as No_3^-	121	109	97	86
Cl-	ppm as CL^+	112	121	150	83
Hardness	ppm as $CaCO_3^{2-}$	420	440	410	367
Ca+2	ppm as Ca^{2+}	71	86	75	68
Mg+2	ppm as Mg^{2+}	59	55	54	48
K+	ppm as K^+	5.5	2.8	5.2	1.5
Na+	ppm as Na^+	40	54	70	42
fecal coliform	Colony / 100 ml	0	0	0	0

Table (4.6): Result of Lab. analysis of ground water samples (in summer)

parameters	name of sample	well # 2	well # 3	well # 4	well # 5
	Symbol of samples	W2	W3	W4	W5
	Date Unit	May	May	May	May
Turbidity	NTU	0.28	0.18	0.23	0.29
TDS	ppm	567	667	710	490
No_3^-	ppm as No_3^-	123	112	100	88
Cl-	ppm as CL^+	117	119	140	97
Hardness	ppm as $CaCO_3^{2-}$	413	471	478	355
Ca+2	ppm as Ca^{2+}	78	89	80	68
Mg+2	ppm as Mg^{2+}	52	61	60	45
K+	ppm as K^+	6.1	2.9	5.5	1.5
Na+	ppm as Na^+	40	55	75	40
fecal coliform	Colony / 100 ml	0	0	0	0

4.10 Discussion of the Results

4.10.1 Nitrate (NO_3^-)

The Concentration of nitrate in storm water is low, between (7-13 mg/L) , and when storm water penetrated 2m of sand, it was noted that no change occurred in the concentration of nitrate.

However, the concentration of nitrate in the wells in the study area is high, between (85-120 mg/L) compared to the maximum concentration of nitrate in the World Health Organization standards (WHO) which is 50 mg/l as shown in Figure (4.3). This means the groundwater in the study area (under the infiltration basin) is deteriorated by nitrate which is like the case of the northern aquifer of Gaza.

The artificial recharge of storm water in the study area, may work to improve concentration of nitrate of the ground water. No change of concentration of nitrate in wells around storm water infiltration basin in summer and winter was encountered, because groundwater movement takes long time to reach the wells.

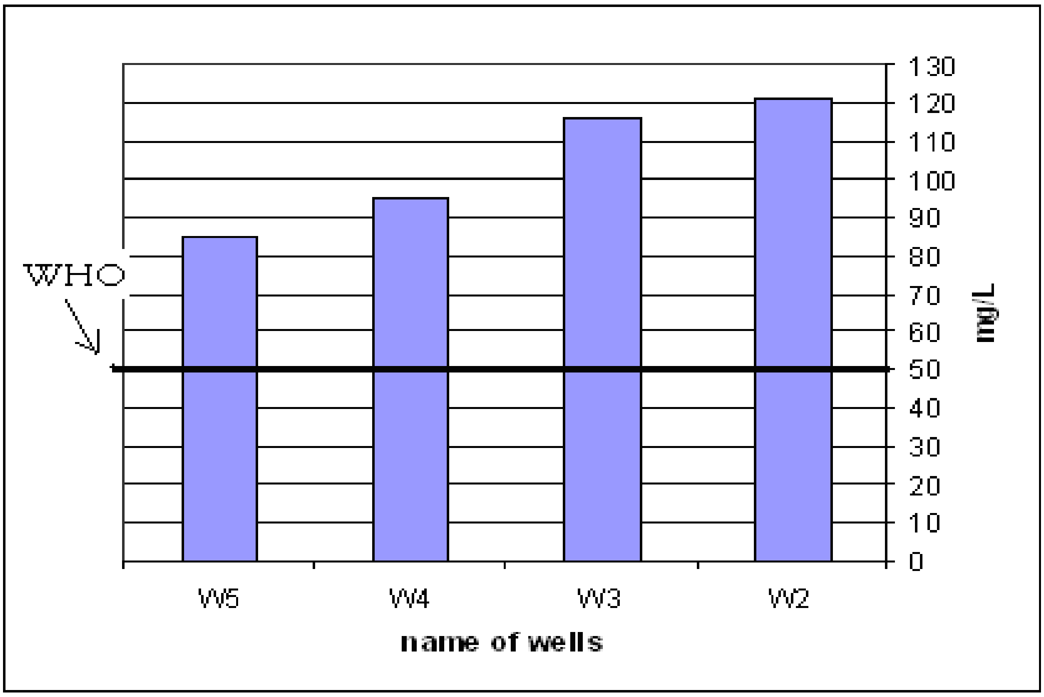


Figure (4.3): Concentration of nitrate in the wells in the study area .

4.10.2 Fecal Coliform

The concentration of fecal coliform is high in storm water, above100colony /100ml , compared to the maximum concentration of fecal coliform in the (WHO) standards which is zero colony/100ml. When storm water penetrates 2 meters of sand, the fecal coliform decreased to (80-110 colony/100mL). The 2 meters of sand were not enough to remove fecal coliform as shown in figure (4-4).

The fecal coliform was not found in wells around storm water infiltration basin. This means that the groundwater is not contaminated with biological contaminants.

This indicated that artificial recharge of storm water in the area study may pollute the groundwater by fecal coliform, therefore the storm water should be treated before infiltration into the groundwater.

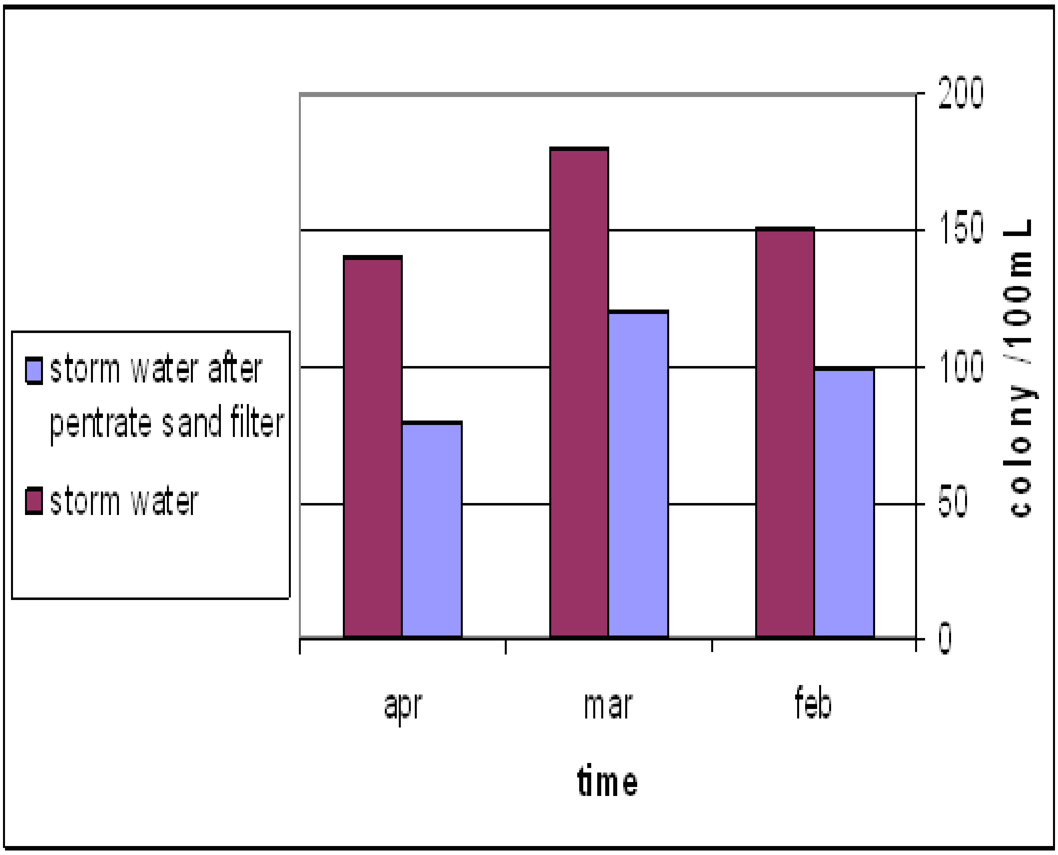


Figure (4.4): fecal coliform of storm water versus storm water after penetrating 2m of sand

4.10.3 **Turbidity**

Turbidity in the storm water of the basin is high, ranging between (30-39 NTU), but when storm water penetrated 2 meters of sand, the turbidity reduced to (2.5-3.5 NTU) which is acceptable, as the highest value set by the WHO is 5 NTU as shown in Figure (4.5), (4.6). These results revealed that the sand filter is good to improve the turbidity in storm water. The turbidity in ground water in study area was between (0.2-0.4 NTU), which is less than WHO limit.

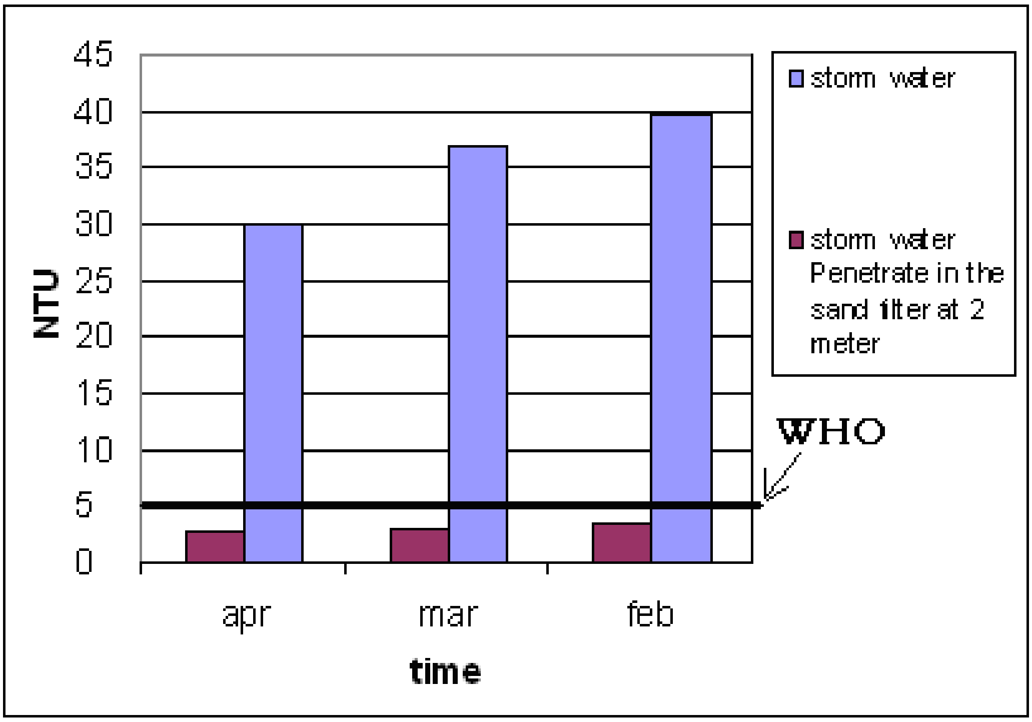


Figure (4.5): Turbidity of storm water versus storm water after penetrating 2m of sand

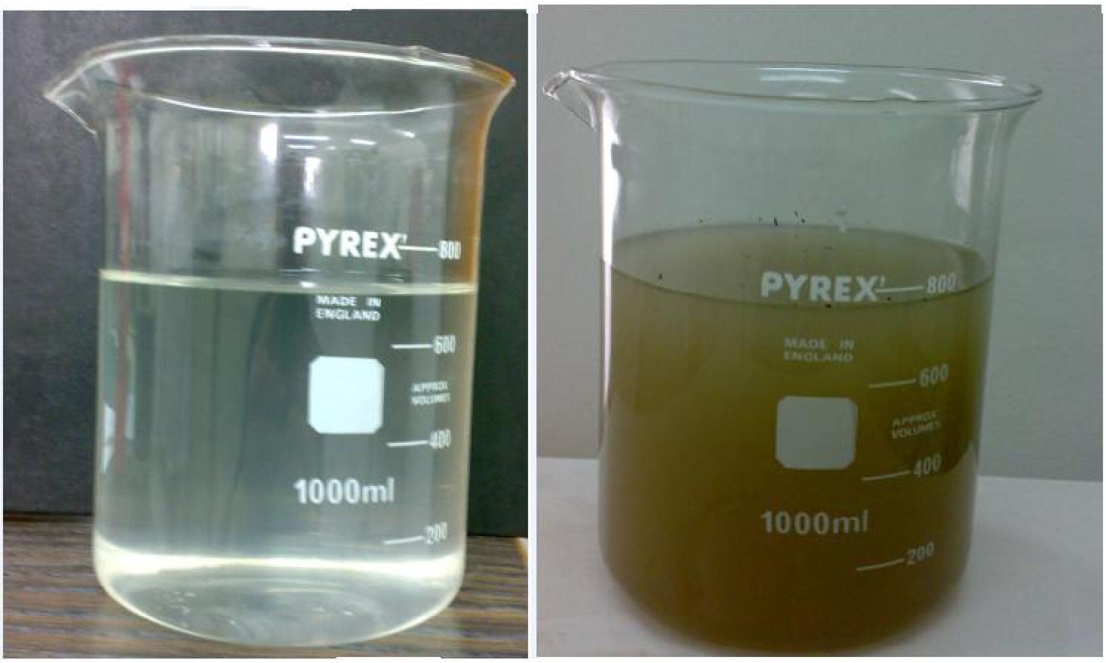


Figure (4.6) : Turbidity of storm water versus storm water after penetrating 2m of sand (photo)

4.10.4 Total Suspended Solid (TSS)

The total suspended solid in the storm water is very high between (290-600 mg/l), when storm water penetrated 2 meters of sand, the concentration of TSS reduced to (40-60 mg/l), see figure (4.7), that means sand filter removes TSS in high percentage.

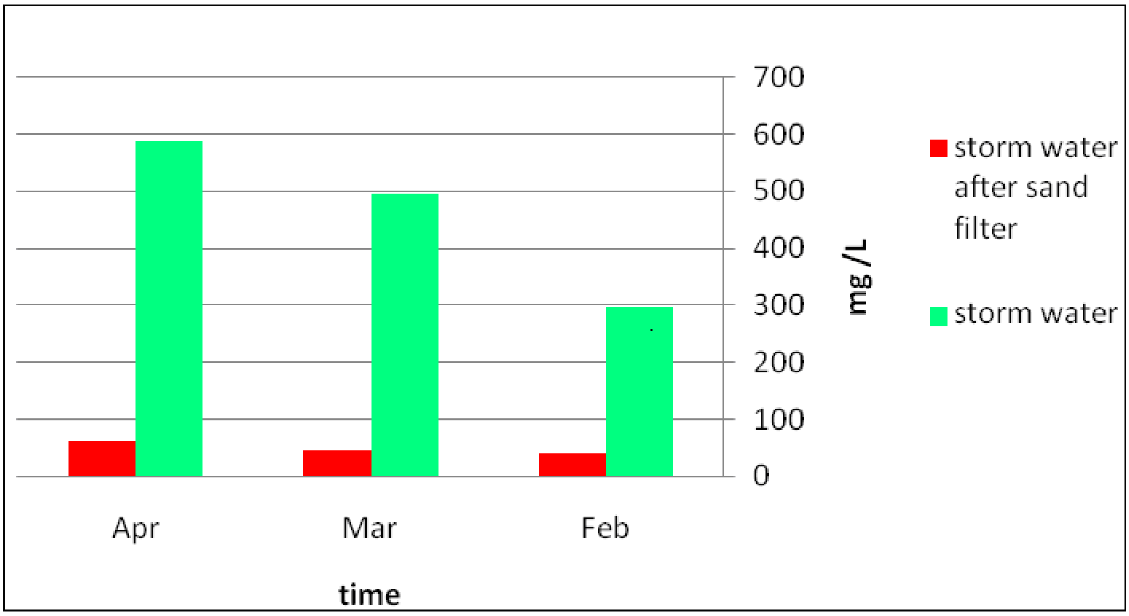


Figure (4.7): TSS of storm water versus storm water after penetrating 2m of sand

4.10.5 Detergent

The concentration of detergents in the storm water is small ranging between (0.17- 0.25) mg/l. This concentration is acceptable, as the concentration of detergent in drinking water must be no more than 0.5mg/l according to the WHO recommendation. When storm water penetrated 2 meters of sand, no change in concentration of detergent was encountered.

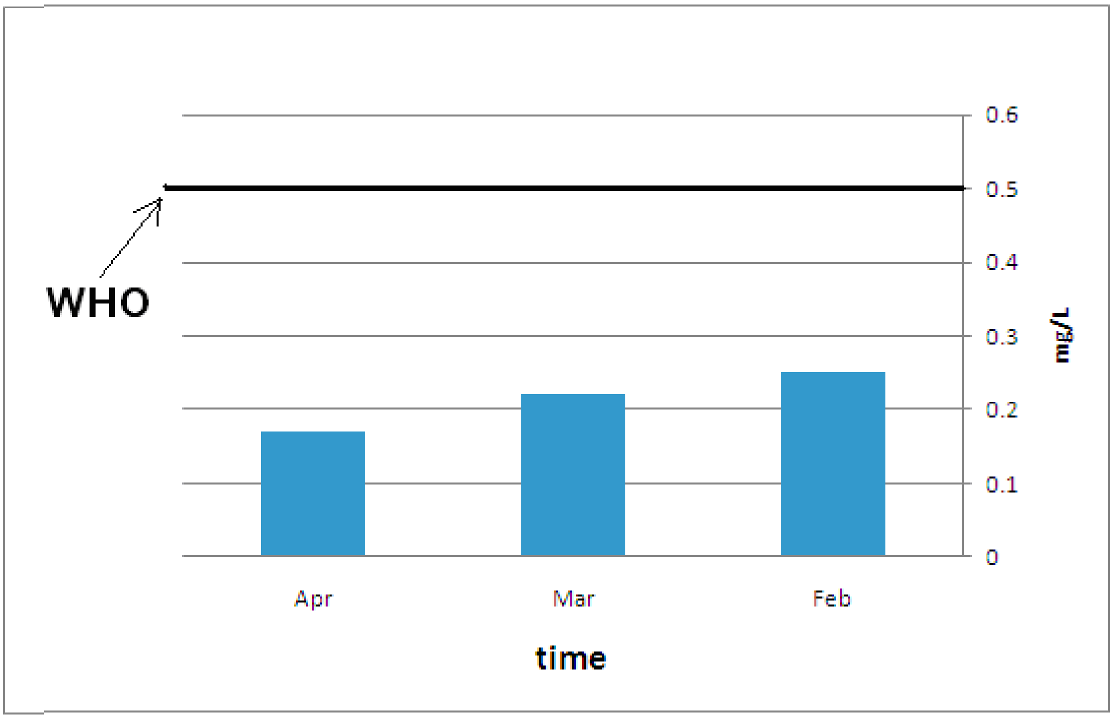


Figure (4.8): Detergent of storm water

4.10.6 Chloride (Cl^-)

The concentration of chloride of all samples in storm water, ranged between (20-50 ppm as Cl), when storm water penetrated 2 meters of sand, no change in chloride was encountered, which means that 2 meters of sand does not reduce chloride .

The chloride in the wells surrounding the basin range between (80-150 ppm as Cl^-), That means using the artificial recharge of storm water in the study area may reduce the concentration of chloride in the groundwater.

4.10.7 Other parameters

The concentration of TDS, Ca^{+2}, Na^+, Mg^{+2}, and k^+, in the storm water is less than those in the ground water of the study area where these concentration parameters of both the storm water and the groundwater are accepted according to WHO levels. This means that using the artificial recharge of storm water in the study area may reduce concentration of TDS, Ca^{+2}, Na^+, Mg^{+2}, and k^+ in the ground water. Tables (4.3) and (4.4) show that there are no changes of these parameters when using sand filter.

4.11 Summary of Laboratory Analysis

1- The quality of storm water collected in the infiltration basin in Biet Lahia is acceptable in many parameters as No_3^-, Cl^-, Mg^{+2}, Ca^{+2}, Na^{+1}, TSS, k^+, detergent, turbidity, TDS, and Hardness if comparing with the maximum level of WHO.

2- Fecal coliform in storm water infiltration basin is high, above maximum level of WHO .

3- Using artificial recharge of storm water to ground water in the study area, may reduce concentration of (No_3^-, Cl^-, Mg^{2+}, Ca^{2+}, Na^+, K^+, detergent, TDS, Hardness) in the ground water.

4- 2 meters of Sand filter is good to improve TSS and turbidity, but not enough to destroy biological parameter, (test Fecal coliform as indicator).

5- The concentration of all parameters in the wells always changes in winter and summer, but the analysis of the wells around the basin shows that the results of samples did not change for the following reasons :

   a. Water takes a long time to flow into the wells.
   b. The distance between the wells and the basin is long .
   c. The quantity of rainfall is little.

Chapter 5
Groundwater Model

5.1 Introduction

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

The V-MODFLOW (2.8.2) Computer code was applied for simulation of three dimensional coupled flows and transport in the Gaza coastal aquifer. It is a numerical engine based on finite difference grid.

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

Developing of a conceptual model provides better understanding of the current site conditions and the physical behavior of the groundwater flow system. It simplifies and defines the hydrogeological problem and organizes the data to easily develop the mathematical model and selection of the most suitable numerical model. The mathematical model is based on many differential equations for calculating hydraulic heads accompanied with specifications of system geometry, boundary and initial conditions. Dimensions of the numerical model and the design of grids are based on available data regarding the study area, mainly inflows, outflows and system hydrogeology. The conceptual model must be as much as representative of real system as possible, in which constructing the numerical model depends on the conceptual model.(McDonald and Harbaugh, 1988).

