The Islamic University Of Gaza
Civil Engineering Department
Water Resources Management Program

Evaluation of Groundwater Quality in North Governorates of Gaza Strip (1994-2004)

تقييم نوعية المياه الجوفية في المحافظات الشمالية لقطاع غزة في الفترة (2004-1994)

Master Thesis in Water Resources Management

Prepared by

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QURAAN

بسم الله الرحمن الرحيم

(وَقَالَ رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَى وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا تَرْضَاهُ

وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ) النمل (19)

DEDICATED TO:

My Father and My Mother
My Wife
My Son Mohammed
My Daughters Sondos, Sedeka,
Asmaa and Heba
My Brothers

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ABSTRACT

The northern part of the coastal area of Gaza Strip, Palestine, considered as one of the most densely populated areas in the world (MOH, 2003) with population density 5778 capita/km^2. Groundwater is the only source of fresh water in this area while its inhabitants and its water consumption increased rapidly.

This study shows the analysis of 9 hydrological years data record (1994/1995-2003/2004) for the north Governorates of Gaza Strip. It aims at determining the spatial distribution of chlorides representing salinization and nitrates representing pollution in the aquifer at three stages (1994/1995, 1999/2000, and 2003/2004) and the main factors affecting them Add to, defining the status of groundwater quality and its suitability for domestic use. Chloride maps with chlorographs and nitrate maps have been drawn and correlated with drawn rainfall maps, rate of abstraction maps, water level maps, 3-D topography map and aquifer lithology cross sections to determine their effects on groundwater quality through the study period.

It is found that this immensely important resource has been salinized severely. The percentage of salinized wells (> 250 mg/l) increased from (55.3%) to (58.2%) then (61%) at the three stages respectively, forming a significant number of discrete salinity plumes with chloride concentration exceeds 1000 mg/l.

The dry period with decreasing in rainfall from 1994/1995 till 1998/1999 accelerated the salinization process between the first and the second stage. Meanwhile, the aquifer has been overexploited with high rates of abstraction exceeded the recommended maximum value 100 m^3/hr by PWA. The high rate wells percentage decreased from 64.5% to 47% between the second to the third stage, while the number of abstraction wells and their duration of production has increased to cover the population demand. The result was dramatically lowering of water levels and expanding in the cone of depression till reached to 4 m below MSL and its area below zero level is about (44 km^2) that leads to seawater intrusion and up coning of deep brine water. This is observed from plumes of high salinity and chlorographs in areas of sandy lithological characters with little clay lenses. The seawater intrusion and up-coning of brines leads to raising the chloride concentration to more than 2500 mg/l in areas far from the seashore by about 2 Km

The other main quality problem is the pollution with nitrate. The level of nitrate contamination has been rising so rapidly where the percentage of polluted wells (>50 mg/l) increased from (72%) to (78.5%) then (85.5%) at the three stages respectively. So, most of

the water wells in the study area are no longer adequate for human consumption. The deterioration was higher through the second and the third stage. This coincides with increasing in rainfall amount after 1998/1999. This means that rainfall amount has played a role in increasing nitrate pollution.

The agriculture human activities and wastewater from urban areas are the two major factors responsible for nitrate pollution in the study area. The rainfall distribution, nature of the soil, lithological facies, and the topography of the study area have played important roles in accelerating in nitrate pollution in some areas than others. It is found that, the depressed areas with higher rainfall, sandy soil, little clay in the unsaturated zone with the presence of pollution sources are higher in nitrate concentration. This situation is observed in the agricultural area at the western side of North Governorate where it reached to 432 mg/l in Beit Lahia while below urban area reached to 388 mg/l in Jabalia Town. The high concentration of nitrate in the urban areas indicate that wastewater return flows through leakage from septic tanks and seepage from the unlined drains carrying municipal effluents probably play an important role in causing groundwater pollution in this area. Intensive use of nitrogen fertilizer and poorly managed irrigated systems may lead to nitrate leaching and pollution of groundwater.

Severe deterioration of the quality of groundwater resources has been occurred in this area as a result of overexploitation of the groundwater and improper environmental management conditions. So, quick decisions by decision makers must be taken to reduce at least this crisis and to begin in making a wise management for this only and immensely important resource.

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ACRONYMS AND ABBREVIATIONS

Coastal Aquifer Management Program	CAMP
Coastal Municipal Water Utility	CMWU
Cubic meters per hour	m^3/hr
Environment Quality Authority	EQA
Gaza Meteorological Staton	GMS
Liter per apita per day	L/c/d
Lyonnaise des Eaux and Khatib and Alami	LEKA
Mean Sea Level	MSL
Melliequivalent perLiter	Meq/L
Millgrams per Liter	mg/l
Millimeter	mm
Milllion Cubic Meter per year	Mm^3/ y
Ministry of Agriculture	MOA
Ministry of Health	MOH
Ministry of Planning	MOP
North North East	NNE
Palestinian Central Bureau of Statistics	PCBS
Palestinian National Authority	PNA
Palestinian Water Authority	PWA
South South West	SSW
Total Dissolved Solids	TDS
United States Environmental Protection Agency	US EPA
Wastewater Treatment Plant	WWTP
World Health Organization	WHO
Year	Yr

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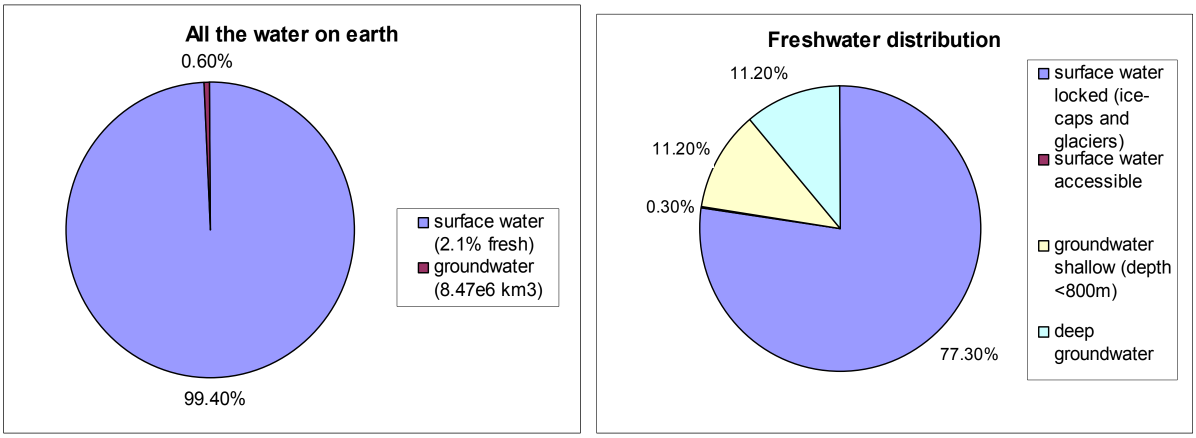
Chapter(1)

Introduction

1.1 General

Water is the most important natural resource on our planet and perhaps the scarcest commodity of the 21st Century. It plays an important role in our life and can be considered as life's blood of every living creature on earth. Groundwater is the most important component of the freshwater resources of the world. Its percentage related to all water distribution on the earth is about 0.60% while it accounts for nearly all usable water related to freshwater distribution on earth as shown in (figure 1. 1) *(Qahman, 2005)* . On global scale, groundwater has been gaining increasing attention as essential and vital water resource. Its demand has been rising rapidly in the last several decades with the overpopulation and enhanced standards of living. It is the only source of freshwater for many communities owing to its relatively low susceptibility to pollution in comparison to surface water, and its relatively large storage capacity.



(Figure 1.1): Groundwater percentage related to all the water on earth and to the freshwater distribution (Qahman,2005)

Groundwater pollution problem is a complex phenomenon result from natural and/or anthropogenic factors. It has a bad impact not only on our health but also on society, economy and the overall quality of life. This problem is clear mainly in coastal areas which considered as the most densely populated areas in the world. The coastal areas of the world accommodate high population with about 50% of the world population lives within 60km of the shoreline (Narayana et al, 2006) . In many coastal regions in the world, severe deterioration of the quality of groundwater resources has been occurred as a result of overexploitation of the groundwater where good quality groundwater is available. Coastal areas and especially the southern part of the Mediterranean region, faces many causes of unacceptable groundwater quality that related mainly to human activities (Almahallawi,2004).

Once groundwater has been contaminated, its reclamation is possible but usually very difficult, costly and prolonged process, frequently taking decades. When ground-water supplies become contaminated, the community bears the cost through diminished property values, replacement or expansion of public water supplies, and replacement or abandonment of private domestic wells (U.S. Environmental Protection Agency (EPA), 2004). Clearly, prevention is the most effective element of groundwater management, and prevention begins with quality evaluation.

1.2 Problem Identification

1. Limited rainfall and negligible surface water resources while the groundwater is the only reliable resource for all uses.
2. Tremendous increase in population together with enhanced standards of living.
3. Absence of proper sewer system.
4. Inappropriate design of wastewater treatment plants (WWTPs) and disposing of untreated wastewater, solid wastes in any available open areas as in Wadi Gaza.
5. Highly intensive irrigated areas with excessive use of agrochemicals

The long term overexploitation of groundwater reservoir for recovering different uses beside the variation in sources of contamination from anthropogenic activities have led to three significant problems:

(1) The lowering of water level and formation of large drawdown cone.
(2 Salinization of the aquifer.
(3) Contamination of the aquifer by nitrates.

So, there is a distinct danger of exhausting both quantitatively and qualitatively this limited groundwater resources. Consequently, a complete evaluation with determination of the factors behind this situation is a must to help decision makers in taking the right decisions in groundwater quality management, and pollution control measures.

1.3 Objectives

The main objectives of this thesis can be summarized as follows:

1. To obtain a comprehensive picture about the spatial distribution of chlorides and nitrates in the aquifer at three stages (1994/1995, 1999/2000, and 2003/2004) through the study period (1994/2004) based on the hydrological year data.
2. To define the role of:
   - ✓ Aquifer hydraulic situation (rate of abstraction and water level).
   - ✓ Aquifer lithology, rainfall distribution and topography.

   On groundwater salinisation and pollution.
3. Groundwater suitability for domestic use.
4. The proximity of groundwater wells to specific sources of salinisation (e.g. seawater)
5. To provide considerable information that can be used in groundwater quality management, and pollution control measures.

1.4 Methodology

To achieve the objectives of this study, the following methodology has been considered:

1. Data gathering including rainfall, geographical, geological, hydraulic (rate of abstraction , water level) and chemical (chlorides and nitrates) data. All of these data collected from, Palestinian Water Authority (PWA), Ministry of Agriculture (MOA), Ministry of Planning (MOP), Environment Quality Authority (EQA), Gaza Municipality and Gaza Meteorological Station (GMS).
2. Data analysis will be done using softwares Surfer 8, WinLog 4, WinFence and Excel.
3. Data presentation and dissemination of results will be done in appropriate various forms of data output (e.g. statistics, graphs, cross sections, maps etc).
4. Data interpretation of the results will be done for the period (1994to 2004) to be sufficient and acceptable to describe the overall developmental trend in north Governorates groundwater.
5. Data integration will be done to be an effective preliminary tool for planning, policy and operational levels of decision making concerning groundwater protection and management.

1.5 Thesis Outline

This study will beconsist of five chapters:

* **Chapter One (Introduction)**: General introduction follows by problem identification, study objectives, methodology and tools used in order to achieve the objectives and finally a plan for thesis outline.

* **Chapter Two (Literature Review)**: Chapter two covers a general literature review on the meaning and importance of groundwater quality and its evaluation, then groundwater contamination and pollution as meanings and sources and the factors that affecting them. Finally chloride as a representative for salinization with the case of seawater intrusion and nitrate as indicator for pollution.

* **Chapter Three (Study Area Description)**: Describes the study area with respect to its geography, geology, hydrology and hydrogeology, and land use. The available studies on the groundwater quality status of the area in order to continue as much as possible the progress of the related works that this thesis is prbably based on.

* **Chapter Four (Approach, Methodology and Tools)**: It discuses the data collection, treatment and analysis and representation of it in different forms of maps, graphs, sections, tables etc using different softwares Surfer version 8,WinLog version 4,WinFenceand Excel .

* **Chapter Five (Results and Discussion)**: Present the collected data in chapter four after their treatment through the softwares with a discussion for these results.

* **Chapter Six (Conclusions and Recommendations)**: The data and information gained from chapter five were utilized to conclude the groundwater quality situation as spatially and temporally and the factors that affecting its situation and recommend the possible ways to overcome groundwater chemical pollution problems in the study area.

Chapter(2)

Literature Review

2.1 Introduction

Groundwater quality is a measure of its suitability as a source of water for a certain purpose. This suitability depends mostly on the chemical composition of groundwater and in some cases, microbiological components may be important as well. The natural chemical quality of groundwater is generally good. It reaches to us usually carries a certain amount of minerals and elements which it acquires from its source, treatment, storage, distribution, and household plumbing conditions. These minerals and elements generally occur at very low levels of concentration and do not pose a significant risk to health (www.purdue.edu., 2006). Any changes on groundwater chemical quality can lead to contamination and pollution and consequently can have serious consequences on ecosystem health and function and can cause problems for water use. So, it is important to monitor groundwater quality for early warnings of change and to detect its sources either from natural systems and/or resulting from human activities. Also, it is important to know the factors that affecting on the changes in groundwater quality.

Groundwater quality evaluation is the process of evaluating the physical, chemical and biological nature of the groundwater. The main reasons for the evaluation is to verify whether the observed water quality is suitable for intended uses and to determine trends in the quality of the groundwater and how that quality is affected by natural and / or anthropogenic factors (Chapman, 1992). Evaluation is very important for groundwater protection, this means that to protect the remained amount of groundwater in the aquifer from pollution and to prevent if possible the pollution to spread out in large areas.

2.2 Groundwater Contamination

Groundwater contamination may be a result of many known and unknown processes occurring between chemical contaminants, soils, aquifer lithology, and water in the vadose and saturated zones (Appleyard, 1995; Melloul and Azmon, 1997). Human activities can alter the natural composition of groundwater causing undesirable change in groundwater quality in the form of contamination or pollution. The difference between contamination and pollution terms is:

- Groundwater Contamination: The word 'contamination' as used by Freeze and Cherry (1979) implies that human activities have increased the concentration of a constituent, though not necessarily harmful.
- Groundwater Pollution: Contaminant levels that exceed acceptable limits result in pollution. Groundwater pollution is any physical chemical or biological change in groundwater quality that has a harmful effect on living organisms or makes water unsuitable for desired uses.

2.2.1 Sources of Groundwater Contamination

Groundwater contamination sources can be classified as naturally and anthropogenically contamination. Natural sources refer to natural deposits of salts, gypsum, nutrients, and metals in soils and sediments material in unsaturated zone between soil and groundwater that leach into groundwater. Anthropogenic activities create various contaminated leachate, which can migrate downward from the vadose zone to groundwater, transferring contaminants, including some hazardous ones (Melloul, and Azmon, 1997). The anthropogenic sources include urban, agriculture and industrial sources.

In urban areas the tremendous speed of the population growth that can radically change the spatial distribution of groundwater recharge. Changes in recharge in urban areas may change groundwater quality, either directly by allowing chemicals used to be leached into a groundwater system, or indirectly by changing chemical conditions within an aquifer (Appleyard, 1995). As urban areas grow, there is an increase in rain water runoff caused by the addition of paved surfaces. Diffuse recharge by infiltration through soil profiles is partly replaced by new point sources, including septic tanks, leaking sewers and water mains, intensive irrigation of domestic and municipal gardens, and the recharge of storm water runoff.

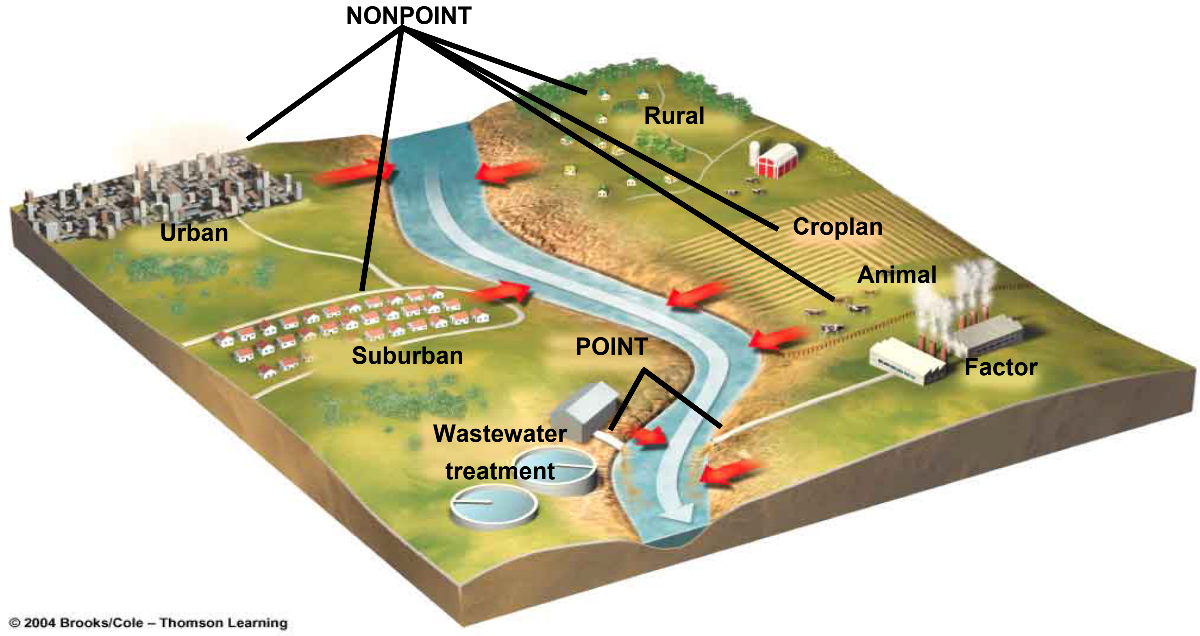
Agrochemicals and animal waste are agricultural sources for groundwater contamination. The means of agricultural contamination are varied and numerous, as mixing and distributing pesticides and fertilizers with irrigation water can cause groundwater contamination if more chemicals are applied than crops can use. Contamination of groundwater due to agricultural activities (irrigation and fertilization) in arid zones is usually expressed in increasing salinity and nitrate concentrations.

The disposal of industrial wastes associated with the above activities contributes another source of groundwater contamination. Dry holes and cesspools introduce wastes directly into the ground. Septic systems cannot treat industrial wastes.

Sources of groundwater contaminants can be classified in space as either point sources (single sources) and distributed (dispersed) sources, or non point sources as shown in (figure 2.1)

Point Sources: These types of sources discharge contaminants at specific locations (factories, sewage treatment plants, leaking septic tanks, municipal landfills sites, waste dumps, underground mines and oil tankers) through drain pipes or sewers lines into bodies of surface.

Non- Point Sources: These types of sources are scattered or diffuse, not having a specific location over a widespread area (acid deposition, runoff from cropland, livestock feedlots, agriculture land use (pesticides and fertilizers), urban streets and lawns) and cannot be traced to any single site of discharge (difficult to control).



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(Figure 2. 1) Sources of groundwater contaminants; point sources and non-point sources (Qahman, 2005).

The non-points sources contaminants do not cause immediate pollution, but their contamination is very complex and a long-term problem (Graham, 1996). They contribute to more widespread, or regional, contamination of groundwater than point sources although the levels of contamination are typically less acute.

Groundwater contamination is discovered frequently long after it has occurred. This often results in a delay in the detection of groundwater contamination and pollution. In some cases, contaminants introduced into the subsurface decades ago are only now being discovered. This a1so means that the environmental management practices of today will have effects on groundwater quality in the future.

2.2.2 Factors Affecting Groundwater contamination

There are many factors that affecting the likelihood of groundwater contamination. The geological conditions, site conditions and human actions and management practices are the main aspects which could have a significant impact on groundwater contamination.

2.2.2.1 Geologic Conditions

Permeability of Soil and Sediments

It is important to look at the permeability of the soil and sediments between the surface and groundwater. Groundwater moves very slowly through soil and sediments with low permeability, such as clay. This allows more time for minerals to dissolve. In contrast, sediments with high permeability, such as sand and gravel deposits, allow groundwater to move downward very quickly. There is less time for minerals to dissolve and thus the groundwater usually contains lower levels of dissolved minerals (http://www1.agric. /wwg406, 2006). Dissolved chemicals are carried along with water and thus more likely to reach groundwater in soils that are highly permeable.

Chemical Makeup of Soil and Sediments

Some rock and soil release ions very easily when water flows over them. On the other hand, many cations in a solution of groundwater will have a tendency to become absorbed onto the surfaces of clay minerals. This occurs because the clay mineral surfaces tend to have many negative electrical charges that can react with the positive cations. If a contaminant ion is reactive (easily absorbed onto clay minerals), it will travel slower through an aquifer than a non reactive contaminant.

2.2.2.2 Site Conditions

Depth to Groundwater

Water is the world’s greatest and most abundant solvent that attempts to dissolve everything it comes in contact with. As a result, the longer groundwater takes to move through the sediments, the more mineralized it becomes. Thus, shallow groundwater aquifers have a lower level of mineralization, or total dissolved solids (TDS), than deeper aquifers.

Sediments between the surface and groundwater act as a filter. The shallower the depth to groundwater means the less soil there is to act as a filter, more leaching and the fewer opportunities there are for adsorption degradation of pollutants. Therefore, extra precautions need to be taken to protect groundwater in areas where it is close to the ground surface.

Climate and Rainfall

Climate is another consideration at every location. Climatic variations such as rainfall duration and frequency and total amount of rainfall and evaporation rates also play an important role in groundwater quality. In semi-arid regions discharging groundwater often evaporates as it approaches the surface. The minerals from the water are deposited in the soil, creating a salt buildup (http://www1.agric. /wwg406, 2006) . Rainfall infiltrating through the soil can re-dissolve the salts, carrying them back into the groundwater. In areas with higher rainfall and lower evaporation rates, rainfall that reaches groundwater is less mineralized especially if the soils are highly permeable. Cold soils slow the rate of degradation and increase the time the chemical is available for leaching (www.italocorotondo.it.,2006).

2.2.2.3 Human Actions and Management Practices

Human actions, such as groundwater abstraction, result in drawdown of the groundwater tables and piezometric levels and inflow of saline groundwater, leading to a rise of the interface between fresh and saline groundwater. Another example is the application of agrochemicals as pesticides, fertilizers or other chemicals is regulated by the landowner or applicator. Application methods and the rates and timing of application can influence the leaching of the chemical. The larger the amount used and the closer the time of application to a time of heavy rainfall or irrigation, the more likely that some chemicals will leach to groundwater. Irrigation practices with old methods could increase the mount of return flow as a source of groundwater recharge and consequently will affect on groundwater quality. This can be accomplished by using agrochemicals which are less susceptible to leaching and surface runoff.

2.3 Chlorides and Nitrates in Groundwater

In this study chloride and nitrate are chosen for groundwater quality evaluation since these parameters potentially contributing to salinity and pollution and therefore monitoring is mostly carried out for them in all wells. Chlorides are considered here as representative of salinity, owing to their highly conservative properties (i.e., not subject to adsorption) and their direct relationship with total dissolved solids (TDS). Nitrates, although not conservative, are used here as indicative of anthropogenic pollution mainly from intensive agriculture and domestic sewage disposal (Melloul and Bibas 1990; Wollman 1991).

2.3.1 Chlorides

Chlorides are salt compounds present in nearly all natural waters and usually found at low concentrations in groundwater. Its range of concentrations can vary widely. Chlorine in combination with a metal such as sodium is essential for life but high chloride levels can cause human illness and also can affect plant growth at levels in excess of 1000mg /l (www.italocorotondo.it., 2006). Taste threshold is about 250mg /l for most people. Therefore, public drinking water standards require chloride levels not to exceed 250mg /l (recommended World Health Organization WHO) level (WHO,2003).

Chlorides in groundwater may come from many processes such as dissolution of rocks containing chlorides, irrigation drainage, seawater intrusion in coastal aquifers, and salt water up-coning of ancient seawater (connate water). Also, it may come from application of fertilizers or pesticides, effluent of wastewater treatment plants and industrial waste and from lateral movement of saline groundwater from up gradient areas of the aquifer, or upward movement from connected aquifers. Heavy pumping led to water level declines and changes in flow directions in the aquifers. In some cases, this has induced saline water from the sea or deep brines, to move into and contaminate an aquifer.

The salinization of the near shore inland aquifers by infiltrating seawater represents a world wide phenomenon. It becomes a problem in coastal regions where inland fresh groundwaters are hydraulically connected with seawater. Seawater intrusion is the result of disturbance of the equilibrium between inland fresh groundwater and denser seawater due to fluctuations of the sea level and / or groundwater level (Tavitian,1994).

In case of 2% of seawater mixed with freshwater, it can render the water un-potable (www.mckenziefamily.free-online.co.uk, 2006). Many years may pass before a well that is unaffected by saltwater intrusion suddenly may become contaminated (Reilly and Goodman, 1987). The extent of saltwater intrusion into an aquifer depends on a number of factors such as aquifer geometry and properties (hydraulic conductivity, anisotropy and porosity), abstraction rates, and depth, recharge rate, and distance of pumping wells from the coastline (Ghassemi et al,1993).

Management of limited groundwater resources in such situations is a delicate task and requires special attention to minimize the movement of the saltwater wedge into aquifers and upconing of saltwater near pumping stations. Groundwater pumping is the primary cause of saltwater intrusion along the coasts. Other hydraulic stresses that reduce freshwater flow in coastal aquifers, such as lowered rates of groundwater recharge in urbanized areas, also could lead to saltwater intrusion.

One of the most widely used approaches to detect the presence of saline water in an aquifer is measurement of chloride concentration. Salinization of aquifers by chlorides appears as sharper trends in chlorographs, as sudden change or fluctuation in chloride concentration especially when groundwater exploitation of an aquifer is carried out in close proximity to a massive highly saline source such as seawater.

2.3.2 Nitrates

Of the inorganic contaminants found in groundwater, nitrate receives the most attention. Nitrate has been reported above background concentrations in groundwater world-wide and it has been identified to be the most common and widespread chemical contaminant in groundwater (Spalding and Exner, 1993). It is commonly associated with diffuse sources such as intensive agriculture, high density housing with unsewered sanitation and point sources such as discharge of sewage effluent onto land (Keeney, 1986; Eckhardt and Stackelburg, 1995). It is highly soluble, very mobile and usually not adsorbed much by soil particles and so it can leach into groundwater if not absorbed by plants. Nitrate (as N) is usually present naturally at least in low concentrations between 0.45 and 2.0 mg/l have been reported in groundwater in Europe and the USA (Hallberg, 1989; Juergens-Gschwind, 1989) and from 1.15 to 2.3 mg/l in Australia (Lawrence, 1983). Some studies show that groundwater concentrations exceeding an arbitrary threshold of 3 mg/l may be indicative of contamination of natural groundwater as a result of human activities (referred to as the human affected value; (HA V; Echardt and Stackelberg, 1995). Nitrate concentrations in excess of a few milligrams per liter indicate that water is arriving at the well from shallow aquifers was polluted from human or animal waste or from excess nitrates used in agriculture.

Decomposition of organic matters in soils, leaching from excess fertilizer application in agriculture area, human and animal excreta, untreated effluents of nitrogenous industries and sewage disposal are potential sources of nitrate contamination in groundwater. Madison and Brunett (1985) list the following as major anthropogenic sources of nitrate: "fertilizers, septic tank drainage, feedlots, dairy and poultry farming, land disposal of municipal and industrial wastes, dry cultivation of mineralized soils and the leaching of soil as the result of the application of irrigation water." Natural sources include: "soil nitrogen, nitrogen-rich geologic deposits, and atmospheric deposition." This contaminant commonly results from the application of fertilizers and the disposal of sewage on or beneath the land surface (Freeze and Cherry 1979). Numerous studies worldwide shows that nitrate levels in groundwater are often higher in areas of intensive agriculture (http://res2.agr.ca/06, 2006). Septic tanks are the most frequently reported cause of groundwater contamination (US EPA 1977). Leaching is more likely in areas of coarse-textured soils, irrigated agriculture or heavy rainfall and intensive cropping or livestock production. Leaching of nitrate from various sources is more concerned in areas where shallow groundwater is the only source of potable water.

The groundwater nitrate problem is international in scope. This is due to the fact that nitrate is easy to detect and excessive concentrations of nitrate can cause ecological damage and health hazards. Nitrate is of most concern for humans and its level in drinking water is extremely important for infants. Nitrates are especially toxic to children less than six months of age (www.dnr.state.oh.us., 2006). Several studies document adverse effects of high NO_3^- levels, most notably methemoglobinemia, and stomach cancer (Addiscott et al., 1992; Mohsen Jalali, 2005). So, WHO has been recommended (50 mg/l) as a maximum limit for nitrate in drinking water.

Chapter(3)

Study Area Description

In this chapter a description for this area (northern part of Gaza Strip) had been done but in a little cases when there was an absence of data for intended area, a description for the whole strip had been used.

3.1 Geography

The geography of the study area includes its location, topography, population, climate and rainfall and soil.

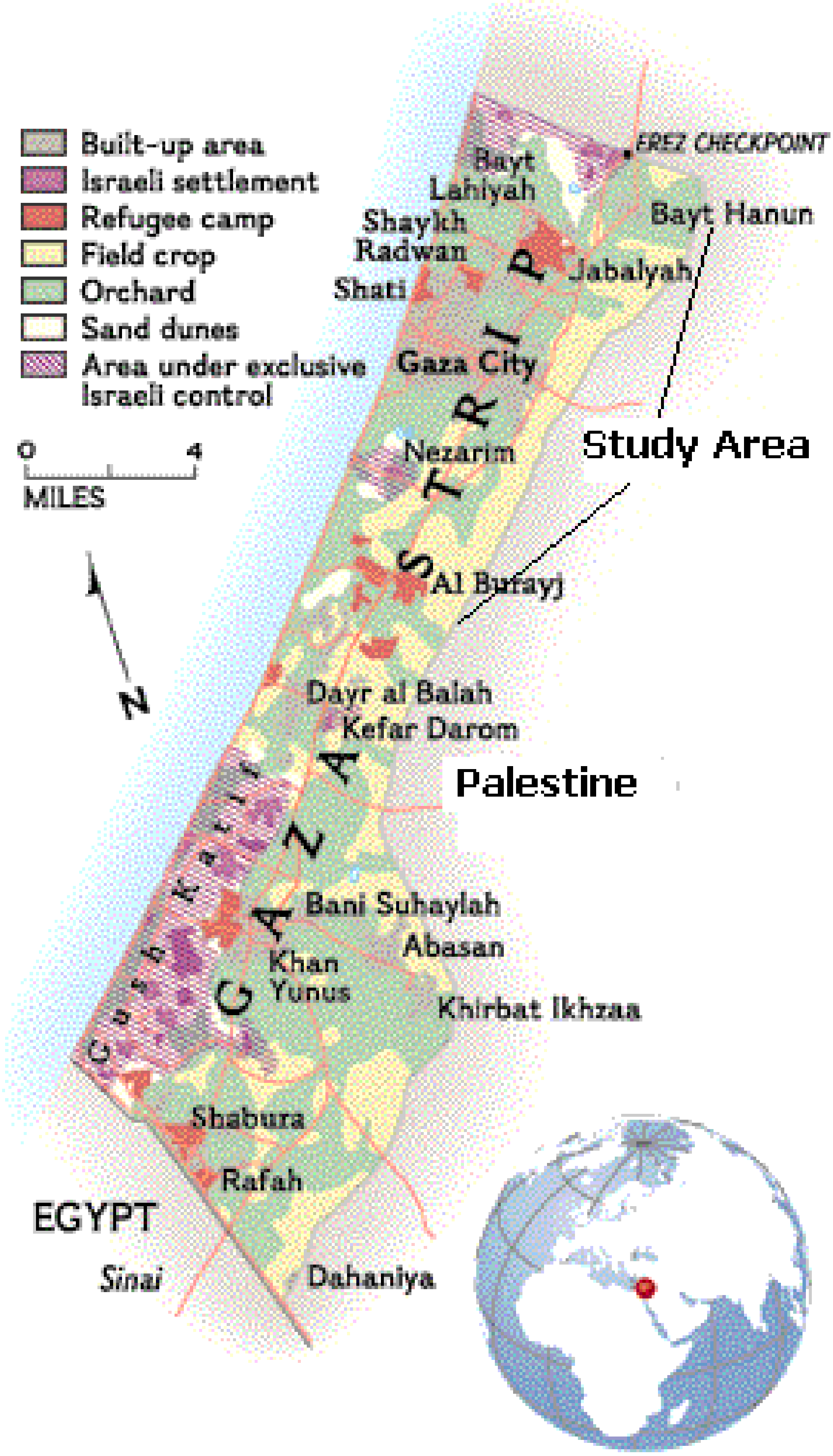
3.1.1 Location

Gaza Strip is the southern part of the Mediterranean Coastal Plain of Palestine with total area of 365 km^2 and a form of long and narrow rectangle (MOPIC, 1998) (figure 3.1). The study area is the northern part of Gaza Strip which located between longitude 34° 33′ to 34° 23′ and latitude 31° 36′ to 31° 26′. Its boundaries are Mediterranean Sea from the west, the 1948 Palestinian occupied areas to the east and north and Wadi Gaza to the south. It covers an area of about 135 km^2 with a length along the coast about 18 km and width ranges from 6 km in the south to 9.5 km in the north. It consists of two Governorates named as North and Gaza Governorates. Israel settlements before has occupied areas of about 9.88 km^2 that form about 7.3% of the study area.

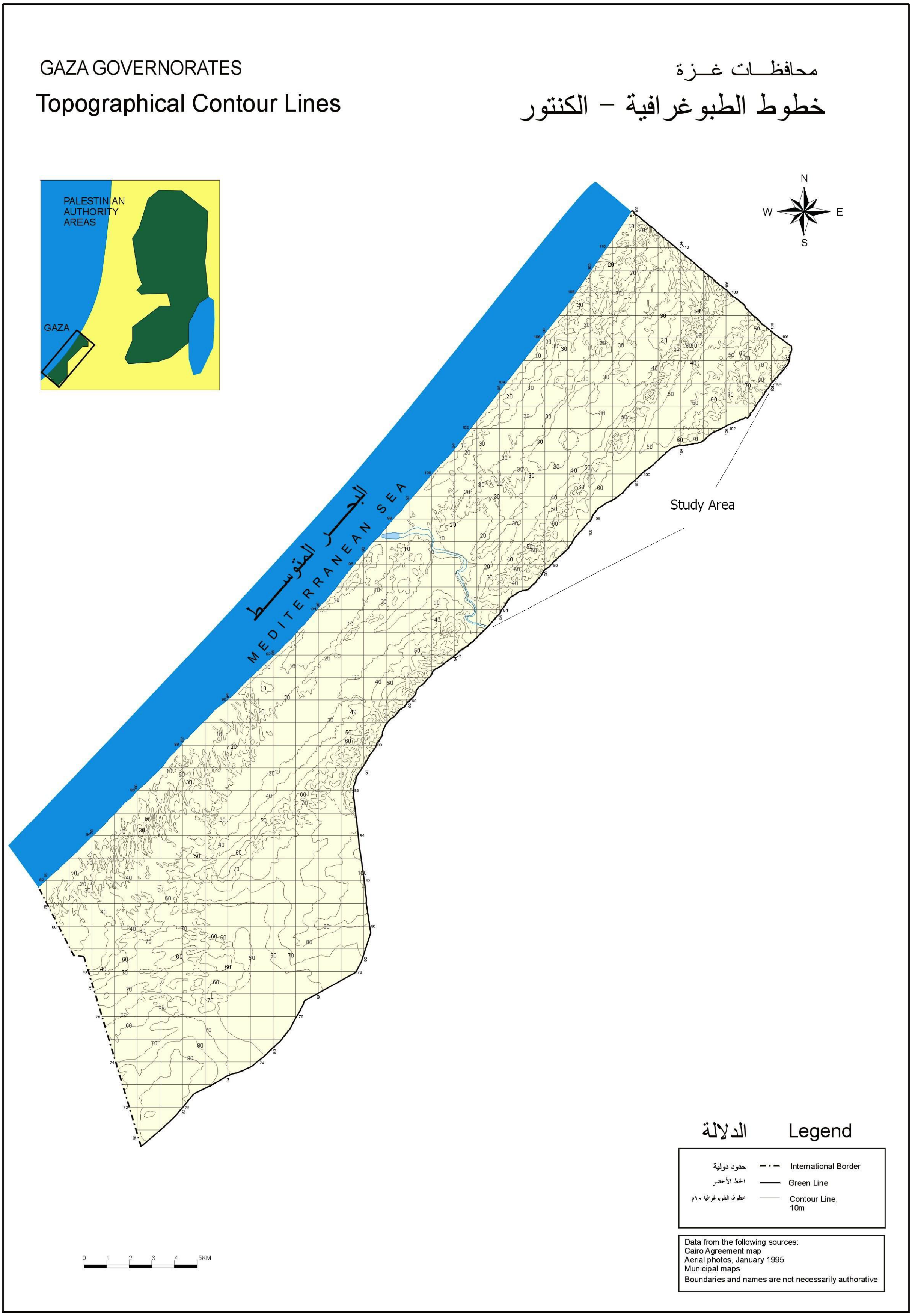
3.1.2 Topography

A three dimensional topographic map for the northern part of Gaza Strip is shown in (figure 3.2). This area is characterized by narrow elongated ridges and depressions extend parallel to the shoreline (NNE-SSW). The ridges have been dissected by two Wadis crossing Beit Hanoun in the north and Wadi Gaza in the south of study area. Wadi Gaza is larger and rarely flows due to upstream obstacles in occupied areas.

The surface land elevation is ranging from zero at the shoreline to about 90 meter above mean sea level (MSL) in some places in the eastern side of the study area. The ridges and depressions show considerable vertical relief in some places up to 60m . Surface elevation of individual ridges range between 20 m and 90 m . Sand dunes are dominant along the shoreline with elevations up to 50 m above MSL



(Figure 3.1) Location map of northern part of Gaza Strip



(*Figure 3.2: Topographical map of the Gaza Strip* (MOPIC,1998)

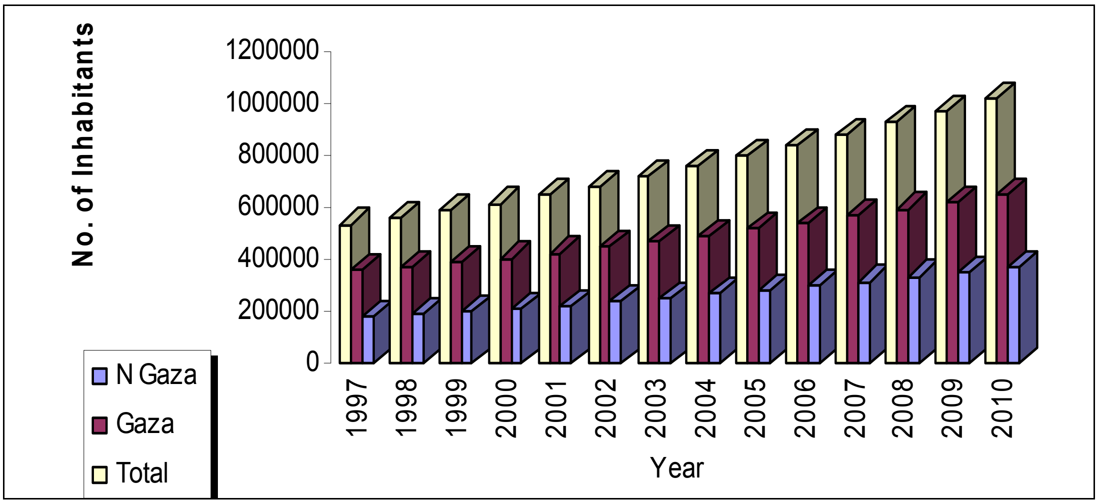
3.1.3 Population

The northern part of Gaza Strip is considered as one of the most densely populated areas all over the world where at year 2004 more than 780,000 inhabitants are crowded into an area of about 135 km ^{2}. Demographic distribution in the Gaza and North Governorates is shown in table (3.1). The population situation here is strongly influenced by political developments which have played a significant role on the growth rate and population distribution. According to the Palestinian Central Bureau of Statistics, the natural rate of growth of population in Gaza strip is estimated at 4% per year. The projected population of Gaza Strip has increased from 1997 to 2010 (PCBS,2004) as shown in (figure 3.3).

Table (3.1) The demographic distribution for the Gaza and North Governorates.

Governorate	Size: Area (km^2)	Population			Population density/ km^2	
		1997	1999	2004	1997	2004
North	61	178,605	198,660	265,980	2,928	4,360
Gaza	74	357,768	388031	492,621	4,835	6,657
Total	135	536,373	586,691	758,601	3,973	5,778

Study area has experienced a 41.5% increase in population in the last 7 years. Gaza Governorate has experienced a 37.5% while North Governorate has experienced a 49 % increase in population in the last 7 years. The increase in population is as a result of natural growth and the Palestinians returning to their homeland. This high population growth rate in the study area has proved to be a serious challenge in the provision of essential services like water, sanitation and health care.



(Figure 3.3): Projected Population for the Gaza and North Governorates (Data; PCBS,2004)

3.1.4 Climate and Rainfall

The study area has a characteristically semi-arid Mediterranean Sea climate. It is located in transitional zone between a temperate Mediterranean climate to the west and north, and the arid Negev and Sinai deserts to the east and south. Rainfall is the main source of almost all water in this area.

