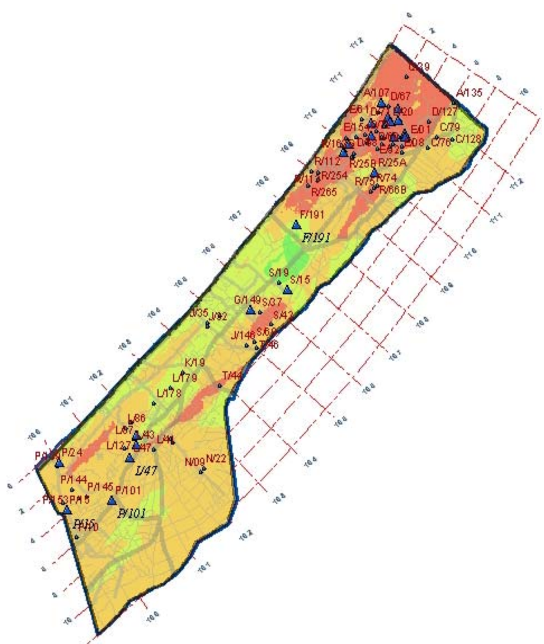
Islamic University of Gaza
Faculty of Engineering
Master Programme

Vulnerability of Gaza Aquifer to Pesticides Contamination

Using GIS-DRASTIC Index



Dissertation submitted in fulfillment of the requirements for the award of the degree of master degree in Water Resources Engineering

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Abstract

Vulnerability of Gaza aquifer for pesticides contamination has been examined using GIS based DRASTIC model. All physiographic and hydro-geologic data collected from concerned agencies have been carefully studied, arranged, tabulated in such format accepted by the GIS model, and utilized to produce the vulnerability to pesticides maps. As a result of DRASTIC model, 5,768 hectares (16%) of Gaza aquifer were found under severe vulnerability. 20,607 hectares (57%) were under high vulnerability. 8,973 hectares (25%) are under moderate vulnerability. The remaining small part which is 652 hectares (2%) were under low vulnerability. The most vulnerable area in Gaza strip is North and parts of Gaza area, so much care and monitoring have to be applied for the land use management. South area and east part of middle area were found under high vulnerability. The study shows that the man activities on the land can exert offensive impact on the level of contamination. On the other hand, if the provision of pest management has been followed, the vulnerable areas could be less contaminated.

To my wife and my lovely daughter

Ro'a, I dedicate this research

With Warm wishes

Acknowledgment

I have the pleasure to extend my appreciation and worm thanks to Dr. Abd Al-majeed Nassar for awarding me the chance to study the effect of organic pollutant on the Gaza aquifer, concentration on the sensitivity of the aquifer for pesticides contamination. Simultaneously, I would like to thank Dr. Ahmad Mughari for providing scientific bases and all means of support needed to collect live data regarding pesticides characteristics and related human activities in Gaza strip.

Following continuous support and encouragement by Palestine Water Authority staff, specially Eng Mazen Al Banna, I have to thank them very much for facilitating the flow access to original hydro-geological data available in the PWA library.

I also would like to thank Eng. Ziad abu Zaid, for his full support and providing all needed data from pesticides section of MoA, regarding pesticides management in the Gaza strip.

I would like to thank all those giving much more support and encouragement to proceed with high rates and active modes.

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List of Abbreviations

1	AAR	Average Annual Rainfall
2	CAMP	Coastal Aquifer Management Plan
3	CRD	Cumulative Rainfall Departure method
4	DDT	Dichloro-diphenyl-trichloroethane insecticide
5	DEM	Digital Elevation Model
6	DRASTIC	Overlay Index model to evaluate GW vulnerability
7	DSS	Decision Support System
8	EIA	Environmental Impact Assessment
9	EPA	Environmental Protection Agency
10	ESP	Exchangeable Sodium Percentage
11	ETo	Crop Evapo-transpiration
12	GIS	Geographic Information System
13	GPS	Global Position System
14	GW	Groundwater
15	IDW	Inverse Distance Weighted
16	IPM	Integrated Pest Management
17	MCM	Million Cubic Meter
18	MoA	Ministry of Agriculture
19	MODFLOW	Model for water pollution contamination
20	NRC	National Research Center
21	PWA	Palestine Water Authority
22	SAR	Sodium Absorption Ratio
23	WHO	World Health Organization

CHAPTER 1

Introduction

1.1 Preface

The presence and the potential presence of pesticides in groundwater (GW) is a serious problem in many locations (Baalousha, 2006). So this process has to be ongoing *and periodically adjusted*. Before this study, there is little knowledge about whether Gaza aquifer is vulnerable to pesticides contamination and to which extent. Given the present excessive usage of pesticides in the Gaza strip and the importance of groundwater, an assessment of pesticide contamination in groundwater resources is appropriate (Close, 1993).

Once groundwater is contaminated, analyzing the problem and providing alternative water supplies can be quite expensive. Cleanup of groundwater contaminated by pesticides often is impossible. It may take decades for the contaminated water to flow beyond the affected wells due to slow movement of groundwater. Cold temperature and low microbial activity in the groundwater cause *degradation to occur slowly* than the surface (Trautman, 2006).

Environmental degradation, caused by excess use of tons of pesticides, threatens Palestinians' lives, if not properly solved, may pose and even threaten the well-being of the Palestinian population than the guns and bombs of the military conflict (Gry, 2006). So it will be feasible to have a very intensive intervention to reduce the burden of this pollution.

1.2 Problem Statement

Based on provision of Palestine ministry of agriculture, Pesticides are considered priority pollutants in Palestine. There are more than 400 officially registered pesticides in Israel (CEOHS, 1999). Most of them has been imported to Gaza strip legally or illegally. Excessive and uncontrolled use of dozens of pesticides caused qualitative problems to Gaza aquifer and topsoil (Shomar, 2006). Consequently, a severe water dilemma will appear in the near future from both quality and quantity aspects (Shomar, 2005). Pesticides may have adverse environmental effects if they are transported to groundwater and surface water, so the vulnerability of water resources to contamination of pesticides must be evaluated (Buttler, 2003, Stenemo, 2007).

There are no Gaza-wide maps showing areas that are vulnerable /or susceptible to pesticides contamination. These maps have very essential benefits for examining existing and potential policies for groundwater protection (Stenemo, 2007). The individual initiatives for tackling pesticides contamination to Gaza aquifer are, spatially and temporally very limited, and in bad need for the holistic assessment approach. Consequently, any future prediction for the level of pesticides contamination will be very difficult if not impossible. Here in Gaza strip, due to current un-stable political situation, one can not completely rely on the available data, which is at the most cases not completed and lacks for high level of confidence. There is no proper monitoring for existing wells, no routine lab testing for pesticides, no comprehensive database, and no national plans or strategies can be developed or applied. As a result, no appropriate models can be developed satisfactorily. This study will be an important step in vulnerability assessment to pesticides contamination; and the results will be integrated with originally existing data to enable stakeholders and decision makers for best pest management.

1.3 Research Objectives

The purpose of this vulnerability assessment is not only to create scientific insight, but also to provide a decision making tool based on best available data and good scientific judgment. More specifically, the objectives are to:

1) Develop a technique that utilize commonly available Geographic Information Systems (GIS) database to create GIS-based groundwater-vulnerability to-pesticides maps for Gaza strip.
2) To show how GIS can be used as a powerful tool for validation of both raw data and results.
3) Develop a scientific and dynamic database for pesticides used in the Gaza strip, concentrating on those of environmental degradation and risk on human.
4) Make available for decision makers the best options for possible land use with regard to vegetation and crop cover, based on the result of vulnerability process.

1.4 Contribution of Study

Due to the current situation in Gaza strip, part of the staff working in the concerned regulating surveillance and monitoring divisions can not repot for duties. It was very difficult task to get information or data from some officials who are not ahead of their duties. Moreover the required essential pesticides tests can not be performed locally, due to deficit in apparatus and standards, as informed by MOA's staff contacted. This study is an attempt in this critical situation, to make the followings

1) The formation of spatial database of occurrence of most used pesticides, or detected by tests, in Gaza strip.
2) The formation of vulnerability map of pesticides contamination. This is the first time in Gaza to have this map, using the GIS-DRASTIC tool.
3) Providing details about the occurrence of most genetic and carcinogenic pesticides leaching Gaza aquifer.
4) Producing a strong data base for developing other researches, or scientific technique to monitor the spread or decline of pesticides contamination in the Gaza strip.
5) Enforce and assure the sustainable pest management in the Gaza strip.

1.5 Significance to Human and Environmental Health

No one can deny the fate of pesticides which are, simply, poisons either organic or inorganic compound manufactured to kill insects, like insecticides or to kill weeds like herbicides. Researches overall the world, had proved the transient and moving of pesticides to leach the groundwater. The groundwater in the semi-arid areas like Gaza strip is the main source of domestic and agricultural use. Any investment in keeping it clean, or to clean it up is of a great importance to Gazian health. Moreover, the excess use of pesticides will affect the biodiversity ecosystem, and degrades the environment as well. The human being, the most important component of the ecosystem, is ridiculously affected by these poisons and their by-products. Accordingly, the need for monitoring and detecting these poisons is growing up due to the said fate.

1.6 Outline of Research

The vulnerability study will be implemented using the GIS-based DRASTIC index approach, only theoretical study will be conducted. Consequently, the application of GIS database will be generated and elaborated to produce the Vulnerability maps. This research is divided into six chapters in addition to appendices and references

Chapter One, *Introduction*: sets out the problem statement, objectives, contribution of study, and outline of research projects.

Chapter Two, *Literature Review*: summarizes the existing state of knowledge about properties of pesticides in terms of health effects, potential leaching, persistence and degradation, and the problems of groundwater vulnerability analysis, with particular emphasis on GIS-based approach; DRASTIC approach.

Chapter Three, *Description of study area*: describes the physiography of the study area where all physical and geographic characters of Gaza strip are studied in brief to have a complete and holistic picture of the study area. Moreover, the hydrogeology of the groundwater will be investigated to find out the cross references with factors affecting the Aquifer vulnerability.

Chapter Four, *Materials and Methods*: describes the data analyzed, indicating the captions of each. Also describes the methodologies and approaches followed in this research. In this chapter the "how to" describes the procedures followed to achieve the resulting vulnerability maps.

Chapter Five, *Results and Discussion*: presents maps, tables, and summaries that describe the vulnerability of Gaza aquifer for pesticides contamination. Sensitivity analysis for all data layers used by the DRASTIC model will be checked, and discussed. Then General discussion will be developed to clear area under each level of vulnerability.

Chapter Six, *Conclusion and Recommendation*: the conclusion finishes the discussion by offering a summary of the completed thesis, and the matching with the results of chapter five. *Recommendation*: sets out a group of practical recommendations and advices to all concerned and decision makers, this chapter will recommend some topics for the following researchers to go ahead with next step.

References, all references used for this research are tabulated and arranged for the record.

Appendices, all valuable data collected or generated during this research are sent to appendices, for the matter of documentation and easy references.

CHAPTER 2

Literature Review

2.1 General Discussion of Pesticides Issue

2.1.1 Introduction

Pesticides play great roles in the modern agriculture and human health. Following World War II, the organochlorine, DDT had been extensively used for controlling mosquito-borne malaria and as an agricultural insecticide (Pakdeesusuk, 1998). Based on NRC, 1993, one third of world's food crop is destroyed by pests; they are attacked by tens of thousands of diseases caused by viruses, bacteria, fungi, and other organisms. Moreover, thousands of nematode species reduce the crop vigor and thirty thousand kinds of weeds are competing with crop world wide. Only pesticides can properly, solve these crises in timely manner. Consequently, the use of pesticides became mandatory to deal with such circumstances. However, both accidental spills and routine usage have adverse environmental effects, in case pesticides are transported to groundwater or surface water (Stenemo, 2007). Due to bad impact of pesticides on environment and human as well, the needs for vulnerability assessment are, extremely, increasing on regulatory authorities and water managing levels.

The ability to delineate areas of greater and lesser vulnerability allows us to apply mitigation or restrictive measures to vulnerable areas without interfering with the use of pesticides in the less-vulnerable areas (Sanderson, 2002). The purpose of assessing the vulnerability of groundwater to pesticide leaching, could either identify active ingredients that pose a potential threat (FOCUS, 2000) or identify soils and regions where pesticide usage is more likely to have negative environmental effects on groundwater. The most suitable approach to assess the vulnerability of groundwater to pesticide contamination will certainly depend on the goal of the application and the end-user, as well as the available data (Stenemo, 2007).

2.1.2 Groundwater Contamination by Pesticides

Groundwater is the primary source of water in many rural areas for human consumption, irrigation, and animal watering. Therefore, the occurrence of agricultural pesticides in groundwater represents a threat to public health and the environment (Sanderson, 2002).

Researches that have been conducted based on laboratory tests for the last years, had approved the occurrence of pesticides in the Gaza aquifer (CAMP, 2000, Shomar, 2003). The interaction between hydrogeological assembly, recharge, soil conditions, pesticide use, and pesticide behavior in the vadose zone determines whether groundwater in a particular area is likely to become contaminated with pesticides (Sanderson, 2002). The quantity and types of pesticides being applied are critical factors for contamination level. Because pesticide use is highly variable and difficult to be monitored, the distribution of crop types and the quantities of pesticides sold to applicators may be used to obtain a general approximation in the vulnerability assessment. Sanderson, (2002) sees that the only effective method for detecting groundwater contamination by pesticides is an adequate groundwater monitoring program, with special emphasis on areas where dirty pesticides are being applied and areas where such application is most likely to impact groundwater.

2.1.3 Mechanism of Groundwater Pollution

When we better understand the mechanisms by which pesticides migrate into ground water, we are better able to understand what geographic areas are more vulnerable - and thus deserving of more concentrated efforts to protect ground water - than other less-vulnerable areas (Sanderson, 2002). Groundwater is found in the pores and cracks of underground sand, gravel, and rocks. The formation through which groundwater slowly flows are called an aquifer. The top of water-saturated zone is the water table and water percolating down to it, through soil, is called recharge (Mahler, 2007). In areas of Gaza strip where ground water is most likely to be unconfined, degradation of the aquifer by pesticides would occur whenever chemicals infiltrate through the vadose zone to the aquifer. In confined aquifer settings, pesticides would need to find pathways through confining layers to cause water-quality degradation (Sanderson, 2002). Pesticides reaches groundwater through agricultural and industrial uses, spills and improper disposal, and homeowner uses (Mahler, 2007).

Most pesticides start breaking down naturally as soon as they are applied. This process occurs rapidly in a well-aerated, moist top-soil and slowly in groundwater (Mahler, 2007). The water-soluble pesticide will move down through the soil by irrigation or rain water. The ability of soils at the application site to retard or attenuate the downward movement of pesticides, and the hydrogeologic setting where the pesticides are applied, have a fundamental effect on the likelihood that a pesticide will travel downward to the aquifer (Sanderson, 2002, Mahler, 2007). The wells themselves, if not properly constructed, could provide pathways for pesticides to reach the basin-fill aquifer (Sanderson, 2002).

Four major factors determine whether a pesticide is likely to reach groundwater: *properties of the pesticide; properties of the soil; conditions of the site; and management practices* (Warlron, 1992, Butter, 2003, and Trautman, 2000). It may be useful to say that these process are dynamic and interrelated (Butter, 2003). Many pesticides bind strongly to soil and are therefore immobile. For those that are mobile in soil, their leaching to groundwater can be thought of as a race in time between their degradation into nontoxic by-products and their transport to groundwater (Trautman, 2000). If the pesticide is not readily degraded and moves freely with water percolating downward through the soil, the likelihood of its reaching groundwater is relatively high. If, however, the pesticide degrades quickly or is tightly bound to soil particles, then it is more likely to be retained in the topsoil layers until it is degraded to nontoxic by- products. Even if degradation is slow, this type of pesticide is unlikely to pose a threat to groundwater (Trautman, 2000).

2.1.4 Process Governing Environmental Fate of pesticides

The fate of a pesticide is a result of a complex interaction of soil, crop, weather, & the pesticide properties, plus spray practices. When a pesticide is used in the environment, it becomes distributed among four major compartments: water, air, soil, and biota (living organisms) (Linde, 1994). Figure 2.1 demonstrates the relation between chemical properties and the four environmental compartments.

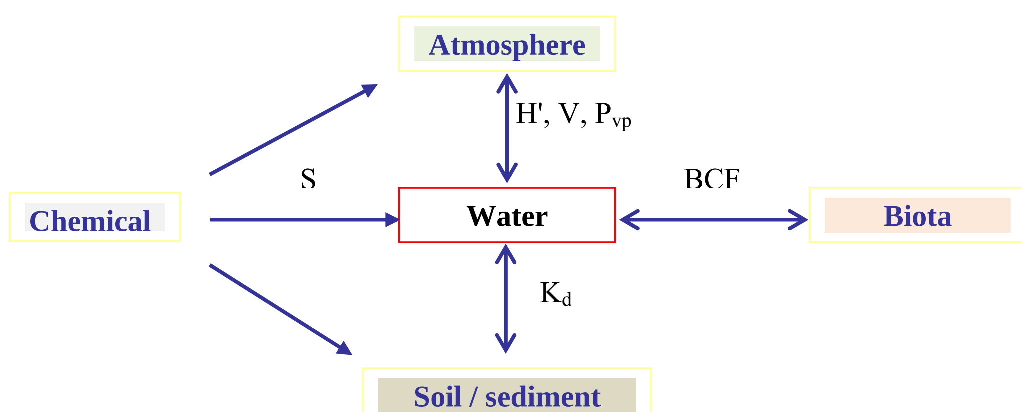


Figure 2.1: Relation between Pesticides properties and environmental compartment,

Where; S: Solubility, H': Henry's low constant, K_{ow}: Partition coefficient, Kd,K_{oc}: Soil adsorption coefficient, BCF: Bio-concentration factor, P_{vp}: Vapor pressure, V: Volatilization (Linde, 1994).

From table 2.1 above, the fraction of the chemical (pesticide) that may transfer/ move into each environmental compartment is governed by the physio-chemical properties of that chemical (Linde, 1994). Based on (Butter et al. 2003 and Mahler et al., 2007), once pesticides are applied to a site, a number of things may occur. Pesticides may undergo hydrolysis by water, may be taken up by plants, volatilized and evaporated into the atmosphere, carried off as drift, broken down by sun light, metabolized and ingested by insects, worms and microorganisms, be oxidized in the soil, or undergo adsorption (attached to soil particles). The pesticide may adhere to soil particles or be dissolved in irrigation- or rain-water. These processes determine the ultimate fate of the pesticide by affecting its persistence and movement in the environment as per figure 2.2. What happens to a pesticide depends on the pesticide and the site on which it is applied.

Table 2.1: Pesticides properties that degrade environment compartment (Linde, 1994)

Parameters	Abbrev	Unit	Definition	Affected by
Solubility	S	PPM Mg/L	Solubility is a measure of the amount of chemical that can dissolve in water.	Polarity, hydrogen bonding, molecular size, temperature, pH, symmetry.
Hydrolysis	H	Half lives $T_{1/2}$	Hydrolysis means that a chemical has reacted with water to form a new product.	Substituents, temperature, pH,
Volatilization	*V*	µg/cm2.sec	The process where a chemical is transported from a wet or dry surface into the atmosphere. Flux: amount of chemical that flows from a unit surface area into the air	Wind, terrain/fetch, temperature, chemical properties, solubility, soil, molecular properties, concentration, vapor pressure
Partition coefficient	K_{ow}	unitless	The ratio of a chemical's concentration in octanol divided by its concentration in water	Polarity, molecular surface area, boiling point, molar volume, molecular weight, and density
Henry's low constant (HLC)	*H'*	Pa-m^3/mol Atm-m^3/mol	*H' = concentration in gas phase / concentration in liquid phase* *H = liquid vapor pressure / chemical solubility*	
Soil adsorption coefficient	K_d, K_{oc}	unitless	K_d = Concentration of chemical in soil/ Concentration of chemical in water $K_{oc} = K_d$ x 100/(% organic carbon)	Organic carbon content, polarity, pH, salinity, organic matter in solution
Bio-concentration factor	*BCF*	unitless	BCF is the accumulation of a chemical in living organisms (biota) compared to the concentration in water.	Polarity, solubility, lipid content, metabolism, habitat
Vapor pressure	P_{vp}	Mm Hg Pascals atm	Vapor Pressure is defined as the pressure that a chemical in the gas phase exerts over a surface. (10^{-5} to 300) mm of Hg	1 atm = 760 mm Hg = 0.1 MPa

The fate processes can be beneficial. They can move a pesticide to the target area or destroy its potentially harmful residues. Fate processes can be separated into three major types: adsorption, which binds pesticides to mineral or organic matter; transfer processes, which move pesticides in the environment; and degradation processes, which break pesticides down (Warldron, 1990).

Soil type, climatic factors, and handling practices can promote or prevent each process. An understanding of the fate processes can help and ensure that pesticide applications can, not only, be effective, but also environmentally safe. It is important to know what are the environmental pathways through which pesticides are transported. Figure 2.3 represents the main processes governing pesticides fate in the atmosphere-plant-soil-groundwater system, which will be described below.

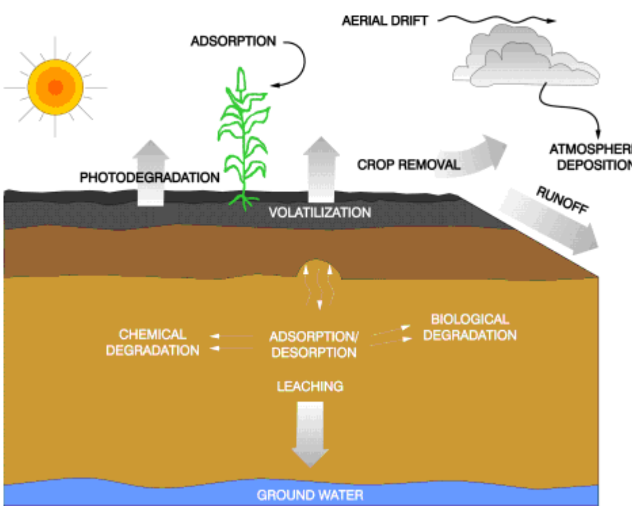


Figure 2.2: Pesticides fate processes (Warldron, 1990)

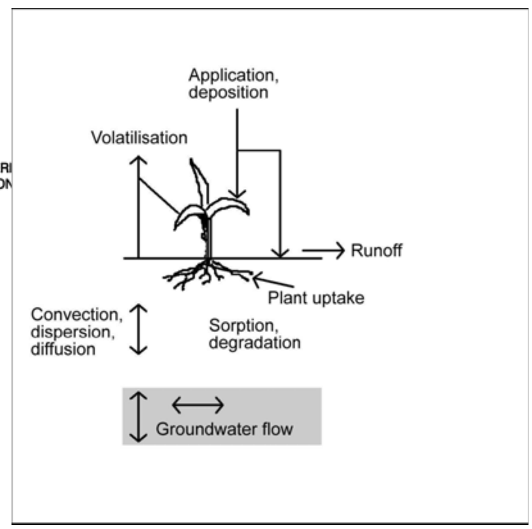


Figure 2.3: Key process governing the environmental fate of pesticides (Leterme, 2006)

Volatilization

In the first days or weeks, and as a result of drift during direct application, or subsequently from soil, plant, and surface water, pesticides can present in the atmosphere around forming the major source of pesticides contamination in air (leterme, 2006). Then the precipitation can lead the pesticides again into surface and subsoil. Volatilization is therefore likely to have a major impact on the environmental balance of pesticides (Vanclooster et al., 2003). It results from a series of dynamic processes occurring in the soil-crop canopy-atmosphere continuum, which can be seen as a diffusive vapor flux across a thin air boundary layer (Vanclooster et al., 2003).

The following factors are mainly affecting volatilization: (1) the physio-chemical properties of a pesticide (vapor pressure being a key parameter), (2) atmospheric conditions (air temperature, humidity, wind), (3) soil conditions (moisture, temperature, (4) soil density, (5) clay and organic matter content), and (6) agricultural practices (application dose and date, tillage) (Bedos et al., 2002; Kubiak, 2006).

Runoff

Runoff and leaching are mutually dependent processes (Flury, 1996). During runoff, a portion of the water is percolated to subsoil and contribute to pesticide leaching. Runoff is function of topography, so increased runoff is related to decreased leaching of contaminants through bulk soil (Flury, 1996).

Plant uptake

Plant uptake of pesticides may be important in some cases, even this process has limited relevance for autumn-applied compounds. The capacity of plants to uptake chemicals is frequently used for the remediation of contaminated soils (Sun et al., 2004).

Water and solute flow

Pesticides flow through the soil and subsoil can be described by two processes; (1) under advection dispersion equation (matrix pore-space or micro-pores) where the soil is porous and homogenous, (2) preferential flow (which can be described as macropores flow through cracks and wormholes, as finger, or unstable flow in homogeneous water repellent sandy soil texture, or as heterogeneous flow in soils with material of different structures (Stenemo, 2007).

The preferential flow process can act as a by-pass of the upper soil layers, thus strongly preventing the attenuation and retardation of pesticide leaching (Leterme, 2006, Robins et al., 1994). Preferential flow may also be caused by funneling of water through high conductivity layers, or as being redirected by sloping less-permeable layers (Van Genuchten et al., 1999; Jarvis, 1999).

Sorption and degradation

Sorption will determine whether the pesticide will *persist* or not, be transported to groundwater or not (Wauchope et al., 2002). Soil sorption is usually characterized by a partition constant, K_d, which is a ratio of solid phase to solute concentrations. High values of

K_d indicate that a pesticide is strongly sorbed and will be immobile in soil, and also resistant to microbial degradation (Wauchope et al., 2002).

There is generally a high correlation between the organic matter content of the soils and K_d (Ahmad et al., 2001). The soil organic matter, act as a non-polar phase that is the main sorbent in soils, attracting pesticides because they are typically non-polar organic molecules (Wauchope et al., 2002). Binding of pesticides to organic matter can occur by three forces (1) sorption (Van der Waal's forces, hydrogen bonding, hydrophobic bonding), (2) also by electrostatic interactions (charge transfer, ion exchange or ligand exchange), (3) covalent bonding or combinations of these reactions (Bollag et al., 1992).
The *Freundlich sorption isotherm* can be applied to define equilibrium sorption as per the equation;

$$\mathbf{X}_{eq} = \mathbf{K}_{f,eq} \times \mathbf{C}_L^N \quad \text{..........} \quad \mathbf{(2.1)}$$

Where; $\mathbf{X}_{eq}$ is pesticide content in the equilibrium sorption phase,

$\mathbf{K}_{f,eq}$ is the Freundlich coefficient for the equilibrium-sorption phase,

$\mathbf{C}_L$ is the concentration in the liquid phase,

N is the Freundlich exponent, N indicates the extent to which adsorption depends on the concentration. If N = 1, the sorption isotherm is linear and K_d is used.

Degradation is a fundamental attenuation process for pesticides and is mainly defined using the term half-life which is the time needed to transform half of the pesticide mass (Leterme, 2006). Degradation depends on many biotic and abiotic factors including the interactions among microorganisms, chemical and soil constituents (Vanclooster et al., 2000a). There may be an inverse relation between sorption and degradation, as the absorbed pesticides can resist degradation by micro-organisms

Groundwater flow

Pesticide leaching through the soil and vadose zone can eventually cause residues to reach the saturated zone. From there, pesticide fate is mainly driven by groundwater flow and degradation (Leterme, 2006).

2.1.5 Pesticides Detected in Gaza Aquifer

In fact, the Coastal Aquifer Management Plan (CAMP, 2000) study, conducted by engineering firm Metcalf & Eddy and drawn up in year 2000, had shown some pesticides detected in Gaza wells with minimum concentrations. The main components of the CAMP

included the amount of water pumped from the aquifer for groundwater irrigation whilst simultaneously improving supply of drinking water to the population by providing additional water from sources other than the aquifer, if implemented on schedule it was expected that the CAMP would bring the Gaza aquifer back into a positive water balance by 2007, where as " failure to implement the CAMP in accordance with the schedule will result in continuing decline in the quantity and quality of the aquifer water" (CAMP, 2000). In the CAMP study, eighteen pesticides from the Organochlorine group and the methyl bromide have been tested for 168 domestic and agricultural wells overall Gaza strip (43: Gaza, 42: Khan-younis, 23: Middle, 43: North, 17: Rafh). From the CAMP study 2000, the following 19 pesticides were *tested*: Aldrin, alpha-BHC, beta-BHC, gamma-BHC (Lindane), delta -BHC , 4,4'DDD, 4,4'DDE, 4,4'DDT, Dieldrin, Endosulfan I, Endosulfan II, Endosulfan sulfate, Endrin, Endrin aldehyde, Endrin ketone, Heptachlor, Heptachlor epoxide, Methoxychlor, mythile promide.
Table 2.2 shows spatial distribution of wells where pesticides were detected.

Table 2.2: Spatial distribution of wells contaminated by pesticides (CAMP 2000)

Area	Well ID	Endosulfan (0.002µG/L)	Endosulfan-I (0.002µG/L)	Endosulfan-II (0.002µG/L)	Endosulfan-Sulfate (0.004µG/L)	Endrine (0.002µG/L)	4,4'DDT (0.002µG/L)	Dieldrin (0.002µG/L)	Heptachlor epoxide (0.002µG/L)
Gaza	R271, F191	0.005				0.01	0.002		
Kh/Y	L47, L66		0.002				0.008		
Middle	S11, S15				0.023		0.002		0.003
North	E45		0.006	0.006					
Rafah	P-10, P-101, P139, P15, P144						0.021 0.002	0.002 0.002 0.002	

Shomar, (2006) has recently conducted a very useful study, published online on March 2006, along three years program to monitor types and levels of contamination by 52 pesticides in 90 groundwater wells in Gaza. The samples, taken for this study, were tested in Germany with co-operation with Institute of Environmental Geochemistry and University of Heidelberg. The results, related to groundwater contamination, are as the following:-

1. Water from 63 wells showed no detectable levels of pesticides, or levels that were much lower than the allowable limit (0.5 µg/L) of groundwater.
2. Atrazine, atrazine-desisopropyl, propazine, simazine were detected in 18, 15, 8 and 5 wells with average concentration of 3.5, 1.2, 1.5, and 2.3 µg/L, respectively.
3. Shallow aquifers in sandy substances in the areas of low annual precipitation in the southern areas of Gaza showed detectable concentrations of pesticides.

The above research proved the occurrence of pesticides in levels higher than the EPA standards. Shomar, 2006 advises that: "Groundwater to be assessed for pesticides contamination on a routine basis to protect the health of Gaza's residents".

From Shomar's research, the following pesticides *were detected*: Atrazine, atrazine-desisopropy, propazine, simazine were detected in the groundwater as indicated in the previous studies. Propazine, sebutylazine, terbutylazine, 4,4-DDT , 4,4-DDE , and 4,4-DDD are detected in soil.

2.1.6 **Pesticides Imported to Gaza Strip** (MoA)

The records in Appendix A shows the amounts of pesticides and fertilizers imported to Gaza strip since 1996 up to year 2007 (MOA, 2007), which have been arranged based on updated data obtained from Ministry of Agriculture's records on 14th Sep 08.

From table 2.3, the following points can be noted:

1. The average amount of pesticides imported to Gaza, since 1996 up to year 2007, is about 500 tons per year.
2. The amount of pesticides varies annually. Figure 2.4 shows that the curve of importing falls down, this can be interpreted as follows:

   First, Due to siege and blockade being applied on Gaza strip since years, the importing of pesticides to Gaza strip has been minimized.

   Second, the economy of the Palestinian is falling down in the agriculture sector, so that they do not have the agriculture practice to consume a huge amount of pesticides.

   Third, a huge agricultural areas have been demolished, consequently, a huge amount of plantations and trees have been expelled by the ax of bitterness during the last period.

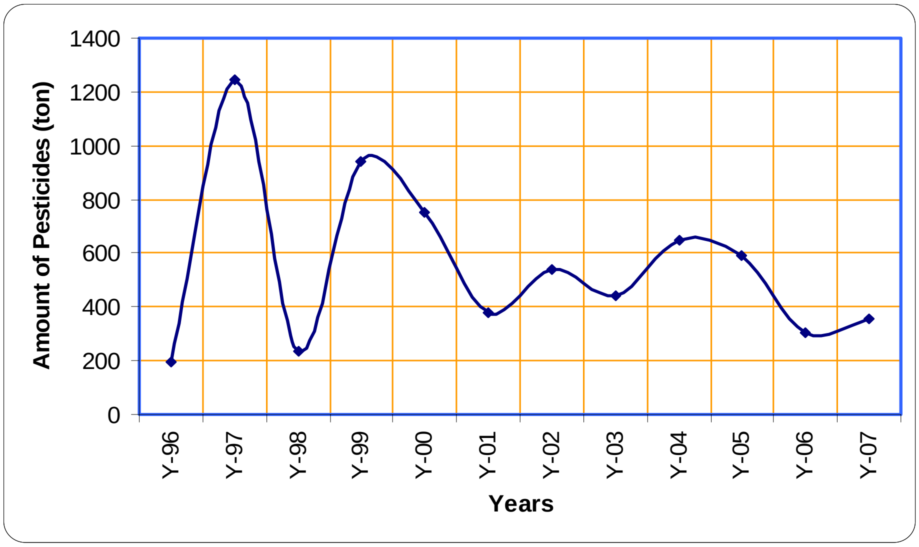


Figure 2.4: Amounts of pesticides imported to Gaza per year (MoA records)

3. The importing of some pesticides, like: amitaz, cyhexan, endosulfan, fenopathrin, methomyle, benomyl, maneb, simazine, coumatetrayl, were blocked since year 2005, may be due to:

***First*;** Restriction imposed by MoA on importing pesticides as part of Pest Management Plan (PMP)

***Second*;** Most of agricultural products are consumed by Israel. It is known that Israel is the main source of pesticides for Gaza strip. So they do the necessary arrangement not to allow for dirty pesticides to be used in Gaza, where the farmers may use!.

4. The sterilant materials like, methyl bromide and metham-sodium, are imported every year and with huge quantities.
5. The amount of pesticides and fertilizers in kg, that have been imported to Gaza strip since 1996 up to year 2007 are listed in table 2.3.
6. The pesticides of groundwater contamination potential are studied in order to exclude those can not leach the aquifer.
7. Some pesticides with total average amount of 436 tons are most frequent use in the Gaza strip. Table 2.4 shows list of pesticides that of most frequent use and detected in Gaza aquifer some years ago. Some dirty pesticides are included even their amount is not as big as the others due to their toxicity and persistence in the environment.

Table 2.3: Amounts of Pesticides and Fertilizers (ton) Imported to Gaza per Year, since Year 1996

Year➢ Type⮟	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG
Insecticides	98.0	132.2	111.0	157.7	73.9	75.6	55.7	91.0	85.1	39.2	32.9	26.2	**81.5**
Fungicides	70.0	159.8	87.7	151.1	55.6	50.8	123.9	116.5	120.4	71.8	54.1	34.2	**91.3**
Herbicides	7.1	19.6	15.5	24.2	15.2	7.4	9.9	16.1	12.4	20.4	24.8	18.8	**15.9**
Nematicides	16.5	32.1	19.9	46.1	24.3	14.2	45.4	36.6	36.8	18.8	0.0	10.8	**25.1**
Sterilant	0.0	831.6	1.6	509.5	537.7	228.2	303.0	136.4	293.2	300.7	111.6	198.2	**287.6**
Grand Total	191.6	1,175	235.8	888.5	706.6	376.2	537.9	396.5	547.9	450.9	223.3	288.2	**501.6**

Data has been taken from MOA on 14 Sep 2008

Table 2.4: Average Amounts of Most frequent and dirty Pesticides and Fertilizers (Kg) Imported to Gaza per year since Year 1996

Generic		Brand Name	Brand-Arabic	Avg. Quantities (kg)
1- Insecticides				
1	Methamidophos	Prodex -Tamaron-Protar-Maraton-Methopaz	بردوكس- تمارون-بروتار- مارتون - ميتوباز	11,031.00
2	Malathion	Malathion	ملاثيون	7,764.00
3	Chlorpyrifos	Pyrinex-Dursban- Dorsan-Drops	بيرنكس - دورسبان – دورسان-]دروبس	7,730.00
4	Cypermethrin	Tarseeb-Ceparin-Titan-Symbush-Sherpaz-Cmshofr	ترسيب - سيبرين - تيتان – سمبوش- شرباز-سيموشوبر	7,460.00
5	Endosulfan	Endol-Thiodan-Thionex-Thiodol- Holidon	إندول - ثيودان – ثيونكس -ثيودول-هليودان	7,353.00
6	Dimethoate	Dimethoate- Rogor-Poligor	دايمو ثويت - بوليكور- روجر- روجر تكس	5,499.00
7	Summar Oil	Levanola-Virotar-Vitol-Livotile-Sanot-Fulic oil-Virol oil	ليفانول-فيروتار-فيتول-سانوت -زيت الفولك-ليفوتيلا-فرول	4,892.00
8	Fenpropathrin	Smash	سمش	3,951.00
9	Cyhexatin	Acritel-Lintex-Balyctran	أكرتيل - لنتكس- بلكتران	3,227.00
10	Azinphos_methyl	Cotnion	قطنيون	2,994.00
11	Carbosulfan	Marshal	مارشال	2,804.00
12	Chlorfluazuron	Attabron	أتبرون	2,080.00
13	Bendiocarb	Necar - Nakar	نيكار - نقار	435.00
14	Carbaryl	sevin	سفين	142.00
15	Isofenphos	Oftanol	أفتانول	134.00
16	Trichlorfon	Danex	دانكس	4.00
		Subtotal of insecticides	**67,500.00**	

Table 2.4: Average Amounts **(continued)**

	Generic	Brand Name	Brand-Arabic	Avg. Quantities (kg)
2- Fungicides				
17	Mancozeb	Manzidan-Mancotel-Mancozan-Mancoday	مانسيدان- مانكوتيل- منكوزان - منكوداي	21,073.00
18	Copper hydroxide	Phongoran-Cocide101-Parasol-Champion-blushield	كوسايد101 – فونجران -بيروسول-شامبيون- بلوشيلد	7,450.00
19	Propamocarb-Hcl	Dynon-Dotan proplant-Brifecur N	داينون-دوتان بروبلانط - بريفيكور ن	5,068.00
20	Maneb	Manebgan	مانيبجان - مانكس	3,707.00
21	Triadimenol	Bayfidan-Shavit	بايفيدان - شافيط	3,287.00
22	Mancozeb+ Cymoxanil+ Oxadixyl	Sandocur	سندكور	2,960.00
23	Propineb	Antracol	أنتراكول	2,638.00
24	Benomyl	Benlate	بنلت	1,461.00
25	Chlorothalonil	Bravo _ Daconil	داكونيل - برافو	905.00
26	Iprodione	Rovral	روفرال	571.00
27	Fenarimol	Rubigan	روبيجان	284.00
28	Thiophanate methyl	Topaz M	طوبسين (توباز)	20.00
			Subtotal of Fungicides	**49,424.00**
3- Herbicides				
29	Glyphosate	Round up-Glyphosate	راوندب- جليفوست	7,675.00
30	Paraquat	Docatalon	دوكتالون	1,239.00
31	Simazine	Simazine-Simanex	سيمازين-سمنكس	283.00
32	Pendimethalin	Stomp	ستومب	33.00
			Subtotal of Herbicides	**9,230.00**
4- Nematicides				
33	Fenamiphos	Nemacur	نيماكور	16,183.00
34	Sodium Fluoroacetat	Syphsan	سفسان	3,696.00
35	Metaldehyde	Metason-Halizan	ميتازون- حلزات	2,283.00
			Subtotal of Nematicides	**22,162.00**
5- Sterilant				
36	Methyl Bromide	Methyl Bromide	بروميد الميثيل	262,902.00
37	Metham Sodium	Metmor-Adegan	ميتامور –أديجان	24,746.00
			Subtotal of Strrilant	**287,648.00**
		Grand Total		**435.964.00**

Data has been taken from MOA on 14 Sep 2008

2.2 Vulnerability Assessment of Pesticides leaching Groundwater

2.2.1 Definitions of Groundwater Vulnerability

The followings are most popular definitions from various sources for the vulnerability of groundwater to pollution:

- The National Research Council (NRC, 1993) defined groundwater vulnerability to contamination, in the case of non-point sources or distributed point sources of pollution, as: The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer.

- Vulnerability is an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/ or natural impact. (International Association of Hydrologists, Vrba & Zoporozec, 1994, Harter, 2001)

- Groundwater vulnerability is a measure of how easy or how hard it is for pollution or contamination at land surface to reach a production aquifer (Harter, 2001). Stated in other words, it is a measure of the level of insulation that natural and/or manmade factors provide to keep pollution away from groundwater.

- Ground-water sensitivity to pesticides is an assessment of natural factors favorable or unfavorable to the degradation of ground water by any pesticides applied to or spilled on the land surface (Sanderson, 2002). Groundwater vulnerability to pesticides is an assessment of how groundwater sensitivity is affected by humans' activities.

Vulnerability is high if natural factors provide little protection to groundwater from contaminating activities at land surface. On the other hand, vulnerability is low if these factors provide relatively good protection (Harter, 2001).

Two questions must be examined and clarified, in describing and defining groundwater vulnerability: vulnerability of what?, and vulnerability to what?. The first question "of what?" refers to the degree of vulnerability will depend on environmental conditions, on how we define groundwater and which part of groundwater we are interested in. the second question "to what?" depends on the time-scale of interest and the presence and type of pollutants (Harter, 2001). In this research pesticide is the targeted pollutant.

The reference location mentioned in the above definition is mainly the water table (NRC, 1993). Based on Foeg et al., (1999) assessments of vulnerability of groundwater resources require analysis of not only the vadose zone, but also of the groundwater system itself. In fact, the purpose of the study can assign the choice of the reference location e.g. the water table, well intakes, recharge or discharge zones (Leterme, 2006).

Depending on the field of study i.e. natural hazards, food security, etc., definitions of vulnerability may intrinsically include a *social* dimension. In this case, vulnerability can be 'human' in its nature, so it can be defined as the 'capacity of groundwater to anticipate, cope with, resist, and recover from the impact of a natural hazard' (Leterme, 2006). In this research, vulnerability does not consider the human aspects (e.g. water consumption and exposure) that could be associated with groundwater contamination.

Intrinsic and specific vulnerability

Vulnerability that is independent of whether or not contaminant (pollutant) are present and that focuses on a description of natural environmental conditions is often referred to as "intrinsic vulnerability", susceptibility, natural vulnerability, or aquifer sensitivity (Harter, 2001, Connell and van den Daele, 2003).

Some studies considered that vulnerability is an intrinsic characteristic of the hydrogeological system (Foster, 1987; Palmer and Lewis, 1998) that account on soil properties and hydrogeological conditions (Stenemo, 2007). A distinction is then sometimes made between intrinsic and specific vulnerability (NRC, 1993; Burkart et al., 1999). The latter is used when vulnerability is related to a specific land use (Harter,2001), a specific contaminant, contaminant class, and/or human activity (Leterme, 2006). Intrinsic vulnerability facilitates the production of a unique vulnerability map for a given land area (Leterme, 2006).

Due to the scarcity of data and information about the interactions between contaminants and the environment, and the easier implementation of intrinsic vulnerability assessment methods, the intrinsic vulnerability is often motivated (Burkart et al., 1999; Lobo-Ferreira, 2003).

Vulnerability is also function of pollutant type. Consequently, different pollutants behave differently, based on their chemical or microbiological make-up (Harter, 2001). It is now widely recognized that the degree of contaminant attenuation can also vary significantly with pollutant type in any given situation (Foster et al., 2002).

2.2.2 Rationale of Groundwater Vulnerability Assessment

Even though vulnerability assessment can create scientific insight for the analysis of groundwater resources, it provides a decision-making tool based on the best available data and good scientific judgment. Based on Harter, (2001) it is important to understand that vulnerability serves more of an economic goal than a scientific analysis, as vulnerability assessment can facilitate protecting environment and public health with least coast.