5.2 Data Management

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

1. Geological maps and cross sections showing the vertical and horizontal extents 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.

The collected data were obtained from many local sources in different formats. The main source of this data is 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 which the model is based on. In addition to the data included in this chapter, an extensive literature review of almost conducted studies was read, as well as online published papers and related researches.

5.3 Ground water model

5.3.1 Model Boundaries

The Model Domain encloses an area of 2x2 km in the north part of Gaza Strip as shown in Figure (3.1) of Chapter 3. A constant head boundary was assigned in all directions (north, east ,south and west), the groundwater levels along the boundary are assigned according to the data from a contour map of groundwater level for the year 2000 .The upper boundary is defined by water table which rise and fall according to hydrologic changes. The lower boundary corresponds to the top of the Saqiya Group which is clay layer defined the bottom of the aquifer.

5.3.2 Grid Size

The model domain is divided into a uniform square grid comprising 100 rows and 100 columns with a grid spacing of 20X20 m, which was judged adequate in view of the available data. However, the grid is 5X5m in the artificial recharge area (Infiltration Basin) as shown in the Figure (5.1).

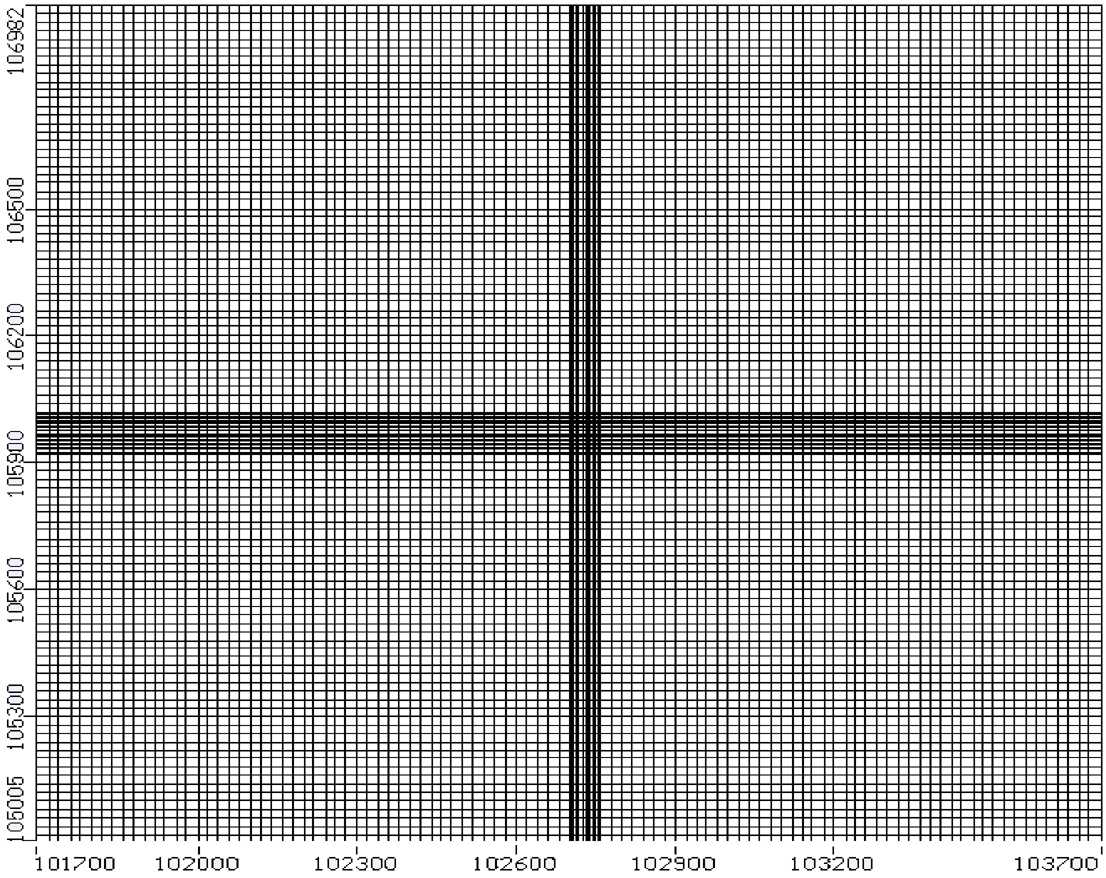


Figure (5.1) :The model domain with the grid.

5.3.3 Aquifer Layers

The model is divided vertically into 3 layers. as shown in Figure (5.2).

- The first layer is a top layer consisting of sand dune with thickness of about 8 meters.
- The second layer is hard clay with thickness of about 14 meters.
- The last layer is sand stone (Kurkar) with a thickness of about 170meters .

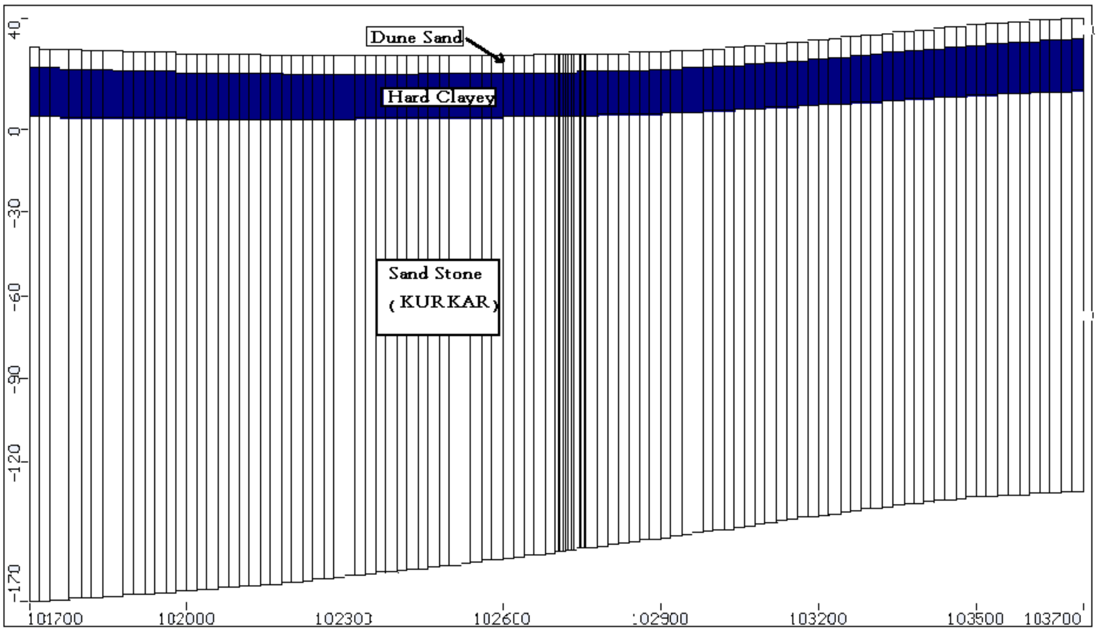


Figure (5.2): Aquifer layers in the study area

5.3.4 Hydraulic Properties

Hydraulic property values are assigned based on the hydrogeological investigation. The hydraulic conductivity is assumed to be constant for each layer. The horizontal hydraulic conductivity of the saturated zone for the soil types investigated is 30 m/d for sand with fine gravel and 0.3 m/d for clay (Metcalf and Eddy, 2000). The vertical hydraulic conductivity of the sandstone aquifer and the phreatic storage coefficient are taken from the pumping test. The default hydraulic parameters of the model is based on Coastal Aquifer Management Plan (CAMP) data and the interpretation of pumping tests in the area. The vertical conductivity was set to 10% of the horizontal hydraulic conductivity in project (CAMP) in 2000 (Metcalf and Eddy, 2000), The assumed or estimated input data in the model are summarized in the Table (5.1).

Table (5.1): Hydraulic parameters value for model inputs

Parameter	Dune sand	Clay	Sand Stone
Hydraulic conductivity (m/d) Kx ,Ky	18	0.3	30
Hydraulic conductivity (m/d) Kz	1.8	0.3	3
Specific storage (m^{-1}) Ss	1.E-05	1.E-05	1.E-05
Specific yield Sy	0.24	0.1	0.24
Effective porosity	0.25	0.4	0.25
Total porosity	0.3	0.5	0.3

5.3.5 Recharge

Recharge from precipitation is not a directly measured value, but it is estimated by various empirical methods that often involve variables that contain a degree of uncertainty. Factors that ultimately influence recharge are: precipitation amount (including rainfall duration and frequency), evapotranspiration, land use, soil type, and irrigation practices .

Average rainfall depth in Beit Lahia station (near the study area) is 460 mm/m^2/y (PWA, 2007). The average runoff coefficient was assumed as 0.48 in the study area , as mentioned in the design report of Beit Lahia Municipality infiltration Basin (IUG, 2007).

5.3.6 Return Flows

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

5.3.7 Pumping wells

Ground water is the main source of Palestinian agriculture, municipal, and industrial demands in north Gaza Governorate. The collected data contained partial data of all known wells in the period between 2000 and 2008, including the location of wells, coordinates, screens depths, abstractions and water quality parameters. There is limited information about the well construction and pumping readings for illegally-dug wells which are were discovered through a survey conducted lately by PWA. There are suspected to be additional existing illegal wells dug after the year 2000, With unidentified locations.

5.3.7.1 Municipal Wells

There are about 6 municipal wells in the study area operated since year 2000 (PWA Database). Detailed abstraction records are shown in Table (5.2).

Table (5.2): Municipal wells abstraction rate (PWA-databank, 2000)

WELL_ID	Location	Q (m^3/day)
A/185	Beit Lahia	3,811.9
A/211	Beit Lahia	2,630.0
A/205	Beit Lahia	2,142.3
E/06	Beit Lahia	1,596.9
E/04	Jabalia	2,803.5
D/72	Gaza	3,326.8

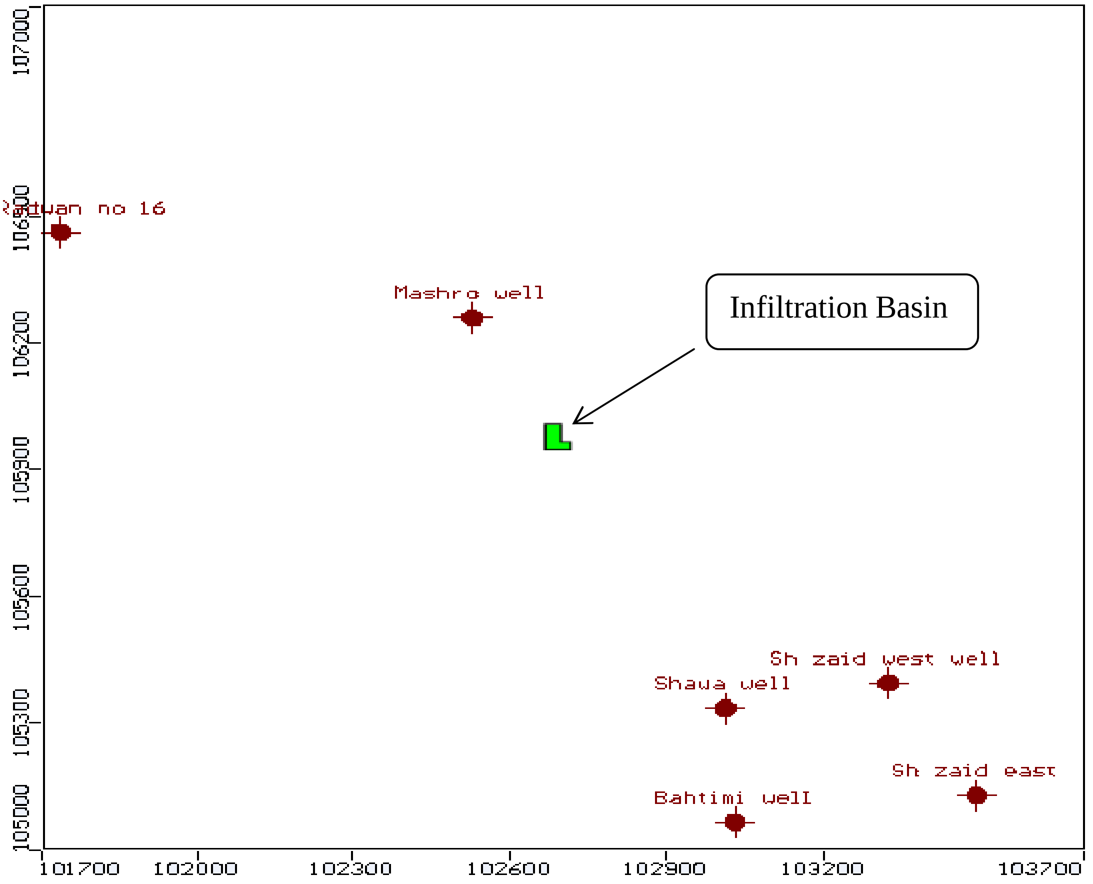


Figure (5.3): Location of Municipal wells in the study area.

5.3.7.2 Agriculture wells

There are about 32 Agriculture wells in the study area in operation since year 2000 (PWA Database). Detailed abstraction records are shown in Table (5.3).

Table (5-3): Agricultural wells abstraction rate (PWA- databank, 2000)

#	Agriculture ID	Q (m^3/hr)
1	A/21	30
2	A/20	30
3	D/12	30
4	A/22	35
5	A/23	42
6	A/19	25
7	D/11	36
8	D/63	21
9	D/13	30
10	A/25	20
11	A/24	27.6
12	A/26	19
13	A/28	30
14	A/31	35.5
15	D/20	30-35
16	D/14	20
17	D/21	40
18	A/30	30
19	D/64	36
20	D/19	37-50
21	D/15	15
22	A/33	37
23	D/18	30-35
24	D/16	25-30
25	D/17	25-35
26	A/122	28
27	A/35	29
28	A/36	31
29	D/24	36
30	D/25	20-30
31	A/37	33.5
32	A/39	36

5.3.7.3 Observation wells

Three wells were selected as head observation wells for the model local calibration as shown in Figure (5.5). The observation wells data were taken from the Palestinian Water Authority (PWA). The location of observation wells of basin as shown Table (5.4) .

Table (5.4): location of observation wells of basin

#	Observation wells	located of obs wells of basin
1	A-21	730 m
2	A-31	90 m
3	A-53	1050 m

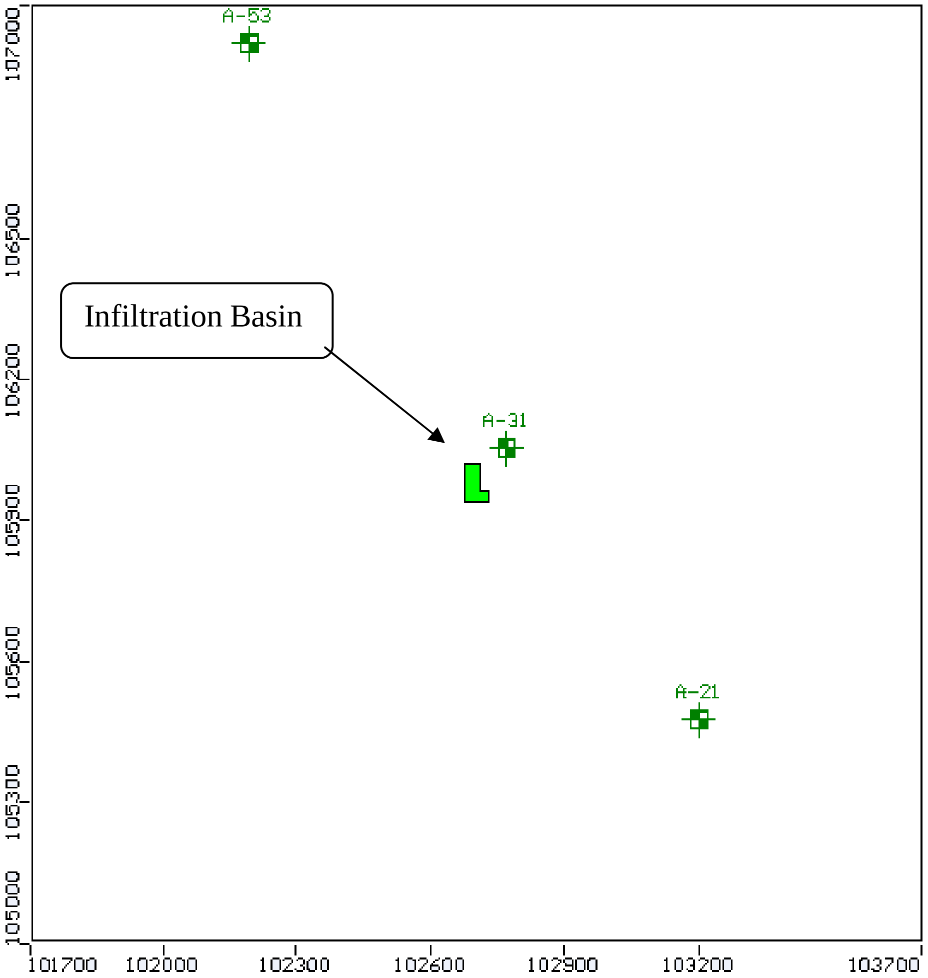


Figure (5.5): Location of observation wells in study area.

5.4 Model Calibration

Calibration is the iterative process of adjusting the parameters in the model, such as hydraulic conductivity, transmissivity and dispersivity, so the model adequately represents the real ground water system. Every model must be calibrated before it can be used as a tool for predicting the behavior of a considered system (EPA,1992). This is accomplished by comparing the model results to a set of field observations. The calibration data set should include measurements over the lateral and vertical extent of the model area. For a flow model this data will often consist of water level measurements from monitoring wells and piezometers.

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

Calibration should proceed by first changing those parameters with the lowest level of accuracy, and then fine-tuning the simulation by adjusting other parameters. It must focus on parameters that are not measurable like recharge which is of regional significance (Barakat, 2005).

Calibration is the process where hydraulic properties and boundary conditions are modified so that the simulated values of groundwater heads approximately meet the observed ones. The model was calibrated under steady-state conditions (Salah, 2007). Through a trial and error procedure a real recharge was suitably adjusted after each simulation run until a good match was achieved between the calculated and observed water levels.

The numerical model was calibrated and tested against both steady state and transient state. The steady state model was simulated for the year 2000. This year was selected because it represents a year when rainfall records were close to the long-term average and a relatively comprehensive set of municipal and agricultural abstraction data are available. The simulation period was conducted over 5 years, starting in 2001 and ending in 2006 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 2001 to 2006. Calibrated groundwater levels for year 2000 conditions are shown in Figure(5.6).

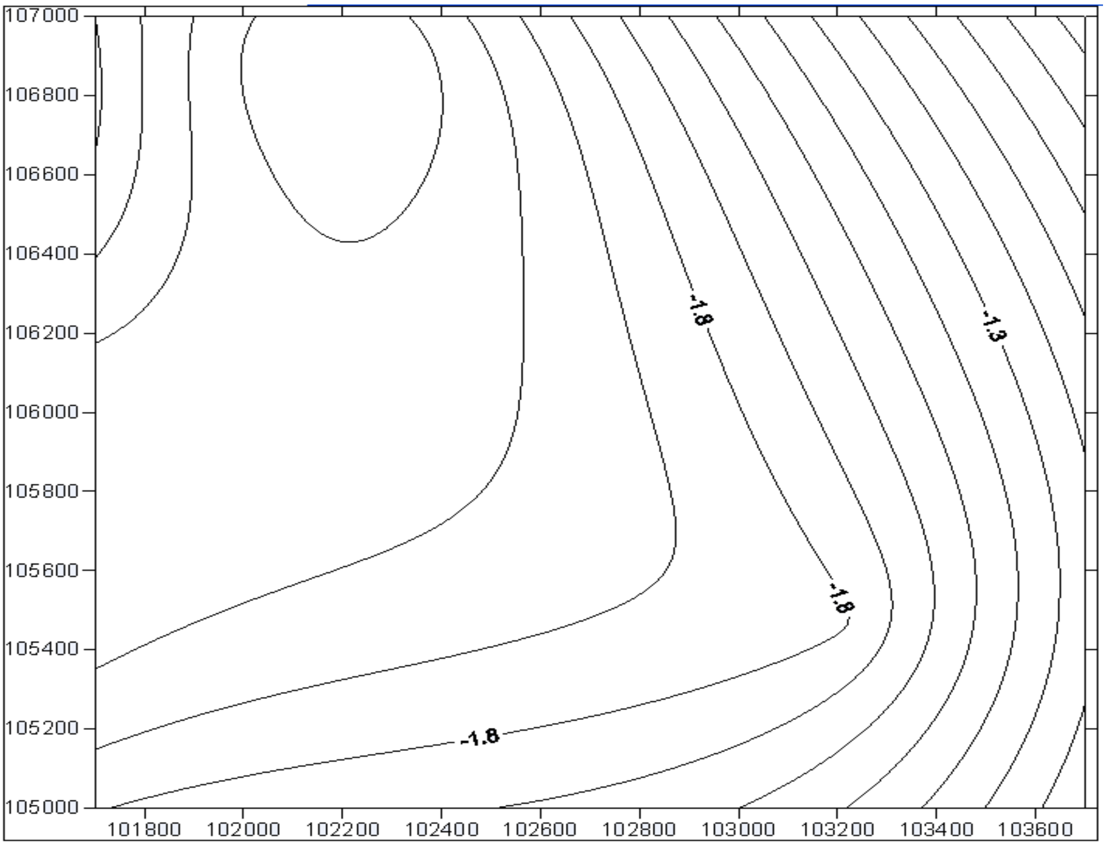


Figure (5.6): Groundwater levels of the coastal aquifer in area study for the year 2000, (PWA, 2000)

Average water levels of year 2000 for 3 wells within the model domain were used as calibration targets. The calculate mean error 0.137m , mean absolute is 0.16m, standard error of the estimate 0.0299m , root mean squared 0.268 m, normalized RMS 9.36% . Calibrated groundwater levels versus measured groundwater levels for the years 2005, correlation is 0.93are shown in Figure (5.7).