3.1.4.1 Climate

There are two distinct seasons; cool and relatively wet season (October-March), and hot and dry season (April-September).The average daily temperature in the Gaza Strip ranges from 26°C in summer to 12°C in winter with the average daily maximum temperature range from 29°C to 17°C, and the minimum temperature range from 21°C to 9°C, in the summer and winter respectively. The daily relative humidity of this coastal area ranges from 65% to 85% in summer and from 60% to 80% in winter in the day time and at night respectively (GMS,2005).

The mean daily evaporation is variable during the year, where it ranges from about 2.1 mm/d, in December to 6.3 mm/d in July. The high potential evaporation is primarily related to high solar radiation incident over the strip at 190 kg -calories/cm^2/year (U.S. National Academy of Sciences, 1999). The generally cloudless summer months (April through September)and consequently open water evaporation is high in the summer, accounting for as much as 70% of the annual total evaporation (GMS, 2005). More water is potentially lost through evaporation than added by precipitation.

3.1.4.2 Rainfall

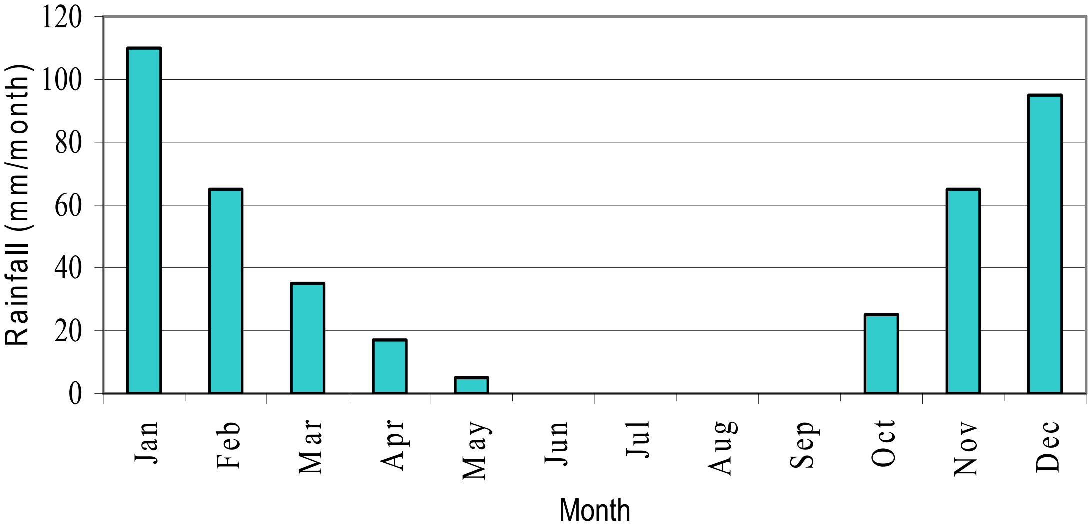
Daily rainfall data are available for 8 meteorological stations in the study area, six of them have daily records back to 1994 and before. The rainfall at any two stations located only few kilometers apart often show very different rainfall totals in any given year. There are distinct dry and wet seasons. The highest recorded one-day total in Gaza Strip was 138 mm at the Beit Lahia Station on November 29,1991 (GMS,2005).

Temporal Distribution

As we can see from the mean monthly rainfall in mm in Gaza Strip (figure 3.4) The rainfall occurs in the winter period, which is between October to March. The period for June to September is dry with no rainfall.

Spatial Distribution of Rainfall

The mean annual rainfall in the northern area of Gaza Strip varies from 350-400 mm/yr. (figure 3.5) shows the average spatial annual rainfall in Gaza Strip.



(Figure 3.4): Mean monthly rainfall in mm in Gaza Strip (MOPIC, 1994)

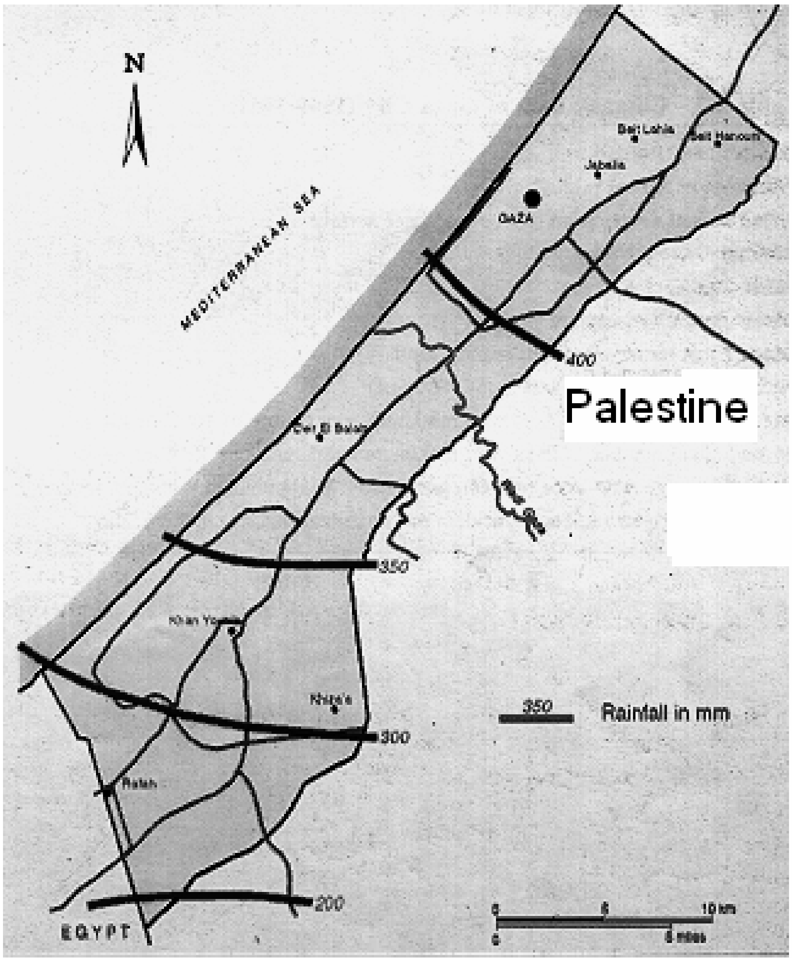
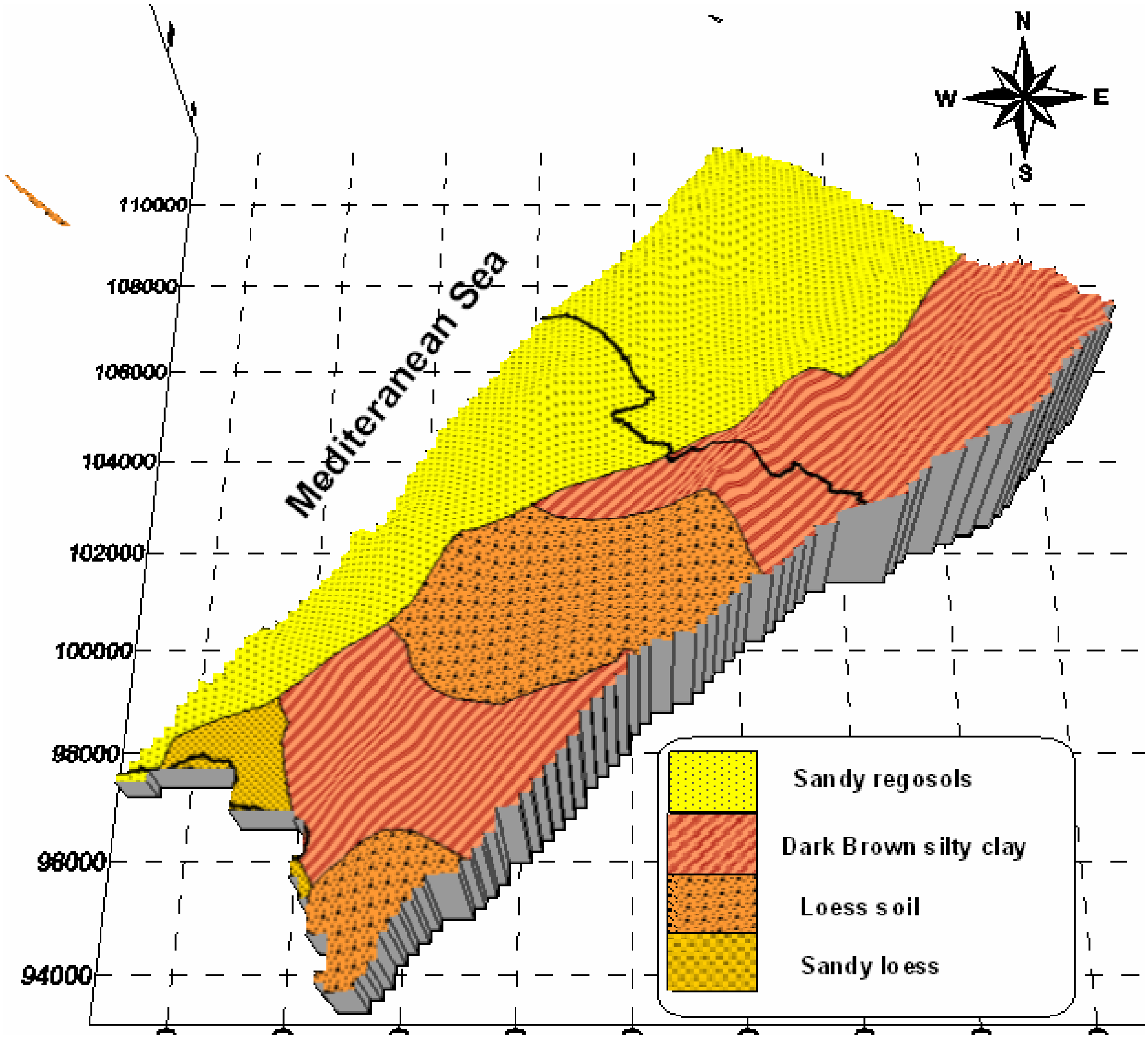


Figure (3.5): Spatial distribution of rainfall)

3.1.5 Soil

Soil media refers to the upper part of the phreatic zone. Soil media is an important factor in terms of movement of pollutants. All the infiltration processes took place in the upper part of soil. The soil varies in the study area. It is composed mainly of three types; sands, clay and loess as shown in the soil map (figure 3.6) . Along the shoreline there is a zone of sand dunes with varying in thickness from two meters to about 50m and extends up from 4 to 5 km in land. This area is wider in the north than in the south of the study area. The dunes have relatively high permeability. Moving eastward, the soil type change and becomes less sandy with more silt, clay, and loess.



(Figure 3.6): Soil map of the Northern part of Gaza Strip (Data source: EQA,2005)

3.2 Geology

Geology of the Gaza Strip was obtained from oil and gas exploitation logs up to depth of about 2000m drilled by Israelis and from wells drilled during the Coastal Aquifer Management Project (CAMP). Geology of the study area consists of a sequence of geological formations ranging from upper Cretaceous to Holocene. This sequence is gradually sloping westwards (PWA, 2000a) as shown in (figure 3.7) and (figure 3.8). Table (3.2) summarizes the geological history of the area. The formations of this sequence are:

1. Tertiary Formations

The Tertiary formations consist of Saqiya group (upper Eocene to Pliocene) underlained by Eocene Chalks and limestones as shown in (figure 3.7). The Saqiya group composed of shallow marine impervious sediments of Shale, Clay, and Marl. The thickness of this group ranges from 400 m to 1000m . This group wedged out rapidly to the east (PWA, 2000a).

2. Quaternary Formations

The Quaternary deposits throughout the Gaza Strip are overlain the Saqiya group, while at the east they overlain the Eocene Chalks and limestones. The thickness of the Eocene deposits reach to about 200 m (PWA,2000a).

Quaternary formations are represented by the coastal plain aquifer of Palestine. These formations extend from the foothills of Mount Carmel (north of Haifa) southwards to the Gaza Strip and northern Sinai. The coastal aquifer composed of loose sand dunes (Holocene age) and Kurkar group (Pleistocene). The Kurkar group composed of marine and aeolian calcareous sandstone (locally known as "kurkar") reddish silty sandstone ("hamra"), silts, interlayers of clay deposited during the Last Glacial stage and during the Holocene (Issar, 1961; Zilberbrand et al, 2001) , unconsolidated sand and conglomerates. The surface morphological features of the Kurkar group are three elongated hills known as "kurkar ridges," located in clusters extends parallel to the shoreline. These belts extend about 15-20 km inland. They unconformably overlie Eocene limestones and chalks deposits to the east and upper Eocene-Pliocene age of the Saqiye group to the west throughout the Gaza Strip. The transition from Kurkar group to the Saqiye group is sometimes obscured by the presence of a thin basal conglomerate. The calcareous sandstones are interbeded with irregular layers and pockets of uncemented sand and thin red brown sands and silty sands (Hamra) and especially at greater depths, marine silts and clays (Zilberbrand et al,2001).

During the Quaternary period, four transgressions and regressions of the Mediterranean Sea occurred in the Coastal Plain. According to (Ecker 1999; Zilberbrand et al, 2001) , deposition occurred partly in marine settings, partly in terrestrial environments, in lagoons, in stable and unstable marshes, and in some cases, in coastal environments. Each younger transgression penetrated inland less than the preceding one and the latest transgression seems to be represented by the Coastal Ridge. Close to the present shoreline, the sequence of the Kurkar Group attains an average thickness of 200m in the south and around 120m in the north, wedging gradually out towards the foothills of the Judea and Samaria Mountains in the east. (Zilberbrand et al, 2001). The Holocene deposits are found at the top of the Pleistocene formation with a thickness up to 25m . These deposits can be divided into four different types:

Sand Dunes:

These dunes extend along the shoreline, and originate partly from Nile River sediments The thickness of these dunes is about 15 m, and their width is small in the south of the study area, increasing northward up to 3 km.

Sand, Loess and Gravel beds:

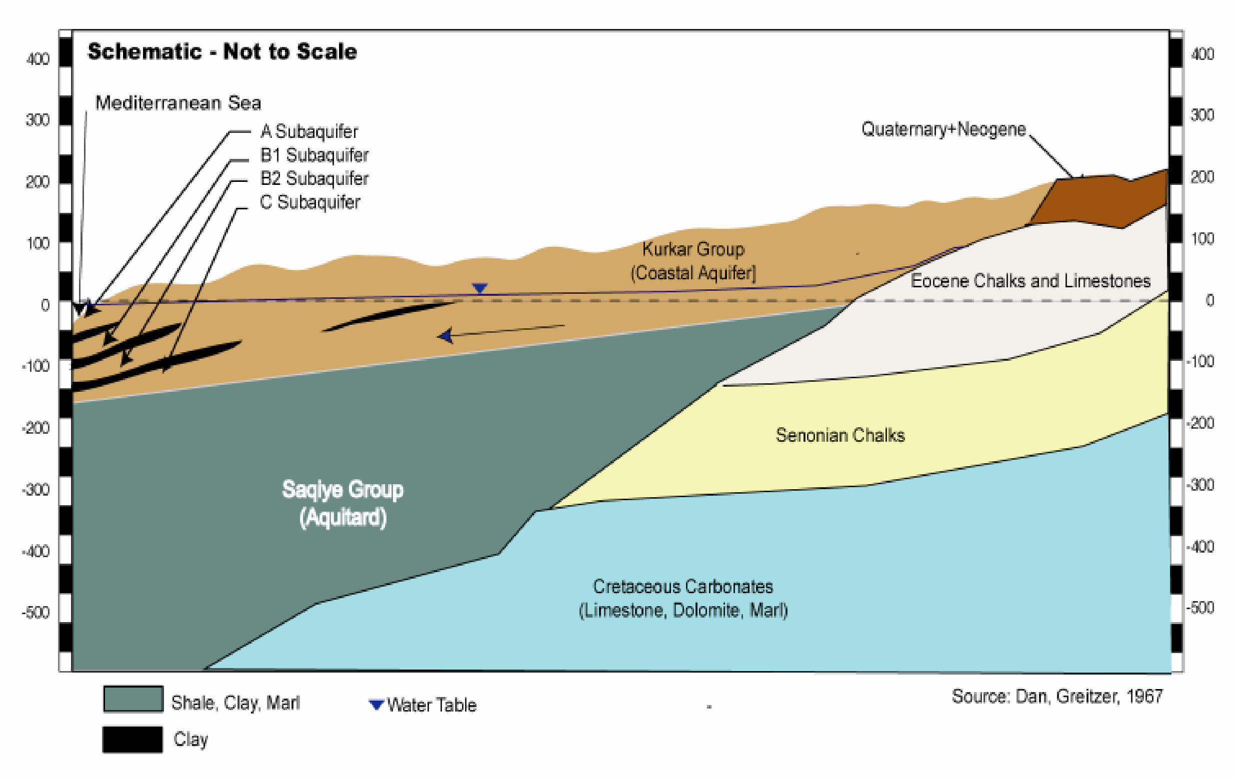
This formation is small in thickness (about 10m) and it is the main formation of the Wadi Gaza area (near surface).

Alluvial Deposits:

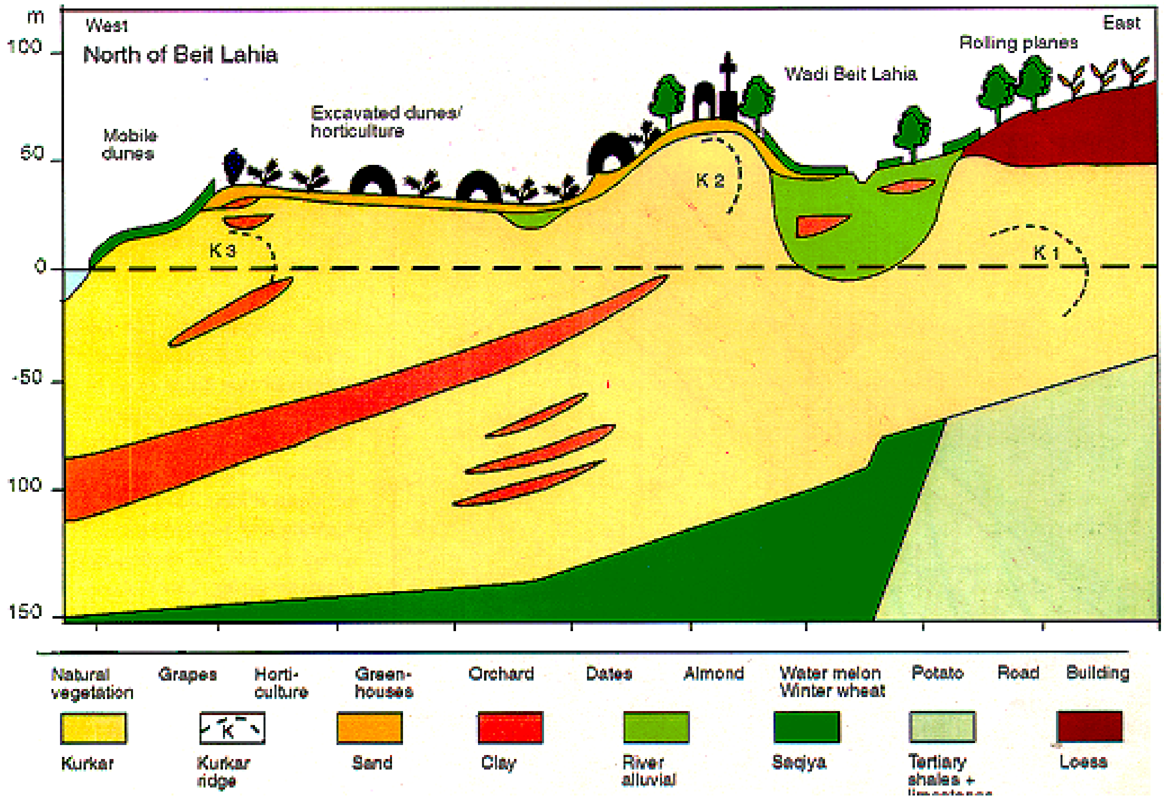
These deposits spread in the area around Wadi Gaza and have a thickness of about 25m .

Beach Formation:

This formation is composed of a relatively thin layer of sand with shell fragments. It is mainly unconsolidated, and in some places it is cemented due to the precipitation of calcium carbonate.

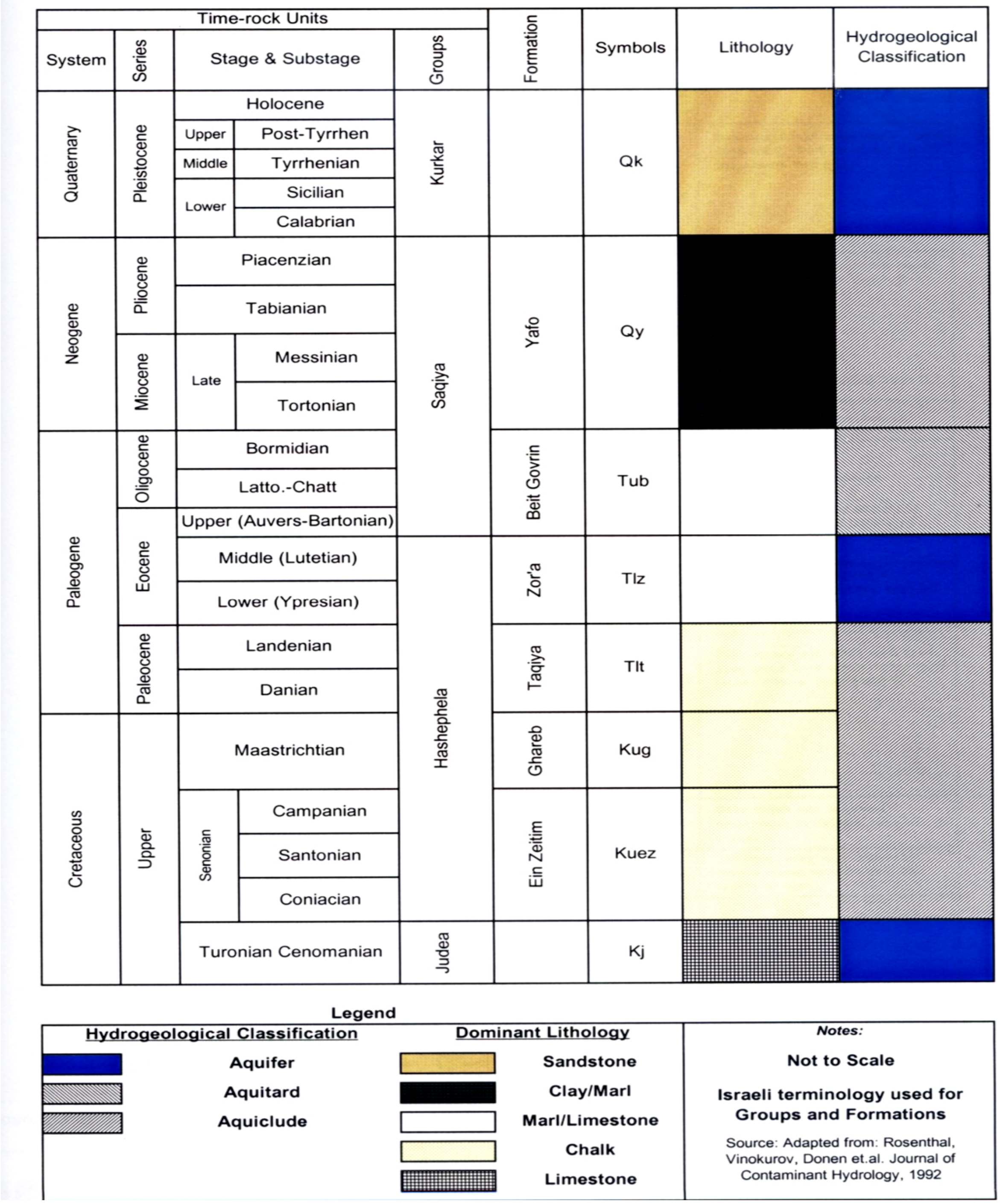


(Figure 3.7): Typical hydrgeological cross section of Gaza Strip source (PWA,2000 a)



(Figure 3.8): Typical hydrogeological cross section in the north of Beit Lahia Gaza Strip (MOPIC,) 1994

Table (3.2): A summary for the geological history of the area (PWA,2000).



Time-rock Units								
System	Series	Stage & Substage		Groups	Formation	Symbols	Lithology	Hydrogeological Classification
Quaternary	Pleistocene	Holocene		Kurkar		Qk	🟫	🟦
		Upper	Post-Tyrrhen					
		Middle	Tyrrhenian					
		Lower	Sicilian					
			Calabrian					
Neogene	Pliocene	Piacenzian		Saqiya	Yafo	Qy	⬛	▨
		Tabianian						
	Miocene	Late	Messinian					
			Tortonian					
Paleogene	Oligocene	Bormidian			Beit Govrin	Tub	⬜	▧
		Latto.-Chatt						
	Eocene	Upper (Auvers-Bartonian)						
		Middle (Lutetian)		Hashephela	Zor'a	Tlz	⬜	🟦
		Lower (Ypresian)						
	Paleocene	Landenian			Taqiya	Tlt	🟨	▨
		Danian						
Cretaceous	Upper	Maastrichtian			Ghareb	Kug	🟨	
		Senonian	Campanian		Ein Zeitim	Kuez	🟨	
			Santonian					
			Coniacian					
		Turonian Cenomanian		Judea		Kj	▦	🟦

Legend

Hydrogeological Classification		**Dominant Lithology**	
🟦	**Aquifer**	🟫	**Sandstone**
▧	**Aquitard**	⬛	**Clay/Marl**
▨	**Aquiclude**	⬜	**Marl/Limestone**
		🟨	**Chalk**
		▦	**Limestone**

Notes:

Not to Scale

Israeli terminology used for Groups and Formations

Source: Adapted from: Rosenthal, Vinokurov, Donen et.al. Journal of Contaminant Hydrology, 1992

3.3 Hydrology

Precipitation falling on land is either returned directly to the atmosphere by evaporation, flows along the land surface to become surface water or percolate into the ground. Water that infiltrates into the ground is either drawn into plants and returned to the atmosphere by transpiration or continues infiltrating and becoming groundwater.

3.3.1 Surface Water

The surface water system in the study area is represented by two Wadis, namely Wadi Gaza and Wadi Beit Hanoun. Wadi Gaza that located at the southern boundary of study area is the bigger. It runs in the central part of the Gaza Strip and discharge into the Mediterranean Sea. Wadi Gaza length is about 9 km in Gaza and it extends into the armistice border for about 95 km where it collects the water fr om a big catchment area (3600 km^2) from the Hebron mountains and the Northern Negeve (MWCP, 2001) . This main stream was diverted by the Israelis to an adjacent area where it's been stopped their and collected at basins located 6 km east of Gaza (MWCP, 2001). The other small and insignificant wadi in the north is wadi Beit Hanoun which flows into occupied area to the north of the study area.

Wadis are ephemeral streams, characterized by short duration floods that occur after heavy rainfall, while most of the time they are completely dry. Freshwater flows into them in the winter season. Israel has retained and changed the course of the two Wadis and they became dry since the early seventies, this means that fresh surface water resources are negligible.

3.3.2 Groundwater Hydrology

The coastal aquifer underlies the Coastal Plain of Palestine and runs parallel to the Mediterranean Sea coast. The coastal aquifer is an underground phreatic reservoir varies in width from 7 km in the north to 20 km in the south; its thickness decreases eastwards from 200 m near the coastline to a few meters in the eastern margins (PWA, 2000a) (figure 3.7). The aquifer (the Kurkar Group of Pleistocene age) consists of sand, sandstone, and silt interbedded with marine clays, and it overlies the impervious marine clays of upper Eocene to Pliocene age (the Saqiye Group). The aquifer is basically phreatic, but clay layers divide it vertically into several subaquifers. The hydraulic connection between groundwaters in the different subaquifers and the sea is not well understood. While Bear and Kapuler (1981) considered that all subaquifers are connected to the sea, Kolton (1988) argued that the lower subaquifers are disconnected (Orit,et al 2005).

In the central and eastern areas the aquifer is uniform and phreatic. The calcareous sandstone (arenites or "kurkar") is composed of several minerals: quartz, feldspar, calcite, aragonite and iron oxides (Vengosh, et al 1996). A schematic cross-section from east to west in the study area (figure 3.9) exhibits disconnected clay-silt layers at different depths. The high permeability of the sand and calcareous sandstone in the upper vadose zone enables rapid migration of pollutants to the saturated zone. There is a structural relationship between the Western Basin of the Mountain Aquifer and the shallow Gaza Coastal Aquifer as shown in (figure 3.9).

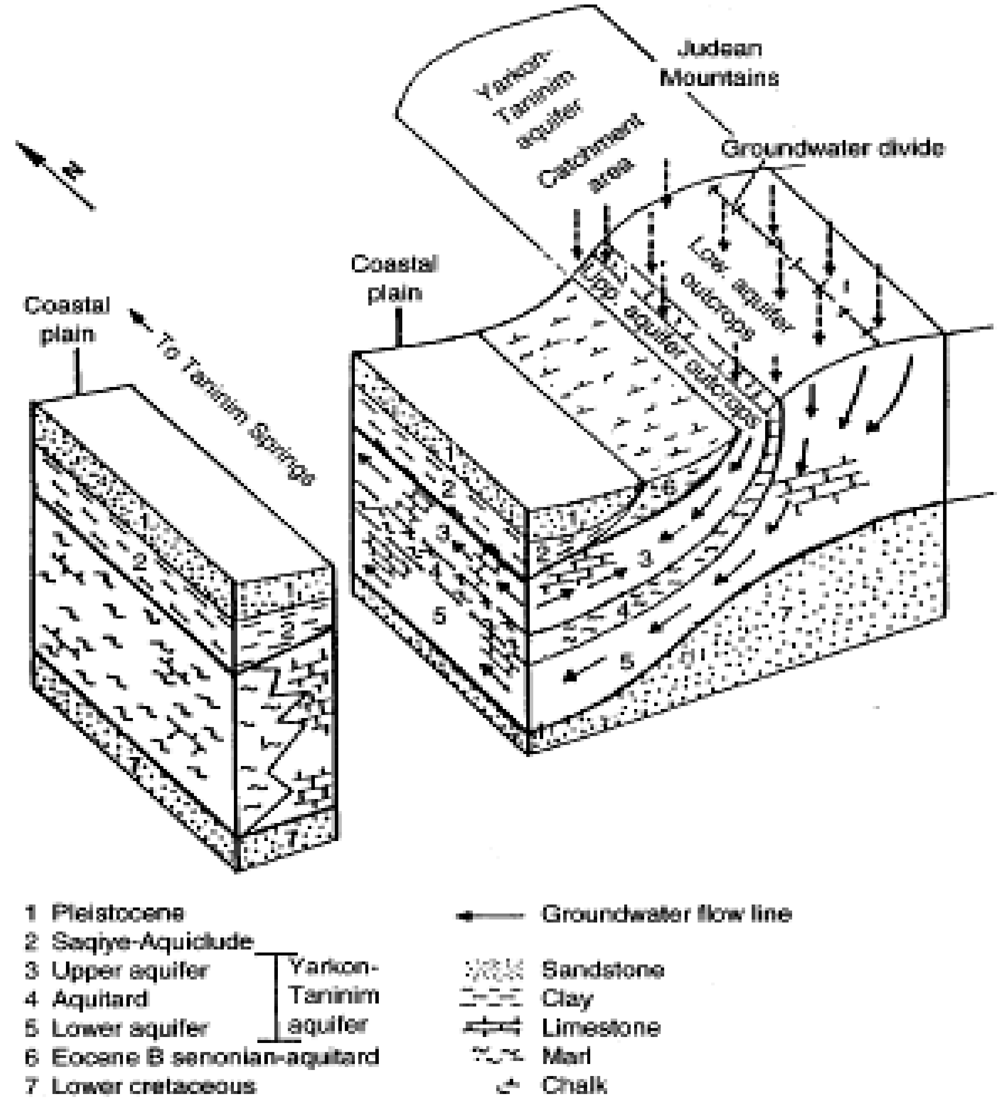
3.3.2. Hydrostratigraphy

In the study area, the coastal plain aquifer contains many diverse hydraulic and hydrologic units and thus, several water-producing zones. The layered stratigraphy of the Kurkar Group subdivides the coastal aquifer from top to bottom into four separate sub-aquifers near the coast A, B1, B2 and C as shown in (figure 3.7) . This subdivision is conditioned by impervious to semi-impervious interlayers alternating with predominantly permeable calcareous sandstones, and persists along the coastal strip but dissipates 4-6 km east of the shoreline. East of the third ridge the Kurkar Group sequence is randomly subdivided by occasional occurrence of impervious to semi-impervious layers and the coastal aquifer can be regarded as one hydrogeological unit. The upper subaquifer “A is unconfined, whereas subaquifers “B1, B2, and C become increasingly confined towards the sea (Al-Jamal, and Al- Yaqubi , 2001).

3.3.2.1. Kurkar Group

Sub-aquifer A

Sub-aquifer (A) occurs in the uppermost and westernmost part of the sequence extends from the shoreline to the east up to 2 km. It is mainly composed of variously cemented concretionary calcareous sandstone mixed and interlayered with loose sand, of both continental and littoral origin. This aquifer is bounded from the top by the water table and at the bottom partly bounded by the first aquitard of silty clay. In the study area, it is 25m thick in the east to about 60-m in the west. This aquifer unit overlies continental-estuarine clay or loam extending eastwards and upwards, reaches in thickness to 15m as will be shown in (figures 5.19 and 5.20) in chapter five. However, the clay-rich base layer of sub-aquifer A is not always continuous and therefore, the hydrogeological and hydrostratigraphical separation between sub-aquifer A and underlying subaquifer B does not always exist or can be clearly identified. Sub-aquifer A may contain thin interlayers of clay, sandy clay and silty clay, which act as aquitards.



(Figure 3.9: Structural relationship between the Western Basin of the Mountain Aquifer and the shallow Gaza Coastal Aquifer The geohydrological cross section setting of the various aquifers of Israel. (Mercado 1980; Weinberger and others 1994; Melloul, and. Azmon, 1997)

Sub-aquifer B1

Based on Israel studies of Ecker 1999sub -aquifer B1 is mainly from Kurkar and micro-conglomerate deposited in a more littoral environment, the cementation of which is harder than in the overlying sub-aquifer A and having a lower proportion of loose sand. The base of this sub-aquifer is formed by marine to lagonal -estuarine clays. Further eastwards, these base layers turn into continental clays and loams and extend 6-7 km east of the shoreline.

Sub-aquifer B2

The calcareous sandstones of this unit are predominantly products of a high-energy littoral depositional environment, such as conglomerates and beach rock overlying a marine clay horizon. Based on Israel studies (Bachmat, 1963; Zilberbrand et al, 2001) sub-aquifer B2 is 20-40 m thick. Near the coastline, sub-aquifer B2 occurs between elevations of (- 120) and (- 150) m below MSL.

Sub-aquifer C

Between the shoreline and 3-4 km inland, the lithology of this sub-aquifer is of a marine type, with no indications of shallower facies. It is characterized by interlayering of clay, silt and silty sand, 10-20 m thick. Generally, the occurrence of calcareous sandstones increases eastwards (Ecker 1999; Zilberbrand et al,2001) on account of silty-clayey beds. The hydraulic conductivities of this unit are significantly lower than in the overlying sub-aquifers. Sub-aquifer C overlies impervious layers related to top of the Saqiye Group. Their occurrence is usually marked by thin streaks of chalky and marly sandstone, yellowish chalky marl, and clays. The top of the Saqiye occurs at elevations of -150 to -160 m below MSL, close to the shoreline.

3.3.2.1.2 The Saqiye Group

The Pleistocene Coastal Plain aquifer system (the Kurkar Group) overlies a very thick complex of shales and marls related to the Plio-Pleistocene Saqiye Group that wedges out gradually eastwards. In the study area its maximum depth reaches 1900 m near the coastline, wedging out in the eastern parts of the Coastal Plain. The top of the Saqiye Group dips 1-2% westwards (Zilberbrand et al,2001).

3.3.2.2 Aquifer Hydraulic Properties

Most aquifer tests have either been conducted on shallow agricultural wells or municipal wells that are screened over relatively long depth intervals. Hence little is known about aquifer hydraulic properties at depth. Relative hydraulic conductivity (K) values for individual sub-aquifers are not well defined. As well, permeabilities of the clay layers separating the sub-aquifers have not been tested. (PWA, 2000a).The transmissivity values range between 700 and 5,000 m^2/d. Corresponding values of hydraulic conductivity (K) are mostly within a range of 20 to 80 m/d. The specific yield values are estimated to be about 15-

30percent while specific storativity is about 10-4 from tests conducted in Gaza (PWA, 2000b).

3.3.2.3 Groundwater Recharge

The groundwater is recharged from different sources, including rainwater, runoff and return flow which includes leakage from municipal water distribution system, sewage infiltration and irrigation return flow. Moreover, recharge comes from inflow from occupied areas and Egypt and from the Mediterranean Sea as a seawater intrusion.

As a result of absence of a specific study on the study area, the situation of the Gaza Strip as a whole has used. Rainfall is considered as the major recharge component that replenishes the aquifer. Only about 35% of the total rainfall can be infiltrated to replenish the groundwater in Gaza strip. Groundwater recharge from rainfall in Gaza strip is estimated as 40.46 Mm ^{3} (Million Cubic Meters) for the season 2004/2005 (PWA, 2005). This value is almost equal to the average rainfall recharge (1974-2005) which is estimated as 40.8 Mm ^{3}. The remaining amount of rainfall evaporates and /or disappears as runoff. The total recharge for this season is almost equal to the season 2003/2004 (PWA,2005).

3.3.2.4 Abstraction and Existing Wells

The northern part of Gaza strip relies mainly on groundwater to fulfill all needs of domestic, agricultural and industrial uses. Generally, most of the abstracted water from wells comes from the upper 30-40m of the aquifer . In the northern part of Gaza Strip most of the wells were used for agricultural purposes and are shallow wells (PWA, 2000a). Now as large as (44.5 Mm ^{3}) of the total amount of water abstracted (62.72 Mm^3) goes to domestic sector. Half of these wells are considered as illegal wells with no permission from PWA (PWA, 2005).

The existing groundwater quality monitoring network all over Gaza Strip has 700 wells for salinity monitoring and 406 wells for nitrate monitoring (PWA, 1997; Qahman, 2005). The existing groundwater abstraction wells in the northern part are about 1556 agriculture wells (year 2000 well survey) and 57 municipal wells (year 2004 well survey) (PWA, 2005). A summary about the number of wells and total calculated and assumed water production for year 2004 is shown in table (3.3). It is believed that the pumping rate is much higher due to illegal connections, illegal wells, leakage in distribution system, Israeli settlement pumping and northern and eastern border Israeli wells (Mogheir,1997).

Table (3.3): A summary about the number of wells and total calculated and assumed water production for year 2004 (PWA,2005)

Item	North Governorate	Gaza Governorate
Population	275,318	507,448
No. of Municipal wells	27	30
Total municipal water production (Mm^3)	17.89	26.63
Total municipal water consumption (Mm^3)	9.87	19.28
Efficiency	55.2%	72.4%
No. of agriculture wells (year 2000 well survey)	814	742
Assumed total agriculture water production (Mm^3)	7.8	10.4
Total water abstracted (Mm^3)	25.69	37.03
Per capita per day(l/c/d)	178 (1)-98(2)	143-104

(1) l/c/d computation with the total water production.

(2) l/c/d computation with the total municipal water consumption.

3.3.2.5 Groundwater Balance

The Gaza coastal aquifer is a transient groundwater dynamic system, with continuously changing outputs and inputs (figure 3.10). The water balance varies from one year to another as a function of rainfall variations and changes in water demands. The water balance of the Gaza coastal aquifer has been developed based on estimate of all water inputs and outputs to the aquifer system as represented by this equation:

Inflow (from all available sources) = outflow +/- changes in storage

The current artificially disturbed water balance of the Gaza coastal aquifer is defined by:
Inflow: Effective recharge + lateral inflow + total return flows + seawater intrusion
Outflow: Lateral outflow including natural discharge to the sea + total abstraction

The present net aquifer balance is negative; this means that there is a water deficit. More water is pumped or discharged from the aquifer than naturally replenishes it. Under defined average climatic conditions and total abstraction and return flows, the net water deficit is about 40-50 Mm^3/y (Million Cubic Meters per year) this means that there is a critical situation of the water resources in Gaza Strip *(PWA,2000)*.

A relatively hydrological assessment of the Gaza Strip aquifer was done by Melloul and Collin (1994) on the basis of estimates of components of the water balance. Estimated pumping in all the Gaza Strip region during 1970–90 was 70-100 Mm^3/yr. The recommended pumping, as noted in Melloul and Bachmat (1975), is about 55 Mm^3/yr. Thus, an over-pumping of 15-45 Mm^3/yr is occurring. This overdraft resulted in a decline of groundwater levels in the Gaza Strip (Yakirevich A.,et al 1998).