The Groundwater Vulnerability Assessment (GVA) is a dynamic and iterative process (Mato, 2002). The Natural Research Council (NRC, 1993) identified four general objectives can be achieved by groundwater vulnerability assessment; (1) to facilitate policy analysis and development at local and regional level; (2) to provide program management; (3) to inform land use decisions; (4) to provide general education and awareness of a region's hydrogeologic resources. In addition to its basic role in monitoring requirement, vulnerability assessment can be used to define area with special regulations for agro-chemical applications (Harter, 2001).

There are a number of pros and cons to vulnerability assessment that makes it under arguments. In contrary to the benefit of vulnerability maps in land use planning, the simulation for groundwater flow and transport process are very complex to be captured by any vulnerability tool (Harter, 2001) , and can not replace the real data (Loague, 1998). The second group of arguments against vulnerability assessment, are the two facts or / lows pointed by the National Research Council, (NCR, 1993) which are; All groundwater is vulnerable, and uncertainty is inherent in all vulnerability assessment. Anyhow, a need exists to provide at least some general guidance to land use planners, decision makers, and water users that help them to make decisions that are economically sensible while at the same time geologically reasonable (Harter, 2001).

Figure 2.5 summarizes the key players in groundwater vulnerability assessment. It can be shown from the figure, that in order to successfully perform a groundwater vulnerability assessment, cooperative efforts of regulatory policy makers, natural resource managers and technical experts are needed, in other words; all parties available on the figure have a common goal of protecting groundwater (Mato, 2002).

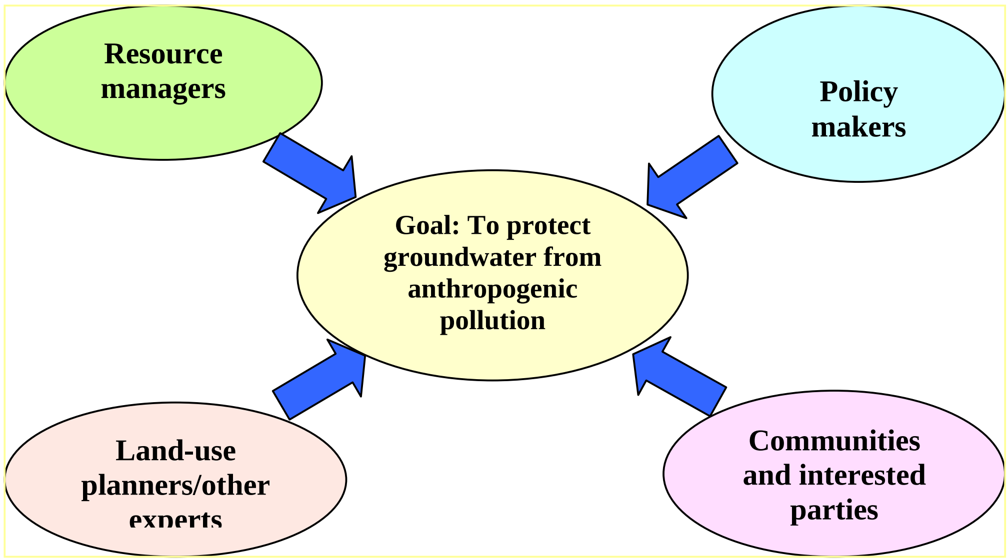


Figure 2.5: Major players in Groundwater Vulnerability Assessment (Mato, 2002)

2.2.3 Factors Affecting Groundwater Vulnerability to Contamination by Pesticides

The factors and their influence on groundwater specific vulnerability to pesticides are presented by table 2.5. The following paragraphs discuss the different points in more details.

Table 2.5: Factors affecting groundwater vulnerability to contamination by pesticides (Leterme, 2006).

#	Factors	Examples
1	Land use/management	Pesticide application rate and timing, tillage
2	Soil and crop properties	Organic matter content, texture, structure, plant uptake
3	Climate	Recharge, Timing of first rainfall, temperature, potential evapotranspiration
4	Subsoil, vadose zone	Thickness/ depth, degradation sites
5	Groundwater	Groundwater flow, dilution, aquifer materials
6	Pesticide properties	Sorption, degradation/ persistence

1. Land use and land management

One of the most important factor affecting groundwater vulnerability is land use , due to it's link with type and amount of applied pesticide (Addiscott and Mirza, 1998). Obviously, leaching cannot be expected if no pesticide input is attributed to a given land use (Leterme, 2006).

The concept of risk is perhaps more appropriate to take the influence of land use into account. Risk is often defined as the combination of hazard and vulnerability: risk = hazard + vulnerability (Passarella et al., 2002*). Thus defined, risk includes the quantification of the probability that a pesticide will be applied at a given space/time location (i.e. hazard); this probability is further combined with the vulnerability of that location to the pesticide applied.*

Management practices can affect groundwater vulnerability, due to the influence of crop and soil properties. The conventional tillage, for instance, has the potential to limit preferential flow and to subsequently affect the rate and amount of pesticide transport (Isensee et al., 1990; Elliott et al., 2000).

The pesticide application rate is a key parameter in estimating pesticide leaching (NRC, 1993; Flury, 1996). Obviously, the apparent adsorption of pesticides in the field increases with time. Consequently, the mass of pesticides leached to groundwater is inversely proportional to the time elapsed between pesticide application and the first infiltration event (Flury, 1996).

2. Soil and crop properties

The biologically active soil zone is the field of the processes causing degradation and/or attenuation of pollutants concentration in the unsaturated zone, as the attenuation of pesticide leaching is affected by sorption on organic matter and clay minerals (Robins et al., 1994). The dominant role of *organic* content in sorption of pesticides is due to the fact that: soil organic matter has a great number of binding sites, because it has a very large surface area and is chemically reactive. Thus the pesticides transport in soil is influenced by its sorption capacity (Leterme, 2006).

The hydrological behavior of soils that affect the percolation rate of contaminants can be determined by its structural characteristics. Soil structure, macroporosity, and the occurrence of preferential flow may significantly affect groundwater vulnerability (Leterme, 2006).

The effects of the initial *water content* on pesticide leaching depends on soil texture: under dry conditions, sandy soils tend to show less leaching, whereas loamy and clayey soils show more leaching when exposed to a strong rainfall shortly after pesticide application (Flury, 1996).

Crop properties such as root distribution, root depth, and pesticide uptake rates, can significantly affect groundwater vulnerability (NRC, 1993). As all these factors can increase pesticides degradation.

3. Climate

In general, pesticide leaching is much less sensitive to climatic variability than to soil variability (Leterme, 2006). Anyhow, it has been noted that both factors act independently on pesticide leaching (Van Alphen and Stoorvogel, 2002). The climatic factors like temperature, radiation, wind and humidity, are indirectly affecting groundwater vulnerability e.g. by determining potential evapotranspiration and hence affecting the water balance. Finally, as pesticide degradation is a temperature dependent, soil temperature acts on pesticide degradation, and thus affects groundwater vulnerability under different climatic conditions (Leterme, 2006).

4. Subsoil and vadose zone

Vadose zone : the zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric. Soil pore space also typically contains air or other gases. The capillary fringe is included in the vadose zone (Leterme, 2006).

Nature and thickness of vadose zone seems to be very important to evaluate groundwater vulnerability, if water table is deeper than the soil layer. In the vadose the attenuation and degradation of pesticides will be decreased, except for some cases with a high degradation potential may occur in the vadose zone (Robins et al., 1994).

The transport processes in vadose zone are very complicated, moreover, data on vadose zone parameters (such as hydraulic conductivity and retention factors) are scarce. (Fogg et al., 1999). Consequently, the estimation of the vadose zone influence on groundwater vulnerability will be processed using weighting factors or vulnerability classes in index methods (Gogu and Dassargues, 2000).

Because the shallowest groundwater zone is typically the most vulnerable, vulnerability assessment are mostly concerned with the vulnerability of the uppermost aquifer, in a multi-aquifer system, or with the water table in an unconfined aquifer system (Harter, 2001).

The time element is an important part of defining a vulnerability assessment. So deep groundwater is considered less vulnerable than shallow groundwater, because of the longer travel time necessary for pollutant to reach a well (Harter, 2001).

5. Groundwater

The hydro-geologic properties of groundwater at the saturated zone can affect estimate of groundwater vulnerability (Leterme, 2006). Groundwater flow has to be considered in the vulnerability assessment, particularly for groundwater resources at important depths, because of the significant time lag existing between the solute arrival at the water table and its presence in water supply wells (Fogg et al., 1999).

6. Pesticide properties

The properties of pesticides play a key role in assessing pesticides leaching, as will as the properties of soil, where sorption and degradation parameters will be used (Leterme, 2006). The persistence of pesticides influences the ability for contamination. The longer the pesticide lasts before it is broken down, the longer it is subject to the forces of leaching (Thapinta, 2002). However, many highly persistent pesticides may not reach groundwater because of their low solubility and strong adsorption to soil particles. On the other hand, some soluble pesticides of low persistence may be able to contaminate groundwater (Waldron, 1992). Pesticides that dissolve readily in water are highly soluble and easily transferred with the water flow. Such pesticides have greater potential of moving downward through the soil, and possibly leaching to groundwater (Thapinta, 2002).

Based on their molecular description, derived from the chemical structure, some pesticides where found able to leach to groundwater, while others can not (Worrall, 2001). Aqueous solubility, Henry's constant, and saturated vapor density among others complete the pesticide parameters that determine the environmental fate of compounds in interaction with site properties (NRC, 1993). ***(See sec 1.4 above)***

2.2.4 Source of Prediction Uncertainties

Although environmental modeling is increasingly performed within a Geographic Information Systems (GIS) framework, analysis of the associated error is far from routine, and rarely presented with the results. An important benefit of performing error analysis is its value in determining which elements of a vulnerability assessment framework need improving (Posen, 2006).

The model can be defined as a simplified description of reality aiming to describe one or several specific aspects (Stenemo, 2007). Because not all of processes are correctly described in a model and some are ignored, the models are, by definition, always more or less "wrong". So simulating models can not represent the reality. Moreover, factors and processes affected transport of pesticides in the soil interact in several ways that make it a very complex system. Accordingly, modeling of pesticides transport is associated with several sources of uncertainty (Stenemo, 2007).

The results of the analysis showed how inclusion of low quality input data can lead to a large increase in output uncertainty. It is suggested that error propagation analysis should be routinely included in groundwater vulnerability assessment (Posen, 2006). Figure 2.6 provides an overview of the various sources of errors.

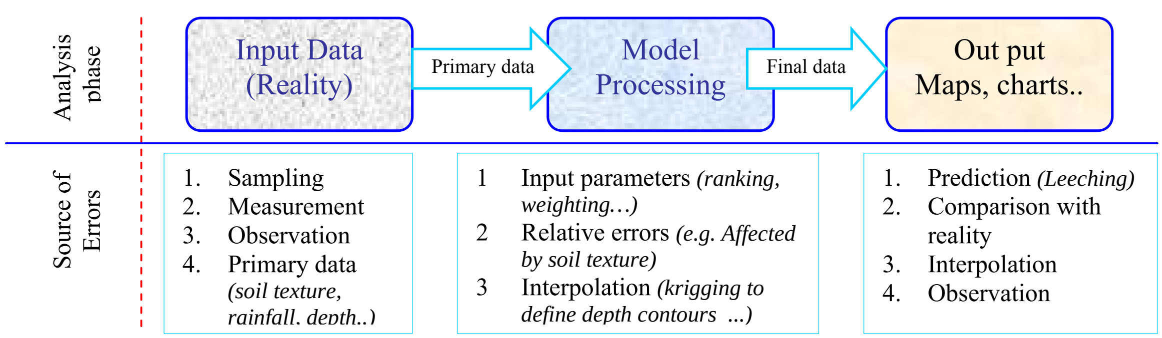


Figure 2.6: Schematic overview of source of error in vulnerability assessment

Figure 2.6 shows that: errors can be classified, based on its source, into three categories; (1) errors in input data, (2) errors during the intermediate steps in modeling process, and (3) errors for the final output i.e. predicting data (Leterme, 2006, Dubus et al., 2002).

The uncertainty assessment can be graphically presented by Figure 2.7, adapted after Stenemo, (2007) where individual pesticides can be classified as being likely, unlikely or uncertain to pose threat to groundwater. Uncertainty of pesticide leaching can be assessed based on the attenuation factor. The uncertainty can be studied by comparing the calculated attenuation factor of the pesticide under subject with two reference (well known) chemicals that represent leacher and non-leacher. Uncertainty band represents the attenuation factor ± error. If the attenuation factor is close to left, then pesticide is likely to leach, if it is close to right, then we can say: pesticide is unlikely to leach. Finally, if it is in the middle, then pesticide leaching is uncertain.

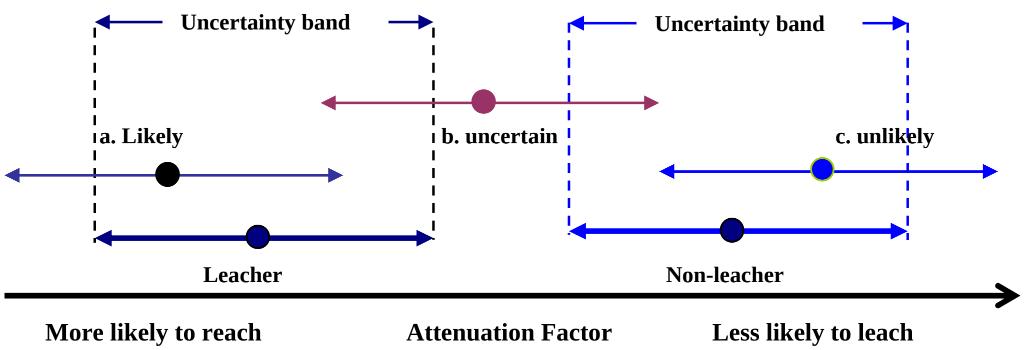


Figure 2.7: Classification scheme used in vulnerability assessment tool (Stenemo, 2007)

2.2.5 Methods of Groundwater Vulnerability Assessment

The process of vulnerability assessment is assembled to produce *maps* that distinguish areas of greater or lesser groundwater vulnerability. Numerous schemes have been developed for assessing and mapping vulnerability (Harter, 2001). In this section, these methods can be grouped into three major categories: (1) Index-based and overlay method, (2) Process based and computer simulation, and (3) Monitoring based and statistical inference method (NRC, 1993, Harter,2001, Leterme, 2006, and Stenemo, 2007).

- **Index-based and overlay method.**

These methods are based on assembling maps of various physiographic attributes (soil type, geologic formation, recharge, etc…) which then is interpreted by scoring, integrating, or classifying the formation to produce and index, rank, or class of "vulnerability (NRC, 1993, Harter 2001). Qualitative or quantitative indices are derived, so as to bring together the key factors that to determine pesticide transport processes (Connell and van den Daele, 2003). Early examples of this type of assessment are the DRASTIC index (Aller et al., 1985) and the GOD index (Foster, 1987). The output of these methods consists of *vulnerability maps*.

Some index-based methods are based on physical and chemical principles governing pesticide transport in soil (Connell and Van, 2003) and considers both pesticides properties (e.g. pesticides half-time, sorption and volatilization), soil properties (e.g. recharge) (Stenemo, 2007). It depends on the purpose of vulnerability; if it is to rank pesticides for specific soil, then recharge rate, water content at field capacity and compliance depth do not matter. However, if the purpose is to rank different soil, in different locations, with respect to leaching risk for specific pesticide, these parameters need to be determined for each location (Stenemo, 2007). The second approach is to be tackled by this research.

Strengths and weakness

They are easy to implement in a geographic information system (Stenemo, 2007) which is a digital form of map making (Harter, 2001). They provide relatively simple algorithms or decision trees to integrate a large amount of spatial information into maps of simple vulnerability classes or indices (Harter, 2001). Index and screening methods require relatively few parameters, which are often available with the concerned authorities, but still based on the theory of solute transport in soil (Stenemo, 2007).

The index-based approaches are associated with uncertainties related to spatial and temporal variability of the model parameters, as well as measurement errors and model errors (Stenemo, 2007). Overlay and index methods have a number of arguments. First, weightings are chosen arbitrarily and solely based on expert opinion (NRC, 1993; Connell and van den Daele, 2003). Second, systems based on indices do not capture the probabilistic nature or the uncertainty of groundwater vulnerability (Worrall, 2002). Third, uncertainties in the data themselves and in the actual relevance of each weighted factor question the reliability of the vulnerability maps (Merchant, 1994; Fogg et al., 1999). Fourth, the use of indices makes validation difficult. Worrall (2002) stressed that validation may be inherently impossible for this category of methods that assess vulnerability outside of a probabilistic framework. Finally, these methods have a greater focus on the distribution of environmental attributes rather than on processes directly controlling groundwater contamination by pesticides (Fogg et al., 1999; Connell and van den Daele, 2003).

The main disadvantage is that several processes and factors that have important impact on groundwater vulnerability are not accounted for in the index-based approach (Stenemo, 2007). For example, the attenuation factor does not account for macropore flow that strongly affects pesticide leaching. Moreover, timing of application and application management may be not accounted for (Stenemo, 2007).

Process-based and computer simulation

These methods account for complex physical and chemical process and at a very detailed scale (Harter, 2001). Assessment methods in this category are usually more elaborated than simple overlay or index methods, and include great amount of realistic complexity to allow for a three-dimensional maps (Leterme, 2007, Harter, 2001). Process-based computer models concentrate on recreating the flow and transport patterns and compute the travel time or the concentrating of a contaminant in the unsaturated zone or in an actual aquifer (Harter, 2001). The most popular groundwater computer process-based models are MODFLOW, FRAC3DVS, and MACRO. Simulation models are generally, data intensive and require detailed information about the soil physical and hydraulic properties (Stemeno, 2006). These data are not usually available or not easy to derive from existing survey database. Models parameters can be derived by calibration against the result of field or laboratory experiments (Larsbo and Jarvis, 2005).

In fact, computer simulation models are rarely an economic alternative for vulnerability mapping, but Harter, (2001) sees that these models are excellent and economic tool of vulnerability mapping if:

- A sufficient data are available or can be collected to prepare the computer model.
- A number of "what-if" scenarios involving complex processes need to be evaluated for making important land use planning decisions.

Strengths and weakness

The advantages of process-based methods are that they can account for the most important processes affecting the fate and transport of pesticides in the soil (Stenemo, 2006). In the advanced models of this category, allow the analysis to compute the uncertainty that is certainly associated with computer model errors and due to our limited knowledge of what the underground actually looks like (Harter, 2001).

The computer models are not commonly used for vulnerability assessment due to their huge and expensive amount of data requirement and the expertise needed to implement them. For example, the soil data required to parameterize the model are time-consuming and expensive to obtain (Harter, 2001, Stenemo, 2006).

The simulation or / process-based models are relatively slow to execute! causing a serious practical limitation in regional leaching assessment (Stenemo, 2006).

Monitoring based and statistical inference methods

Statistical methods use dependent variables such as the frequency of contaminant occurrence, contaminant concentration, or contamination probability (leterme, 2006). These methods are based on the concept of uncertainty, which is described in terms of probability distributions for the variable of interest (NRC, 1993). These methods depend on observed changes in environments as well as scientific equations and model prediction. They can determine statistical relation between observed contamination, observed environmental conditions (e.g. unsaturated zone properties, recharge…), and land uses which are the potential source of contamination (e.g. fertilizer applications, septic tank occurrence..) (Harter, 2001).

Once a model of this dependence variable or the said relationship has been developed, using the statistical analysis, then the process can be used to predict -in similar area elsewhere- the likelihood of risk contamination (leterme, 2006, Harter, 2001). Department of Pesticides Regulation (DPR) in the USA had developed a statistical method nicknamed CULVUL to determine the specific vulnerability of groundwater to pesticides residue (Harter, 2001).

This vulnerability assessment is thus based solely on monitoring data and does not need explanatory variables. However, the application of this method requires extensive data sets (and hence is limited to large, intensively monitored areas) and appears to be less sensitive for boreholes with a low relative vulnerability (Worrall, 2002).

Worrall and Kolpin (2004) developed a logistic regression model of groundwater pollution that brings together variation in chemical properties with land-use, soil and aquifer properties. They discovered that vulnerability, as explained by the independent factors that produced the best regression fit, could be comprised of two parts: an intrinsic vulnerability factor (consisting of variables related to the depth to groundwater, the organic matter and the sand content) and a molecular factor (consisting of variables related to molecular connectivity). However, the regression output is limited to the presence/absence of a compound, and hence limits the discrimination to vulnerable vs. invulnerable wells (Leterme, 2006).

Strengths and weakness

The advantage of statistical methods is that the statistical significance can be explicitly calculated, that provides a measure of uncertainty or certainty of the model (Harter, 2001). The disadvantage is that statistical models are difficult to develop and require much more data sets, but on the other hand, once it has been established, can ONLY be applied to regions that have the same similar environmental conditions to the region for which the statistical models was developed (Harter, 2001).

2.2.6 How to Select an Appropriate Method?

In order to take a decision on the best method that can be used to assess groundwater vulnerability, several questions have to be set into scientific discussion. The decision of which method to use depends on the following points:

(1) Objective of vulnerability analysis;
(2) Available data sets;
(3) Available funding.

The objectives include the traditional questions; "Vulnerability of what?" and "Vulnerability to what?". It is very necessary to consider what needs to be achieved with vulnerability analysis, who will use the results of the analysis, what decision it will influence, and what the cost will be if a wrong decision is made due to wrong or in adequate information (Harter, 2001). The available data is steering the decision of vulnerability method, where some models can do nothing if there are any deficit in data set required. Some data are expensive and not easy to obtain or to extract from available survey or existing database. Reference is made to table 2.6, where the comparison among the three approaches is elaborated. Then and based on the above condition the proper selection will be fairly convenient.

Table 2.6: Comparison among Vulnerability Assessment Methods

#	Methods ➢ Factors ⮟	Overlay and Index-based	Process-based and Computer simulation	Monitoring and Statistical inference
1	Application environment	• Groundwater	• Groundwater + soil	• Groundwater
2	Input	• Maps of various physiographic attribute • Chemical principals affect pesticides transport (Pesticides properties and soil properties)	• Complex physical and chemical process • Detailed information about soil physical and hydrological properties	• Statistical variable (frequency, concentration, probability of occurrence(• Monitoring data, observed changes in environment
3	Output	• Vulnerability Maps	• Vulnerability Maps	• Statistical relation between contamination , environment, and land use
4	Methodology	• Scoring and integrating to produce an index, rank, class of vulnerability.	• Recreate flow and transport patterns. • Compute travel time or concentration of contaminant	• Once model is developed, the process can be used to predict –in similar area elsewhere- the risk of environmental contamination.
5	Advantages	• Easy to implement using GIS • Require relatively few parameters	• Account for most important process affecting fate and transport of pesticides • More elaboration than other methods and allow for 3D maps	• Can explicitly calculate statistical significance • Allow for probabilistic approach.
6	Disadvantages	• Weighing based on expert opinion • Associated with uncertainty due to measurement and model errors • Not capturing probabilistic nature	• Not easy to drive data from survey database • Not economical; huge and expensive amount of data • Time consumable and slow to execute	• Expensive data set • Difficult to develop • Only applied to region of developed model
7	Models	• DRASTIC • GOD • SEAPAGE	• GeoPEARL • MACRO, FRAC3DVS • MODFLOW	• CULVUL

Index and overlay methods seems more stable for vulnerability mapping (Harter, 2008). For the decision and planning sessions, it is more suitable. But for hydro-logically trained people it may not be at the first priority, where the interpretation of the result requires rather professional judgment (Harter, 2008). This judgment can be considered as an integral part of the vulnerability assessment. Where the hydrogeology and unsaturated zone conditions are well known, and the detailed data exist to build a well-calibrated groundwater model (Harter, 2001), the trend will go to the process-based approach.

Statistical methods are feasible where widespread contamination exist to build a well-founded statistical prediction model, which can be used for other similar areas. In fact the statistical methods are specific for a region, it is not wise to map or transfer to other geographical different region (Harter, 2001). This method implies a certain degree of validation and quantifiable measure of vulnerability. It should be stressed that "not every model is good for every purpose", so based on the boundaries of the problem it self, the selection of vulnerability method will be considered.

As a conclusion, the situation here in Gaza strip potentially leads to the first method which is the overlay-index methods. Because there are few data and poor information about most of models parameters, especially those related to hydroheological parameters. We would hope to have a special unit to be responsible for availing all needed variables, completely supported with a well organized monitoring system to enable developing and conducting a real and useful vulnerability assessment.

2.3 Previous Studies in Gaza strip

The presence and the potential presence of pesticides in groundwater is a serious problem in many locations (Hahn, 1997). The Gaza aquifer is under deteriorating quality conditions due to the excessive application of fertilizers (Almasri, 2007). Before this study, there is little knowledge about whether any location is vulnerable to pesticides practice. Given the present excess usage of pesticides in the Gaza strip and the importance of groundwater, an assessment of groundwater vulnerability to pesticide contamination is appropriate. All vulnerability studies conducted for Gaza aquifer for nitrate contamination did not target the pesticides contamination directly (Baalousha, 2006, Almasri, 2007). Other pesticides researches had proved the occurrence of pesticides in the Gaza aquifer and correlation between exposure to pesticides and carcinogenic disease, but did not interested in producing vulnerability maps for pesticides contamination (Safi, 2001, Shomar, 2006).

2.3.1 CAMP 2000

In fact, the Coastal Aquifer Management Plan (**CAMP**) study conducted by engineering firm Metcalf & Eddy and drawn up in year 2000, had shown some pesticides detected in Gaza wells with minimum concentrations (Metcalf & Eddy, 2000). Eighteen pesticides from the organochlorine group have been tested for 168 domestic and agricultural wells all over Gaza strip. The CAMP did not concentrate on vulnerability of Gaza aquifer to pesticides, it concentrated on reducing the amount of water pumped from the aquifer for agriculture irrigation whilst simulation improving supply of dinking water to population by providing additional water from sources other than the aquifer (Metcalf & Eddy, 2000).

2.3.2 Shomar 2003

Shomar B. (2006), has conducted a study along three years program to monitor types and levels of contamination by 52 pesticides in 94 groundwater wells in Gaza (Shomar, 2006). Some pesticides such "Atrazine, atrazine-desisopropyl, propazine, simazine were detected in 18, 15, 8 and 5 wells with average concentration of 3.5, 1.2, 1.5, and 2.3 µg/L, respectively" (Shomar, 2006). The above research proved the occurrence of pesticides in levels higher than the EPA standards.

2.3.3 Almasri 2007

Using the DRASTIC approach, Almasri (2007) discovered that 10% and 13% of Gaza strip area is under low and high vulnerability of groundwater contamination, respectively and the remaining 77% can be considered as an area of moderate vulnerability of groundwater contamination of nitrate concentration (Almasri, 2007).

2.3.4 Baalousha 2006

Baalousha (2006) has used the GIS tools to sum up the products rating and weights for seven hydrological parameters that contribute to aquifer vulnerability. Depending on the available data, maps of DRASTIC parameters were prepared for the Gaza strip area. Each map was given the rate and a special weight factor realized. The final vulnerability map for nitrate level of contamination is obtained (Baalousha, 2006).

2.3.5 Summary of previous studies and discussion

Accordingly, the vulnerability of Gaza aquifer to contamination by pesticides has not been targeted by any one. CAMP 2000, and Shomar had approved the occurrence of pesticides in Gaza aquifer, but they did not provide vulnerability maps to pesticides contamination. The other researchers provided maps for vulnerability of Gaza aquifer to nitrate pollution. It seems that this research is the first trial to conduct vulnerability to pesticides maps for Gaza aquifer. The complementary study that may be conducted in future will concentrate on the levels of contamination of pesticides leaching Gaza aquifer. So, field experimental tests and monitoring system has to be developed to follow up the historical update of pesticides contamination.

CHAPTER 3

Description of Study Area

3.1 Physiography of Study Area

3.1.1 Geography

Gaza Strip , the southern part of Palestine, is located on the south-eastern coast of the Mediterranean Sea, between longitudes 34° 2” and 34° 25” east, and latitudes 31° 16” and 31° 45” north (Aish, 2004). Figure 3.1 shows location map of Gaza strip. The area of Gaza strip is about 365 km^2 and its length is approximately 45 km along the coast line. Its width ranges from 6 to 16 km. The Gaza strip is bounded by the Mediterranean Sea from the west, Egypt from south, and is surrounded by Israel from east and north. The terrain is flat or rolling, with dunes near the coast, and the floor of Gaza strip varies in elevation between -20 m below mean sea level to +120 m above the mean sea level (PWA, 2007).

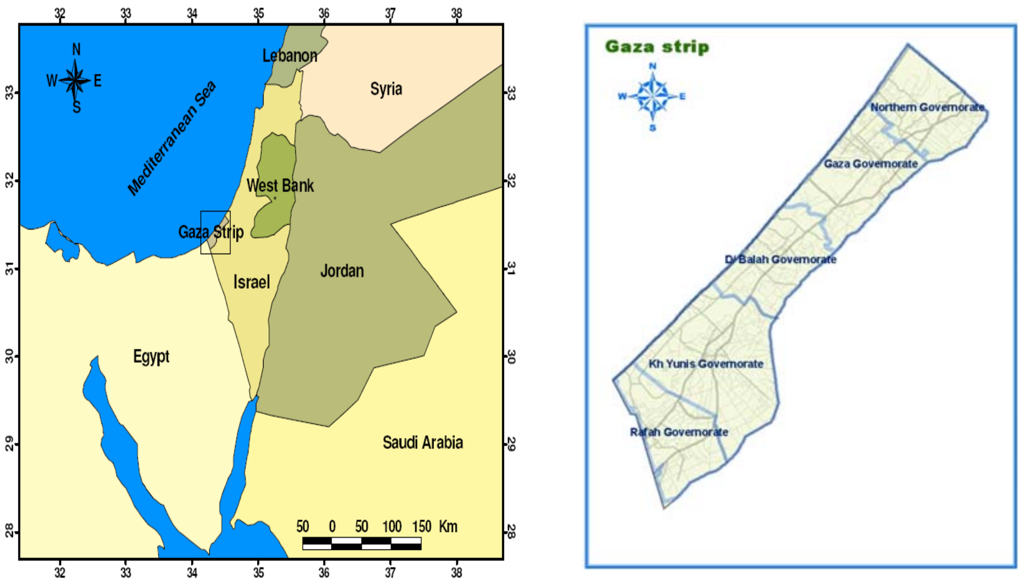


Figure 3.1: Location of Gaza strip (Aish, 2004)

Based on Ministry of Environmental Affair (MEnA, 1998), Gaza Strip forms part of the coastal foreshore plain bordering the Hebron Mountains in the north-east, the Northern Negev desert in the south-east, and the Northern Sinai desert in the south. It is situated in the shadow of the Nile Delta and Northern Sinai. The curve in the coastal starts from El Arish towards north of Gaza. According to Dudeen, (2001) Gaza Strip region has a substratum of Tertiary limestone, calcareous sandstone marls, clay and marine diluvium. Partially fossilized dune sand deposits cover wide stretches of land. These dune sands are often cemented by calcareous sediments and cemented infiltration, and form therefore compact masses of hard rocks.

3.1.2 Population

Based on Palestinian Center Bureau of Statistics (PCBS, 2007) the total populations of Gaza strip has increased from 1.02 million in year 1997 to 1.42 million in year 2007, increasing the population of 39% by the year 2007. The current population density 3,881 capita/km^2 of the total area in the Gaza strip. As per table 3.1, the current population growth rate is around 3.8%, the fertility rate is 5.4 births per mother, the birth rate is 36.7 births per 1000 population, and the mortality rate is 3.8 deaths per 1000 population. From table 3.1; the crude fertility and mortality rate have decreased by 22% and 19% as from year 1997 up to year 2007 respectively.

Table 3.1: Comparison between population parameters for 1997 and 2007 for Gaza strip (PCBS, 2007)

Parameters	Unit	Year		Percentage change (%)
		1997	2007	
Population	capita	1,022,207	1,416,539	**39**
Population density	person / km^2	2,801	3,881	39
Fertility rate	birth / female	6.9	5.4	-22
Birth rate	birth / 1000 population	42.7	36.7	-14
Mortality rate	death / 1000 population	4.7	3.8	-19

3.1.3 Climate

The Gaza Strip has a temperate climate, with mild winters, and dry and hot summers, subject to drought. The study area is a part of the coastal zone in the transitional area between the temperate Mediterranean climate to the east and north and the arid desert climate of the Negav and Sinai deserts to the east and south (figure 3.1). As a result, the Gaza Strip has a characteristically semi-arid climate (Shomar, 2006). Due to the above fact, the big difference, between rainfall quantities of about 445 mm /year in the north of Gaza strip and around 244 mm /year in the south of Gaza strip, can be verified in this relatively small area.

3.1.3.1 Temperature

Figure 3.2 presents the maximum, minimum and mean monthly air temperatures as observed in the meteorological station of Gaza city for the period lasting from 1970 until 2005. Temperature gradually changes throughout the year, reaches its maximum in August (summer) and its minimum in January (winter) (Aish, 2004 and PCBS, 2007). Table 3.2 shows average monthly maximum and minimum temperature, where the average monthly temperature varies from 13 degree Celsius in winter to 25 C° in summer based on temperature records from 1970 to 2005.

Table 3.2: Mean monthly min, average, and max temperature (1970-2005)

Season	Minimum (C°)	Average (C°)	Maximum (C°)
Winter (January)	9.6	13	22.7
Summer (August)	17.6	25	29.4

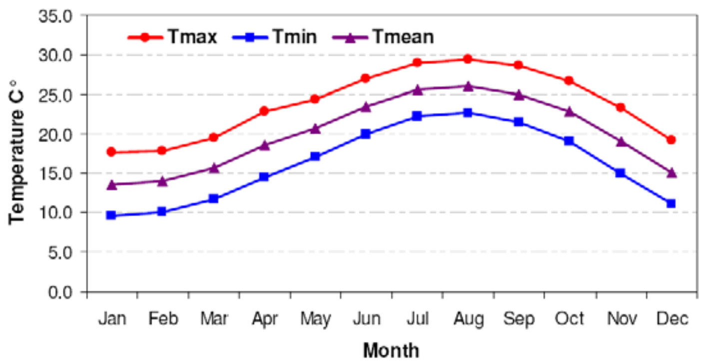


Figure 3.2: Mean monthly max, min and average temperature (C°) for the Gaza Strip (1970 – 2005) (Aish, 2004 and PCBS, 2007)

3.1.3.2 Rainfall

All data related to this section is taken or derived from data obtained from Palestine Water Authority (PWA, 2007). Rainfall data is an essential element of basic data input to any

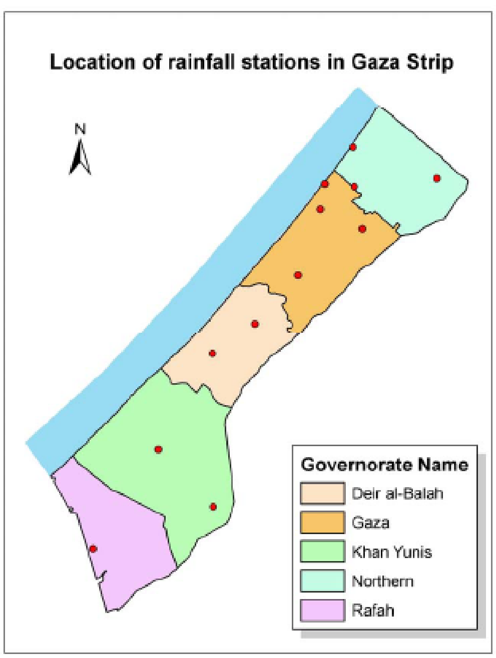


Figure 3.3: Location of 12 rainfall stations

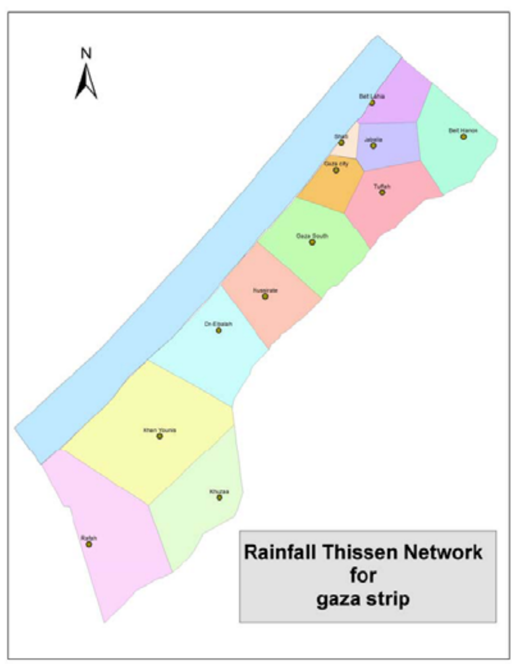


Figure 3.4: Rainfall Thissen Network

hydrologic and engineering studies like rainwater harvesting, storage analysis, water supply and the whole water resources management. In the Gaza Strip, as a semi-arid zone, rainfall is the main source of groundwater recharge. Consequently, a detailed knowledge of rainfall regime and its seasonal, monthly, and spatially distribution is a perquisite for water resources planning and management. In Gaza strip there are 12 manual rainfall stations distributed overall Gaza strip as shown in figure 3.3. Data from these stations are collected on a daily basis, these stations are operated by ministry of agriculture and data obtained from these stations are entered manually in PWA's database.

The average rainfall depth fallen in Gaza strip catchments' area is calculated from daily rainfall records, sourced from 12 manual stations, using Thissen network method, where each station represents sub-area of the catchments, and it involves in determining the area of influence for each station, as shown in figure 3.4, each representative area is computed using GIS tool. The variation of the annual rainfall for the meteorological station of whole Gaza strip, for the period from 1985 to 2007, is presented in figure 3.5.

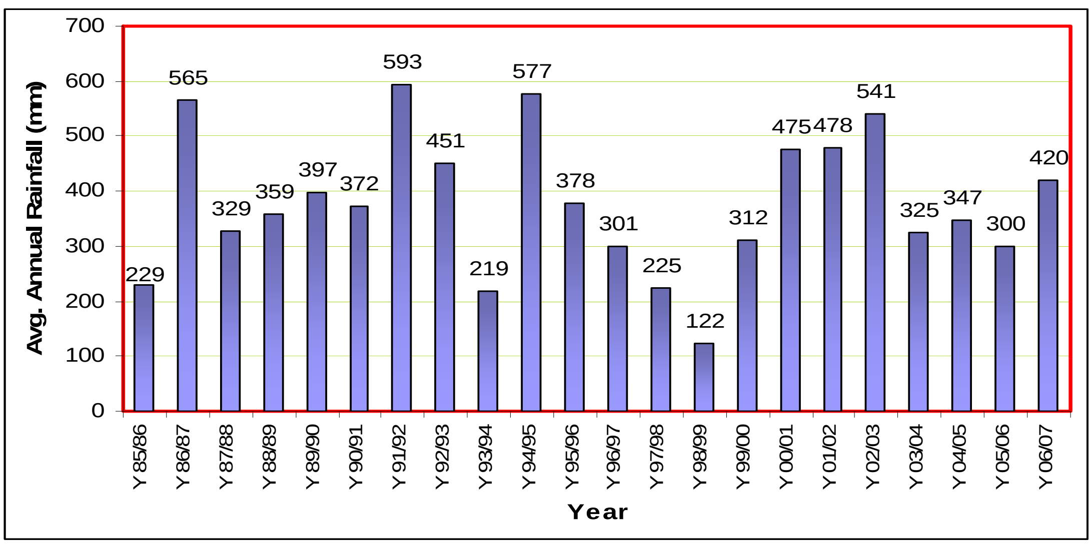


Figure 3.5: Average annual rainfall in the Gaza Strip (as from 1985 to 2007)

Despite of the small area of Gaza strip (365km2), the level of rainfall varies significantly from one area to the next with an average seasonal rainfall of 445 mm in north area (north governorate), to 244 mm in the southern area (Rafah governorate). The spatial annual average rainfall distribution is shown in figure 3.6.

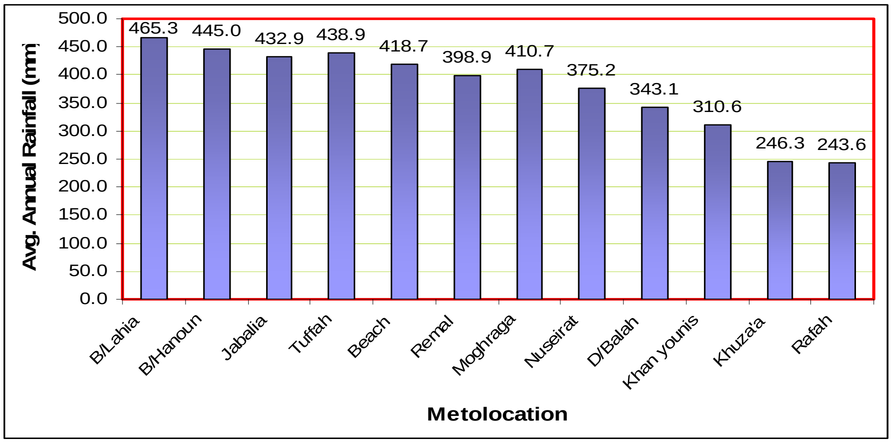


Figure 3.6: Spatial Distribution of Average Annual Rainfall of Gaza Strip (1985 – 2007)

PWA records show that, most rainfall occurs in the period from October to March, the rest of the year is completely dry. Precipitation patterns are classified as thunderstorms and rain showers. The peak of rainfall takes place during December and January. The rainy days range from 45 to 50 days. The average annual volume of rainfall is about 110-115 MCM/yr. The potential recharge is between 40 to 46 MCM/year. Based on Baalousha (2005), the average recharge in Gaza strip is about (30-40) % of average rainfall.

Records of year (2006-2007) only, shows that, the average rainfall depth over Gaza strip area is estimated about 364.7 mm with total amount 133.1 MCM received through 46 rainy days. Table 3.3 shows that the average seasonal rainfall is 521.9 mm in north area, and 225 mm in the southern area. Notice that the rainfall amount decreases to almost half as we move 40 km to the south. This is so because Gaza Strip is located in the transitional zone between a semi humid climate north of Gaza Strip and arid climate of Sinai desert of Egypt in the south. Figure 3.7 shows the monthly rainfall for year 2006-2007.

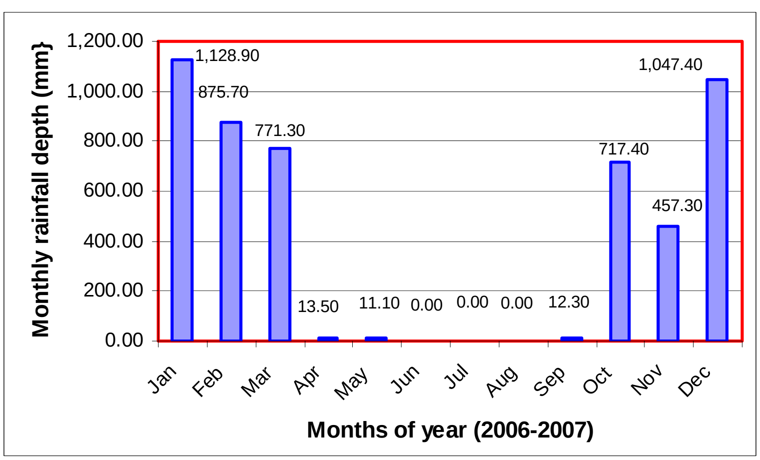


Figure 3.7: Monthly rainfall depth for year 2006-2007 (PWA, 2007)

Table 3.3 : Monthly rainfall depth (mm) for year 2006-2007 per location (PWA, 2007)

Moth→ Location	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year 2007
B Hanoun				47	21.1	112.2	141.1	96.5	90.8	1.2			509.9
B/Lahia				88	19.5	109.5	158	85	70.3				530.3
Jabalia			2.5	56.5	25.3	106.9	143.6	116	85.9				536.7
Shati			0	50.5	18.6	96.5	128.1	106	69.3				469
Remal			2.3	51.8	26.5	103.2	151.2	86.8	77.8	0.7	0.9		501.2
Tuffah			2.5	64.9	36.5	107.1	157.5	95.9	78.9	1.2	1		545.5
Moghraga			1.5	50.2	49.3	65	69.4	76.9	74.3	0.4	1.2		388.2
Nuseirat			1	92.5	57.5	74	46	64	66		2		403
D/Balah			1	85	103	78.5	35.5	63.5	49.5		2		418
Khan Younis			1.5	51.5	25.5	51.5	28	36.8	51.7	3	2.5		252
Khuzaa				48.5	28.5	82	32.5	30.3	32.8	1	0.5		256.1
Rafah				31	46	61	38	18	24	6	1		225
Total (mm)	0.0	0.0	12.3	717	457.3	1047	1129	875.7	771.3	13.5	11.1	0.0	364.7

Figure 3.8 shows the rainfall depth contour map for year 2006-2007 using the kriging interpolation technique integrated in the Arc GIS model.