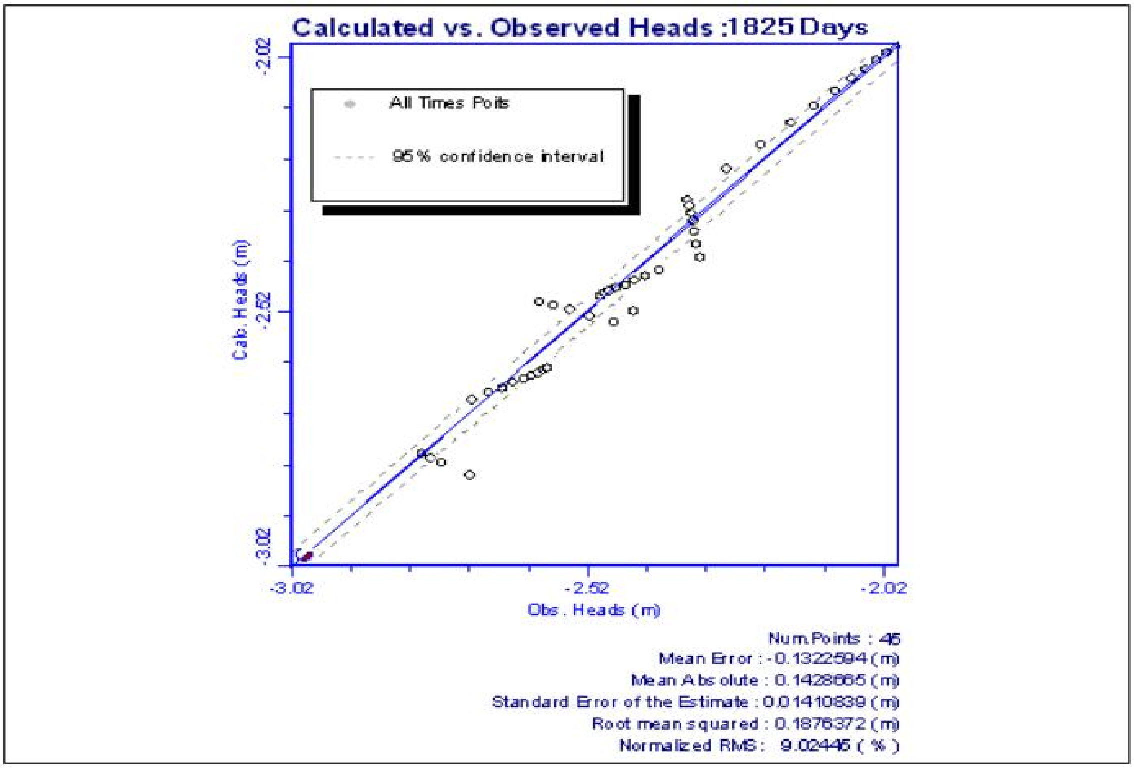


Figure (5.7): Calibrated versus measured groundwater levels at the year 2006

Figure (5.8) shows simulated and observed hydrographs in well A-31, near the study area.

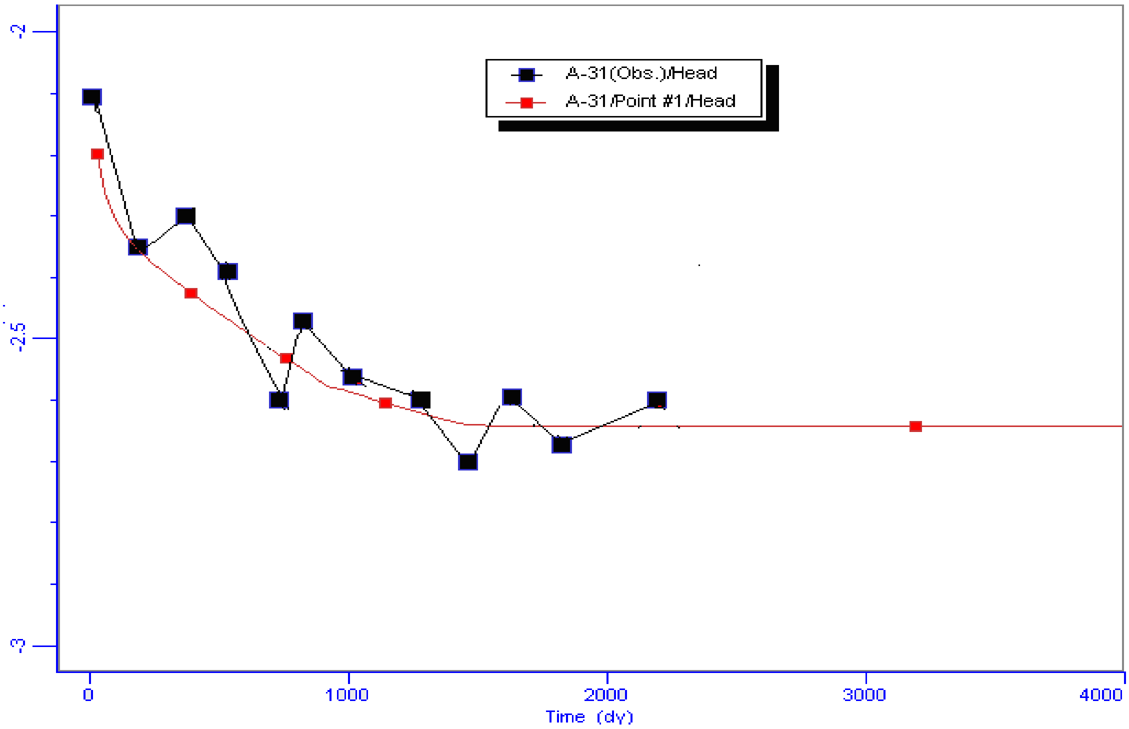


Figure (5.8): Observed and calculated heads versus time for well A-31

5.5 Artificial recharge simulation

5.5.1 Introduction

Artificial recharge in Beit Lahia Municipality infiltration Basin occurs by infiltration wells (type of artificial recharge) as described in Chapter 1. The number of infiltration wells in the infiltration Basin is 76 wells of 18 m depth as shown in Figure (5.9).

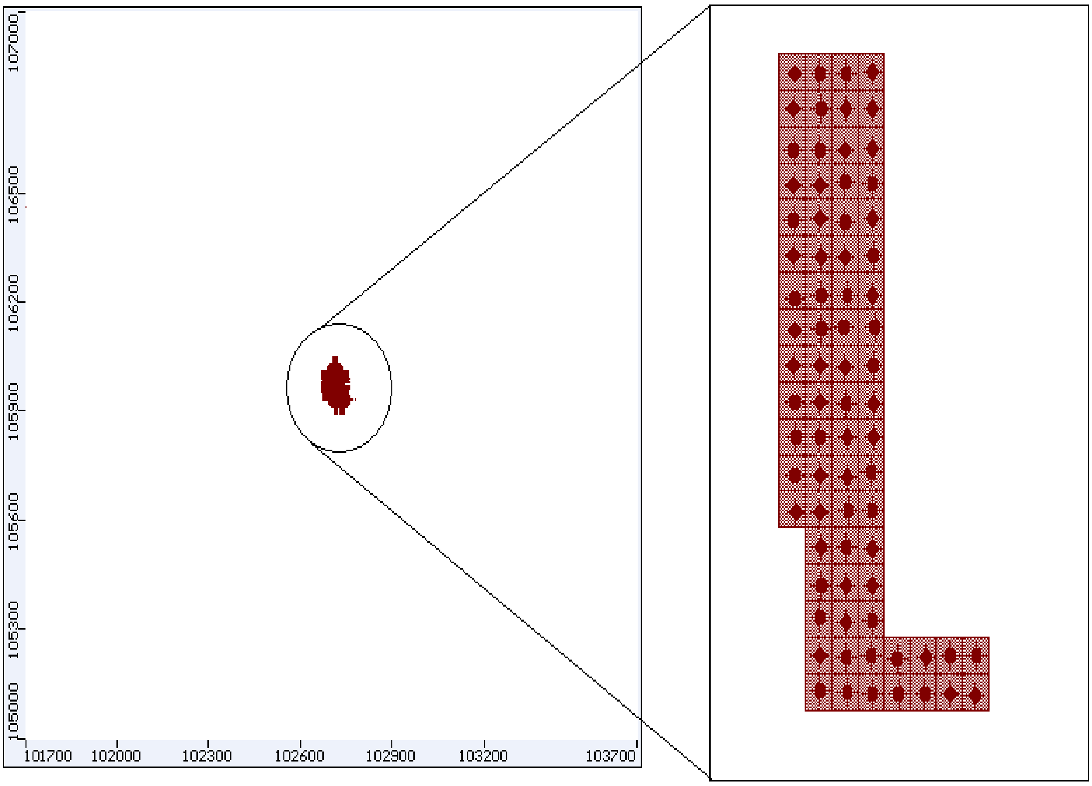


Figure (5.9): Infiltration wells in Beit Lahia Municipality infiltration Basin.

5.5.2 Calculation quantity of storm water

The quantity of storm water that is infiltrated each year through the infiltration basin is calculated as follows:

- Average rainfall depth in Beit Lahia station is 460 mm/m^2/y (PWA,2007) .
- Catchment's area for the infiltration basin is 700,0000 m^2 then the volume of storm water is :

$$\frac{460 \text{ X } 700{,}000}{1000} = 322{,}000 \text{ m}^3/\text{y}$$

- Runoff volume = V X C

- C = run coefficient = 0.48
- Runoff volume = 322,000 X .48 = 154560 m^3/y
- Rainfall occurs in six months alone (182 days in a year)
- Runoff volume = 154560 / 182 days = 850 m^3 / days
- The maximum infiltrated volume during the rain in one day is computed as 11,738 m^3 (infiltration rate is 3 m/d).
- Runoff volume (850 m^3)< maximum infiltrated volume (11,738 m^3)
- Number of bore holes = 76
- 850/76 = 11.1 m^3 / day / bore holes .

5.5.3 Predicted Groundwater Table

The simulation shows that the groundwater mound beneath the center of the recharge basin can be expected to rise to about 25 cm above the present water table in winter ,then drop in the summer and so on. This makes water table oscillatory under the basin. Figure (5.10a) shows the groundwater levels of initial heads. The storm water infiltration has given full effect on the groundwater level change as shown from transient simulation after 182 days (after winter), 1 years and 10 years in Figures (5.10b), (5.10c) and (5.10d) respectively. The model simulations indicate that the water level will be increased in the area and the cone of depression will diminish substantially due to the infiltration.

To monitor the impact of the artificial recharge on water level, observation wells in different distance of infiltration basin were used. Figure (5.11) presents the simulated water level in observation wells located in the center of the basin, 100 m, and 200 m of the basin.

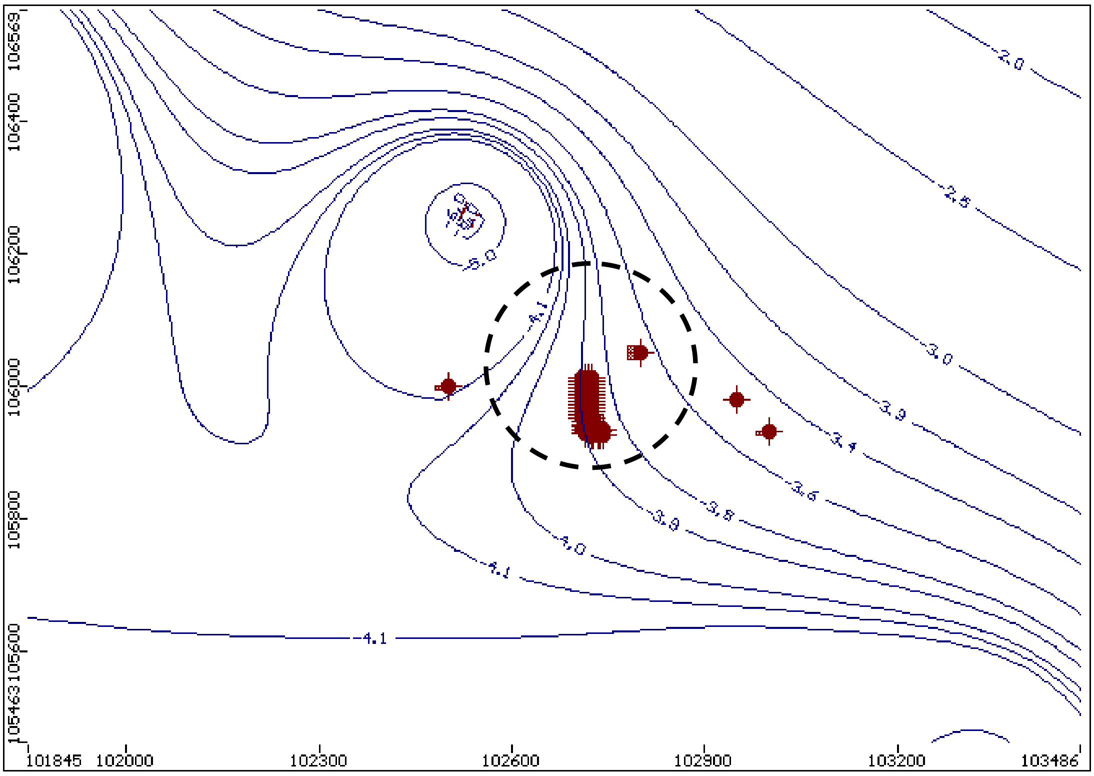


Figure (5.10a): The groundwater levels of initial heads in area study.

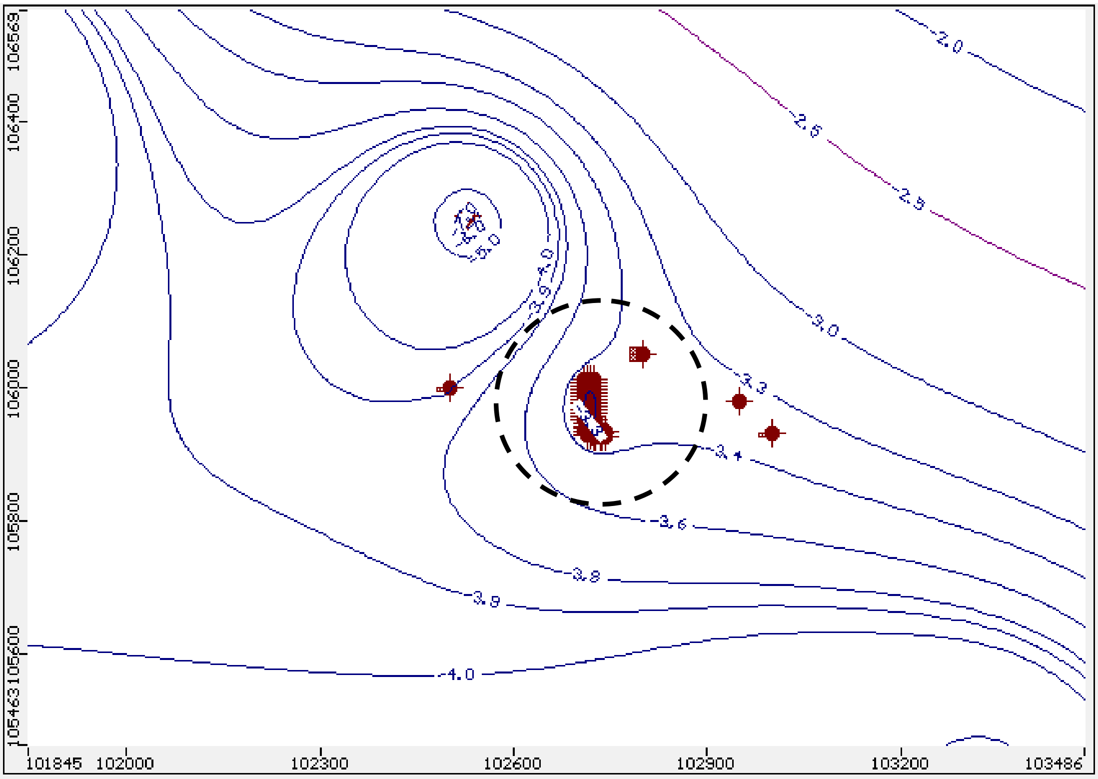


Figure (5.10b): Simulated groundwater levels with infiltration after 182 day (Half a year)

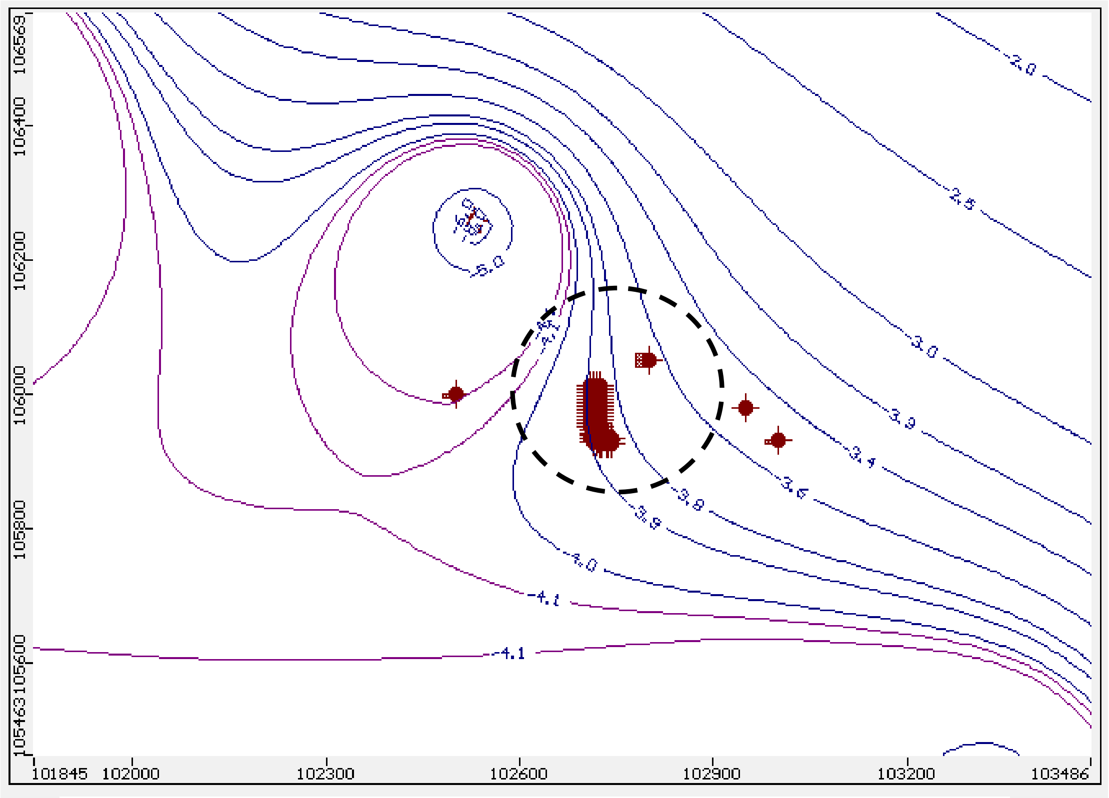


Figure (5.10c): Simulated groundwater levels with infiltration after 1 years.

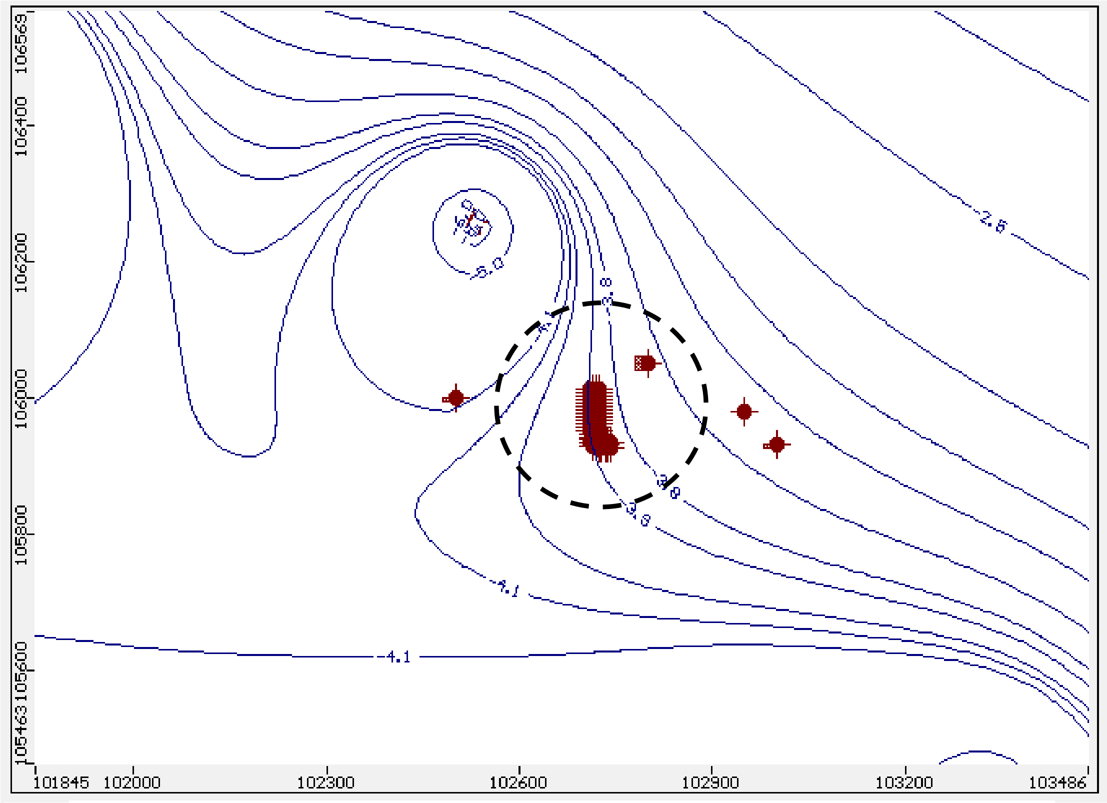


Figure (5.10d): Simulated groundwater levels with infiltration after 10 years.