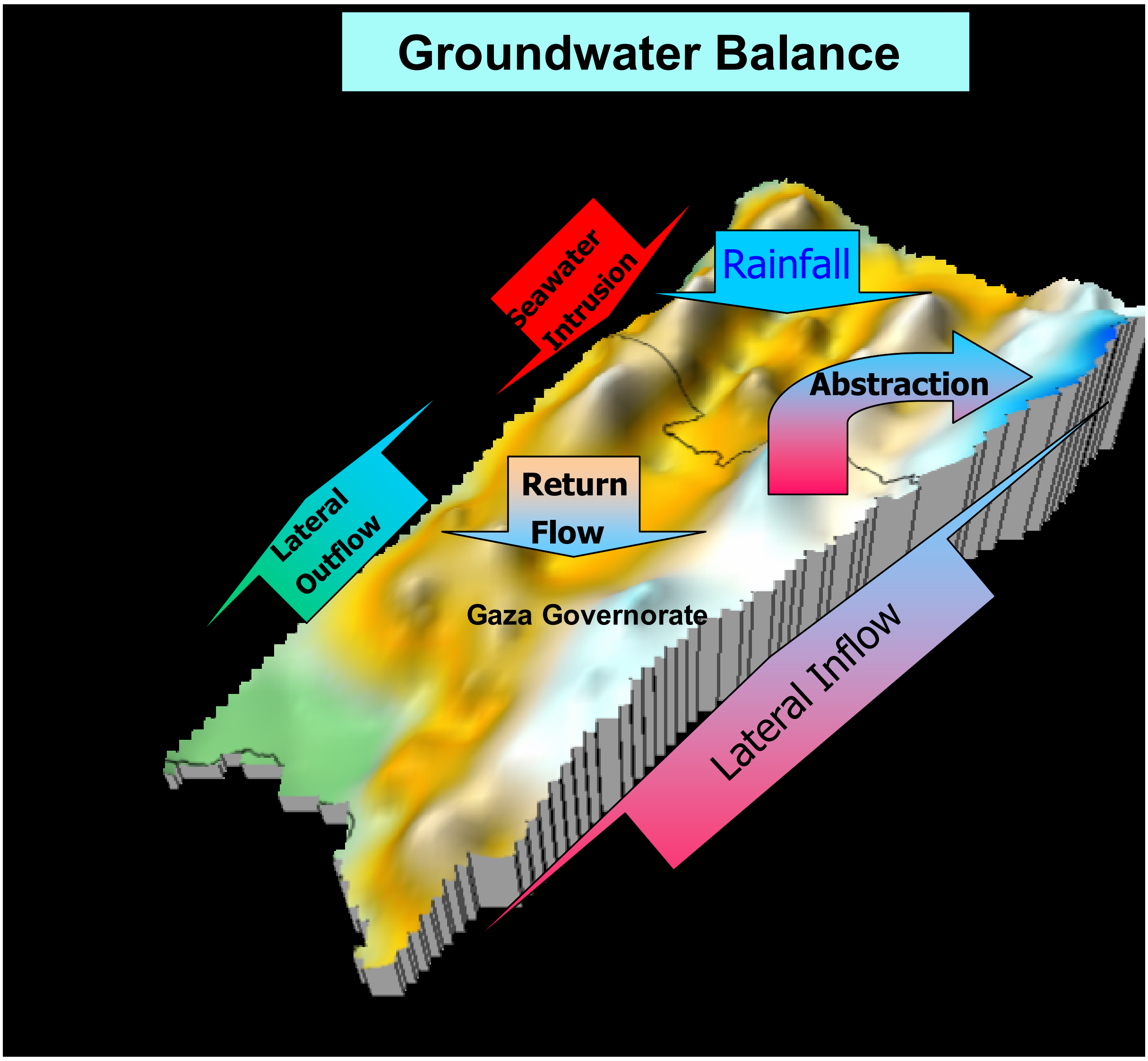


Figure (3.10): Water balance of Gaza Strip

Estimated maximum water balance in 1998 of the Gaza aquifer is shown in the table (3.4). As shown in this table, outflows exceed inflows by about 18 Mm 3/y. This quantity of water is believed to be replaced by deep seawater intrusion and/or up coning of deep brines in the study area.

The water deficit is a result of:

- The water consumption greatly exceeds the available resources, which result in a strong depletion of the groundwater reserve.
- Groundwater extraction from Israel, through wells on the borders of the occupied areas and the construction of upstream dams on Gaza Wadis behind the borders of 1967 to prevent the natural flow of these wadis with freshwater that coming as a result of rainfall precipitation.

The water deficit leads to:

- A drop of the water level in the aquifer (documented).
- An increase in the salinity content and consequently reduction in availability of fresh groundwater (documented).

Table (3.4): Estimated maximum water balance in 1998 of the Gaza aquifer (PWA,2000b).

Inflows (Mm^3/yr)		Outflows (Mm^3/yr)	
Rainfall recharge	45	Municipal abstraction	47
Lateral inflow (Israel)	30	Agricultural abstraction	100
Lateral inflow (Egypt)	5	Israeli abstraction	8
Saltwater intrusion	15	Discharge to the sea	15
Water system leaks	15		
Wastewater return flows	10.5		
Other recharge	3.5		
Irrigation return flows	25		
Loss of aquifer storage	3.0		
Total	152		170
Net balance	-18		

3.3.2.6 Groundwater Level and Flow Regime

About 130 agricultural wells throughout the Gaza Strip are presently monitored for water levels every month (PWA, 2000b). In the study area for the years 1994/1995, 1999/2000 and 2003/2004 there were 45, 49 and 64 agricultural wells respectively for monitoring water levels every month. Because all the wells are shallow, water level contour maps that have been generated for the Gaza Strip to date provide a depiction of the shallow part of the aquifer only (PWA, 2000b). The natural flow regime in the aquifer is from southeast to northwest towards the Mediterranean Sea, where it discharges to the sea. Thus, the groundwater flows from the occupied area downstream toward the Gaza Strip. However, natural flow patterns are impacted by major pumping centres near Gaza City and Jabalia. Deep hydrological depressions have formed as a result of the overexploitation of the aquifer where water levels are below mean sea level by more than 2m as a function of continued high total abstraction. The lowering of regional water tables has continued and hydraulic gradients have been significantly reversed (from the sea) around Gaza City.(PWA,2000a).

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 includes small industry located on the site. The agricultural land is considered dominant and economic sector. Urban and agriculture expansion is concentrated in the western coastal zones of Gaza Strip. There is overcrowdness and related housing problems, especially in the refugee camps areas. Also there are inappropriate design 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. Land uses map (figure 3.11) were developed by the MOPIC in 1996 and modified by the Environment Quality Authority 1998 It was a physical plan that defines development and protection needs until the year 2015.

3.4.1 Urban Areas

The period (1994 2004) can be called the urban transformation period, where huge development legally and illegally has been started. The Palestinian National Authority PNA was established in 1994 in Gaza and West Bank . The urban areas in study area territories have to accommodate the rapid growth in population. These areas have been developed faster than adequate infrastructure, which lead to a largely uncontrolled and increasing environmental quality degradation. The present and future built up areas per governorates in study area as estimated and predicted by MOPIC in 1998 is shown in table(3.5).

Table (3.5): Built-up areas per Governorate (Data Source: MOPIC, 1998)

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	33.8	25	45.65	33.82	65.8	48.74	80.21	59.41

* % of the total area (135 km^2)

3.4.2 Agriculture Areas

Agricultural land is divided into rain-fed and irrigated areas, according to what is the main water source. The annual rainfall is insufficient for most cultivation, so, all farmers depend on groundwater for irrigation.

The rain-fed areas are located in the eastern part of Wadi Gaza. Production in agricultural areas is gradually declining as a result of water salinity problems, expected increase of water price and the low return of existing crops. So, the current agriculture areas will not expand in the future (Almahallawi,2004).

On the other hand, from the beginning of the Aqsa Intifada at 28 September, 2000, more than 20.271 km ^{2} of planted areas has scorched by Israel Military. The scorched lands represent about 33.07% of the total planted area in the Gaza and North Gaza Governorates. Most of the scorched lands located along the eastern northern borders and the middle of the southern of Gaza Governorate of the study area as shown in (figure 3.12). This may be impact the quality of the groundwater.

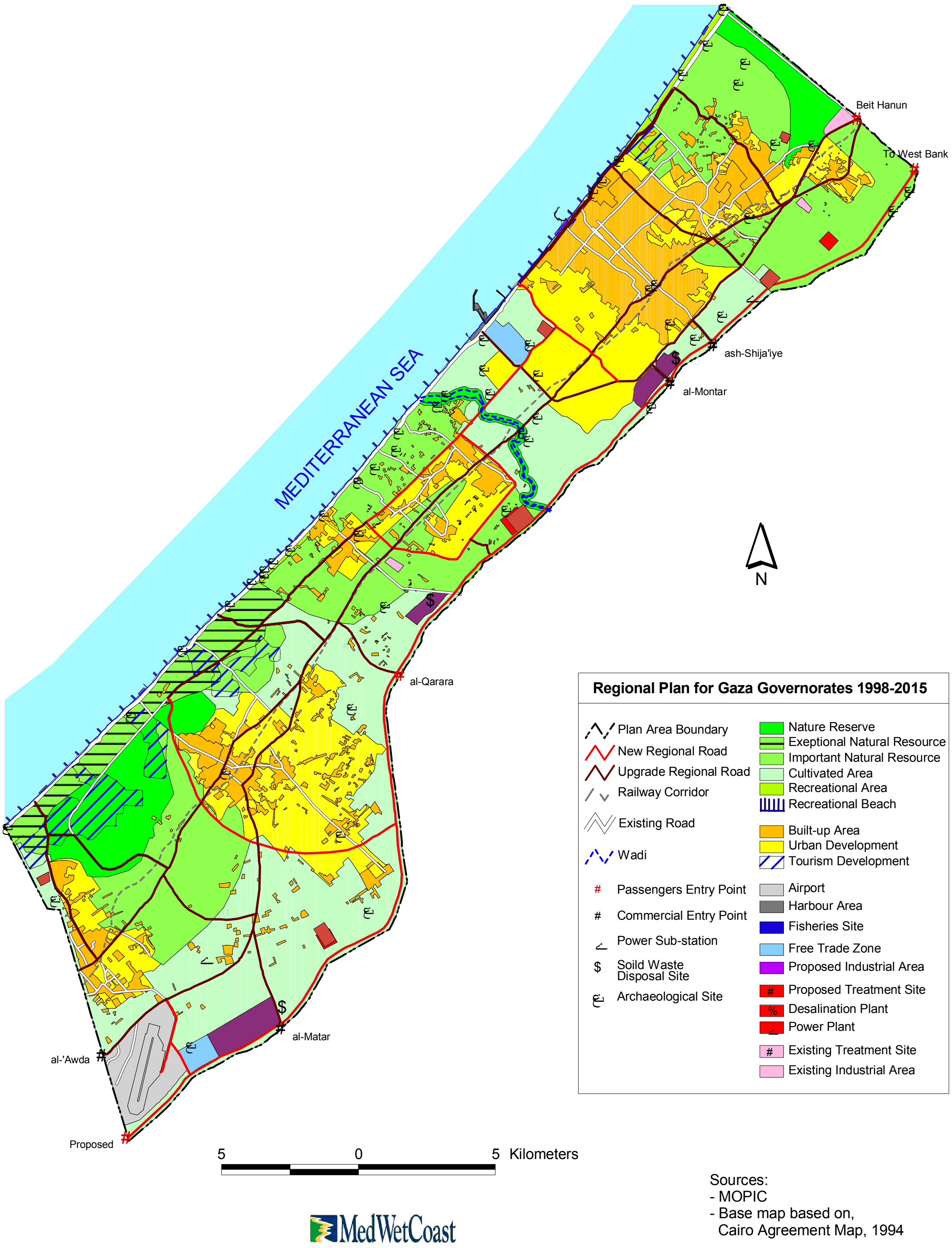
Through the last ten years, the cultivated areas decreased also due to the increase in urban areas from 25% at 1997 to 33.82% at 2005 as expected by MOPIC . Agriculture production area before and after Al Aqsa intifada are shown in Table (3.6)

This overloaded the Palestinian economy especially in the agriculture sector and led to negative impacts on the local Palestinian farmers and their living level. To maximize the revenues from the agriculture, the farmers started to over use of organic and chemical fertilizers without any control. Also there was over use of pesticides either allowed or prohibited. This, of course led to the pollution of groundwater.

Table (3.6): Agriculture areas before and after Aqsa Intifada.(Data source MOA and MOP,2005)

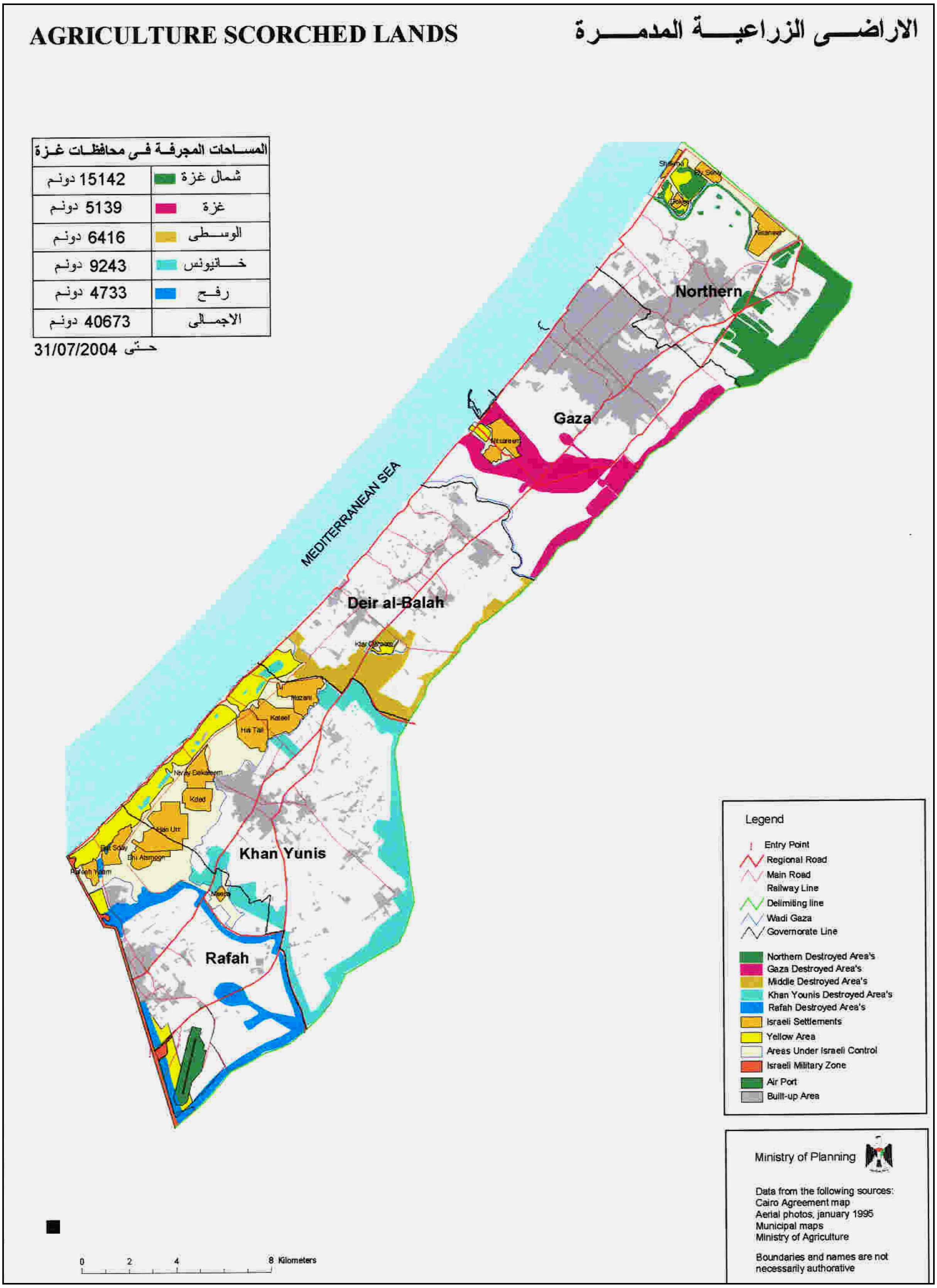
Area	Agriculture areas before Aqsa Intifada		Destroyed planted areas		Agriculture production areas after Intifada	
	km^2	%*	km^2	%*	km^2	% *
Gaza Governorate	35.386	26.21	5.139	3.8	30.247	22.4
North Gaza Governorate	25.91	19.19	15.142	11.22	10.768	7.98
Total	61.296	45.4	20.271	15.02	41.015	30.38

* % of total area of the northern part of Gaza Strip (135 km^2).



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

(Figure 3.11): The present land use and future industrial land use distribution (1998 2015) (MWCP, 2001)



المساحات المجرفة فى محافظات غزة	
شمال غزة 🟩	15142 دونم
غزة 🟥	5139 دونم
الوسطى 🟨	6416 دونم
خانيونس 🟦	9243 دونم
رفح 🟦	4733 دونم
الاجمالى	40673 دونم

حتى 31/07/2004

Figure (3.12) Agriculture scorched lands (MOP,2004)

3.4.3 Industrial Areas

The industrial sector is one of the main sources of income for the people in Gaza Strip, in spite of that the industrial sector is at present undeveloped. The existing industries are found within residential areas. Several problems are associated with these areas such as improper disposal of solid and liquid waste and inappropriate infrastructure (EQA, 2004). Industrial activities generate liquid and solid wastes. Most of the wastewater generated from these industries is discharged without any treatment into the municipal sewerage system or surrounding environment. About 75% of the industrial activities dispose their wastewater into the sewers while the rest use cesspits. Furthermore, the solid waste, which may include hazardous waste, is badly managed and is dumped without separation in the municipal landfills or open areas (MOPIC,1998).

The industrial activities in the Gaza Strip are one of the most polluting sources, especially in the absence of regulations that force the industry owners to follow the national standards during the production process. The main polluting industries include the textile dyeing, electroplating, painting, and foaming industries (EQA, 2004). The quantities of the industrial wastewater are considerably low. So, industrial pollution does not seem to be of major concern when compared with other sources of groundwater pollution.

The number and distribution of the existing and proposed industrial zones to be constructed in the near future in the Gaza Strip are shown in (figure 3.11). The number and distribution of industrial sectors over Gaza Strip are shown in table (3.7)

Table (3.7): The number and distribution of industrial sectors over the study area. (Source: MOPIC, 1998)

Area	Industry (km^2)	Trade and commerce (km^2)
North Governorate	1.15	0.92
Gaza Governorate	2.50	1.98
Total	3.65	2.90

3.4.4 Settlement Areas before Disengagement

Before disengagement process, there are three settlements in North Gaza Governorate and one in Gaza Governorate occupy about 9.88 km^2 that represent about 7.3% of the total land of the studied area (figure 3.12). Some of these settlements are urban in nature and the others agriculture. Settlements consist primarily of agriculture land with intensive farming in greenhouse. Around the settlement there was a security zones that have been established from Israeli authorities, which further reduce access to surrounding land.

3.4.5 Domestic Wastewater Treatment and Disposal

There are two wastewater treatment plants in the northern part of Gaza Strip. One is in the North Gaza Governorate and namely, Beit-Lahia WWTP, and the second is in the southern part of Gaza Governorate and namely Gaza City WWTP, which are not function effectively. Approximately 70-80% of the domestic wastewater produced in Gaza is discharged into the environment without treatment, either directly, after collection in cesspits, or through leakage and over loaded treatment plants. Most wastewater is discharged into the Mediterranean via 18 different pipelines (UNEP, 2003). The percent of population in the area connected to sewer networks is shown in table (3.8). Cesspits and boreholes are the other wastewater disposal systems in the area.

Northern part of Gaza strip is facing serious wastewater and sanitation problems. There are large scale discharge of untreated wastewater, leakage of collected wastewater from sewer systems and cesspits, inefficient or partially functioning wastewater treatment plants, and uncontrolled reuse of untreated or partially treated wastewater for irrigation (Almahallawi, 2004). The effluent from the Gaza treatment plant is discharged into the Mediterranean, while a substantial quantity of wastewater infiltrates into the ground, contaminating soil and ground water in the area of the Beit Lahia treatment plant.

Table (3.8): Population served by public sewer

Governorate		1994(1)	1997(2)	2004
North	Beit Hanoun	62%	70%	~ 80-85%
	Beit Lahia	N.A.	20%	
	Jabalia	77%	83%	
Gaza		N.A.	60%	~ 85% (4)

(1) Almahallawi, 2004 (2) PWA, 2000a (3) Gaza Municipality

N.A. Not available

3.4.5.1 Gaza City Treatment Plant

The Gaza City treatment plant is located to the southwest of the Gaza City, rehabilitated, with influent flow rate of 35,000m ^{3}/d at the year of 1994 and at 2004 influent flow rate of 50,000 - 60,000m ^{3}/d. The plant now receives wastewater quantity that is more than its capacity which is 35,000m 3/d. So, most of the effluent is discharged to the

Mediterranean Sea through an old pipeline and ten thousand cubic meters of the effluent is allowed to infiltrate through 2 infiltration basins to the east of the plant (Almahallawi,2004) .

3.4.5.2 Beit -Lahia Wastewater Treatment Plant

The existing wastewater plant was designed as a lagoon system with polishing ponds, without any treatment facility. It is located some 1.5km east of Beit Lahia town in the northern part of the Gaza Strip. This plant was constructed in 1976 to serve the town of Jabalia as well as the nearby refuge camp and the communities of Beit Lahia and Beit Hanoun. The flow rate value is about 10,000 m^3/d (120,000 population equivalent) The plant was rehabilitated in 1996 by adding additional ponds (Almahallawi, 2004). The plant has no pre-treatment facilities and a peak flow capacity of 5,000 m^3/d. The main goal of the plant was to produce an effluent with a high enough quality that it would be suitable for direct use in irrigation. However, the poor quality of the treated wastewater is below World Health Organization (WHO) guidelines for agriculture use (Amani Alfarra and Sami Lubad,2000)

As a result of inadequate design and inappropriate operation an overflow from the last pond occurs on a permeable sandy soil above the aquifer (which has the best water quality in comparison with other aquifers in the Gaza Strip). The lake, constituted by the effluents of Beit Lahia WWTP (more than 36 Mm^3 released since the beginning and more than 1.5 Mm^3 lake kept by a continuous effluent from the Beit Lahia WWTP. The lake expanded rapidly from an area of about 70 dunums in 1995 to about 110 dunums in August 1997 and continued in expanding for the year 2001 Now, it covers an area of more than 400 dunums (40 hectare). The lake depth reaches to 9m in some places with average depth of 4 to 5 meters (Ali, 2005) . The lake was threatening every day more cultivated areas in the western area and inhabited areas in the Bedouin village and lower Beit Lahia areas.

3.4.5.3 Waste water Disposing in Wadi Gaza

In Wadi Gaza untreated wastewater has been disposing since 1991 till now so this Wadi becomes wet all the year but unfortunately with a big resource of pollution. The amount of this water was 2,500 to 3,000 m^3/day till 1999 (MWCP, 2001) and after the Danish project for sewer system to the middle area of Gaza Strip and dispose it to the wadi without treatment the amount reached 15,000 m^3/day. This huge source of pollution becomes a crisis for the environment of the Wadi Gaza area as a whole. The freshwater resource that replenish the groundwater becomes polluted and a source for pollution to the groundwater. Consequently, deterioration of the groundwater is occurring and it may be increase in the near future.

3.4.6 Landfills and Dump Sites

Active landfills and used dump sites in the Gaza Strip are shown in (figure 3.1). Approximately 95% of the population in Gaza is serviced by a collection system. There are currently two landfills in the study area. According to the EQA, the landfills in North Gaza is located on impermeable ground outside the recharge area for the coastal aquifers, and thus do not have liners or leachate collection system installed. At the Gaza City landfill, a designated site for disposal or storage of hazardous waste has been established (EQA,2004).

3.4.7 Sand Excavation

The sand resources in Gaza Strip, especially the coastal sand dunes, represent important environmental values. These dunes traditionally project the coastal areas against the sea and play a vital role in natural water cleaning capacity. I addition to, they represent certain natural landscape values. Meanwhile a total amount of at least 25 Mm^3 of sand is estimated to have been excavated – mainly for building purposes in the last 20 years, from an area of about 5,200 dunums . Only 12% of the sand excavations are licensed (EQA, 2004) . The major part is removed without permission, mainly by farmers. Sand mining occurs without serious planning or regulation; it is hardly recognized as an activity responsible for a large scale destruction of natural landscape in Gaza Strip (EQA,2004).

3.4.8 Land Use as Point and Non-point Sources of Pollution

For shallow unconfined aquifer system, potential contaminants can enter the groundwater at numerous points that may not always be associated with identifiable sources. A comprehensive survey of all potential point-sources of contamination such as dump sites, landfills, petrol stations, auto repair facilities, electrical substations, and factories should be carried out. These types of facilities should be accurately located and investigated with respect to potential discharges to the environment that could directly affect groundwater quality (PWA, 2006). Figures (3.13) shows the sources of groundwater pollution in the study area as a point and nonpoint sources.

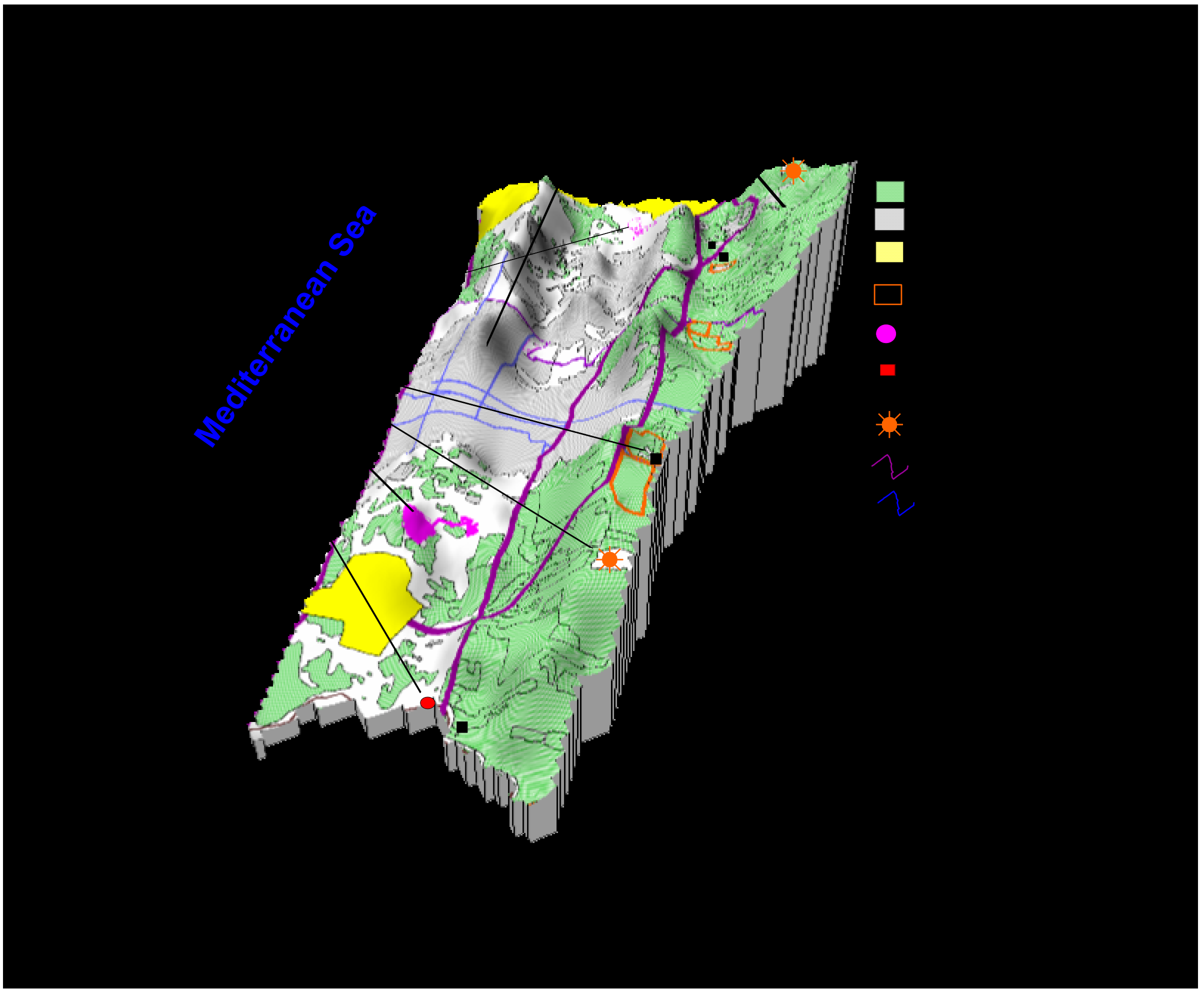


Figure (3.13): Point and non-point sources of pollution in the study area (Data source: EQA,2005)

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. The water level contour map which have been drawn in 1935 by British Govern ment showed a high water level declined from east to west in lines parallel to seashore line. This level dropped by 8 meters within 1935-1969 (PWA, 2000) clearly in the north as a result of extensive exploitation of groundwater, in addition to the sudden increase in population in year 1948 (Qahaman, 2004). The continuation in 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.

Also, the main 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/year to about 260 Mm^3/year by the year 2020 (PWA, 2000). The freshwater resources will be ultimately completely exhausted, when groundwater pumping will increase at the same rate, while the brackish water resources will become increasingly saline (PWA, 2000). 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 the groundwater. Also, Israel has retained and changed the course of the two main Wadis in the study area as a sources of freshwater that recharge the aquifer and they became dry Wadis since the early seventies (MWCP,2001).

Qualitatively, numerous sources of pollution are present especially in major urban centers. In the same time, the aquifer is highly vulnerable to pollution especially the western part which covered with sand dunes. Human activities including agriculture (intensive cultivation and excessive use of agrochemicals) and inadequate waste management (collection, treatment and disposal of wastewater and solid waste) have affected the groundwater quality parameters and presently they exceed WHO standards.

A slow, but continuing decline in groundwater levels has been observed in most areas of Gaza, since the mid-1970s (PWA, 2000). While some 2,800 to 3,000 agricultural wells are scattered throughout the Gaza Strip, the greatest densities of wells is near Gaza City. Total municipal pumping is also highest in this area and major cones of depression have formed with water levels up to 2 meters below sea level for the year 1998 (PWA,2000).

El-Nakhal and Abu Heen 1997 studied and evaluated the changes in groundwater quality in Gaza Strip during the last three decades before 1994 for domestic and irrigation purposes. The results of the evaluation shows that the chemical characteristics of water samples for the period 1964 and 1994 are better than for 1984. They found that the suitability of the water wells for domestic use for the years 1964, 1984 and 1994 are 25%, 5% and 18% respectively.

According to Abu Heen and Lubad, (2005) decreasing of water quality is a function of time. Chemical analysis the quality of water for eighteen domestic wells in the Gaza City from 1994 to 2004 shows that for the years 1994, 1999 and 2004 about 33%, 44% and 67% of the samples respectively are unsuitable for drinking based on WHO and Palestinian standards.

3.5.1 Salinity Problem

Since the beginning of the 1970s, many studies have described the hydrological situation of the Gaza strip. Parallel to the long term water shortage, saline water replacing 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 situation (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 are generally better in the north of the Gaza Strip than in the south (Al-Jamal, 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 (Fink 1970; PWA, 2004b). The deepest sample showed brine with a chloride concentration with approximately of 2 times of seawater. (60,300mg/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 as yet 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 10,000mg/l with depth (PWA, 2004b). 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 fluctuates from 300 to 600mg/l which is double the recommended value be the WHO. 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,2004b).

The high concentration of chloride in the groundwater in Gaza aquifer is due to many different water sources. Those sources including 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 (PWA, 2001b). 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, 2001b).

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. (Juanico et al., 1992; Vengosh et al., 1999). Chloride concentrations up to 2,000 mg/l have been measured in wells that tap the Eocene system (Vengosh et al., 1999). The chemical and isotopic data show that most of the salinity phenomena in the Gaza Strip are derived from the natural flow of saline groundwater from the eastern part of the aquifer toward 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 (Qahman, 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,2004).

3.5.2 Nitrate Problem

An additional source of water quality deterioration in the Gaza Strip is the nitrate which is used as indicator of pollution, especially when salinity is low. Nitrate pollution of groundwater in Gaza, has particular concern due to environmentally sensitivity of the area and the large number of people in city and rural areas relying on groundwaters 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 the 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 per year. Now nitrate level in most of the wells between 100 and 150 mg/l. This value exceeds the recommended value by WHO which only 50 mg/l (PWA, 2004). More than 50% of the domestic municipal wells in Gaza Strip have nitrate concentrations that exceed WHO guidelines of 45 mg/l (UNEP 2003; Vengosh et al., 2005).

There are numerous sources of nitrate contamination, including agriculture fertilizers, waste dumping, and especially direct discharge of raw sewage to wadis 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 abundant use of agricultural fertilizers and pesticides contributes to rise in the nitrate level especially in and around areas of arable land. The contribution of fertilizers in agricultural areas can not be ruled out, although this has never been quantified (i.e. quantities applied vs. levels in groundwater) (PWA,2000 b).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 the Gaza Strip especially in the northern part has almost nitrate concentration less than 50 mg/l. Since this water mixed with the local aquifer the quality of water regarding nitrate contamination decreases. Two reasons are believed to explain the phenomena of the nitrate concentration 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 deep in depth in the range of 50 - 120 meter .

Chapter(4)

Approach, Methodology and Tools

4.1 Introduction

In this study a principle of using data for a hydrological year has been applied. The hydrological year consists of wet season (October to March) and dry season (April to September). This means that it begins with October and ending with September. This approach in dealing with a hydrological year data has been applied for avoiding the break down of data of a complete rainy season, since the rainfall conditions change from year to year. Consequently, the effect of a complete rainy season on the chemistry of the groundwater had been represented well in this study. So, chloride and nitrate beside rainfall distribution maps had been drawn for the three stages which concerned in this study (1994/1995– 1999/2000 – 2003/2004) and a map for the average rainfall for the whole period of study (1994 2004).

Other parameters as water level, rate of abstraction, litholgy and topography had been considered as potential factors influencing groundwater quality in the study area and had been discussed through drawing maps for them based on hydrological year data and 3-D topography and two cross sections for lithology.

Some softwares like surfer version 8, WinLog and WinFenec had been used to draw the maps and cross sections. The cross sections helped to follow the distribution of clays in the study area which played an important role in groundwater vulnerability to pollution (determination the more sensitive areas to pollution).

The standard limits of water quality that used internationally (WHO-Standards) were used in this study to determine the situation of groundwater quality. This standard limits were marked in the drawing maps to evaluate the remaining freshwater in the study area at the three stages.

4.2 Significant Aspects

In preparation of this study, a methodology which involved four significant aspects was established using data held by the PWA database, the MOA, EQA, PCBS, Gaza Municipality and GMS. There are:

1. Mapping of average water level, average rainfall distribution, rate of abstraction from municipal wells for a hydrological year data, ground surface configuration in 3-D map and

drawing two geological cross sections for declaring their effects on groundwater quality.

2. A selection of parameters potentially contributing to salinity and pollution. Chlorides were considered here as representative of salinity, owing to their highly conservative properties and their direct relationship with total dissolved solids (TDS). Nitrates, although not conservative, were used here as indicative of anthropogenic pollution mainly from intensive agriculture and domestic sewage disposal (Wollman 1991; Melloul,and .Azmon ,1997).

3. Presentation of the spatial patterns to the concentrations of chlorides and nitrates through mapping for a hydrological year.

4. Graphic presentation and analysis for the wells next to the shoreline that showing sudden and fluctuation changes in chlorides concentrations.

All the maps were drawn for the three stages 1994/1995 ,1999/2000 and 2003/2004

4.3 Data Collection

In May 1994, Gaza Strip area became under the responsibility of the Palestinian Authority (PA). In 1995 the Gaza Water Department prepared a summary data report of available water levels, water quality, lithology, and meteorology data.

Groundwater quality in Gaza Strip is monitored by different institutions. The ministry of health (MOH) monitors all of domestic water-use wells twice a year in summer and winter for the major anions and cations, and nitrates, to insure that the drinking water is safe. Each summer and winter, Ministry of Agriculture (MOA) also tests agricultural water-use wells for concentrations of chloride and nitrate.

Pumped withdrawal quantity for municipal water-use wells was measured monthly by LEKA (lyonnaise des Eaux and Khatib and Alami) and the Ministry of Health. New wells have recently been constructed. For the period from 1994 to 1996, withdrawal data were not available. Monitoring of pumped withdrawal of agricultural wells was interrupted in 1994 and has resumed recently.

All data on water levels, water quality, and withdrawals were transferred to the PWA, Water Resources Department, Gaza Water Data Bank Section, for quality assurance and entry into the hydrologic database.

4.3.1 Data Storage and Treatment

The collected data may have some errors. Most risk in data errors is associated with human error during written transcription of data from laboratory notebooks or during “keying-in” via a computer keyboard. These input errors can be reduced through careful and integrated design of raw data recording forms and a computer entry template and when data are handled by electronic means for interpretation and reporting procedures.

Also, individuals responsible for data entry in many organizations, have little or no knowledge of water quality. So, it is important to have the database checked periodically by an expert for omitting obvious errors.

4.3.2 Available Data in the Study Area

4.3.2.1 Rainfall Data

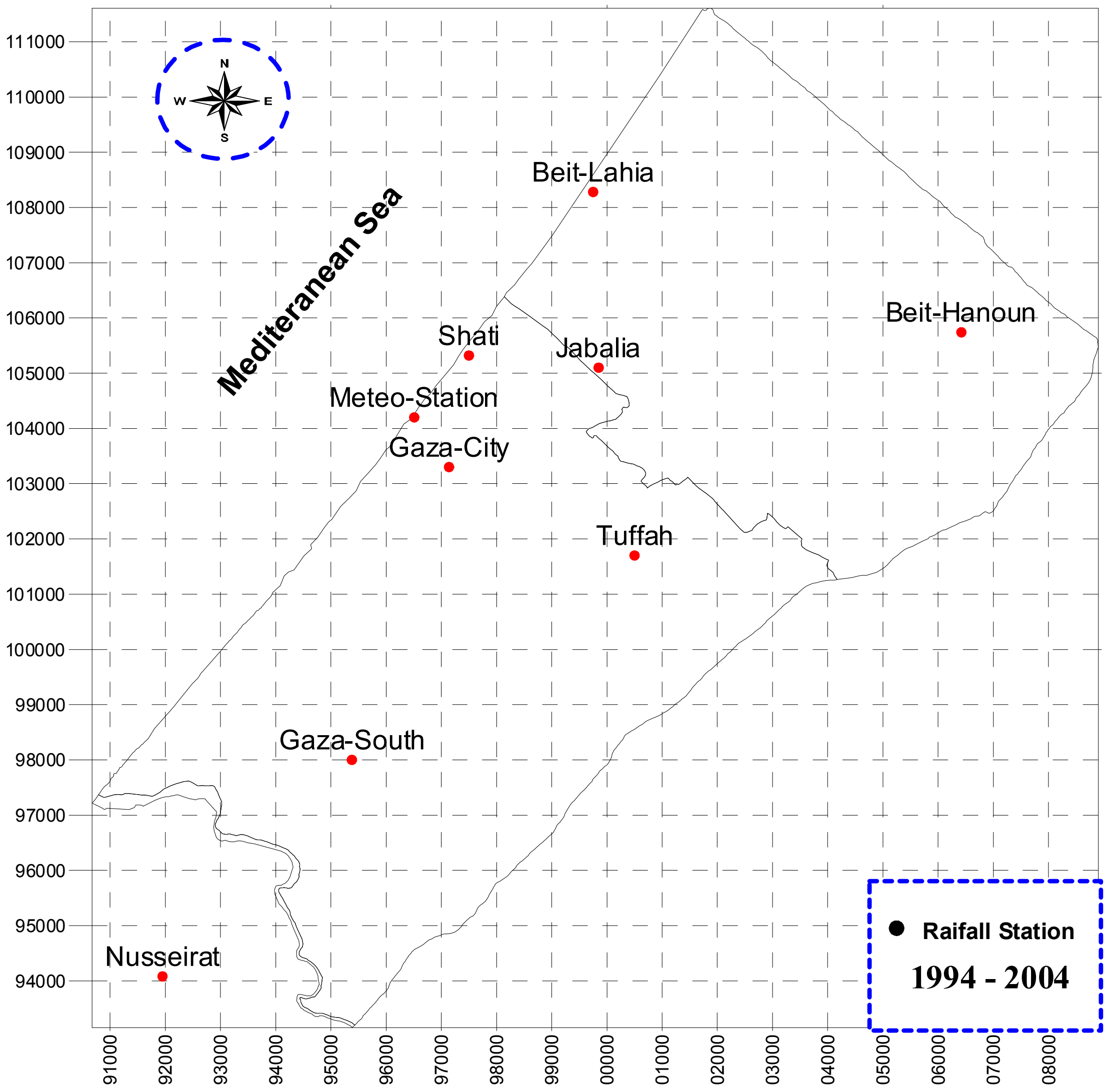
Apart from the variations in the natural input into the groundwater system can be determined by the climate variable (precipitation). Precipitation change affects the natural recharge especially in the sand dunes areas.

Rainfall data used in this study are collected from nine rainfall stations eight of them within the study area and the ninth is Nusseirat station (the data attached in CD). Six of the eight rain stations are manual stations while the other two (Beit Lahia and Gaza City) are automatic stations. The missing data through the study period 1994/2004 in three stations Jabalia, Meteo station and Tuffah are calculated using arithmetic mean method. The locations of these stations are shown in (figure 4.1). Total amount of rainfall for the eight stations with rain depths exceeding 0.1mm has been used in drawing rainfall maps.

4.3.2.2 Rate of Abstraction from Municipal Wells

The production rate data of each municipal well in the North Governorate and Gaza Municipality were collected from LEKA and from the Coastal Municipal Water Utility (CMWU) for the hydrological years (1999/2000) and (2003/2004) respectively (the data attached in CD). There were noproduction rate data for the year (1994/1995).

The data for the year (1999/2000) calculated on the assumption that the wells were working for12hrs /day in the North Governorate and for18hrs /day for the wells in the Gaza Governorate (PWA, 2001b).The number of production wells were (45) wells while for the hydrological year (2003/2004),there were (49) production wells.