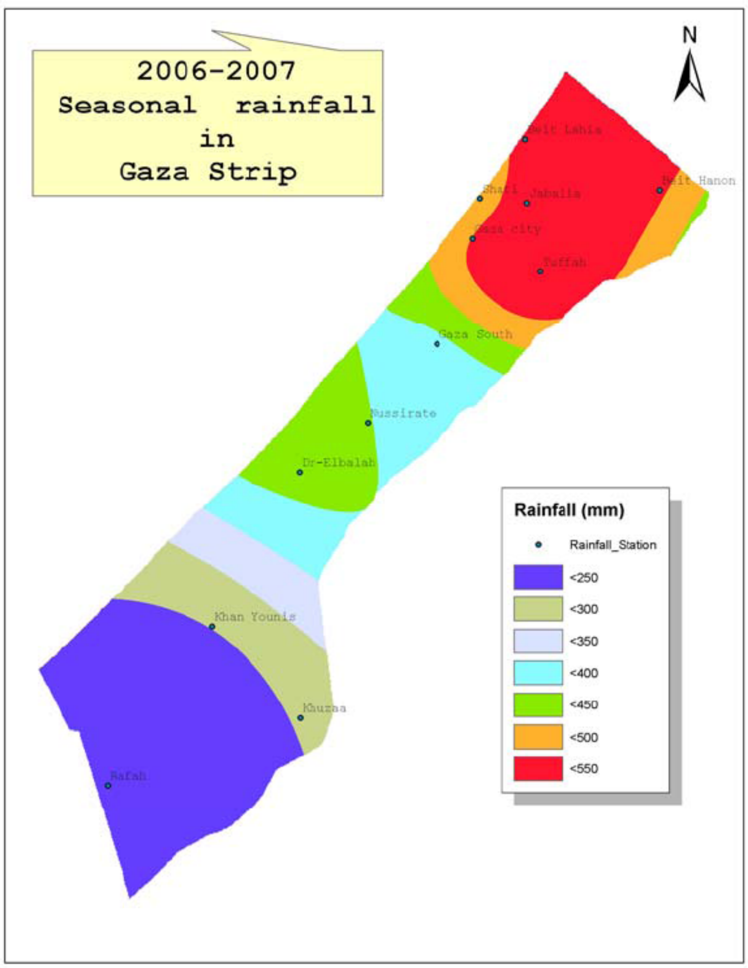


Figure 3.8: Seasonal rainfall depth contour map (PWA, 2007)

3.1.3.3 Crop evapotranspiration

The monthly values for the reference crop evapotranspiration (ETo), as determined with the FAO Penman-Monteith equation paper 56 (Allen et al., 1998) are plotted in figure 3.9. The reference evapotranspiration is a climatic index integrating the effect of air temperature, humidity, wind speed and solar radiation. It expresses the evaporating power of the atmosphere (Aish, 2004). ETo is small in winter about 63-80 mm/month, and reaches its maximum in summer at about 156 mm/month.

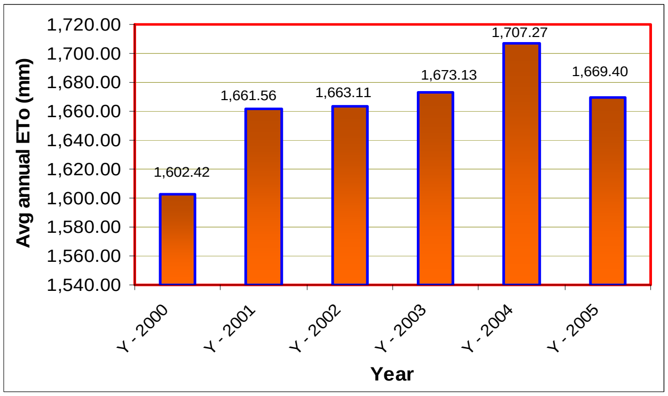


Figure 3.9: Mean monthly reference crop evepotranspiration (ETo) for Gaza Strip (Ghabayen, 2005)

Figure 3.10 represents the average annual ETo for the period of 1999-2005. The calculated average annual evapotranspiration for the Gaza Strip in the period from 1999 to 2005 is around 1660 mm/year (PWA, 2007).

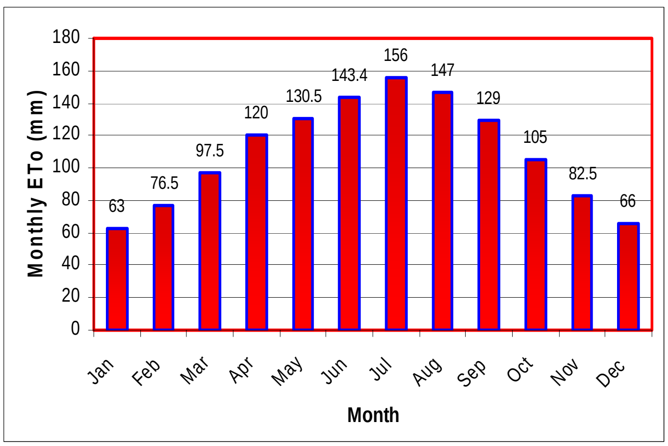


Figure 3.10: Average Annual ETo (mm) (2000- 2005) (Ghabayen, 2005)

Figure 3.11 shows difference between amounts and timely occurrence of both monthly evapotranspiration (ETo) and monthly rainfall in the Gaza strip. From figure, water evaporated by plant is much more than amount of rainfall (PWA, 2007).

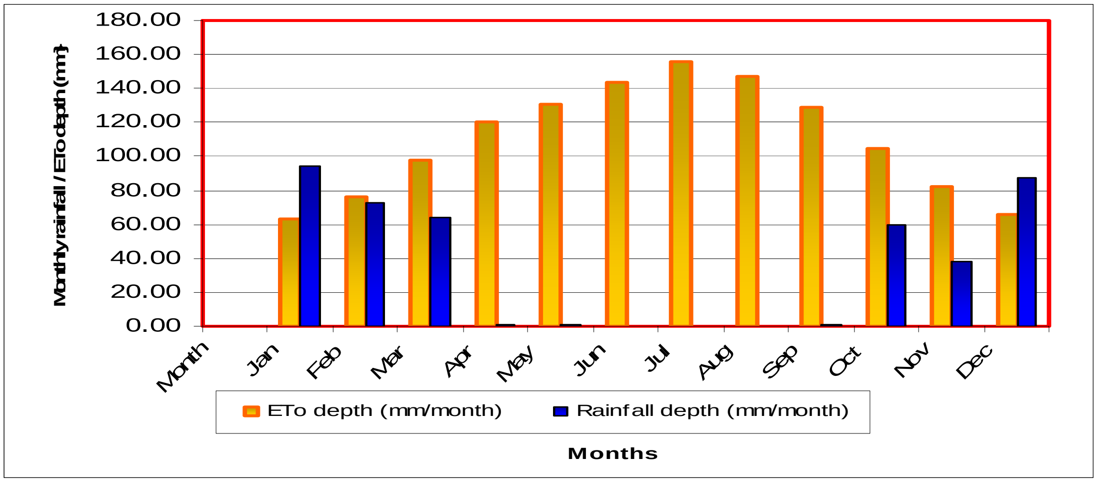
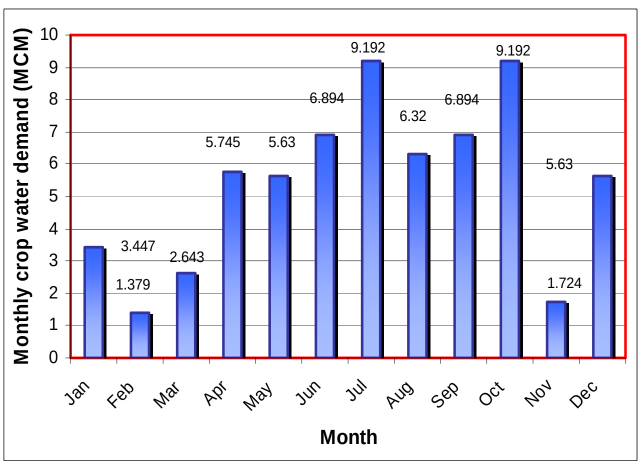


Figure 3.11: Average Monthly variation of total rainfall and evapotranspiration (ETo) (PWA, 2007)

Based on Ghabayen (2005), the crop water demand in the Gaza strip, the crop water demand is about 65 MCM as shown in figure 3.12. Figure 3.13 shows the annual water need for each crop in the Gaza strip, where table 3.4 demonstrate the five crop categories and their specified types.



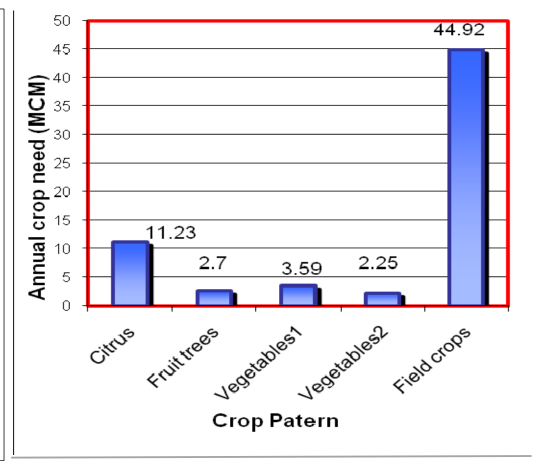


Figure 3.12: Monthly crop water demand for Gaza strip

Figure 3.13: Annual crop need for Gaza strip

Table 3.4: Crop categories

Crop Category	Crop Type
Citrus	Orange / lemon / grapefruit
Fruit trees	Apples / pears / peaches / apricots / almonds
Vegetables1	Cucumber / squash / cabbage
Vegetables2	Tomato / sweet peppers / egg plants / potato

3.1.4 Land use and crop cover

According to PWA (2007) about 216 km^2, is considered as a cropland and it is dominated by one of the densest poultry industry. Due to the growing population, many of the industrial units crept to population districts and discharge their polluted liquid wastes to the domestic waste networks. Based on data extracted from crop pattern database, which has been developed by Ministry of Agriculture (MoA, 2005), the area (that of greenhouses, rain fed crop, horticulture, and grapes) seems under heavy strain of pesticides application is about 164 square kilometers as shown by table 3.5. Fig 3.14 shows the spatial distribution of crop pattern in the Gaza strip. The sensitive area is that includes greenhouses, rain fed, horticultures and grapes crops, where pesticides are dominantly used in frequent and considerable amounts. There is limited need for pesticides for the other crops like almonds, citrus, olives, and dates. So, these areas have minimal considerable influence.

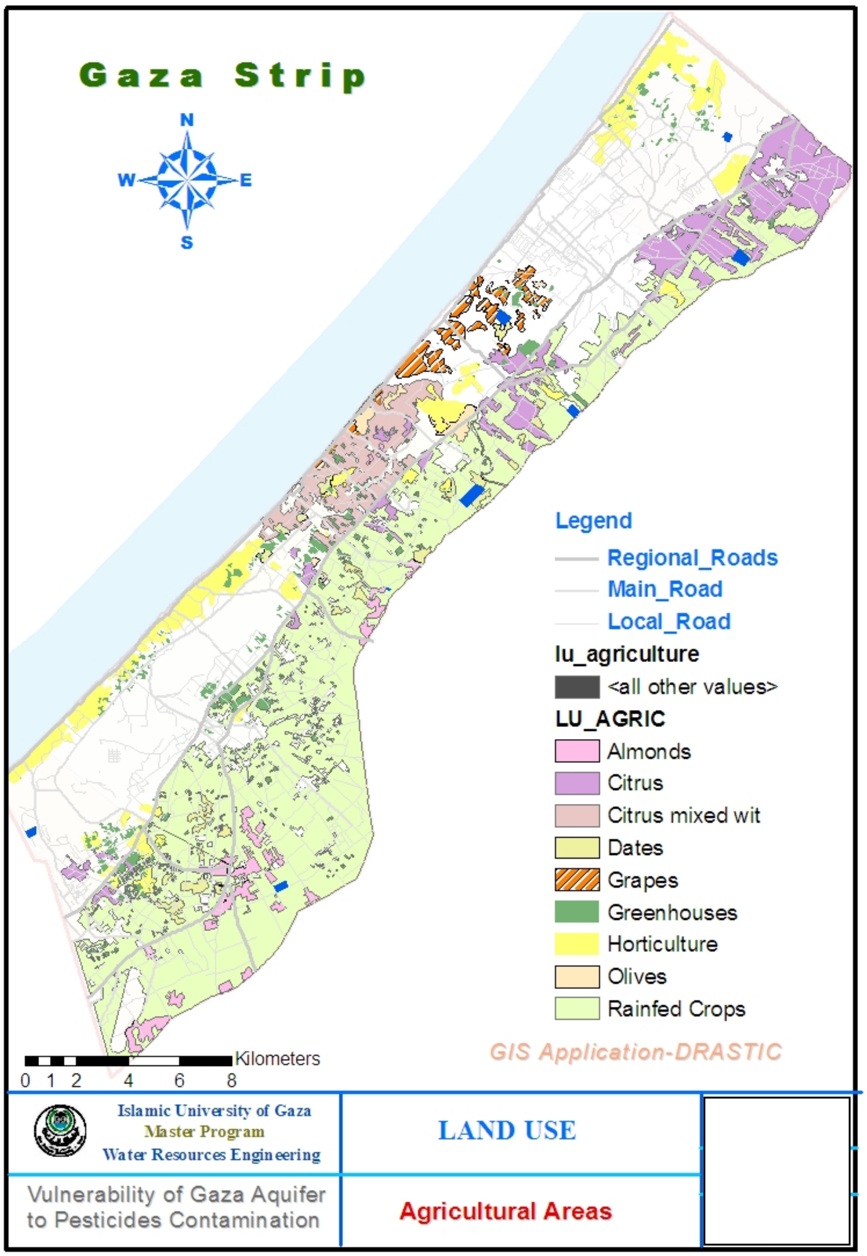


Figure 3.14: Agricultural area of Gaza strip (MoA, 2005),

Agricultural areas that are sensitive to pesticides contamination will be identified using the proper approach in this research.

Table 3.5: Areas of crop pattern in Gaza strip (MOA, 2007)

#	Crop pattern	Area (m^2)
1	Greenhouses	10,723,254.70
2	Rain fed Crops	123,921,309.46
3	Horticulture	23,637,021.25
4	Grapes	5,503,636.02
	Subtotal-1	**163,785,221.42**
5	Almonds	6,272,084.59
6	Citrus	26,201,944.62
7	Citrus mixed wit	12,888,148.89
8	Olives	1,979,683.79
9	Dates	4,889,235.30
	Subtotal-2	**52,231,097.19**

Relation between soil type and type of vegetation

Zaidenberg and Dan, (1981) had found a close relationship between vegetation characteristics and the degree of soil leaching. Vegetation diversity and density decrease with the increase of exchangeable sodium percentage (ESP), sodium absorption ratio (SAR) and salinity values expressed as electrical conductivity. The same is true with respect to the lime content of soils on hard rocks. Zaidenberg and Dan, (1981) refer the reason for this relationship to the soil moisture regime. Based on Dudeen (2004), the factor that is decisive in deciding the type of vegetation is climate and to a certain degree the landform elements. In Gaza Strip irrigated crops are prevailing, where citrus plantations are among the irrigated crops.

3.1.5 Topography

Based on Aish (2004) and Al Masri (2007), the Gaza topography is characterized by elongated ridges and depressions, dry streambeds and shifting sand dunes. The ridges and depressions generally extend in a NNE- SSW direction, parallel to the coastline. They are narrow and consist primarily of sandstone (Kurkar). In the south, these features tend to be covered by sand dunes. Land surface elevations range from -20 m below mean sea level to about 120 m above mean sea level as shown in figure 3.15. The ridges and depressions show considerable vertical relief, in some places up to 60 m. Surface elevations of individual ridges range between 20 m and 90 m above mean sea level.

Thus naturally, huge amounts of the rainwater in the urbanized areas will mostly run to the sea, consequently, there will be no enough time for infiltration to the groundwater. The sand dunes are 30-60 m above sea level; cover a total area of 70 km^2. Moreover, Lucite soil, which is a mixture of sand and loam, is widespread in the middle of the Gaza Strip.

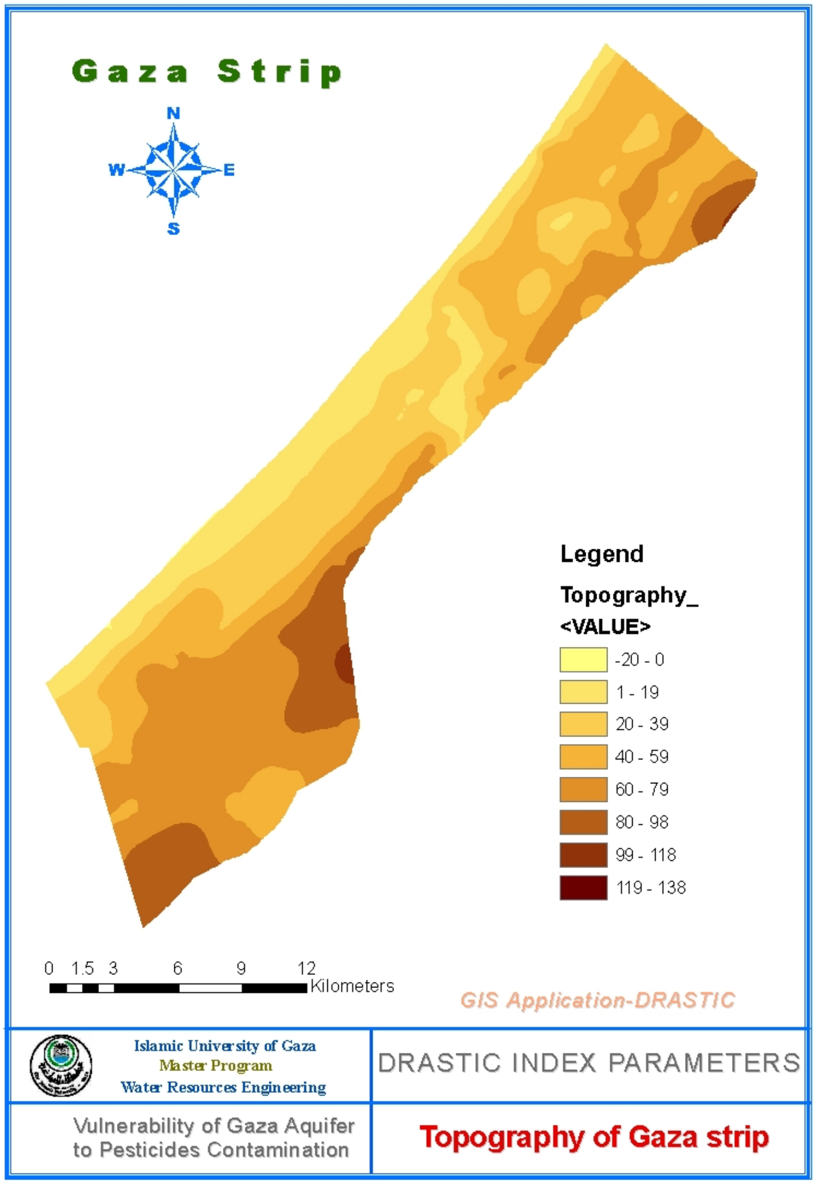


Figure 3.15: Topography of Gaza Strip

Based onMinistry of Environmental Affair's report (MEnA, 1998), Gaza is located on the coast of the Mediterranean Sea, north of the Sinai Peninsula and southwest of Jerusalem, on a road that links Egypt with central Israel. The topography of the coastal plain is determined by the exposure of Kurkar ridges. The age of these ridges increases from the coastline eastwards. In the north of the Gaza Strip there are four ridges: the coastal ridge (20 m MSL), Gaza ridge (up to 50 m MSL), El Muntar ridge (80 m MSL), and Beit Hanoun ridge (90 m MSL). The ridges are separated by deep depression (20-40 m MSL) with alluvial deposits. There is evidence that there are at least three to four younger Kurkar ridges on the continental shelf, parallel to the present coastal line and several kilometers offshore. Kukar ridges of calcareous sandstone appear all along the coast positioned in a south-west-northerly direction parallel to the coast. The influence of these Kurkar ridges on sedimentation and erosion processes is however limited to local disruption of waves and currents.

3.1.6 Soil (top soil and vadose zone)

Based on PWA (2007); the soil in Gaza Strip is composed mainly of three types, sands, clay and loess. The sandy soil is found along the coastline extending from south to outside the northern border of the Strip, at the form of sand dunes. The thickness of sand fluctuates from 2 meters to about 50 meters due to the hilly shape of the dunes. From figure 3.16, the soil map of Gaza strip, the sand dunes varies from 4 to 5 km inland, and are wider in the north and in the south than in the center. More inland to the east, the soil becomes less sandy with more silt, clay, and loess. With reference to Aish (2004) and MEnA (1998), clay soil is found in the north eastern part of the Gaza Strip. Loess soil is found around Wadi Gaza, where the approximate thickness reaches about 25 to 30 m. (Jury and Gardner, 1991). Figure 3.16 and table 3.6 show that the top soil of Gaza strip consists mainly of six soil types:

(1) Sandy soil
(2) Sandy loess soil
(3) Sandy loess soil over loess
(4) Loessal sandy soil
(5) Loess soil
(6) Silty clay

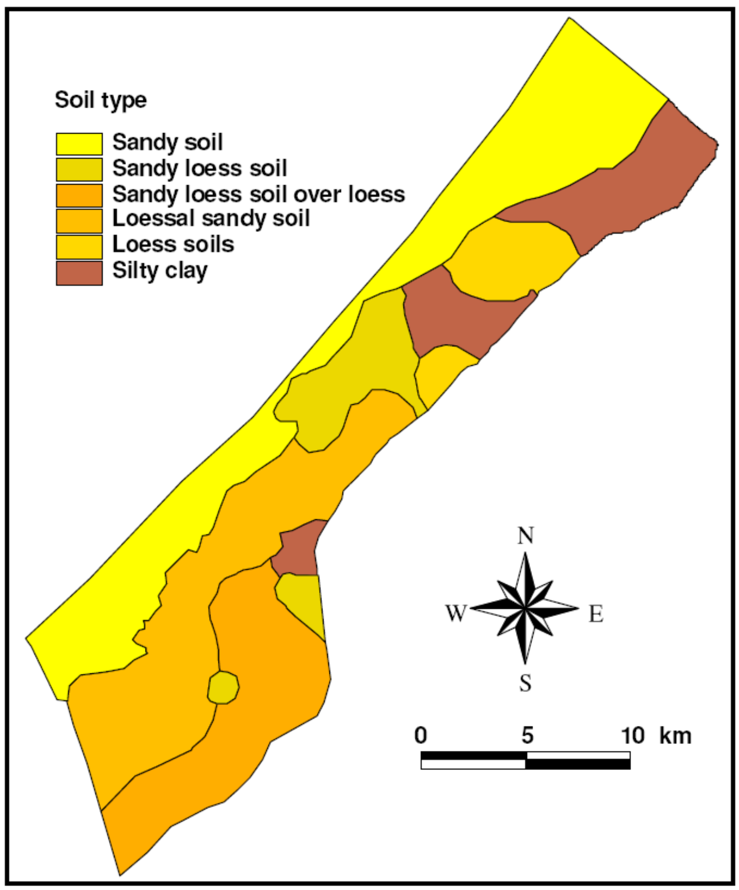


Figure 3.16: Soil map of Gaza Strip (PWA, 2007)

Table 3.6: Soil Type, land form, and dominant land use of Gaza Strip (Is-haq, 1994 and Shomar, 2004)

#	Soil Type	Land Form	Dominant Land Use
1	Sandy regosols (Arenosolic rhegosols)	• Active steep dunes • Undulating stabilized dunes • Calcareous ridges	• Irrigated horticulture in green houses • Irrigated horticulture in tunnels and open fields • El Mawasi rain-fed vegetables/fruit • Raifed grapes
2	Loessial sandy soils (Calcaric Arenosols)	• Flat/rolling interdune areas	• Open horticulture, tunnels
3	Sandy loess soils (Arenosolic Calkaric Soils)	• Flat/rolling plains or depressions	• Dates • Citrus plantation • Some irrigated vegetables, field crops
4	Loess soils (Calcaric Soils)	• Rolling plains	• Citrus plantations
5	Sandi loess soils over loess (Arenosolic Calcaric over Calcaric Soils)	• Gently rolling plains	• Rain-fed field crops • Almonds, olives • Some irrigated vegetables
6	Dark brown/ reddish brown clay loam (Luvisols, Xerosols)	• Ancient alluvial valleys • Depression and slopes	• Citrus orchards • Rain-fed Field crop • Non-rain-fed vegatables

The soil components can be illustrated as follows: (Shomar et al., 2004).

1. **Arenosolic** : (sandy) soils of dune accumulation are regosols without a marked profile. The soils are moderately calcareous (5-8% $CaCo_3$), with low organic matter, and are physically suitable for intensive horticulture.
2. **Calcaric Arenosols** : (loessy sandy soil) can be found some 5 km inland in the central and southern part of the Strip, in a zone along Khan younis toward Rafah, parallel to the coast. This belt forms a transitional zone between the arenosolic soils and the calcaric (loess) soils.
3. **Typical Calcaric** soils are found in the area between the city of Gaza and the Wadi Gaza and contain 8-12% CaCO3.
4. **Arenosolic Calcaric** (sandy loess) soils are transitional soils, characterized by a higher texture. These soils can be found in the depression between the Calcareous (Kurkar) ridges of Deir El Balah
5. **Arenosols over Calcaric** soils are loess or loessial soils (sandy clay loan) that have been covered by a layer (0.20-0.5m) of dune sand. These soils can be found east of Rafah and Khan younis.
6. **Fuvisols (alluvial) and Verisols (grumosolic)**, are dominated by loamy clay textures. It can be found on the slopes of the northern depression between Beit Hanoun and Wadi

Gaza. Boring east of Al montar ridge has revealed that alluvial deposits of about 25 m thick occur. At some depth, calcareous concentration is present. The CaCO3 content can be approximately 15-20%. The alluvial sediments are underlain by a calcareous layer.

With reference to Dudeen (2004) the main soil type originates from the dune sands. Dune sands are overlying al-luvial soils in a shallow layer creating ideal conditions for fruit plantations. Unfortunately, Citrus plantations – currently - dominate the area. These dune sands have exceedingly low water holding capacity and very high water permeability. In addition to the sandy soils, loess soils are also occurring in the Gaza Strip. These soils owe their origin mainly to the dust storms of the desert. They are rich in calcium but poor in iron and aluminum, have a high percentage of fine particles, which belong mainly to the fine sand fraction. They are easily permeable by water and air, therefore their texture is most suitable for cultivation of root crops.

3.2 Groundwater

3.2.1 Hydrogeology of Mediterranean Coastal Aquifer

The hydrogeology of Mediterranean coastal aquifer, where Gaza aquifer is a small part of, is to be briefly discussed as an introduction to Gaza aquifer hydrogeology. The coastal aquifer of Palestine is a Pleistocene granular groundwater formation extending from the Carmel horst in the north to the Gaza Strip in the south, and from the seashore to the limestone Yarqon-Taninim aquifer on the east as per figure 3.17 and 3.18 (Melloul et al., 2006). 57 cross-sections had been conducted and modified since 1968: one for every two kms (Melloul et al., 2006). The Tolmach re-modified cross sections, e.g. figure 3.19, have been used, owing to the fact that they form a complete and continuous set, adapted for purposes of hydrological assessment (Melloul et al., 2006).

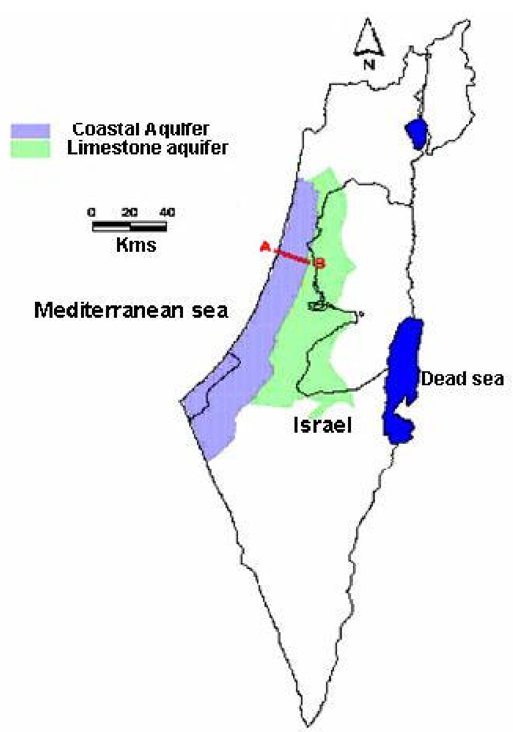


Figure 3.17: location map for Mediterranean Coastal aquifer (Melloul etal., 2006)

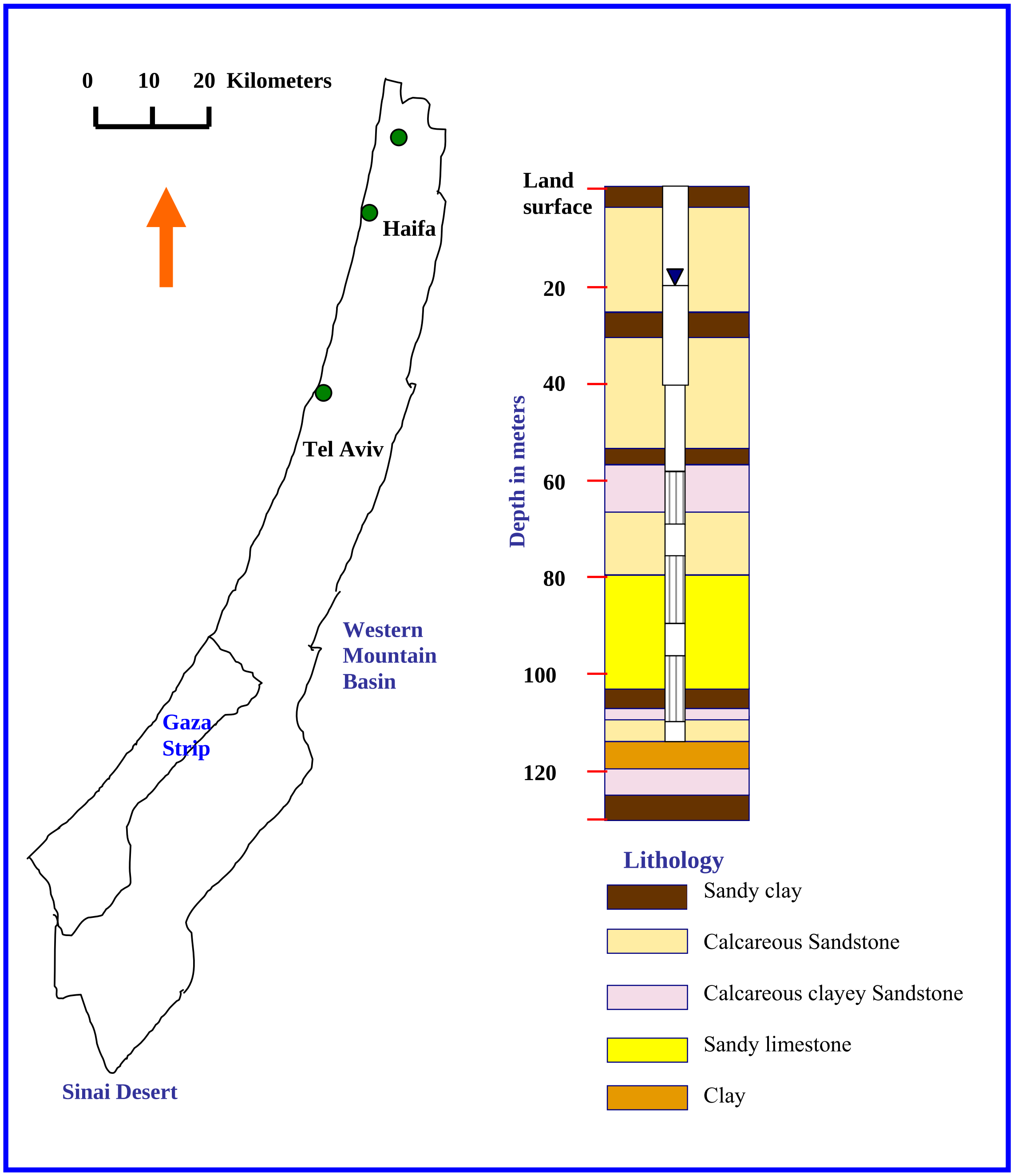


Figure 3.18: Coastal Aquifer Basin and Lithology (Melloul et. al., 2006)

"Geologically, the aquifer is composed of wedge-shaped layers of dune sand, sandstone, calcareous sandstone, and silty loams, as well as intervening clay lenses. The top of the aquifer is covered by thin layers (of zero to two meters) of sandy to silty and/or clayey soils. The aquifer's layers and aquitard lenses are at their thickest along the coast and feather out between two and five km from the sea, separating the aquifer into sub-aquifers. Within around 12 km of the coast, the aquifer is built upon the Saqiya sea clays of Neocene age.

Further east, the aquifer rests upon limestone rocks of Eocene, Senonian, Turonian, and Cenomanian age" (Melloul et al., 2006).

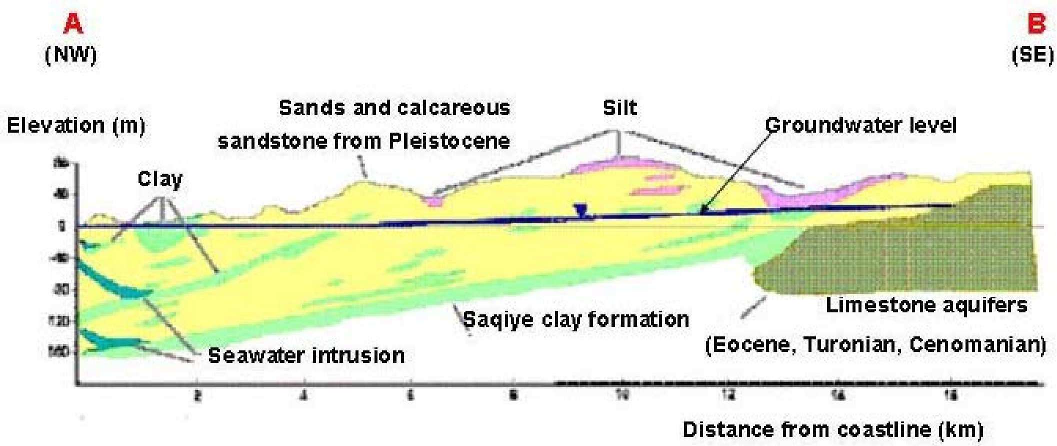


Figure 3.19: Hydro-geological cross-section A-B, transect from Figure 3.17 (Melloul et al., 2006).

3.2.2 Hydrogeology of Gaza Aquifer

Geology and stratification

The coastal aquifer of the Gaza strip consists of the Pleistocene age Kurkar group (Gvirtzman, 1984) and recent (Holocene age) sand dunes. The Kurkar group consists of marine and Aeolian calcareous sandstone (Kurkar), reddish silty sandstone (Hamra), silts, clays, unconsolidated sands and conglomerates. Regionally, the Kurkar group is distributed in a belt parallel to the coastline, from Haifa in the north to the Sinai in the south.

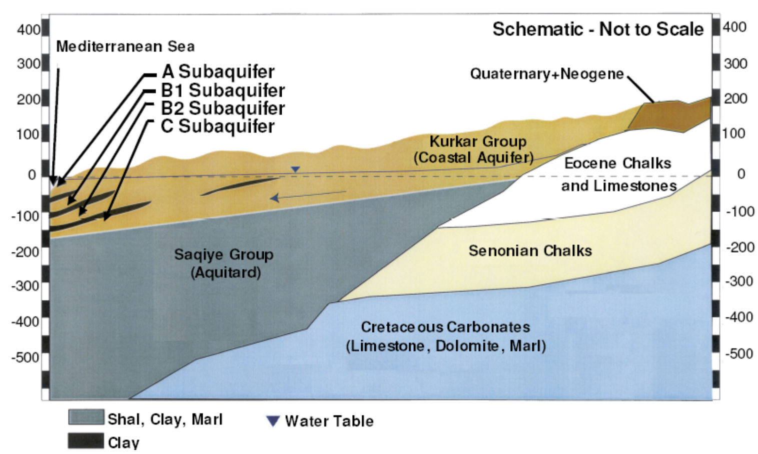


Figure 3.20: Generalized geological cross-section of the coastal plain (Metcalf and Eddy, 2000)

Near the Gaza Strip, the belt extends about 15-20 km inland, where it unconformable overlies Eocene age chalks and limestone (the Eocene), or the Miocene-Pliocene age Saqiye group, a 400-1000 m thick aquitard beneath the Gaza Strip, consisting of a sequence of marls, marine shale’s and clay-stones (Aish, 2004). Figure 3.20 presents a generalized geological cross-section of the coastal aquifer (Metcalf and Eddy, 2000). Meanwhile Melloul (1991) provided longitudinal and transverse cross sections for Gaza strip describing litho-logical stratification of coastal aquifer. These sections are arranged in *appendix B.*

The Gaza aquifer is composed of Quaternary deposits that include layer of loess, dune sand, calcareous sandstone, silt, and clay. It forms a seaward sloping plain, which ranges in thickness from about 40-50 m near the eastern border with Israel to 150-200 m at the shore. Clay layers, which begin at the coast and feather out approximately 4 km from the sea, separate the main aquifer into various subaquifers near the shore. The base of the aquifer is the low-permeability Saqiya Formation (Tertiary age), and approximately 1 km thick wedge of marine clay, shale, and marl (Qahman and Zhou, 2001).

Using MODFLOW, Aish (2004) conducted a visual perspective of Gaza strip. The geological data were taken from Palestinian Water Authority and the Gaza coastal aquifer management program (Metcalf and Eddy, 2000). Accordingly, there are 4 sub-aquifers of sand with gravel (Kurkar formation) and 3 major clay layers. The base of the model consists of Saqiye group, assumed to be impermeable. General model stratigraphy is depicted as 3-D representation in figure 3.21.

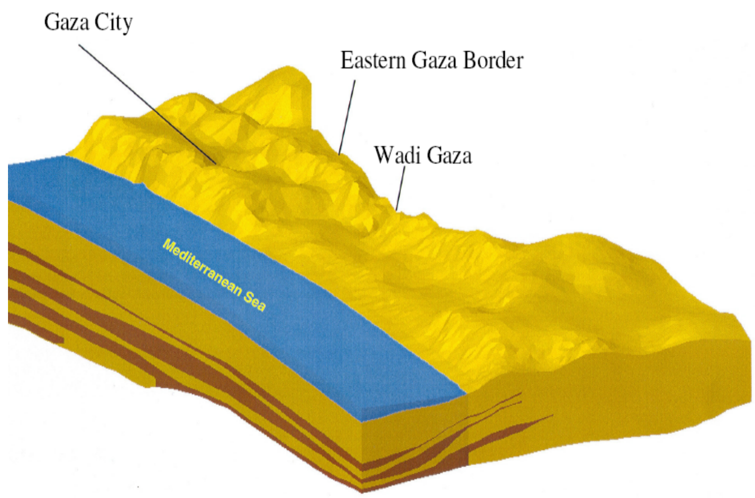


Figure 3.21: Model topography and 3-D view of Stratigraphy in Gaza Strip (Metcalf and Eddy, 2000)

Groundwater level and depth of water table

The Gaza strip coastal aquifer is under severe hydrological stress due to over-exploitation (Qahman and Zhou, 2001). Excessive pumping during the past decades in the Gaza region has caused a significant lowering of groundwater levels, altering, in some regions, the normal transport of salts into the sea and reversing the gradient of groundwater flow. The sharp increase in chloride concentrations in groundwater indicates intrusion of seawater and / or brines from the western part of the aquifer near the sea (Sorek, 1997). During the CAMP study conducted by Mtcalf and Eddy, (2000) the groundwater contours maps had been conducted to measure variation in groundwater levels over years; from 1935 up to 2006, as shown by figure 22 (a, b, c, d, & e).