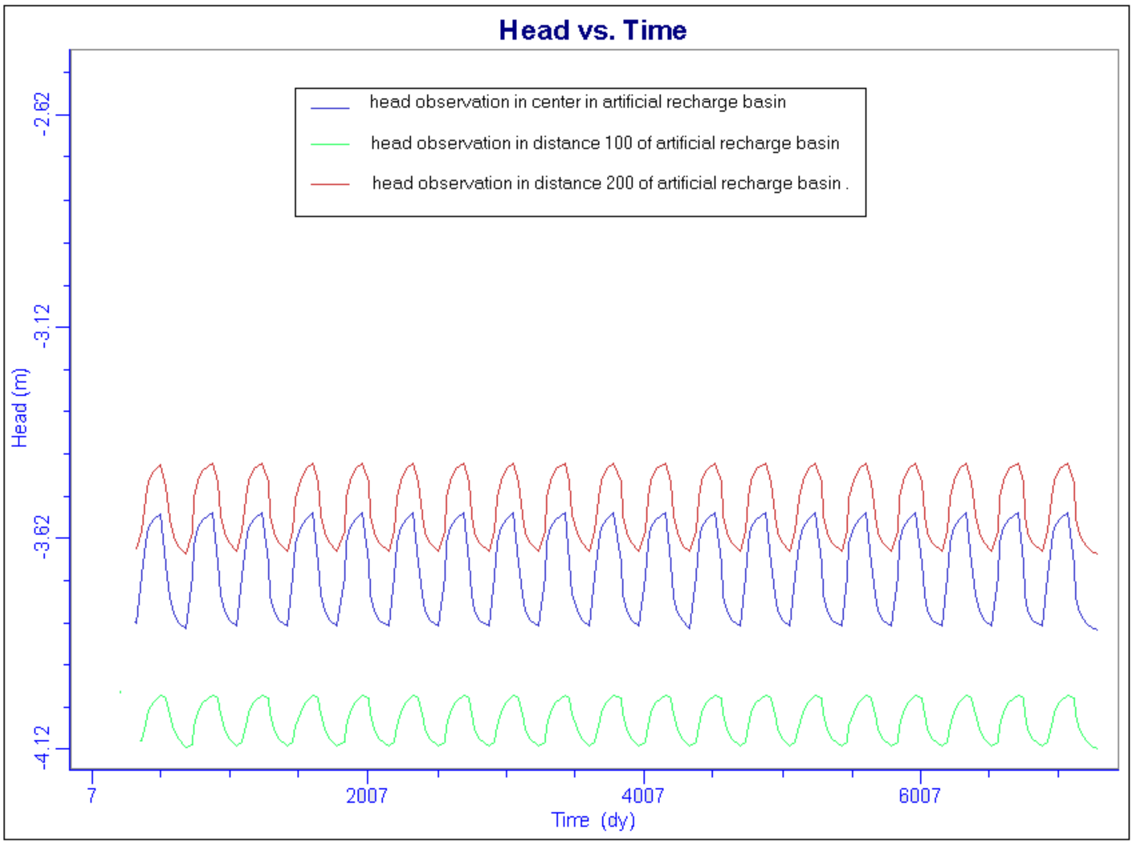


Figure (5.11): presents the simulated water level in observation wells in different location.

The storm water artificial recharge did not affect the rise of groundwater table in the study area, because the amount of storm water is little, and the storm water is not continuing in during the year .

5.5.4 Particles pathlines

In order to simulate the penetration of the injected water in the original groundwater layer, we will make use of MODPATH for tracking of flow lines from the injection site. The pathlines for imaginary particles that are infiltrated in the recharge area will spread radially about 100 m after 2 year, 250 m after 10 years, 400 m after 20 years, as shown in Figures (5.12a), (5.12b), (5.12c), (5.12d) respectively**.**

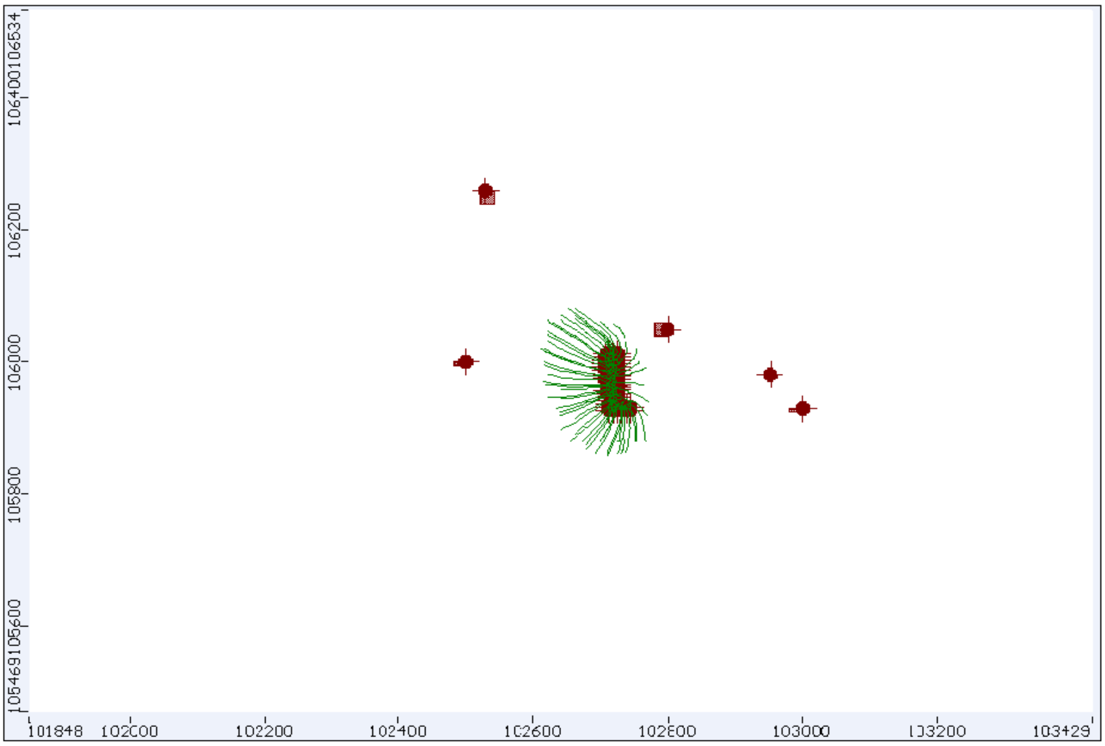


Figure (5.12a): Pathlines for virtual particles infiltrated after 2 years.

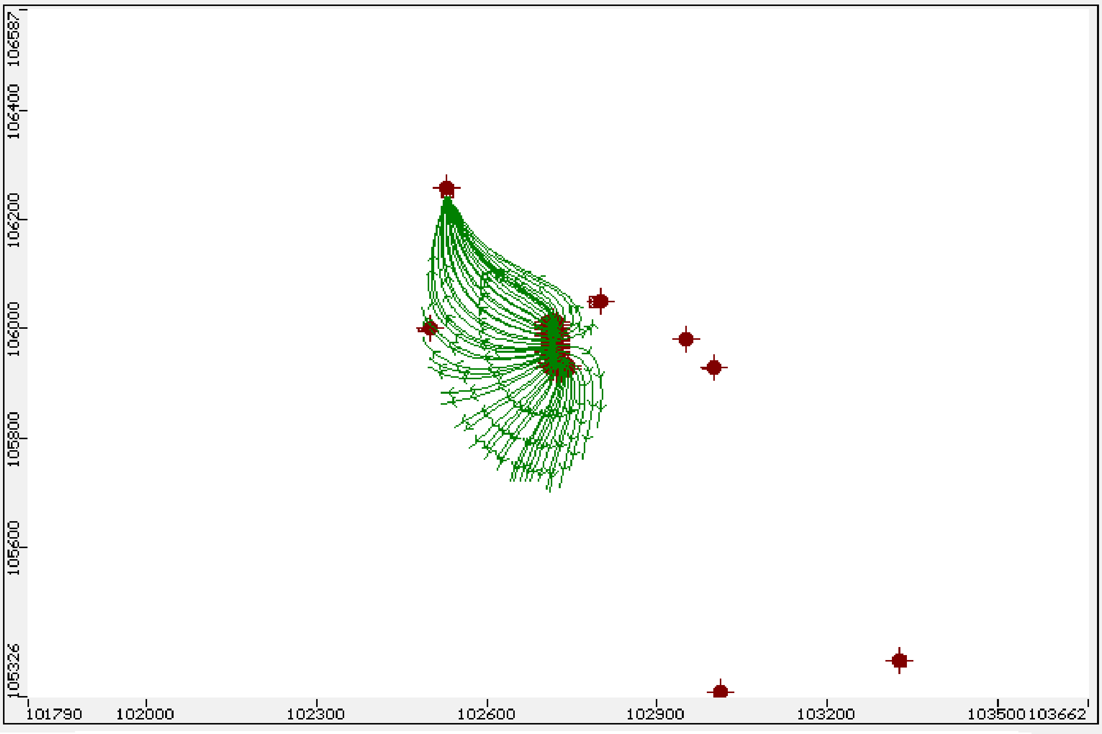


Figure (5.12b): Pathlines for virtual particles infiltrated after 10 years.

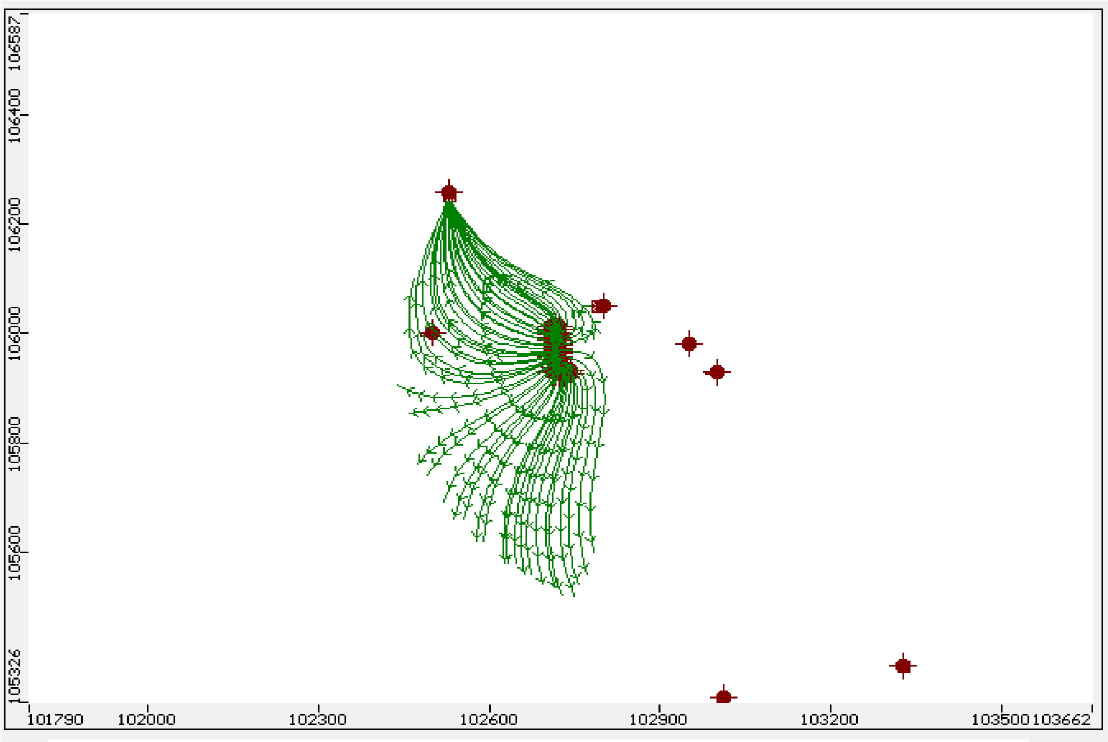


Figure (5.12c): Pathlines for virtual particles infiltrated after 20 years.

5.5.5 Solute transport model

The solute transport model MT3D (Zheng, 1994) describe the process of advection, dispersion-diffusion and chemical reactions. The model set-up was conducted based on the results of the regional flow model. The parameters values adopted in the solute transport model are chosen based on previous modeling in Gaza Strip aquifer such as (Aish , 2004) and CAMP 2000. In these studies the longitudinal dispersivity is about 50 m, horizontal dispersivity ratio 0.1, vertical transverse dispersivity ratio 0.01 and molecular diffusion coefficient 10^{-4} m^2/day.

In order to study the solute transport due to dispersion, it is assumed that a conservative trace does not degrade and are not absorbed or adsorbed. It is assumed that infiltration water has a concentration of 100 mg/l is present, while the material concentration in the aquifer is set to 0 mg/l .

The infiltrated water will spread outward with decreasing percentages in the surrounding area, as shown in Figures (5.13a), (5.13b), (5.13c), (5.13d) and (5.13e), where simulation periods are after 1, 2, 5, 10 and 20 years respectively. Figure (5.13f) shows the infiltrated storm water quality in cross section shape after 20 years.

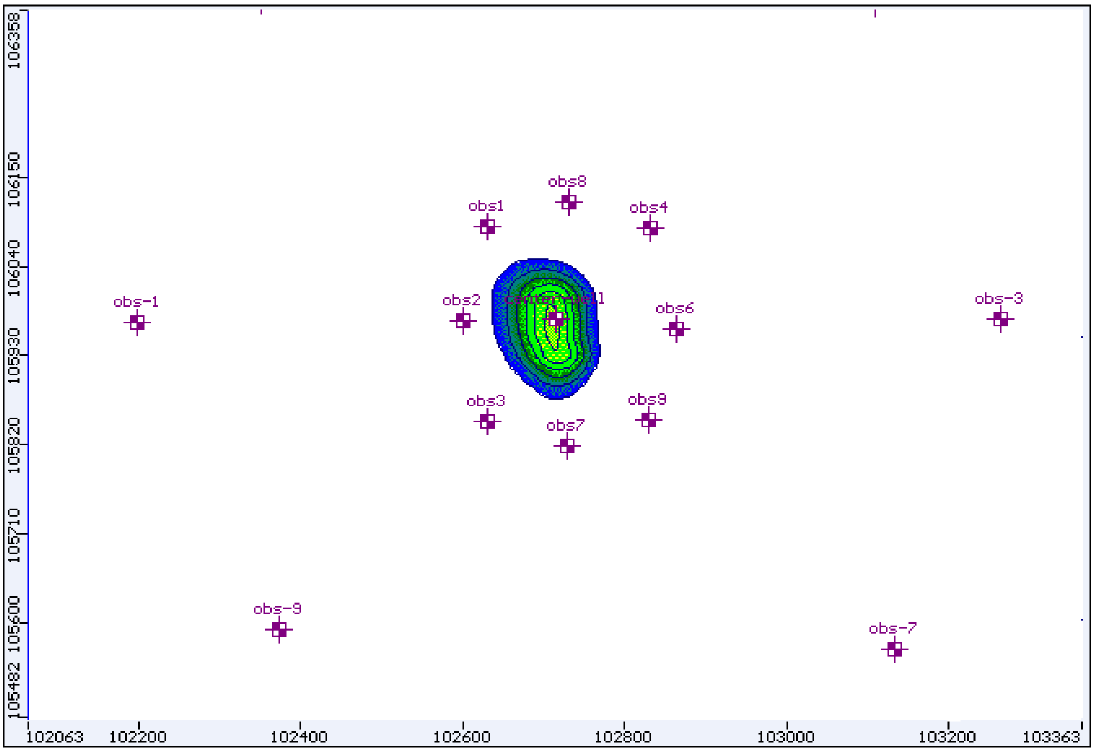


Figure (5.13a): Simulation of mass transport after 1year.

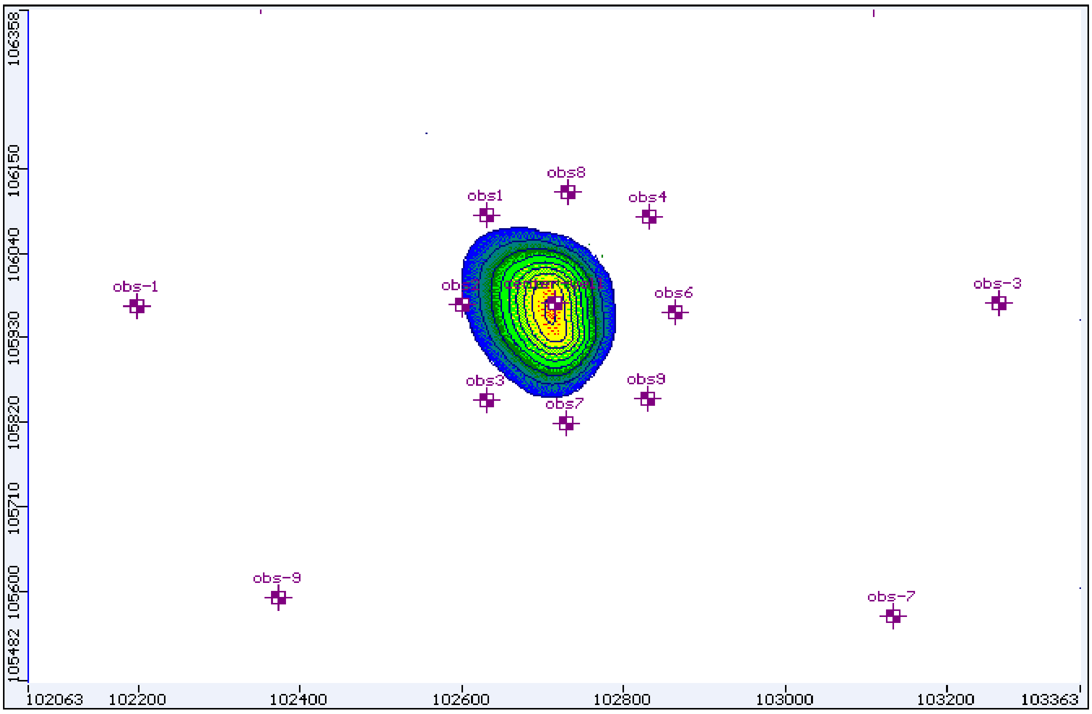


Figure (5.13b): Simulation of mass transport after 2years.

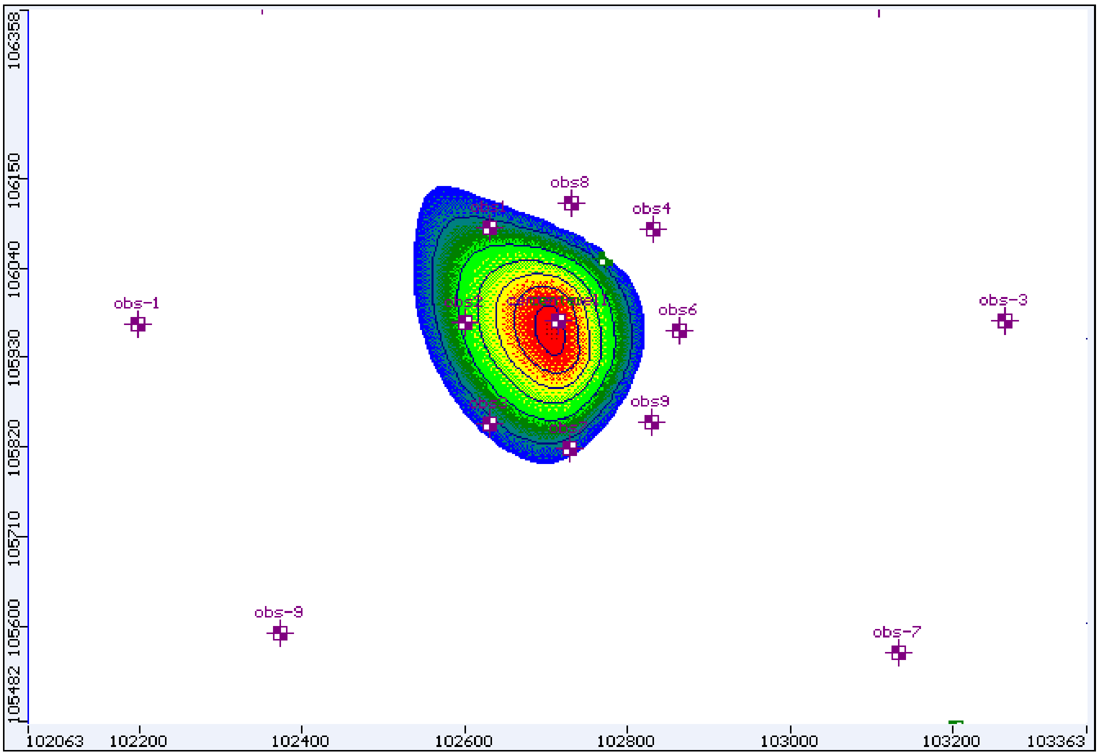


Figure (5.13c): Simulation of mass transport after 5 years.