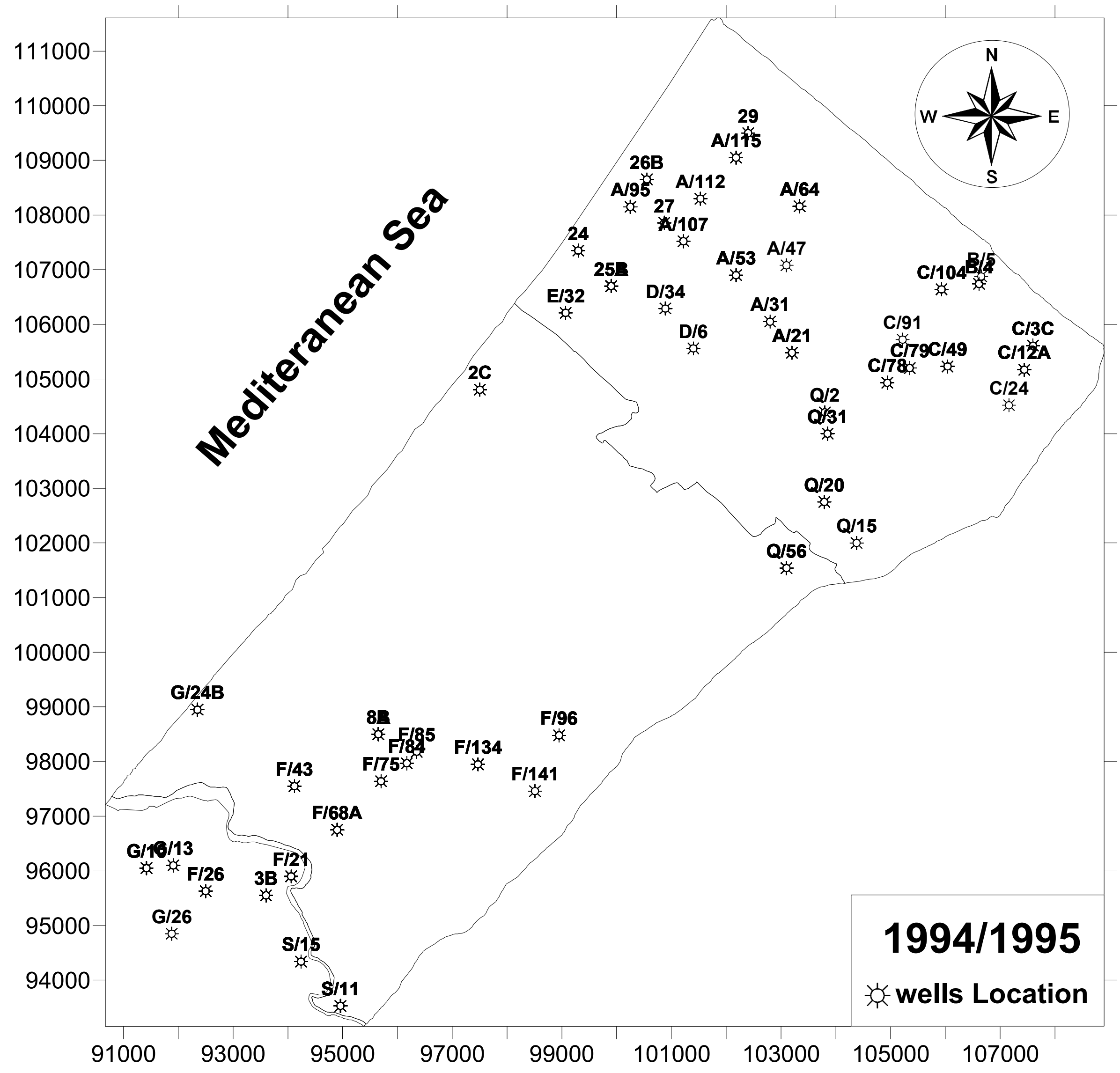


(Figure 4.1): Location map of rainfall stations in the study area

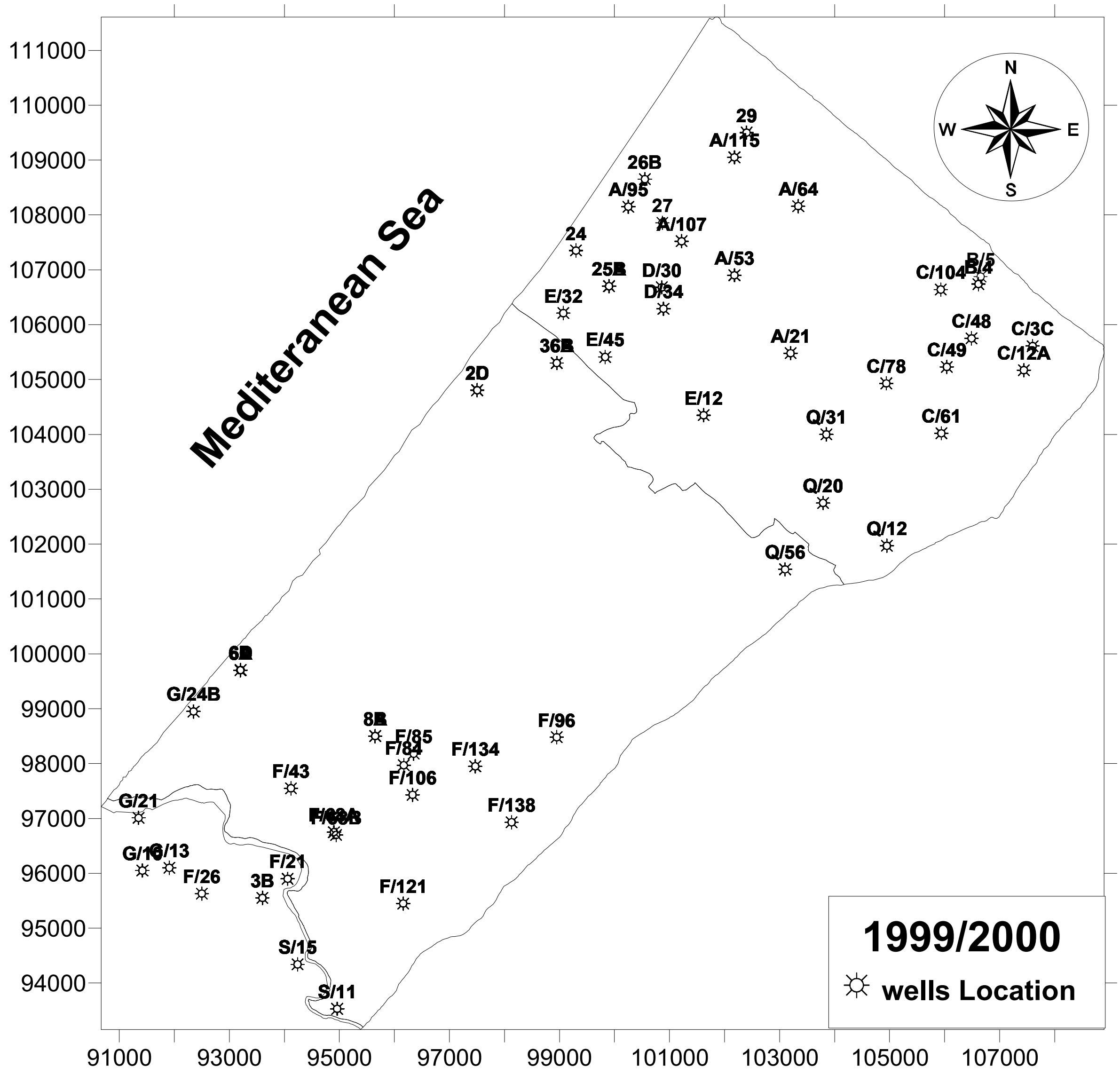
4.3.2.3 Water level Data

It is important to study and follow the groundwater levels as a function of location and of time as they are indicators of the groundwater flow and of the depth of the interface or the transition zone between fresh and saline groundwater and thus for the volume of fresh groundwater in storage. The observations of groundwater levels should be carried out with intervals of a few weeks, for instance twice a month. In the study area, the observations carried out one time each month.

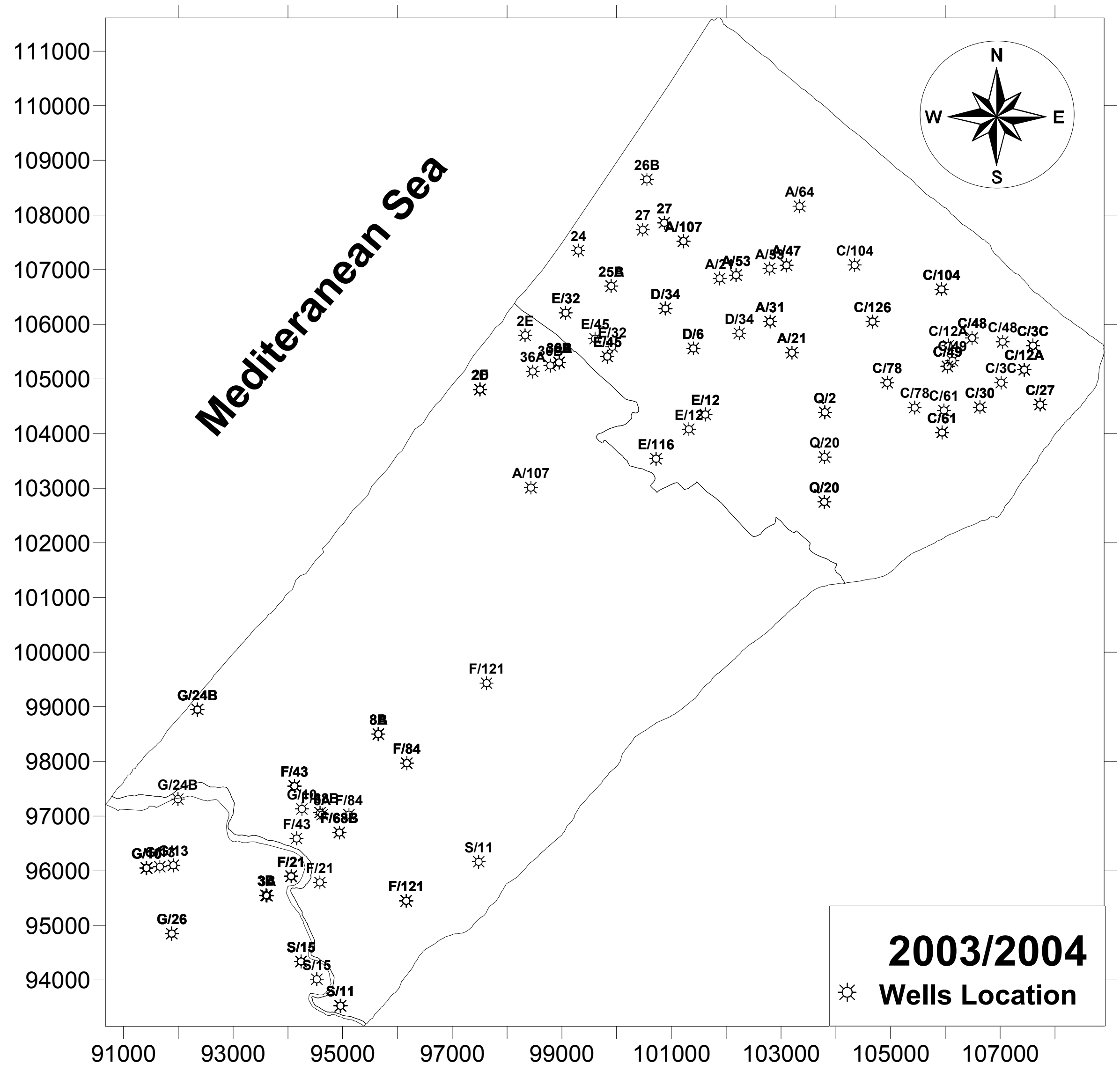
For the hydrological years 1994/1995, 1999/2000 and 2003/2004 there were 45, 49 and 64 agricultural wells respectively throughout the study area for monitoring water levels every month (figure 4.2 a ,b and c) (the data attached in CD).



(Figure 4.2a): Location map of water level wells in the study area in 1994/1995



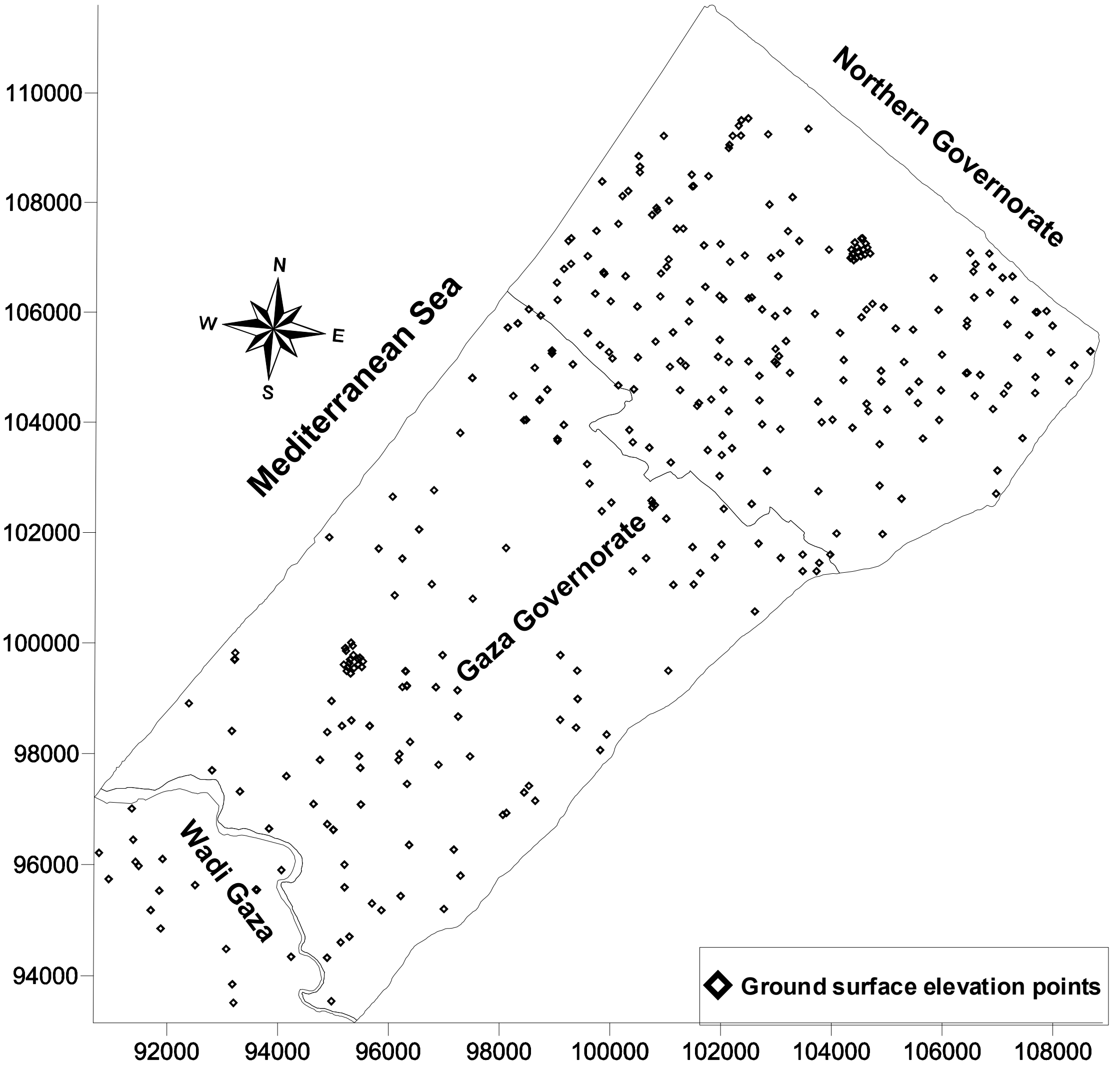
(Figure 4.2b): Location map of water level wells in the study area in 1999/2000



(Figure 4.2c): Location map of water level wells in the study area in 2003/2004

4.3.2.4 Topographic Data

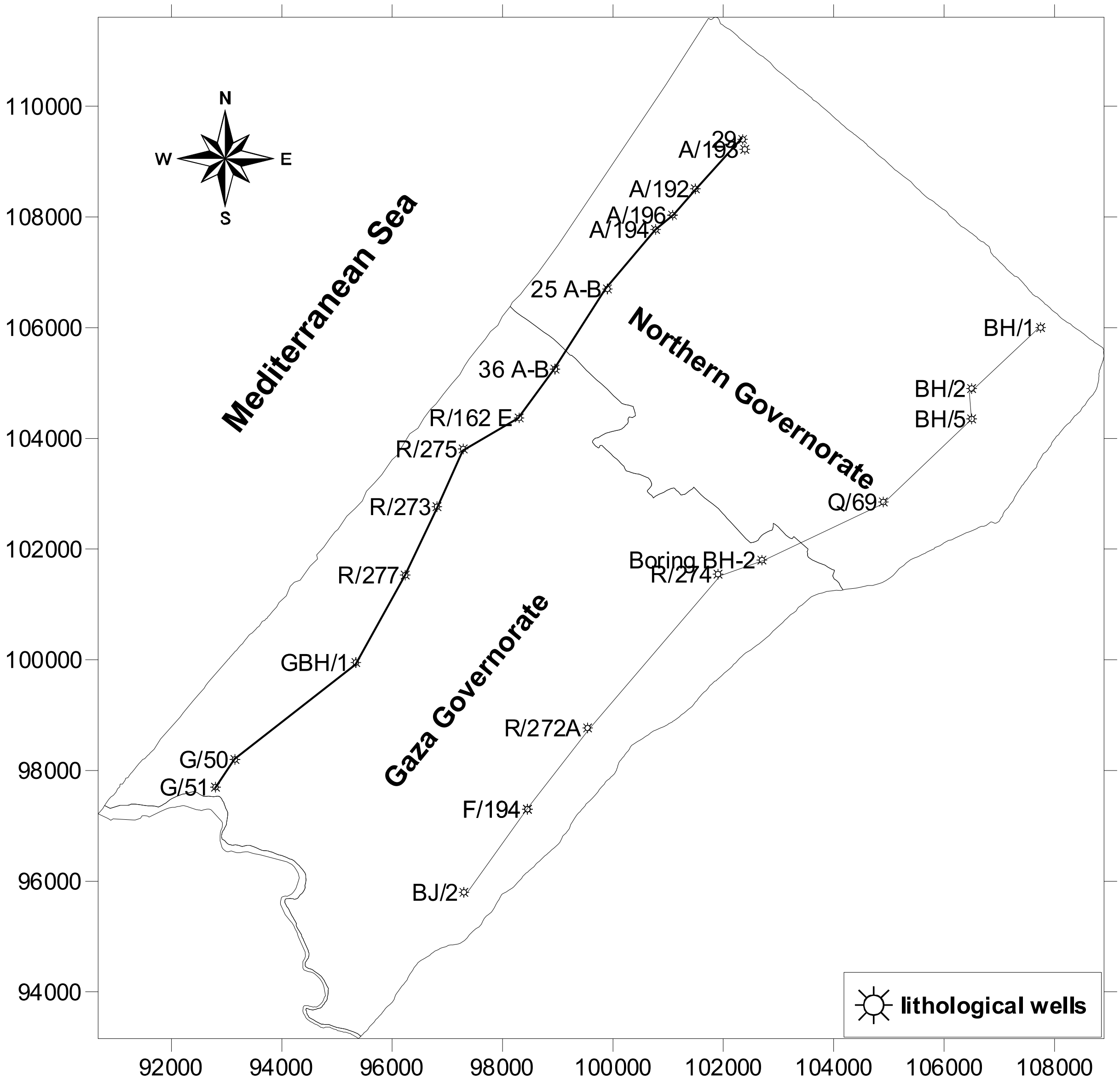
Ground surface elevation data of (378) location had been collected from data of lithological wells and municipal wells (the data attached in CD). These data were related to MSL and shown in (figure 4.3). This helped in drawing three dimensional map.



(Figure 4.3): Location map of (378) location that used to draw the topography of the study area.

4.3.2.5 Lithological Data

Information on the geologic structure of the subsoil comes from the geologists, whom obtain their information from boreholes and geophysical prospecting, mainly the geo-electrical methods and from seismic prospecting. Moreover, geophysical well-logging in the boreholes gives additional geophysical information. Unfortunately, the litholgical data were collected mainly by engineers who were not specialist in geological sciences. Consequently, it is believed that some errors were present in the lithological data that interrupted the complete picture on the lithological situation in this study.



(Figure 4.4): location map of the selected lithological wells used in drawing cross sections

In this study, 22 lithological wells had been selected in two trends. The locations of these wells are shown in (figure 4.4). A correlation between these wells were presented in the form of two cross sections using WinLog and WinFence softwares. The directions of these sections are:

1) NE –SW cross section close to the shoreline in the western side.
2) NE –SW cross section parallel to the first one but in the eastern side.

4.3.2.6 Chemical Data

Groundwater quality is determined by a great number of chemical parameters, which determine the suitability of the water for the various uses. In this study chloride and nitrate were chosen for groundwater quality evaluation since monitoring is mostly carried out for them in all wells. The data used for drawing contour maps for the two water quality parameters (chloride and nitrate) were taken from analysis data for agriculture wells, domestic wells and monitoring wells around Beit Lahia wastewater treatment plant (WWTP) and the infiltration basins of Gaza WWTP (figure 4.5) (the data attached in CD). Table (4.1) provides a summary of the monitoring wells at the three stages of the study period. Monitoring is carried out by PWA, MOA and MOH. The monitoring wells around the WWTPs were taken into consideration in drawing nitrate and chloride maps in spite of the shortage in available data and its absence before 1999 Moreover there was no data for wells around Beit Lahia WWTP for the year 2004 ?

The wells which had been used for drawing the maps should be at least located in the same sub-aquifer. Unlikely, not all the wells that used for drawing the map have well depth data. It can be seen that most of the wells are penetrated in the shallow aquifer, which is about 45m depth from the mean sea water level (PWA, 2001a). Consequently, maps that had been constructed were representing the same sub aquifer.

Table (4.1): A Summary for aquifer nitrate and chloride monitoring data for the selected three stages.

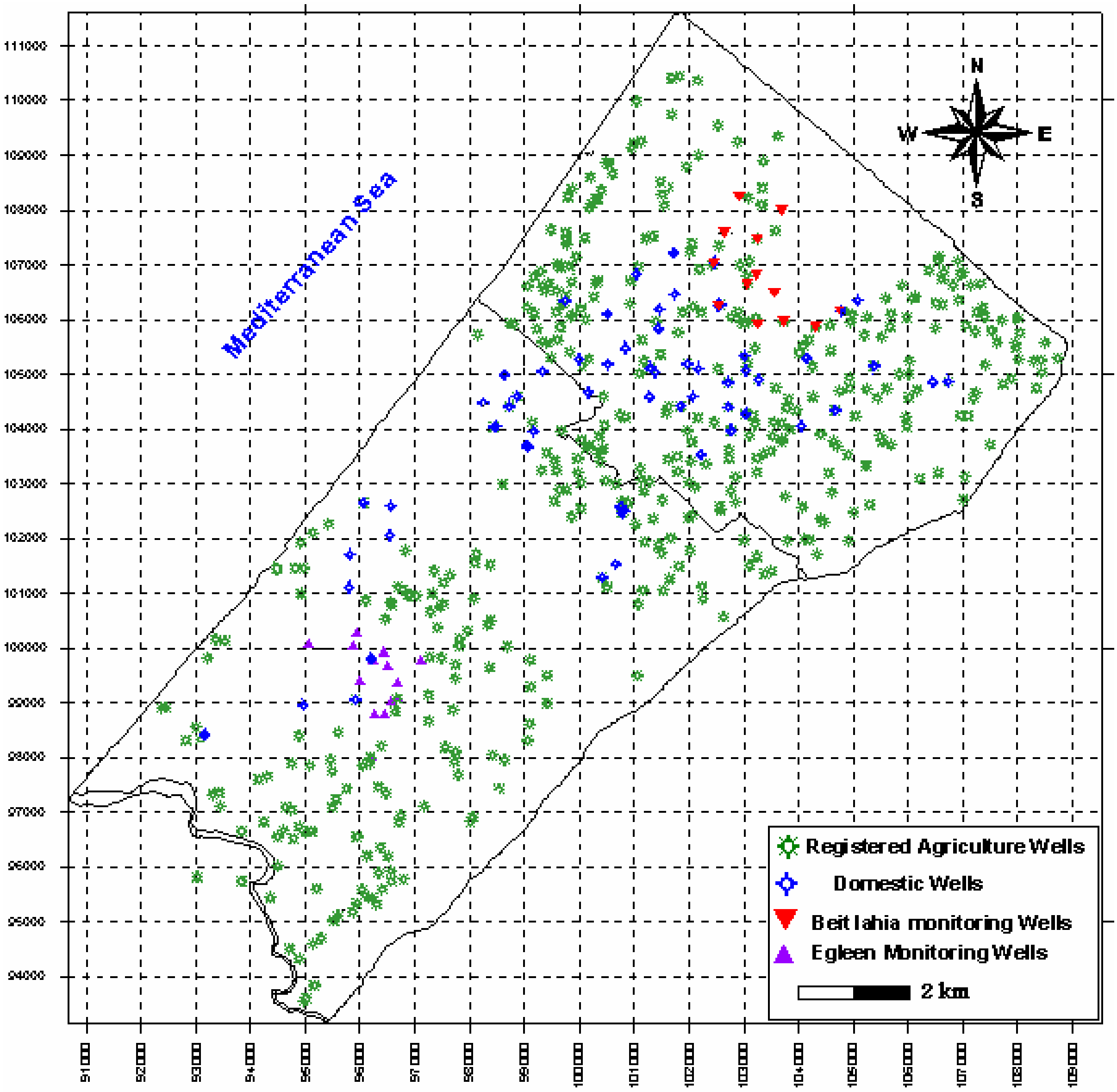
Parameter	No. of analysis / year	1994/1995		1999/2000		2003/2004	
		No. of wells	No. of readings	No. of wells	No. of readings	No. of wells	No. of readings
Nitrate	Two	233	308	242	403	205	336
Chloride	Two	253	458	239	407	206	333

4. 4 Data Compilation

Long-term trend analyses were done on four sets of data (Domestic wells data and agricultural wells data, monitoring data around WWTPs between 1999 to 2003 in Beit Lahia WWTP and between 1999-2004 around infiltration basins of Gaza WWTP). The criteria for the data used in the tests were:

- The well was sampled in the period between 1994 and 2004 except those around WWTPs.
- The sample was collected in the summer months from April to June or the sample

was collected in the winter months from September to November. The well had data from at least 4 calendar years



(Figure: 4.5): location map of different wells used in drawing chloride and nitrate maps

4.5 Tools for Data Analysis

The quantity and quality of available water varies over space and time, and is influenced by various natural and human activities including climate, hydrogeology, management practices, pollution, etc. As a foundation for water resources decision-making, data must be continuous over space and time. Computer systems now offer the possibility of handling and manipulating very large databases in ways which were not previously a practical option.

Data analysis had beene done using softwares programs involving the use of:

1) Excel for drawing graphs, tables and making statistics for data.
2) Surfer (Version 8) for drawing maps.
3) WinLog 4 and WinFence to graphically create detailed, full-color, cross-sections and fence diagrams to interpret and map soil and rock layers

As a part of this study municipal wells were evaluated using parameters in terms of quantity and quality of produced water. The produced groundwater was evaluated with respect to the concentration chloride and nitrate. Their concentrations were compared to the WHO standard for the drinking water limitation. The production rate of the wells was calculated based on information collected from LEKA for the years 1999/2000 and 2003/2004. This data was also evaluated according to the PWA recommended production rate.

4.5.1 Surfer Version (8)

4.5.1.1 Drawing Contour Maps

It is not easy job to draw a contour map by free hand because there is big difference in Chloride and nitrate between two wells while these wells are very adjacent. Adding to that there are some areas which are empty of wells, and there are no records available in these areas. Therefore it was concluded to present the chloride concentration maps as contour maps

4.5.1.2 Mapping Method

In the present study, kriging method was utilized to describe the spatial variations of nitrate and chloride concentration in the northern part of Gaza Strip. Kriging is a geo-statistical griding method that has proven useful and popular in many fields. This method produces visually appealing maps from irregularly spaced data. Kriging is a method commonly used in groundwater quality analysis. This method produces a statistical uncertainty in estimates of unmeasured sites as functions of distance between measurement location and determines a best estimate at unmeasured locations by the averages of the values at known points weighted inversely to their uncertainty at the unknown point by minimizing the kriging variance. Kriging can be applied to network design by finding the point with the maximum uncertainty based on the assumed statistical uncertainty functions.

4.5.1.3 Illustration Method

The spatial distribution of nitrate and chloride concentrations in the Gaza Strip groundwater is illustrated in chapter 5. The maps were created by calculating a single, average nitrate and chloride concentration for each well in the database, then plotting these average values on the maps as colour-coded contours lines. The average concentration for each well was calculated using all available data, regardless of whether the well was sampled once, twice,or many times between 1994 and 2004.

4.5.2 WinLog 4 and WinFence

They can be used to graphically create detailed, full-color, cross-sections and fence diagrams quickly and easily. The program can be used to interpret and map soil and rock layers, contamination, fossils, minerals and hydrocarbons.

Chapter(5)

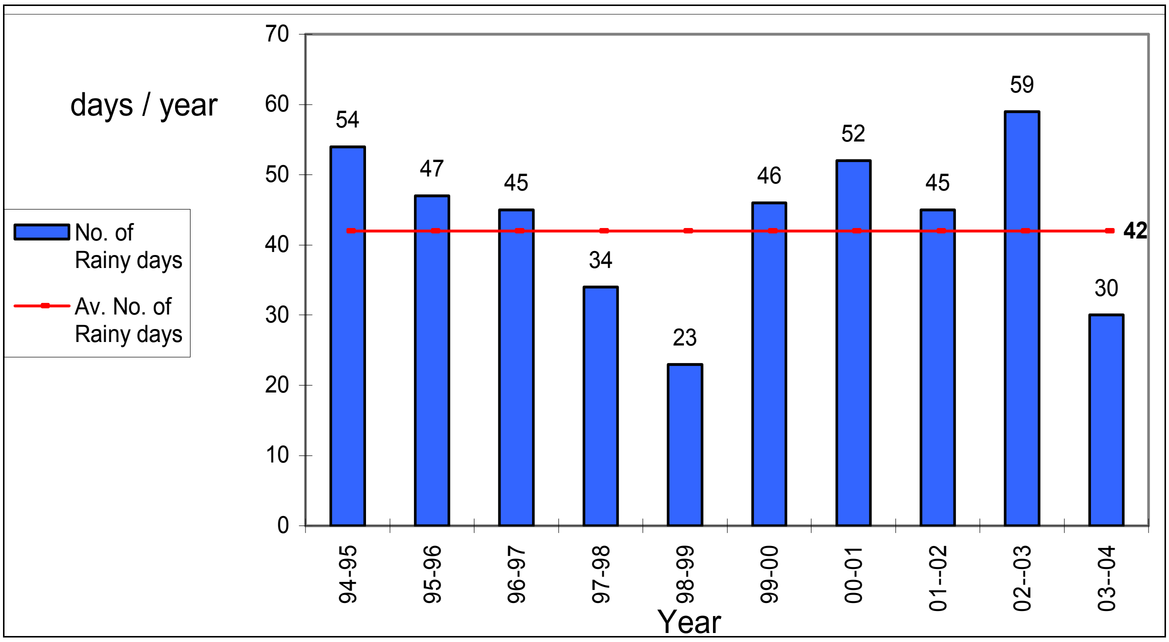
Results and Discussion

The results of rainfall conditions, rate of abstraction of the municipal wells, water level conditions, topographical situation and lithological distribution with the soil situation and land use have been discussed with the results of groundwater salinization and pollution at the three stages (1994/1995), (1999/2000) and (2003/2004). This is to obtain a comprehensive picture about the spatial distribution of chlorides and nitrates and to show the roles of these factors on groundwater quality.

5.1 Rainfall Conditions

The major renewable resource of groundwater recharge in the study area is the rainfall. The following points can be achieved from rainfall data analysis:

1) The number of rainy days per year through the study period fluctuated from the lowest (23) days in (1998/1999) to the highest (59) days in (2002/2003) and the average number of rainy days/year was (42) as shown in (figure 5.1). The highest daily recorded precipitation was (92) mm at Gaza South station on (26/2/2003).



(Figure 5.1): The average number of rainy days/year

2) The lowest rainfall amount was (112mm /year) in Tuffah station in (1998/1999) while the highest one was (802mm /year) in Beit Hanoun in (2002/2003) table (5.1).

3) Average amount of rainfall in all rain stations decreased from (1994/1995) till it reached to lowest value in 1998/1999 as shown in (figure 5.2). Then, it began to increase till it reached to the highest value in 2002/2003 and then decreased again in (2003/2004).

Table (5.1): The total annual amount of rainfall in the eight stations through (1994/2004).

Date	Beit Hanon	Beit Lahia **	Jabalia	Shati	Gaza City **	Tuffah	Gaza South	Meteo Station
94/95	618.1	679.5	507*	580.9	601.3	507*	466.8	507
95/96	455	460.2	395*	480.6	433.7	395*	208.5	331.5
96/97	294.7	333.5	286*	228.1	296.7	286*	282.1	280
97/98	303.5	277	252*	212.5	250.9	252*	162	308.9
98/99	161.5	164.8	115.5	133.7	157.5	112	183.5	164.7
99/2000	409.4	395.5	392.5	428.6	336.6	361.8	397.7	344.1
2000/2001	494.5	485.4	536	475.4	510.1	528.8	534.2	481.8
2001/2002	548.4	542	565.5	522.1	544.4	604.3	660.5	430.2
2002/2003	801.5	724	692.6	627	599	653.5	790.7	367.7
(2003/2004)	352.9	373.1	372.9	339.5	383.4	431.1	501.5	400.25 *

*: Missing data that calculated using arithmetic mean method ** Automatic stations

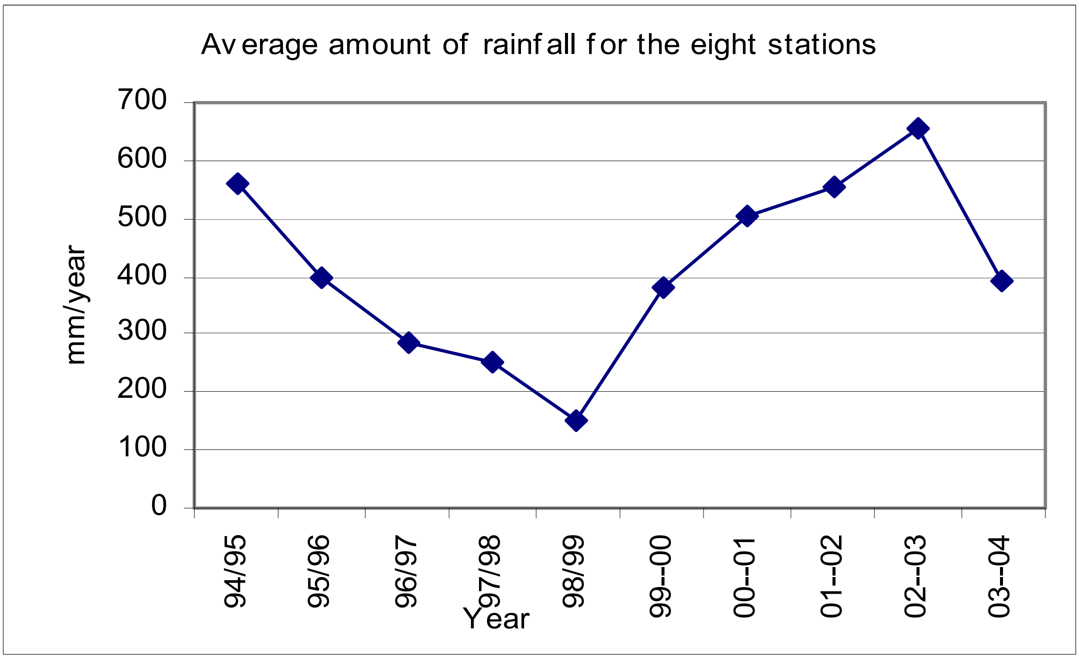


Figure (5.2): Average amount of rainfall in the eight stations during the period 1994-2004

It is clear that the annual rainfall amounts is a function of time and space, so it is changed from year to year and from place to another. Clear variation in annual rainfall at any given year can be seen between any two rain stations located only few kilometers apart. The study area passed through a period of drying that reached to its lowest level in 1998/1999 followed by a wetting period that reached to its highest level in 2002/2003.

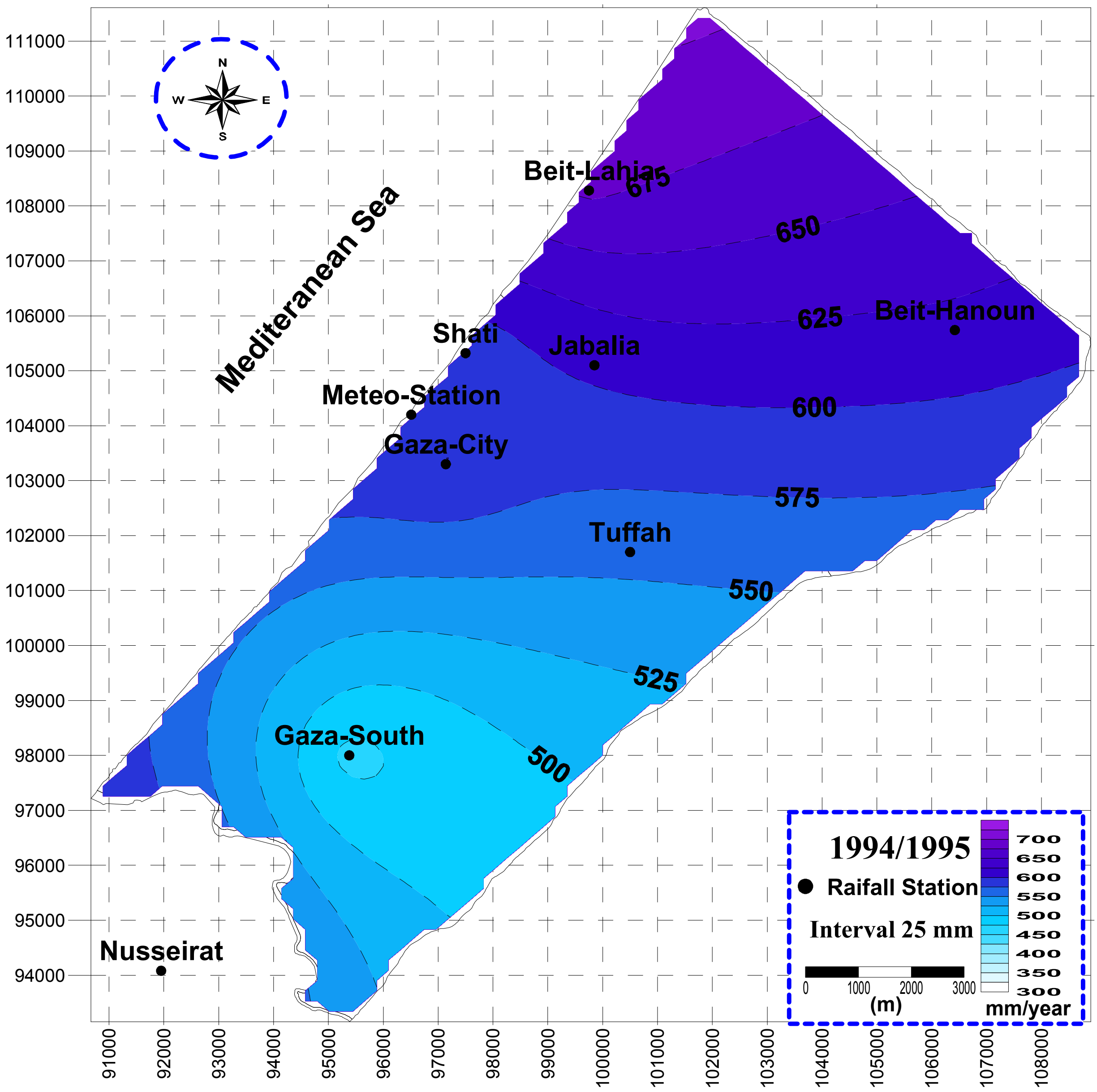
The natural recharge depends on many factors such as duration and frequency of rainfall, evapotranspiration, land use, soil type, topography and irrigation practices. The recharge occurs along the flow paths through the unsaturated zone in areas of sand dunes that characterized by high infiltration capacity but is restricted by the thick layers of loss and clay soils, particularly in the eastern areas of the aquifer. However, recharge rates in semi arid regions are generally lower due to the higher potential evaporation.

Rainfall Maps

The rainfall data has been used in drawing three rainfall maps for the rainfall years (1994/1995), (1999/2000) and (2003/2004). There is not a uniform distribution for rainfall stations in the study area. Most of these stations are concentrated in the middle part to the west, while to the south, in more than one third of the area there is only one station (Gaza South). This distribution has effect on the degree of accuracy when drawing contour maps for rainfall.

Rainfall Map (1994/1995)

In this season, Gaza South station received the lowest amount (467mm /y) which is higher than its annual average (323mm /y) while, the highest amount received in Beit Lahia station (680mm /y) which is higher over twice than its annual average (321mm /y). The rainfall contour map for this season that presented in figure (5.3) shows a general decrease in rainfall amount from northwest (about 700mm in Beit Lahia) to the south (about 470mm next to Wadi Gaza area). The bulk rain quantity that precipitated on the study area (on the 135 km^2) in this season is about 82Mm^3 as estimated through software surfer version(8).