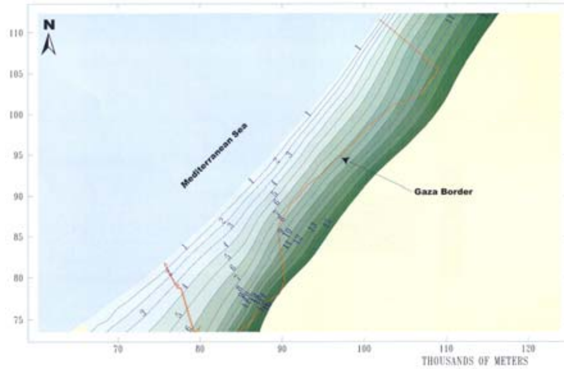


Figure 3.22.a: Average water table contour (1935)

Figure 3.22.b: Average water table contour (1989)

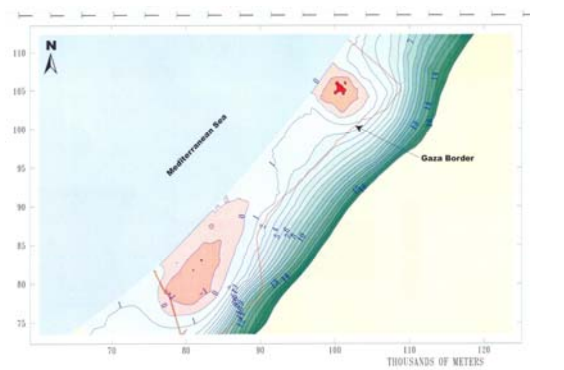


Figure 3.22.c: Average water table contour (1998)

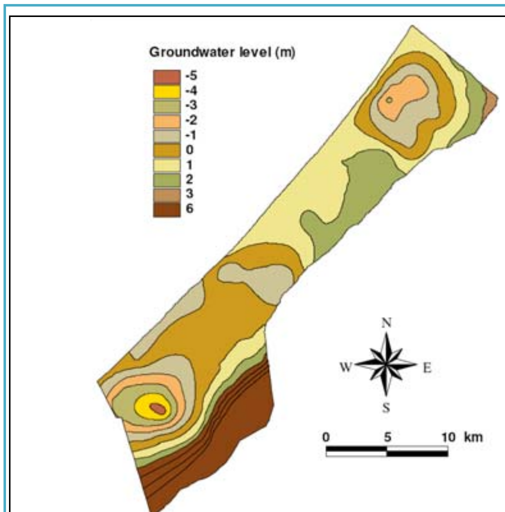


Figure 3.22.d: Average water table contour (2000)

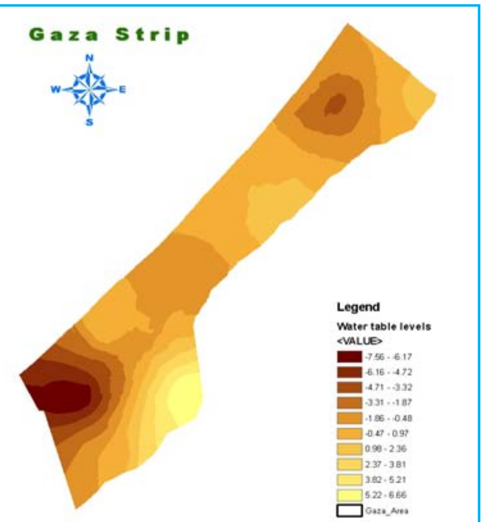


Figure 3.22.e: Average water table contour (2007)

Figure 3.22: (a-e) Average water table contour over years

From figure 3.22, the groundwater levels dropped by more than 14 meters between year 1935 and 2007, the groundwater level ranges between 7.6 m below mean sea level (MSL) to about 6.9 m above mean sea level as shown in figure 3.22. The groundwater level corresponds to depth below the soil surface between 0 and 100 m as shown in figure 3.23 (PWA, 2007)

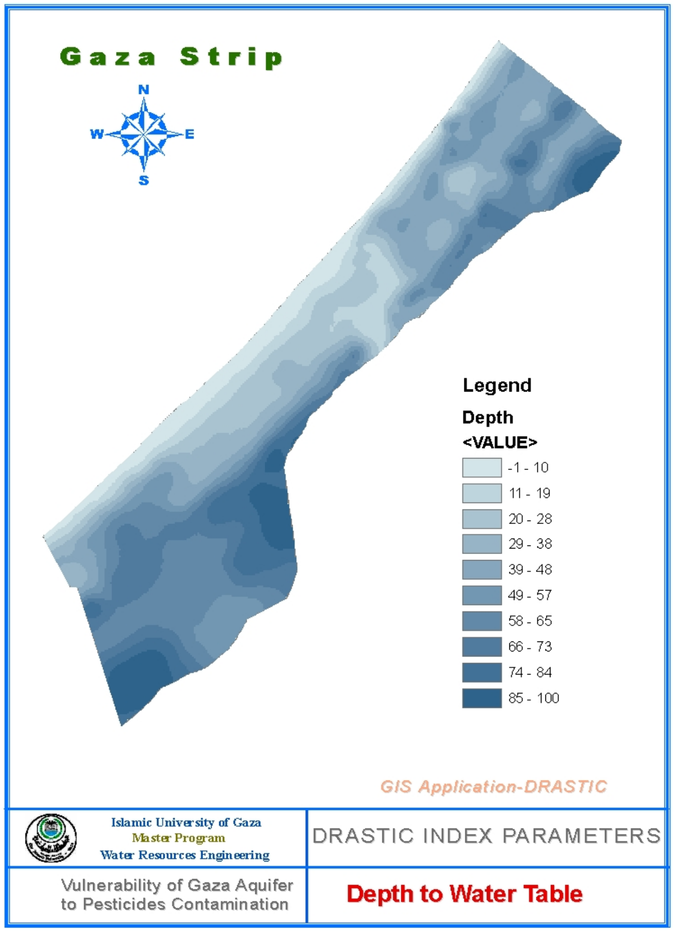


Figure 3.23: Average groundwater depth of Gaza aquifer for year 2007

Groundwater flow

During the 1930's, before intensive exploitation of the aquifer began, the predominant direction of water flow was from east to west (figure 3.19), with groundwater draining ultimately into the sea. Gradient levels varied between 0.1 - 0.3%. Since the 1930's, water exploitation has come to exceed natural replenishment, resulting in a steady lowering of the water table as well as accompanying alterations in direction of groundwater flow (figure 3.22). Over-pumpage of the Coastal aquifer has led in certain areas to the development of hydrological depressions, preventing outflow of contaminants from these areas to the sea, and leading to a deterioration of groundwater quality of the more inland zones of the Coastal aquifer (Melloul et al., 2006).

Recharge

Recharge from the rainfall is the most important line in the water budget of Gaza coastal aquifer were it can be considered as a renewable resources. Using the WetSpass - Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State (Batelaan and De Smedt, 2001) - model by Aish (2004); the average annual recharge was estimated to be about 41 MCM/year; the recharge map is presented in figure 3.24.

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

Based on CAMP study, 2000, the average annual recharge was estimated 40-45 MCM/year, using groundwater modeling of Gaza coastal aquifer, and estimated 37 MCM/year using the land use recharges coefficient (Metcalf and Eddy, 2000). Table 3.7 summarizes the results of recharge estimation according to different methods.

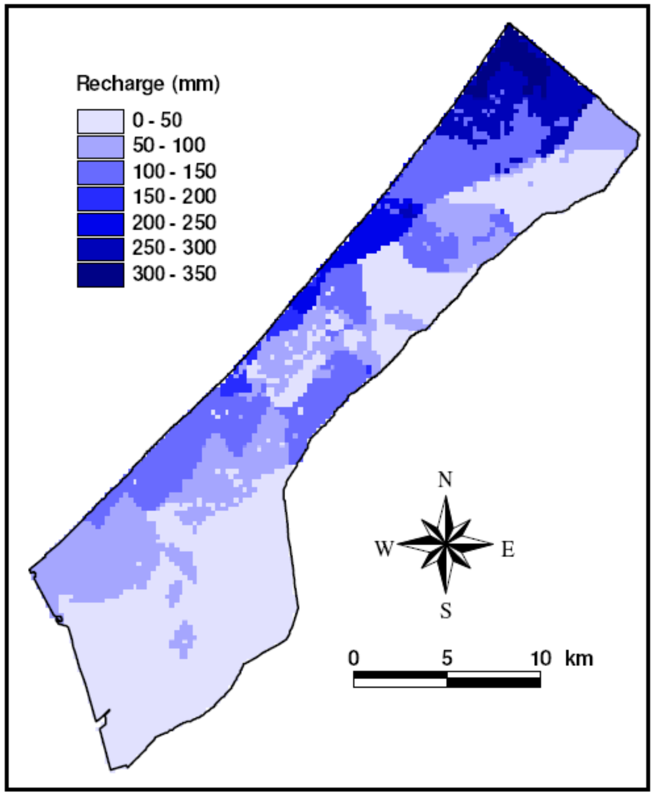


Figure 3.24: Annual groundwater recharge, calculated by the WetSpass model (Aish, 2004)

The spatial distribution of Recharge is summarized in table 3.8 using the CRD model. The average groundwater recharge as a percentage of rainfall in the entire area of the Gaza Strip is calculated as 36.74% (Baalousha, 2005). The average groundwater recharge as a percentage of rainfall in the entire area of the Gaza Strip is calculated as 36.74% (Baalousha, 2005). Since the average annual rainfall for year 2006-2007 is 364.7 mm/Area (PWA, 2007), and the area of Gaza Strip equals 365 km^2, the calculated recharge value from rainfall amounts to 48.91 MCM per year.

Table 3.7: Summary of estimated recharge in Gaza based on different methods (Baalousha, 2005)

#	Source	Method	million m^3/year
1	Fink 1970	Change in aquifer storage	33-67
2	Melloul and Bachmat 1975	Recharge coefficients	41
3	IWACO and WRAP 1995	Chloride mass balance	46
4	CAMP 2000	Land use and recharge coefficients	37
5	CAMP 2000	Groundwater modelling	40-45

Table 3.8: Recharge Amount for Year 2006-2007

Location	Area (Km^2)	Rainfall (2006 - 2007)		Recharge (2006 - 2007)		
		Depth* (mm)	QTY* (MCM)	CRD** (%)	Depth (mm)	QTY (MCM)
North	61	521.90	30.7	37.4	195.02	11.90
Gaza	74	460.40	33.8	34.8	160.22	11.86
Middle	58	411.50	28	33.5	137.73	7.99
Kh/ Younis	108	253.40	31.9	33.6	85.14	9.20
Rafah	64	225.00	8.7	41.1	92.48	5.92
	365	**364.70**	**133.1**	**36.74**	**133.99**	**48.91**

* Data is taken from PWA, 2007
** Recharge percent based on CRD modeling by Baalousha, 2005
MCM = million cubic meter

Return flows

There are three primary sources of return flow in the Gaza Strip: leakage from municipal water distribution system, wastewater return flows and irrigation return flow (Aish, 2004). According to the Palestinian Water authority, the return flow in Gaza strip can be summarized in table 3.9. Total amount of return flow of Gaza strip for year 2000 is about **41.79** million cubic meters (Mtcalf and Eddy, 2000). Based on water balance in table 3.10 below, the value of return flow for year 2006 ranges from 44.5 to 50 MCM.

Table 3.9 Return flow components in Gaza strip for year 2006 (Metcalf and Eddy, 2000, Aish, 2004)

#	Return flow source	Percent (%)	Total amount* (MCM)	Return flow amount (MCM)
1	Leakage from water distribution system out of total domestic abstraction	29	70-80	20-23.2
2	Wastewater (Jabalia WWTP- north) and (Gaza WWTP- Gaza city) out of total disposal	25	18-22	4.5-5.5
3	Irrigation out of total agricultural abstraction	25	80-85	20-21.3
	Total	26.28	159	44.5-50

***** *values are taken from table 3.10: water balance*

Hydraulic conductivity

Pumping tests were used to determine the hydraulic properties of the Gaza strip aquifer system; where transmissivity values range between 700 and 5,000 m^2/day. Corresponding values of hydraulic conductivity (K) are mostly within a relatively narrow range, 20-80 m/day. Specific yield values are estimated to be about 15–30% while specific storativity is about 10^{-4} m^{-1} (PWA, 2007 and CAMP, 2000). Figure 3.25 conducted by Metcalf and Eddy (2000), shows the distribution of hydraulic conductivity values for Gaza strip.

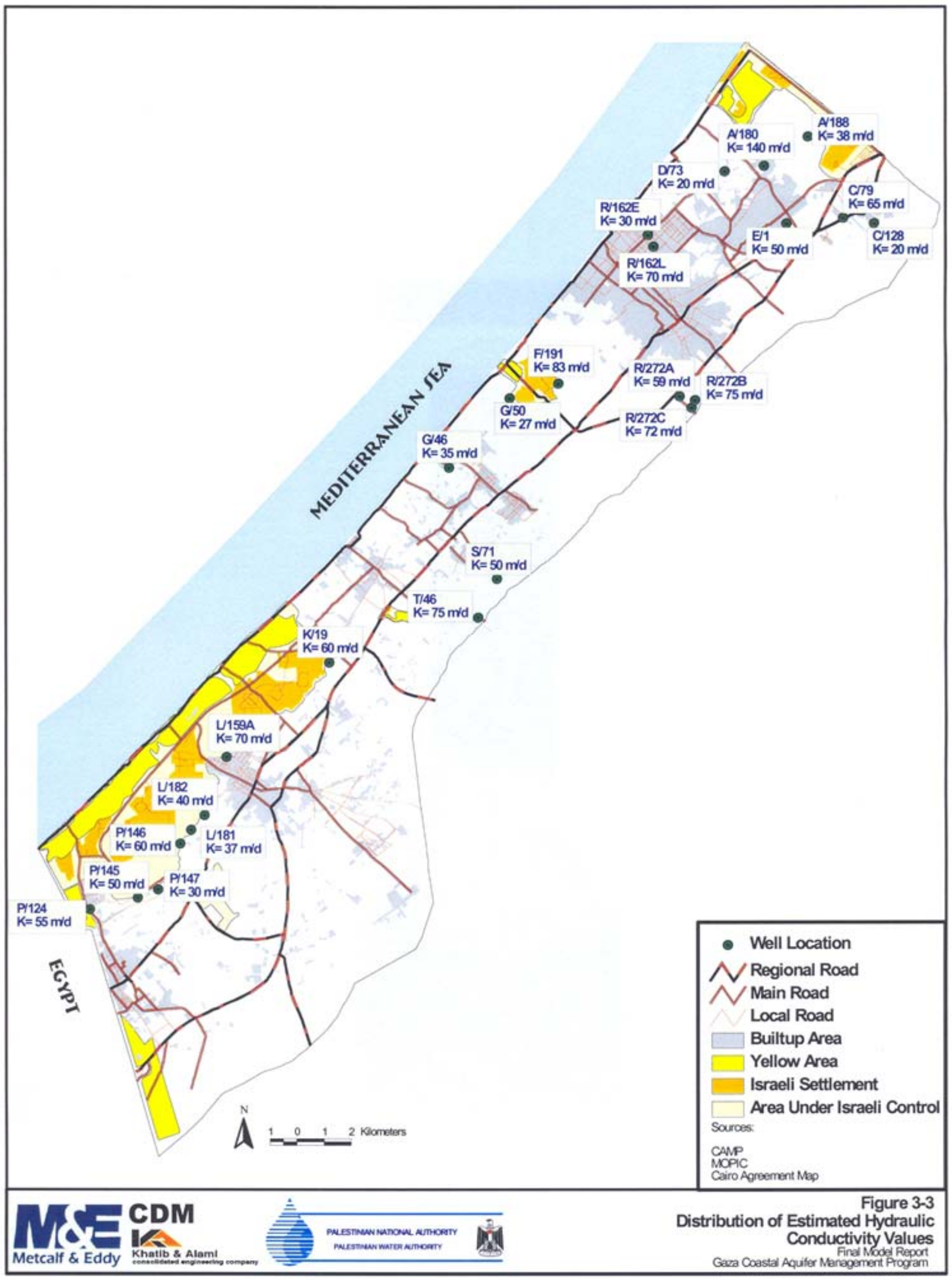


Figure 3.25: Distribution of Estimated Hydraulic Conductivity Values (Metcalf and Eddy, 2000)

Hydraulic budget

Lowering of water levels, reduction in availability of fresh groundwater and seawater intrusion, and potentially upcoming of deep brines are considered as indicators for water deficit in aquifer balance in the Gaza strip. It should be indicated that the Gaza coastal aquifer is a dynamic system, with continuously changing inflows and outflows (Aish, 2004). Lateral inflow is an important parameter in the overall water balance of the Gaza Strip; however, this is subject to considerable variation from one year to another depending on the hydraulic regime in Israel (Aish, 2004). In order to assess the water budget of Gaza hydraulic system, the inflow and outflow water has to be estimated. Comparing amount passed to the system with that taken out, the deficit in water balance will be clearly assigned. Depending on the quality of estimation, the closer figure we can achieve for water management level. Table 3.10 summarizes most budget lines of Gaza aquifer for the year 2006 (PWA, 2007)

Table 3.10: Summary of Water balance of Gaza strip 2006, (PWA, 2007)

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

From table 3.10, it seems that Gaza coastal aquifer is extremely overexploited in the last few decades. Under the current inflow and outflow conditions; the net deficit is about 27 to 44 MCM/year. The major source of new groundwater in the aquifer is rainfall were it generally, varies from 445 mm/yr in the north to about 244 mm/yr in the south (see Para 1.3.2 above).

3.2.3 Groundwater Quality

A severe water dilemma will appear in the near future from both quality and quantity aspects. Water in both municipal and private wells is polluted by one parameter or another , the results showed that only 90 % of the municipal wells are not suitable for drinking purposes, because of the high contents of nitrates, chlorides and fluorides and some heavy metals which exceed 2-7 times the WHO standards (Shomar, 2006).

Based on continuous tests provided by PWA and ministry of health over the years, the aquifer is currently being overexploited, with total pumping exceeding total recharge (PWA, 2007). In addition, anthropogenic sources of pollution threaten the water supplies in major urban centers. Many water quality parameters (e.g. chloride, nitrate) currently exceed World Health Organization drinking water standards. The major documented water quality problems are elevated chloride (salinity) and nitrate concentrations in the aquifer (Aish, 2004). Figure 3.26, shows the elevated contamination level of chloride and nitrate in Gaza strip.

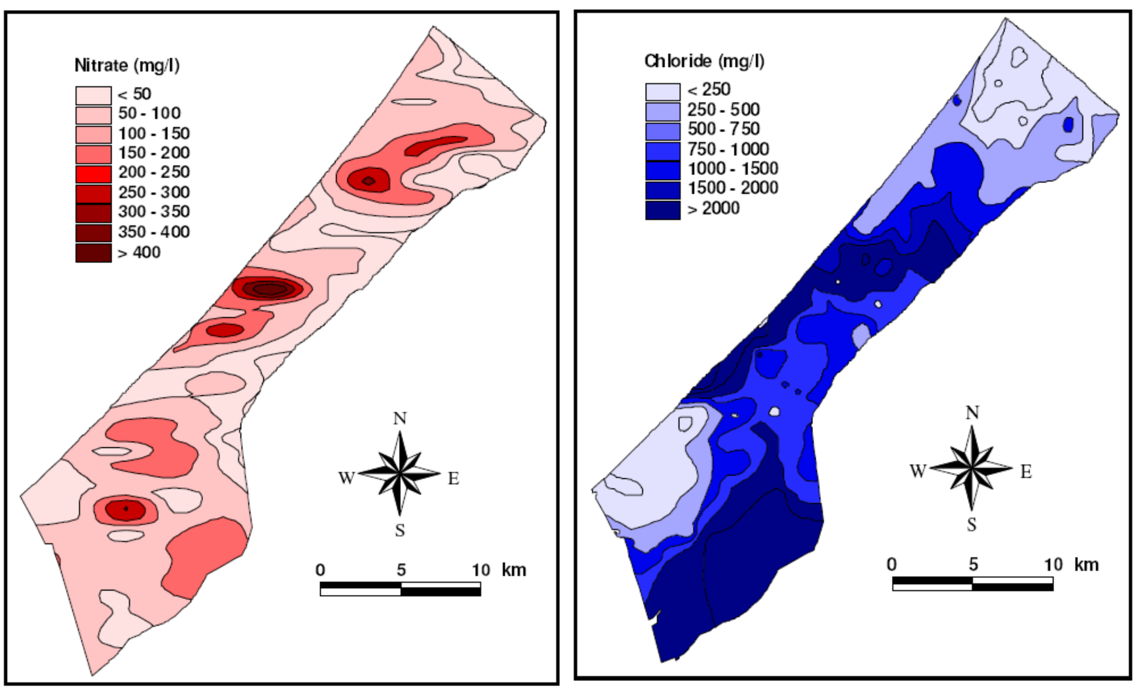


Figure 3.26: Nitrate and Chloride Concentration map of Gaza strip for year 2000 (PWA, 2003)

Based on Shomar (2006), the chloride and nitrate contamination of the groundwater in Gaza is not the only threat to the groundwater and therefore the drinking water. Many of the agricultural wells have large surface openings (greater than 1m) where oil products, fertilizers, or any other items stored in the well housing may enter the aquifer by carelessness or accidental spilling of materials into the well.

Little information is, however, available with regard to the occurrence of the trace constituents, hydrocarbons, pesticides, and microbes in the groundwater of the Gaza Strip. Trace elements are contributed to the groundwater from a variety of natural and anthropogenic sources (Shomar, 2006). Once elements are taken up by the groundwater, their distribution is continually reset by complex geochemical processes (e.g. equilibrium and non-equilibrium water/solid interactions, advection, dispersion, absorption, precipitation, co-precipitation, chelating, colloidal interaction) and biological processes (Shomar, 2006).

During his research, Shomar (2006) detected several pesticides in the groundwater of Gaza with concentrations exceeded their respective WHO maximum contaminant levels or health advisory levels for drinking water. Even though, the occurrence of pesticides in Gaza strip has been assured by different researches (Shomar, 2006 and CAMP, 2000), and data from MoA (2007) and PWA (2007) indicate the excess use and carelessness of users in pesticide application, up till now, there are no pesticides concentration maps for the Gaza strip. In fact, tests and MoA records show many dirty pesticides available in the Gaza aquifer. This increases the need for vulnerability assessment of pesticides contamination in Gaza aquifer.

Chapter 4

Method Used

4.1 Conceptual Framework and Theoretical Background

Geographic Information Systems (GIS) as a powerful tool allows spatial data collecting and, at the same time, gives a means for data processing, such as geo-referencing, integration, aggregation, or spatial analysis (Burrough and McDonnell, 1998). The drastic model can be a useful tool for identifying areas vulnerable to pollution, even though it cannot reflect the characteristics of individual contaminant (Mato, 2002). Integration of GIS and vulnerability drastic indices that allows generation of contamination potential maps could improve management of water resources and land use (Connell & Daele, 2003, Dixon, 2005)).

Drastic is the most commonly used method for aquifer sensitivity assessment (US EPA, 1985). Since its formulation in the United States, the drastic model has been extensively applied and validated (Baker, 1990; Rundquist, et al., 1991; Kalinski, et al., 1994). The drastic method has been used for vulnerability mapping projects in the United States and considered as a possible tool for such assessments (Kalinski et al., 1994). Navulur and Engel (1996) recommended drastic model as a useful tool in policy and decision-making in groundwater management strategies. Modifications can be made using the overlay and index approach such as that used by drastic (EPA, 2003) so, the modified drastic model can also be used.

Using existing hydro-geologic parameters in GIS tool, drastic can be used as to investigate specific geographic areas susceptible to GW contamination by pesticides (Fritch, McKnight, Yelderman, & Arnold, 2000; Rosen, 1994). However, Lowe and Butler, (2003) indicated that some applications of drastic to predict vulnerability of GW to pesticides were successful and some were not. The results of the drastic model were further validated against the local hydrogeological knowledge and found to be useful (Mato, 2002). The output maps produced using this methodology can be used as a screening tool to ascertain whether the area is more or less vulnerable to GW pollution (Rahman, 2008).

The availability of input data is the corner stone of how to choose the appropriate model as the lack or insufficient input data to the model presents a practical problem (Wang, 1997). In Gaza strip, there are two levels of constraints; first, insufficient well-trained professionals who can assist in choosing appropriate models, two; limitation in basic data required in many groundwater models (Mato, 2002). Therefore, absence or inadequacy of data presents a major limiting factor in groundwater models application in Gaza strip. In such circumstances, empirical models (e.g. drastic) become useful tools for assessing groundwater vulnerability. Finally, A GW vulnerability mapping methodology (like drastic index) that requires less extensive site-specific data, and at the same time, is robust when data are uncertain and incomplete will be a useful screening tool (Rahman, 2008).

4.2 Methodology and Digital Database

The drastic method, as a standard system for evaluating groundwater pollution potential is used in this study. The drastic model is widely used in many countries because the input information required for its application is either readily available or can easily be obtained from various government agencies (Rahman, 2008). Due to availing conditions in Gaza strip, where the authorities are operated with less proper data management, it would be difficult to have updated, precise and correct dataset 100%. Consequently, data can be questionable and subjective to more doubt and queries.

The drastic model was originally developed in USA-Environment Protection Agency (EPA) for the purpose of protecting the groundwater resources (Aller et al., 1985; 1987). Drastic is an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydrogeological settings of that area (Aller, et al., 1985, 1987). A hydrogeological setting is defined as a mapable unit with common hydrogeological characteristics (Engel et al., 1996).

The drastic model employs a numerical ranking system that assigns relative weights to various parameters (Mato, 2002). The drastic model is based on seven parameters, corresponding to seven layers to be used as input parameters for modeling, whose required information were obtained from various government and semi-government agencies at a desired scale (Rahman, 2008) as shown by table 4.1. The acronym drastic corresponds to the initials of the seven base maps or layers:

DRASTIC

[D] Depth to water;

[R] Net Recharge;

[A] Aquifer media;

[S] Soil media;

[T] Topography (slope);

[I] Impact of the vadose zone;

[C] Hydraulic Conductivity.

Table 4.1: Data used for creation of hydro-geological parameters for DRASTIC model (Rahman, 2008)

#	Data type	Source	Format	Output layer
1	Borehole data (water table level)	PWA, 2007	Table	**Depth to water (D)**
2	Average annual rainfall	Meteorological unit	Table	**Net Recharge (R)**
3	Geology map	PWA, 2007	Map	**Aquifer (A)**
4	Soil map	PWA, 2007	Map	**Soil (S)**
5	Topographical sheet	Survey dept	Table	**Topography (T)**
6	Geological profile	PWA, 2007	Map	**Impact of vadose zone (I)**
7	Hydraulic conductivity	PWA (CAMP, 2000)	Table	**Hydraulic Conductivity (C)**

Each drastic factor is assigned a weight based on its relative significance in affecting pollution potential (Mato, 2002 and Rahman, 2008). The final vulnerability map is based on the drastic index (Vi) which is computed as the weighted sum overlay of the seven layers using the following equation:

DRASTIC Index **Vi** = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw …….. **(4.1)**

Where;

D, R, A, S, T, I, and **C** are the seven parameters, **r** is the rating value, and **w** the weight assigned to each parameter.

The higher the value of drastic index, the more susceptible the area in question is to groundwater pollution (Mato, 2002). The parameter ratings are variable, which allow the user to calibrate the model to suit a given region (Dixon, 2005), and a given purpose of vulnerability. The typical weights of each parameters range from 1-5 (Mato, 2002), with higher weights representing greater pollution potential as shown by table 4.2 (Dixon, 2005 and Rahman, 2008). A second weight in table 4.2 has been assigned to reflect the agricultural usage of **pesticides**, where the first weights in table 4.2 has been assigned to reflect normal drastic applications (Aller, et al. 1987 and Lobo-ferreira, 2000).

Table 4.2: Assigned weights for DRASTIC parameters (Aller, et al. 1987 and Rahman, 2008)

#	Hydrological settings	Description	Relative Weight	
			normal	pesticides
1	**Depth to water**	It is depth from ground to water table, deeper the water table lesser will be the chances of pollutants to interact with ground water.	**5**	**5**
2	**Net Recharge**	It is the amount of water/unit area of land that penetrates the ground surface and reaches the water table, it is the reporting agents for pollutants to the ground water.	**4**	**4**
3	**Aquifer**	It is the potential area for water storage, the contaminant attenuation of aquifer depends on the amount and sorting of fine grains, lower the grain size higher the attenuation capacity of aquifer media.	**3**	**3**
4	**Soil**	Soil media is the uppermost and weathered part of the ground, soil cover characteristics influence the surface and downward movement of contaminants.	**2**	**5**
5	**Topography**	It refers to slope or steepness, areas with low slope tend to retain water for longer, this allows a greater infiltration of recharge of water and a greater potential for contaminant migration and vulnerable to ground water contamination and vice versa.	**1**	**3**
6	**Impact of vadose zone**	It is the ground portion found between the aquifer and the soil cover in which pores or joints are unsaturated, its influence on aquifer pollution potential similar to that of soil cover, depending on its permeability, and on the attenuation characteristics of the media.	**5**	**4**
7	**Hydraulic Conductivity**	It refers to the ability of the aquifer formation to transmit water; an aquifer with high conductivity is vulnerable to substantial contamination as a plume of contamination can move easily through the aquifer.	**3**	**2**

Ratings and weights of each parameter are shown in table 4.3, which vary from 1 to 10, with higher values describing greater pollution potential. A higher rating of 9 was assigned to higher recharge areas, e.g. water bodies and coarse sand aquifer. This is because in these areas the pollutants can easily reach to the groundwater and there is greater pollution vulnerability (Rahman, 2008).

The numerical weights and ratings, which were established using the Delphi technique (Aller et al., 1987), are well defined and have been used worldwide (Al-Adamat, Foster, & Baban, 2003; Anwar et al., 2003; Babiker, I., Mohammed, M., Hiyama, T., & Kato, K., 2005; Dixon, 2005; Margane, 2003; Napolitano, 1995; Rundquist et al., 1991; Shahid, 2000). The Delphi technique utilizes the practical and research experiences of professionals in the area of interest to assess levels of risk. Typically, the experts are asked to rate the risk level of certain activities under a set of initial conditions. The activities and conditions presented are general in nature and not specific to a certain site (Rahman, 2008). Rating and weighting still estimate and depends on expert opinion. Thus, the modifications to the drastic were incorporated in both the selection and weighting of these factors. So they are to some level of accuracy subjective. Consequently sensitive analysis will be mandatory. A scale of risk is established prior to start of the project (e.g. a scale of 1–5 with 5 being the highest possible risk). The highest weight 5 has been assigned to two parameters. The depth to water and impact of the soil media because, the lower the water table, the higher will be the chance of pollutants to reach to groundwater (Rahman, 2008).

Table 4.3: DRASTIC Parameters (Lobo-Fereira, 2000, Matto, 2002, Dixon, 2005, Ckarkraborty, 2007, and Rahman, 2008)

Parameters	Range			Rate		Weight	Index
Depth to water	Ranges (m)			Dr		Dw	V
	< 5		0-30	10	10-2	5	50
	5-15			8			40
	15-30			5			25
	>30			2			10
Net Recharge	Land use	Ranges (mm)		Rr		Rw	V
	Built up	<75	0-250	1	1-9	4	4
	Vegetation	75-100		3			12
		100-180		6			24
		180-250		8			32
	Wet lands	>250		9			36
Aquifer media	Aquifer range (dimensionless)			Ar		Aw	V
	Clay and silt		Sand and Gravel	3	5-8	3	9
	Clay sand			6			15
	Coarse sand			8			24
Soil media	Soil type (dimensionless)			Sr		Sw	V
	Clay		Soil series	2	2-10	5	10
	Loam			5			25
	Sandy loam			6			30
	Sand			9			45
	Gravel			10			50
Topography	Slope Ranges (%)			Tr		Iw	V
	<5		0-10	10	10-1	3	30
	5-10			5			15
	>10			1			3
Impact of vadose zone	Lithology type (m)			Ir		Iw	V
	Clay and silt		Soil series	3	3-8	4	12
	Sandy clay			4			16
	Clay sand			6			24
	Sand and gravel			8			32
Hydraulic Conductivity	Ranges (m/d)			Cr		Cw	V
	<5		0-90	1	1-10	2	2
	5-15			2			4
	15-30			4			8
	30-50			6			12
	50-70			8			16
	70-90			9			18
	>90			10			20

These seven sets of data layers were built up and were converted to raster data sets that were processed using GIS-ArcMap 9.2 of ESRI (Rahman, 2008). Once the drastic index has been computed, using any suitable models, it is possible to identify areas that are more likely to be susceptible to groundwater contamination compared to other areas. The higher the drastic index, the greater is the groundwater pollution potential. The flow chart of the drastic methodology is shown in figure 4.1.

Based on table 4.3, the minimum value of the drastic index is therefore 47 and the maximum value is 242. Such extreme values are very rare, the most common values in Gaza strip are expected to be within the range 100 to 200.

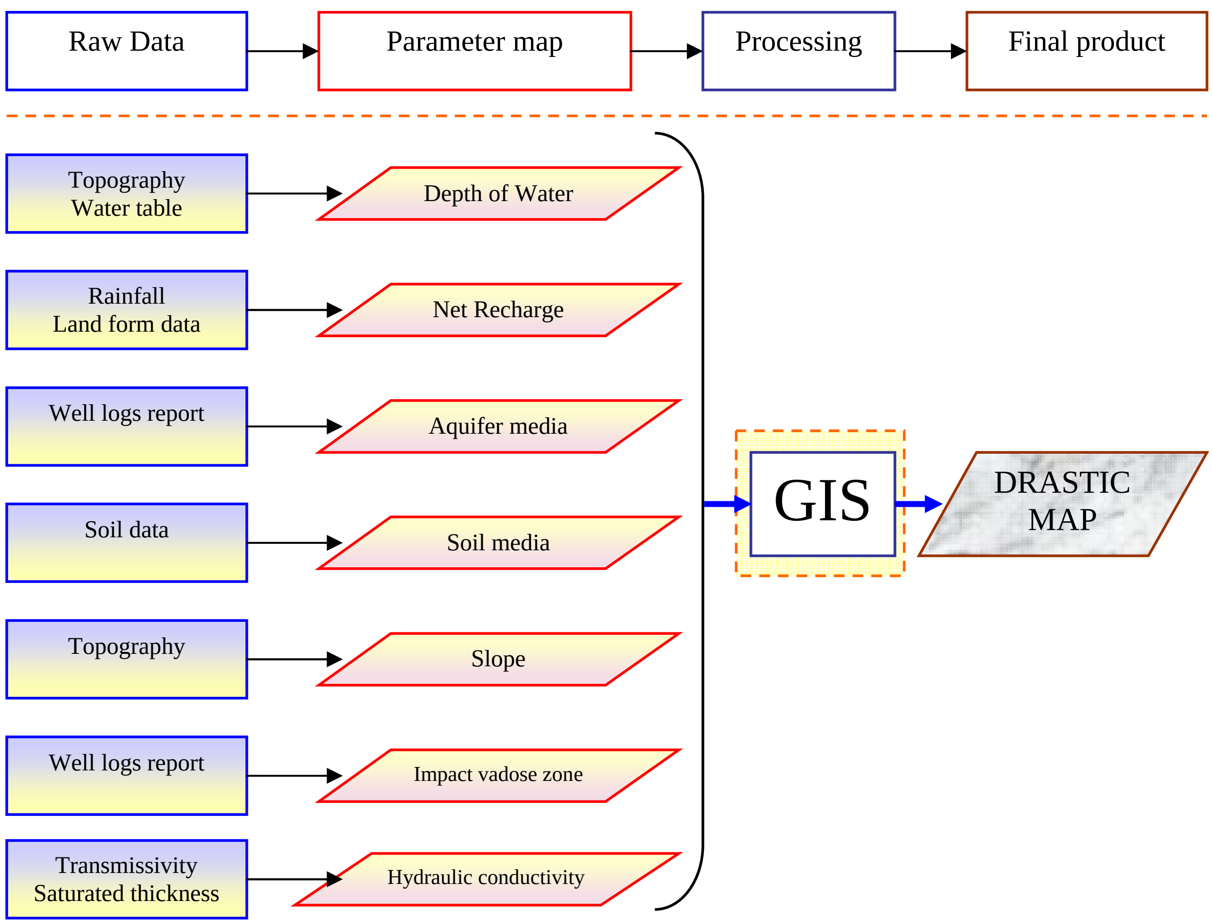


Figure 4.1: Flow chart of methodology for ground water vulnerability analysis using DRASTIC model in GIS (Rahman, 2008)

Thus vulnerability is distinct from pollution risk. Pollution risk depends not only on vulnerability but also on the existence of significant pollutant loading entering the subsurface environment. It is possible to have high aquifer vulnerability but no risk of pollution, if there is no significant pollutant loading; and to have high pollution risk in spite of low vulnerability, if the pollutant loading is exceptional. It is important to make clear the distinction between vulnerability and risk. This because risk of pollution is determined not only by the intrinsic characteristics of the aquifer, which are relatively static and hardly changeable, but also on the existence of potentially polluting activities, which are dynamic factors which can in principle be changed and controlled (Lobo-ferreira, 2000).

4.3 Application of the DRASTIC Model to Gaza Aquifer

The drastic model was used to develop the groundwater vulnerability to pesticides map of Gaza strip. The weights and ratings were adopted as specified in the pesticides model as per table 4.2. Using available hydrogeological data with the help of a GIS 9.2-ArcMap, the seven maps needed for the drastic approach were prepared and set ready. Table 4.1, shows the different sources of data, including the Palestinian Water Authority (PWA), Ministry of Agriculture (MOA), and Ministry of Environmental Affairs (MEnA). A sensitivity analysis were done to reduce subjectivity and to check the suitability of these weights and rating for local hydrogelogical data set in Gaza strip. Figure 4.2 shows the DRASTIC model parameters in nature.

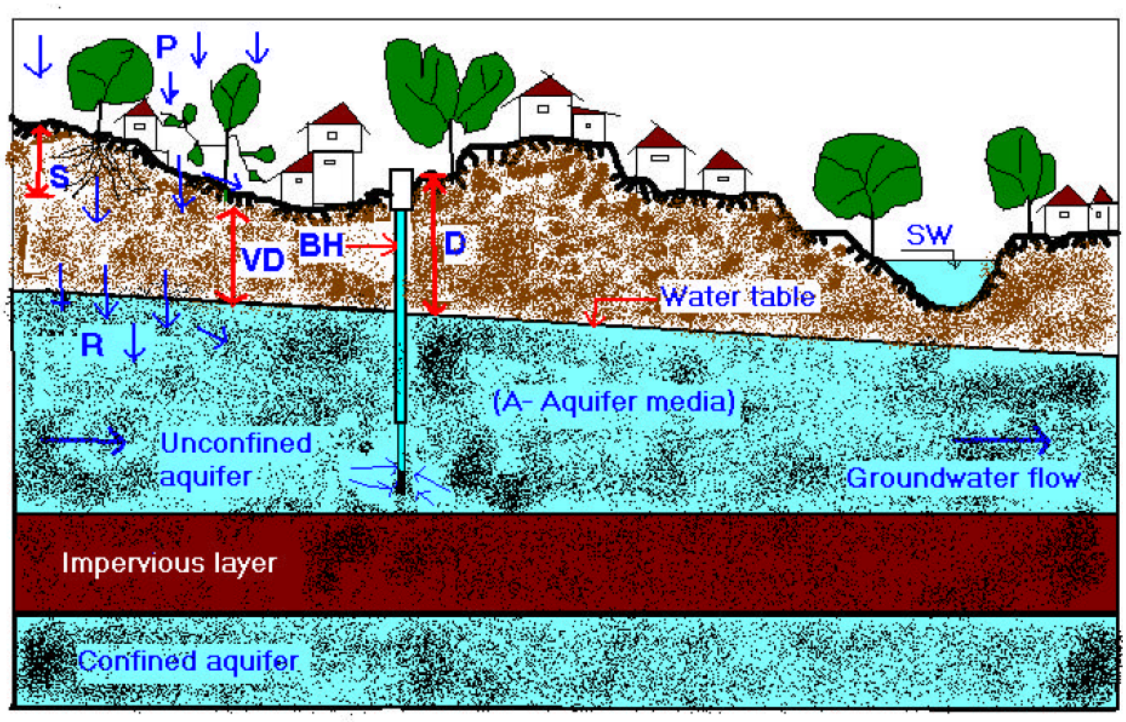


Figure 4.2: DRASTIC model parameters (Mato, 2002)

Notes: S: Soil, P: Precipitation, R: Recharge, VD: Vadose zone, BH: Borehole, D: Depth to water table, SW: Surface water

Depth to water table

The depth to water is the distance from the ground surface to the water table, where the water is firstly struck in the assigned boreholes (figure 4.3). The depth to water table contour map was obtained by subtracting the groundwater contour map from the topographic map (Balousha 2006). This determines the depth of material through which a pollutant has to travel before leaching the aquifer. The presence of low permeability layers, like clay or silty clay, that confine the aquifer, limits the travel of pollutant into an aquifer. In general, as the depth to water increases there will be a greater chance for attenuation to occur, because deeper water levels imply longer travel times (Mato, 2002). Depth to water table map as per figure 4.4 was conducted utilizing the topographic data sets and the groundwater level data for the year 2006 (PWA, 2007).

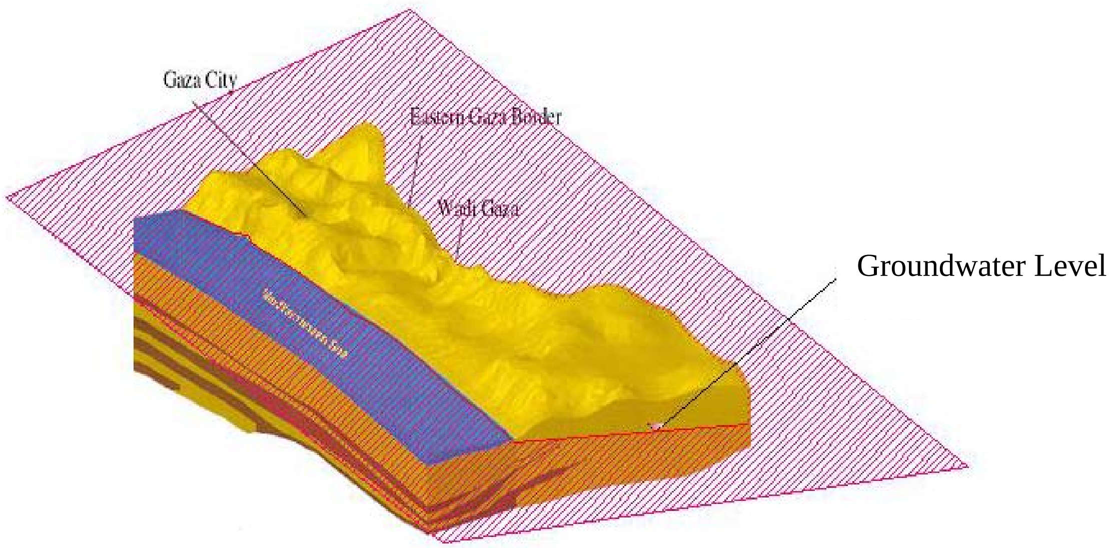


Figure 4.3: Horizontal Cross-section at Groundwater level (CAMP, 2000)

Depth to water table in the area varies between few meters in the west near the coast to about 100 m at some locations. According to the drastic approach, and table 4.3, the rating for depth to water table varies from 10 for small depths (<5 m) to 2 for depths larger than 30 m. The selected rating was then multiplied by the assigned weight for depth to water, which is 5 (Table 4.3) to get Vi component for depth to water. Figure 4.5 shows the depth to water map, using GIS-ARC map. This map will be integrated to other layers of the drastic model to build the vulnerability maps.

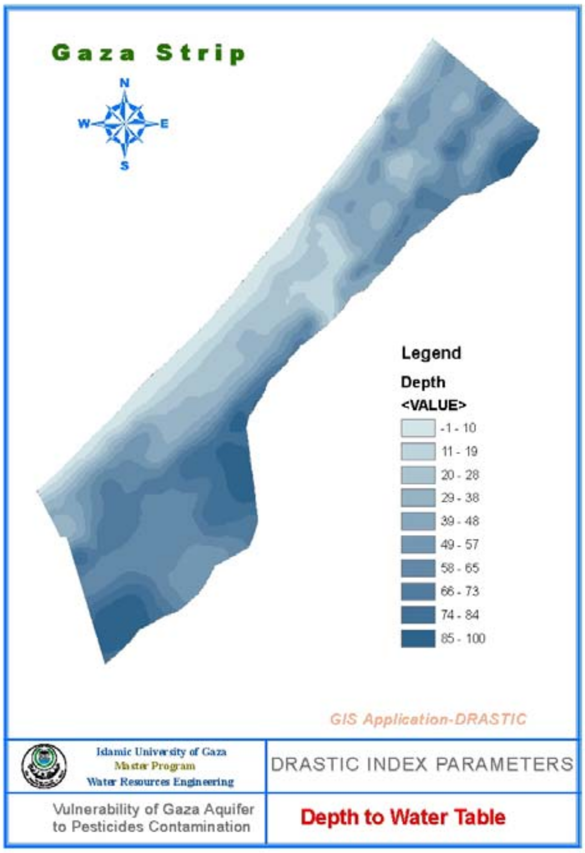


Figure 4.4: Depth to Water Table (Water level data was obtained from PWA, 2007)

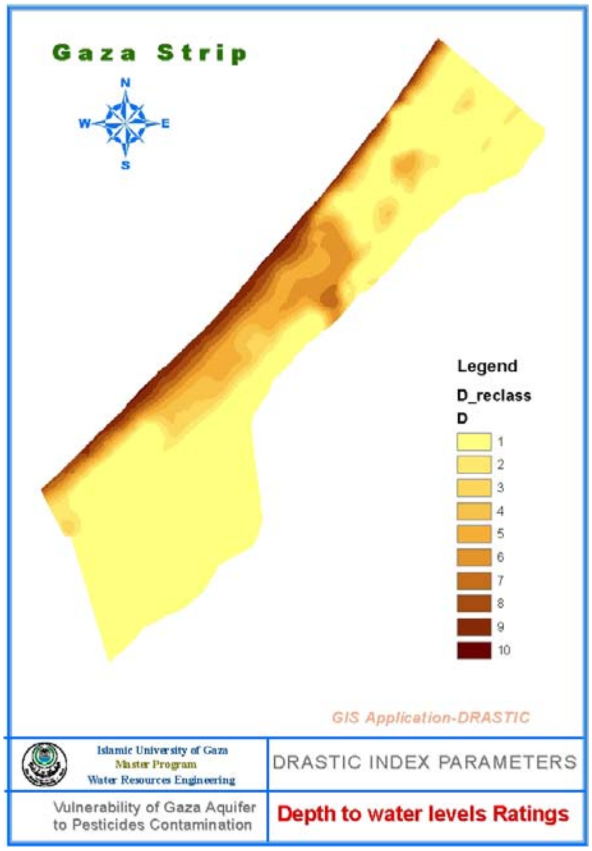


Figure 4.5: Depth to Water Table Ratings (1 to 10)

Net recharge

Net recharge represents the amount of water per unit area of land, which penetrates the land and reaches the water table. Recharge water is the principle vehicle for leaching and transporting contaminants vertically to the water table and horizontally within the aquifer. The greater the recharge, the greater the potential for ground water pollution (Mato, 2002).