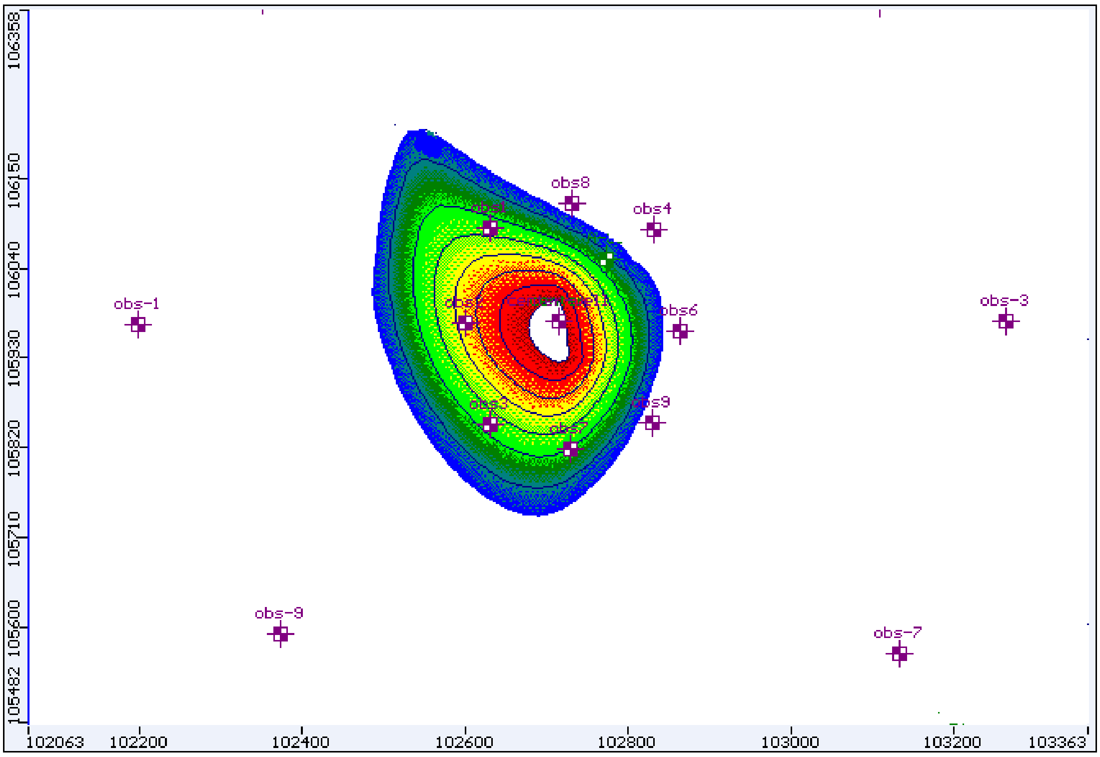


Figure (5.13d): Simulation of mass transport after 10 years.

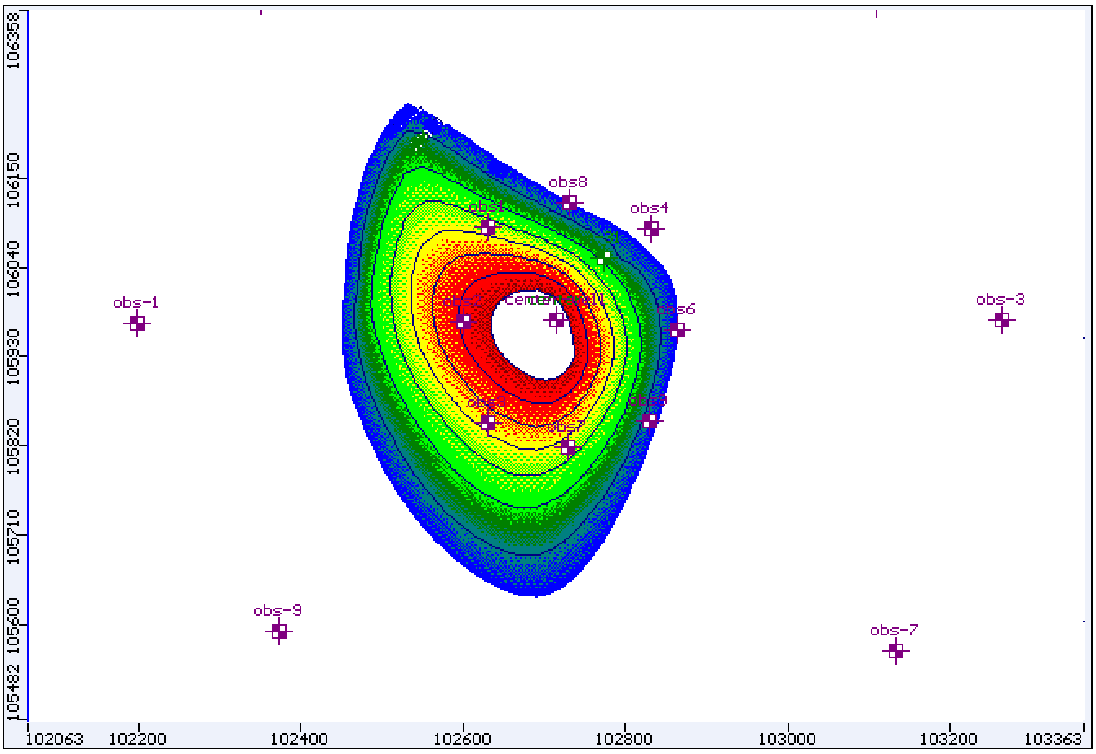


Figure (5.13e): Simulation of mass transport after 20 years.

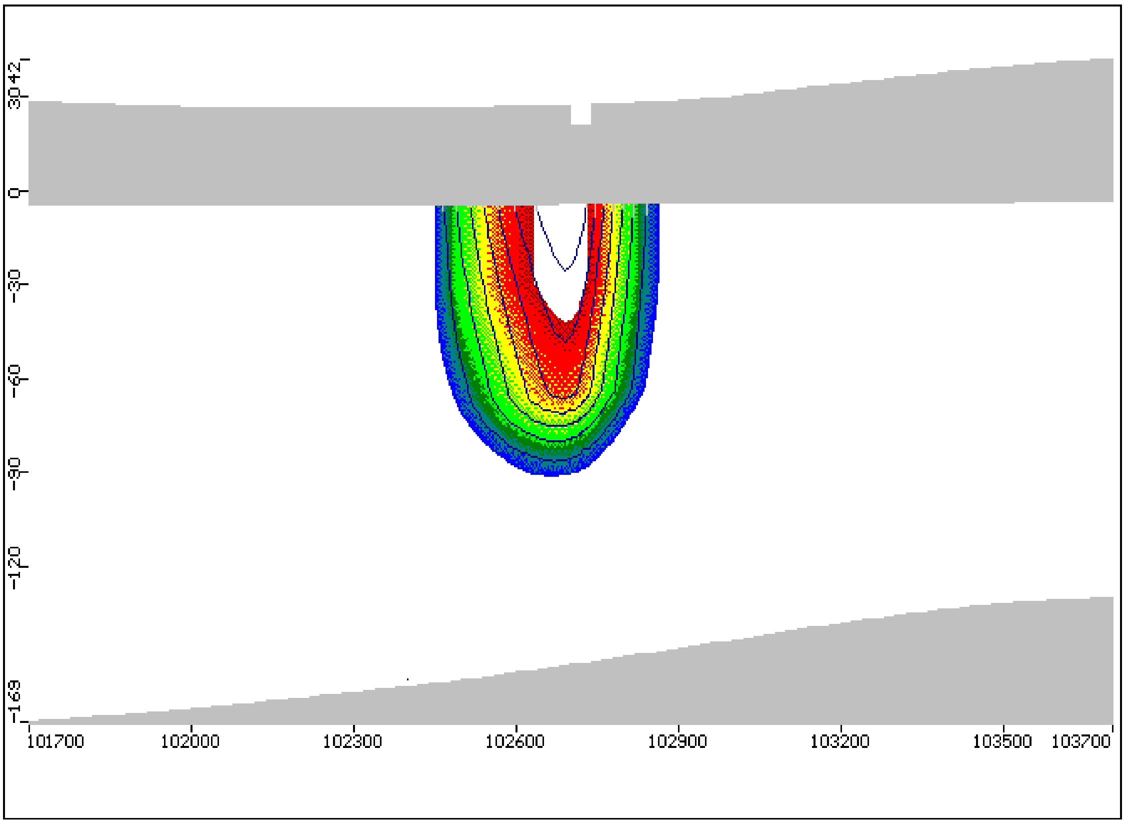


Figure (5.13f): Simulation of mass transport after 20 years in depth of layer .

To monitor the impact artificial recharge in water quality, observation wells in different distance of infiltration basin were used, as Figure (5.14) :

- center in artificial recharge basin .
- distance 100 about artificial recharge basin .
- distance 500 about artificial recharge basin .

Figure (5.15a) presents the simulated water quality in observation wells located in the center of the basin, in the depth 30, 90 in the surface. Figure (5.15b) presents the simulated water quality in observation wells located 100 m of the basin in downstream, in the depth 30, 90 in the surface. Figure (5.15c) in below, presents the simulated water quality in observation wells located 100 m of the basin upstream, in the depth 30, 90 in the surface. Figure (5.15d) in below, presents the simulated water quality in observation wells located 500 m of the basin, in the depth 30, 90 in the surface.

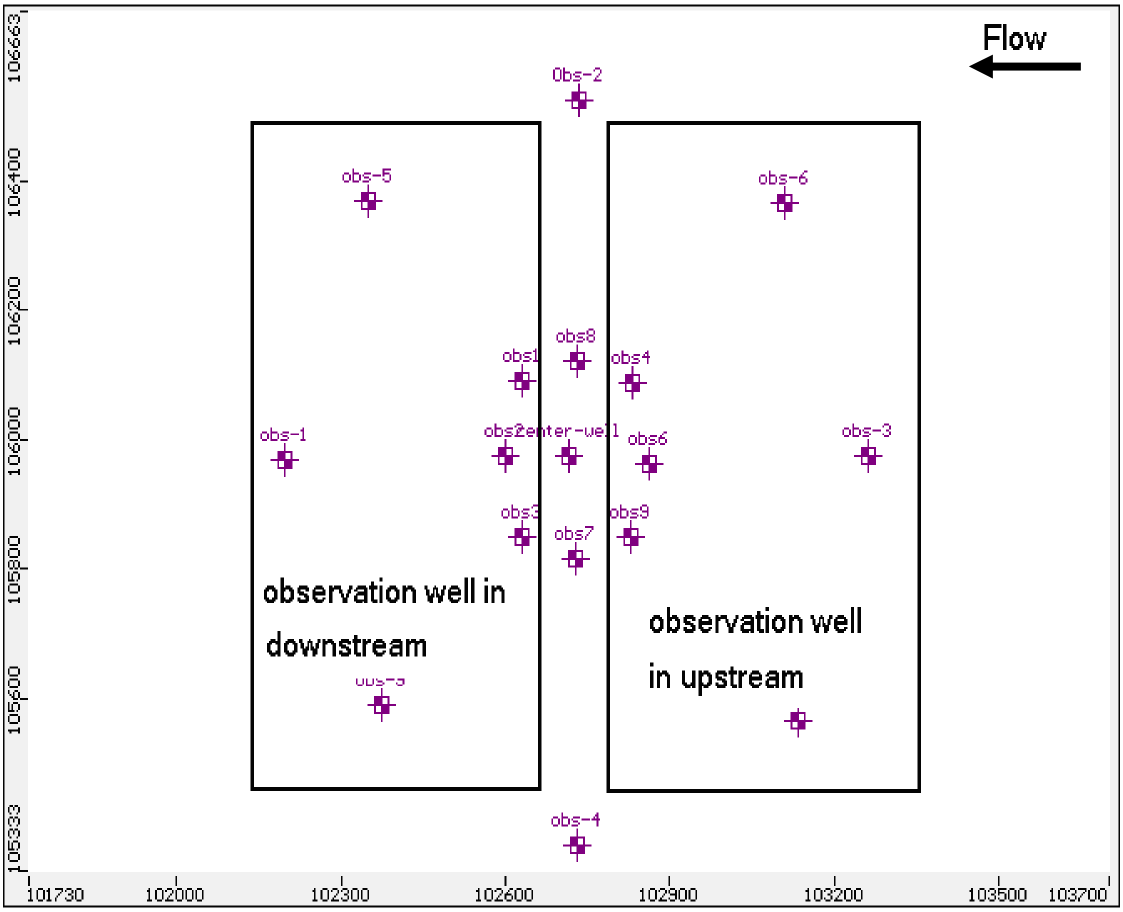


Figure (5.14): location of concentration observation wells.

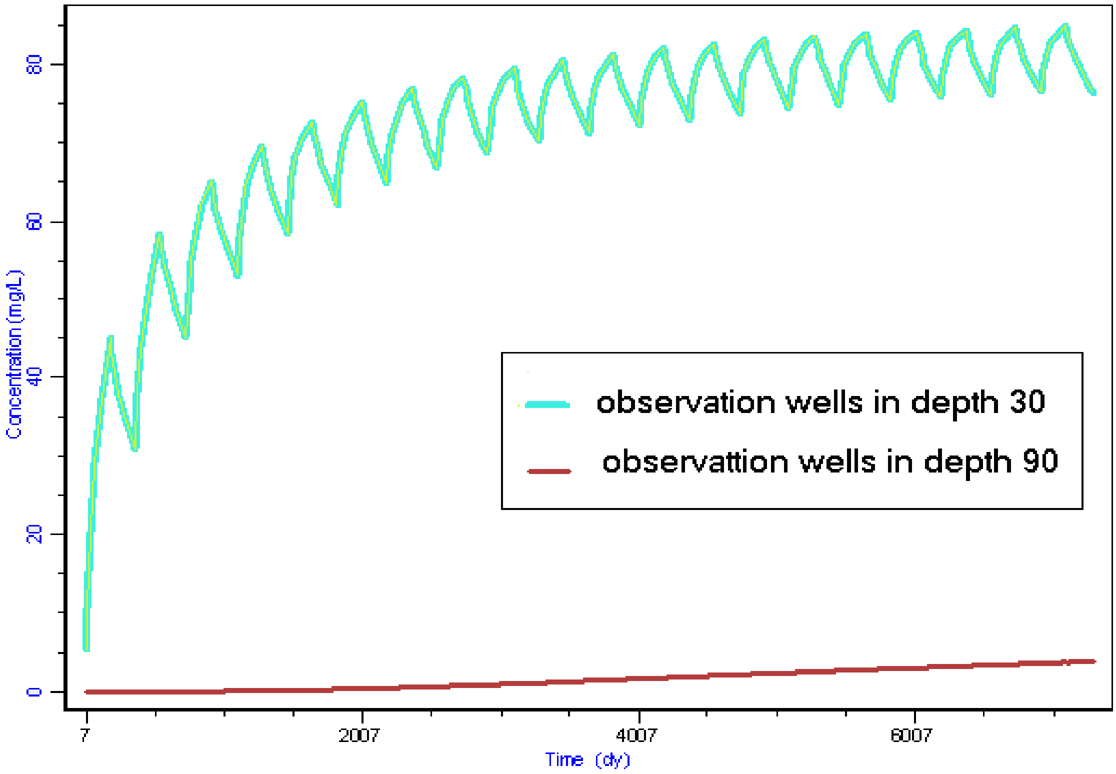


Figure (5.15a): Time series of NO_3^- in observation wells in center of the basin.

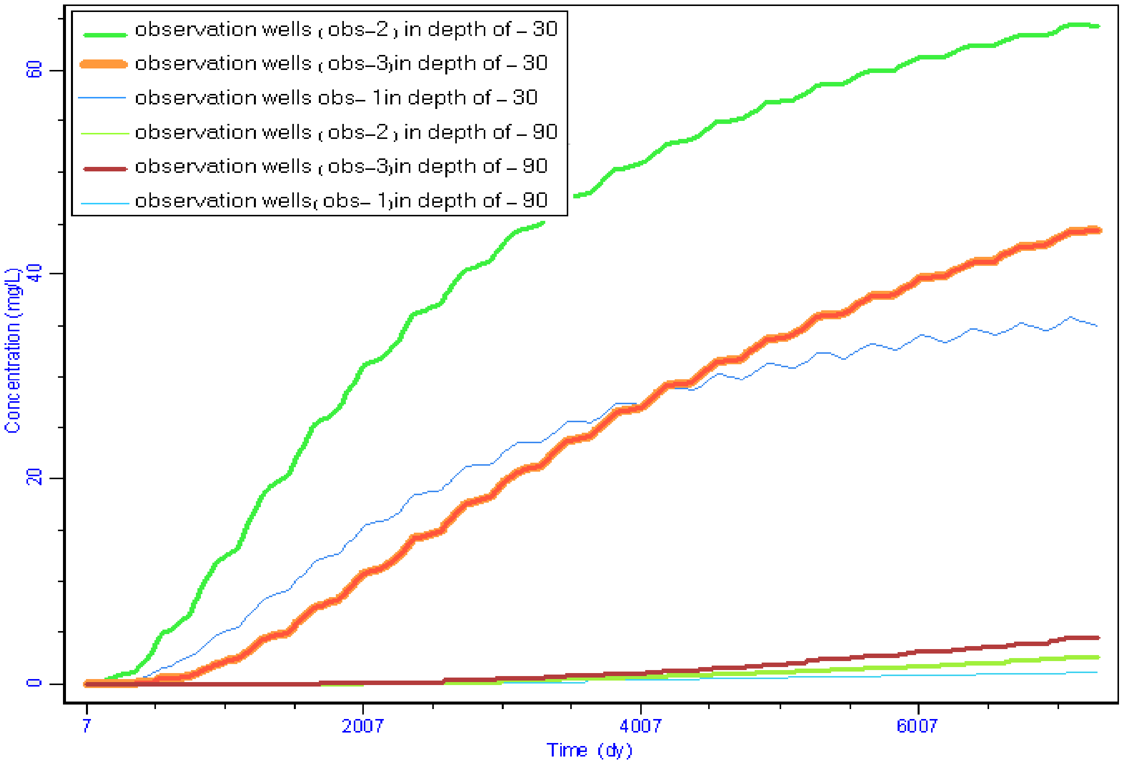


Figure (5.15b):Time series of NO_3^- in observation wells located 100 m of the basin in downstream.

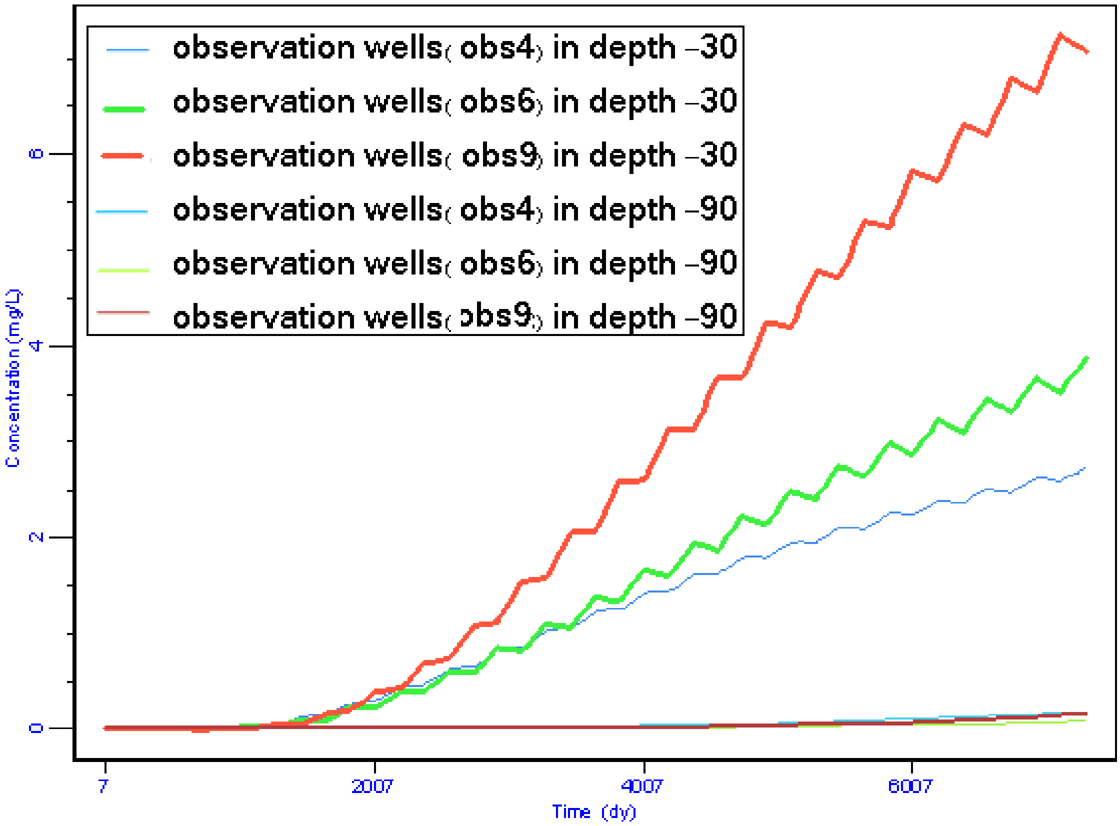


Figure (5.15c) : Time series of NO_3^- in observation wells located 100 m of the basin in upstream.