Figure(5. 3): Rainfall distribution map (1994/1995)

Rainfall Map (1999/2000)

In this rainfall season, Gaza City station received the lowest amount of rainfall (337 mm/y) (higher than its annual average (316mm /y)) while, the highest amount received in Shati station (429mm /y) (higher than its annual average (297mm /y)). The rainfall contour map for the season (1999/2000) is presented in (figure 5.4). It shows that, the rainfall distribution is higher in the north than in the south. The total amount of rainfall varied from about (310mm) at wadi Gaza, the southern part of the study area, to more than (390mm) at South Gaza station and of about 420mm in the North Governorate and the western part of

Gaza City. The bulk rain quantity that precipitated on the study area over the 135 km^2 area in this season was about (54 Mm^3) as estimated through software surfer version (8).

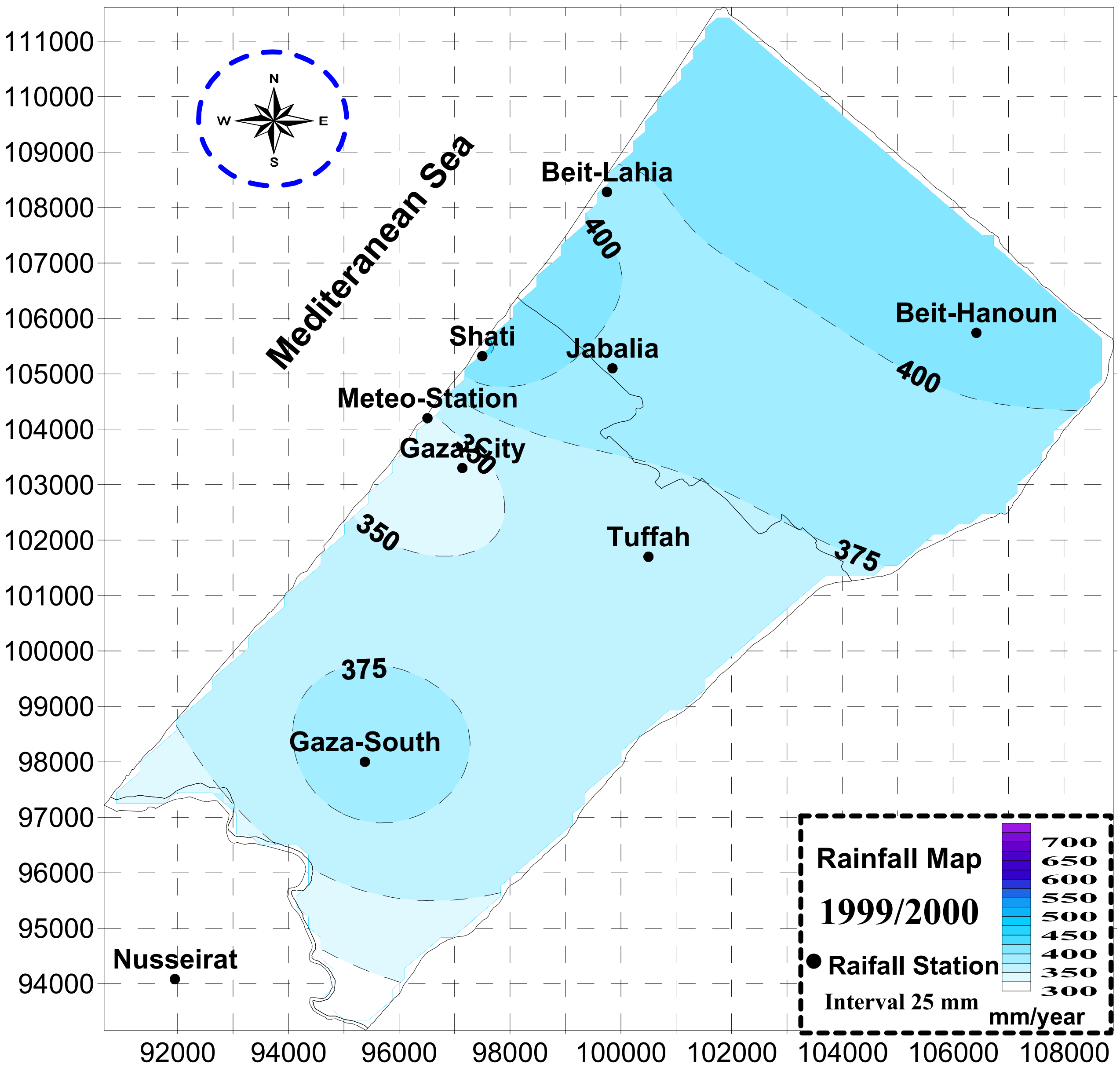


Figure (5.4): Rainfall distribution map (1999/2000)

Rainfall Map (2003/2004)

In this rainfall season, Shati station received the lowest amount of rainfall (340 mm/y) (higher than its annual average (297 mm/y)) while, the highest amount received in Gaza south station (502 mm/y) (higher than its annual average (323 mm/y)). The rainfall contour map for the season (2003/2004) is presented in (figure (5.5)). It shows that, the rainfall distribution generally decreased in the northern direction with total amount of rainfall varied from about

340mm at Beit Lahia to about 500mm at wadi Gaza . The bulk rain quantity that precipitated on the study area over the 135km^2 area in this season was estimated through software surfer version (8). It is found to be about (58Mm^3).

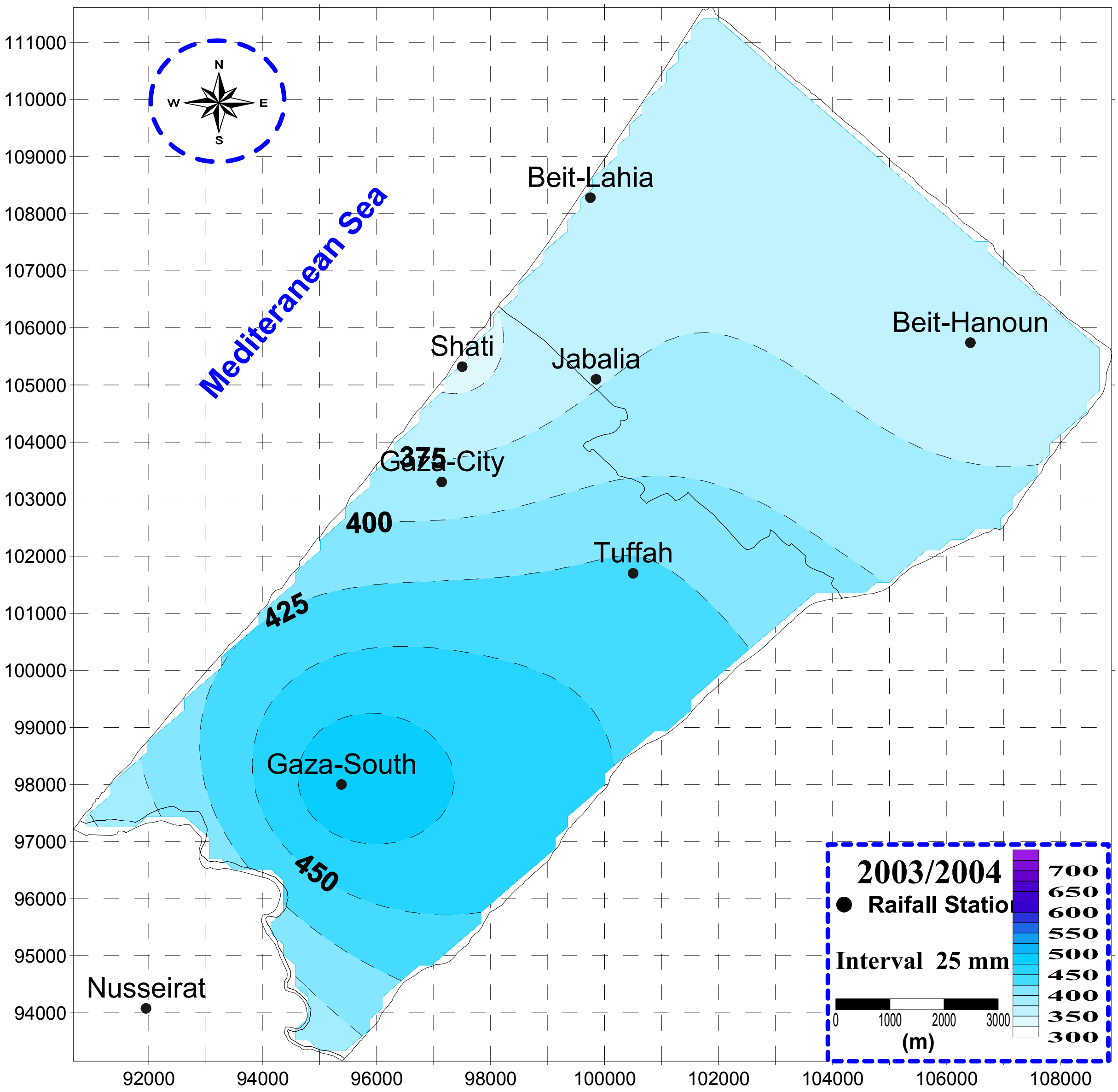


Figure (5.5) : Rainfall distribution map (2003/2004)

Average Rainfall Map(1994 2004)

For the rainfall period (1994-2004) , Meteo station received the lowest average amount of rainfall (362 mm/y) while, the highest average amount received in Beit Lahia and Beit Hanoun stations (444mm /y) which is higher than Beit Lahia annual average (321mm /y) and Beit Hanoun annual average (359mm /y). The average rainfall contour map for this period is presented in (figure (5.6). It shows that, the average rainfall amount decreased in the southern direction and increased eastward direction (inland) due to orographic effects. The total amount of rainfall varied from about 360mm at Meteo station to about 450mm at Beit Hanoun. The average bulk rain quantity that precipitated on the study area over the 135 km^2 area in this period (1994 to 2004) was estimated through software surfer version (8). It is found to be about (60 Mm^3).

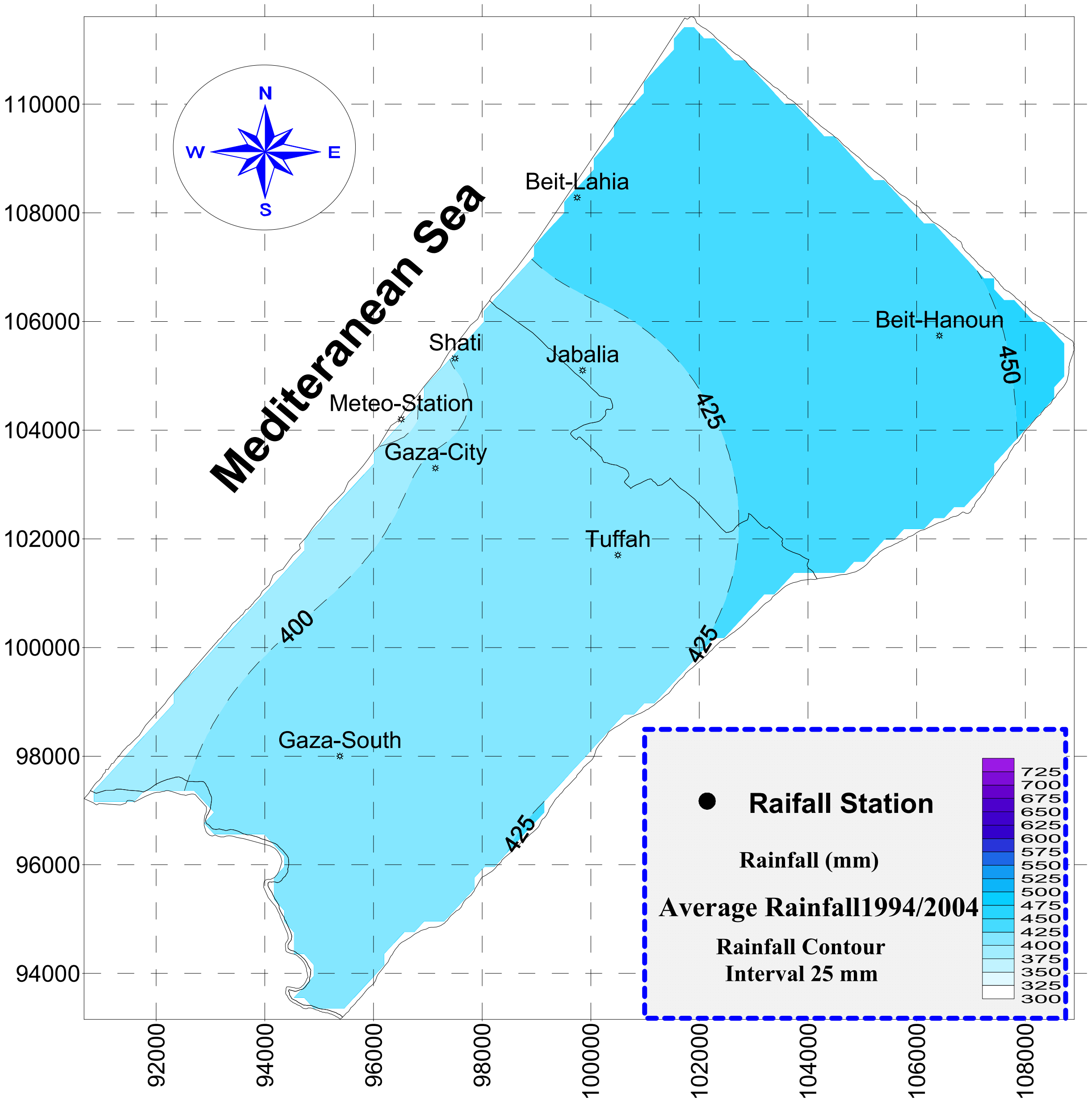


Figure (5.6): Average spatial annual during (1994-2004)

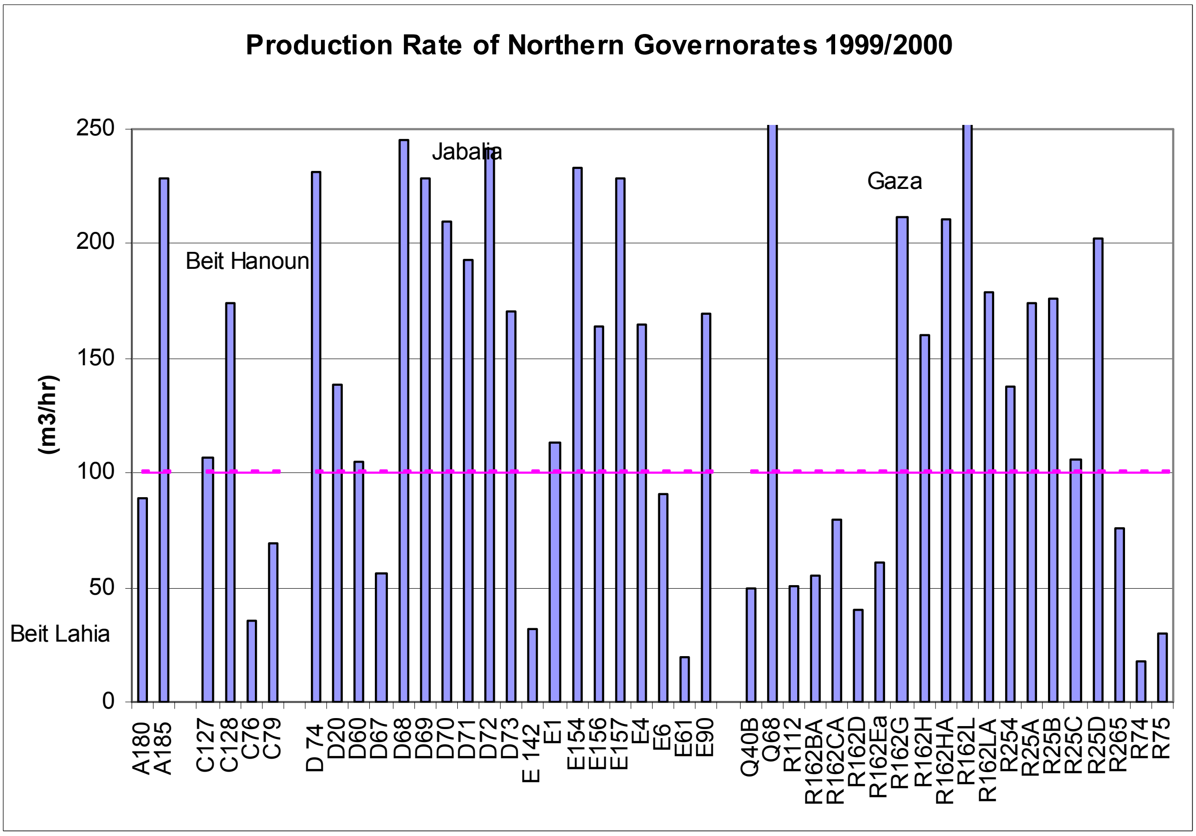
These variations in distribution of rainfall will affect the quality of the groundwater especially in areas with high permeability soil type and in areas of little thickness of unsaturated zone. The high evaporation rates in the study area, combined with transpiration of soil moisture by plants, returns high percentage of the precipitation directly to the atmosphere before it can infiltrate below the soil zone (in “ground-water recharge) or flow directly to wadis or streams (as “storm water runoff). Only about 35% of the total rainfall can be infiltrated to replenish the groundwater in Gaza strip (PWA,2005).

5.2 Rate of Abstraction Conditions

The number of production wells and their working hours for municipalities has been increased through the study period to cover the rapid increasing in population in the study area. With the absence of data for the first stage (1994/1995), the other two stages of production at 1999/2000 and 2003/2004 considered only. On the other hand, no doubt that the high density of agriculture wells especially in the north, add to illegal ones had played a sharing role in water level declination and groundwater quality deterioration. Unfortunately, there were no data for their rates of abstraction consequently, we were concerened here with the municipal wells only as follows:

5.2.1 Rate of Abstraction (1999/2000)

It can be seen from the graph (figure 5.7) that of the total of (45) production wells, (27) wells (60%) were located in the North Governorate (Jabalia, Beit Hanoun and Beit Lahia) and the others(18) wells (40%) are in Gaza.



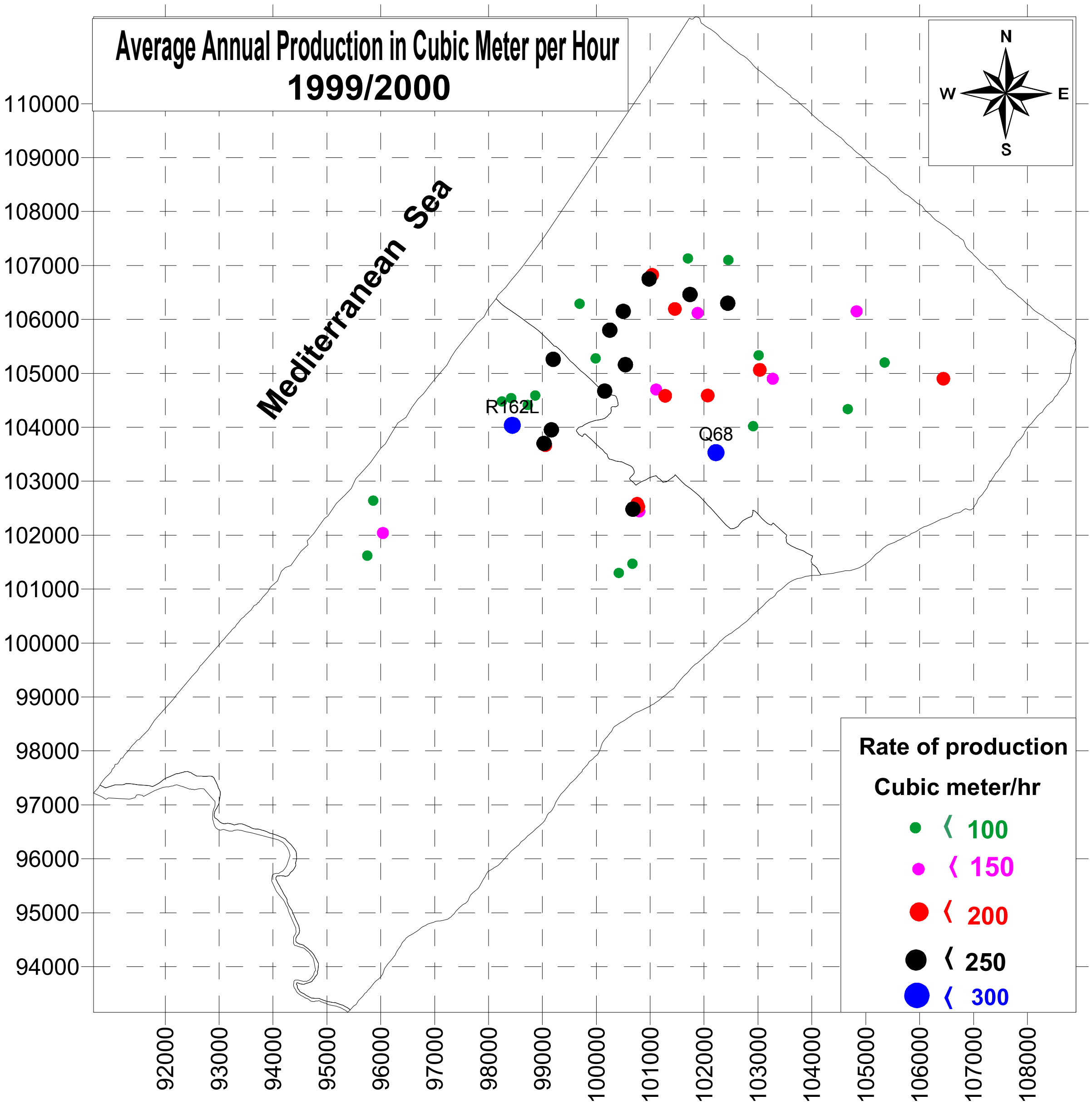
(Figure 5.7): A graph showing the rate of production of North and Gaza Municipal wells (1999/2000)

This figure shows that, in the North Governorate, (19) wells (70%) exceeded the recommended production rate from PWA while (10) wells (56%) of the Gaza Governorate wells exceeded the recommended rate. As a whole, from the (45) production wells we found that only (16) wells (35.5%) had a production rate less than (100m ^{3}/hr) and (29) wells (64.5 %) had a production rate more than100 m^3/hr. These data are summarized in table (5.2). The highest rate of production reached to (250m ^{3}/hr) in well Q68(in the North) and R162L (in Gaza). The wells distribution and their rates of abstraction had been affected by the urban area and their rapid growth in a limited areas.

Table (5.2) showing the number of wells and their rate of production in study area (1999/2000)

location	No. of wells	Production rate > 100	Production rate < 100
North	27	70%	30%
Gaza Municipality	18	56%	44%
North and Gaza	45	64.50%	35.50%

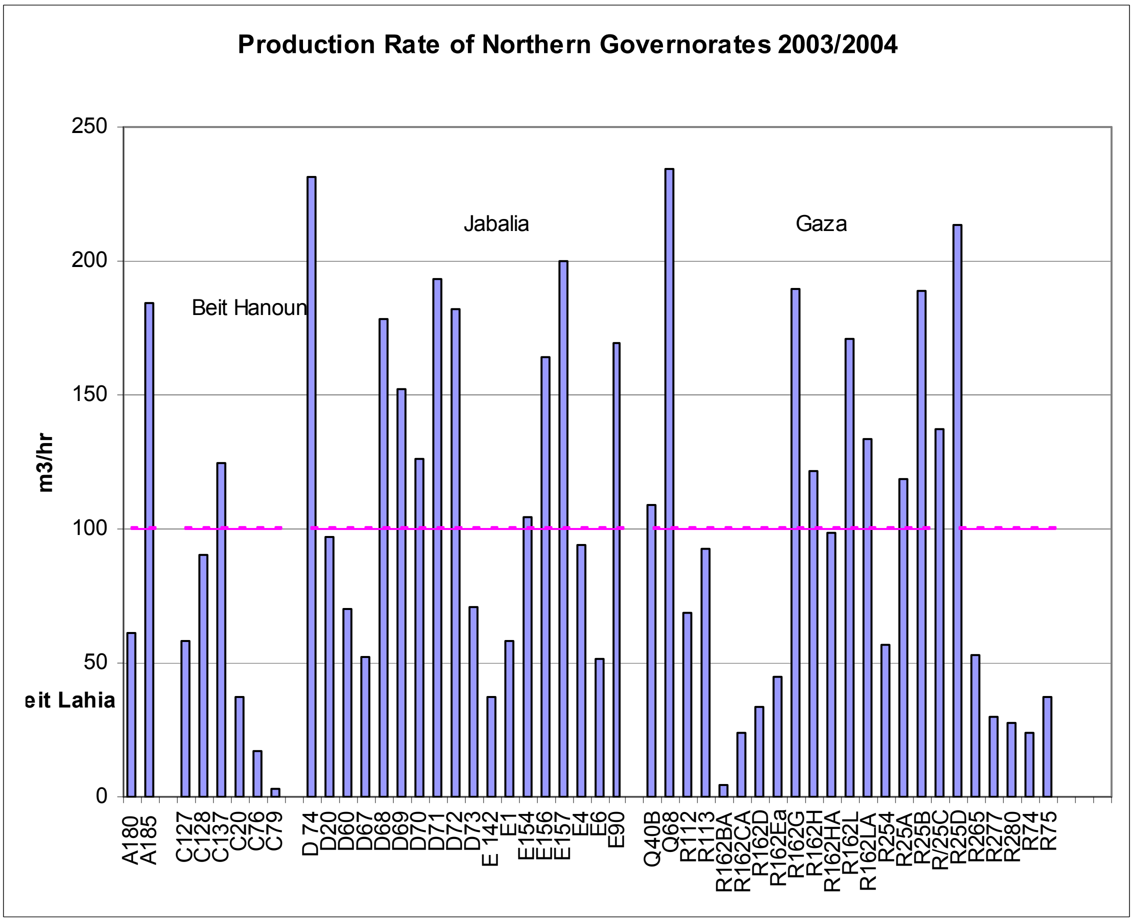
It can be seen also from the map (figure 5.8) that the production wells mostly concentrated within a limited part of the study area. Most of the wells with high rate of production were found in the western side of the North Governorate and Gaza City and especially in the North Governorate. The highest rate of production in the North in well (Q68) was toward the eastern part while highest rate of production in Gaza in well (R162L) was toward the western part. Most of the production wells with rate above (200m ^{3}/hr) were toward the western part of the study area. The total amount of water abstracted from the study area for the hydrological year (1999/2000) was about (41) Mm^3.



(Figure 5.8): A map showing the rate of abstraction of North and Gaza Municipal wells (1999/2000)

5.2.2 Rate of Abstraction (2003/2004)

It can be seen from the graph (figure 5.9) that of the total of (49) production wells, (28) wells (57%) was located in the North Governorate. In the North Governorate, (14) wells (50%) exceeded the recommended production rate from PWA while, of among the total of (21) wells of the Gaza City, (9) wells (43%) exceeded the recommended rate. As a whole, from the (49) production wells we found that only (26) wells (53%) had a production rate less than 100 m^3/hr and (23) wells (47%) had a production rate more than (100 m^3/hr). These data are summarized in table (5.3). The highest rate of production reached to (234 m^3/hr) for well (Q68) and (231 m^3/hr) for well D 74 (in the North) and (214 m^3/hr) (R25D) (in Gaza).



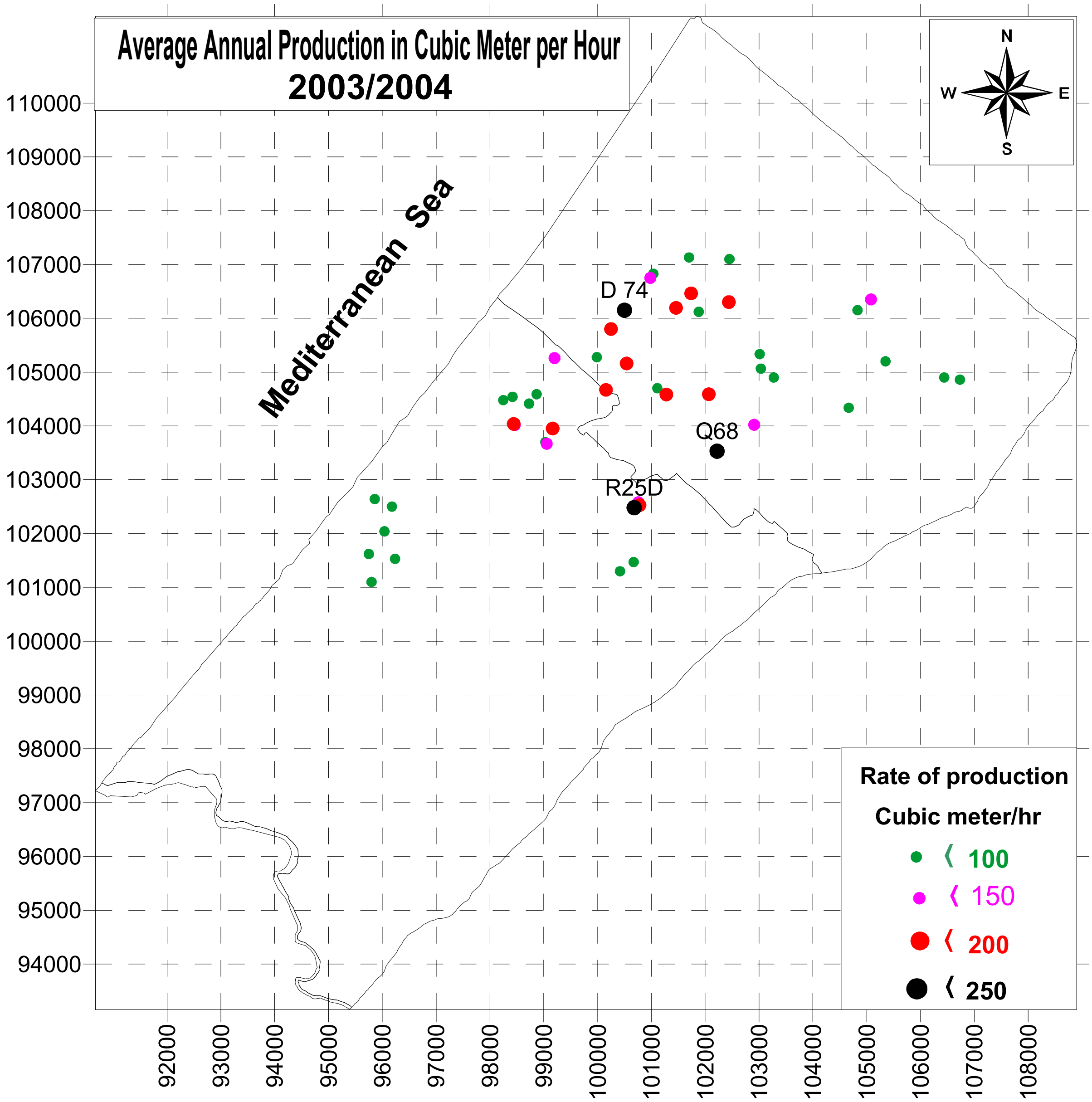
(Figure 5.9) A graph showing the rate of abstraction of North and Gaza Municipal wells (2003/2004)

Table (5.3) showing the number of wells and their rate of production in study area (2003/2004)

location	No. of wells	Production rate > 100	Production rate < 100
North	28	50%	50%
Gaza Municipality	21	43%	57%
North and Gaza	49	47.00%	53.00%

Figure (5.10) shows that most of the wells with rate above 200m ^{3} /hr were found toward the western part of the study area and especially in the North Governorate. The production wells mostly concentrated in a limited part of the study area. The highest rate of production in the North in wells (Q68) which was toward the eastern part and (D74) which was toward the western part, while highest rate of production in Gaza in well (R25D) was toward the eastern part. The total production of the wells for this year was about (44.5Mm ^{3}) (PWA,2005).

The high rate of production exceeds the recommended production rate from PWA (100m ^{3}/hr) of course will affect extremely the produced water quality with time. It will accelerate the water salinity problem with time especially in the western areas which are near to the seashore.



Figure(5.10) Rate of abstraction of North and Gaza Municipal wells (2003/2004

5.3 Groundwater Level and Flow Regime Conditions

Changes in water levels in wells reflect changes in recharge to and discharge from an aquifer. Groundwater level can be influenced by many factors, including precipitation, abstraction, lateral flow, intrusion, upconing of brackish or saline water, return flow from irrigation, wastewater and urban storm water. Water-level changes leads to changes in groundwater flow direction.

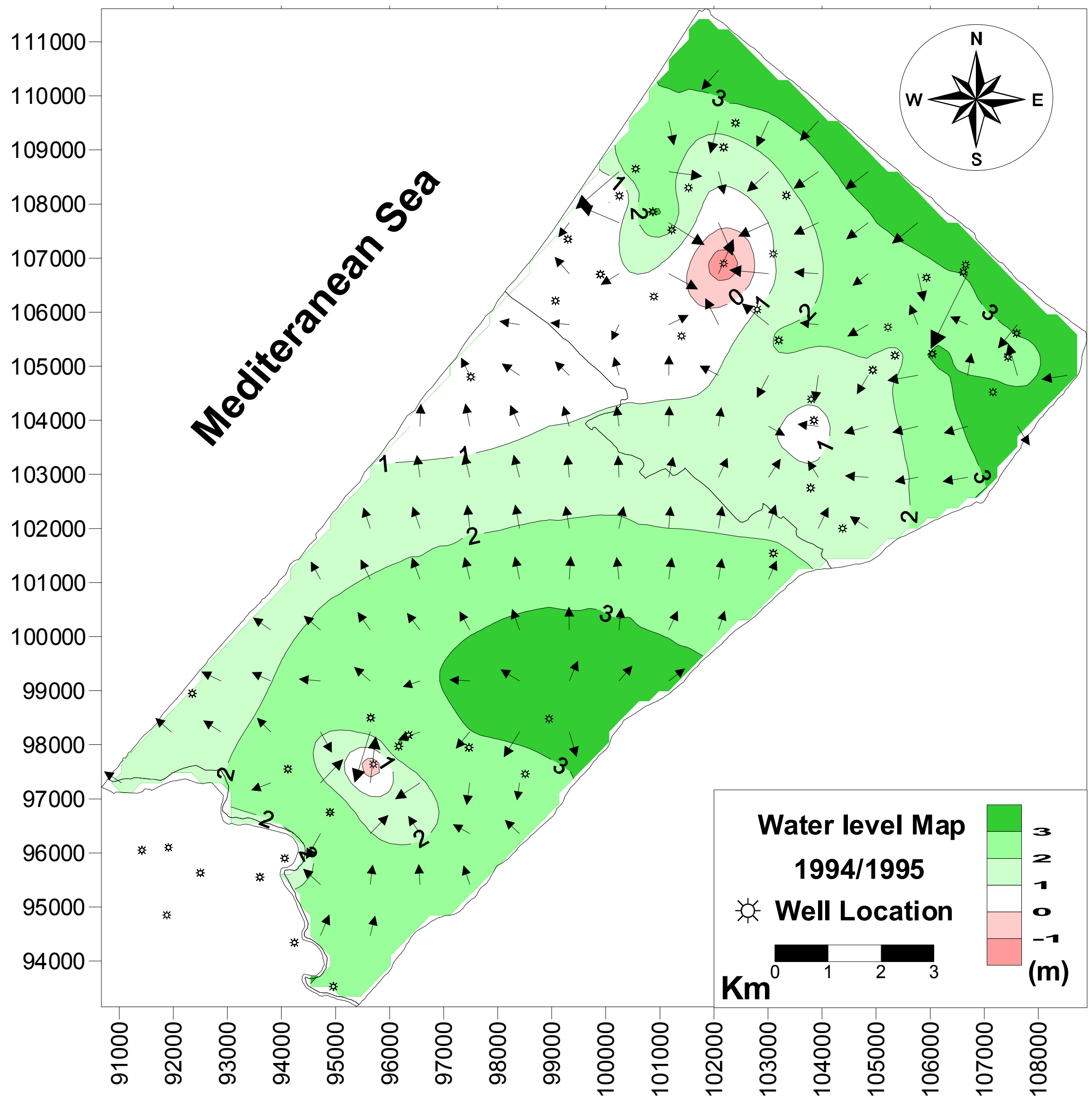
Trends for groundwater levels in the northern Gaza Coastal aquifer during 19942004 are shown in (figures 5.1, 5.2 and 5.3). These three maps have been drawn using agricultural water level monitoring wells data. The number of wells that used for the hydrological years (1994/1995), (1999/2000) and (2003/2004) were (45, 49 and 64 wells) respectively. These maps provide a depiction of the shallow part of the aquifer because all the wells are shallow.

It can be observed from the maps that there was not a uniform distribution for water level monitoring wells in the study area. Most of these wells are concentrated in the north and south while middle part. More than one third of the area is with a very little water level monitoring wells. This will affect on the degree of accuracy when drawing contour maps for water level

5.3.1 Groundwater Level and Flow Regime Map (1994/1995)

Figure (5.1) shows an average groundwater level contour map for the hydrological year (1994/1995). The figure shows two small prominent depletion cones formed. The bigger one in the northern part with water level less than 1m below MSL, and its area below zero level was about (2 km^2) whereas the smaller identified in the southern part of the study area with water level less than (zero meter). The two cones are separated by a high groundwater level saddle, which probably reflects natural hydrogeological conditions such as local low conductivities and low consumption rate.

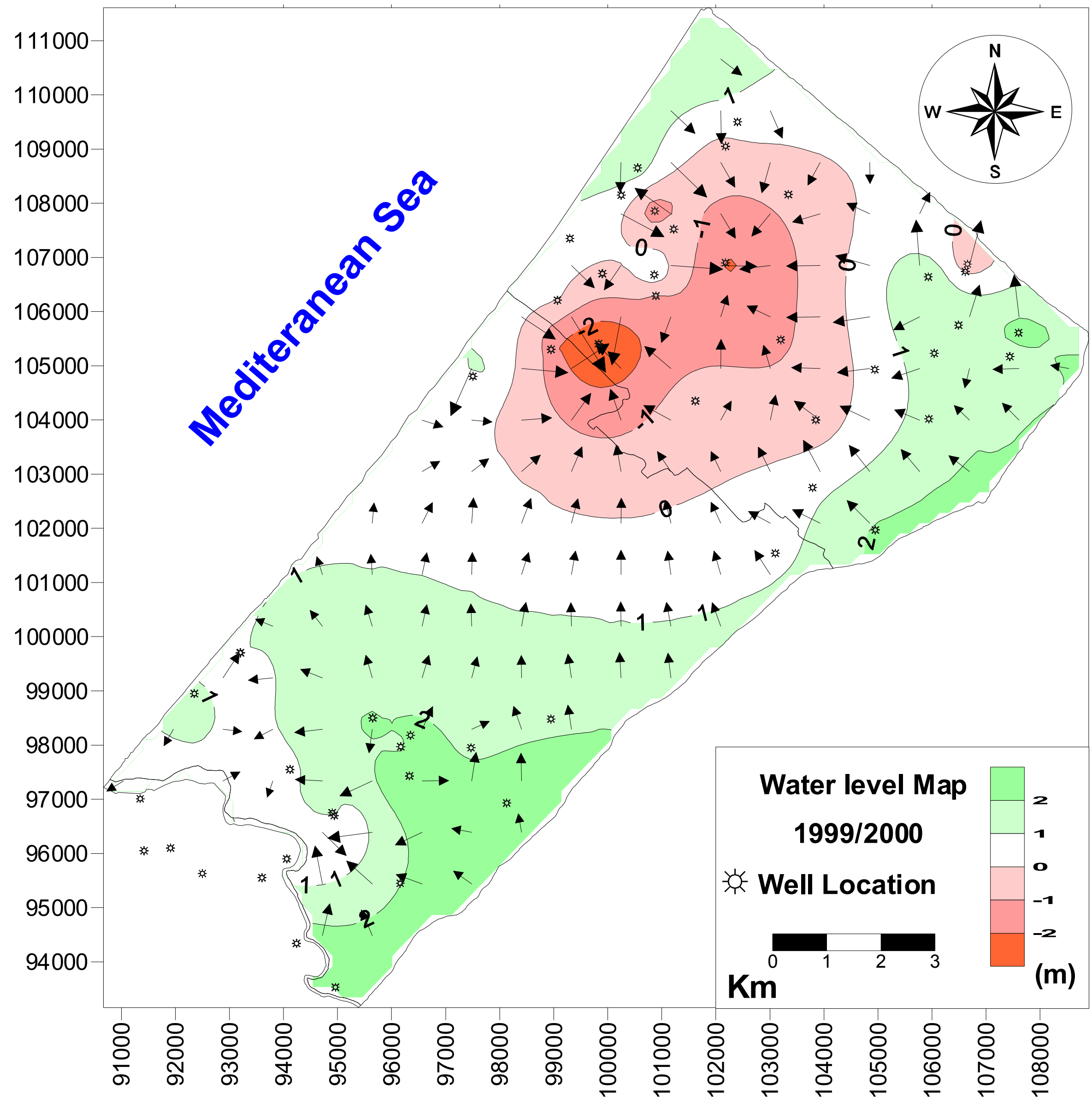
The general direction of groundwater flow was to the north and northwest at the south and the middle of the study area and to the southwest direction in the northern part of the study area. In the two depression areas at the north and south, the groundwater flow is directed toward the center of these cones of depression. Farther inland, water levels generally increased in the North Governorate and central part of Gaza Governorate. The highest level was at the northern and eastern part of the study area with average level of three meters above sea level. In spite of the higher amount of rainfall in the northern part of the study area than the southern the bigger cone formed in the northern part. This may be due to the higher amount of abstraction from the northern part than the amount supplied from rainfall.