The amount of recharge that percolates into the aquifer depends on the vertical flow path from the land surface. Since the aquifer in the Gaza strip is phreatic, the recharge is a very important factor (Baalousha, 2006). For Gaza strip, other sources of recharge include leaking underground water supply pipes, effluents from soak-away pits and irrigation water.

The net recharge (the amount of precipitation that percolates the aquifer) varies from 30 to 40% of the annual rainfall (Baalousha 2004). The amount of recharge to be used in the drastic model is shown by table 4.4. Figure 4.6, built using GIS drastic model, shows the Net recharge map. Figure 4.7, produced by the drastic model, shows the recharge ratings. Drastic assigns a rating of one for small recharge amounts and a rating of 9 for large recharge (Aller et al. 1986). In Gaza strip as per figure 4.7, the rating was from 3 to 6 based on values of recharge estimated.

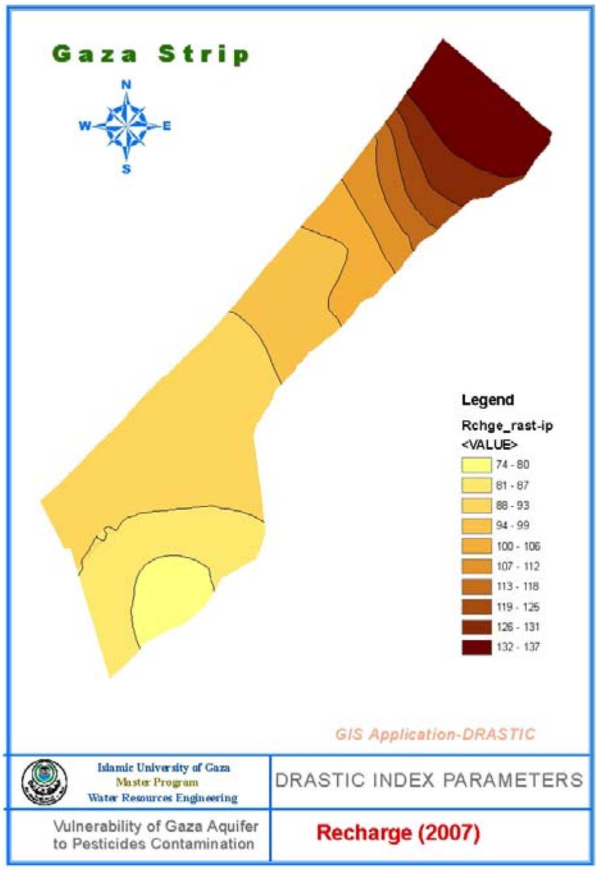


Figure 4.6: Recharge to Gaza aquifer (recharge values were obtained based on rainfall data of year 2007)

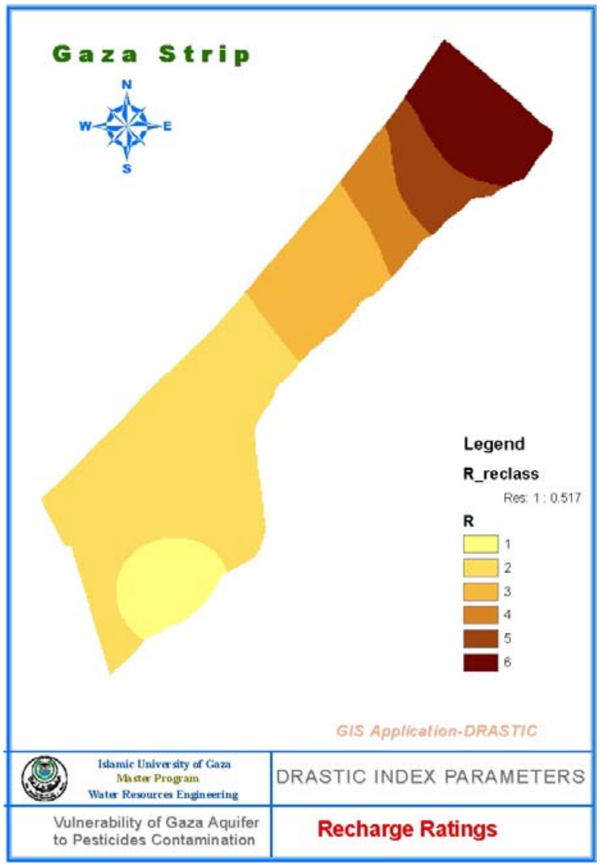


Figure 4.7: Recharge Ratings (1 to 6)

Table 4.4: Amount of recharge and return flow used in the drastic model

Recharge (2006 - 2007)			
Location	Area (Km^2)	Depth (mm)	QTY (MCM)
North	61	195.02	11.90
Gaza	74	160.22	11.86
Middle	58	137.73	7.99
Kh/ Younis	108	85.14	9.20
Rafah	64	92.48	5.92
	365	**133.99**	**48.9**

Return flow (2006- 2007)			
Source	Area (Km^2)	Depth (mm)	**QTY (MCM)**
Leakage from water distribution system (urban areas)	144.7	149	21.5
Wastewater (WWTP-North, Gaza, Middle, Kh yunis, and Rafah)	1.3	3846	5
Irrigation (exclude rain fed crops areas)	95*	217	20.6
	241	195	47.1

* Rain fed crops areas = 124 Km^2

Aquifer media

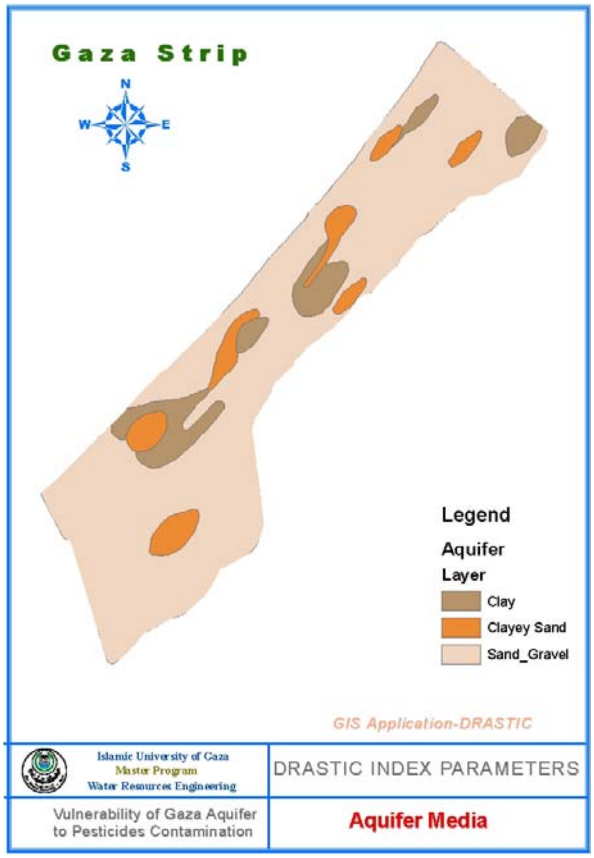
Mato, 2002 defines the aquifer as a subsurface unit that will yield useful quantities of water. The aquifer medium influences the amount of effective surface area materials, with which contaminants may come into contact. The larger the grain size and the more fractures or openings within the aquifer, the higher the permeability and the lower the attenuation capacity of pollutants in the aquifer media (Baalousha, 2006, Mato, 2002).

The aquifer media was obtained by taking depths at which water was struck (as it was the case for depth to water table determination) and correlating those depths with the lithological description of the cross section or strata description to identify the type of the aquifer media (Mato, 2002). For example, if water was struck at the depth of say 25 m, and lithological description indicates that strata from say 20m – 30 m is composed of calcareous sandstone then the aquifer media will be calcareous sandstone. The shallow depth was selected to be the aquifer media.

The aquifer media of Gaza strip as a part of the coastal aquifer is identified by the available geological cross-sections of the area developed by Melloul and Yesraeli (1991) (Appendix B). As shown in figure 3.7, the Gaza aquifer is composed of Quaternary deposits that include layer of loess, dune sand, calcareous sandstone, silt, and clay *(see sec 3.2.1 and 3.2.2)*. In a brief summary, the Gaza aquifer is mainly composed of sandstone and gravel (Baalousha, 2006).

Based on drastic standards shown in table 4.3, the rating of Gaza aquifer media varies between 3 and 8. Due to lack of information regarding horizontal map just underneath the free water table, some simplifications and approximation had been adopted by researchers in the drastic index for the vulnerability of Gaza aquifer for pollutant contamination, based on Baalousha (2006), the aquifer media is composed mainly of sand, gravel, and clayey sand, there is no weighted distinction between these types of media. Consequently, the aquifer media for the study area is located almost in one class (Baalousha, 2006).

After determining the type of aquifer media, rating of aquifer media the drastic model was done by obtaining the value as per table 4.3. Then the Vi component for the aquifer media can be obtained by multiplication of the selected rating by the assigned weight for the aquifer media, which is 3. Figure 4.8 and 4.9 show the aquifer media map and Aquifer ratings of DRASTIC layers respectively.



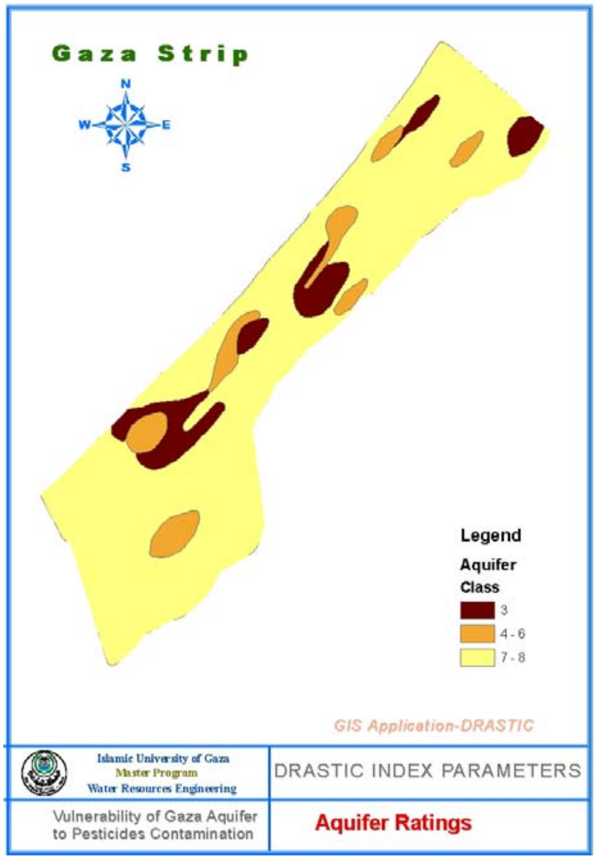


Figure 4.8: Aquifer Media (based on cross sections conducted by Melloul, and Yesraeli (1991)

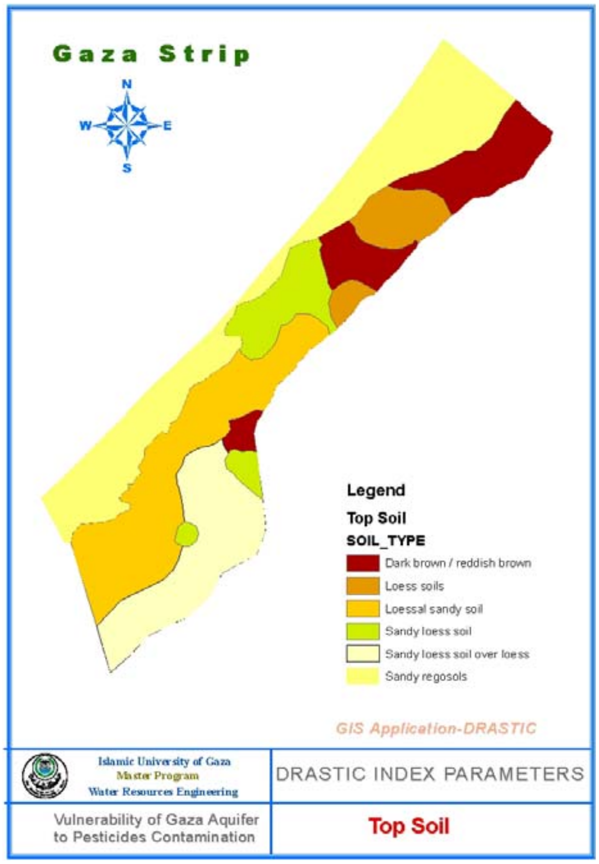
Figure 4.9: Aquifer Media Ratings (3 to 8)

- **Soil media**

Soil media of the drastic model can be defined as the uppermost portion of the vadose zone, one meter or less, characterized by significant biological activity (Mato, 2002). Based on Rahman (2008), the characteristics of soil affect the amount of recharge infiltrating the ground surface, the amount of potential dispersion, the purifying process of contaminants, etc. Soil characteristics have a significant impact on the downward movement of contaminants into the vadose zone (Rahman, 2008, Mato, 2002). The smaller the grain size, the less the pollution potential. In the other hand, the presence of fine grain size materials, such as clay, peat, or silt, and the percentage of organic matter within the soil cover can decrease intrinsic permeability, and retard or prevent contaminant migration via physico-chemical processes, i.e., absorption, ionic exchange, oxidation, and biodegradation (Rahman, 2008).

Based on section 3.1.6, the upper one meter of soil in the Gaza Strip is composed mainly of three types, sands, clay and loess. The sand dunes vary from 4 to 5 km inland, and are wider in the north and in the south than in the center. Most of Gaza top soil – except for limited areas in north and middle - is sand and lose with high permeability.

Weights and ratings were assigned in table 4.3. These areas have large ratings from 6 to 9 and maximum weight of 5, consequently, high vulnerability to pollution. Figure 4.10 and 4.11 show the soil media map and Soil ratings used for the drastic model respectively.



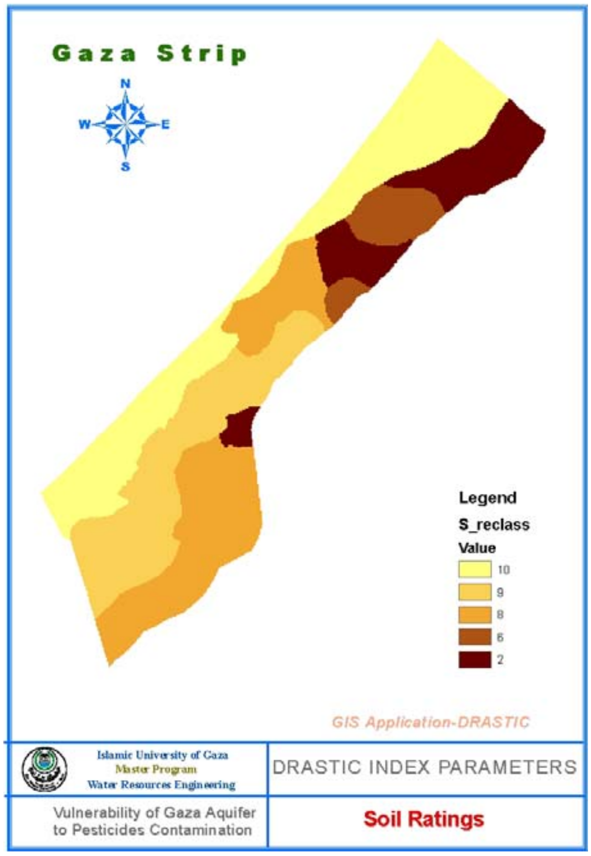


Figure 4.10: Top soil media (shape file data was obtained from CAMP 2000)

Figure 4.11: Top soil Ratings (2 to 10)

Topography

Topography refers to slope and its variability of an area. Topography is expressed in the form of slope in drastic model. This factor influences the flow rate at the surface, and consequently affects biodegradation and attenuation of the pollutant (Baalousha, 2006). Topography helps control the likelihood that a pollutant may runoff or pool and remain on the surface in one area long enough to infiltrate into vadose zone (Rahman, 2008 and Mato, 2002). Areas with steep slopes, having large amounts of runoff and smaller amounts of infiltration are less vulnerable to GW contamination and vice versa (Rahman, 2008). The topographic map was prepared from the survey of Gaza strip (PWA, 2007). Contours of proper intervals were developed and then digital elevation model (DEM) was prepared in ArcMap-GIS software.

Based on Baalousha (2006), there is relatively little variation in slope in the Gaza Strip and the topography contour elevations vary between few meters at the shoreline to about 85 m in the east. Using the topography contour map the percent slope map will be produced thereafter. Based on table 4.3, rating from 0 to 10 and weight of 3 were assigned according to drastic standards. Figure 4.12 and 4.13 show the topography slope of Gaza strip and slope ratings used for drastic model respectively.

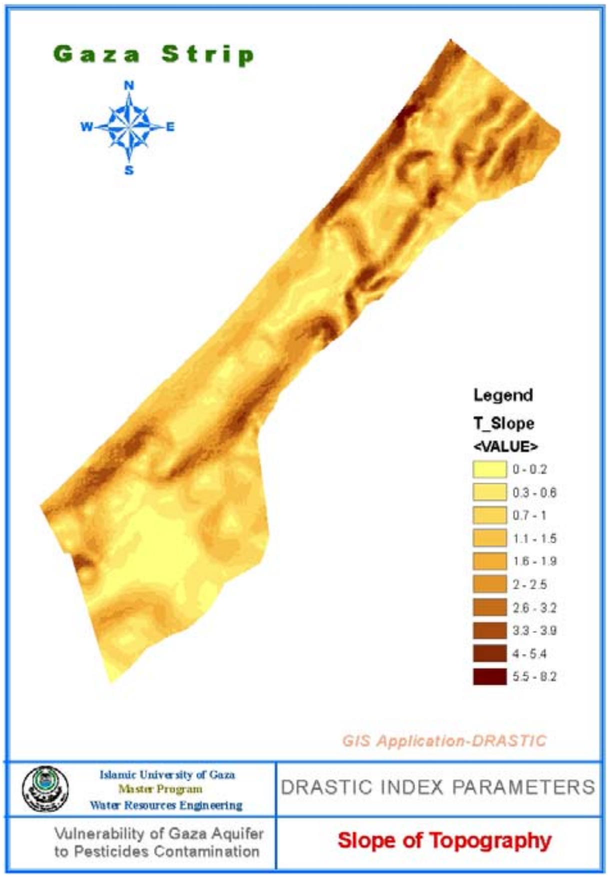


Figure 4.12: Slope of top layer (estimated from topographic map using ArcMap GIS 9.2)

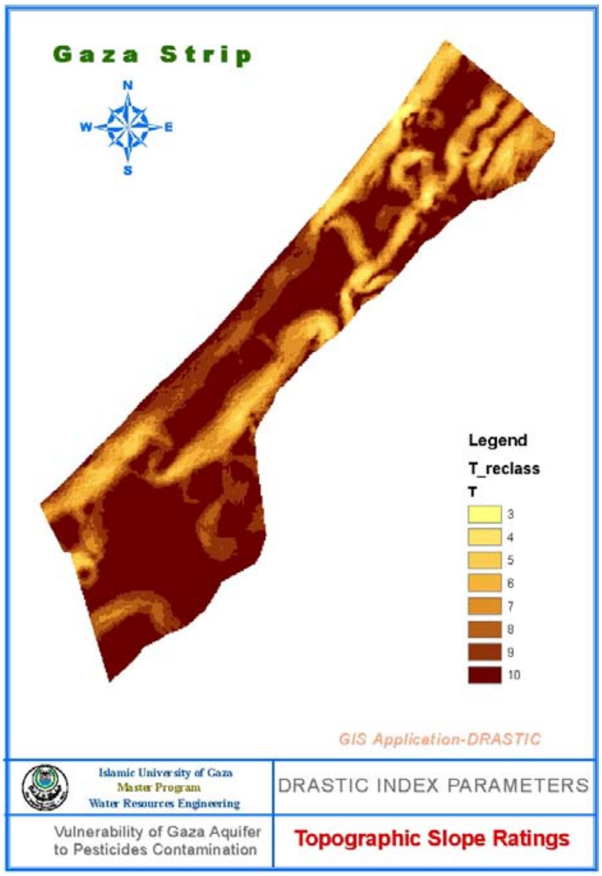


Figure 4.13: Topographic Rating (3 to 10)

Impact of Vadose zone

The impact of vadose zone is a complex phenomenon that combines aquifer media and topographic characteristics. So, movement of water within the vadose zone is carefully studied in hydro-geology, and found very important to contaminant transport or migration (Rahman, 2008). The vadose zone is defined as the unsaturated or discontinuously saturated zone above the water table and below typical soil horizon (Mato, 2002). Many processes that influence the pollution potential of the aquifer system take place in the vadose zone (Baalousha, 2006).

The vadose zone's impact on aquifer pollution potential is essentially similar to that of soil cover, depending on its permeability, and on the attenuation characteristics of the media above water table (Baalousha, 2006, and Rahman, 2008). In summary words, this zone controls the path of contaminant particles to the aquifer system (Baaloush, 2006).

Based on appendix B, the main components of vadose zone in Gaza strip are sandstone, gravel, medium soil and very fine clay or silty soil. Soil media of vadose zone was developed from the lithological cross-sections obtained from 13 vertical (E-W) cross sections and 3 vertical (N-S) cross sections were developed by Melloul and Yesraeli (1991).

The ratings for the vadose zone from 3 to 8 are shown in table 4.3. Carefully studying these sections regarding the vadose zone lithology, the rate can be taken 3 to 8 with regard to Gaza case. These rate then multiplied by the assigned weights for the vadose zone, which is 4, to obtain the Vi component for the vadoze zone. Vadose zones have been mapped as shown in figures 4.14 and 4.15 for vadose zone media and Ratings respectively.

Figure 4.14: Vadose zone media (based on cross sections conducted by Melloul, and Yesraeli 1991)

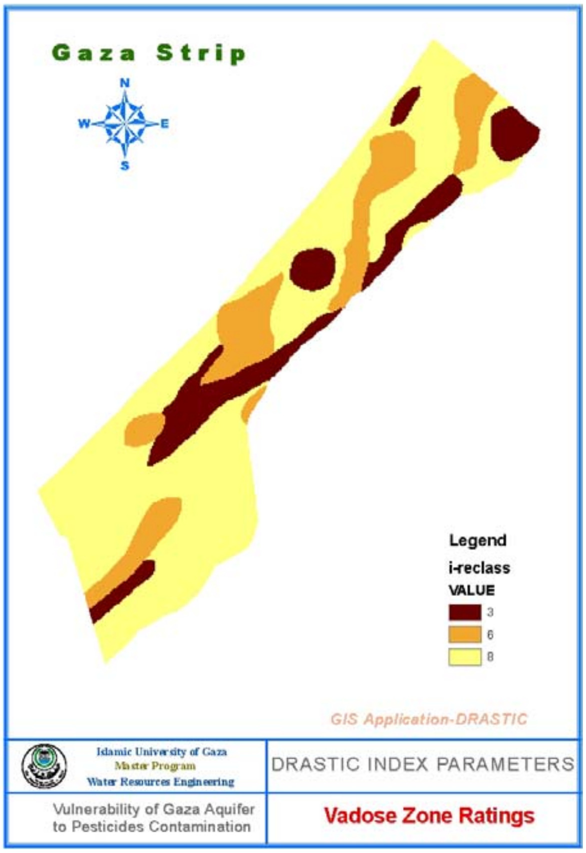


Figure 4.15: Vadose zone Rating (3 to 8)

Hydraulic conductivity

Aquifer hydraulic conductivity is the ability of the aquifer formation to transmit water. It depends on the intrinsic permeability of the material and on the degree of saturation. The rate of groundwater flow within the aquifer media controls the contaminant movement rate and dispersion from the injection point within the saturated zone and, consequently the plume concentration in the aquifer (Rahman, 2008 and Baalousha, 2006). One can say that an aquifer with high conductivity is vulnerable to substantial contamination. This is different from an aquifer media as an aquifer with an impermeable media can still conduct water in the presence of fractures (Fritch et al., 2000).

Hydraulic conductivity values are calculated from aquifer pump tests data and may also be estimated from aquifer material grain size charts (Mato, 2002). Based on pumping tests and geophysical investigations for Gaza aquifer, the hydraulic conductivity varies between 10 and 80 m/day (Baalousha 2004). Based on section 3.2.2, the spatial distribution of hydraulic conductivity was conducted by Metcalf and Eddy (2000). The standard rating values of drastic for this parameter are shown in table 4.3 to be varied from 1 to 10 with little weight of 2. Figure 4.16 shows the hydraulic conductivity maps interpolated using ArcMap GIS 9.2. The drastic index can then be calculated and mapped as in figure 4.17.

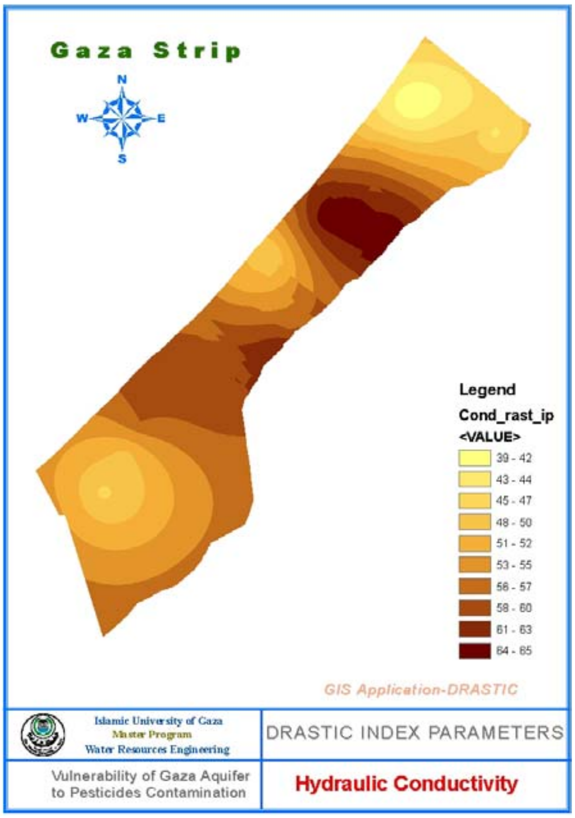


Figure 4.16: Hydraulic conductivity (interpolated based on data obtained from CAMP 2000)

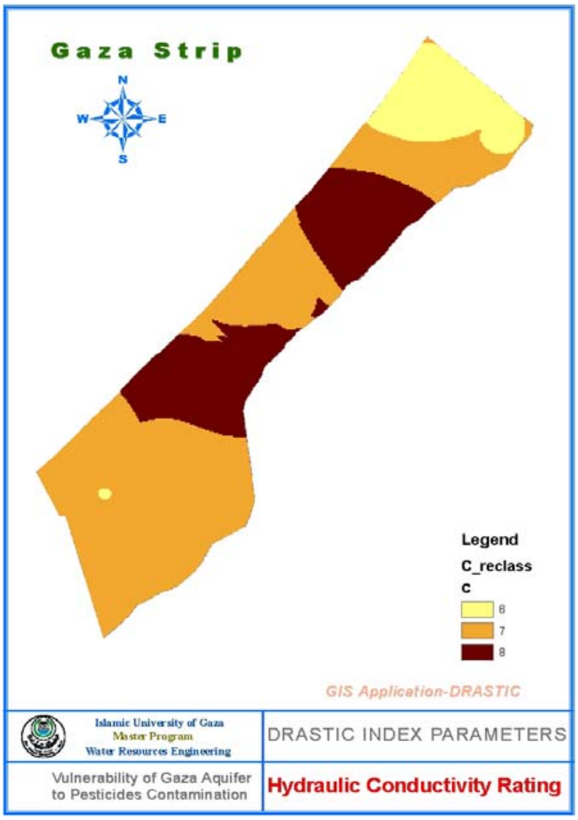


Figure 4.17: Hydraulic conductivity Ratings (6 to 8)

4.4 Sensitivity analysis

The argument that: Groundwater vulnerability may be worked out without using all parameters of drastic model is supported by some scientists (Barber, Bates, Barron, & Allison, 1993; Merchant, 1994). Moreover, weights and ratings in this model are subjective, so no justification for not doubting the accuracy of vulnerability index (Napolitano and Fabbri, 1996, Rahman, 2008). The author came from a school saying that: without supporting experimental evidence the results can be doubted. Due to current situation in Gaza strip, such experiments are no way appropriate. Consequently we can continue with the model taking into account the tests conducted by both CAMP, 2000 and Shomar, 2006 studies . In order to remove all these doubts, and to avoid subjectivity, sensitivity analysis of the model and groundwater contamination analysis are carried out. Based on Surajit et al., (2007) sensitivity analysis characterizes the distribution of both individual variables and input parameters. Sensitivity analysis provides valuable information about the influence of both rating values and weights given to each parameter, and help hydro-geologist to judge the significance of subjective elements (Al-Adamat et al., 2003). The rated parameters (D, R, A, ..) of the model have been examined for interdependence and variability as a high degree of interdependence of the parameters may lead to the risk of miss-adjustment (Babiker et al., 2005; Rosen, 1994). Two sensitivity tests can be carried out: the map removal sensitivity analysis and the single parameter sensitivity analysis. The first test was for the first time carried out by Lodwick, et al. (1990) and the second test was introduced by Napolitano and Fabbri (1996). These two tests are also used by the Babiker et al. (2005).

4.4.1 Map removal sensitivity test

Map removal sensitivity test identifies the sensitivity of vulnerability map by removing one or more layer maps and is worked out using equation 4.2:

$$S = \left(\left| V/N - V'/n \right| / V \right) \times 100 \qquad \text{……………………….. (4.2)}$$

Where: S = the sensitivity measure (%)

V and V' = the unperturbed and perturbed vulnerability indices, respectively

N and n = the number of data layers used to compute V and V'

The unperturbed vulnerability index is the actual index obtained by using all seven parameters and the perturbed vulnerability index was computed using a lower number of parameters

4.4.2 The single parameter sensitivity test

The single parameter sensitivity test is carried out to assess the influence of each of the seven parameters of the model on the vulnerability measure. In this analysis real or ''effective'' weight of each parameter was compared with its assigned or ''theoretical'' weight. The effective weight of a parameter in a sub-area was calculated by using equation 4.3.

$$\mathbf{W} = \mathbf{(\ Pr \times Pw / V\ ) \times 100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Where: W = refers to the ''effective'' weight of a parameter in a polygon

Pr and Pw = the respective rating and weight of that parameter, respectively

V = the overall vulnerability index of that polygon

The single parameter sensitivity analysis is to compare their ''theoretical'' weights with that of ''effective'' weights. The effective weight is a function of value of the single parameter with regard to the other six parameters as well as the weight assigned to it by the DRASTIC model (Babiker et al., 2005).

4.5 ArcMap GIS 9.2

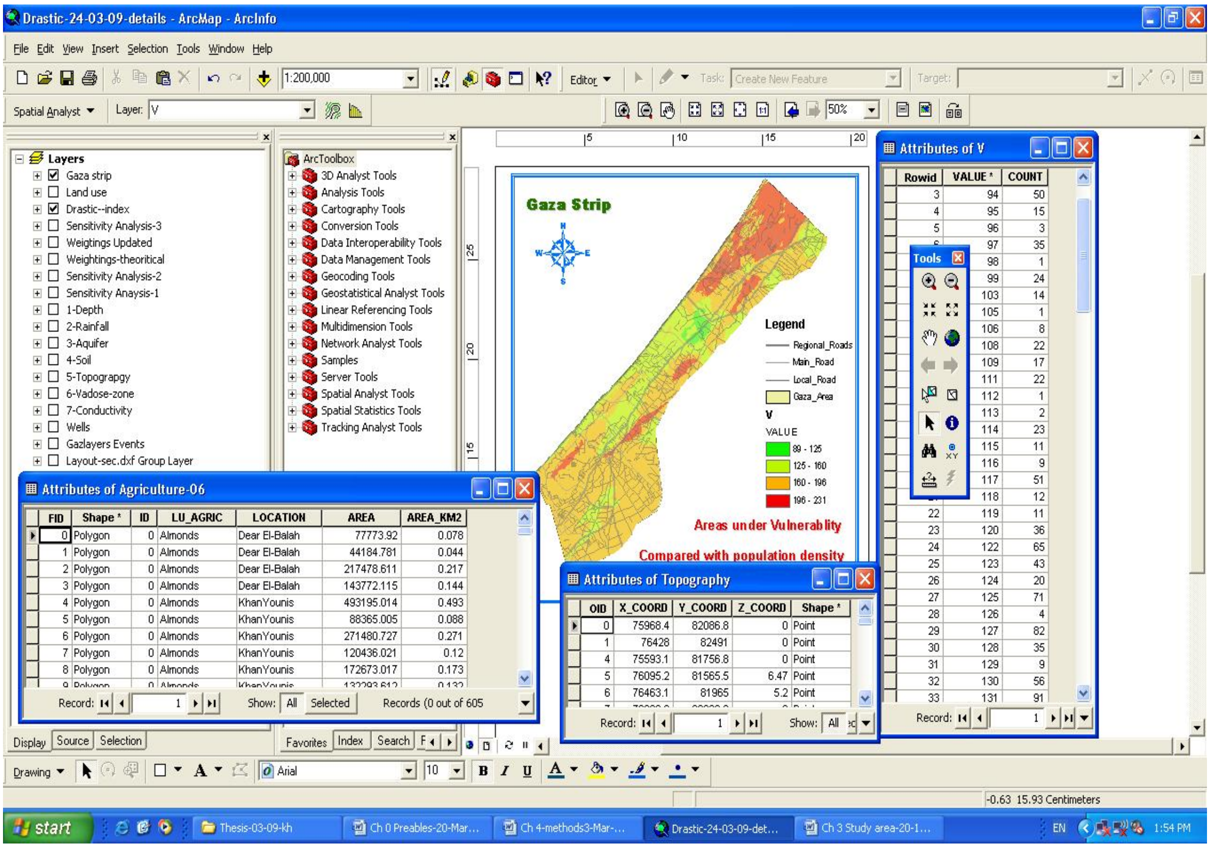


Figure 4.18: GIS ArcMap 9.2 Menu

What are Geographic Information Systems (GIS)?

GIS are “a powerful set of tools for storing and retrieving, transforming and displaying spatial data from the real world for a particular set of purposes” (Clarke, 1999). GIS can be defined as a decision support system (DSS) that involve the integration of spatial data in a problem solving media (Cowen, 1988). GIS provide technical basis to solve problems that are spatial, multidisciplinary, and holistic in nature (Thapinata, 2002).

No need to prove that: geographic information systems (GIS) play an important role in evaluating and predicting the pollution potential for groundwater on a regional scale. Policy makers, administrators, and leaders have a growing desire to utilize GIS technology for this purpose. This study aims to use geographic information systems (GIS) technology for assessing groundwater pollution potential by pesticides in Gaza strip. This technology can help produce maps of the study area showing relative vulnerability of groundwater to pesticide pollution. Figure 4.18 shows the GIS ArcMap 9.2 used for this study. The flow chart of the GIS method used and steps followed in this study can be viewed in figure 4.19. The application of GIS methods for this study is described in the following sessions.

4.5.1 Identification of data layers (Add data)

By this research, seven variables, affecting the migration of pesticides to groundwater, have been focused on to use for the GIS approach. These seven variables; depth, recharge, topography, conductivity, aquifer media, top soil, and vadose zone are tabulated in table 4.1 above, where the first four factors are in database format, whereas the last three variables are in Auto-cad format. All hydrogeological parameters needed, will be converted into GIS format as vector or raster features, where we can apply the necessary process as well.

Conversion of well depth and rainfall data into GIS format can be accomplished by the method called “Add data”. This method is used to add a new feature to a view of any GIS project using dataset table. A dataset table contains geographic locations such as name, latitude and longitude coordinates, or a route location (Hohl and Mayo, 1997). In this research, however, the geographic locations of wells, rainfall stations, conductivity locations and topographic data are both in the Global Position System (GPS) coordinate.

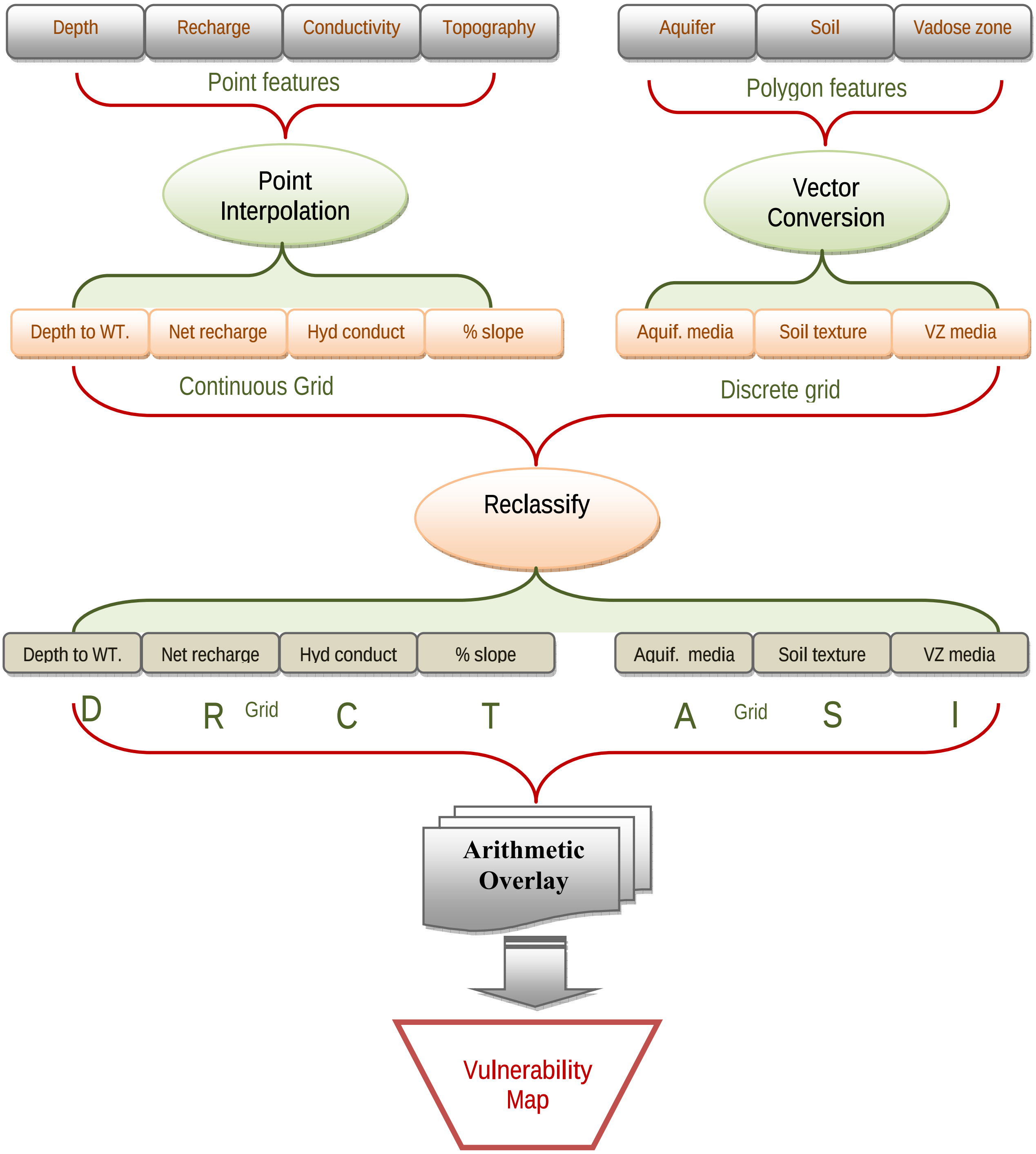


Figure 4.19: Flowchart of GIS methods used in this research

As a result of "Add data", well depth was converted into GIS data in the form of a point feature layer. This layer contained 99 points representing depths of all wells used for this study. In the same manner, rainfall was also converted into point feature layer of 12 points representing average annual rainfall (AAR) of all meteorological stations in the study area; Gaza strip **(see figures 3.3 to 3.8)**. The topographic data representing network of the topographic levels of Gaza strip was added by the same procedures into GIS data in the form of a point feature layer. Conductivity estimated values are also added similarly. The remaining layers were added in the form of DXF files where GIS ArcMap can convert them into polygon feature (shape file), where the model can softly use in the Overlay process thereafter.

As a result of "Add data", also, the three maps for top soil, vadose zone media and aquifer media were added in the form of *Polygon shape* files. It's worth mentioning that conversion of all dataset tables or maps into vector format were performed by ArcMap version 9.2. Table 4.5 below, illustrates that depth, net recharge, slope, and conductivity data layers are in the form of point feature, while aquifer, soil, and vadose zone data layers are polygon features.

Table 4.5: list of data layers included in this research

#	Data Layer	Feature	Variable
1	Depth	Point	Depth to water table (m)
2	Recharge	Point	Net recharge to groundwater (mm/year)
3	Aquifer media	Polygon	Soil texture
4	Soil media of top layer	Polygon	Soil texture
5	Slope / topography	Point	Percent slope
6	Vadose zone	Polygon	Soil texture
7	Conductivity	Point	Hydraulic conductivity (m/d)

4.5.2 Manipulation of data layers

The seven data layers used to evaluate groundwater vulnerability to contamination by pesticides need to be manipulated by major three methods as follows:

1) Converting polygon feature layers from vector to raster data. Because, many functions, especially those involving surfaces and overlay operations, are simpler to perform with raster than vector data structure. Moreover, raster data structures are relatively easy to conceptualize as a method of representing space (DeMers, 2000).
2) Point feature layers need to be interpolated into continuous grid cells. This means that they are converted from vector to raster data.
3) Reclassification of each data layers into a certain group. This is to produce a consistent scheme among all layers or themes and to limit the number of classes to the level of detail in individual data layer (Thapinata, 2002).

Converting polygon feature themes

The process of converting a polygon feature layer from vector to raster data structure is called "Vector conversion" or "Rasterization" (Bernhardsen, 1999). Polygons are converted to cells, and each cell falling within a polygon is assigned a value equal to the polygon attribute value. The cells are usually in square shape called “grid cells”. All grid cells are the same size, and each occupies the same amount of geographic space as any other. Common cell size varies from 10 x 10 m, 100 x 100 m, 1 x 1 km, and 10 x 10 km (Bernhardsen, 1999). The smaller the cell size and the greater the numbers of cells that represent an area, the more accurate the representation of that area. In this study, each cell had a square size of 100 x 100 m or 1 hectare. The size was chosen on the basis of spatial resolution of available data and computational considerations. Vector conversion of soil, aquifer media, and vadose zone media layers were performed using ArcMap spatial analyst.

- **Interpolating point feature layers**

Interpolation is a function used to generate a continuous surface from sampled point values. Interpolation predicts values for cells in a raster from a limited number of sample data points. It can be used to predict unknown values for any geographic point data, such as elevation, rainfall, chemical concentrations, noise levels, and so on .The assumption that makes interpolation a useful technique is that spatially distributed objects are spatially correlated; in other words, things that are close together tend to have similar characteristics. By this assumption, the values of points close to sampled points are more likely to be similar than those that are further apart (ArcGIS, 9.2 Desktop Help).