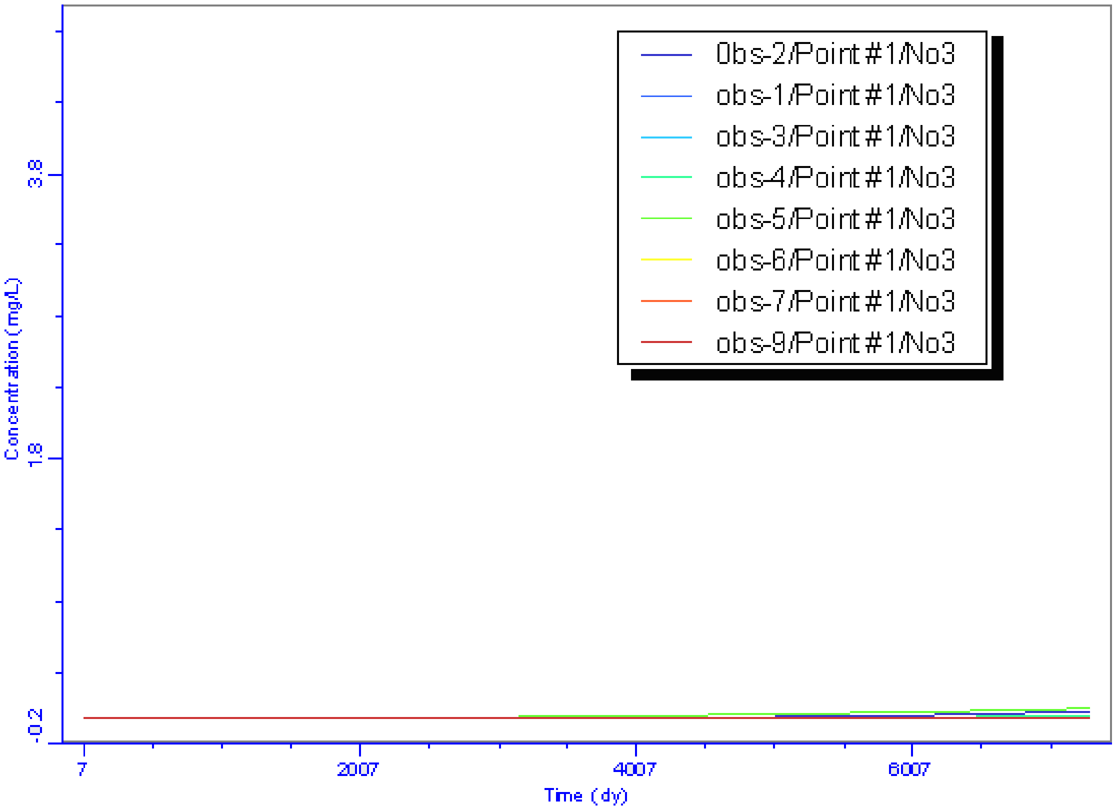


Figure (5.15d): Time series of NO_3^- in observation wells located 500 m of the basin.

5.5.6 Dilution of Nitrate Transport Model

In chapter four (Laboratory Analysis), it is mentioned that the artificial recharge of storm water to ground water in the study area will reduce the concentration of nitrate in the ground water. In this section this hypothesis will be tested. The concentration of nitrate in storm water in basin is 15 mg/l where the concentration of nitrate in 2008 of the aquifer under the basin is shown in Figure (5.16a). The simulation of dilution of No_3^- after 1, 2, 5 and 10 years are shown in Figures (5.16b), (5.16c), (5.16b), (5.16e) respectively.

The time series of the Nitrate in different locations from of the infiltration basin are shown in figure(5.17a) (observation wells in center of basin), figure (5.17b), (5.17c) observation wells in distance 100m in down stream and upstream respectively.

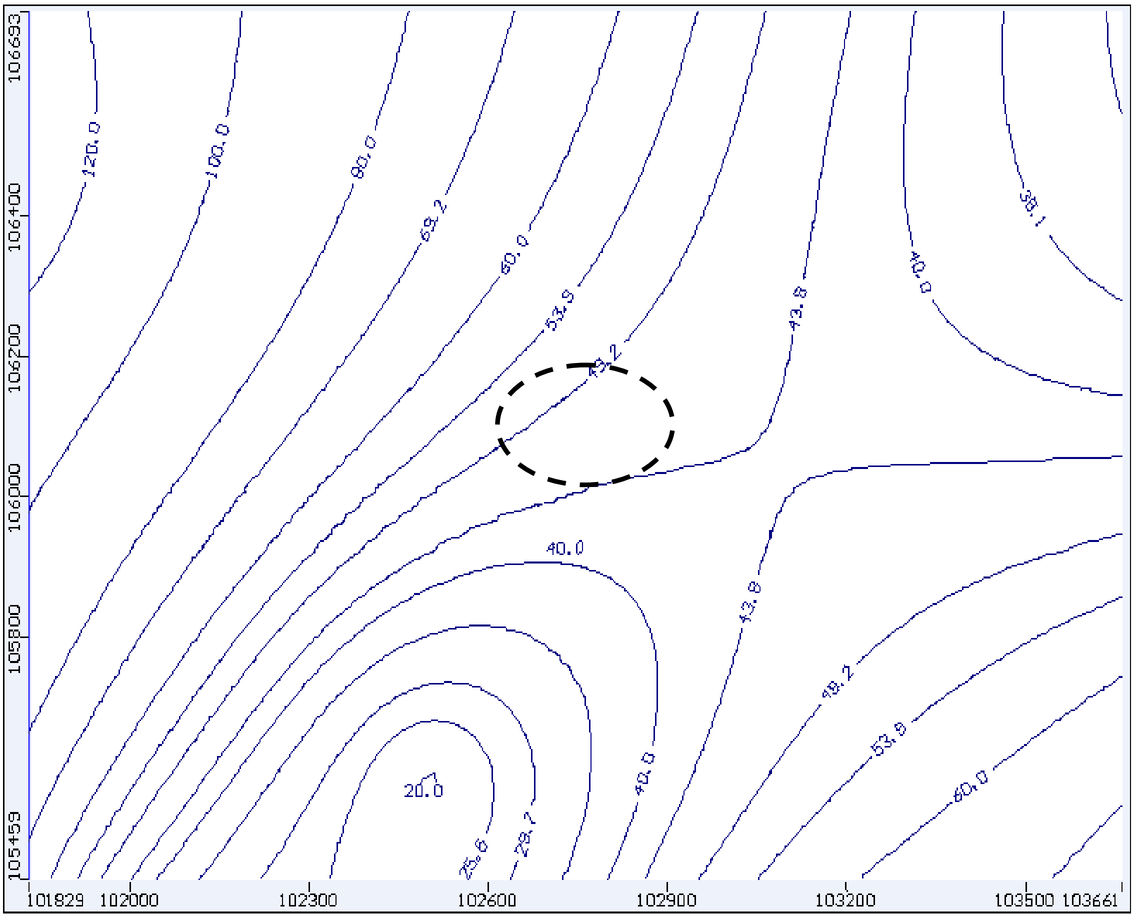


Figure (5.16a): Concentration of No_3^- in 2008 of the aquifer under the basin.

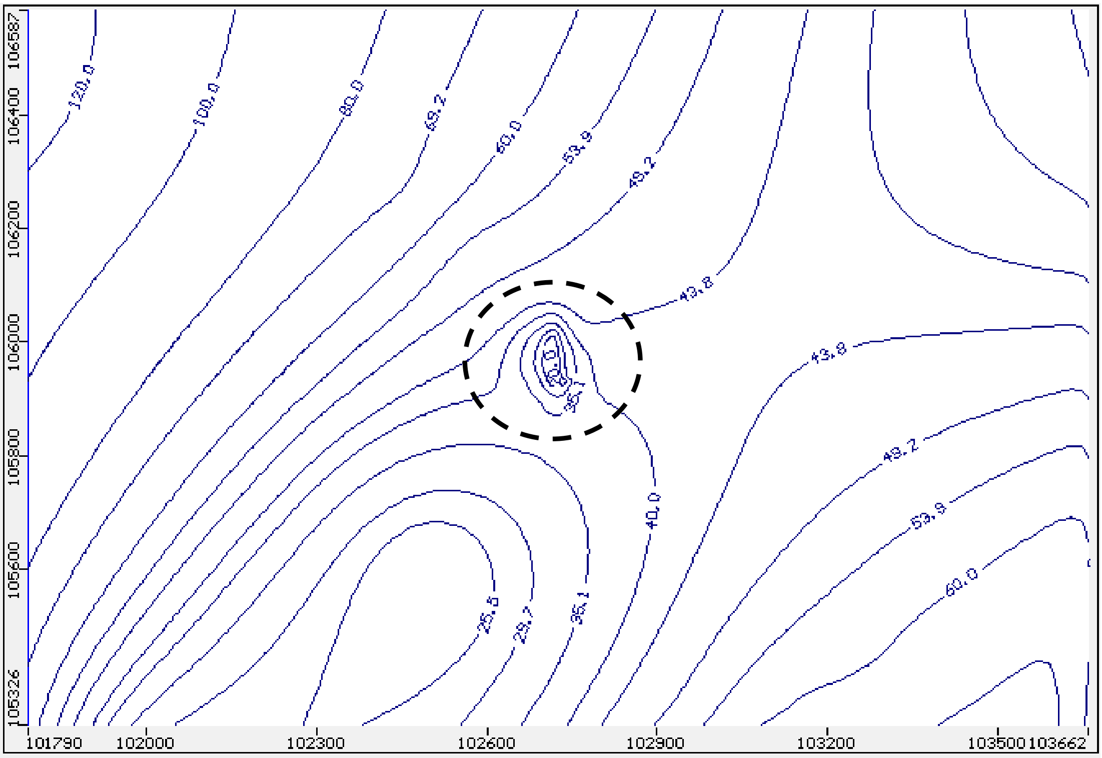


Figure (5.16b): Dilution of No_3^- in the area study after 1year.

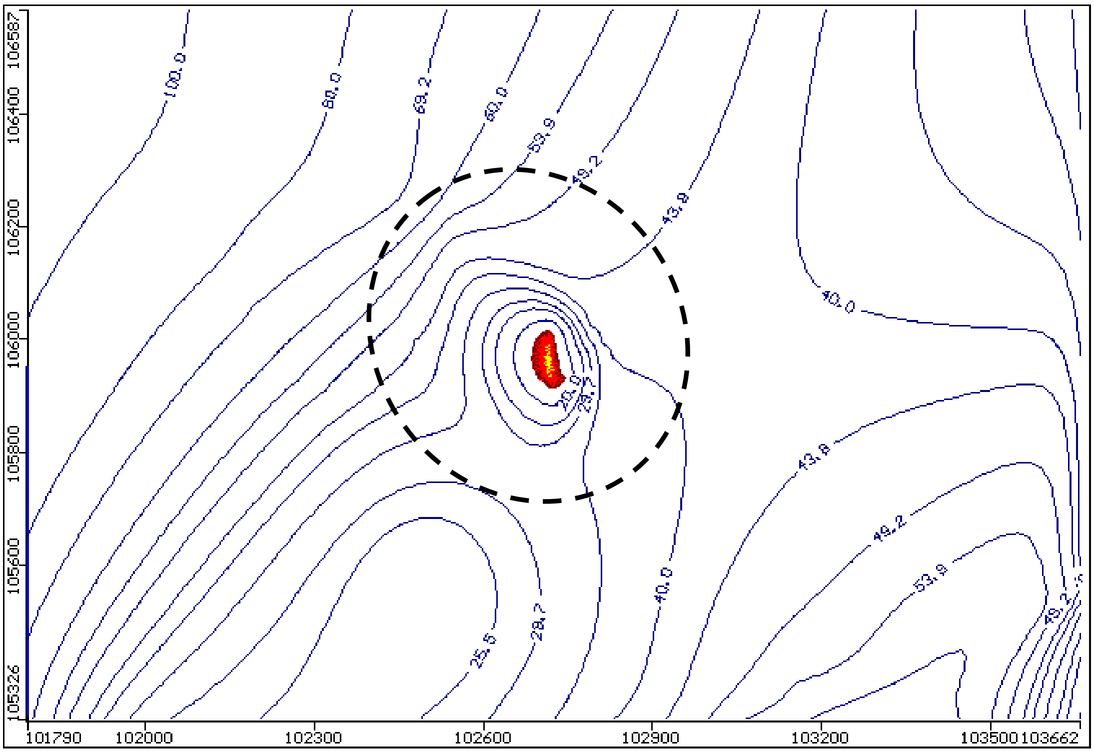


Figure (5.16c): Dilution of No_3^- in the area study after 5years.

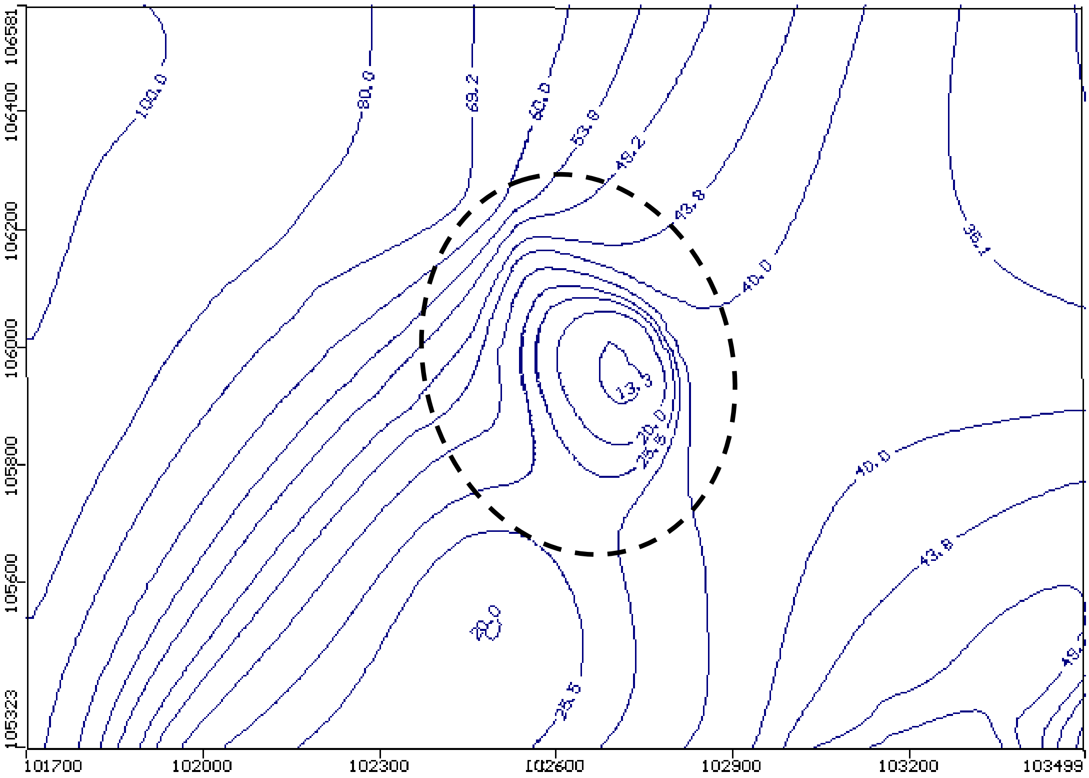


Figure (5.16d): Dilution of No_3^- in the area study after 10 year.

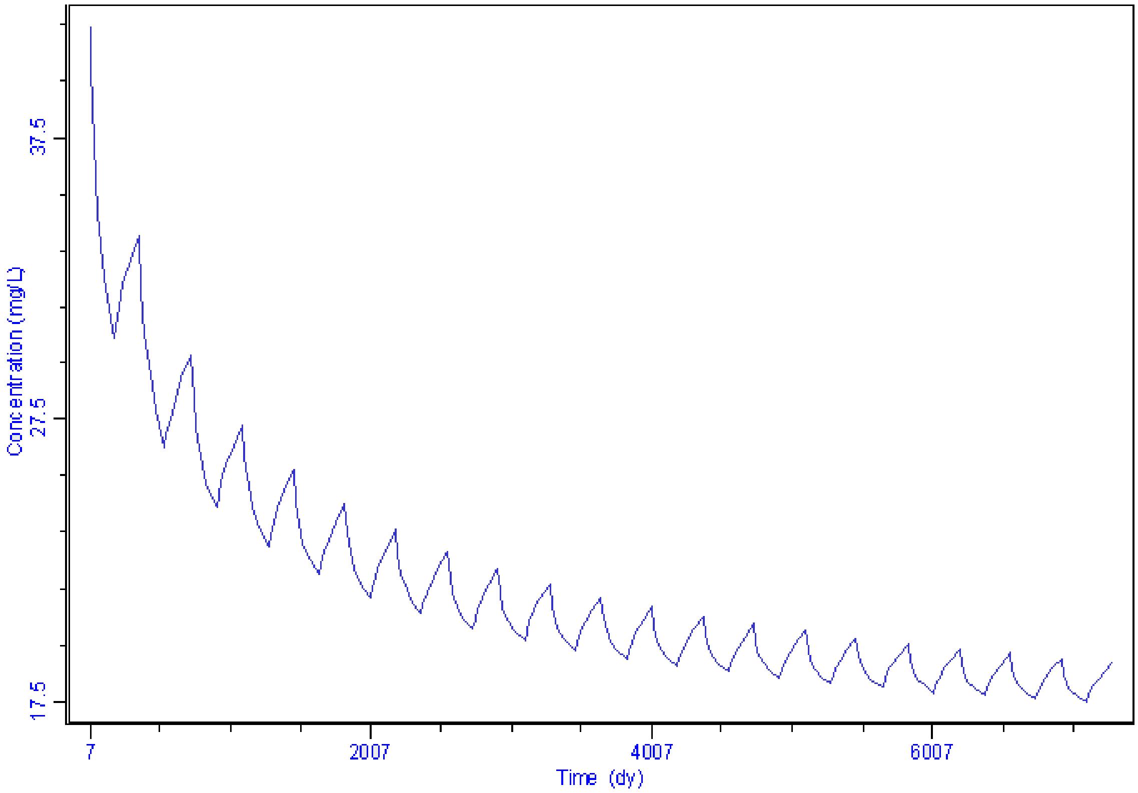
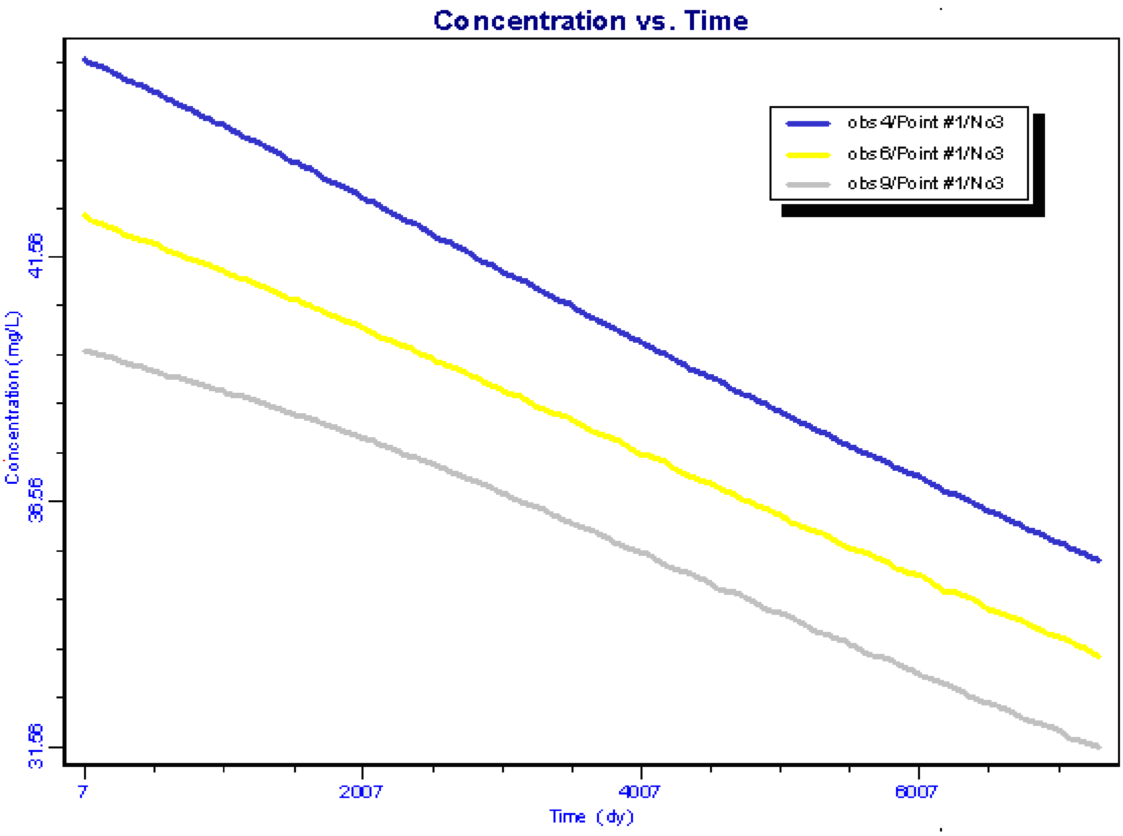


Figure (5.17a): Time series of No_3^- in observation wells in center of the basin.



Figure(5.17b): Time series of No_3^- in observation wells located 100 m of the basin in downstream.