Figure(5.1) : A map of average groundwater levels and direction of movement (1994/1995)

5.3.2 Groundwater Level and Flow Regime Map (1999/2000)

For the hydrological year (1999/2000), the data was drawn and presented in (figure 5.2). As shown in this figure, the lowering of regional groundwater level has been continued. One prominent depletion cone formed in the northwestern area. This one expanded rapidly from the proceeding one in (1994/1995). This cone had water level less than 2 m below MSL and its area below zero level was about (35 km^2). This hydrological depression which formed as a result of the overexploitation of the aquifer, have diverted the natural flow direction. The general direction was to the northwest toward the sea while the local direction was to the center of the cone of depression that covered a large area within the middle and the western parts of the North and Gaza City. Hydraulic gradients have been significantly reversed from the sea in this area. A small new cone of depression has been formed in the most northeastern part of the study area that may reflect a type of high abstraction on the northern border by Israel. The high groundwater level saddle still present as before but moved little to the southwest direction. The highest level was at the most eastern part of the North and the eastern of Gaza Governorate with average level of two meters above sea level.



(Figure 5.12) : A map of average groundwater levels and direction of movement (1999/2000)

As mentioned before there is a decreasing in the amount of rainfall from (1994/1995) till it reached to lowest value in (1998/1999) then it increased to some extent in (1999/2000) and the rainfall distribution was not taken a certain direction of increase or decrease in this season. Moreover, there is an over-exploitation of groundwater for domestic and agricultural uses especially in Gaza City and Jabalia that has led to an over-increasing gap between available supply and demand. So, the cone of depression in the northern part has expanded rapidly.

5.3.3 Groundwater Level and Flow Regime Map (2003/2004)

For the hydrological year (2003/2004), the lowering of regional water tables has been continued, and the proceeding cone has been expanded over a larger area as shown in (figure 5.3). The hydraulic gradients have been significantly reversed (from the sea) between the North and Gaza City with water level less than 4 m below MSL and its area below zero level is about (44 km^2). This was a function of increasing the number of abstraction wells and high total abstraction near Gaza City and the North especially in Jabalia as a result of rapidly increasing in population with water demand.

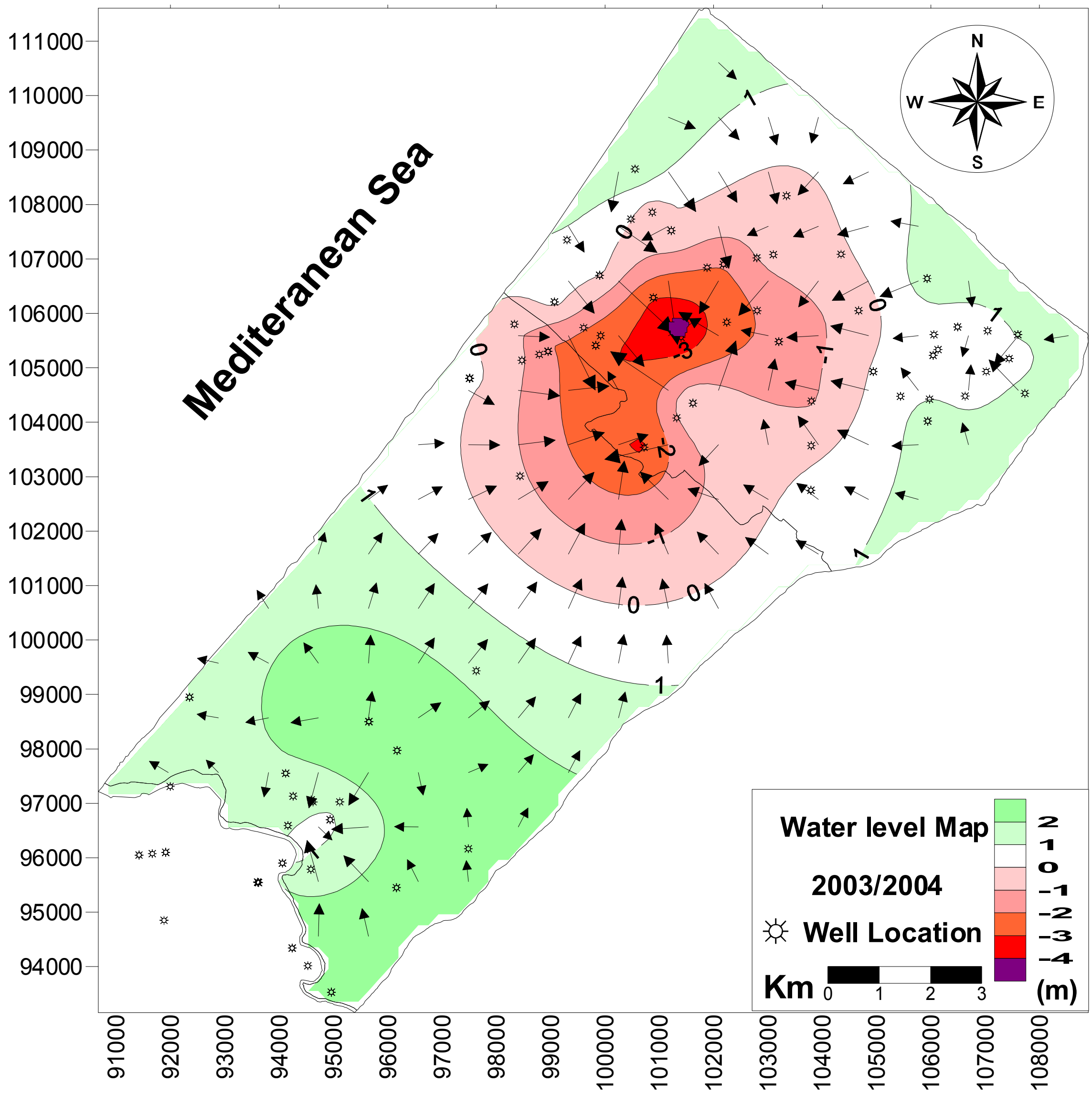


Figure (5.3): A map of average groundwater levels and direction of movement (2003/2004)

The flow direction has been disturbed sharply and so it becomes mainly in two parts: in the north to center of the cone of depression and in the south generally to the west. The high groundwater level saddle still present, which confirm the mentioned hydrogeological condition. The highest level was at the southeastern part of the study area with average level of two meters above MSL.

The municipal wells have been operate almost 24 hours a day with an abstraction rate exceeds a 100 m^3/hr, noting that these wells are very close to each others which led to a low pressure zone that leads to seawater intrusion to invade this low pressure zones.

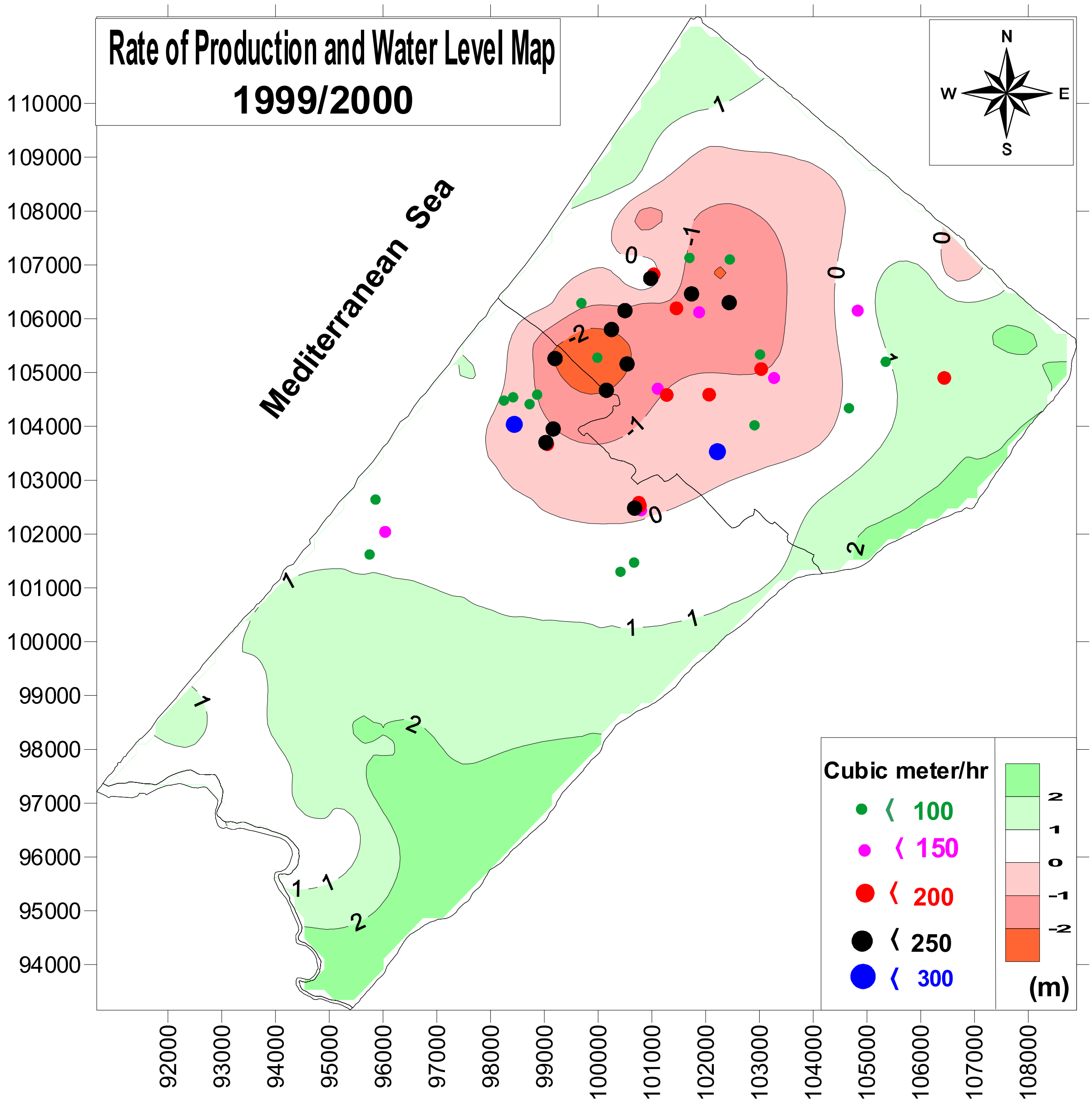
In spite of the increasing trend in rainfall amount from (1999/2000) to (2002/2003) and decreased in (2003/2004) to some extent, there is a continuity in increasing of over-exploitation of groundwater. Moreover, the rainfall distribution generally decreased in the northern direction. So, the cone of depression in the northern part has continued in expanding rapidly due to high abstraction in this area of low precipitation while the water level in the southeastern part is increased to some extent than the proceeding stage (1999/2000). This increase in water level may be a result of presence of a wide scorched lands in this area as shown in (figure 3.12). The abstracted water from agriculture wells nearly decreased or stopped while the received rainfall percolate without interception on the surface by plants.

5.4 Impact of Rate of Abstraction on Water Level

5.4.1 Impact of Rate of Abstraction on Water Level (1999/2000)

An overlay for correlation has been made between water level map and rate of abstraction map for the hydrological year (1999/2000) as shown in (figure 5.14). It is well observed that the two lowest parts of the big cone of depression with average level below 2 meters (below M.S.L) are located between Gaza City and Jabalia town and between Jabalia and Beit Lahia. These areas are densely populated with high density of wells and high rate of abstraction. The area around Gaza City/Jabalia is densely populated, and abstractions for water supply are large. The bigger lowest part coincided with four wells D/68, D/69, E/154 and E/157 while the smaller one was next to two wells D/72 and A/185. All of them were with a rate of abstraction above 200m ^{3}/hr. Also, these areas coincide with the lowest depression (20 m) behind the first elongated ridge to the west.

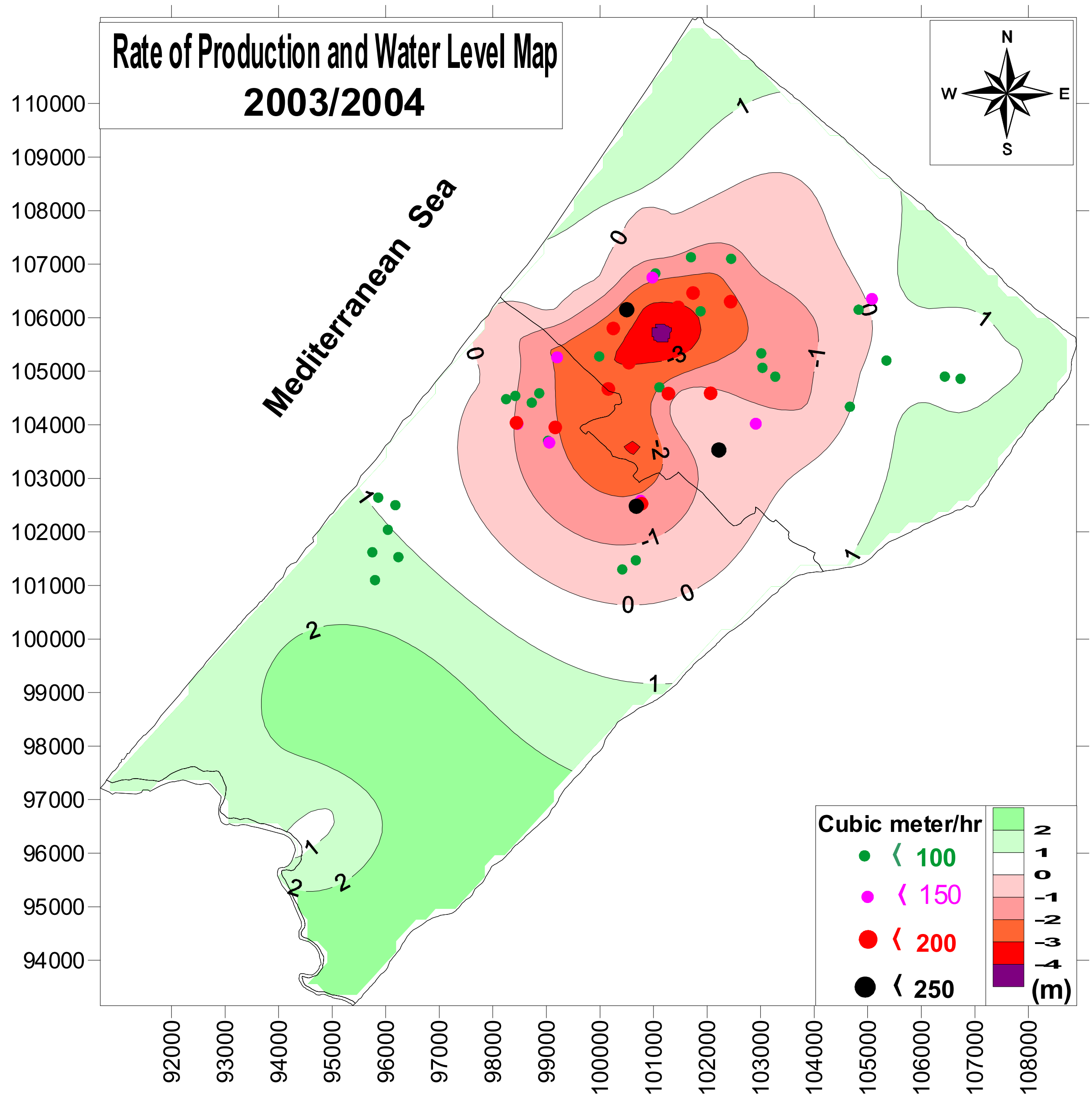
We can conclude that there is a direct effect of the rate of abstraction on the water level in the aquifer. Pumping is the other main factor affecting the water level beside rainfall. The effect of rainfall is regional in scale while the effect of pumping is local.



(Figure 5.14): Overlay between water level map and rate of abstraction map (1999/2000)

5.4.2 Impact of Rate of Abstraction on Water Level (2003/2004)

An overlay for correlation has been made between water level map and rate of abstraction map for the hydrological year (2003/2004) as shown in (figure 5.15). It is well observed that the lowest parts of the big cone of depression with average level below 4 meters (below M.S.L) are located in Jabalia town. This area was conceding with the area of high rate of abstraction of well D/74 (above 200 m ^{3}/hr) and high density of wells most of them above 150 m^3/hr such as D/68, D/69, D/71, E/157, A/185 and D/72. Also this area coincides with the lowest depression (2 m) behind the first elongated ridge to the west.



(Figure 5.5): A map of average groundwater levels and direction of movement (2003/2004)

5.5 (3-D) Topographical Map

The depth to groundwater at a specific location is important because the soil and sediments between the surface and groundwater acts as a filter. Therefore, extra precautions need to be taken to protect groundwater in areas where it is close to the ground surface. Since water level is around zero above or below by few meters, so we can have approximate view about the thickness of the unsaturated zone from the topographic map. Two and three dimensional (3-D) topography maps for the study area are drawn and shown in (figures 5.6a,b) . It is clear that pollutants in the depressed areas (little thickness for the unsaturated zone) especially in the northwestern part of the study area (sand dunes areas) have a higher chance to leach rapidly to the aquifer.

The maps shows that there are three narrow elongated ridges and depressions extend parallel to the shoreline. A part of the fourth ridge appears in the North Governorate. These ridges are dissected by depressions .Ground surface elevation generally is higher in the eastern side than the western and also higher in the northern side than the southern side till we reach Wadi Gaza. The first ridge next to the shoreline is reaching in elevation to about 50 m above MSL. The next one is limited in its width and lower in elevation that reach to about 40 m above MSL. The third one to the east is the widest and the highest in elevation that reaches to about 70m above MSL . The fourth one which appears in the north only reaches in elevation to about 90m at the eastern part of Jabalia on the eastern border of North Governorate. The lowest part of the area is located at western side of Jabalia and Beit Lahia on the shoreline with elevation (0) while the highest part is located at the eastern side of Jabalia on the borders with elevation about (91) m above MSL. The elevations of depressions range from (20) m to west to (40) m above MSL to the east.

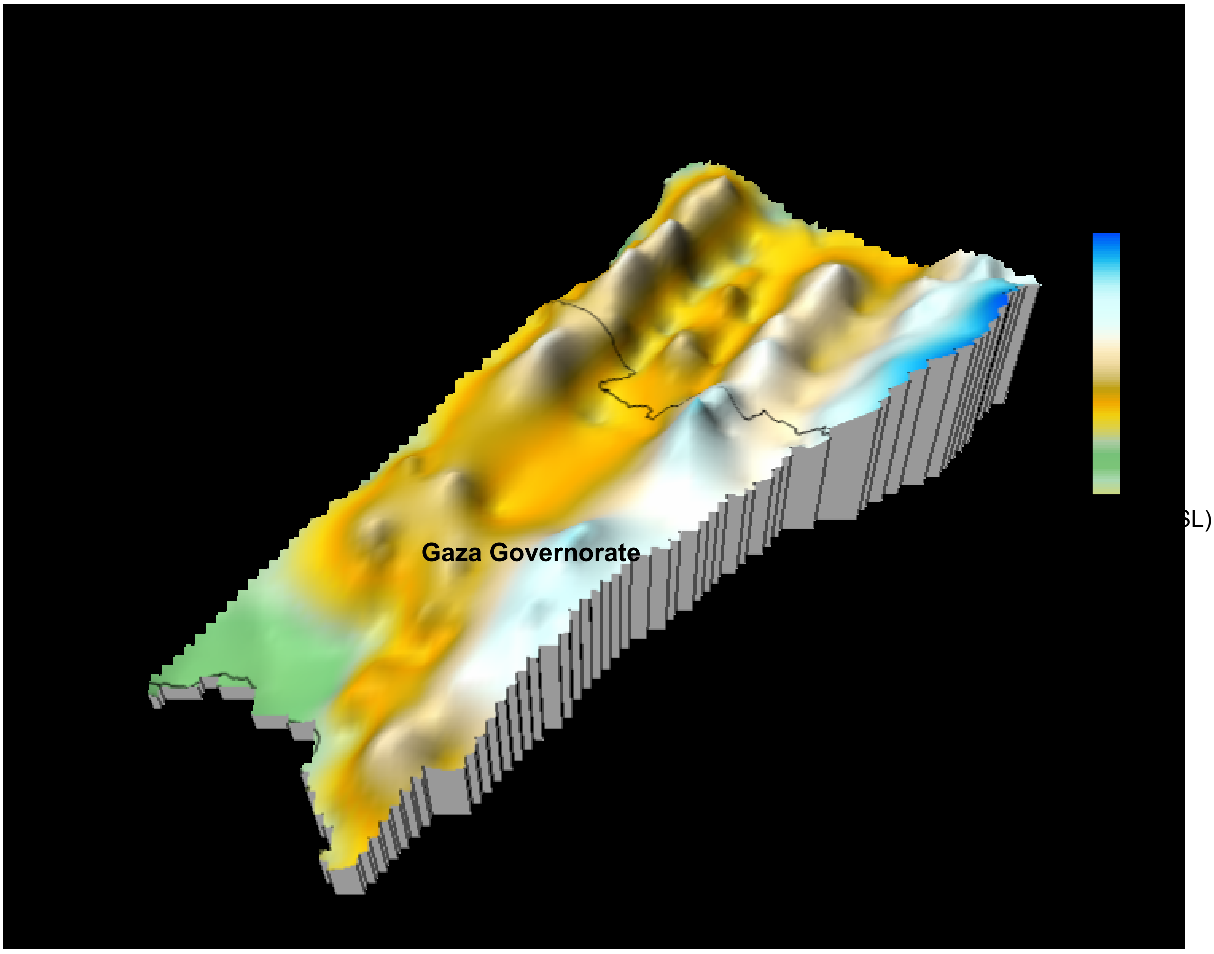
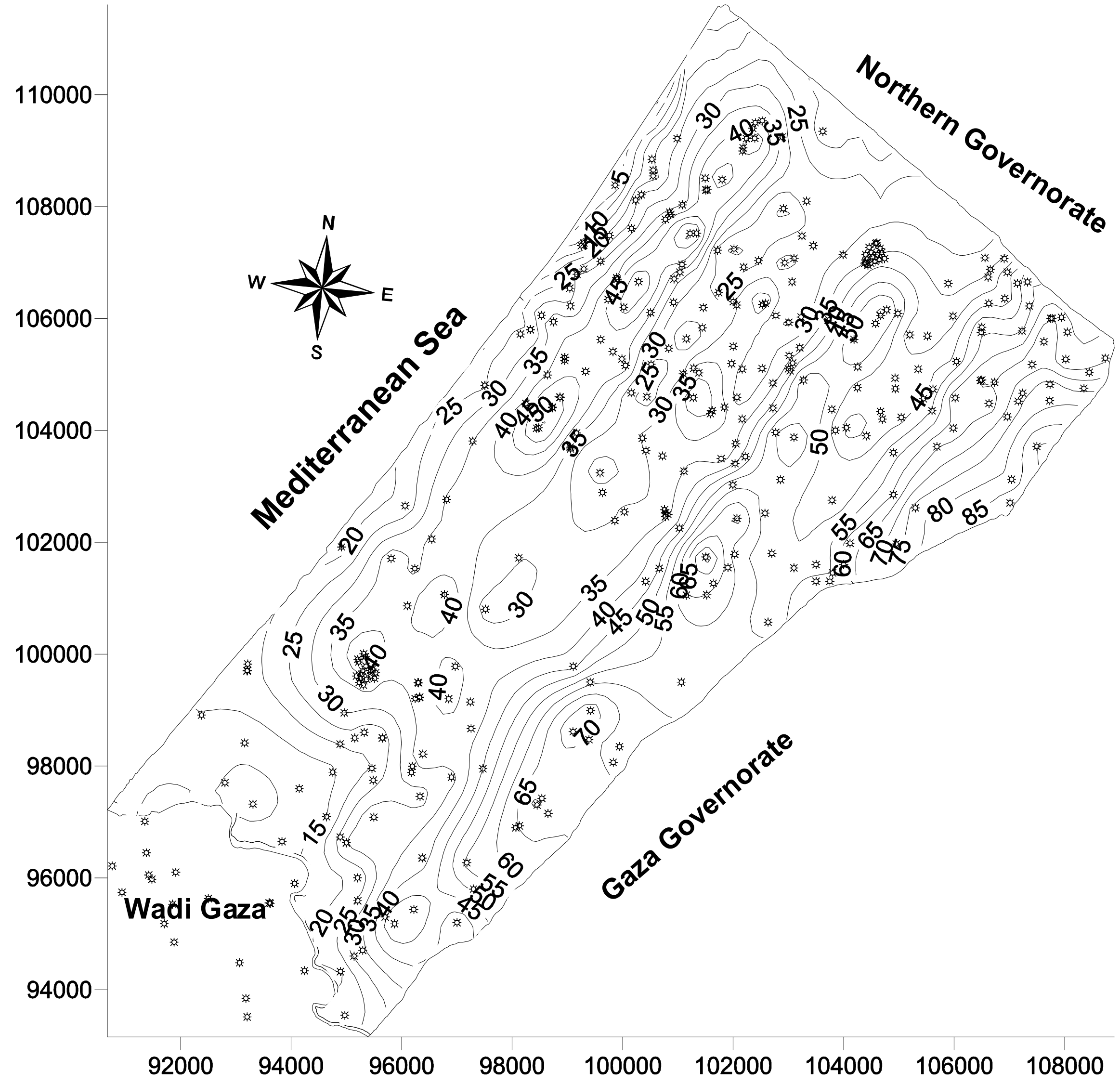


Figure (5.16a) 3-D topography map



(Figure 5.16b) 2-D topography map

5.6 Lithological Cross Sections

For studying the role of lithology in groundwater quality situation in the study area, data of (22) lithological wells are used in drawing two cross sections (NE–SW) as shown before in (figure 4.4). One of these sections have been drawn by a correlation between (13) lithological wells in the western side and the other one between (9) lithological wells in the eastern side as shown in (figures 5.17 and 5.18) respectively.

These cross sections show the distribution of impervious to semi-imprevious layers and lenses alternating with predominantly permeable sand and calcareous sandstones. These sections represent the upper part of the Kurkar Group (coastal aquifer) since the depths of the available wells are limited. Clay layers divide the aquifer vertically into four subaquifers as mentioned before A, B1, B2 and C. These sections helped in studying the effect of lithology on the groundwater quality

The importance of the western side cross section is to show the role of the aquifer's lithological characteristics on limiting seawater intrusion where seawater can intrude into the aquifer at different rates, depending on the hydraulic regime inland and lithological characteristics. The western section extends along NE - SW parallel to the shoreline and far by about (1-1.5km) It can be observed from this cross section that the lithological log of wells (A/196, 25A- B and R/162E) does not contain clay within their lithological record. The high permeability of the sand and calcareous sandstone in the upper vadose zone and absence of clay layers or lenses in these wells enables rapid leaching of pollutants to the saturated zone. Moreover, these conditions are suitable for seawater intrusion easily.

The other cross section that extends along NE -SW is far from the shoreline by about (6-7.5km) and parallel to it. The lithological log of all the wells contain clay in their lithological record that divide the aquifer vertically into two subaquifers A and B. The presence of clay with silty clay, sandy clay and sandy silty clay on the surface will retard the movement of contaminant to travel very slowly until reach to groundwater.

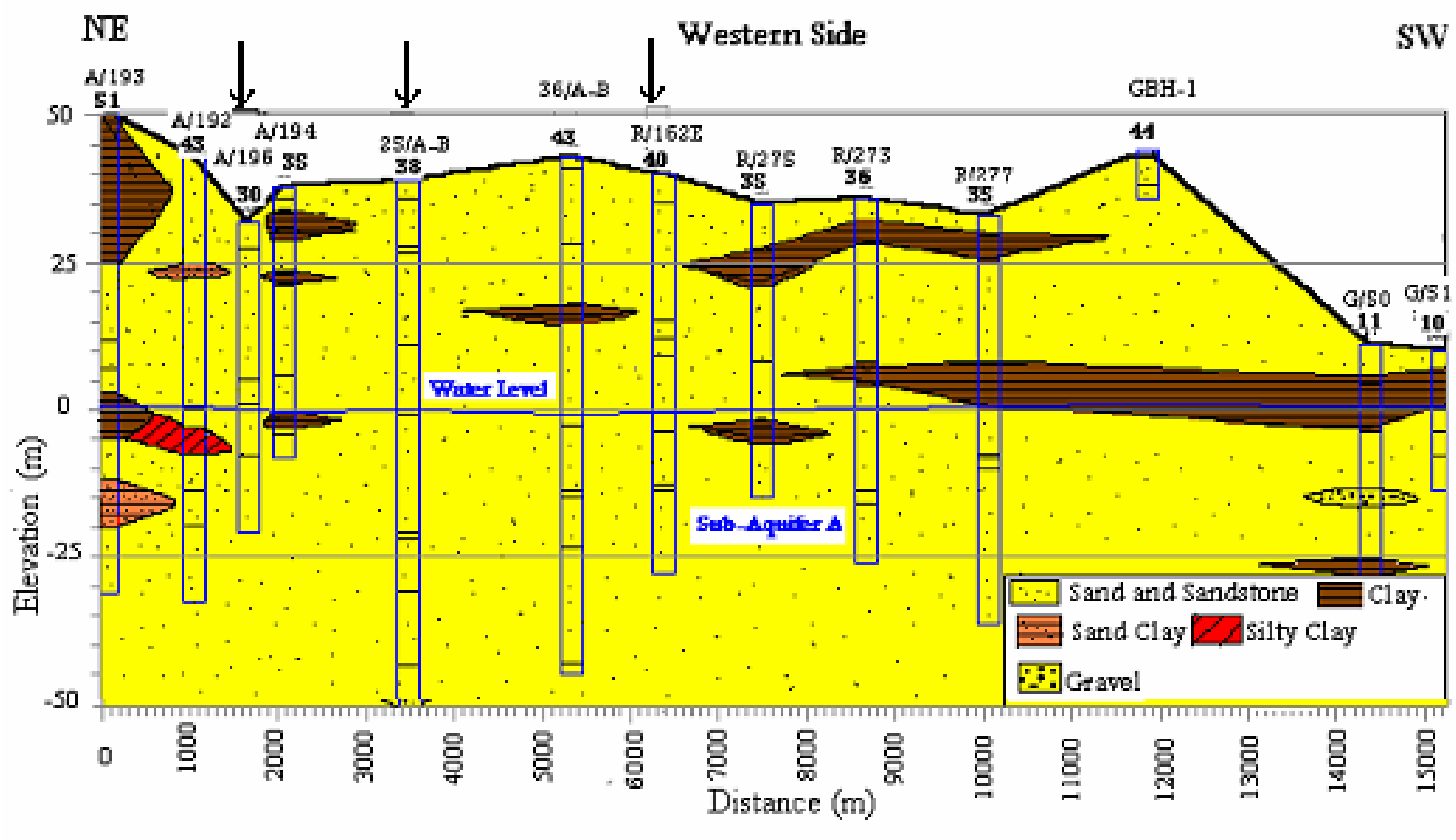


Figure (5.7): Cross section along the western border in the direction of NE SW

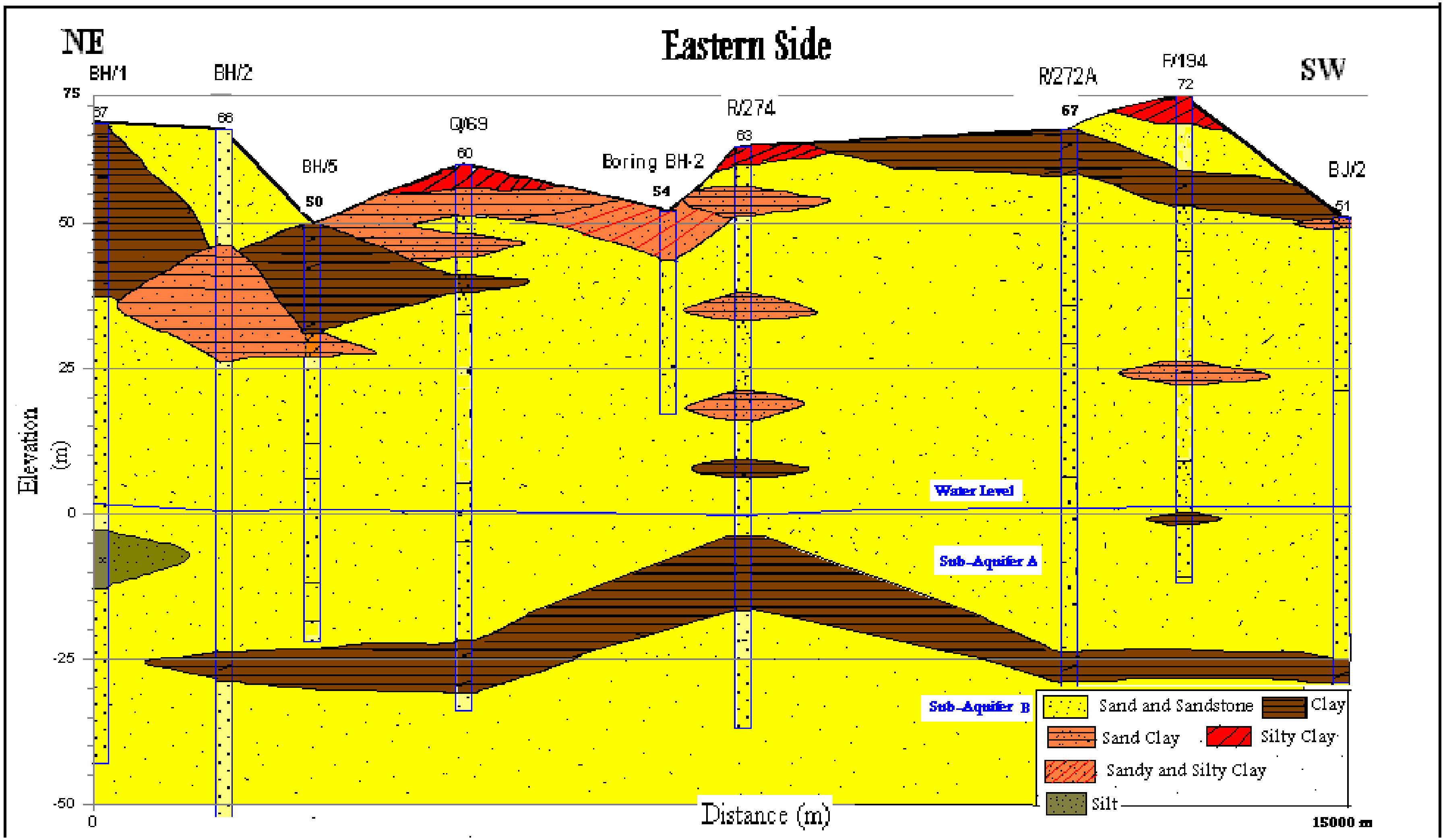


Figure (5.18): Cross section along the eastern border in the direction of NE-SW

5.7 Groundwater Chemistry Situation (1994-2004)

Chloride and nitrate concentrations in groundwater were evaluated for the period (1994-2004). This was done at three stages (hydrological years) (1994/1995), (1999/2000) and (2003/2004). Different factors that affecting the chloride and nitrate concentration will be discussed.

5.7.1 Chloride Evaluation

5.7.1.1 Chloride Contour Maps

Generalized chloride contour maps of the northern part of Gaza Strip for hydrological year (1994/1995), (1999/2000) and (2003/2004) are shown in (figures 5.19, 5.20 and 5.21). The total number of wells, which were used for drawing these maps are 253, 239 and 206 wells respectively. Most of them are shallow i.e., screened a few meters immediately below the water table.

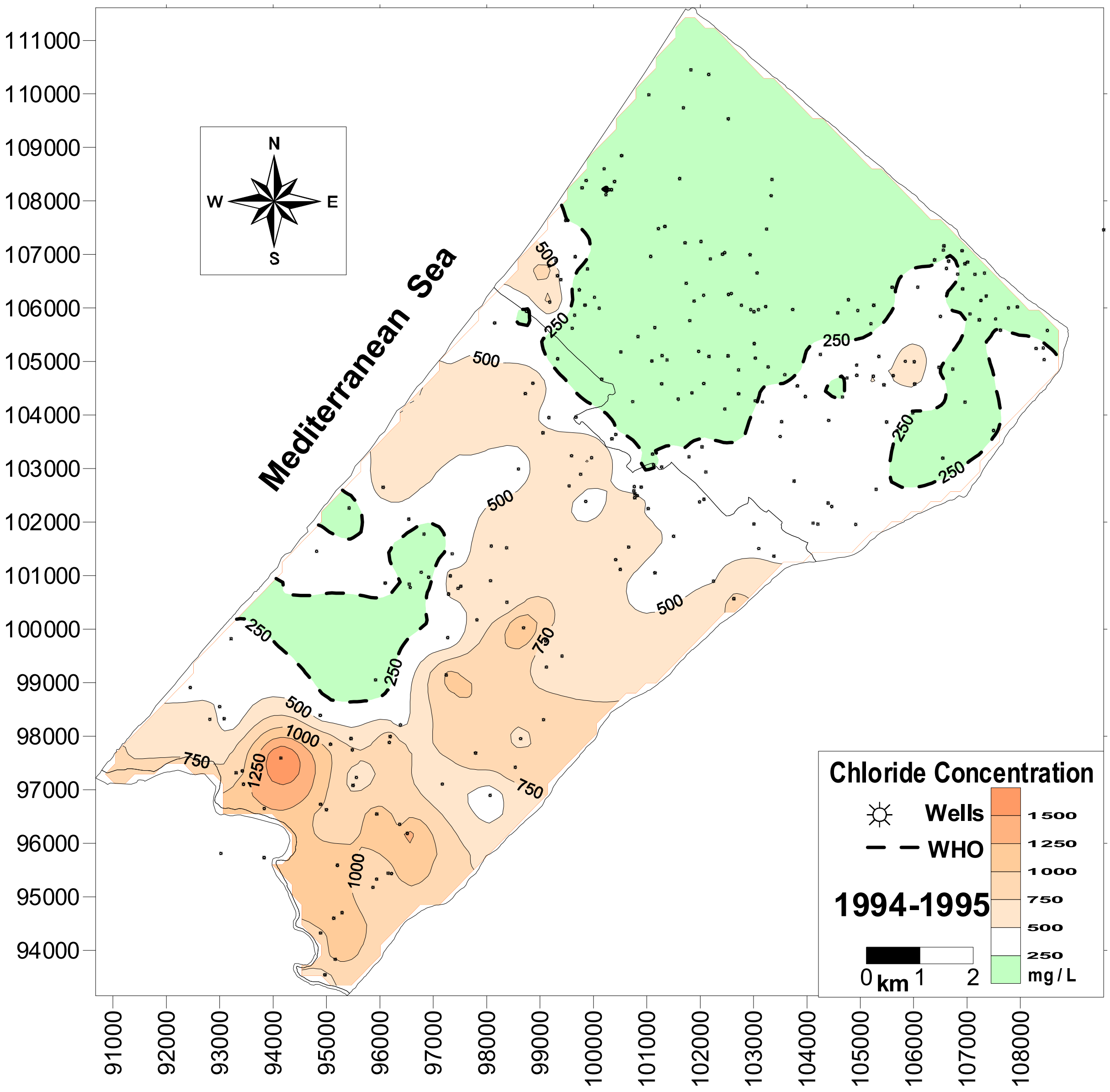
Chloride Map (1994/1995)

Data of 253 wells were used in drawing the chloride concentration map (figure 5.19). The freshwater wells with chloride concentration (< 250 mg/l) (WHO standard for drinking water) were about 113 well (44.7%). Most of freshwater wells are located in the North Governorate, while the rest of wells were (>250mg/l) and most of them in the Gaza Governorate.

Chloride concentration map shows chloride concentration in different ranges. It can be observed that most of the North Governorate was a freshwater area (< 250 mg/l) while a big part of its eastern side and a small part in its western side (west of Jabalia) were above 250 mg/l . In the Gaza Governorate, freshwater area occupied only a limited area located under and next to Netsareem settlement (before). Around these areas, the chloride concentration increased gradually.

Based on the factors that affected the groundwater chloride concentration distribution, it can be observed that:

The rainfall rate distribution was higher (about 82 Mm^3) than the average for the study period (about 60 Mm^3) and showed a general trend of increasing from south to the northwest. This trend coincides with the chloride concentration distribution that was lower in the north than in the south. Also, based on the sandy soil distribution, rainfall in this stage replenished the groundwater in the North more than in the Gaza Governorate. So, the best water quality was found under the sand dune areas mostly in the north with concentrations reaching below 50 mg/l.



*(Figure 5.*19*): Spatial variation of chloride in the study area (1994/1995*)

Based on land use, chloride concentration under the agriculture areas in the eastern part of the study area and next to the middle part of Wadi Gaza (the highest value about 1890 mg/l (well No. F/43) were higher than other areas. The high chloride concentration in these areas was related to the inflow of saline groundwater from occupied areas (PWA, 2001b) and intensive use of agrochemicals. In urban areas, there was high concentration of chloride >100 mg/l reaching 1379 mg/l at well R/93 in Gaza City toward the south borders of these areas. Also, under a limited urban area in Beit Hanoun there was a small plume of high chloride concentration (>500mg /l). These plumes may be related to low infiltration with paved urban area and from return flow of wastewater from septic tanks where the population served by public sewer in this year was not available but in 1997 was about 60%.

At the western part of Jabalia Town, chloride concentrations reached to 882mg /l (well E/35) and to 847mg /l (well E/37). These high concentrations may be related to seawater intrusion in this area. This expectation is a result of fluctuation in chloride concentration with time as will be shown later from chlorographs for wells E/35 and E /37 and the presence of some factors that can lead to seawater intrusion. These factors are water level decline, sandy lithology, high well density and high rate of abstraction. Unfortunately, the data for the rate of abstraction were not available in this year to know its effect on the groundwater quality. On the other side, there was a local lateral flow for groundwater along the northern borders that may be replenished the groundwater in the north with freshwater.