There are three common methods of point interpolation, namely (1) Inverse Distance Weighted (IDW), (2) Spline, and (3) Kriging. The Inverse Distance Weighted (IDW) and Spline methods are referred to as deterministic interpolation methods because they assign values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface. A second family of interpolation methods consists of geostatistical methods, such as kriging, that are based on statistical models that include autocorrelation (the statistical relationship among the measured points). Because of this, not only do geostatistical techniques have the capability of producing a prediction surface, but they also provide some measure of the certainty or accuracy of the predictions (ArcGIS, 9.2 Desktop Help).

No matter which method is selected, the more sample points and the greater their real coverage, the more reliable the results (McCoy and Johnston, 2001). However, it is important to say that having more sample points does not always improve the accuracy or quality of the output. Indeed, it quite often increases the computation time and the data volume. In some cases, too much data tends to produce unusual results because clusters of points in areas where the data are easy to collect are likely to yield a surface representation that is unevenly generalized and therefore unevenly accurate (DeMers, 2000). Following are descriptions of each interpolation method:

Inverse Distance Weighted (IDW) interpolation

IDW interpolation estimates the value for each grid cell in an output grid theme by averaging a set of sample points in a point feature theme. An average value is calculated based upon sample point values and their distance from the grid cell. Therefore, sample point values closer to the cell have a greater influence on the cell's estimated value than those that are farther away. The IDW interpolation method provides two options to select the sample points, a fixed number of nearest points to the grid cell and a fixed radius around a grid cell. With the first option, a number of nearest sample points to be used for estimating each grid cell will be specified. In contrast, the second option assigns a radius to define which sample points are used. It means that all samples falling within this radius will be used to calculate the average for the cell. Generally, the IDW method is particularly well suited to deal with abruptly changing data because it can incorporate barriers into its estimation process (ArcGIS, 9.2 Desktop Help).

Spline interpolation

This technique estimates the value of geographic features in an area by using a set of sample points. This method divides the theme into regions, and uses the sample points found in each region to predict individual cell values for that region. Basically, the number of regions in a theme is based upon the number of points selected for estimating the cell values. If the number of points selected decreases, the number of regions will increase. As a result, the area of each region is smaller and the estimated cell values are closer to local sample point values (ArcGIS, 9.2 Desktop Help). There are two options in this method, which are Regularized and Tension interpolation. The Regularized option creates a smooth, gradually changing surface with values that may lie outside the sample data range. On the other hand, the Tension creates a less smooth surface with values more closely constrained by the sample data range (McCoy and Johnston, 2001). It is noted that Spline interpolation is better for showing a gradually changing surface while the IDW method is better for showing extremes in the data. Spline interpolation would also be the better choice for irregularly spaced data; in other words, it will create the better result when dealing with unevenness in the distribution of sample points (ArcGIS, 9.2 Desktop Help). This method is best for gently varying surfaces such as elevation, water table heights, or pollution concentrations (McCoy and Johnston, 2001).

Kriging interpolation

Kriging is a statistical method that quantifies the correlation of the measured points through variography or spatial modeling. When making a prediction for an unknown location, Kriging weights the nearby measured points by their configuration around the prediction location and uses the fitted model from variography to determine a value. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multi-step process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology (ArcGIS, 9.2 Desktop Help).

- **Reclassifying data layers**

Reclassifying your data means replacing input cell values with new output cell values. The reasons behind data reclassification is to replace values based on new information, to group certain values together, and to reclassify values to a common scale (ArcGIS, 9.2 Desktop Help). In this study, each data layer needs to be reclassified to a common scale showing its potential to cause contamination of groundwater by pesticides. This scale consists of ten (10) classes for each data layer with a value from 1 to 10, meaning low to high pollution potential (Thapinata, 2002).

4.5.3 Analysis of data layers

The last step of GIS application in this study is the “Overlay” process, through which all data layers will be analyzed. Overlay is a spatial operation in which a thematic layer is superimposed onto another to form a new layer. Overlay analysis can be used to combine the characteristics of several datasets into one, and find specific locations or areas that have a certain set of attribute values in order to match the criteria you specify. This approach is often used to find locations that are suitable for a particular use or are susceptible to some risk very similar to our case (ArcGIS, 9.2 Desktop Help). Overlaying events is another way to create new event data. This process combines two input event tables to create a single output event table. The new table can be used to analyze event data in ways not possible using traditional spatial analysis techniques (ArcGIS, 9.2 Desktop Help).

This operation can be performed both in vector and raster data; however, raster overlay is often more efficient than vector overlay. This is because attribute values in raster data are not listed in tables as in vector data, but are represented by grid cells in thematic layers. Therefore, arithmetic operations and some other statistical operations can be performed directly during the overlay process. In other words; two or more thematic layers may be combined, subtracted, multiplied, etc., to create a new layer with new value for each grid cell (Bernhardsen, 1999).

There are a number of different rules associated with the overlay process as follows:

First, Dominance rule determines the result of combination by selecting a single value that dominates all the others.

Second, Contributory rule uses each layer's attribute value to create a composite result, often using a mathematical operation like addition.

Third, interaction rule goes beyond independent contribution to exploit the interaction between values. The result depends on the specific combination of attribute values for some layers taken together (Chrisman, 1996).

In this study, the second contributory rule will be used in the overlay process, using arithmetic operation as a key function. This kind of overlay is so called "Arithmetic overlay", which means that values assigned to two or more input features are combined arithmetically (+, -, *, /) to produce an output grid (ArcGIS, 9.2 Desktop Help). In the case of addition operation, those values are first multiplied by influence factors and then added together to produce an output grid. This kind of arithmetic overlay is, therefore, named "Additive overlay" (Ormsby and Alvi, 1999). The arithmetic or additive overlay can be conducted by using ArcMap GIS 9.2, spatial analyst.

During the process of additive overlay, all the seven data layers used in this study were superimposed to yield a composite vulnerability map. In this process rates assigned to all cells in each layer were multiplied by their weight or influence factor (see table 3). As each data layer differs with respect to its impact on groundwater contamination by pesticides. Then, cells values at the same location (or same coordinates x, y) of all layers will be added together to produce an output layer with a new value for each cell.

CHAPTER 5

Results and Discussion

The GIS based drastic model was applied considering the seven hydro-geological factors, based on data obtained from concerned organizations. These data sheets or drawings related to the hydrogeological factors were arranged and adapted as an electronic unified tables or polygons. These data were processed using ArcGIS-9.2 to produces seven hydro-geological maps. The maps were converted into raster maps for easy calculation. Rates for each map were carefully adapted to cope with Gaza conditions. Then each raster map were weighted according to pesticides' scale and overlaid accordingly to produce the vulnerability to pesticides maps using equation 4.1. Sensitivity analysis was conducted also using equation 4.2 and 4.3. Finally the vulnerability maps were conducted, discussed and verified as below.

5.1 Results of DRASTIC model

Based on Belmonte, et. al. (2005), the levels of vulnerability for the drastic method, the scaling is low vulnerability when drastic index is below 100, medium from 100 to 140, and high vulnerability when the said index is higher than 140. Depending on weights assigned, the value of drastic index will be. In fact, there are no standards for the scale of vulnerability valid for every area. Others divide the total area into four zones and five zones. The researcher used the scale of four zones; low, moderate, high and very high as the targeted area can be considered as one of the most crowded area in the world.

The final vulnerability was obtained by running the model in the GIS environment by using the seven hydro-geological data layers. The drastic scores obtained from the model vary from 89 to 231. The mean value of drastic index for all Gaza strip is 173.4. Table 5.1 shows the drastic results in terms of scaling, reciprocal areas and percentage of each zone of vulnerability. Figure 5.1 also; delineate spatial vulnerability of Gaza strip. The map marks out areas with varying sensitivity (low, moderate, high and very high). The demarcated area are relative indication of susceptibility of groundwater to pollution from diffuse sources especially pesticides.

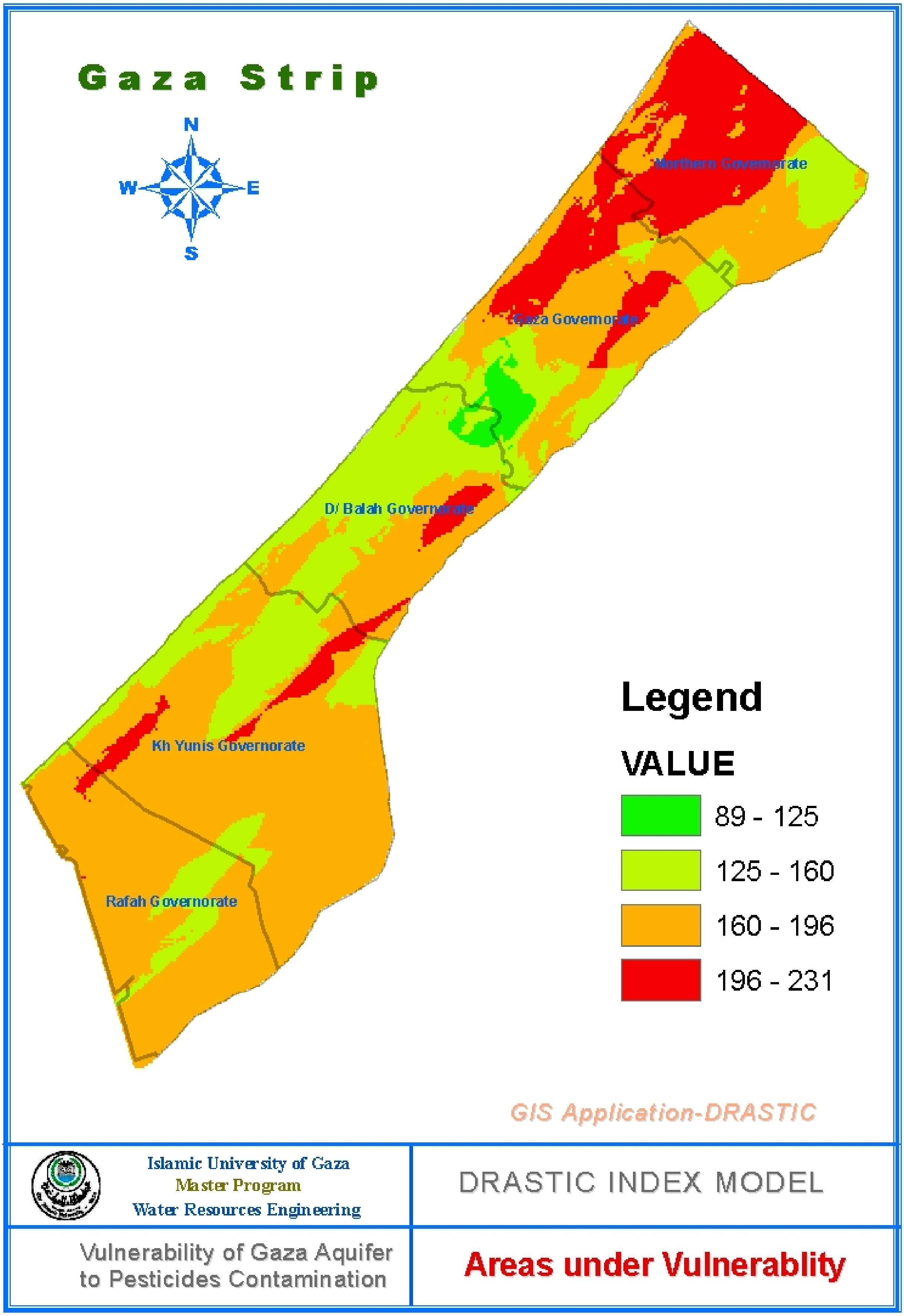


Figure 5.1: Areas under Vulnerability to Pesticides Contamination in Gaza strip (Mean value = 173.4)

Table 5.1: Area under vulnerability to Pesticides contamination in Gaza strip

Vulnerability Zone	From	to	Area (hectare)	Percent
Low	89	125	652	1.81%
Moderate	125	160	8,973	24.93%
High	160	196	20,607	57.24%
Very High	196	231	5,768	16.02%

With reference to table 5.1, about 73% of Gaza area is classified under high vulnerability, the remaining 25% and 2% are under moderate and low vulnerability respectively. Figure 5.1 shows areas of high, moderate and low vulnerability respectively. It seems that north area, definitely Jabalia and Beit Lahia, west of Gaza area, small strips east of middle area and Khan younis, and west of Rafah are the most vulnerable areas in Gaza strip. The majority of Gaza strip areas are of high vulnerability. Area at middle area, Khan younis are moderately vulnerable. The areas under high vulnerability classes are generally characterized with soil profiles dominated with sandy/ gravel materials (which allow fast pollutant transport), relatively low topography (which provide a better chance for infiltration), and shallow groundwater table.

Looking at vulnerability to pesticides map of north area, one can easily discover that this area must be at risk. The location of wastewater treatment site in that area adds more complication to already deteriorated situation there. The flooding of wastewater can be very dangerous. The author recommends that much care and restrict monitoring plan have to be assured by all concerned at that area, to minimize burden of contamination. So a robust plan supported by continuous testing program for assigned wells has to be maintained by the local authorities.

Appendix C shows areas of vulnerability in more details that can be used by stakeholders and decision makers to build land use strategies.

Figure 5.2 shows relation between areas of green/ plastic houses, solid waste disposal sites, wastewater treatment sites and areas under vulnerability. The figure alarms the danger of these locations except for one solid waste disposal site located to the east of Gaza. It can be shown also that a huge number of green houses lies within high or very high vulnerable areas. So the application of pesticides has to be strictly controlled according to the proper integrated pest management technique. As shown by appendix D the areas under vulnerability are mapped with areas of green/ plastic house and waste water and solid waste sites in each governorate.

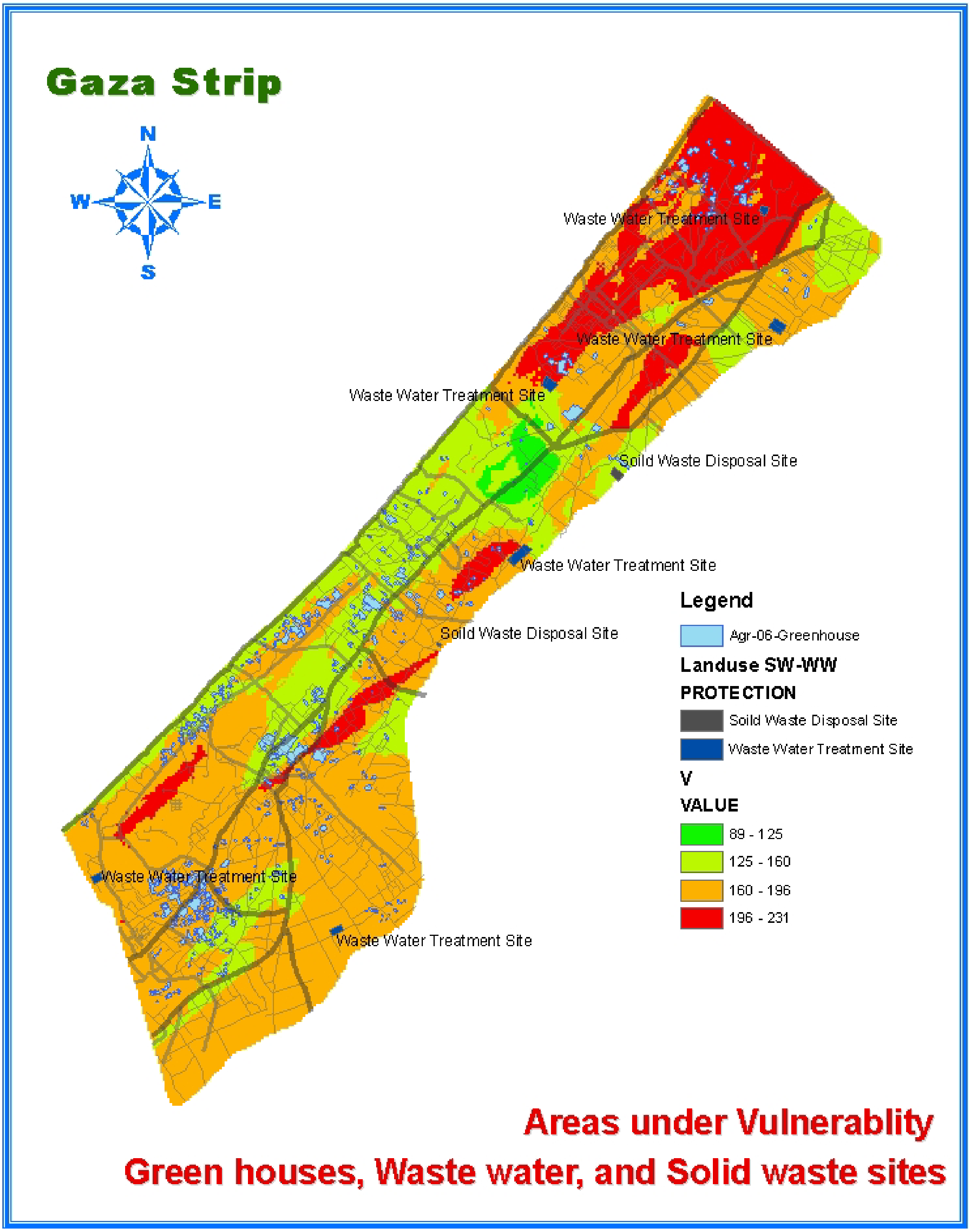


Figure 5.2: Area under vulnerability and close to Green houses, solid waste damps, and waste water plants.

Figure 5.2 and appendix D, shows that most of agricultural areas lay within high vulnerable areas. This reflects the need for strict pest integrated management plan.

5.2 Pesticides Contamination Analysis

In order to calibrate the model, and evaluate the risk that may be imposed on Gaza aquifer, field laboratory test has to be applied. But due to current situation in Gaza strip during the implementation of this research, it was very difficult to have these lab tests be conducted. The author referred to previous tests conducted by CAMP, 2000 and Shomar, 2006 in order to calibrate the model.

<u>CAMP Sudy, 2000</u>

Figure 5.3 and figure 5.4 show spatial distribution of all wells tested, and those found contaminated by CAMP (2000). Only 12 wells out of 168 well tested, were found contaminated with pesticides with levels around the allowable WHO standard. Figure 5.5 shows level of pesticides contamination based on CAMP study. Figure 5.6 shows also pesticides detected in Gaza aquifer based on CAMP (2000) study.

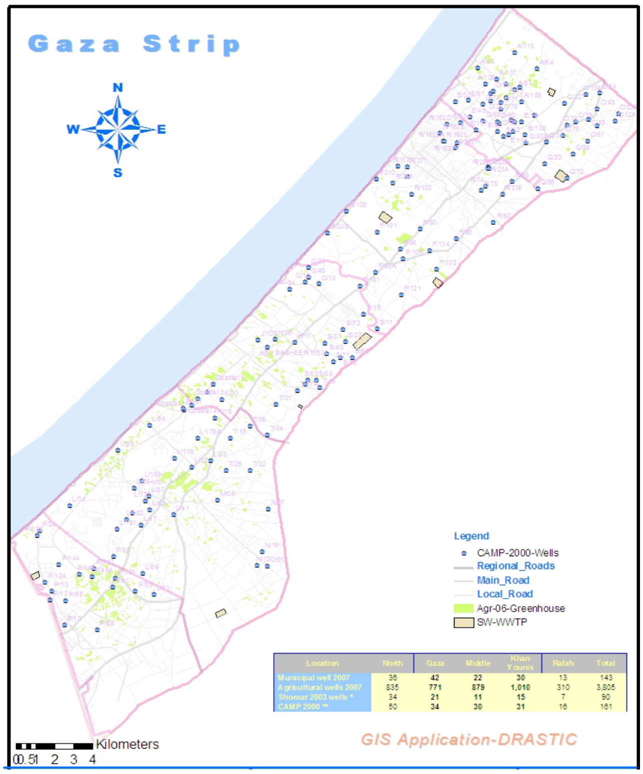


Figure 5.3: Spatial distribution of 168 CAMP's wells

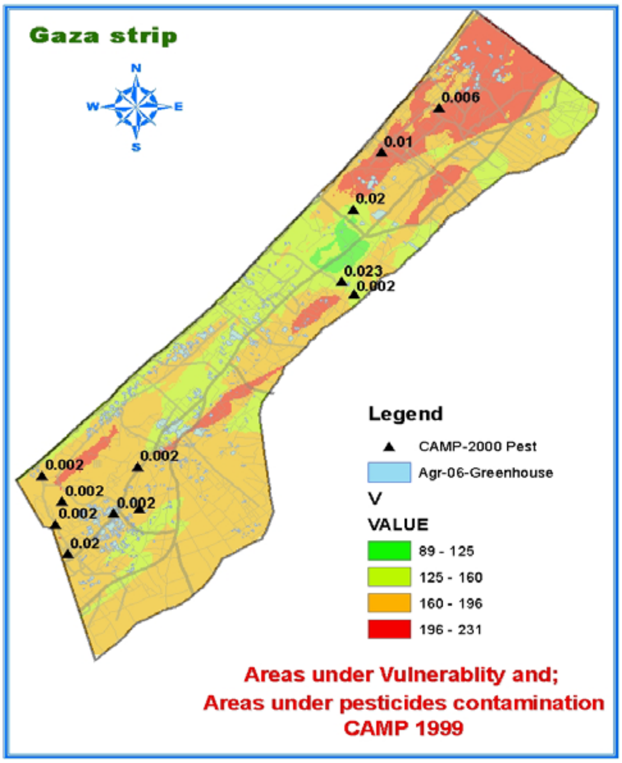


Figure 5.4: Spatial distribution of contaminated wells in CAMP study

From figures 5.4: wells located in areas under moderate and low vulnerabilities, are not contaminated by pesticides. Those contaminated wells are located in areas with high vulnerability to pesticides. This gives more confidence for the vulnerability maps produced by the drastic model.

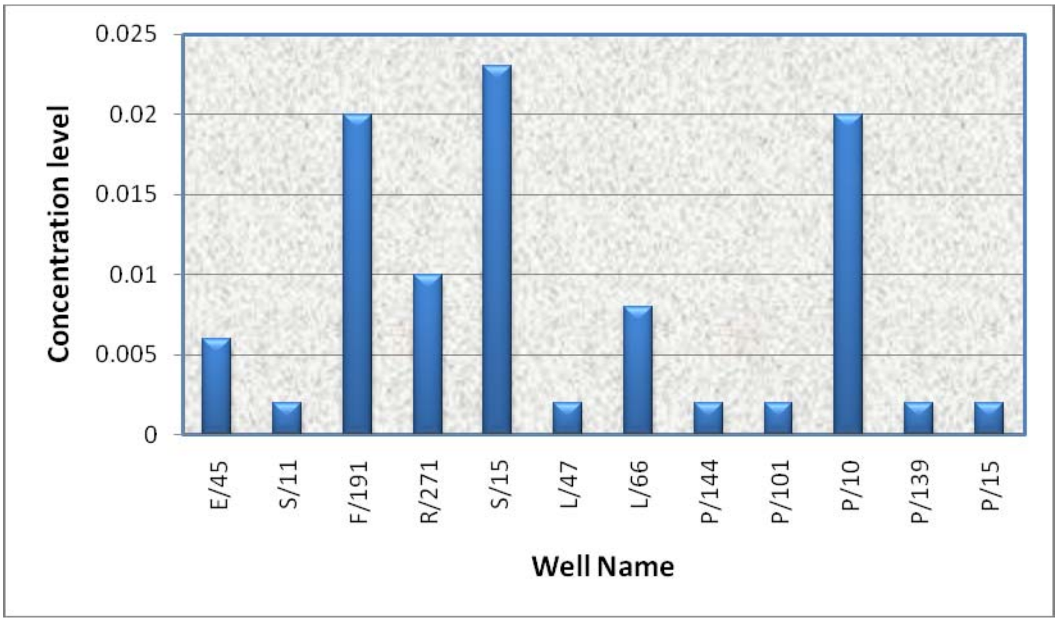


Figure 5.5: Level of pesticides contamination in μg/l for contaminated wells (CAMP, 2000)

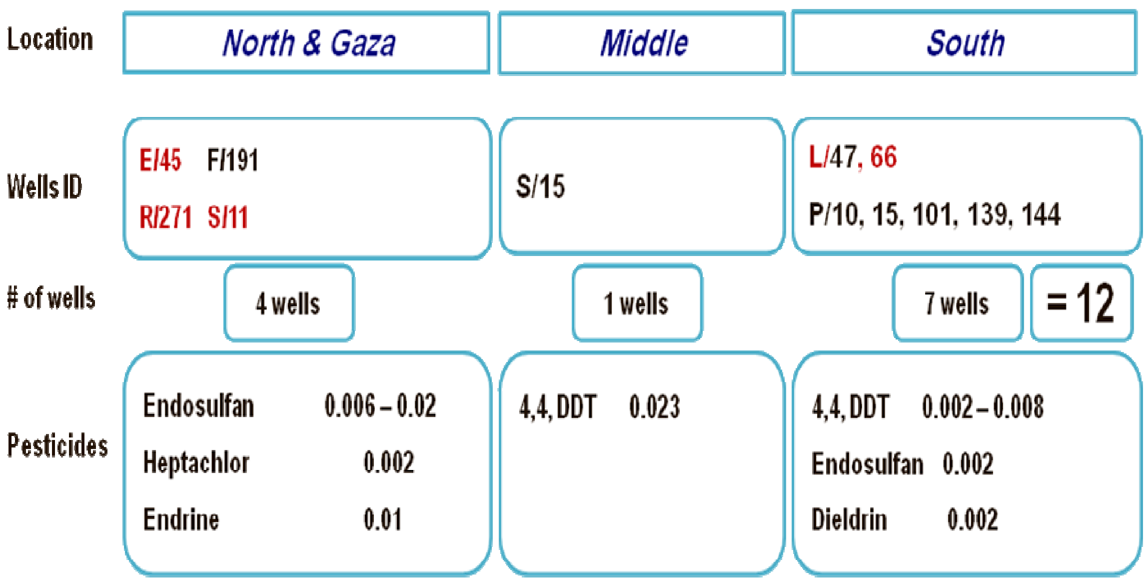
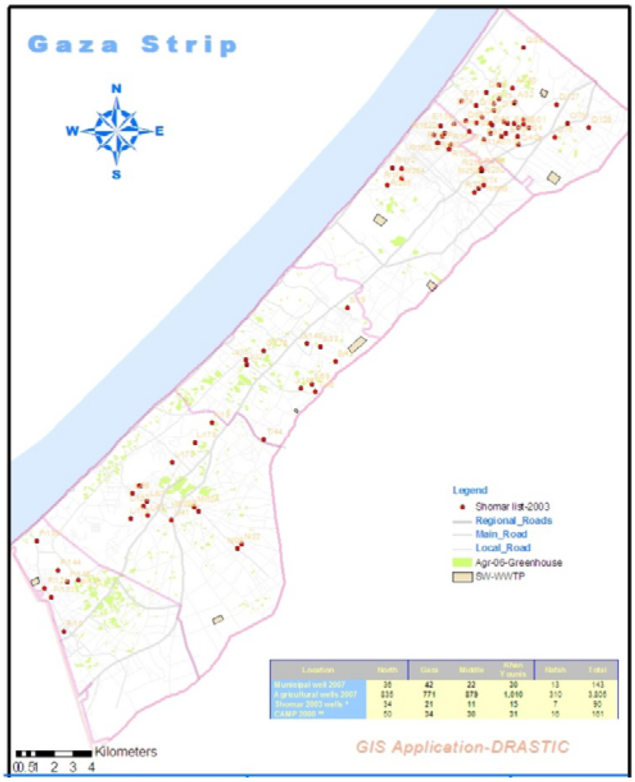


Figure 5.6: Pesticides detected in Gaza aquifer (CAMP, 2000)

Shomar study 2006

Figure 5.7 and figure 5.8 show spatial distribution of all wells tested, and those found contaminated by Shomar (2006). Only 26 wells out of 90 well tested, were found contaminated with pesticides with levels much higher than the allowable WHO standard. Figure 5.9 shows level of pesticides contamination based on Shomar study. Figure 5.10 shows also pesticides detected in Gaza aquifer based on Shomar (2006) study.



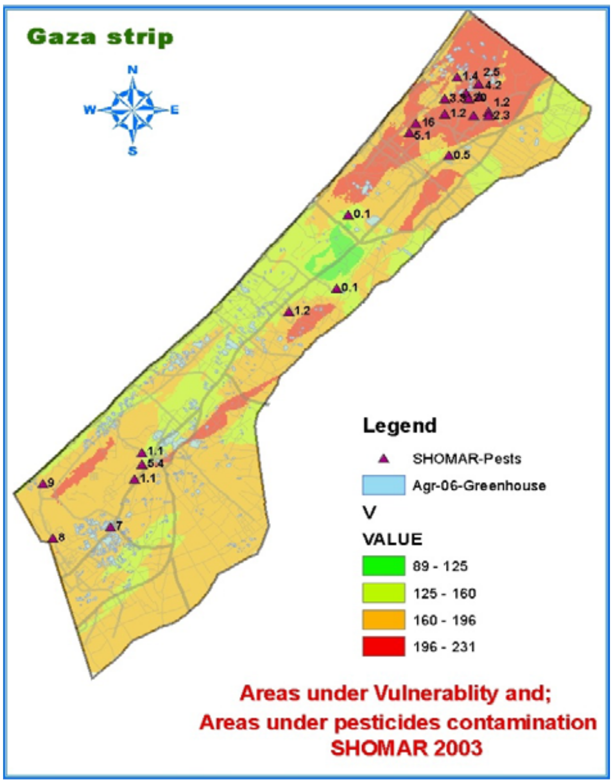


Figure 5.7: Spatial distribution of 90 Shomar's wells

Figure 5.8: Spatial distribution of contaminated wells (Shomar. 2006)

From figure 5.8, wells located in areas under moderate and low vulnerabilities are not contaminated by pesticides. Other contaminated wells are found in areas under high and very high vulnerability to pesticides contamination. This gives more confidence for the vulnerability maps conducted by the drastic model.

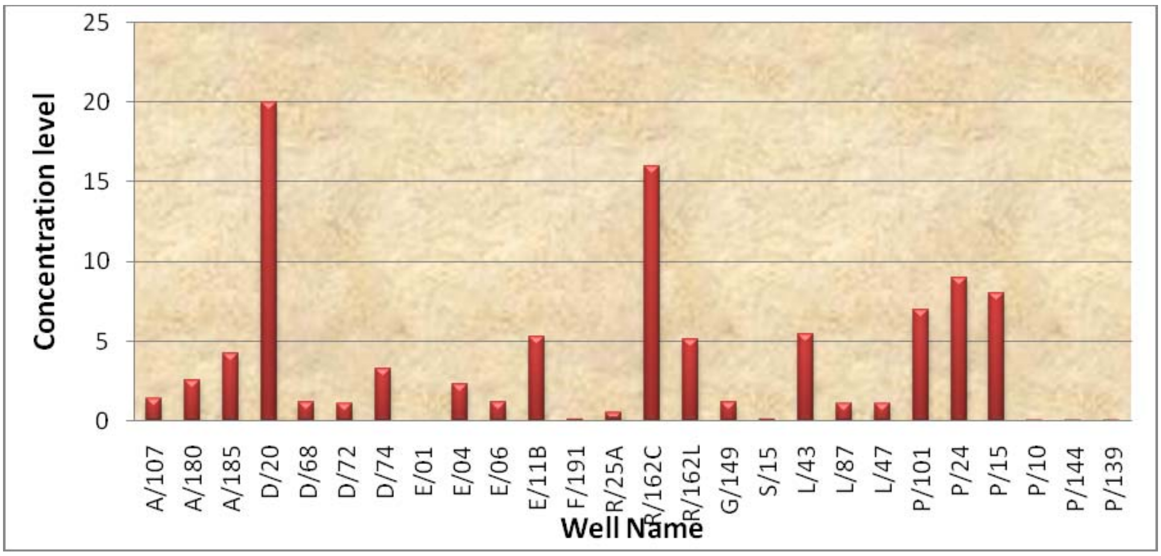


Figure 5.9: Level of pesticides contamination in µg/l for contaminated wells (Shomar, 2006)

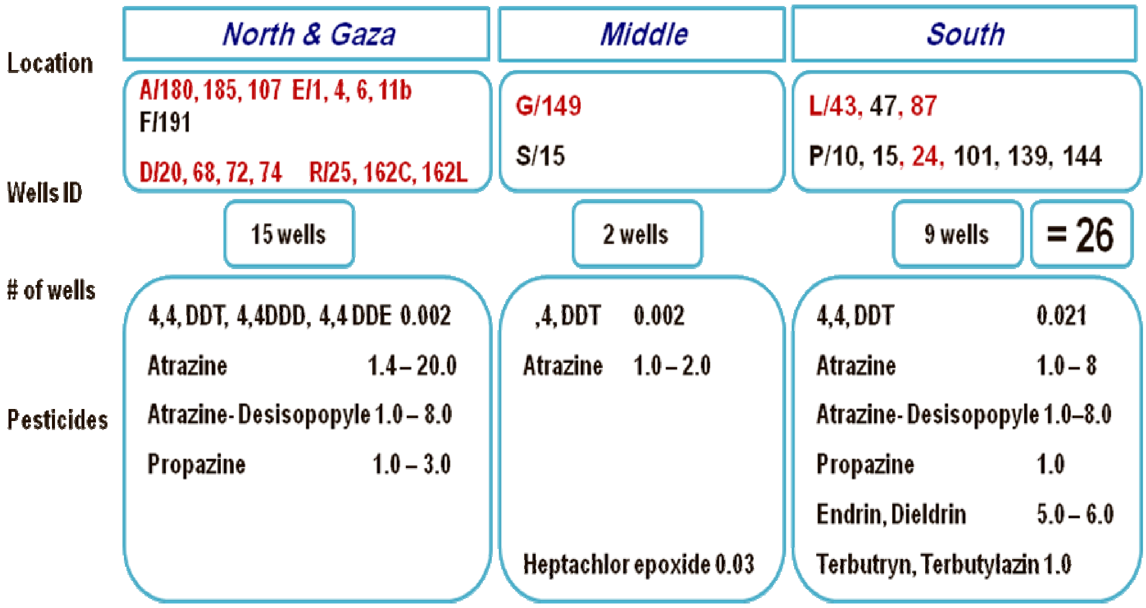


Figure 5.10: Pesticides detected in Gaza aquifer (Shomar, 2006)

From both studies

1. The occurrence of pesticides in Gaza aquifer have been approved by both studies.
2. Level of pesticides contamination in CAMP study, conducted in 1999, is around the WHO standard, or little bit more.
3. Level of pesticides contamination in Shomar study, conducted in 2003, is much more higher than WHO standard. Where Shomar recommend proper monitoring and continuous observation for Gaza aquifer.
4. Some pesticides like 4,4 DDT were found at the same levels in both study, this mean that DDT is widely used everywhere during the last period. Even the MoA imposed restrictions on importing this dirty pesticides, the level of contamination still the same. This reflects the persistence of DDT.
5. Both studies have its own way in selection of wells and selection of type and name of pesticides, as the CAMP study tested for only 18 organochlorine pesticides, while Shomar study tested 90 wells for 52 pesticides. There is no unified system for pesticides observation in Gaza aquifer.
6. The author found that only 8 infected wells are found common in both CAMP and Shomar lists of wells. This number of common wells cannot be a solid base for model calibration. Figure 5.11 shows the common wells and pesticides detected in both studies.

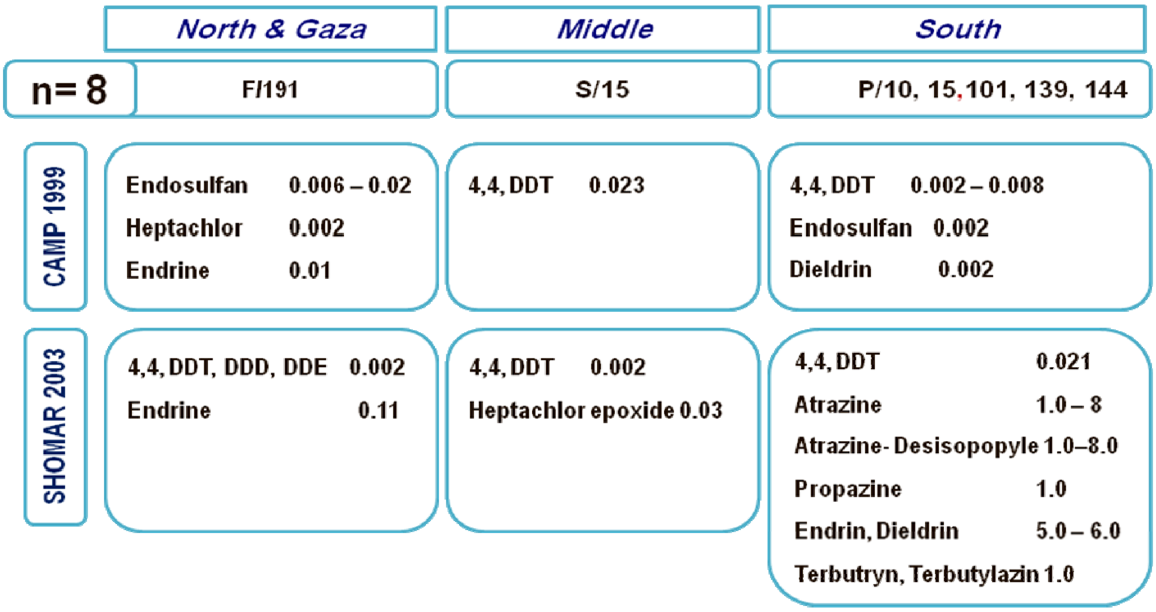


Figure 5.11: Pesticides detected in common contaminated wells in both CAMP and Shomar studies.

5.3 Sensitivity Analysis

5.3.1 Independence of parameters

Table 5.2 shows the statistical summary of the seven parameters rated and processed using the GIS model in order to get the vulnerability of Gaza aquifer for pesticides contamination. Testing the means of the hydro-geologic parameters shows that the highest contribution to the vulnerability index is made by depth (mean = 8.5). The soil is next (mean = 7,9) and so on for Aquifer media, Impact of vadose zone, and Hydraulic conductivity. Recharge and slope having means of 4.5 and 4 contribute lowest to the contamination of groundwater. The coefficient of variations indicate that a high contribution to the variation of vulnerability index is made by recharge (65.6%), then by slope (51.3%) and so on as per table 5.2 reaching to the end with aquifer media (20.5).

Table 5.2 Statistical Summary of the Drastic Parameters Map

Hydro-geologic parameters	D	R	A	S	T	I	C
Weights >	5	4	3	5	3	4	2
Min	1	1	3	2	3	3	6
Max	10	6	8	10	10	8	8
Mean	**8.5**	**4.5**	**7.4**	**7.9**	**4**	**6.8**	**6.1**
Standard Deviation (SD)	2.41	2.95	1.52	2.59	2.05	1.84	2.07
Coefficient of Variation (CV)*	**28.4%**	**65.6%**	**20.5%**	**32.8%**	**51.3%**	**27.1%**	**33.9%**
Rank of mean	**1**	**6**	**3**	**2**	**7**	**4**	**5**
Rank of CV	**5**	**1**	**7**	**4**	**2**	**6**	**3**

* *CV = SD / Mean*

In order to check out the interdependence of the rated seven hydro-geologic parameters of the drastic model, 21 spearman's rank order correlations are computed. Table 5.3 shows the rank of the seven parameters used in computing Spearman's correlations. Number of correlations = n (n-1)/2 (where n is the number of parameters =7) as per table 5.4. Spearman's correlation coefficient detailed calculations are shown in appendix E.

Out of these 21 correlations, nine (red color) are significant at more than 95% level of confidence. The author reveals that even though 43% of total relations computed by Spearman formula showed strong correlation, we cannot conclude that the factors are necessarily dependant. One can say they may be dependant. For example; the correlation depth-topography, is strong due to similarity in the way of action of both factors (the increase in depth or slope of topography leads to decrease in vulnerability index) but they are not necessarily dependent. The same way is applicable for the relations depth-aquifer media, depth-vadose zone, and net recharge-hydraulic conductivity. The other five correlations may be due to chance. It means that parameters are largely independent and there is little risk of mis-adjustment in the final index.

Table 5.3: Rank values for the seven hydraulic parameters (data is taken from GIS-Drastic model)

D	**R**	**A**	**S**	**T**	**I**	**C**
10.0	1.0	8.0	2.0	10.0	8.0	6.0
9.1	1.6	7.8	5.0	8.5	7.0	6.2
8.2	2.1	7.3	6.0	8.0	6.6	6.4
7.2	2.7	7.0	6.5	7.3	6.0	6.7
6.2	3.3	6.9	7.0	6.7	5.8	6.9
5.3	3.8	6.5	7.5	6.0	5.6	7.1
4.5	4.3	6.2	8.0	5.5	5.0	7.3
3.7	4.9	6.0	8.5	5.1	4.0	7.6
2.6	5.5	5.0	9.0	4.0	3.5	7.8
1.0	6.0	3.0	10.0	3.0	3.0	8.0

Table 5.4: Spearman's correlation coefficient matrix for the seven hydraulic parameters

Parameter	D	R	A	S	T	I	C
D							
R	-0.960606						
A	0.948485	-0.833333					
S	-0.969697	0.99697	-0.854545				
T	0.99697	-0.957576	0.951515	-0.966667			
I	0.972727	-0.921212	-0.924242	0.975758	0.97576		
C	-0.833333	0.957576	-0.715152	0.954545	-0.8303	-0.8182	

Note : see appendix E for Spearman's coefficient calculations

5.3.2 Map removal Sensitivity analysis

As per tables 5.5 to 5.8, the map removal sensitivity analysis is performed by two processes. The first; by removing one data layer, the second; by removing one or more data layers.

- One parameter is removed

Table 5.5, shows min, max, and means values of drastic index obtained from the drastic model, where one parameter is removed. The values of vulnerability index; **V'** are calculated. Then the sensitivity analysis for map removal is calculated according the sensitivity equation 4.2, then the values of variation index (S %) are tabulated in table 5.6.

Table 5.5 shows that there is a clear variation in vulnerability index due to the removal of a layer at any time. On ranking sensitivity of means as per figure 5.12, the variation of groundwater vulnerability index is to be expected highest upon the removal of depth, then the removal of soil parameters from computation, as the mean variation indices are 1.7% and 1.4% respectively.

Table 5.5: Statistics of map removal sensitivity analysis (one parameter is removed) values of V and V' are tabulated

V' (=drastic index if one parameter is removed)	Min	Max	Mean	SD
V (= drastic index)	**89**	**231**	**173.4**	**21.1**
D is removed	64	181	130.9	18.9
R is removed	73	195	155.5	19.8
A is removed	80	207	151.3	19.5
S is removed	75	186	134	20.3
T is removed	86	204	161.4	19.4
I is removed	77	199	146.2	19.3
C is removed	75	223	161.2	22.8

Table 5.6: Statistics of map removal sensitivity analysis (one parameter is removed) values of Sensitivity values (variation index S) are tabulated

Parameter removed	Variation Index (S %) = (| V/N – V'/n | / V) x 100				Rank order
	Min	Max	Mean	SD	
D	2.30	**1.23**	**1.70**	0.64	**1**
R	0.62	**0.22**	**0.66**	1.35	**5**
A	0.70	**0.65**	**0.26**	1.12	**6**
S	0.24	**0.87**	**1.41**	1.75	**2**
T	1.82	**0.43**	**1.23**	1.04	**3**
I	0.13	**0.07**	**0.23**	0.96	**7**
C	0.24	**1.80**	**1.21**	3.72	**4**

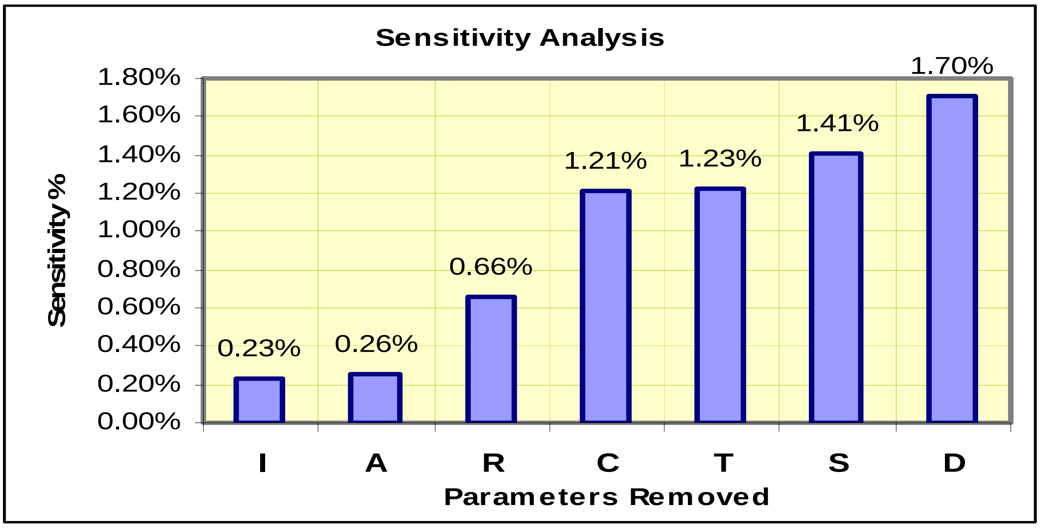


Figure 5.12: Sensitivity Analysis, Ranking order, if one parameter is removed

Straight forward, this can be referred to the high theoretical weight assigned for depth to water and soil media which is 5. The vulnerability index seems sensitive to the removal of slope and hydraulic conductivity, as the mean variation is 1.23% and 1.21%. The least sensitive parameter in computing the vulnerability index is impact of vadose zone and aquifer media. This can be not realistic based on less confidence in data layers obtained for both aquifer media and vadose zone of Gaza aquifer. This indicates the need for more precise and accurate electronic maps for Vadose zone and aquifer media which are not available in the local concerned affairs.