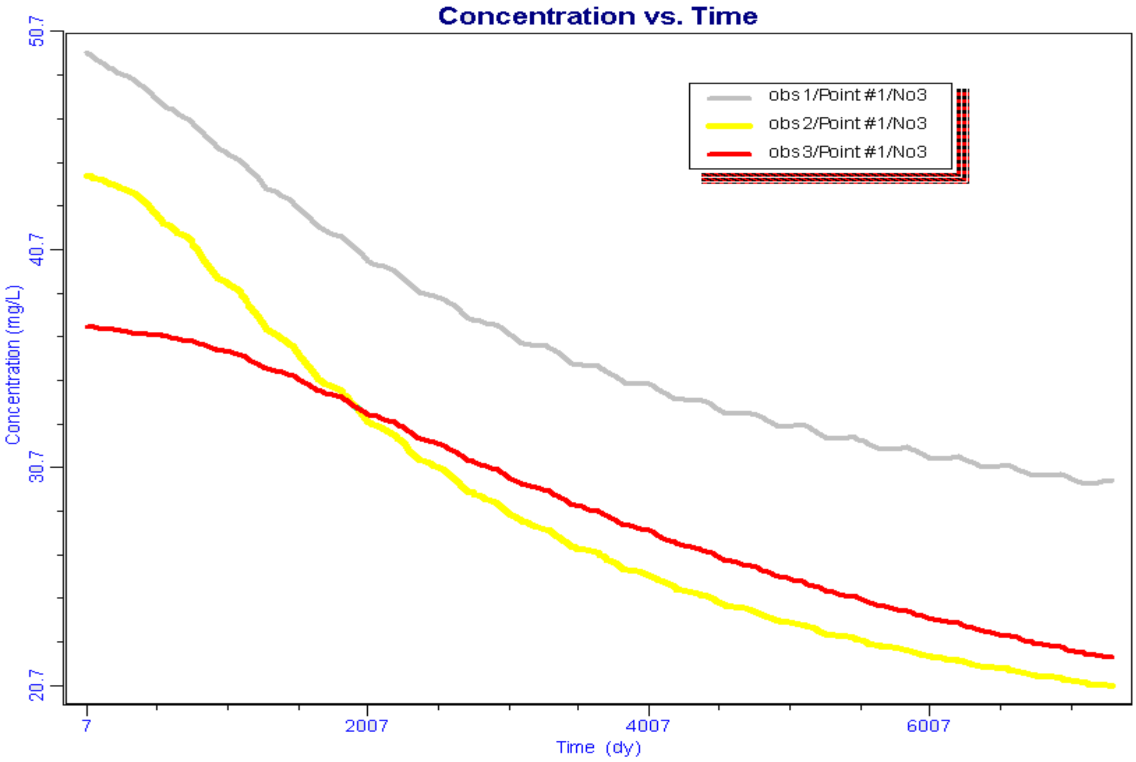


Figure (5.17c) : Time series of No_3^- in observation wells located 100 m of the basin in upstream.

5.6 Monitoring system to Ground water

It is suggested to monitor the groundwater system under the basin in the short time by monitoring wells located 100 m of the basin in downstream in depth 5 m under groundwater level, and 50 m in upstream direction from the basin, in depth 5 m underground level. For long term monitoring, it is suggested to monitor the groundwater system by monitoring wells located 300 m of the basin in downstream in depth 20 m under the groundwater level, and 150 m in the upstream direction of the basin, in depth 20 m from groundwater level. The location of the suggested monitoring wells is shown in Figure (5.18).

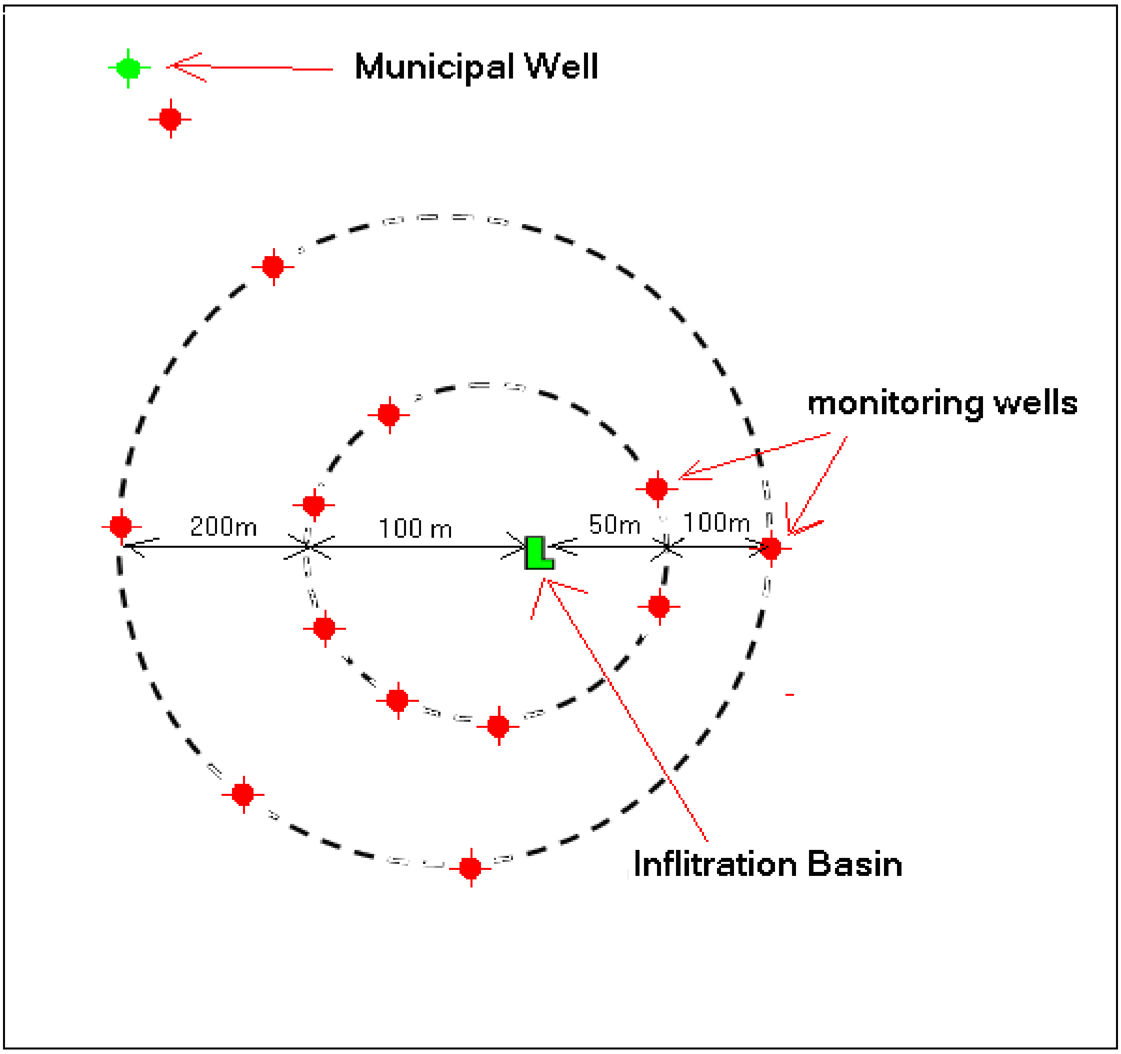


Figure (5.18): Diagrammatic representation of the monitoring wells.

It is recommended to take the measurements form the monitoring wells three times during a year: before start of winter (September), in the middle of winter (January), after the end of winter (June). It is also suggested to measure the followings parameters: feical coliform, nitrate, heavy metal, and water level.

5.7 Future Management the basin

5.7.1.1 Recharging Treated Waste water

As noted previously, the storm water artificial recharge can only be employed between October to March and through 182 days in a year. Therefore, the infiltration basin can be used to recharge the treated waste water from Beit Lahia waste water treatment plant (WWTP) in the north. Although the quality of effluent of wastewater in the Beit Lahia treatment plant is not suitable for artificial recharge, one must be sure that the waste water treatment process is adequate before artificial recharge by minding the following:

- the maximum infiltrated volume during the rain in one day is computed as 11,738 m^3 (infiltration rate is 3 m/d).
- The quantity of effluent from Beit Lahia waste water treatment plant (WWTP) is 8000 m^3/ days .
- Then, the quantity volume (8000 m^3) < maximum infiltrated volume (11,738 m^3),
- Therefore, the quantity volume of artificial recharge in one wells = 8000/ 76 wells = 105 m^3 / days / well .

For this case, the groundwater levels when the infiltration has given full effect on the groundwater level change as shown from transient simulation after 1, 2, and 20 years in Figure (5.19a), (5.19b), and (5.19c) respectively. The model simulations indicate that the water level will be increased in the area and the cone of depression will diminish substantially due to the infiltration.

The simulation shows that the groundwater beneath the center of an infiltration area can be expected to rise to about 1.2 m after 1 yeas as shown in Figure (5.20a).

Figures (5.20b) and (5.19c) show the time series of the water level of two observation wells in distance 100 and 500 m of infiltration basin respectively .

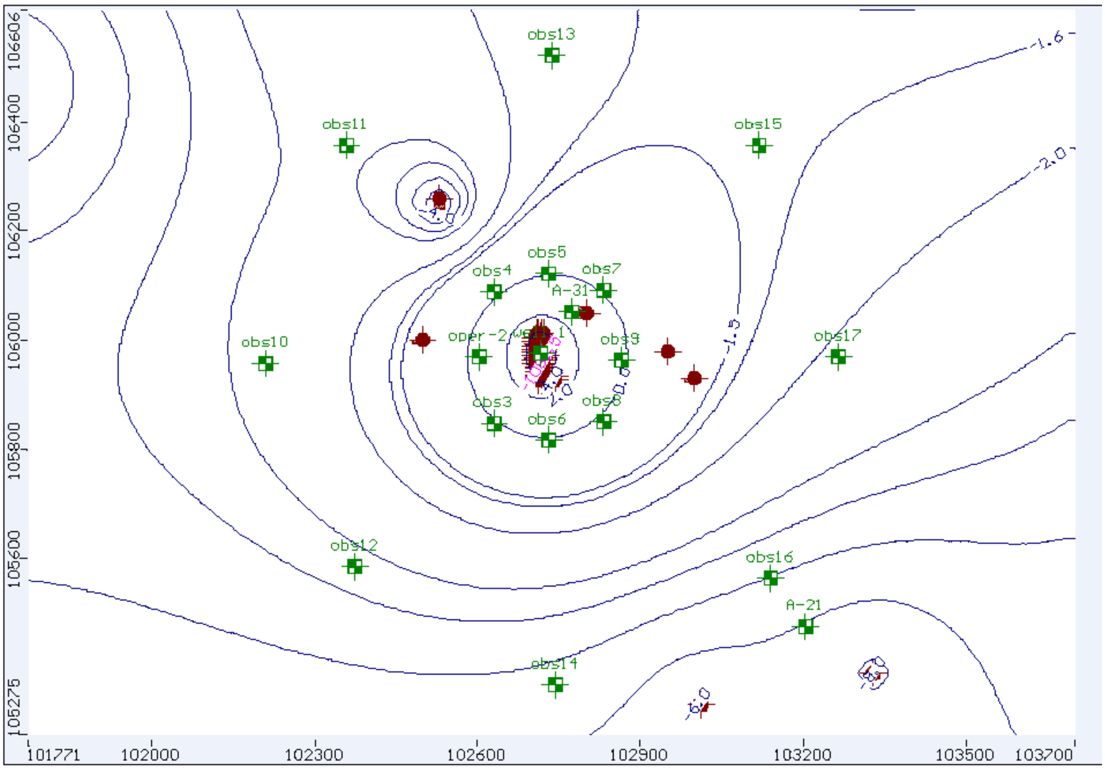


Figure (5.19a): Simulation water table after 1 year.

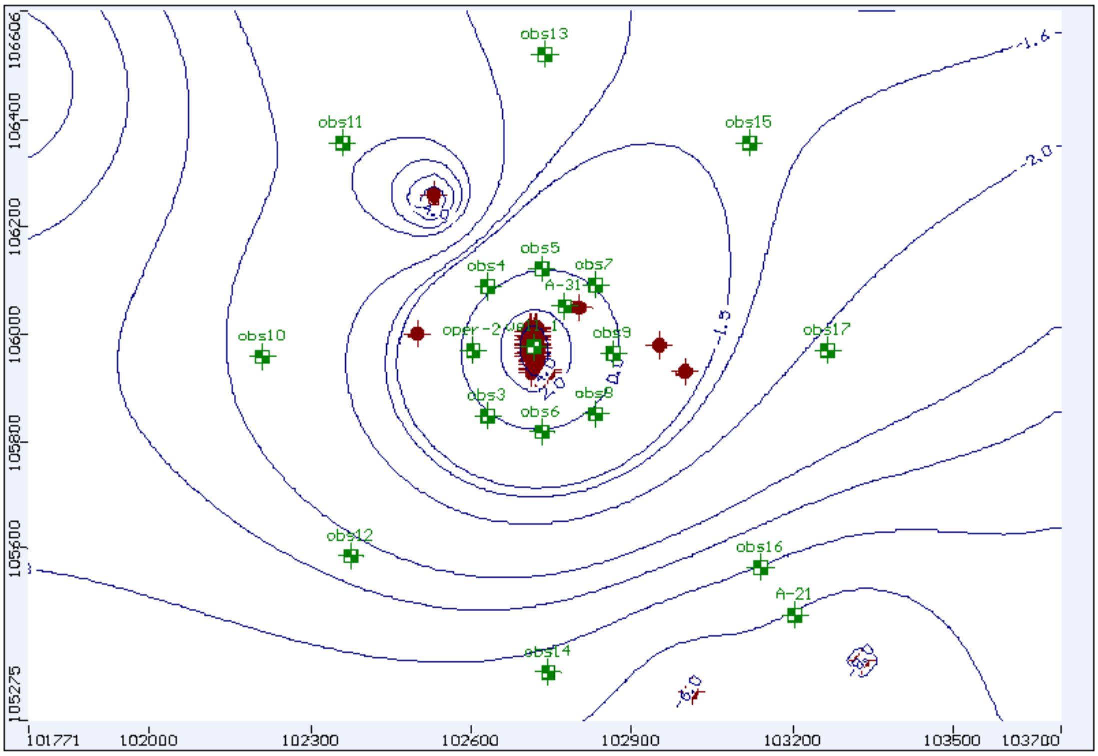


Figure (5.19 b): Simulation of water table after 2 years.

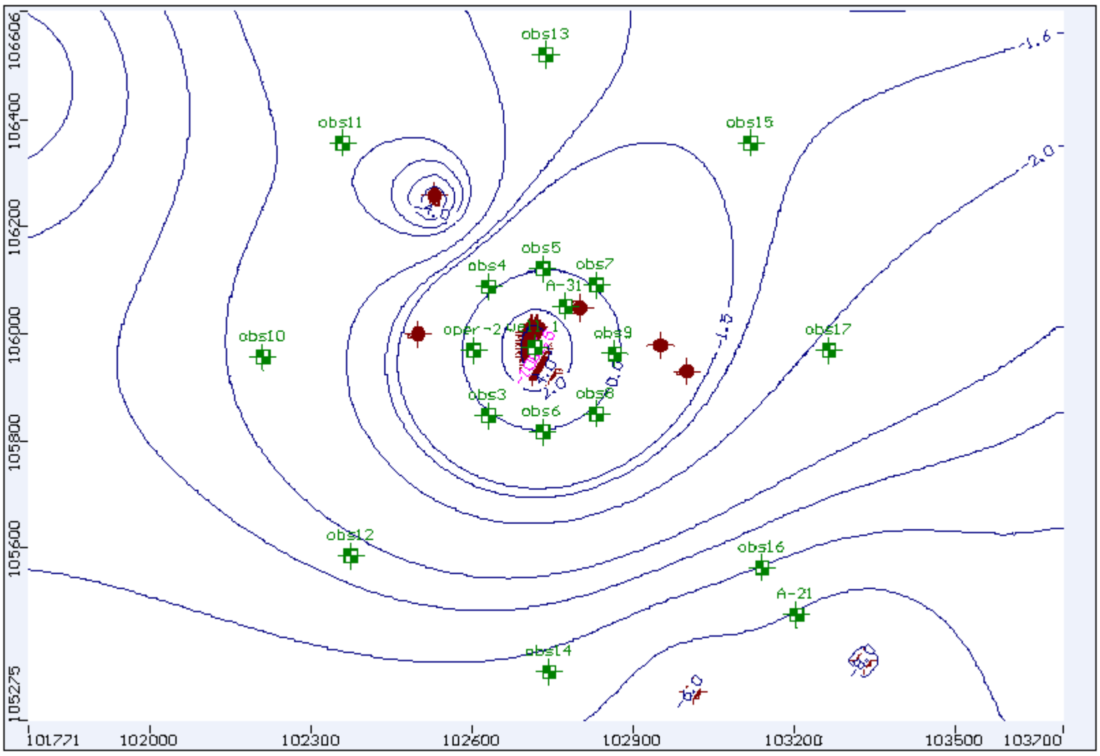


Figure (5.19c): Simulation water table after 20 years.

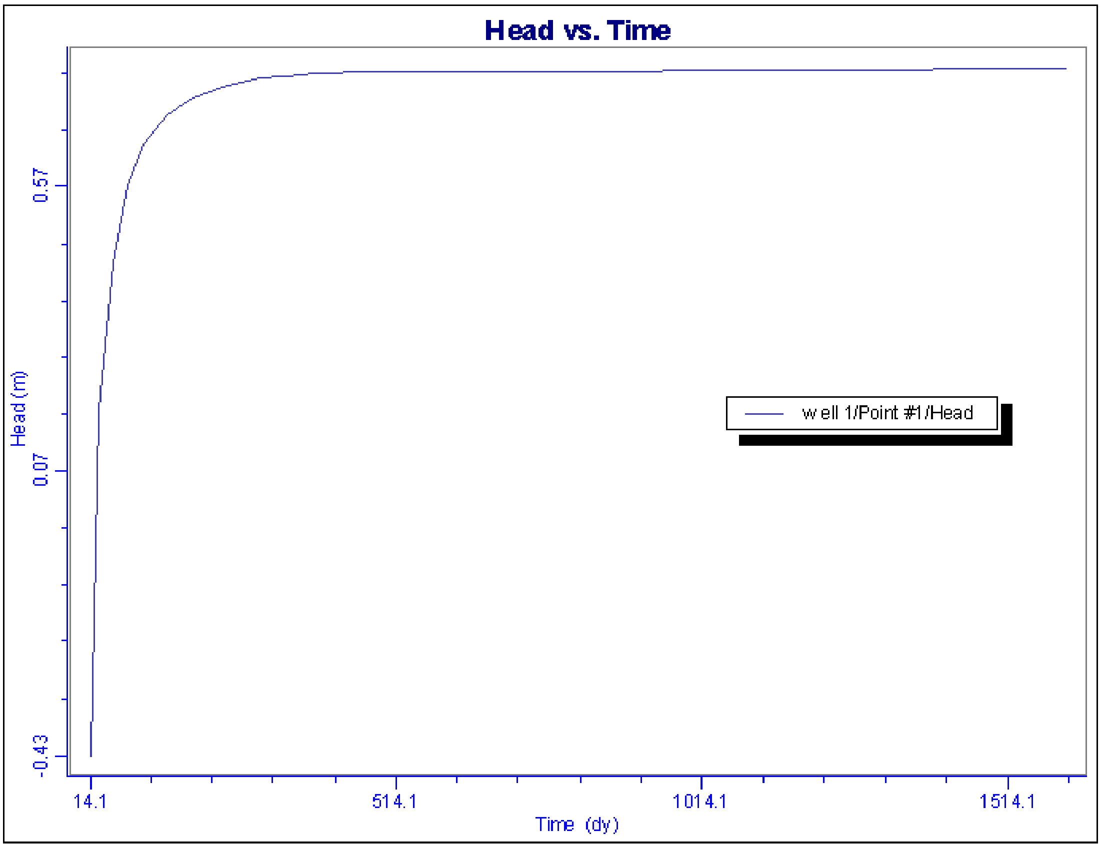


Figure (5.20a): Presents the simulated water level in observation wells located in center of basin.