The highest concentrations of chloride seem to show local pollution with large distances from any obvious point source of pollution such as WWTPs. This is due to the absence of data from monitoring wells around Beit Lahia WWTP and its lagoon (700 dunums in 1995) and around Gaza WWTP and its infiltration basins. So, the real situation of groundwater quality around these serious point sources of pollution may be obscured.

It is clear in this stage that the agriculture activities and the inflow of saline groundwater from the occupied areas in the eastern side were the major contributor in groundwater salinization. On the other hand,, seawater intrusion at the western part of Jabalia has affected chloride distribution. Also, rainfall amount distribution, soil type, water level and lithology of the unsaturated zone had affected groundwater chloride concentration distribution in this area.

Chloride Map (1999/2000)

Data of 239 wells were used in drawing this map . The results is shown in (figure 5.20). About 100 wells (41.8%) were (< 250mg /l) most of them are also in the North Governorate. This percentage of freshwater wells is lower than the proceeding stage.

The drawn map shows chloride concentration in different ranges with higher values where some parts of the aquifer exceeded 1000mg /l and reached to 2014mg /l at the western part of Jabalia Town and to 2220mg /l next to the middle part of Wadi Gaza. These concentrations were much higher than the upper acceptable limit for drinking water in Palestine (500mg /l) and the recommended WHO (250mg /l). The freshwater areas decreased especially in the North Governorate from its eastern and western sides. In the Gaza Governorate, freshwater area still occupied a limited area around Netsareem settlement before. Around these areas, the chloride concentration increased gradually except at western part of Jabalia Town and next to the middle part of Wadi Gaza where it increased rapidly.

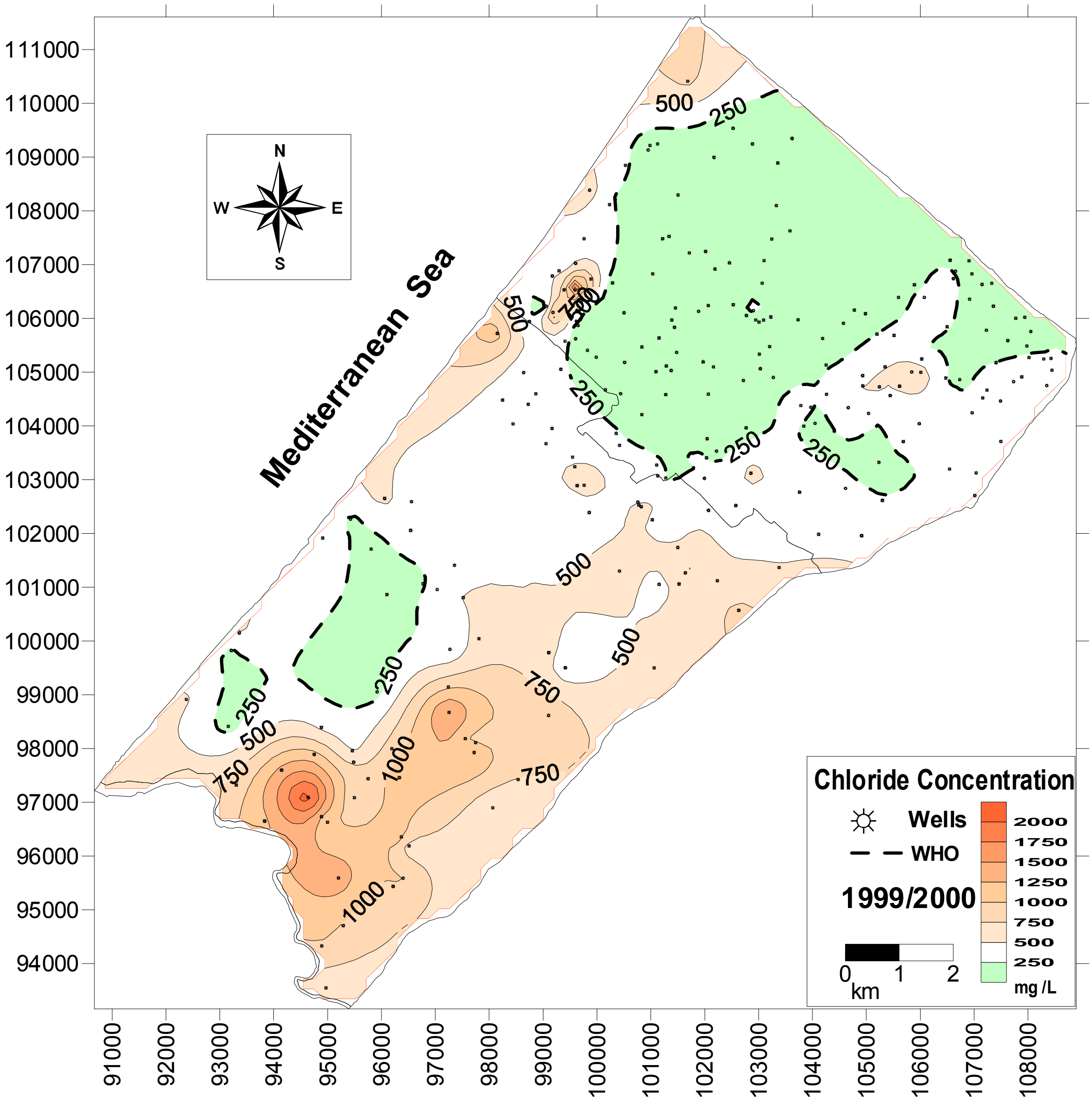


Figure (5.20): A generalized chloride contour map (1999/2000)

Based on the factors that affected the groundwater chloride concentration distribution in this stage, it can be observed that:

The deterioration in this stage was a result of the continuity of causes of salinization. A major one was the decreasing in the rainfall amount which reached its lowest value in 1998/1999. The rainfall distribution in this stage in general is still higher in the north than in the south and its amount was (54) Mm^3. So, the best quality water is still found in the sand dunes areas in the North with chloride concentrations less than 250mg /l.

There is an unexpected improvement of chloride concentration beneath the urban area under Gaza City in spite of increasing in population and the decreasing in the amount of rainfall and the area of recharge with paved urban areas. It may be due to the shortage of data collected in this year from this area. An example for the data shortage is the absence of data for well (R/93) which was the highest in concentration 1379mg /l in 1994/1995 under south borders of urban areas in Gaza. Lack of field data from the current monitoring network leads to highly uncertain results. This lack of data is more significant when comparing hydrological situations between separate periods. This is beside the percentage of population served by public sewer in this year has been improved to about more than 60% to reduce this source of pollution. In the agriculture areas at the middle part of wadi Gaza the chloride concentration was above 2000mg /l and reached to 2220mg /l for well (F/53). This was a result of intensive use of agrochemicals.

In this stage,it has been found that 64.5% of the municipal production wells exceeded the recommended production rate (100m ^{3}/hr) and reached to about 250 m^3/hr. Most of the wells with high rate of production (> 200 m^3/hr) like (D/69, D/70, D/74and E /154) as shown in (figure 5.21) were at the western part of Jabalia Town/Gaza City next to the sea shore line. This heavy pumping for domestic uses through the dry period add to the decreasing in recharge area (with expanding in the urban area) and increasing in the density of agriculture wells in especially in the north, led to water level declines and forming a big cone of depression with level less than 2 m below MSL and an area of about 35km ^{2}. Consequently, this situation has led to change in flow directions in the aquifers and induced saline water from the sea or deep brines, to move into the aquifer and form a plume of high salinity in this area. At the western part of Jabalia Town the chloride concentration was above 1500mg /l and reached to 2014mg /l at well E/64far from the seashore by about 1.5Km while at the western part of Gaza City was above 1000mg /l and reached to 1155mg /l at well E/28 . It can be observed that the salinization process was rapidly in western part (next to seashore) of both of Jabalia Town and Gaza City due to some reasons which believed to be: 1) the municipal and agricultural wells which concentrated in this area. 2) the deepest part for the cone of depression is located in this area. 3) the water level for this year reached to more than 2 meters below MSL and the cone of depression expanded rapidly. 4) the sandy lithological characters of this area which marked by two bold arrows as shown in (figure 5.22) where landward-penetrating seawater passed through permeable sands and calcareous sandstones more easily than clayey sediments.

There were other sources of salinization such as solid waste dumps and wastewater treatment plants and the inflow of saline groundwater from occupied areas (PWA, 2001b). The highest concentrations of chloride seem to show local pollution with large distances from waste dumps or wastewater treatment plants.

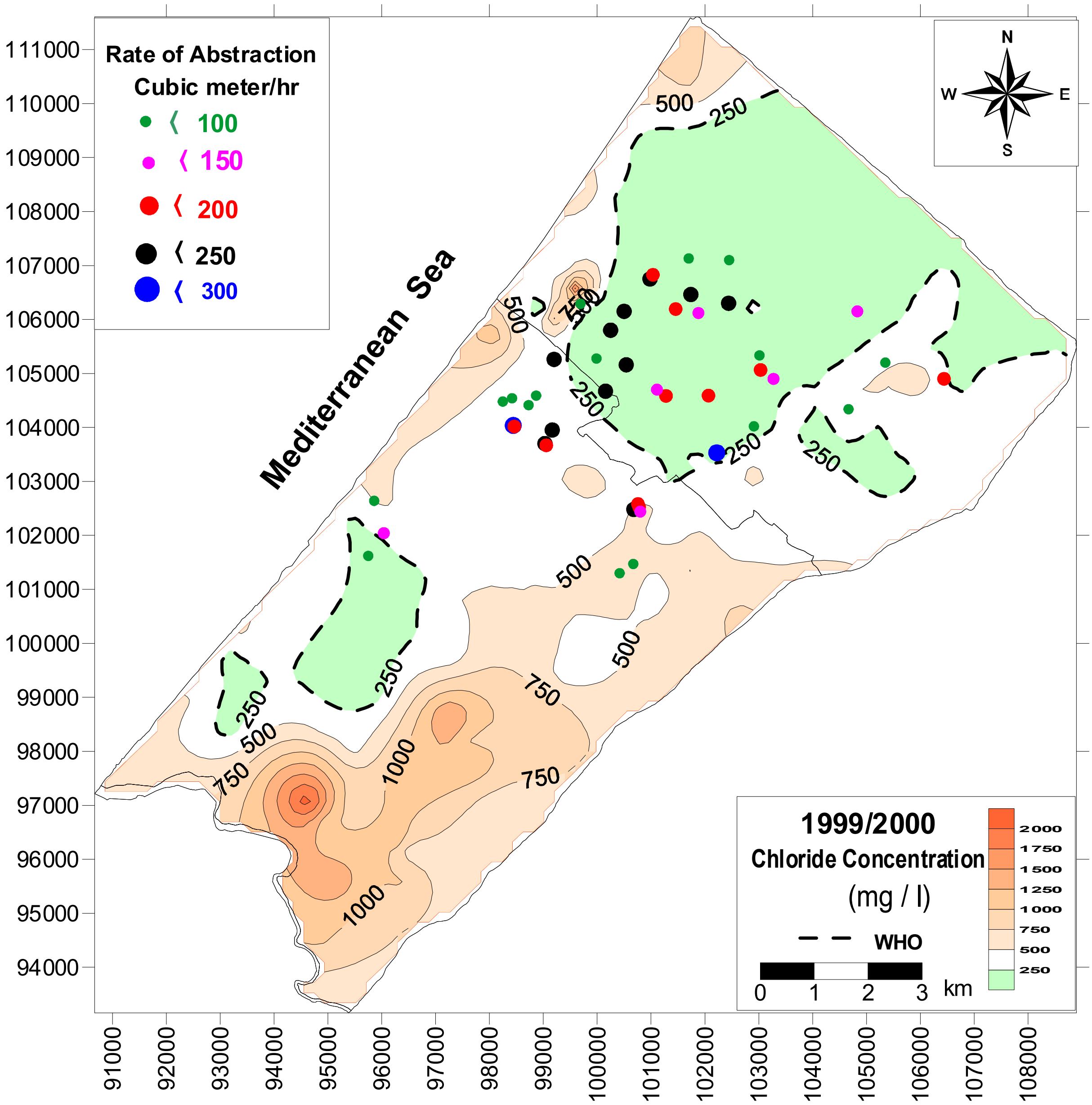


Figure (5.21): Overlay between chloride concentration map and rate of abstraction map (1999/2000)

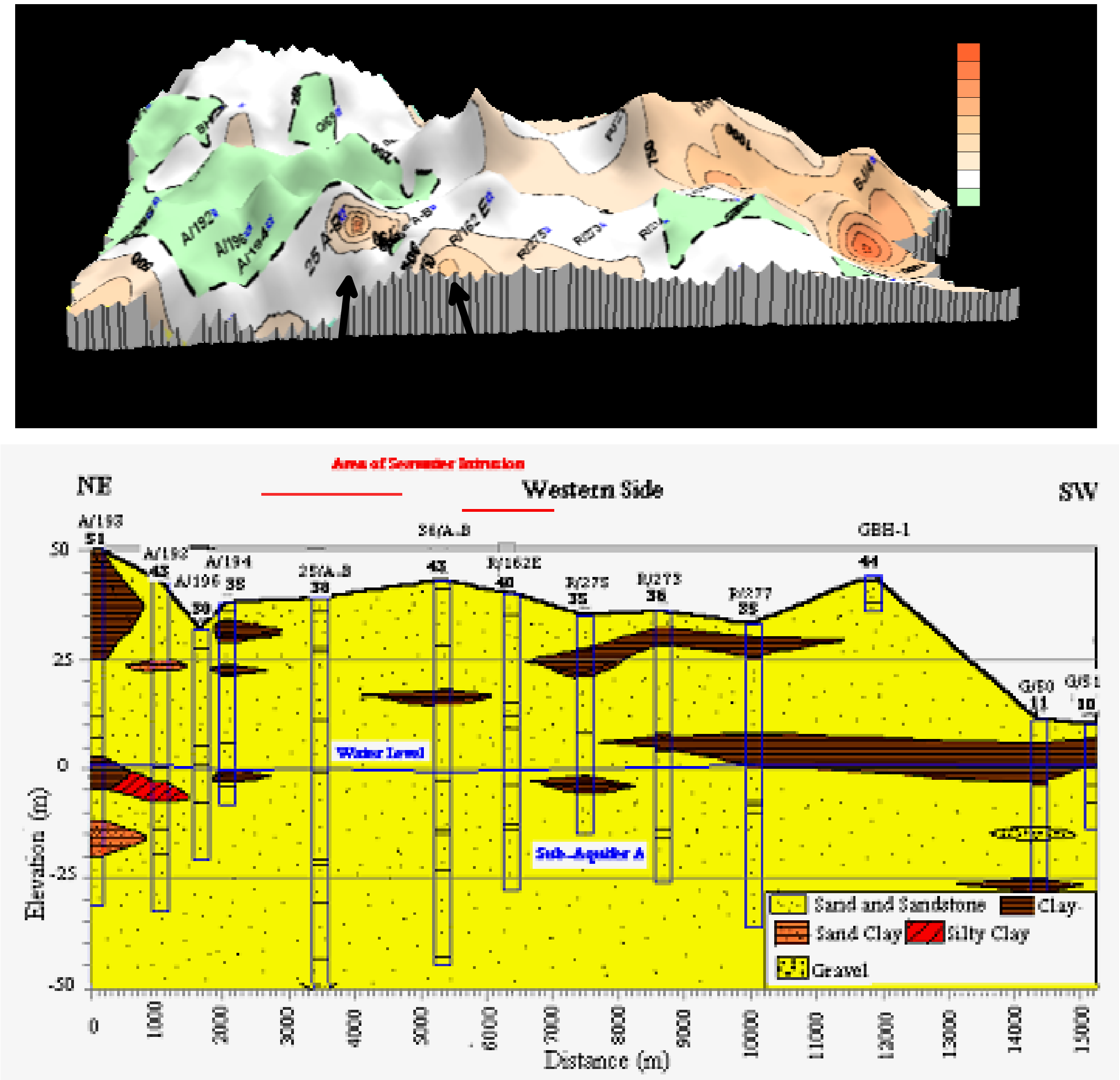


Figure (5.22) Area of seawater intrusion in the western part of Jabalia Town/Gaza City (1999/2000)

Chloride Map (2003/2004)

Data of 206 wells were used for drawing this map (figure 5.23). There were 80 freshwater wells (39%) with chloride concentration (< 250mg /l) and most of them also in the North Governorate. This percentage of freshwater wells is less than the proceeding stage.

This stage showed a rapid deterioration in some areas mostly along the seashore borders and under the urban and agricultural areas in the middle part of the study area. The drawn map shows higher concentration of chloride in several parts of the aquifer exceeded 1000mg /l and reached to 3346mg /l at the western part of Jabalia Town (Well E/85) next to seashore line. The areas of freshwater decreased especially in the North Governorate from its eastern and western sides to reach about the half of the total area. In the Gaza Governorate, freshwater area still occupied a limited area around Netsareem settlement before.

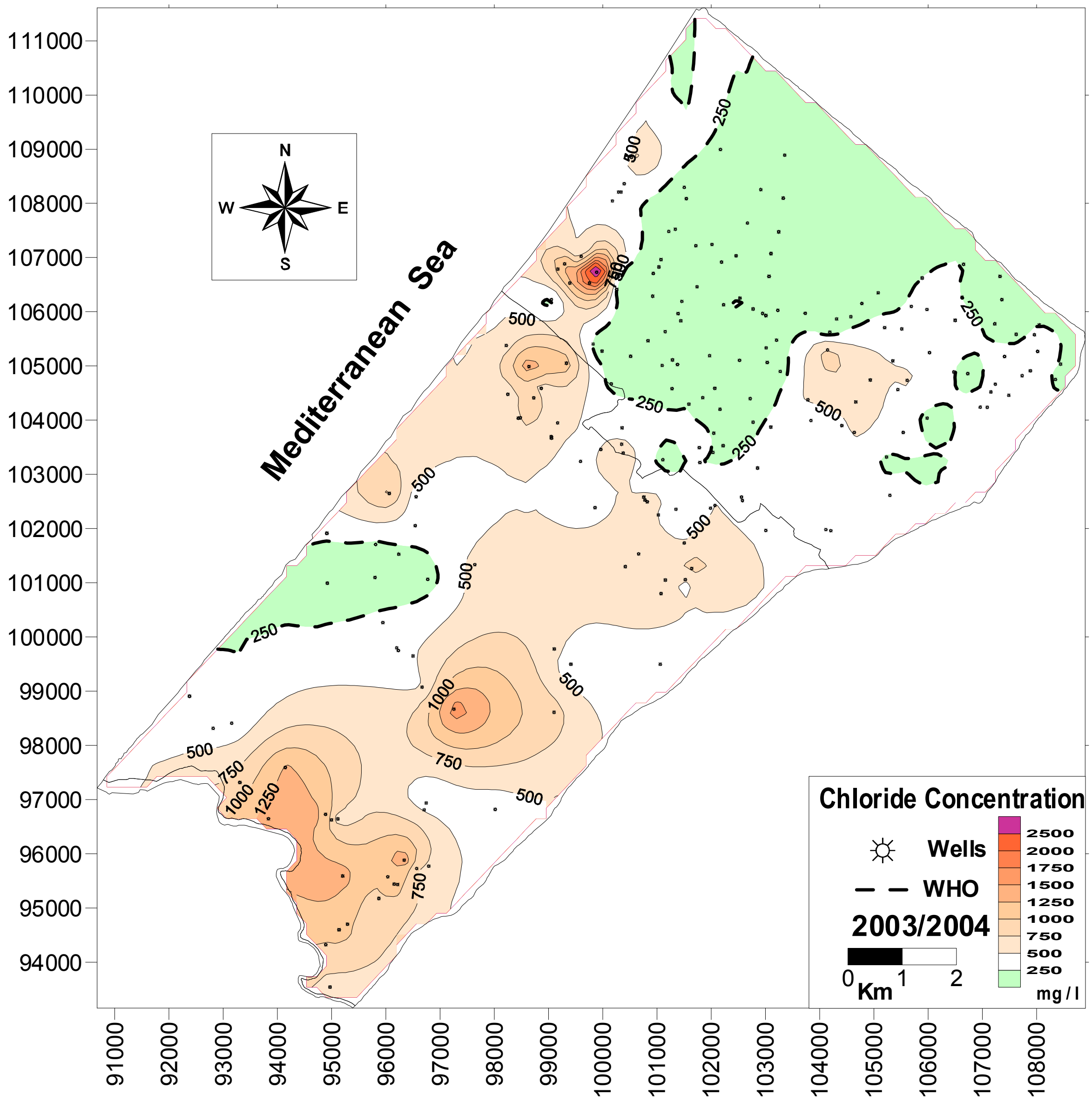


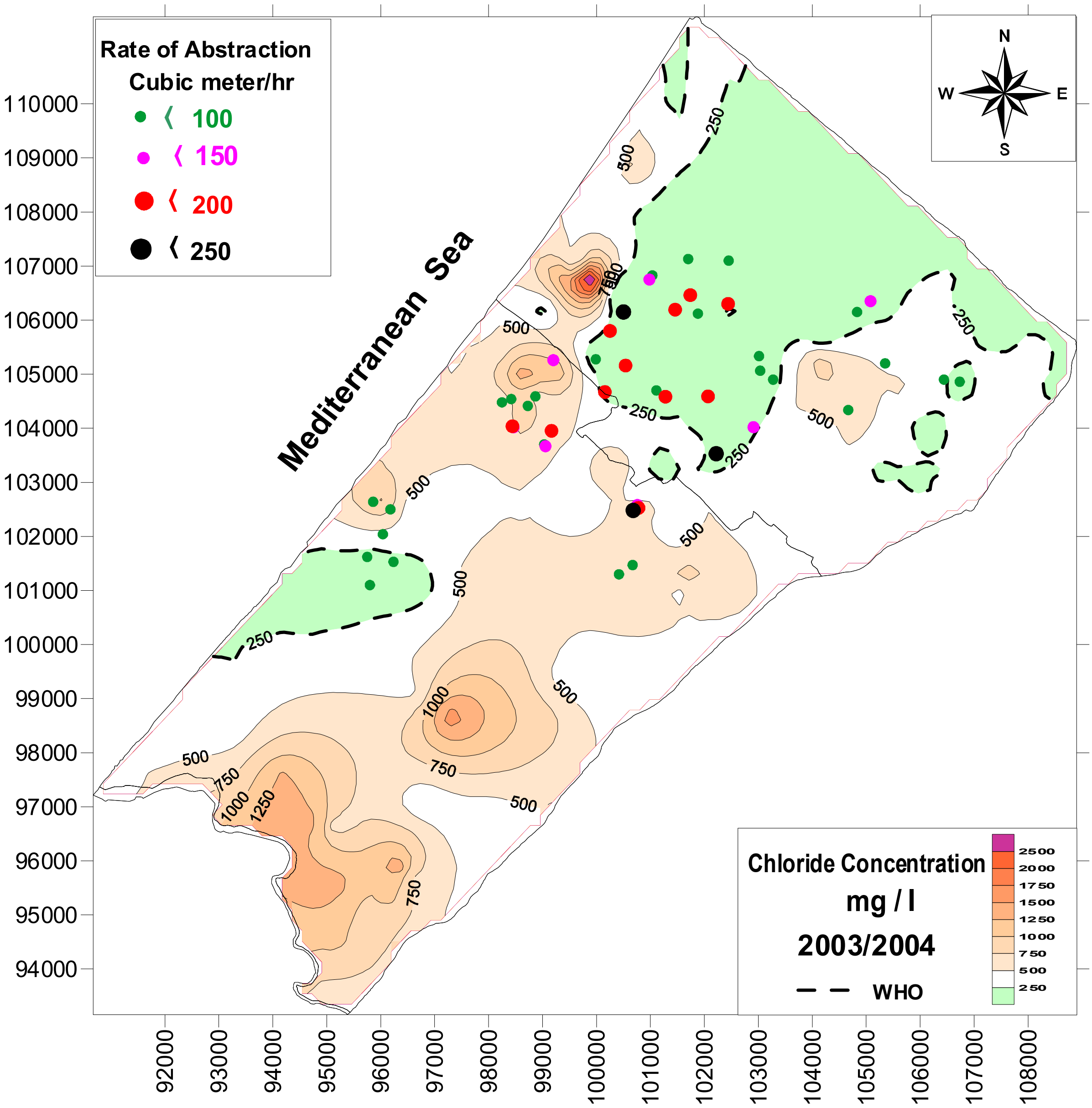
Figure (5.23): A generalized chloride contour map (2003/2004)

Based on the factors that affected the groundwater chloride concentration distribution in this stage, it can be observed that:

The rainfall trend in this year was in opposite direction where its distribution generally decreased to the northern direction with total amount of rainfall (58Mm^{3}). Consequently, the deterioration in chloride concentration in the north was more rapidly than in the south in the middle and western sides of the study area Meanwhile, there was an improvement in the southeastern part of the study area both in water level and chloride concentration. This improvement is attributed to the presence of a wide scorched lands where the recharge by rainfall became higher while the abstracted water from agriculture wells nearly decreased or stopped. Also, some improvements in chloride concentration appeared along the eastern side of the study area. In spite of this trend of rainfall in this year, the best water quality is still found under the sand dunes areas in the north but with a smaller area. This is because of the fluctuation of rainfall. Rainfall amount was in trend of increase from 1998/1999,till it reached to the highest value in 2002/2003 in all stations to replenish groundwater especially through sand dune areas at the north. Yet, in spite of dilution effect with this trend of increase in rainfall, the concentration of chlorides have continued to increase.

There is a deterioration in chloride concentration beneath the urban area under Gaza City with the increasing in population and their water demand add to the decreasing in recharge area with expanding in the urban area. Due to the increase of groundwater salinity, some wells were shut off and thus the pumping rate was reduced but the number of wells and their pumping duration increased to cover the population demand. So, in this stage (47%) of the municipal wells exceeded the recommended production rate (100m ^{3}/hr) and reached to less than 250m ^{3}/hr. This heavy pumping for domestic uses add to the decreasing in recharge area (with expanding in the urban area) and increasing in the density of agriculture wells in especially in the north, led to water level declines rapidly to reach about 4m below MSL and area of about 44km ^{2}. This situation has induced saline water from the sea or deep brines, to move into and contaminate the aquifer at western part of Jabalia Town/Gaza City. Some of the wells with high rate of production (> 150to < 250m ^{3}/hr) which are (D/74(231m ^{3}/hr), D/69(152m ^{3}/hr) and R/162L (171m ^{3}/hr)) were still next to the plume of high salinity at western part of Jabalia Town/Gaza City as clear in (figure (5.24). At this area the salinization process was rapidly increased by the seawater intrusion and up-coning of brines that leads to sharp rising in the chloride concentration. The chloride concentrations was above 3000mg /l and reached to 3346mg /l at well E/85at the western part of Jabalia Town far from the seashore by about 1.5 Km.At the western part of Gaza city (next to seashore) was above 1000 mg/l and reached to 1459mg /l at well R/16D far from the seashore by about 2 Km

The sandy lithological characters of this area accelerate the seawater intrusion. The four bold arrows in (figure (5.25) shows the areas of seawater intrusion. The new plume signed by an arrow in the area to the south is located within water level between (0 and 1 m) as shown in water level map (figure 5.13). As a result of the absence of water level monitoring wells in this area, as shown in (figure 4.2) , the degree of accuracy in drawing contour maps for water level is weak in it. So, the water level in this area could be below mean sea level and seawater intrusion with chloride concentration 1042mg /l at well (R/112 occurred. This plume of high concentration next to seashore line was confirmed through drawing chlorograph for well R/112 which shows fluctuation in chloride concentration with time.



(Figure 5.24): Overlay between chloride concentration map and rate of abstraction map (2003/2004)

Under agriculture area at the middle part of Wadi Gaza the chloride concentration was above 1000 mg /l and reached to 1353 mg/l at well F/109 and 1359 mg /l at well F/62 while the well F/53 with a concentration 2220 mg /l in 1999/2000 (may be closed or its data was not recorded).

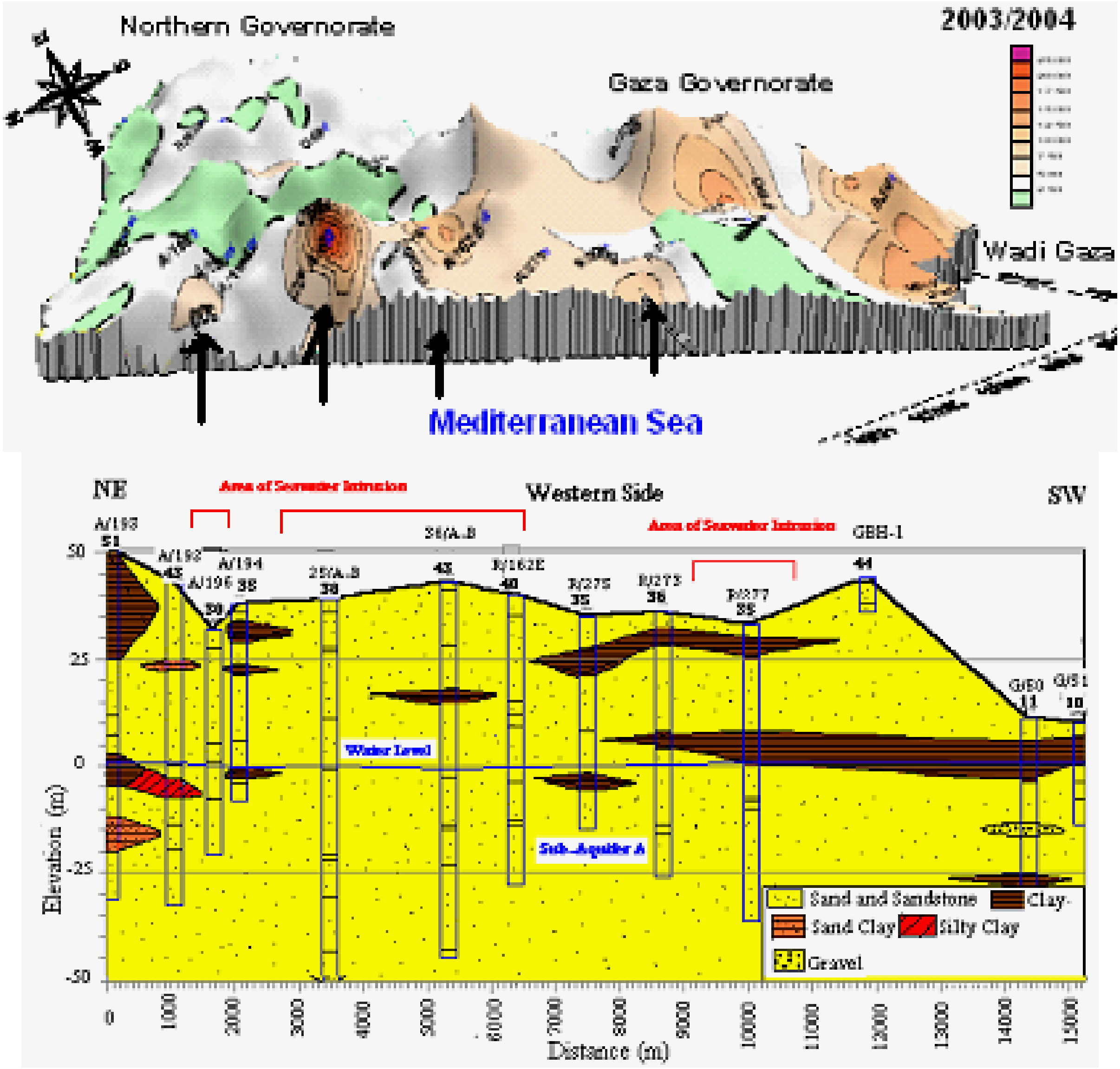


Figure (5.25) Area of seawater intrusion in 2003/2004

5.7.1.2 Chlorographs along the Seashore Line

In the study area where continuous heavy pumping causes a reduction of the water levels and forming a big cone of depression reached to 4 m below MSL, seawater intrusion or a vertical up-coning in summer season due to the increase of the abstraction rate of the pumping wells results in a salinity breakthrough. Thus a time-series of chloride concentrations can record the early evolution of relatively rapid salinization (Bear, et al 1999). Some of the municipal and agricultural wells that are close to the seashore line shows a sudden and/or fluctuating increase in the concentration of chloride with time from 1994 until 2004 as shown in (figures 5.26 and 5.27).

Since 1994, groundwater salinization increased, mainly in the northwestern part of the study area, and progressed inland through the area with little or without clay in its lithology to prevent rapid salinization as shown in (figures 5.22 and 5.25). This situation is confined through drawing chlorographs for the wells next to the shore line. Wells such as E/85, E/154, R/162D, R/112, E/144, E/60 E/61 E/62 E/85 E/37 E/65, E/35, E/65 and A/159 have been impacted by localized shallow seawater intrusion, as demonstrated by the chloride breakthrough curves. In well E/85, chloride values reached 3498 mg/l during the summer season of 2002. Reduced pumping as a result of the wet year 2002/2003 helped in recovering of the salinity in this well to about 2357 mg/l, but in 2004, chloride levels started increasing sharply once again to about 3346 mg/l. Well No. (E/80) is located about one km from the shoreline with chloride concentration is 12124 mg/l at 2003, and is presently shut down. Similarly, by well No E/65 that located at about 750 m far from the shoreline has chloride concentration increased from 558 mg/l in (1994/1995) to 595 mg/l in 1999, then sharply to more than 2,260 mg/l in 2001.

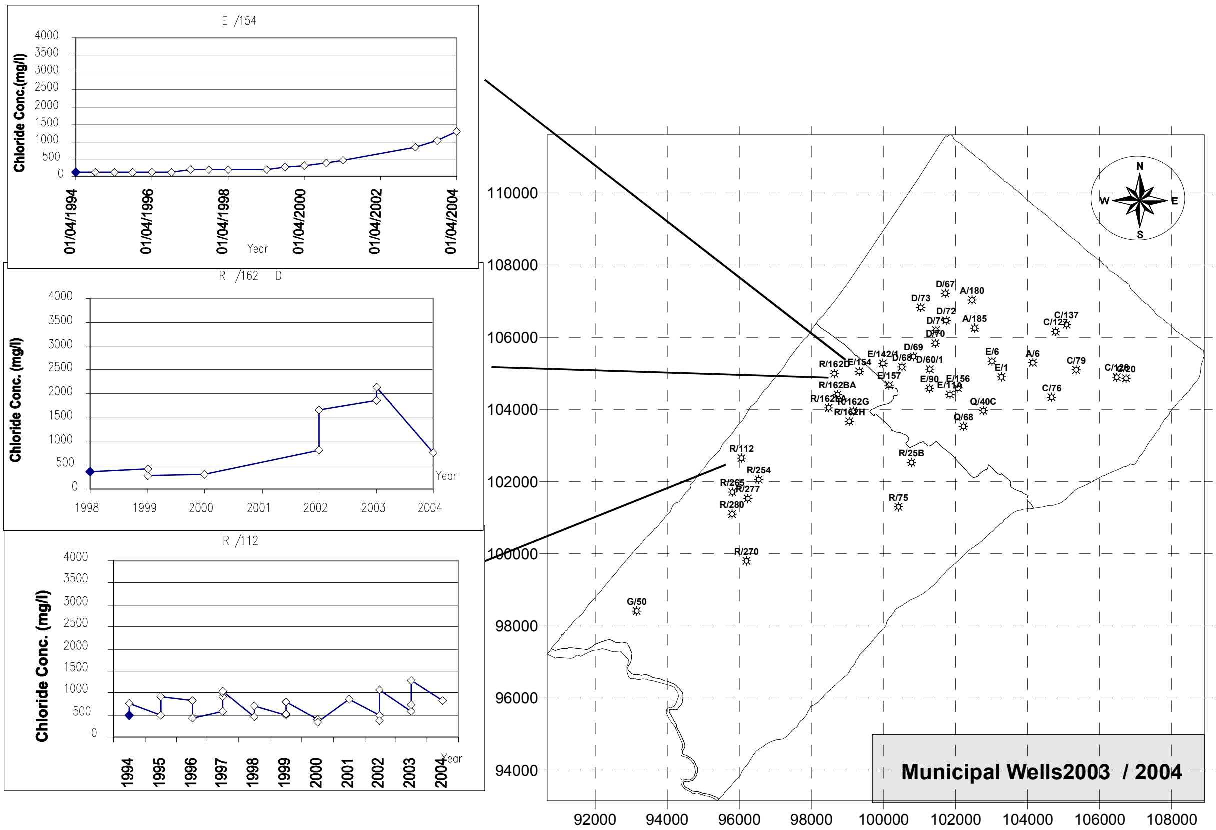


Figure (5.26): Municipal wells show sudden and fluctuating increase in salinity)

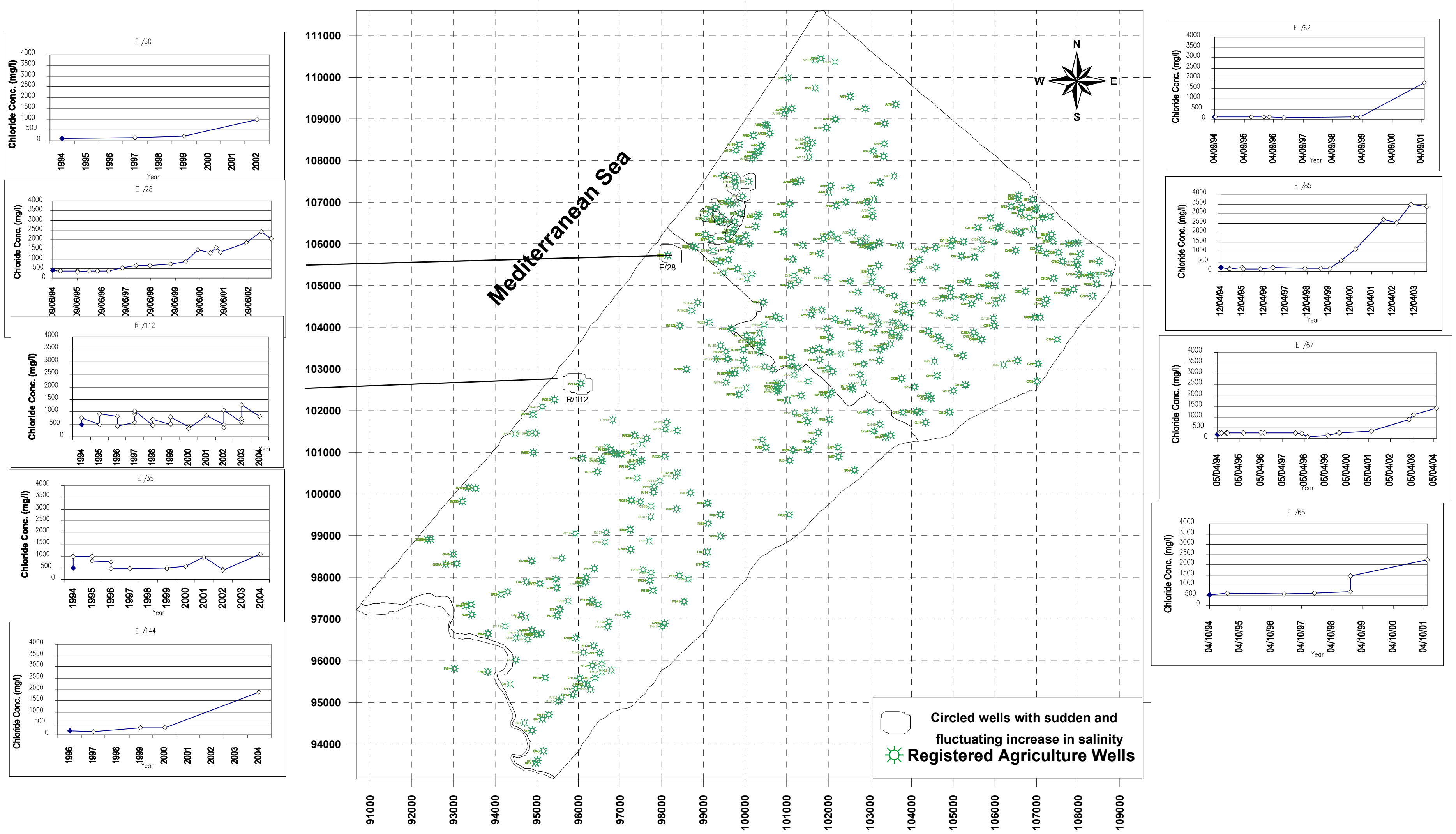


Figure (5.2): Agriculture wells show sudden and fluctuating increase in salinity

5.7.2 Nitrate Evaluation

To estimate the extent of pollution in the study area, maps of the most important water quality parameter, nitrate, are drawn using the available data for the three stages 1994/1995, 1999/2000 and 2003/2004. The spatial distribution of the mean values of nitrate concentrations in groundwater are presented in contour maps. The contour maps allow identification of possible nitrate problem areas and their related sources to isolate them (Robertson 1979).