- One or more parameters are removed

Table 5.6, shows min, max, and mean values of drastic index obtained from the drastic model, where *one or more* parameters are removed. The values of vulnerability index; **V'** are computed. Then the sensitivity analysis for map removal is computed using GIS drastic index according the sensitivity equation 4.2, then the values of variation index (S %) are tabulated in table 5.8.

Table 5.7 was developed based on ranking order of table 5.6 as it can be clear in figure 5.13, where the layers, which results less variation in the final vulnerability index, were removed first and then next lesser one and so on. The least variation index can be found when vadose zone layer (with sensitivity of the mean = 0.23%) is removed. Referring to percentage of variation in the mean as per table 5.8 and figure 5.13, no consistency in the trend of values of mean variation index is observed when more layers are removed. Even though the trend goes to increase the variation index as more layers are removed. This trend shows that almost all the parameters are necessary important to develop the vulnerability index.

Table 5.7: Statistic of map removal sensitivity analysis (one or more parameters are removed) values of V and V' are tabulated

Parameter used	V & V' (Starting with excluding the lowest mean value first)			
	Min	Max	Mean	SD
D S T C R A I	**89**	**231**	**173.4**	**21.1**
D S T C R A I	77	199	146.2	19.3
D S T C R A I	68	175	124.1	18.1
D S T C R A I	52	139	106.2	15.9
D S T C R A I	38	130	94.0	16.5
D S T C R A I	35	100	82.0	16
D S T C R A I	5	50	42.4	12.1

Table 5.8: Statistics of map removal sensitivity analysis (one or more parameters are removed) values of Sensitivity values (variation index S) are tabulated

Parameters used	Variation Index (S %) = (| V/N – V'/n | / V) x 100			
	Min	Max	Mean	SD
D S T C R A I	0.13	0.07	0.23	0.96
D S T C R A I	1.00	0.87	0.03	0.029
D S T C R A I	0.32	0.76	1.03	4.55
D S T C R A I	0.05	4.47	3.78	11.78
D S T C R A I	1.18	7.36	9.36	23.63
D S T C R A I	8.67	10.68	10.17	43.06

When focusing on the first segment of the curve in figure 5.13, it may be useful to indicate that the removal of one parameter which can be vadose zone alone or aquifer media alone is more sensitive than removing two parameters including both vadose zone and aquifer media. This indicates low quality of raw data assigned for both parameters.

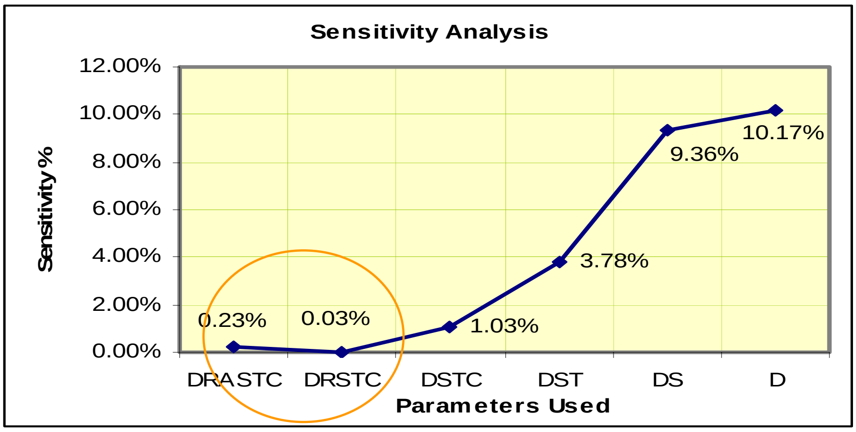


Figure 5.13: Sensitivity Analysis, if one or more parameters are removed

5.3.3 Single Parameters Sensitivity Analysis

The Single parameters sensitivity analysis means: comparing the theoretical weights that have been assumed before applying the model with the effective weights produced by the model itself (Rahman, 2008). The effective weight is a function of value of the single parameter with regard to the other six parameters as well as the weight assigned to it by the drastic model as per equation 4.3 (Babiker et al., 2005). There may be some deviation imposed by the effective weights of the drastic parameters from that of the theoretical weights both theoretical and effective weights of the seven parameters have been compared as in table 5.9.

Table 5.9: Comparing between theoretical and effective weights of the seven hydro-geological parameters

Parameter	Theoretical value	Theoretical weight (%)	Effective weight (%)	Mean = Pr x Pw	Min	Max	SD
D	5	19.23	24.44	**42.4**	5	50	12.1
R	4	15.38	10.32	17.9	4	40	11.8
A	3	11.54	12.74	22.1	9	24	4.5
S	5	19.23	22.77	**39.5**	10	50	12.9
T	3	11.54	6.92	12	3	30	6.2
I	4	15.38	15.79	27.4	12	32	7.4
C	2	7.69	7.03	12.2	2	20	4.2
Total	**26**	**100**	**100.00**	**173.5**	**45**	**246**	

Figure 5.14 shows comparison between theoretical weights and effective weight of the seven hydraulic parameters. Table 5.9 and figure 5.14 reveal that depth to water and soil layer tend to be the most effective parameters in the vulnerability assessment. They are effective because their mean effective weights, 24.44% and 22.77%, respectively, are higher than their respective theoretical weights. The aquifer media (12.74%) and vadose zone (15.79) also show a slightly higher effective weight compared to its theoretical weight. All other layers (namely; recharge, hydraulic conductivity topography) show lower effective weights when compared with their theoretical weights. This shows the importance of depth to water, soil, vadose zone and aquifer media layers in the drastic model. So it can be useful to get accurate and detailed information on these three specific factors in order to get more confident vulnerable maps for the Gaza strip.

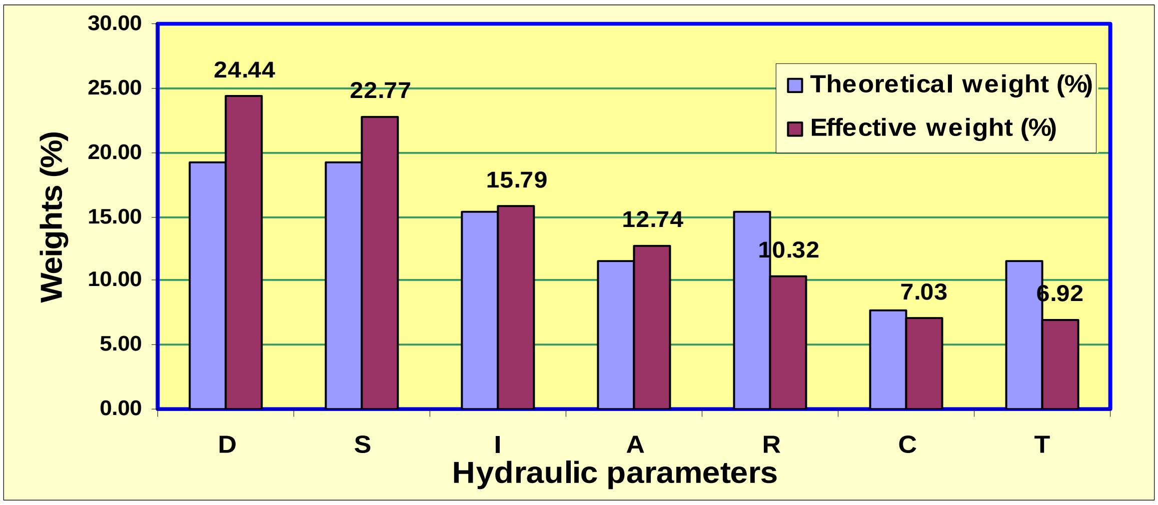


Figure 5.14: Comparison between theoretical and effective weights of the seven hydro-geological parameters

5.3.4 Dominant Parameters Affecting Vulnerability

Sensitivity analysis was performed with the drastic model to check its adaptability to local conditions in Gaza strip. The weights of the factors in the model were changed, while retaining the ratings of the other factors. The depth to groundwater, Soil media, net recharge, and impact to the vadose zone, which are assigned highest weight scores in the generic model were changed to minimum value of 1, each at a time. The same application is repeated for the other three factors just for checking. The drastic indices were then recalculated to obtain seven sets of results, which were used to generate maps of the different sensitivity analysis as per table 5.10 and figure 5.15. The results are shown in figures 5.16 to figure 5.23. The results of the sensitivity analysis reveal that all the four factors severely affect the zones of the vulnerability in Gaza aquifer. It should be indicated that figure 5.16 is adapted from figure 5.1, to facilitate comparison process among all sequent figures.

Table 5.10: Comparison of vulnerability index using the generic model and vulnerability index when setting the weight of one parameter to its minimum value of one.

Vulnerability Index (V')	Min	Max	Mean	Difference	SD
Generic model	**89**	**231**	**173.4**	**0**	**21.1**
Dw = 1	69	191	**139.4**	34.0	18.7
Sw = 1	81	192	**141.8**	31.6	19.8
Rw = 1	80	207	**153.0**	20.4	19.5
Aw = 1	83	215	**158.5**	14.9	19.9
Iw = 1	77	201	**160.0**	13.4	19.4
Tw = 1	87	213	**165.4**	8.0	19.8
Cw = 1	82	227	**167.0**	6.4	21.9

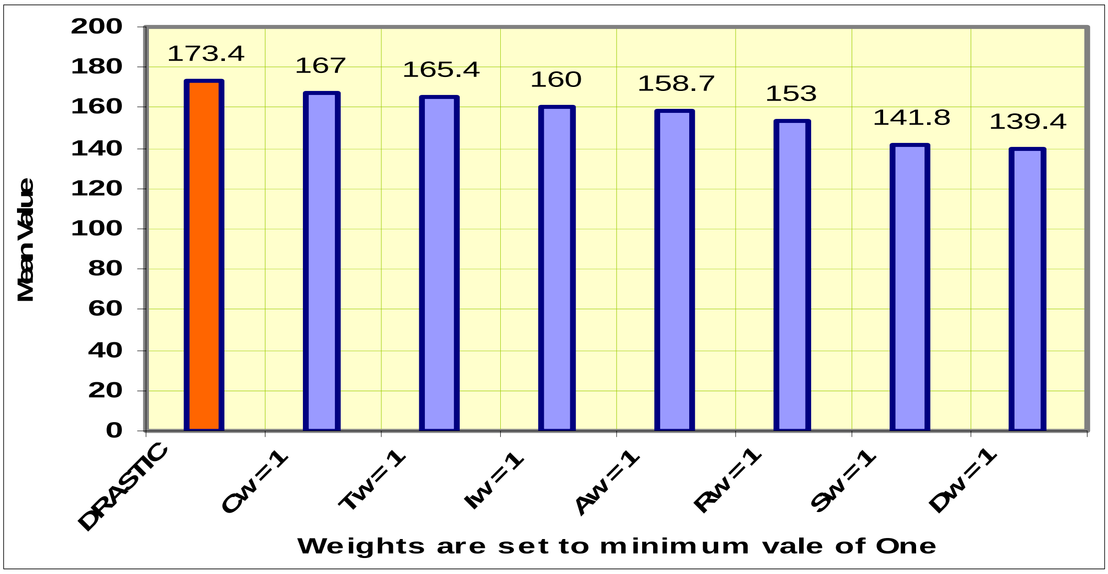


Figure 5.15: Sensitivity analysis where the weight of parameter is set to value of one each time of testing

Of the seven factors tested, as shown by table 5.10, the mean value of depth to ground water, showed to have the most influence to the drastic index. Consequently, depth to groundwater is the most important parameter in the drastic model to fit local conditions in Gaza strip. Out of the seven factors tested the mean value of hydraulic conductivity, showed to have the least influence to the drastic index. Net recharge factor (weight = 4) seems to have more influence to the drastic index than vadose zone (weight = 4). Moreover from figure 5.15, the aquifer media, (weight = 3) seems to have more influence to the drastic index than vadose zone (weight = 4).

From figure 5.16 to figure 5.23:

1. Depth to groundwater factor is the most important parameter in the drastic index computation. As when depth to water table, D_w is set one, the mean value of drastic index decreases from 173.4 to 139.4. So most of Gaza strip except for north area and part of Gaza will be under moderate and low vulnerability.

2. Figure 5.17 is a clear indicator that the water table is very deep. This is due to overexploiting imposed by both municipal and individual pumping.

3. Soil media reduces the mean value of vulnerability to 141.8 similar to depth factor. Both parameters have been assigned the same weight which is the maximum imposed by drastic model.

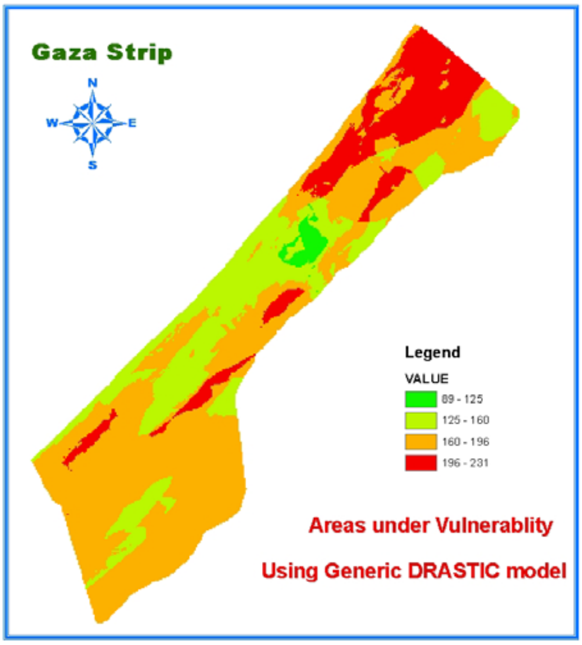


Figure 5.16: Vulnerability map for Gaza strip

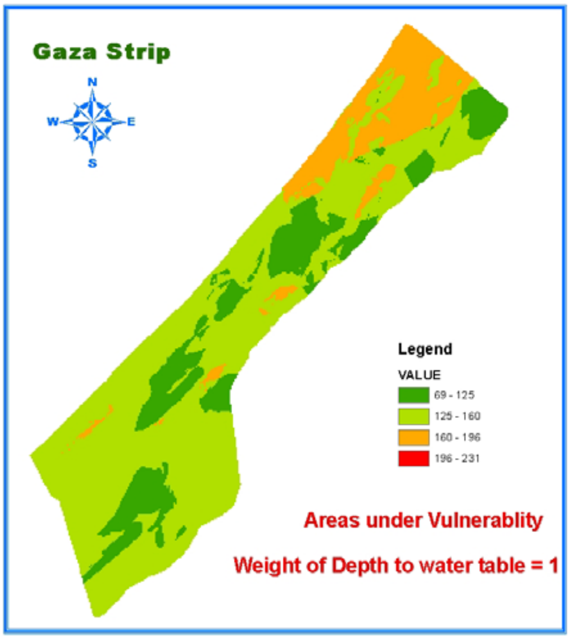


Figure 5.17: Sensitivity Analysis $D_w = 1$

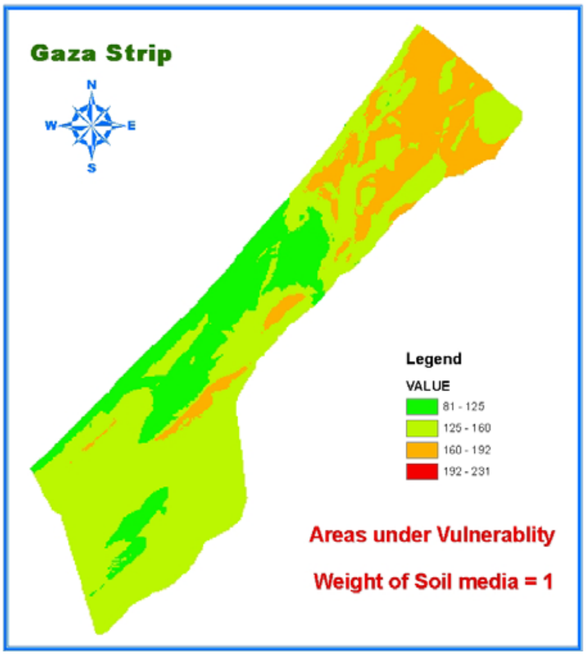


Figure 5. 18: Sensitivity Analysis $S_w = 1$

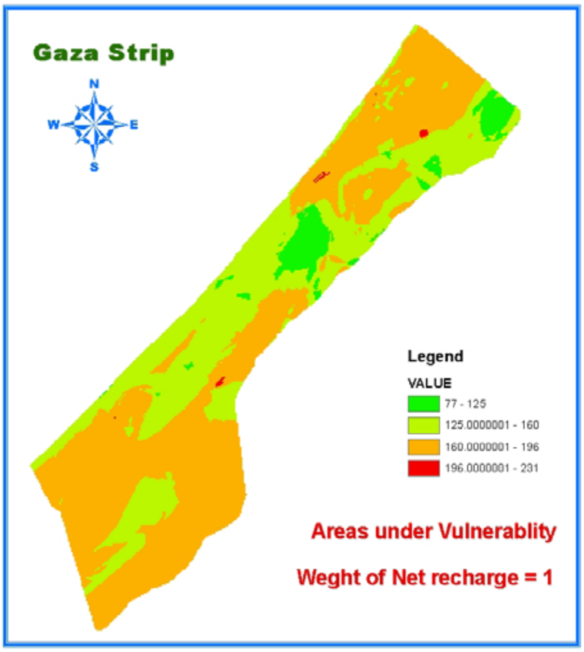


Figure 5.19: Sensitivity Analysis $R_w = 1$

4. Net recharge, as per figure 5.19, reduces the mean value of vulnerability to 153.0 the distribution of drastic index in south became similar to north; the middle area has minimum effect. Comparing figure 5.19 with figure 5.16 reveal the important of net recharge factor in the north Gaza strip.

5. The vadose zone and the aquifer media have similar effect on drastic index in north and south areas with more effect of vadose zone in north area.

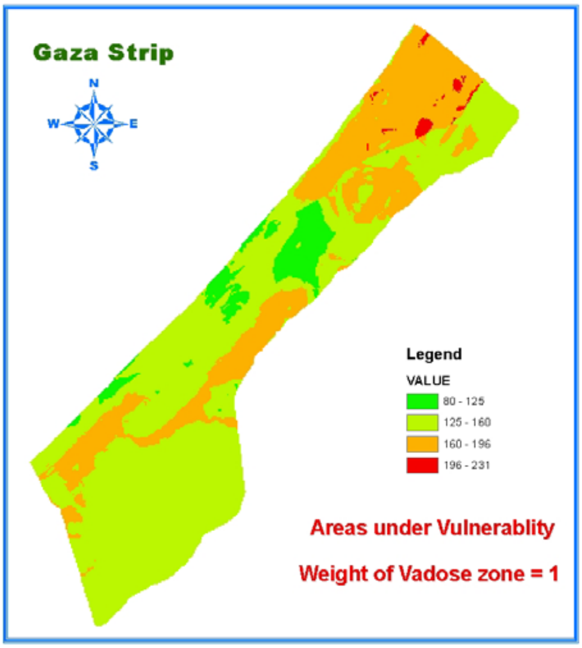


Figure 5.20: Sensitivity Analysis $I_w = 1$

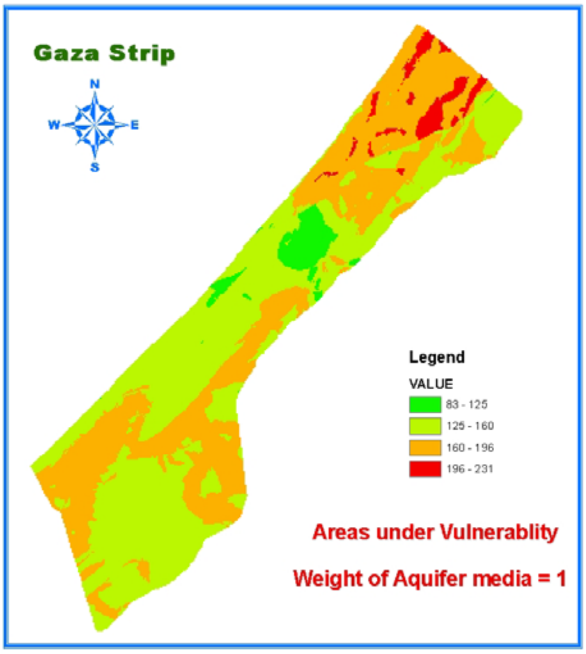


Figure 5.21: Sensitivity Analysis $A_w = 1$

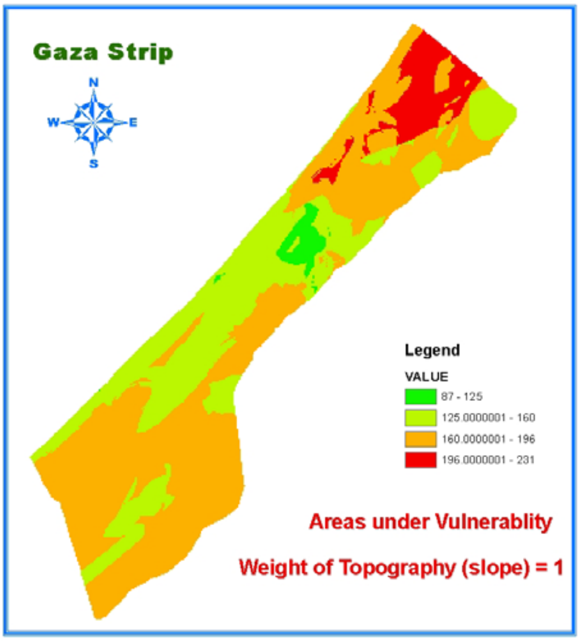


Figure 5.22: Sensitivity Analysis $T_w = 1$

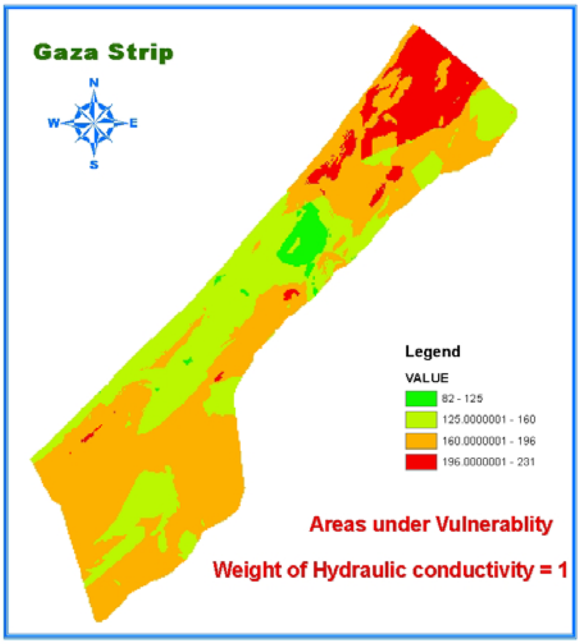


Figure 5.23: Sensitivity Analysis $C_w = 1$

6. In all cases, the costal aquifer become less vulnerable for all figures as the assigned weight is set to minimum value (one).

7. Figure 5.22 & 5.23 reveal that the effect of both slope of topography and hydraulic conductivity is the least compared to the effect of other factors. Moreover, the schematic distribution of vulnerability index still similar to figure 5.16.

CHAPTER 6

Conclusion and Recommendations

6.1 Conclusion

The conclusion of this research can be categorized into three main lines: first; pesticides issue, second; GIS based drastic model, third; availability of data.

6.1.1 Pesticides

1. Quantities

- It was found that the annul amount of pesticide imported to Gaza since 1996 up to now is about 500 tons. These amounts are improperly used in vulnerable areas in the Gaza strip.

- The annual amount of dirty pesticides and fertilizers imported to Gaza is about 435 tons. But the amount of imported pesticides is decreasing during the last three years, based on MoA records.

2. Dirty pesticides

- Some dirty pesticides were blocked by the MoA since 2005, so their names are not found in the MoA records.

- Nobody can guarantee the non availability of dirty pesticides between farmers' hands in Gaza strip. Some pesticides can pass to Gaza in different ways!. The absence of monitoring approach causes difficulties in defining areas violating regulations.

6.1.2 GIS-bases DRASTIC model

1. Percentage of vulnerability

- According to results of GIS-based drastic index model, 73% of Gaza strip's aquifer is found under high or/ and severe vulnerability to pesticides contamination. One fourth of Gaza strip's aquifer is found under moderate vulnerability. Only 2% of Gaza strip area is under low vulnerability. The most vulnerable area is north of Gaza strip and parts of Gaza city. On the other hand middle area is under moderate or low vulnerability.

2. Areas of high vulnerability
   - Comparing between pesticides contamination and chloride and nitrate contamination being concentrated at south and north areas, it seems that areas found vulnerable to pesticides are found under high level of chloride and nitrate pollution.

3. Calibration of Model
   - This study is only theoretical, with no site sampling, no laboratory tests due to current blockade of Gaza strip. No way to transfer samples outside Gaza for testing. No way to have pesticides tests in-house.

   - There is no monitoring system for groundwater contamination to pesticides such as other inorganic materials such as chlorides, nitrates, total dissolved solids, etc. consequently, no historical data at any well to follow up the dissemination of organic contaminants in the aquifer. The author has no options, but to calibrate the model using the existing data set adopted by both CAMP, 2000 and Shomar, 2006 Studies.

   - Pesticides were detected by both CAMP and Shomar studies in wells located in areas under high and very high vulnerability to pesticides.

4. Plastic/green agricultural houses
   - Due to large areas categorized under high vulnerability, based on the model's result, most plastic agricultural houses are located in sensitive areas, specially, near coast and in north areas. Inside and near plastic houses the pesticide pored to groundwater is expected to be excessive.

5. Waste water sites
   - All waste water treatment sites are located in high vulnerable areas. This may threaten the Gaza aquifer if the mitigation measures are not restrict and sharp

6. Population density
   - The areas of population density specially, in Jabalia and Gaza city are under severe or high vulnerability to pesticides contamination. In south Gaza strip,

definitely in Khan younis and Rafah, the most popular area are found under high vulnerability. The households may pore pesticides to the surface in considerable quantities. This action can severely, affect the Gaza aquifer.

6.1.3 Availability of Data

1. The lack of proper organizational frame work adds more difficulties and constrains on obtaining even very normal data. It depends on the person entitled there, if he has motivation or individual research, then he has the updated data. But no one will update thereafter.

2. Lack of unified electronic shape files for vadose zone and aquifer media, add uncertainty to output data.

3. Regarding pesticides data, there is no active and live database for the pest management and pest distribution at any sections in the concerned authorities. So you do not know where to go and who to contact to study and issue related to pesticides.

4. Even though, there are a pesticides testing laboratories at the custodian of MoA, no proper, even irregular, tests are done in the Gaza strip. It seems very difficult to implement the routine maintenance for the existing lab. Consequently, the author found no history for pesticides contamination for any well.

6.2 Recommendations

The recommendation of this study is also, categorized into three main lines, first; pesticides issue, second; GIS-based drastic model, third; availability of data. The following points describes –in brief- the possible recommendations that can enrich and empower the practical approach in monitoring groundwater contamination to pesticides.

6.2.1 Pesticides

1. It would be grateful to have a thermal on-line Palestinian database for pesticides, where users, researchers, and decision makers can refer for any needed information with regard to all technical issues about pesticides in Gaza strip. The database must include lists for dirty pesticides, instructions and advises for those dealing or exposed to pesticides.

2. Give pesticides a priority in Gaza strip. The first step is to rehabilitate the existing pesticides testing laboratory if possible, or exert more efforts to establish a reliable in-house organic laboratory in order to get the proper pesticides analysis to enable a holistic integrated pest management..

3. It would be appreciated if the concerned pesticides stakeholders can have several awareness activities for Integrated Pest management among the farmers and monitoring staff. Moreover, to disseminate advises and instructions for customer and those exposed to pesticides how to behave to minimize the impact of un-controlled usage of pesticides.

4. The excessive use of pesticides in plastic agricultures house need more focusing and concentration on the Gaza strip, as if the location of plastic house are located in high vulnerable areas. Consequently, restriction and mitigation measurement can be applied.

5. Land use unit (if not exists, to be established) should be responsible for human activities, to assign suitable vegetation that can affect areas vulnerable to pesticides. The Environmental Impact Assessment (EIA) must be checked by this unit.

6.2.2 GIS-based drastic model

1. In order to have real vulnerability to-pesticides contamination maps, it should be supported by on site sampling for assigned number of domestic, industrial and agricultural well spatially distributed to cover all Gaza strip area. So it is highly recommended to start this monitoring project soon.

2. It is highly recommended that the validated vulnerability to-pesticides maps can be available on-line within the thermal database of pesticides, for all concerned specially those working in agriculture field.

3. The sensitivity of Gaza aquifer to organic contamination required more efforts and researches on periodic approaches to follow up the dissemination of pollution in the Gaza aquifer. This will required a well organized monitoring system that has recognized monitoring wells with regular tests and history for the levels and types of pesticides in Gaza strip. This task can be given to special unit followed to MoA.

4. Wastewater treatment sites and solid waste landfill sites to avoid the leaching of organic pollution to groundwater.

5. More study exploring the correlation between pesticides and arising level of chlorides in Gaza aquifer.

6.2.3 Availability of data

1. Cover the gap in hydro-geological data, so any missing data has to be filled properly by the concerned staff, even though; the political situation has its offensive impact on.

2. Recheck and update the validation of existing hydro-geologic data.

3. Facilitate the access to existing data and information among all researches and scientists, through systemizing these data to enable the proper analysis and future studies.

6.3 Complementary Studies

One statement, just before coming to the end, the author is introducing the following subjects for those interested in studying the impact of organic pollutants and their dissemination to groundwater in Gaza strip:

1. Correlation between the arising level of chlorides and pesticides in Gaza aquifer.
2. The impact of plastic agriculture houses on the pesticides contamination to Gaza aquifer
3. Vadose zone exploration model.
4. Vulnerability of some pesticides to contaminate Gaza aquifer.
5. Thermal on-line pesticides database, this could be with coordination with Information Technology unit.
6. Monitoring system for Gaza aquifer contamination to pesticides.
7. Pesticides Risk and hazard on Gaza aquifer.

End

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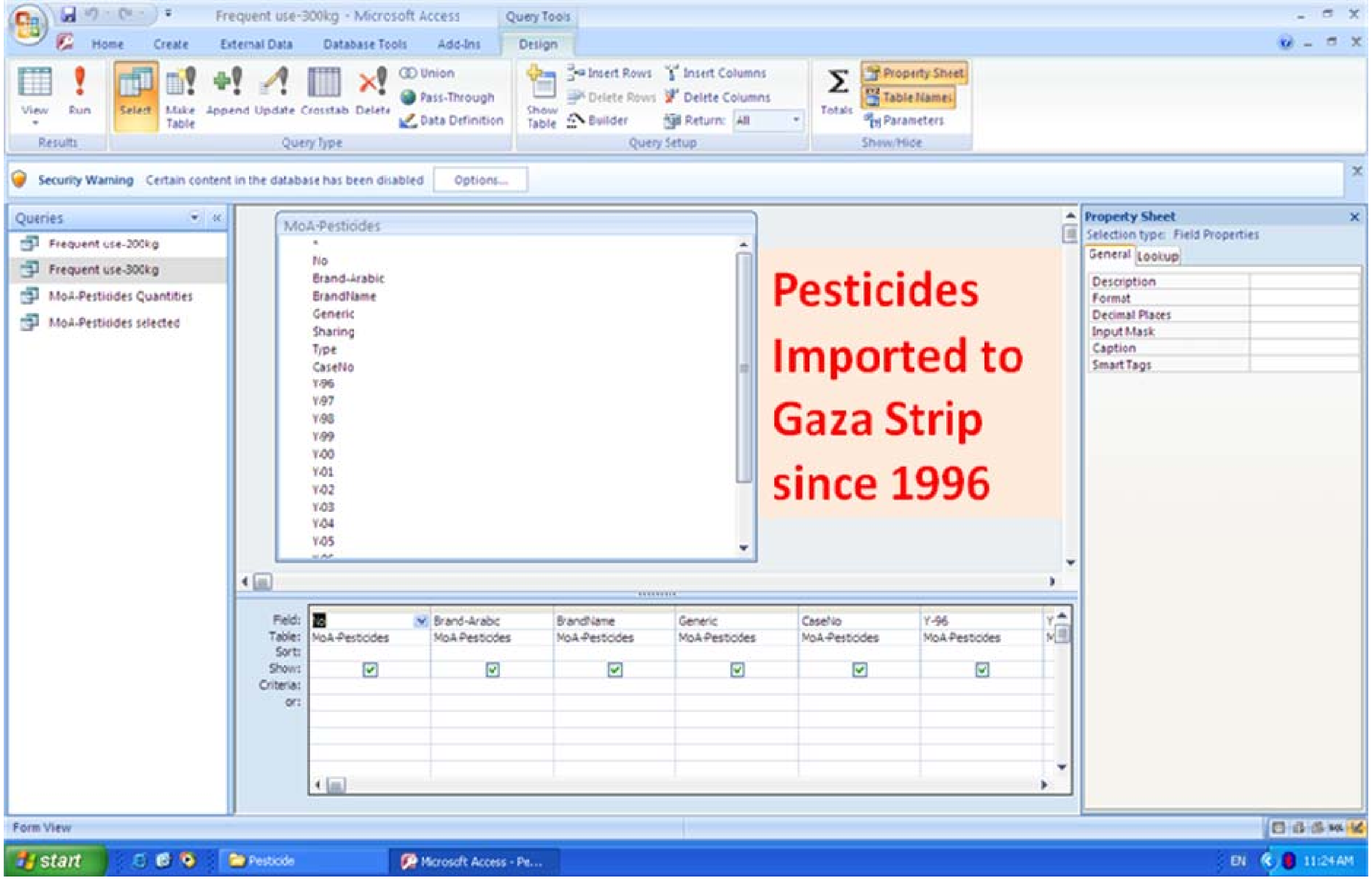
Appendices

Appendix – A ***Amounts of Pesticides and Fertilizers (ton) Imported to Gaza per Year since 1996***



18-Apr-09

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
1- Insecticides																
1	Abamectin	Vertemic- Romactin- Vertigo	فيرتميك - رومكتين-فرتيجو	326	150	310	420	750	320	300	2,480	3,030	1,340	100	1,800	944
2	Acetamiprid	Mosblan	موسبلان	0	438	168	1,512	20	0	400	0	50	164	20	20	233
3	Aluminum phosphide	Phostoxin	فوستوكسين	30	100	0	0	0	0	0	0	0	0	0	0	11
4	Amitraz	Mitac	ماتيك	1,500	1,000	980	1,000	0	0	200	408	2,112	0	0	0	600
5	Azinphos_methyl	Cotnion	قطنيون	7,604	3,920	6,800	2,960	2,000	1,750	1,500	2,500	4,640	0	0	2,250	2,994
6	Azocyclotin	Peropal	بروبال	600	750	300	1,350	200	600	1,250	600	1,650	740	4,850	1,400	1,191
7	Bendiocarb	Necar - Nakar	نيكار - نقار	540	856	1,500	400	300	200	0	800	620	0	0	0	435
8	Bifenazate	Florameit	فلورمايت	0	0	0	0	0	0	0	50	100	0	880	0	86
9	Bifenthrin	Talstar	تالستار	140	250	0	0	0	0	0	0	0	0	0	0	33
10	Bromopropylate	Neoron	نيرون	1,200	780	350	1,000	1,300	1,020	800	1,660	2,460	3,500	4,400	2,000	1,706
11	Buprofezin	Oplord	أبلورد	0	0	48	250	0	0	60	0	0	0	0	0	30
12	Byriproxfen	kobra	كبرا	0	0	0	0	0	0	0	0	0	0	0	600	50
13	Carbaryl	sevin	سفين	700	1,000	0	0	0	0	0	0	0	0	0	0	142
14	Carbosulfan	Marshal	مارشال	6,450	2,802	3,100	4,520	900	2,040	2,100	4,580	7,040	120	0	0	2,804
15	Chlorfenapyr	Forate- perate	فوريت- بيريت	0	67	150	0	60	0	0	100	200	0	0	0	48
16	Chlorfluazuron	Attabron	أتبرون	1,104	3,144	1,600	2,297	960	1,500	1,854	0	3,590	2,170	6,740	0	2,080
17	Chlorpyrifos	Pyrinex- Dursban- Dorsan- Drops	بيرنكس - دورسبان - دورسان- دروبس]	7,590	12,511	9,500	19,800	2,720	1,100	6,814	13,904	9,620	4,400	0	4,800	7,730
18	Cyfluthrin	Baythroid	باثيروئيد	0	600	500	1,000	500	600	1,100	1,000	1,100	400	150	0	579

Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
19 Cyhexatin	Acritel-Lintex-Balyctran	لنتكس - أكرتيل- بلكتران	630	3,440	2,844	15,720	1,144	9,400	450	600	4,500	0	0	0	3,227
20 Cypermethrin	Tarseeb-Ceparin-Titan-Symbush-Sherpaz-Cmshofr	ترسيب - سيبرين - تيتان - شرباز -سمبوش- سيموشوبر	9,465	13,439	13,000	10,656	9,748	1,600	4,710	13,560	6,580	3,050	0	3,710	7,460
21 Cyromazine	Trigard	تريجارد	0	300	0	20	120	50	0	0	0	0	0	0	41
22 Deltamethrin	Decis	ديسيس	0	0	50	0	0	0	0	0	0	0	0	0	4
23 Diafenthiuron	Pegasus	بجاسوس - بسيس	40	0	10	50	0	0	0	408	2,012	350	0	0	239
24 Diazinon	Dizictol	ديزكتول	160	700	450	0	200	0	300	0	500	80	0	0	199
25 Dichlorvos	Divipan-Dybs	ديفيبان-ديبس	1,113	780	1,250	200	600	200	836	1,620	1,438	1,020	0	2,100	930
26 Dicofol	Acareen	أكارين	0	0	300	0	0	0	0	0	0	0	0	0	25
27 Dicofol + Tetradifon	Mition Combi-Mesholaf	ميثيون- موشلاف	500	0	300	0	0	200	0	0	0	0	0	0	83
28 Dimethoate	Dimethoate-Rogor-Poligor	- ثويت دايمو روجر -بوليكور- روجر تكس	3,444	5,120	5,304	15,800	6,144	7,504	1,052	3,604	9,340	3,820	0	4,850	5,499
29 Endosulfan	Endol-Thiodan-Thionex-Thiodol- Holidon	ثيودان - إندول - ثيونكس- ثيودول-هليودان	16,924	16,534	10,435	19,596	5,516	7,875	5,250	6,100	0	0	0	0	7,353
30 Ethalcluraline	Sonelan	سونيلان	0	0	0	0	0 0	0	0	300	0	0	0	0	25
31 Ethaxozol	Spidar	سبيدار	0	0	0	0	0	0	0	0	0	300	0	0	2532
Etofenprox	sensor	سنسور	260	0	0	0	0	0	0	0	0	0	0	0	22
33 Fenazaquin	Magestar	ماجستر	96	992	500	50	0	0	200	120	50	530	0	0	212
34 Fenbutatin Oxide	Akrimaite	اكريميت	0	0	0	0	0	200	0	0	0	0	0	0	17
35 Fenpropathrin	Smash	سمش	8,210	11,766	4,000	11,320	2,000	1,200	5,400	2,800	720	0	0	0	3,951

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
36	Fenpyroximate	Meteor	ميتيور - ميتاسبور	200	200	15	50	0	0	0	0	0	0	0	0	39
37	Fenthion	Lebaycide	ليباسيد	0	120	0	0	0	0	0	0	0	0	0	0	10
38	Fenvalerate	Mustang	موستانج	2,300	0	0	0	0	0	0	0	0	0	0	0	192
39	Fluvalinate	Mavrik	مافريك	60	0	0	0	0	0	0	0	0	0	0	0	5
40	Hexaflumuron	Consult	كونسلت	234	0	200	1,048	0	0	0	0	200	0	0	0	140
41	Imidacloprid	Confidor	كونفيدور	180	1,185	1,280	800	370	100	200	300	540	3,700	2,010	1,900	1,047
42	Isofenphos	Oftanol	أفتانول	600	165	440	0	0	0	200	0	200	0	0	0	134
43	Lambda Cybalothrin	Karate	كراتيه	1,100	576	1,012	800	0	0	0	0	0	0	0	0	291
44	Lufenuron	Match	ماتش	0	0	200	0	0	0	0	250	1,000	950	1,200	0	300
45	Malathion	Malathion	ملاثيون	6,000	14,250	9,200	15,000	23,200	0	10,000	10,000	3,620	1,300	600	0	7,764
46	Methamidophos	Prodex - Tamaron- Protar- Maraton- Methopaz	بردوكس- بروتار-تمارون- مارتون - ميتوباز	16,515	24,053	24,300	17,620	12,800	3,500	5,420	18,320	4,060	5,780	0	0	11,031
47	Methidathion	Superthion	سوبر ثيون	0	0	1,000	0	0	0	0	0	1,500	40	0	0	212
48	Methomyl	Lannate- Methomex- Rostop	لانيت - ميثومكس- رستوب	1,489	3,200	1,400	0	1,400	870	800	0	2,000	0	0	0	930
49	Methoxyfenozide	Runner	رنر	0	0	0	0	0	0	0	0	500	0	350	0	71
50	Monocrotophos	Monocron	مونكرون	0	0	0	500	0	500	0	0	0	0	0	0	83
51	Novaluron	Rimen	ريمون	0	0	500	0	0	150	0	1,300	0	2,000	0	0	329
52	Oxamyl	Vydate	فايدت	0	0	0	60	0	2,725	1,800	1,200	3,430	0	0	0	768
53	Oxmatrine +prouler	King Bu	كنج بو	0	0	0	0	0	0	0	0	0	100	0	0	8
54	Oxydemeton Methyl	Metasystox	ميتاسيستوكس	200	1,899	1,100	0	600	0	700	500	560	0	0	0	463