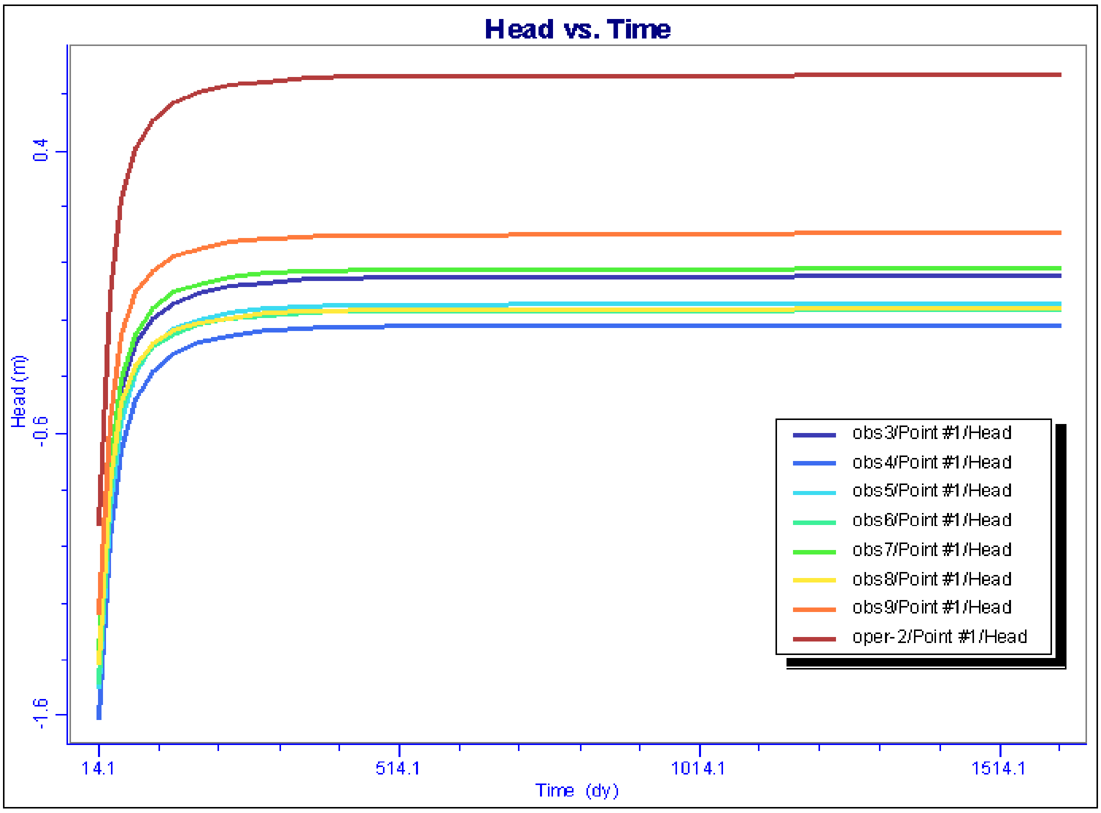


Figure (5.20b): Presents the simulated water level in observation wells located in 100 of basin.

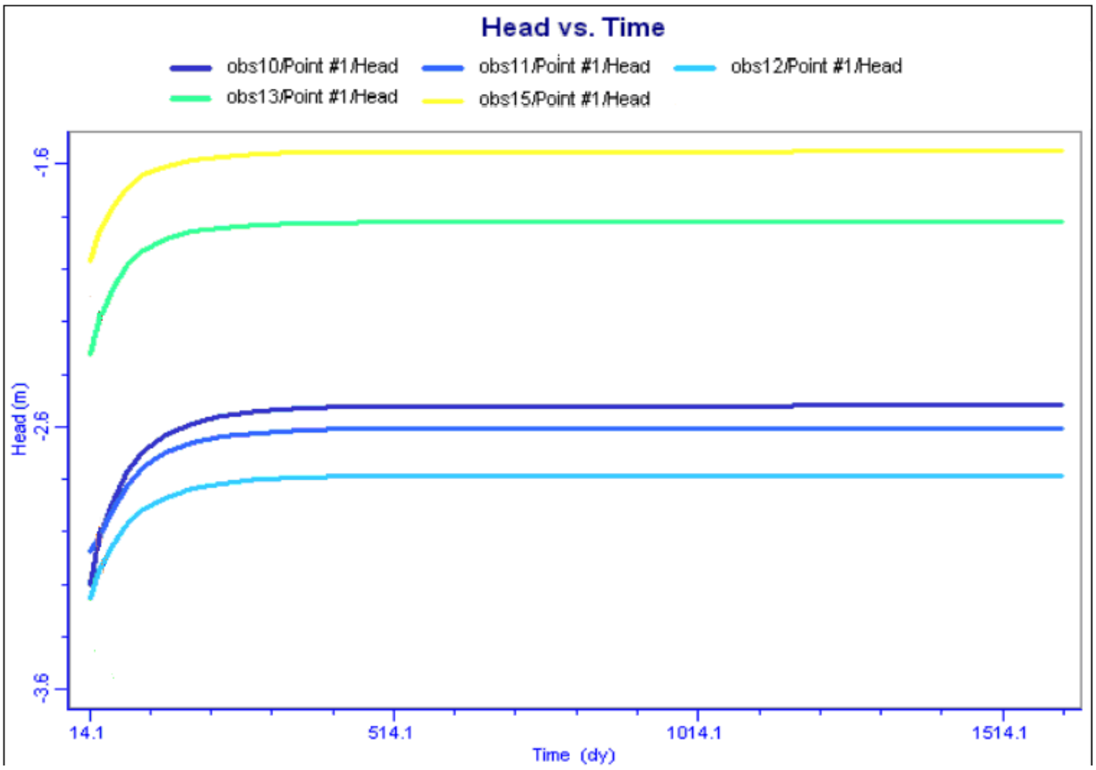


Figure (5.20c): Presents the simulated water level in observation wells located in 500of basin.

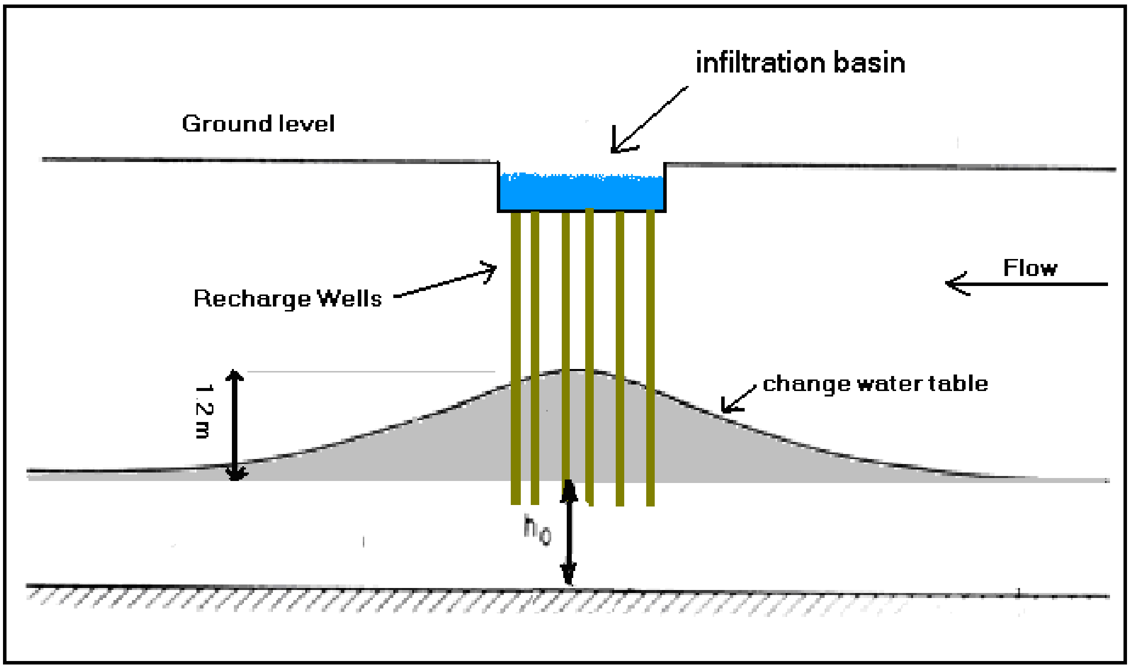


Figure (5.21) : Diagrammatic representation of the rise of the water table by artificial Recharging.

Chapter 6
Conclusion and Recommendations

6.1 Conclusion

1- The quality of collected storm water in the infiltration basin of Biet Lahia is acceptable in many parameters as No_3^-, Cl^-, Mg^{2+}, Ca^{2+}, Na^+, TSS, k, detergent, turbidity, TDS, and Hardness if comparing to the maximum level of the WHO. However, the Fecal coliform in storm water is not acceptable.

2- Due to the artificial recharge of storm water, the expected rising of the groundwater table is 25 cm in the center of the basin. This will rise in the end of winter, while it will drop in the summer and so on. This make water table oscillatory near the basin.

3- The artificial recharge of treated wastewater (8000 m^3) will raise the groundwater level to about 1.2 m after 1 year.

4- The pathlines for imaginary particles that are infiltrated in the recharge area will spread radially about 100 m after 2 year, 250 m after 10 years, 400 m after 20 years.

5- Storm water can be infiltrated to groundwater without increasing the risk of pollution if it is not mixed with wastewater. The storm water could however, carry large amounts of sediments and suspended solids.

6- Using 2 meter of fine Sand filter is effective to remove TSS and turbidity from Storm water, but it not enough to destroy biological parameters..

7- The quality of storm water is better than the quality of ground water in the aquifer under the basin, if storm water is not mixed with industrial pollutants, fertilizing, and wastewater. Using the artificial recharge of storm water to groundwater in the study area will reduce the concentration of nitrate in the groundwater.

6.2 Recommendations

1- Using artificial recharge of storm water is good to improve the quantity and quality of the groundwater. Therefore, it is recommended to increase such practice by governmental institutions.

2- The allocated monitoring system should be used by the PWA and the Municipality of Beit Lahia in the future.

3- Protected area around the Biet Lahia Municipality infiltration Basin (distance 400 meters of basin) is important to prevent the flowing of pollutants to ground water..

4- The wastewater should be treated and reused to the maximum extent feasible. a recommended alternative for reuse can be treated wastewater recharge which helps in relief the stress on the aquifer.

5- Due to the difficulty of measuring the heavy metals in this research, they should be strictly measured because heavy metals are likely to be found in the storm water.

6- It is recommended to measure some heavy metals and others parameters as White Phosphorus that reflect the effect of the last war on Gaza. These heavy metals can reach the groundwater through the collected storm water.

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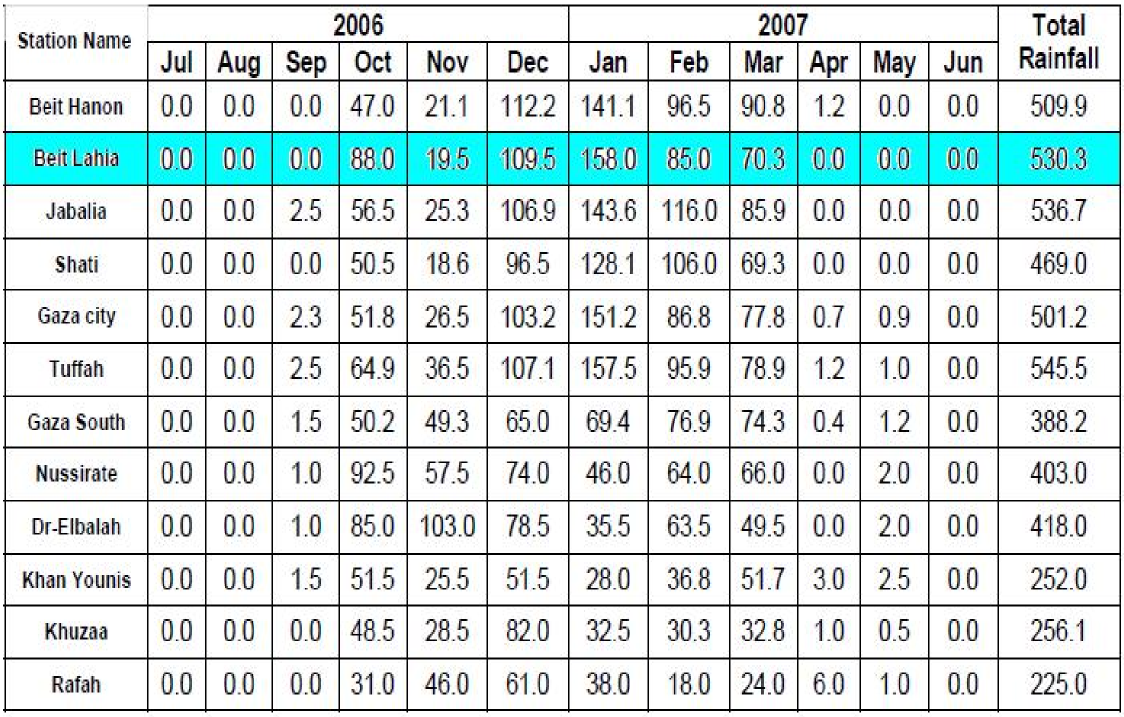
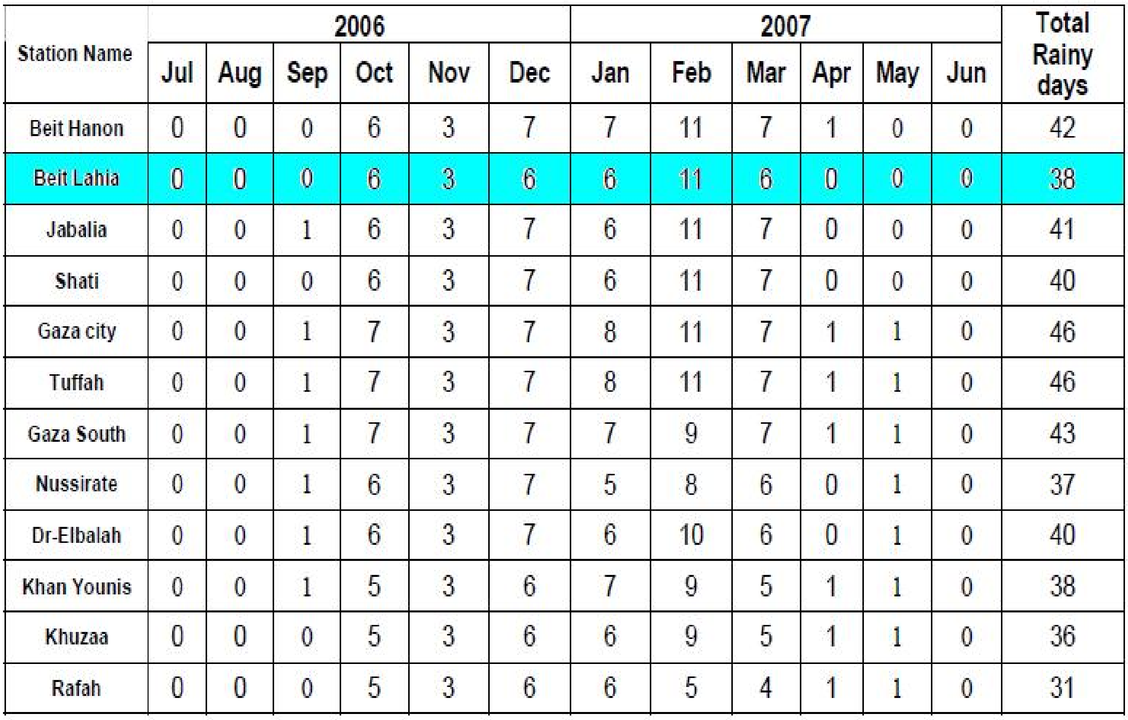
Annex A

Table (A.1) the monthly rainfall depth in 2006-2007 (PWA, 2007)



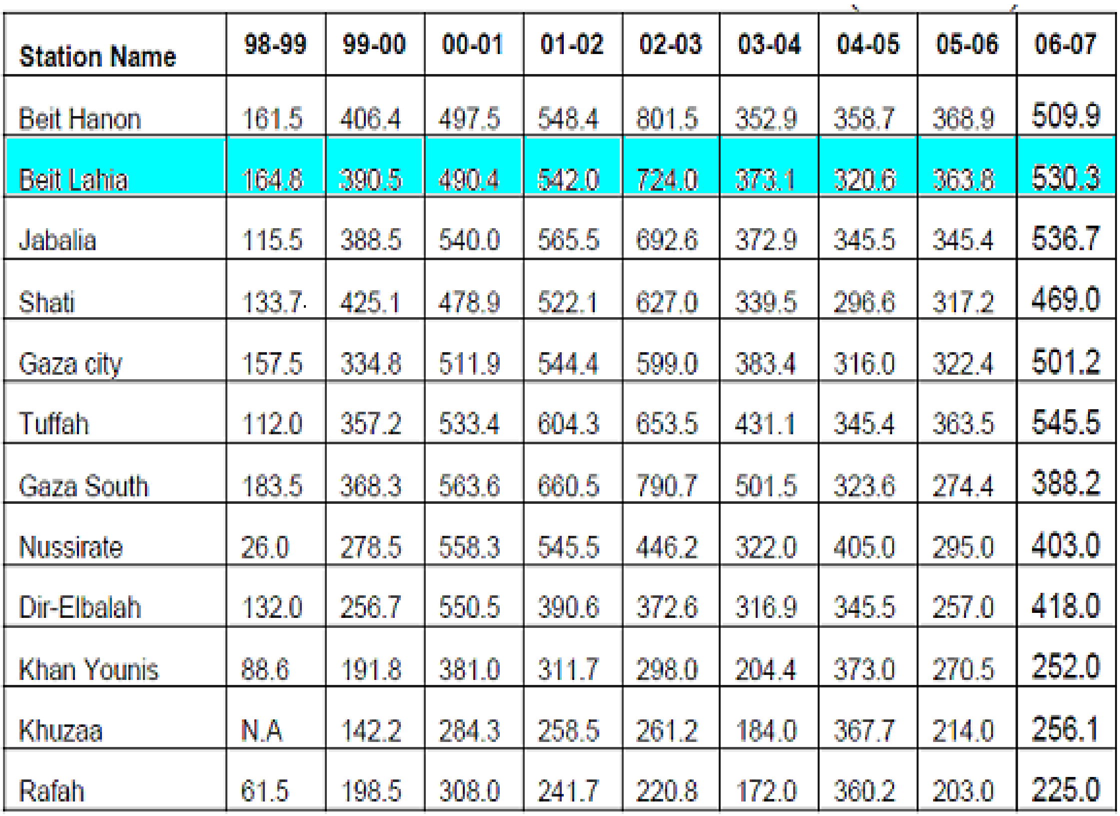
Station Name	2006						2007						Total Rainfall
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
Beit Hanon	0.0	0.0	0.0	47.0	21.1	112.2	141.1	96.5	90.8	1.2	0.0	0.0	509.9
Beit Lahia	0.0	0.0	0.0	88.0	19.5	109.5	158.0	85.0	70.3	0.0	0.0	0.0	530.3
Jabalia	0.0	0.0	2.5	56.5	25.3	106.9	143.6	116.0	85.9	0.0	0.0	0.0	536.7
Shati	0.0	0.0	0.0	50.5	18.6	96.5	128.1	106.0	69.3	0.0	0.0	0.0	469.0
Gaza city	0.0	0.0	2.3	51.8	26.5	103.2	151.2	86.8	77.8	0.7	0.9	0.0	501.2
Tuffah	0.0	0.0	2.5	64.9	36.5	107.1	157.5	95.9	78.9	1.2	1.0	0.0	545.5
Gaza South	0.0	0.0	1.5	50.2	49.3	65.0	69.4	76.9	74.3	0.4	1.2	0.0	388.2
Nussirate	0.0	0.0	1.0	92.5	57.5	74.0	46.0	64.0	66.0	0.0	2.0	0.0	403.0
Dr-Elbalah	0.0	0.0	1.0	85.0	103.0	78.5	35.5	63.5	49.5	0.0	2.0	0.0	418.0
Khan Younis	0.0	0.0	1.5	51.5	25.5	51.5	28.0	36.8	51.7	3.0	2.5	0.0	252.0
Khuzaa	0.0	0.0	0.0	48.5	28.5	82.0	32.5	30.3	32.8	1.0	0.5	0.0	256.1
Rafah	0.0	0.0	0.0	31.0	46.0	61.0	38.0	18.0	24.0	6.0	1.0	0.0	225.0

Table (A.2) The monthly number of rainy days in year 2006-2007 (PWA,2007)



Station Name	2006						2007						Total Rainy days
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
Beit Hanon	0	0	0	6	3	7	7	11	7	1	0	0	42
Beit Lahia	0	0	0	6	3	6	6	11	6	0	0	0	38
Jabalia	0	0	1	6	3	7	6	11	7	0	0	0	41
Shati	0	0	0	6	3	7	6	11	7	0	0	0	40
Gaza city	0	0	1	7	3	7	8	11	7	1	1	0	46
Tuffah	0	0	1	7	3	7	8	11	7	1	1	0	46
Gaza South	0	0	1	7	3	7	7	9	7	1	1	0	43
Nussirate	0	0	1	6	3	7	5	8	6	0	1	0	37
Dr-Elbalah	0	0	1	6	3	7	6	10	6	0	1	0	40
Khan Younis	0	0	1	5	3	6	7	9	5	1	1	0	38
Khuzaa	0	0	0	5	3	6	6	9	5	1	1	0	36
Rafah	0	0	0	5	3	6	6	5	4	1	1	0	31

Table (A.3) Historical rainfall records / station sites for different season (1998-2007)



Station Name	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07
Beit Hanon	161.5	406.4	497.5	548.4	801.5	352.9	358.7	368.9	509.9
Beit Lahia	164.8	390.5	490.4	542.0	724.0	373.1	320.6	363.8	530.3
Jabalia	115.5	388.5	540.0	565.5	692.6	372.9	345.5	345.4	536.7
Shati	133.7	425.1	478.9	522.1	627.0	339.5	296.6	317.2	469.0
Gaza city	157.5	334.8	511.9	544.4	599.0	383.4	316.0	322.4	501.2
Tuffah	112.0	357.2	533.4	604.3	653.5	431.1	345.4	363.5	545.5
Gaza South	183.5	368.3	563.6	660.5	790.7	501.5	323.6	274.4	388.2
Nussirate	26.0	278.5	558.3	545.5	446.2	322.0	405.0	295.0	403.0
Dir-Elbalah	132.0	256.7	550.5	390.6	372.6	316.9	345.5	257.0	418.0
Khan Younis	88.6	191.8	381.0	311.7	298.0	204.4	373.0	270.5	252.0
Khuzaa	N.A	142.2	284.3	258.5	261.2	184.0	367.7	214.0	256.1
Rafah	61.5	198.5	308.0	241.7	220.8	172.0	360.2	203.0	225.0