Nitrate map (1994/1995)

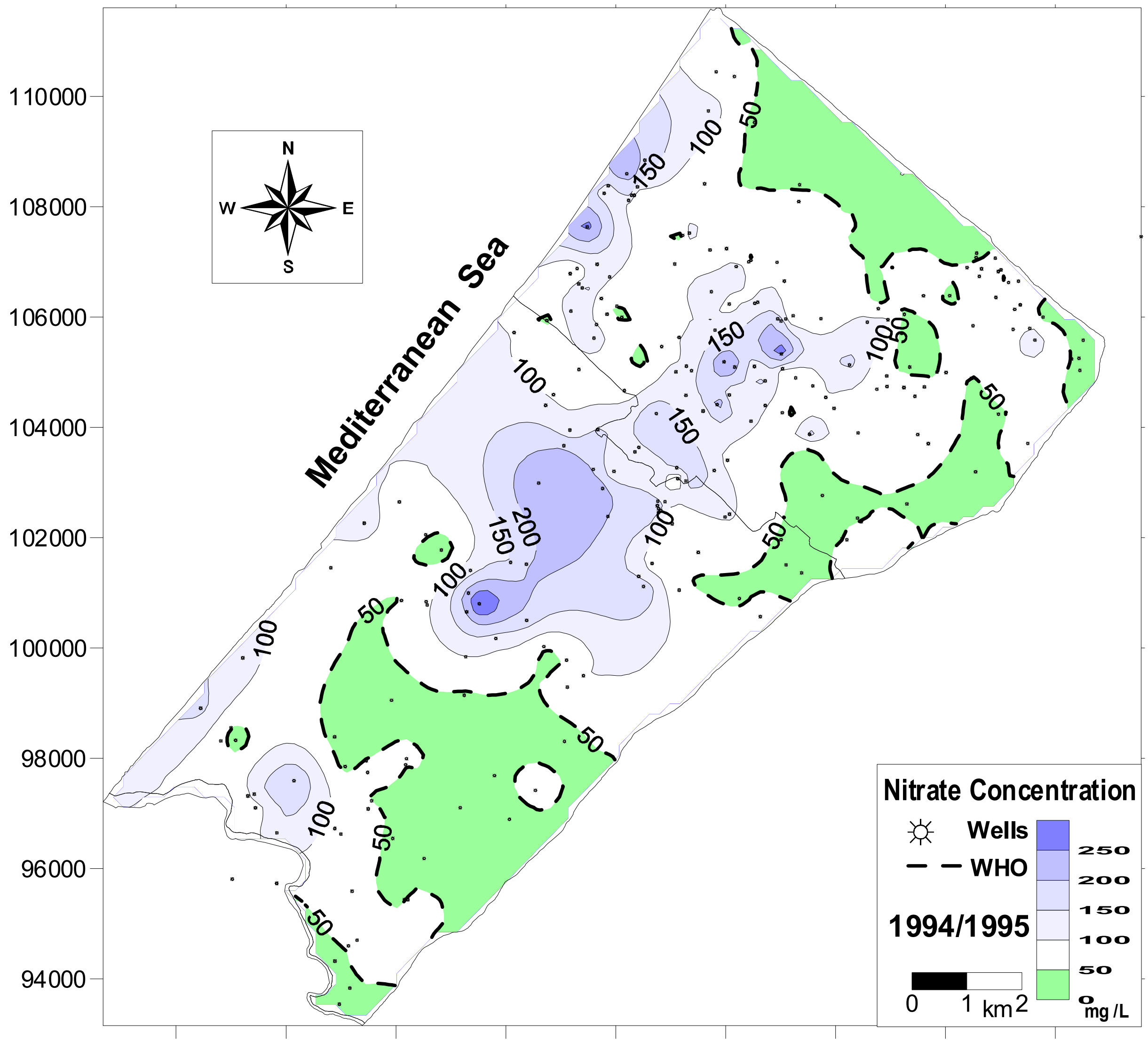
The spatial distribution of nitrate concentration in the study area is shown in (figure 5.28). This map incorporates results from about 233 wells , almost all of them are shallow (i.e., screened a few meters immediately below the water table). It is found that the nitrate concentrations of 72% of the wells exceeded the upper limit of 50 mg /l (the recommended maximum concentration limit from WHO,2003).

The nitrate concentrations are highly variable in the study area where it ranged from 20 mg \l (well R/116) to 290 mg \l (well E/1B) . It can be observed from the nitrate map that many parts of the shallow aquifer in this area are adversely affected by the nitrate pollution. A limited areas with nitrate less than 50 mg /l can be observed to the northeast and south of the study area.

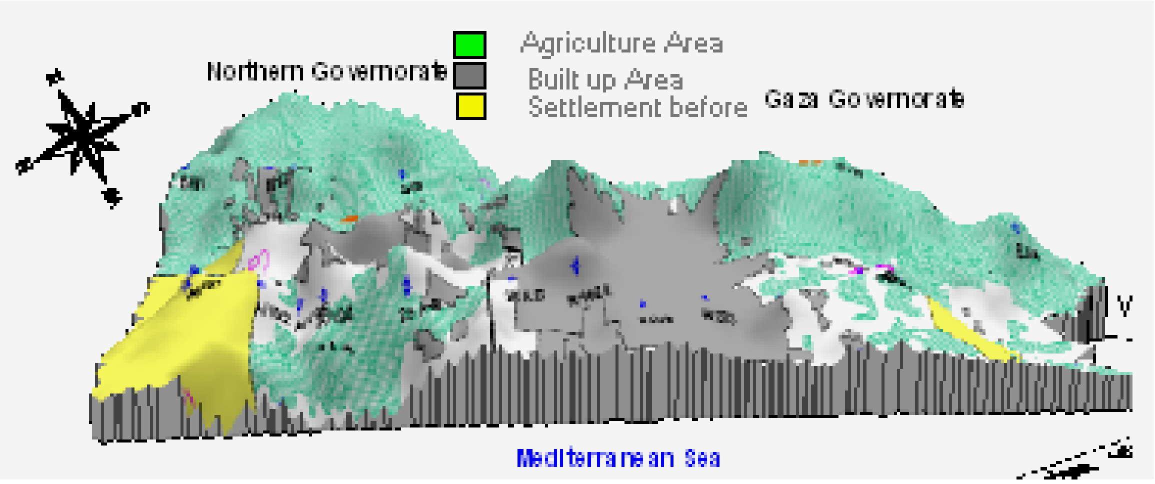
The best quality areas with concentration below 50 mg/ l are very limited and restricted in the eastern and northern parts of the North Governorate and to the eastern part of Gaza Governorate. The eastern parts characterized by less permeable soil types and a thick, continuous clay layer in the unsaturated zone as shown in the cross section (figure 5.18) . This can be an effective barrier to movement of contaminants. However, clay layers also limit the rate at which precipitation can percolate through the soil to recharge aquifers. The nitrate concentrations decrease in a north-eastward and north directions in the North Governorate and south-eastward direction areas eastward to the Netsareem settlement. .

When comparing the nitrate map with 3-D topography map and some land use map (figure 5.29) , it is found that nitrate plumes are originating under urban areas in Gaza City and Jabalia Town and under agricultural areas. The nitrate concentration under urban areas has significantly exceeded the maximum permissible limit, 50 mg /1 and reached to above 250 mg/l at central part of Gaza City with concentration reached to 277 mg /l (well R/147). Under urban areas of Jabalia Town the recorded concentration reached to 290 mg /l (well E/1B) and

265mg/l (well E/1C). The anomalies of nitrate concentration in the urban areas believed to be as a wastewater return flows through leakage from septic tanks and seepage from the unlined networks carrying municipal effluents. The use of fertilizers in urban areas increase nitrate concentrations in the groundwater. The most of anomalies were located under sand dunes with high permeability characters and low adsorption capacity. The quick migration of nitrate occurred in this depressed area as shown in (figure 5.30) where there is a little thickness of the unsaturated zone.



(Figure 5.28): A generalized nitrate contour map of the study area for (1994/1995)



(Figure 5.29): overlay between 3-D topography map and some land use map

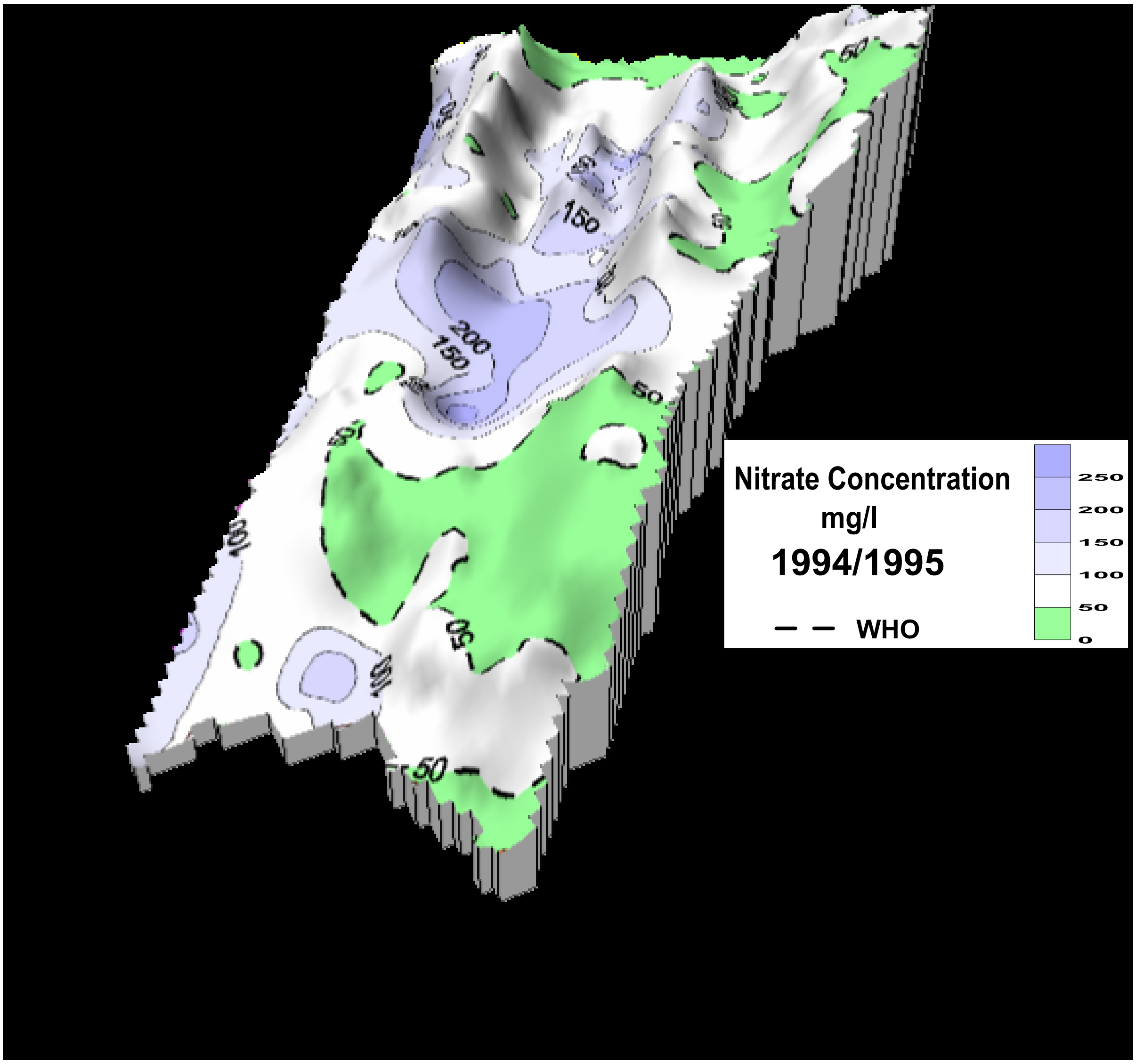


Figure (5.30): An overlay between 3-D topography map and nitrate map

Nitrate pollution outside the urban area originates mainly from agricultural activities. The highest nitrate concentrations were observed in the agricultural areas at the west of the North Governorate. The concentration exceeded 250mg /l and reached to 275mg /l (well E/73) west of Jabalia Town and 240 mg/L (well A/89) west of Beit Lahia Town. This high concentration is believed to the following reasons: 1) The intensive agricultural activities. 2) wastewater return from septic tanks because of absence of propersewer system in this area. 3) The presence of sand dunes with high permeability and low adsorption capacity. 4) Irrigation return flow in area of poorly irrigated system. 5) The quick migration of nitrate in this depressed area. 6) This area received the highest amount of rainfall in this year as shown in (figure 5.3) 7) The greatest density of wells as shown in (figure 4.5) were located in this area. 8) the unsaturated zone is little in its thickness and mainly of sand and sandstone without or with little clay lenses to retard nitrate mobilization to groundwater.

Under the agricultural areas at the middle and western part of Wadi Gaza, the concentration reached to 205mg /l (well F/43) at the middle and at the west to 160mg /l (well G/42). This high concentration may be attributed to the substantial increase of nitrogen fertilizers application. The high value of nitrate concentration next to Wadi Gaza may be due to direct leaching of untreated sewage effluents of a municipal sewage. This effluent, which is rich in organic nitrogen, is discharged into the Wadi Gaza directly without treatment. Nitrates get leached through the subsoil to the groundwater reservoirs.

Nitrate Map (1999/2000)

The nitrate concentration map (figure 5.31) incorporates results from about 242 wells . Nitrate concentrations of 78.5% of wells exceeded the upper limit of 50mg /l. It can be observed from this map that there is a continuation in deterioration in large part of the study area especially under the three proceeding areas which were urban areas of Gaza City/Jabalia Town and under agriculture area at the western part of North Governorate and at the middle part of Wadi Gaza. The concentrations of the nitrate compounds in groundwater ranged from 14mg \l at well (Q/8) east of Jabalia to 318mg \l at well (R/197) at the middle part of Gaza City. On the other hand there was a limited improvement at the eastern part of Gaza City/Jabalia Town. This confirm that the water comes from the occupied areas in the southeast with direction of water flow has almost nitrate concentration less than 50mg /l.

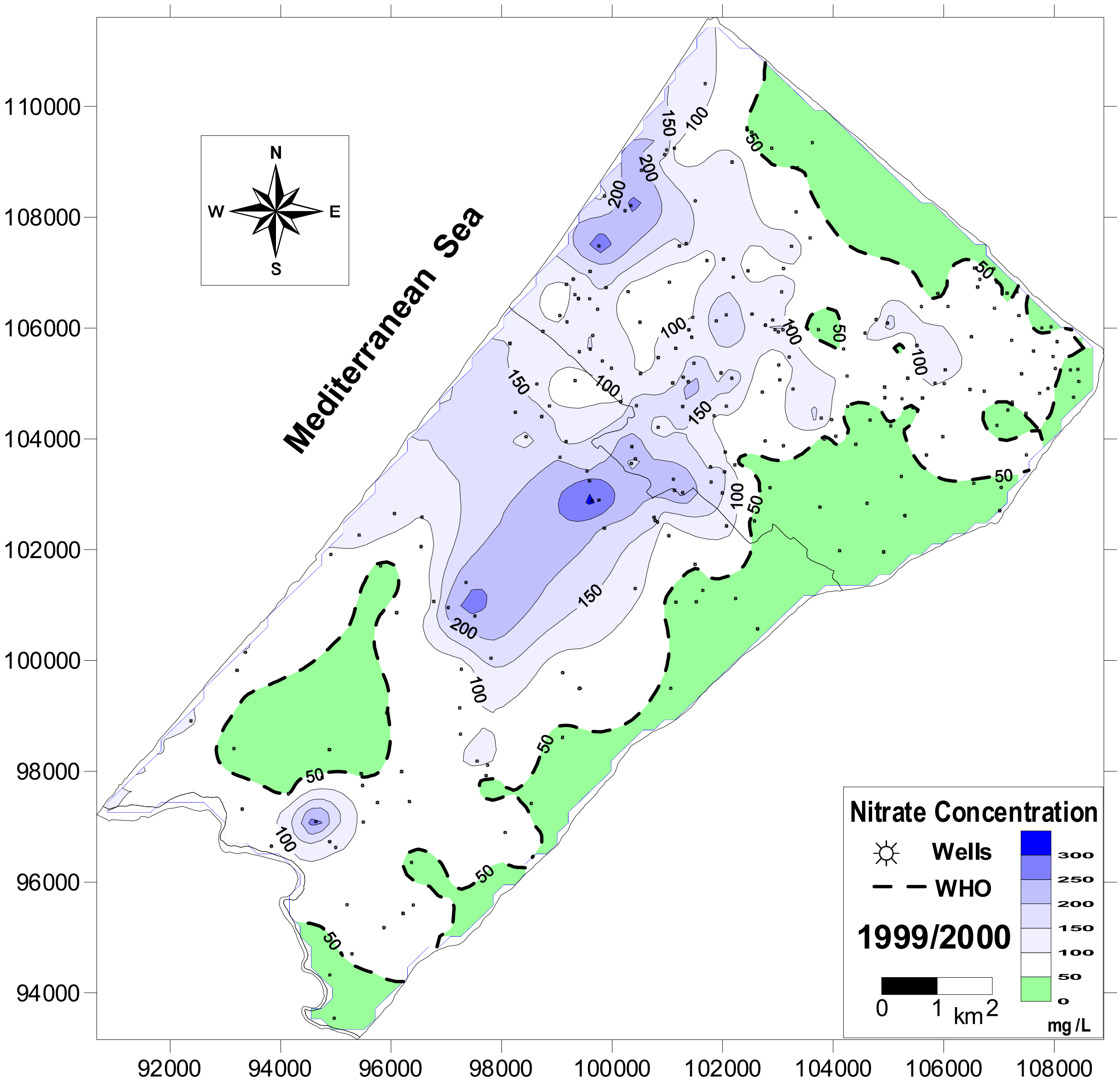


Figure (5.31): A generalized nitrate contour map of the study area for (1999/2000)

Under urban areas the nitrate concentrations reached its highest at the middle part of Gaza City with values 318 mg\l (well R/197), 301 mg/l (well R/199), 270 mg/l (R/185) and 252 mg/l (well R/147). Under these areas there was some improvement in the extent of nitrate pollution as a result of covering a wider area with the sewer system. Under agriculture area at the western part of North Governorate, (signed by two arrows in (figure 5.32) in the overlay maps, the concentration reached to 288 mg/l (well E/158) and 278 mg/l (well A/92). This high concentration in this area was a result of many reasons that mentioned before This deterioration increased rapidly close to middle part of wadi Gaza with concentration reached to 304 mg/l (well F/53). The nitrate concentration around the Beit Lahia WWTP is above 50 mg/l that reflects the impact of this plant as a point source of pollution on the aquifer quality. Notice that there is a little data (about 11 well for this stage) around the plant to declare its true impact on the aquifer.

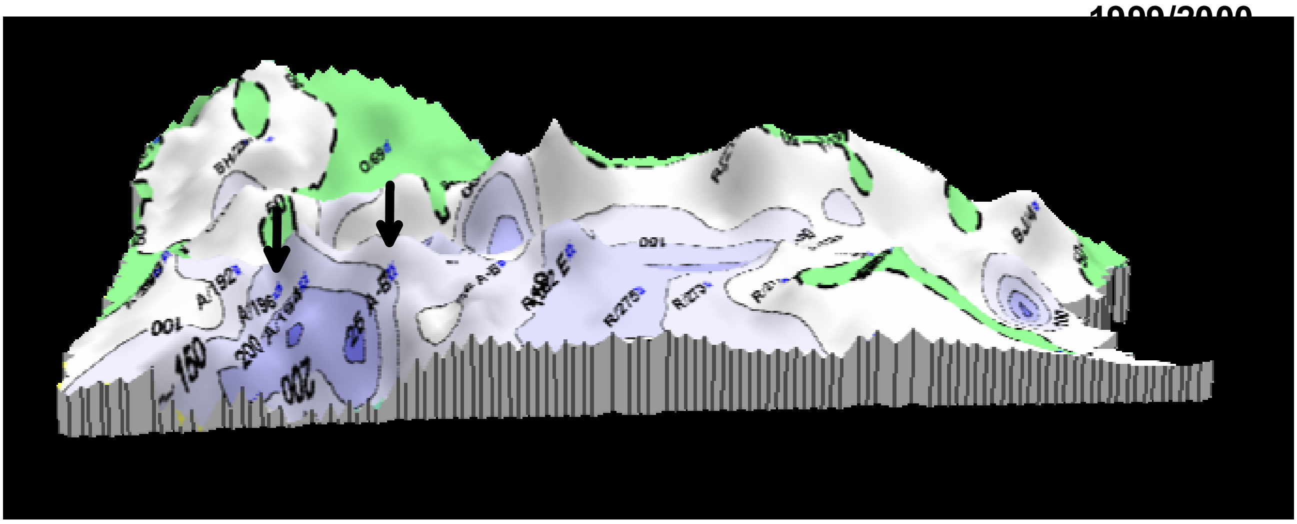


Figure (5.32): An overlay between 3-D topography map and nitrate map

Nitrate Map (2003/2004)

In this stage from 205 wells, few wells remained unaffected by high nitrate levels, and only about 14.5% of the wells remains below the WHO drinking water standard (50 mg /l). The concentrations of the nitrate in groundwater ranged from 15-432 mg \l. In most wells and areas, nitrate concentration is increasing, in some cases rapidly. It can be observed from nitrate concentration map, (figure 5.33), that the low concentrations area were at eastern part of the study area and to the north east of it. The lowest value was 15 mg /l is measured in well (Q/8). The high nitrate concentrations were measured in the western part of the North Governorate close to seashore where it exceeded 400 mg /l and reached to 432 mg /l (well A/93) and 422 mg /l (well A/124) which signed by two arrows as shown in (figure 5.34) in the overlay map. Under the urban areas the plume between Gaza City and Jabalia Town has expanded with the expanding in the urban areas with some improvement in the nitrate concentration as a result of covering a wider area with the sewer system. The nitrate concentration increased in limited parts to above 350 mg /l and reached to 388 mg /l (well E/114A) in Jabalia Town. The small area at Wadi Gaza has a few data so it is not clear in this year. Artificial contour lines were drawn for settlement area and it is found that the nitrate concentration is in the range between 100 to 150 mg /l which is probably due to agricultural activity in the settlement area.

A new area is observed with high concentration above 300mg/l around the area of infiltration basins of GWWTP where it reached 318mg /l at well (R-I-54) . This declares the serious impact of these basins on groundwater quality deterioration in this area. On the other hand the wells around Beit Lahia WWTP has not monitored this year in spite of the expanding of its lake on the sand dunes that means more percolation for nitrate to the aquifer in this area.

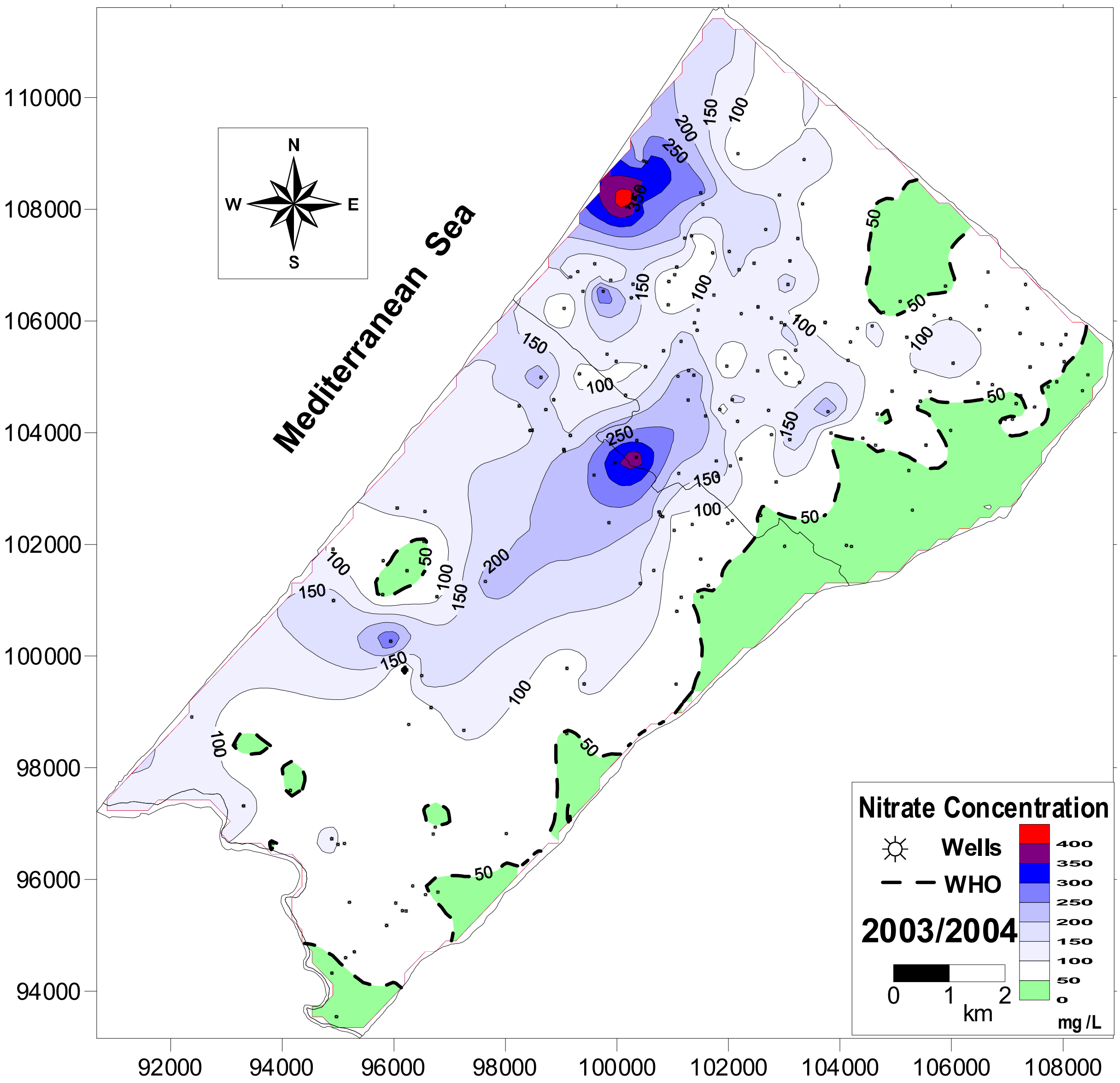


Figure (5.33): A generalized nitrate contour map of the study area for (2003/2004)

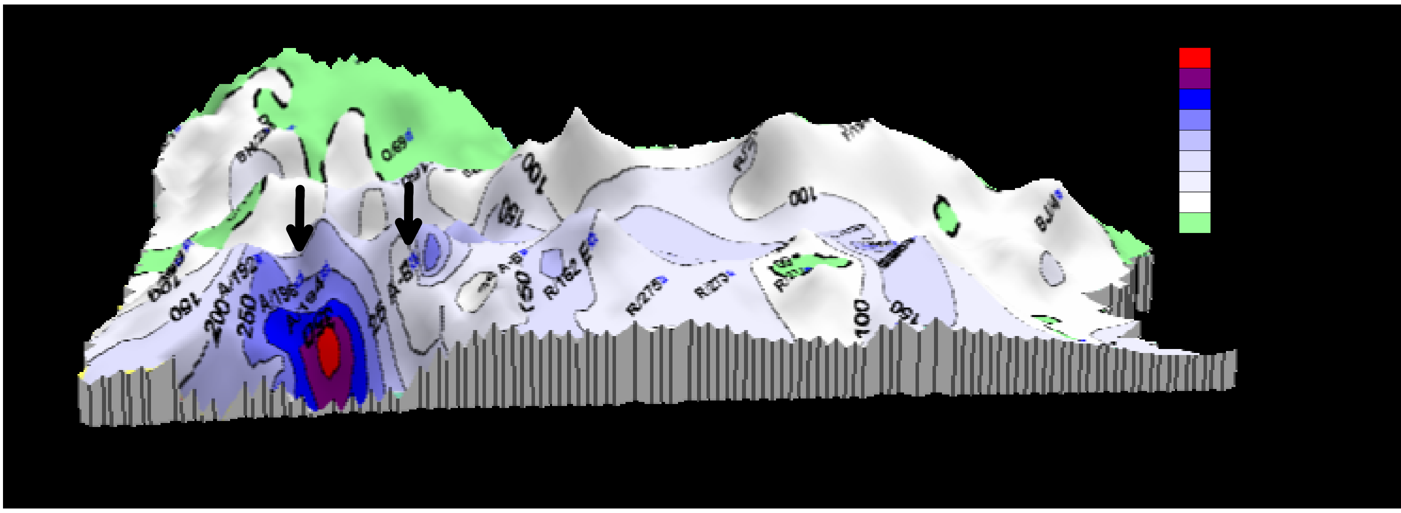


Figure (5.34): An overlay between 3-D topography map and nitrate map

From the three water level maps and nitrate maps it was found a type of concidence between the deepest part of cone of depression and areas of lower nitrate (50 to 100 mg /l) while the areas around it with higher concentration. This may be attributed to the rate of abstraction that would increase the hydraulic gradients around the well and could cause more water to be drawn from areas with lower nitrate concentrations. Unfortunately, the surrounding areas have higher level of nitrate and this area of lower concentration was reduced with time. So, the cause of low concentration may be due to the well depth in this area where its water level is declining with time that leads to abstract water from deeper parts where nitrate concentration decrease with depth.

Chapter (6)

Conclusions and Recommendations

6.1 Conclusions

The northern part of coastal region Gaza Strip, Palestine, considered as one of the most densely populated areas in the world with population density 5778 capita / km^2. Severe deterioration of the quality of groundwater resources has been occurred in this area as a result of overexploitation of the groundwater and improper environmental management conditions. In this area, there are many anthropogenic activities that impact the quality of this immensely important resource. These conditions have led to salinization and pollution of the aquifer. Climatic and hydrological conditions, changes in the amount of groundwater abstracted, groundwater-level fluctuations, aquifer lithology and the topography of the study area with urban and agricultural activities has been affected groundwater quality distribution. After analysis of data for 9 hydrological years (1994/1995 – 2003/2004) through three stages1994/1995,1999/2000 and 2003/2004 the following conclusions could be achieved:

قال تعالى (ظهر الفساد في البر والبحر بما كسبت أيدي الناس.. (41)) الروم

(Pollution has appeared on land and at sea because of what man's hands have accomplished…(41) Arrum.

- This immensely important resource is facing a huge and accelerated salinization with chloride and pollution with nitrates mainly as a result of human activities.
- Due to high levels of salinity and nitrate pollution, most of the groundwater is unsuitable for both domestic and agricultural uses.
- Variations in chloride and nitrate concentrations between the three stages were attributed to: (1) recharge conditions of the groundwater, (2) the changes in the distribution and concentration of the pollution sources, (3) changes of meteorological conditions (precipitation, evaporation), (4) groundwater level fluctuation, and (5) changes in the amount of the groundwater abstracted from wells.
- The approach of using hydrological year data helped in making a complete and accurate correlation between groundwater quality situation (spatially and temporally) with its only source of freshwater (rainfall).

6.1.1 Salinity Problem

The salinization of the coastal aquifer is represented by chloride. Analysis of the chloride maps and the chlorographs leads to the conclusion that:

1. Salinization processes has been occurred along the western and eastern borders, as well as in internal areas of the aquifer forming a significant number of discrete salinity plumes.
2. The percentage of salinized wells with chloride concentration (> 250 mg /l) increased from (55.3%) to(58.2%) and (61%) at the three stages respectively.
3. Freshwater areas (< 250 mg /l) are bigger in the north than in the south as a result of higher rainfall amounts and wider areas of sand dunes that act as a natural filter for the percolated water to the groundwater in the north.
4. The lithological characters increased salinity areas in the west.
5. The salinization rate was lower between the second and the third stage because the area passed with a wet period reached its highest value of rainfall in 2002/2003 after a dry period of decreasing rainfall reached its lowest in 1998/1999. This wet period has played a role in dilution and decreasing the speed of salinization with time.
6. The rainfall trend in the third stage was in opposite direction to its general distribution. This distribution accelerating the salinization in the north than in the south. Meanwhile, there was an improvement in the southeastern part of the study area both in water level and chloride concentration and along the eastern side in chloride concentration as a result of wet period of rainfall.
7. This improvement in the southeastern part of the study area is attributed to the presence of a wide scorched lands where the recharge by rainfall became higher while the abstracted water from agriculture wells nearly decreased or stopped.
8. The high rate of pumping above the recommended was 64.5% of the municipal wells in the second stage and reached to about 250 m^3/hr. Most of the higher ones were at the western part of Jabalia Town / Gaza City next to plume of high salinity. It decreased to 47%, in the third stage but the number of abstraction wells and their duration of production has increased to cover the population demand. The higher ones like D/74 (231 m^3/hr) and R/162L (171 m^3/hr) were still at the same area.
9. This Poor hydrological management of high well density of agriculture wells especially in the north and high rate of abstraction of municipal wells add to the dry period has accelerated the formation of big and deep cone of depression with declining of water levels till it reached below 4 m below MSL in 2003/2004. The area below zero level of

this cone has expanded rapidly from 2 km^2 to 35km ^{2} to 44km ^{2}. So, the hydraulic gradients have been significantly reversed (from the sea) and leads to the seawater intrusion and up-coning of brines with time especially in the western areas of Jabalia town and Gaza City next to the seashore.

10 The seawater intrusion and up-coning of brines leads to forming plumes of high chloride concentration observed clearly in chloride contour maps for the three stages. They raised the chloride concentration as recorded in the third stage to 3346mg /l at well E/85 in the western part of Jabalia Town far from the seashore by about 1.5Km and to 1459mg /l at well R/162D in the western part of Gaza City far from the seashore by about 2 Km

11 Confirming on seawater intrusion, some of municipal and agriculture wells close to the seashore line shows a sudden and fluctuating increase in the concentration of chloride with time from 1994 until 2004 while others closed.

12 The lithological characters of little clay lenses interbeded among sands and calcareous sandstones at the western side of Jabalia Town and Gaza City played an important role in accelerating landward penetrating of seawater intrusion.

13 The highest value for chloride concentration in the first stage 1994/1995 was in agricultural area next to the middle part of Wadi Gaza 1890mg /l (well No. F/43) while the highest one under urban areas in Gaza City reached to 1379mg /l (well R/93).

14 In the second stage 1999/2000, the salinization process was rapidly in western of Jabalia Town / Gaza City. The highest value for chloride concentration was 2014mg /l and recorded at well E/64 at the western part of Jabalia Town while the highest one under agriculture areas at the middle part of Wadi Gaza reached to 2220mg /l at well (F/53). This means that agricultural activities beside disposing of untreated wastewater in Wadi Gaza were still the major contributor to the chloride load followed by seawater intrusion.

15 In the third stage, the highest concentration was 3346mg /l at well E/85 at the western part of Jabalia Town far from the seashore by about 1.5Km . This means that seawater intrusion was the major contributor to the chloride load.

16 As a result of the long-term salinization process, chloride concentration in several parts of the aquifer exceeded 1000mg /l. This is much higher than the upper acceptable limit for drinking water in Palestine (500mg /l) and so it is not fit to be supplied for human consumption or irrigation purpose without proper treatment.

17 The intensive use of agrochemicals in the depressed and little rainfall agricultural areas as next to the middle part of Wadi Gaza leads to the continuity in salinization.

18 Salinization sources are mainly due to seawater intrusion and upconing of deep brines, lateral inflow of naturally brackish groundwater from occupied area in the east, agriculture activities, wastewater return from septic tanks, inappropriate design of wastewater treatment plant (WWTP) and untreated wastewater disposing in Wadi Gaza.

19 West of Gaza City, there are five production municipal wells which affected the water level and leads to seawater intrusion. This is recorded from a salinity plume in the chloride map 2003/2004 and a fluctuation in chloride concentration for the municipal well R/112 On the other hand, the declining in water level in this area in the water level map was obscured due to the absence of monitoring water level in this area.

6.1.2 Nitrate Problem

The pollution of the coastal aquifer is represented by nitrate contour maps for the three stages 1994/1995,1999/2000 and 2003/2004.The main findings of these study are :

1. The quality of groundwater has been impaired due to pollution processes forming a significant number of discrete pollution plumes. Its worst in the urban areas than other areas
2. The level of nitrate contamination has been rising so rapidly. The percentage of polluted wells with nitrates exceeded the upper limit of 50 mg / increased from (72%) to (78.5%) and (85.5%) at the three stages respectively. So, most of the water wells in the study area are no longer adequate for human consumption.
3. The rainfall amount that increased after 1998/1999, has played a role in increasing the pollution rate from 6.5% to 7 % through the three stages.
4. Polluted areas with nitrate (>50 mg /l) are bigger in the north than in the south as a result of higher rainfall amounts and wider areas of sand dunes where nitrates are highly soluble and very mobile and usually not adsorbed much by sand soil and therefore can leach into groundwater easily.
5. The nitrate concentration under urban areas was the highest in 1994/1995 at central part of Gaza City reaching 277 mg /l and Jabalia Town reaching 290 mg /l. The highest nitrate concentrations within agricultural areas recorded at the North Governorate where it reached to 275 mg /l west of Jabalia Town and to 240 mg/l (well A/89) west of Beit Lahia Town. This depressed area is characterized with intensive agricultural activities; covered by sand dunes received the highest amount of rainfall. It has greatest density of wells and its unsaturated zone is mainly of sand and sandstone without or with little clay lenses. At

the middle and western part of Wadi Gaza the nitrate concentration reached to 205mg /l (well F/43).

6. In 1999/2000, under urban areas the nitrate concentrations reached its highest at the middle part of Gaza City with values 318mg \l. Under these areas there was some improvement in the extent of nitrate pollution as a result of covering a wider area with the sewer system. Under agriculture area at the western part of North Governorate the concentration reached 288mg /l while close to middle part of wadi Gaza the nitrate concentration reached 304mg /l.
7. In 2003/2004 nitrate level exceeds 400mg /l in some areas particularly in Beit Lahia which characterized with intensive agricultural activities and absence of proper sewer system. The impact of infiltration basins of GWWTP represented in high nitrate concentration above 300mg /l. This declares the serious impact of these basins on groundwater quality deterioration in this area. On the other hand the wells around Beit Lahia WWTP has not monitored the year 2004 in spite of the expanding of its lake on the sand dunes that means more percolation for nitrate to the aquifer in this area.
8. This high concentration of nitrate in western part of the North Governorate in spite of, this area received the highest amount of rainfall through the study period is related to : 1) The intensive agriculture activities(highly intensive irrigated areas with uncontrolled and excessive use of agrochemicals). 2) The greatest density of wells in this area. 3) The presence of sand dunes with high permeability characters and low adsorption capacity. 4) Irrigation return flow in area of poorly irrigated system. 5) The quick migration of nitrate in this depressed area. 6) the unsaturated zone is mainly of sand and sandstone without or with little clay lenses to prevent nitrate mobilization to groundwater.
9. Wastewater from urban area is the major contributor to the nitrogen load followed by agriculture activities which spread out in a wide area in northern part of Gaza Strip.
10. Groundwater nitrate concentration is the lowest at eastern borders especially in the northern part due to water comes from outside the Gaza Strip which almost nitrate concentration less than 50mg /l (Almahalawe, 2004). The other reason is the higher thickness of the unsaturated zone about 50-90m with thicker thickness of clay beds and lenses than the western borders.

6.2 Recommendations

The rapid rate of population growth in the Gaza Strip and dependence upon groundwater as a single water source present a serious challenge for future political stability and economic development. So, hard effort should be applied to prevent the increase of deterioration of water quality in the area. Accordingly, the following recommendations could be made:

1. نوصي بما قال الله تعالى على لسان نبينا نوح (فقلت استغفروا ربـ م إنـه ـان غفارا (10) يرسل السما عليـ م مدرارا (11)) سورة نوح.

(saying ask forgiveness from your Lord ; He has been so forgiving ; (10) He will send rain to you in abundance (11) Noah

2. و نوصي بما قال الله تعالى (....... و لوا واشربوا ولا تسرفوا إنه لا يـ المسرفين (31)) الأعراف

(….. Eat and drink, yet do not overdo things ; He does not love the extravagant (31) Al–Aruf .

1. A spatial and vertical re-distribution of the municipal wells is a must now to avoid the seawater intrusion and upconning phenomena. This can be achieved by shifting some of agricultural wells, which has freshwater to be used as municipal wells or drilling new wells in the suitable locations of freshwater and use those with elevated nitrate concentration in irrigation to reduce the requirement for inorganic fertilizer applications.
2. These chloride maps with water level and rate of abstraction maps could help the regulator department in PWA for regulating the abstraction rate in the wells which are near to plumes of high chloride concentration.
3. Groundwater quality maps like chloride and nitrate maps and the parameters which have a direct relation with them like water level, rate of abstraction and rainfall distribution should be drawn based on hydrological year data. This is to join the groundwater quality situation with its only source of freshwater (rainfall). Consequently we will obtain a complete and accurate vision on the effect of this source with groundwater quality beside its effect on water level.
4. The chemical monitoring well should be increased and distributed well especially around B-L WWTP and Wadi Gaza with consistent on sampling periods. This will help in drawing the contour map much more accurate and comparing hydrological situations between separate periods.

5. The water level monitoring wells should be cover all the area especially the middle part of the Gaza Governorate especially next to the seashore line.
6. Make a subsurface lithological cross sections and diagrams covering all the area in order to delineate the more sensitive areas for pollution and seawater intrusion.
7. Re-distribution for rainfall stations to be more accurate and representative for the rainfall conditions in the study area.
8. Extra precautions in high permeable depressed areas.
9. Develop guidelines for groundwater protection zones around major potable water supply areas specifically focusing on chloride and nitrate sources.
10 Construction proper sewer system before any new urban area.
11 Carry out projects for artificial recharge using rainwater mainly in any new urban area and especially in disengagement areas.
12 The chloride and nitrate maps indicates the urgent needs to search for new water resources such as seawater desalination and using the treated wastewater for agricultural purposes and look for deeper aquifers with better water quality.
13 Reduction the water demand through: 1) Public awareness. 2) Improving the water system network efficiency. 3) Irrigation water should be managed through apply developed irrigation methods for more efficient use of water. 4) Prevent digging new wells and closing illegal ones.
14 Construction proper sewer system to collect municipal wastewaters and treatment plants to prevent discharge of wastewater to the aquifer system. This must be done according to vulnerability map.
15 The treatment plant in the northern area is located in area with moderate and high vulnerabilities. Accordingly, its removing is very important to protect this area from pollution.
16 Stopping the discharged wastewater to the Wadi Gaza as quick as possible to stop this crisis on the groundwater in this area.
17 Applying of fertilizers and pesticides should be according to crop requirement.

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