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
55	Permethrin	Permethrin	بيرمترين	0	250	0	0	0	0	0	0	0	0	0	0	21
56	Phosphamidon	Dimecron	ديمكرون	0	0	50	0	0	0	0	0	0	0	0	0	4
57	Pirimicarb	Pirimor	بريمور	0	200	0	0	0	0	0	0	0	0	0	0	17
58	Summar Oil	Levanola-Virotar-Vitol-Livotile-Sanot-Fulic oil-Virol oil	-فيروتار-ليفانول - سانوت-فيتول -الفولك زيت ليفوتيلا-فرول	0	2,500	5,500	9,500	0	30,000	0	200	3,000	0	7,500	500	4,892
59	Tebufenpyrad	Masy	مساي	0	0	0	0	0	0	0	50	50	350	0	0	38
60	Teflubenzuron	Molit	موليت	0	0	0	0	0	0	0	500	0	900	0	0	117
61	Thiacloprid	Kalbsio	كالبسيو	0	0	0	0	0	0	0	0	0	0	50	0	4
62	Thiocyclam-hydrogenoxalate	Evisect(s)	إفسكت	470	2,200	1,020	2,400	300	380	2,000	1,450	2,830	2,050	4,020	300	1,618
63	Trichlorfon	Danex	دانكس	50	0	0	0	0	0	0	0	0	0	0	0	4
Total amount (kg) of		**Insecticides**	**=**	***98,024***	***132,237***	***110,966***	***157,699***	***73,852***	***75,584***	***55,696***	***90,964***	***85,142***	***39,154***	***32,870***	***26,230***	***81,535***

2- Fungicides

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
64	Azoxystrobin	Amistar	عمستيار	0	0	0	0	0	0	0	80	50	0	0	0	11
65	Benalaxyl +Copper oxychloride	Galben Copper	جالبين نحوشت	0	0	0	500	300	500	0	200	0	0	0	0	125
66	Benomyl	Benlate	بنلت	350	830	5,300	1,630	500	2,080	2,600	4,140	100	0	0	0	1,461
67	Bromuconazole	Vectra	فكترا	204	330	1,008	780	100	108	200	0	500	0	120	0	279
68	Bupirimate	Nenrod	نمرود	0	0	0	0	0	0	0	0	0	400	0	0	33
69	Calcium polysulphide	Californi Mixture	مرق كليفورني	0	0	0	100	150	150	0	0	0	0	0	0	33
70	Carbenbendazim	Resec-Delsene 50 Bavistin-	- ريسك - 50دلسان بفستين	320	1,580	396	500	1,150	300	1,600	2,475	2,700	2,300	7,200	1,400	1,827

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
71	Chinomethionate	Morestan	مورستان	160	900	105	0	0	0	0	0	0	0	0	0	97
72	Chlorothalonil	Bravo _ Daconil	داكونيل - برافو	1,150	1,575	1,850	2,948	500	200	500	400	1,240	500	0	0	905
73	Coper hydroxide+ Mefenoxam	Rodomil Nahoshat	ردوميل نحوشت	0	0	0	0	0	0	0	0	0	0	0	100	8
74	Copper hydroxide	Phongoran- Cocide101- Parasol- Champion- blushield	كوسايد101 - فونجران- بيروسول- شامبيون-	4,200	7,750	6,700	4,908	4,510	2,350	10,050	2,500	3,210	5,620	14,000	23,600	7,450
75	Copper Oxychloride	Coprox 50- Kobra Intercol	كوبركس50- كبرا انتركول	0	0	1,200	0	1,200	0	0	0	500	2,000	2,900	600	700
76	Copper Sulfate	Copper Sulfate	جنزارة	0	40,000	0	40,000	0	0	0	0	25,000	20,000	4,000	0	10,750
77	Cymoxanil+Mancozeb	Mancur	منكور	210	200	0	300	0	300	0	0	0	0	0	0	84
78	Cyproconazole	Atemi	أتمي	0	0	0	200	0	0	0	0	0	0	0	0	17
79	Cyprodinil + Fludioxonil	Switch	سويتش	0	0	0	0	12	0	0	30	0	0	0	0	4
80	Dichlofluanid+Tebuconazole	Silvacur	سلفاكور	0	310	0	150	0	0	500	0	0	600	0	0	130
81	Difenoconazole	Score	سكور	160	60	500	600	100	210	0	850	800	1,700	1,400	250	553
82	Dimethomorph + Mancozeb	Acrobat	أكروبات	0	0	0	0	0	0	0	650	0	1,300	0	0	163
83	Fenarimol	Rubigan	روبيجان	0	510	0	0	0	2,300	0	0	0	0	0	600	284
84	Fenbuconazole	Indar	إيندار	100	500	400	1,350	168	0	0	0	0	0	0	0	210
85	Flutriafol	Hosan	حوسن	0	200	0	0	168	0	0	0	0	1,000	0	0	114
86	Folpet	Folpan	فولبان	0	1,550	1,060	903	0	0	0	0	1,000	0	0	0	376
87	Fosethyl Aluminium	Aliette	ألييت	250	1,200	0	600	150	0	0	830	1,500	500	0	0	419

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
88	Hexaconazole	Anvil	أنفيل	100	0	50	1,074	1,550	200	0	0	500	1,120	120	0	393
89	Iprodione	Rovral	روفرال	0	350	500	1,500	1,500	450	1,100	350	800	300	0	0	571
90	Iprovalicarb + Propineb	Mlody Do	ميلودي دوو	0	0	0	0	0	0	804	0	0	50	0	0	71
91	Kresoxim Methyl	Stroby	ستروبي	0	0	0	0	0	0	500	175	370	0	0	0	87
92	Mancozeb	Manzidan-Mancotel-Mancozan-Mancoday	مانسيدان-مانكوتيل- منكوزان -	22,090	37,255	38,700	34,190	14,101	22,500	11,240	31,250	32,545	9,000	0	0	21,073
93	Mancozeb + mefenoxam	Ridomil	رادوميل	0	150	800	2,350	500	1,100	0	1,300	1,400	1,750	2,400	300	1,004
94	Mancozeb+ Cymoxanil+ Oxadixyl	Sandocur	سندكور	705	3,705	545	5,500	2,500	6,000	1,000	4,200	11,260	100	0	0	2,960
95	Maneb	Manebgan	مانيبجان - مانكس	9,230	9,000	4,230	9,800	4,700	2,025	1,800	3,600	100	0	0	0	3,707
96	Mepanipyrim	Furpica	فروبيكا	0	0	150	0	0	0	0	0	0	0	0	0	13
97	Metiram	Poliram	بوليرام	0	2,000	0	0	0	0	0	0	0	0	0	0	167
98	Myclobutanil	Systhane	سيستان	1,000	160	900	300	200	160	0	1,000	0	2,000	0	0	477
99	Penconazole	Ofir	اوفير-أوفير توباز	880	750	850	1,800	2,500	560	0	1,050	1,840	1,160	3,600	320	1,276
100	Potassium Phosphate	Canon	كانون	0	0	0	300	0	0	0	0	0	0	0	0	25
101	Prochloraz manganese	Octav	أوكتاف	0	500	100	500	0	50	0	50	250	0	0	0	121
102	Prochloraz zinci + folpet	Mirage F	ميراج F	0	50	300	200	0	0	0	0	0	0	0	0	46
103	Propamocarb-Hcl	Dynon-Dotan proplant-Brifecur N	دوتان-داينون -بروبلانط بريفيكور ن	2,500	3,929	3,510	5,340	1,000	1,100	4,600	4,324	10,572	10,696	8,950	4,300	5,068

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
104	Propicnazole	Tilt	تلت	100	0	0	0	0	0	0	0	0	0	0	0	8
105	Propineb	Antracol	أنتراكول	1,500	700	3,800	4,600	4,100	750	5,360	5,650	4,300	900	0	0	2,638
106	Pyrazophos	Afugan	أفوجان	200	1,200	60	1,100	1,000	1,900	0	0	0	0	0	0	455
107	Pyrifenox	Dorado	دورادو	0	0	50	200	200	1,000	0	400	500	0	2,000	0	363
108	Pyrimethanil	Mithos	ميتوس	0	0	0	550	100	0	0	204	1,608	0	0	0	205
109	Quintozone Captan	Mrvan- Merpan	ميرفان-ميربان	1,500	2,200	5,000	3,700	2,000	1,800	1,740	2,000	2,500	0	0	0	1,870
110	Sulphur	Gofrativ-Sulfur-Microttel-Comolus-Halogafrit	كبريت- جفرتيت -90كبريت- -70 كبريت -رطب كبريت ميكروتيل	16,460	32,500	1,000	13,364	6,000	1,000	79,500	43,800	10,000	1,100	0	1,350	17,173
111	Tebuconazole	Folicur	فلكور	0	200	0	50	200	0	0	0	0	100	0	0	46
112	Tetraconazole	Dumerk	دومارك	0	0	0	0	160	100	300	500	1,400	0	0	0	205
113	Thiophanate methyl	Topaz M	(توباز) طوبسين	0	0	0	240	0	0	0	0	0	0	0	0	20
114	Tolclofos_Methyl	Rizolex	ريزوليكس	3,600	2,000	0	5,140	2,700	1,200	0	1,050	80	0	0	200	1,331
115	Tolyfuanid	Multi oparin	أبارين ملتي	0	0	0	0	0	0	0	0	0	40	0	0	3
116	Triadimenol	Bayfidan-Shavit	بايفيدان - شافيط	3,000	2,057	5,810	3,810	1,600	400	520	2,800	3,790	7,580	6,880	1,200	3,287
117	Triadimenol +Quinomethionat	Littril	ليطريل	0	3,454	2,160	0	0	0	0	0	0	0	0	0	468
118	Trifloxystrobin	Flint	فلنت	0	0	0	0	0	0	0	106	0	0	500	0	51
119	Triforine	Saparol	سبرول	0	100	688	0	0	0	0	500	0	0	0	0	107
Total amount (kg) of		**Fungicides**	=	***69,969***	***159,755***	***87,722***	***151,077***	***55,619***	***50,793***	***123,914***	***116,464***	***120,415***	***71,816***	***54,070***	***34,220***	***91,320***

3- Herbicides

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
120	Ametryn + Terbutryne	Omigan	أوميجان	60	100	600	0	0	0	0	0	0	0	0	0	63
121	Bentazone	Basagran	بازجران	300	236	200	0	60	100	0	200	500	0	0	0	133
122	Bromacil	Uragan - Hyvarx	أورجان - هيفراكس	940	0	500	1,300	1,000	100	250	500	0	0	0	0	383
123	Chlorthal dimethyl	Dacthal	دكتال	0	0	200	0	0	0	0	0	0	0	3,800	0	333
124	Clethodim	Select Super	سلكت سوبر	0	0	0	0	0	0	0	200	0	0	0	0	17
125	Cycloxydim	Focus Ultra	فوكس أولترا	0	0	0	0	0	0	60	200	120	300	0	0	57
126	D 2,4-D Iso Octyl Ester	Sanafen Super	سنافين سوبر	0	0	0	2,000	400	1,500	0	0	1,000	0	0	0	408
127	D 2,4-D	Alber Super	البرسوبر	400	300	1,000	0	204	0	120	0	1,620	120	0	650	368
128	Diuron	Diurex	ديوركس	700	1,260	2,500	500	1,500	500	0	0	860	0	0	0	652
129	Fluazifop butyl	Deganol	دجنول	0	1	0	60	160	0	0	0	0	0	0	0	18
130	Glyphosate	Round up-Glyphosate	راوندب- جليفوست	3,140	8,174	4,700	13,000	6,800	3,800	3,700	7,600	2,380	12,650	13,000	13,150	7,675
131	Glyphosate Trimesium	Touchdown	تاتشداون	0	2,480	2,000	2,000	1,900	0	1,880	1,960	2,220	1,300	0	0	1,312
132	Glyphosate, Isopropyl amine Salt	Taifun-Glyphos-Roudphaz	تايفون-جليفوس- راوند فاز	0	5	1,080	300	0	0	2,000	1,000	0	4,000	8,000	1,500	1,490
133	linuron	Linorex	لينوركس	50	300	0	300	500	600	600	0	0	0	0	0	196
134	Metribuzin	Sencor	سنكور	30	1,685	200	100	1,200	200	60	200	380	320	0	0	365
135	Oxadiazon	Ronistar	رونستار	36	0	0	300	0	160	500	500	700	0	0	500	225
136	Oxyfluorfen	Goal	جول	24	262	200	436	36	300	690	450	310	600	0	0	276
137	Paraquat	Docatalon	دوكتالون	1,204	4,838	2,340	1,900	1,400	0	0	150	1,480	550	0	1,000	1,239
138	Pendimethalin	Stomp	ستومب	0	0	0	0	0	0	0	100	0	300	0	0	33
139	Prometryne	Prometrex	برومتركس	0	0	0	1,000	0	100	0	500	0	300	0	2,000	325

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
140	Pyridate	Lentagran	لنتجران	0	0	0	0	0	0	0	150	0	0	0	0	13
141	Simazine	Simazine-Simanex	سيمازين-سمنكس	200	0	0	0	0	0	0	2,400	800	0	0	0	283
142	Terbutryne	Terbutrex	تربيوتركس	0	0	0	1,000	0	0	0	0	0	0	0	0	83
Total amount (kg) of		**Herbicides**	=	***7,084***	***19,641***	***15,520***	***24,196***	***15,160***	***7,360***	***9,860***	***16,110***	***12,370***	***20,440***	***24,800***	***18,800***	***15,945***

4- Nematicides

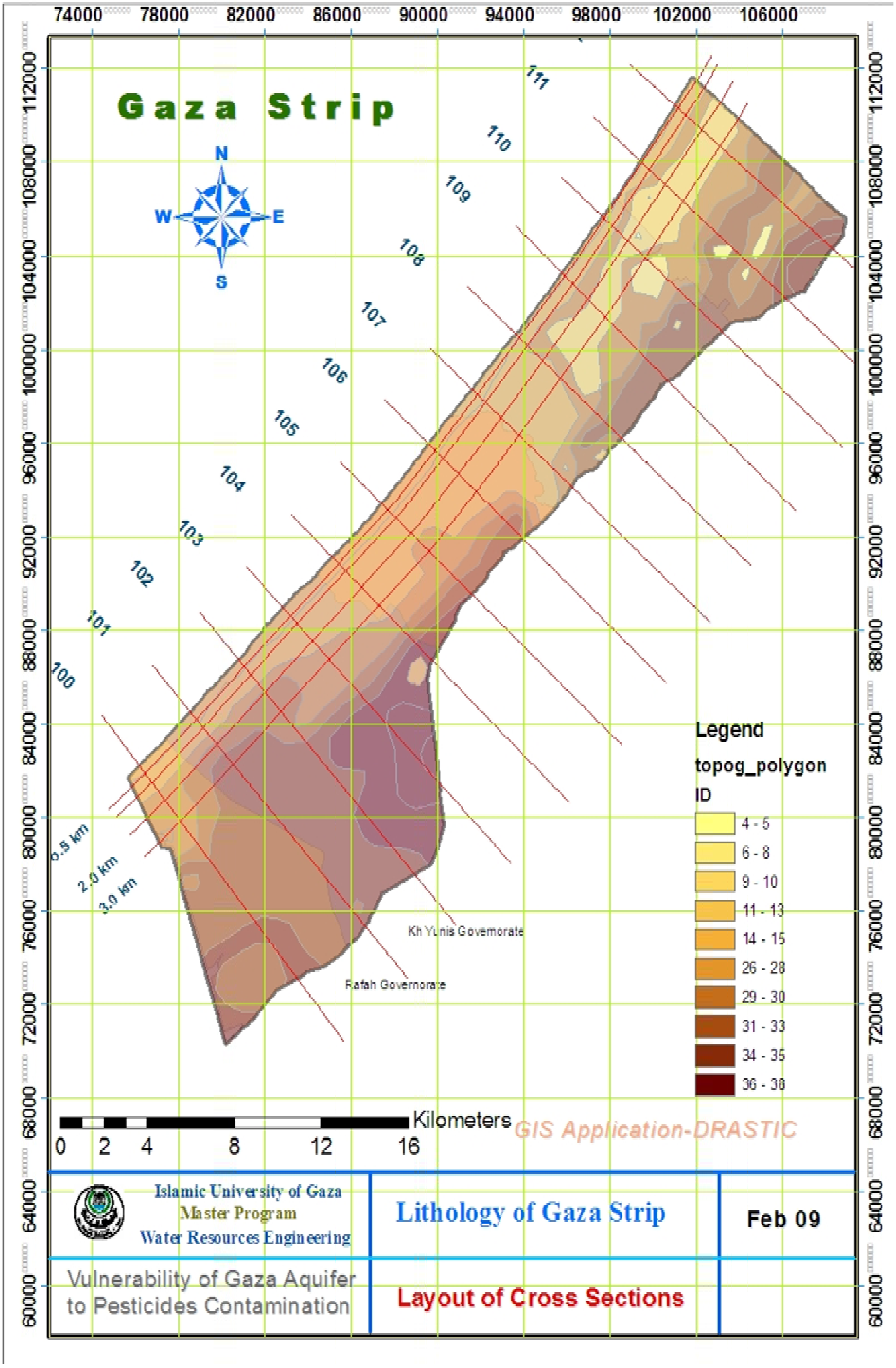
	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
143	Bromadiolone	Ratreem-Ratimon	بلوك رطريم- ريتمون	100	0	1,000	1,000	600	700	1,200	1,800	2,200	680	0	600	823
144	Cadusafos	Rugby	راجبي	700	324	0	980	600	700	500	0	0	0	0	0	317
145	Coumatetralyl	Racumin	روكومين	1,200	600	3,000	2,400	5,500	1,100	1,700	500	1,200	0	0	0	1,433
146	Fenamiphos	Nemacur	نيماكور	9,000	16,400	12,400	31,550	7,200	8,800	33,680	24,970	28,400	14,100	0	7,700	16,183
147	Metaldehyde	Metason-Halizan	ميتازون-حلزات	2,200	2,200	3,500	1,500	10,000	0	3,000	4,500	500	0	0	0	2,283
148	Methiocarb	Mesurol	مسرول	130	817	40	150	200	400	850	840	300	500	0	450	390
149	Sodium Fluoroacetat	Syphsan	سفسان	3,200	11,800	0	8,500	150	2,500	4,500	4,000	4,200	3,500	0	2,000	3,696
Total amount (kg) of		**Nematicides**	=	***16,530***	***32,141***	***19,940***	***46,080***	***24,250***	***14,200***	***45,430***	***36,610***	***36,800***	***18,780***	***0***	***10,750***	***25,126***

5- Sterilant

	Generic	Brand Name	Arabic	Y-96	Y-97	Y-98	Y-99	Y-00	Y-01	Y-02	Y-03	Y-04	Y-05	Y-06	Y-07	AVG (ton)
150	Metham Sodium	Metmor-Adegan	- ميتامور -510ميتامور أديجان	0	2,640	1,000	38,350	14,960	9,000	2,000	29,400	13,200	74,000	16,400	96,000	24,746
151	Methyl Bromide	Methyl Bromide	بروميد الميثيل	0	829,000	602	471,140	522,740	219,240	301,000	107,000	280,000	226,700	95,200	102,200	262,902
Total amount (kg) of		**Sterilant**	=	***0***	***831,640***	***1,602***	***509,490***	***537,700***	***228,240***	***303,000***	***136,400***	***293,200***	***300,700***	***111,600***	***198,200***	***287,648***
Grand Total				***191,607***	***1,175,414***	***235,750***	***888,542***	***706,581***	***376,177***	***537,900***	***396,548***	***547,927***	***450,890***	***223,340***	***288,200***	***501,573***

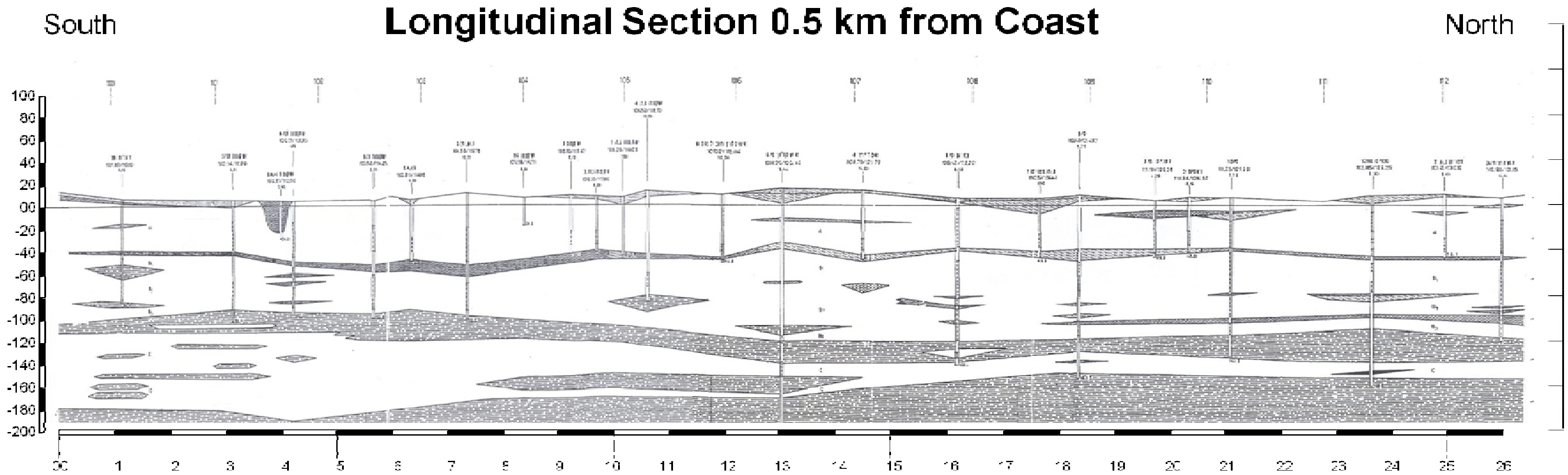
Data has been taken from MOA on 14 Sep 2008

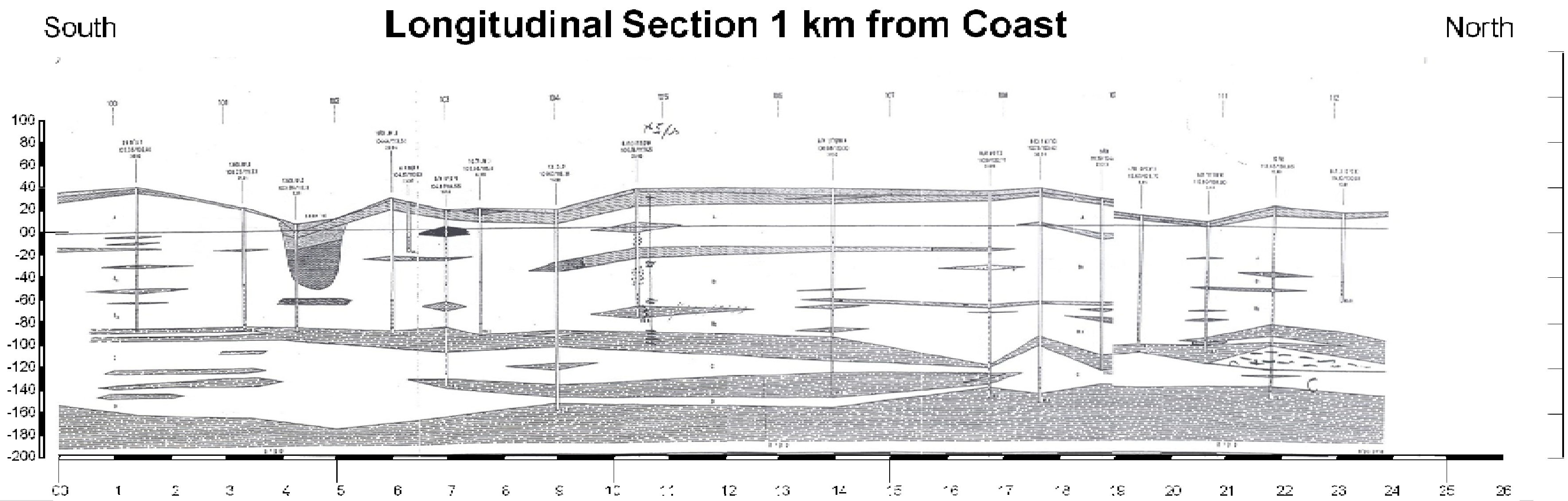
Appendix-B Lithology Cross Sections for Gaza Strip



Lay-out of Lithology Cross Sections for Gaza Strip

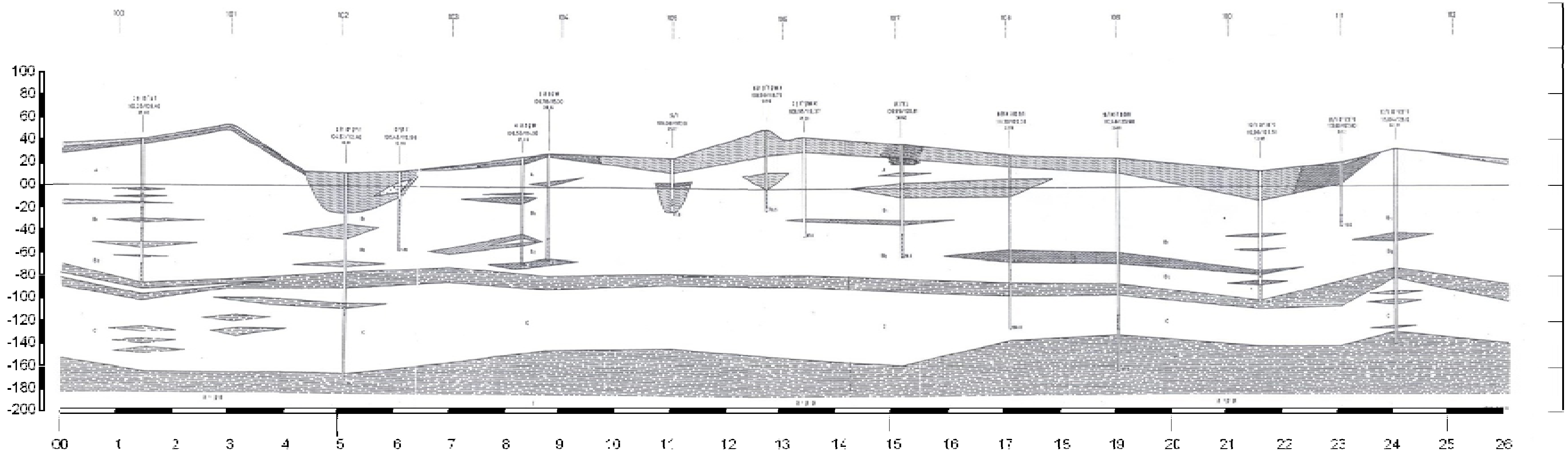
Appendix – B Lithology Cross Sections for Gaza Strip



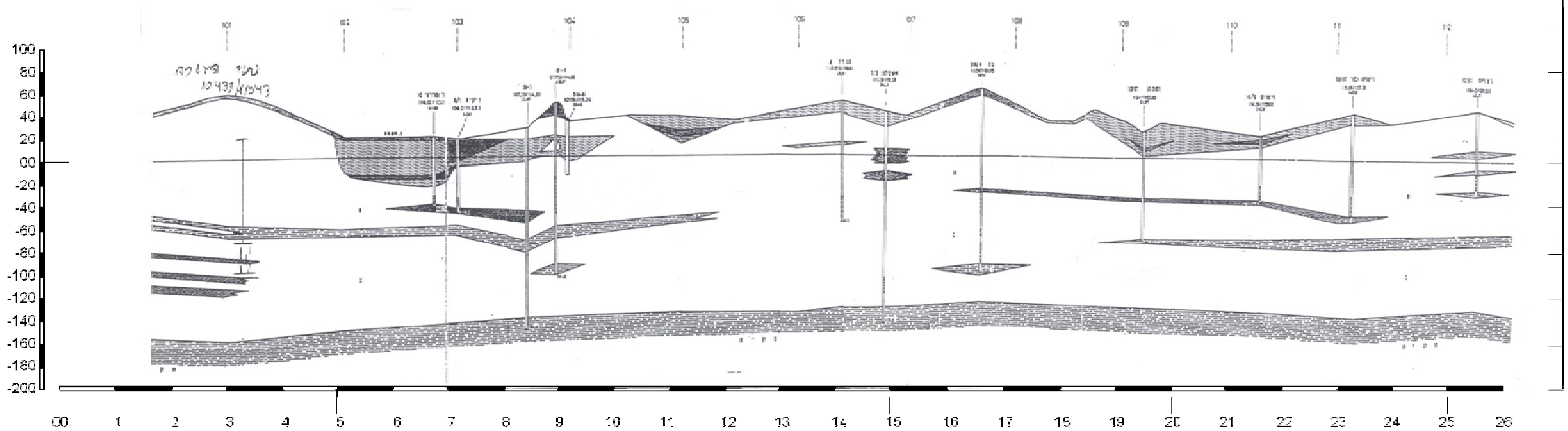


Appendix – B Lithology Cross Sections for Gaza Strip

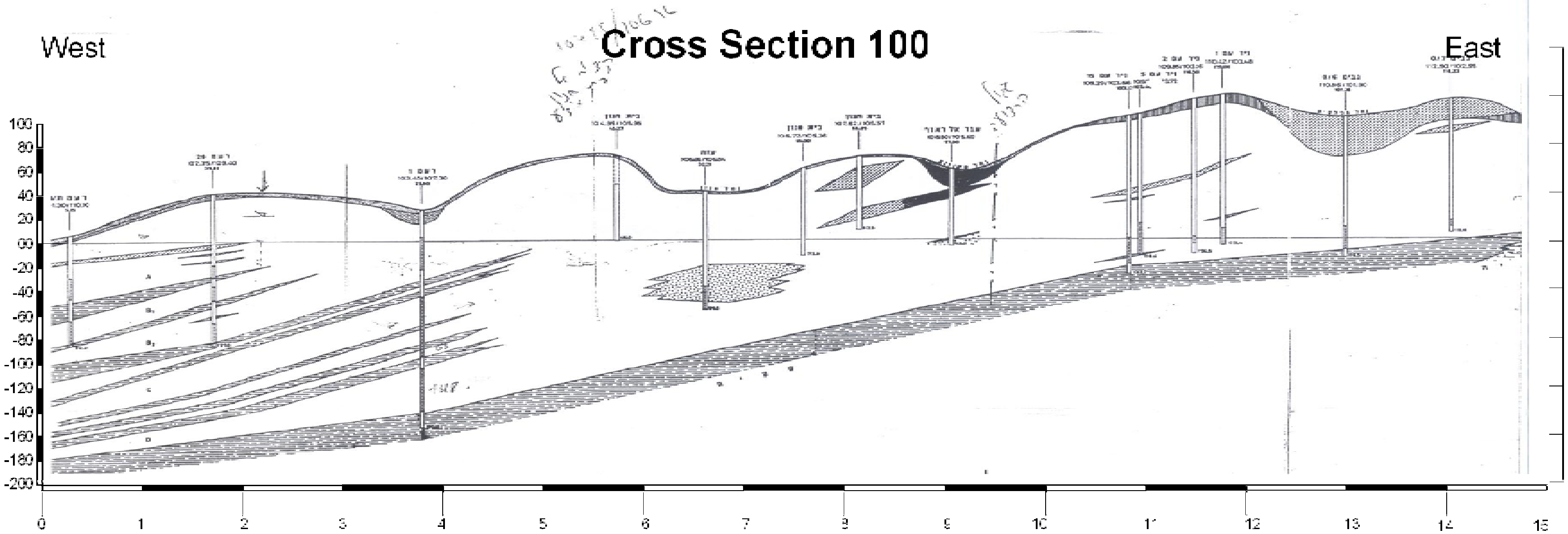
Longitudinal Section 2 km from Coast

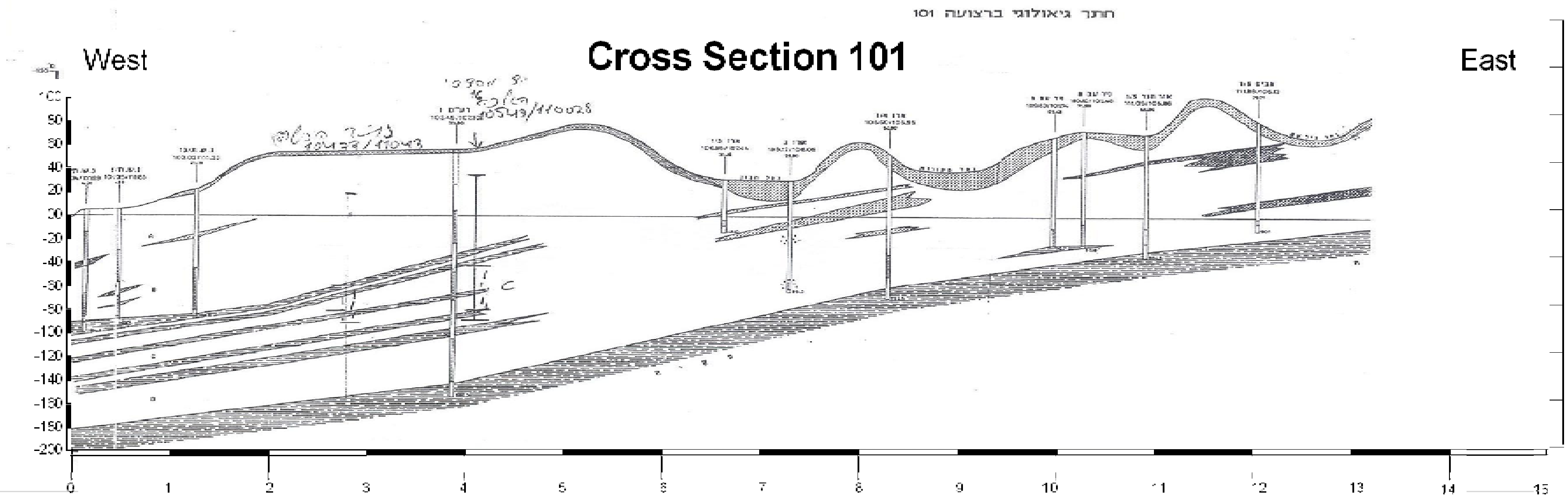


Longitudinal Section 3 km from Coast

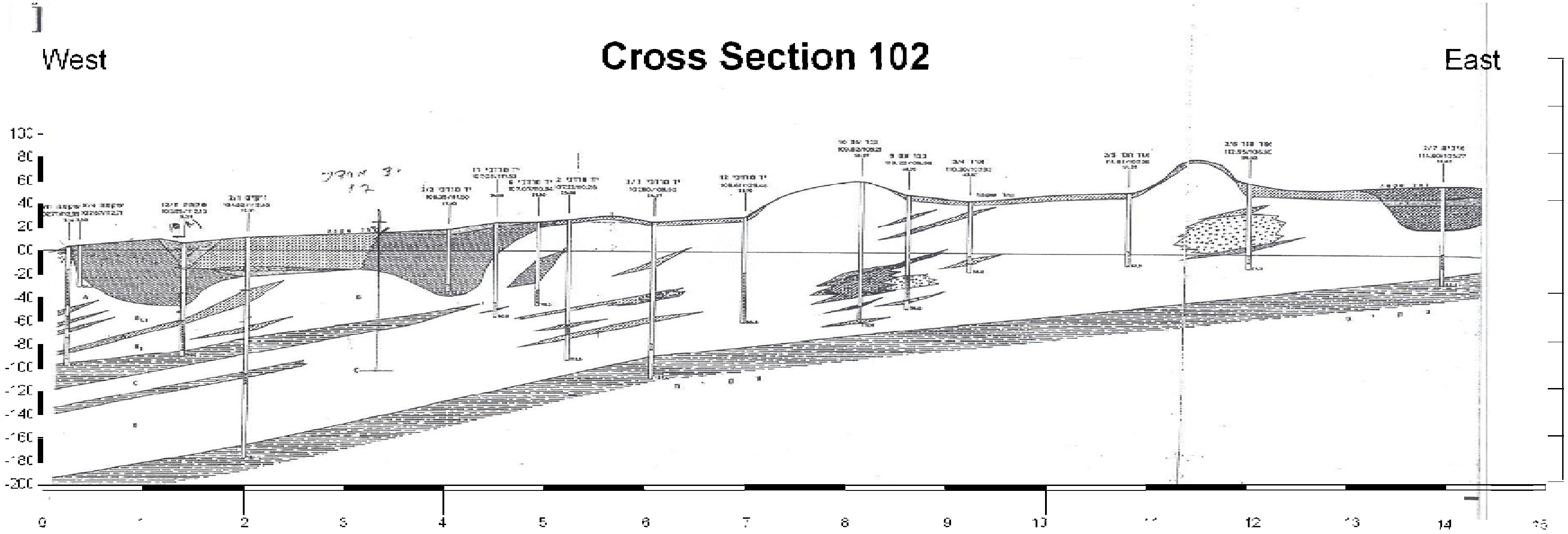


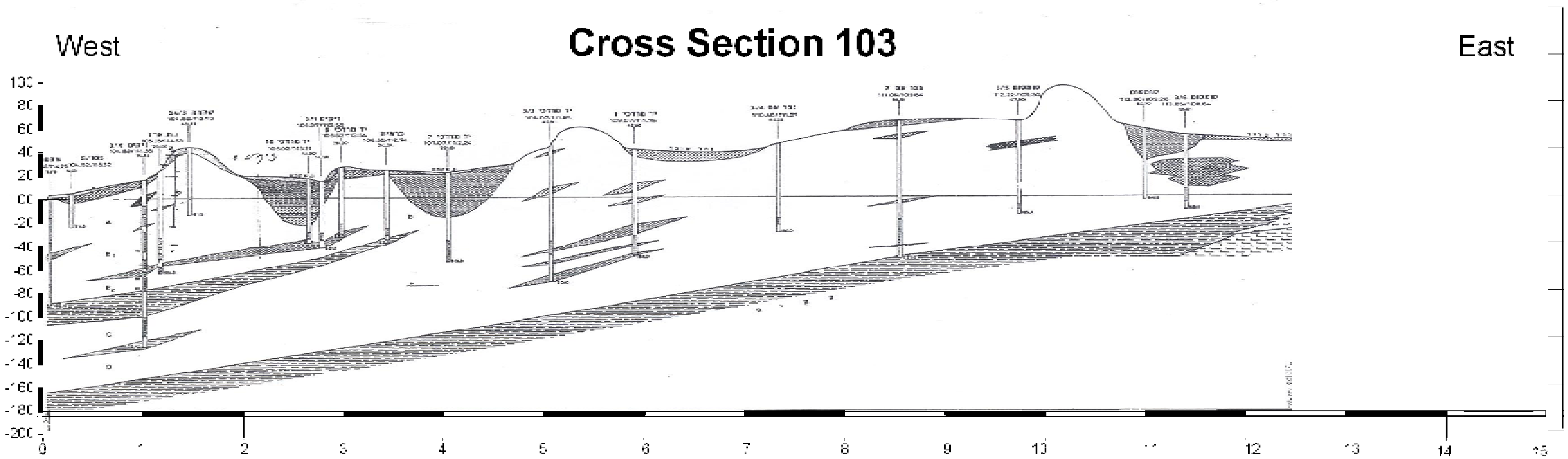
Appendix – B Lithology Cross Sections for Gaza Strip



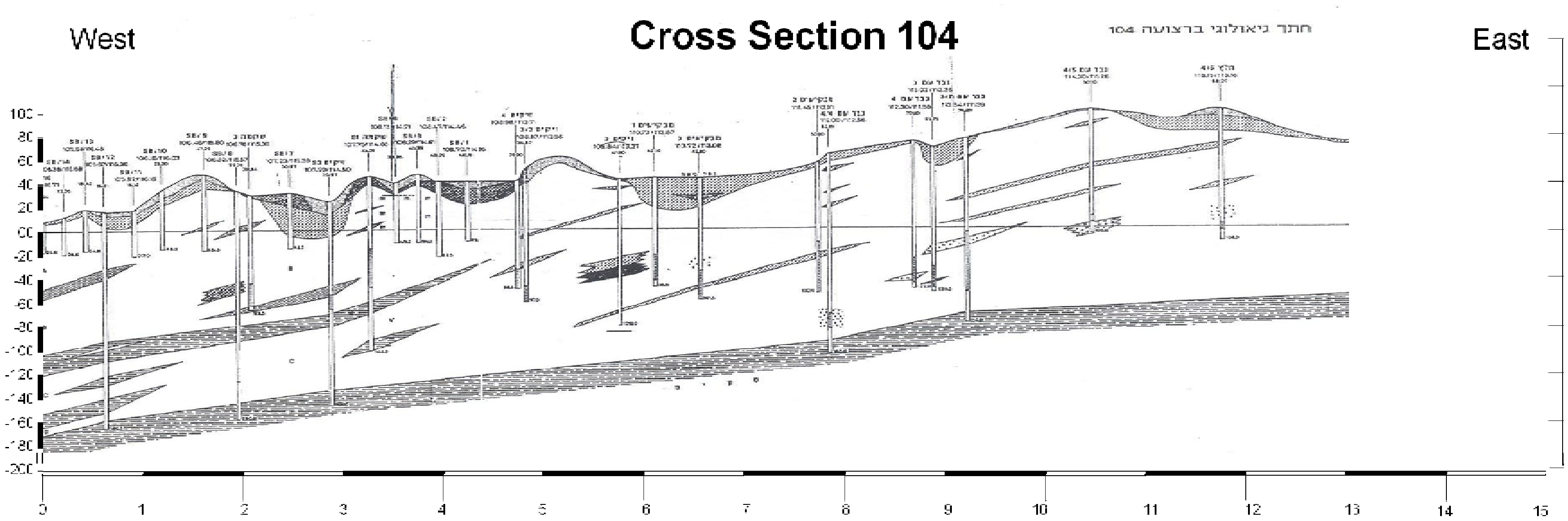


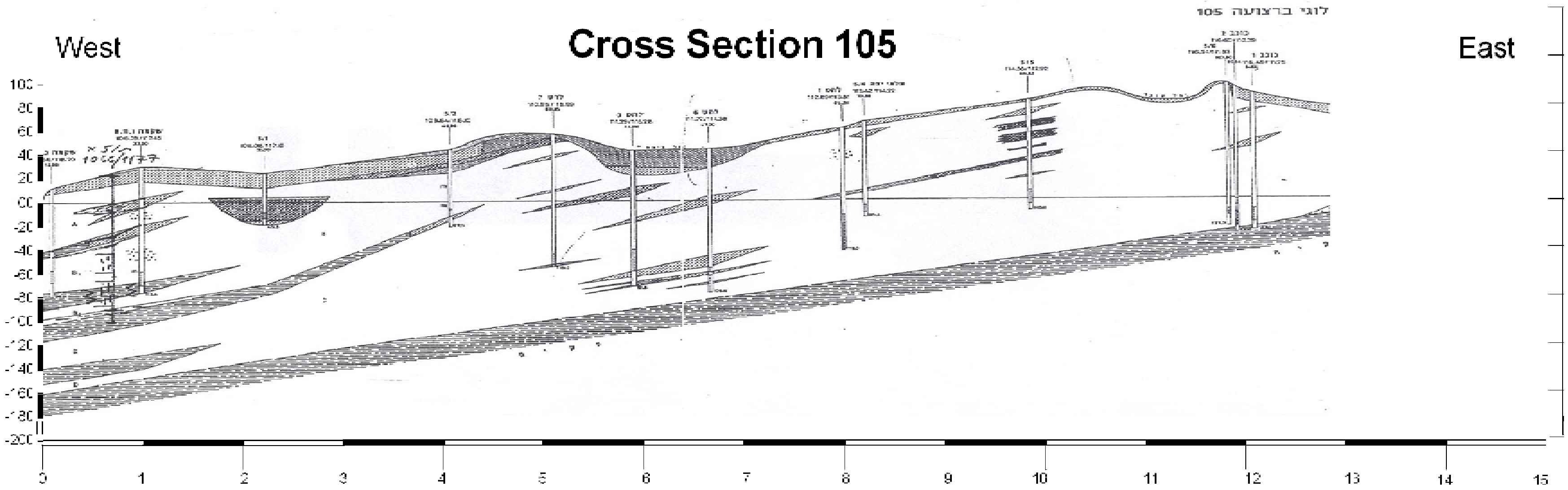
Appendix – B Lithology Cross Sections for Gaza Strip



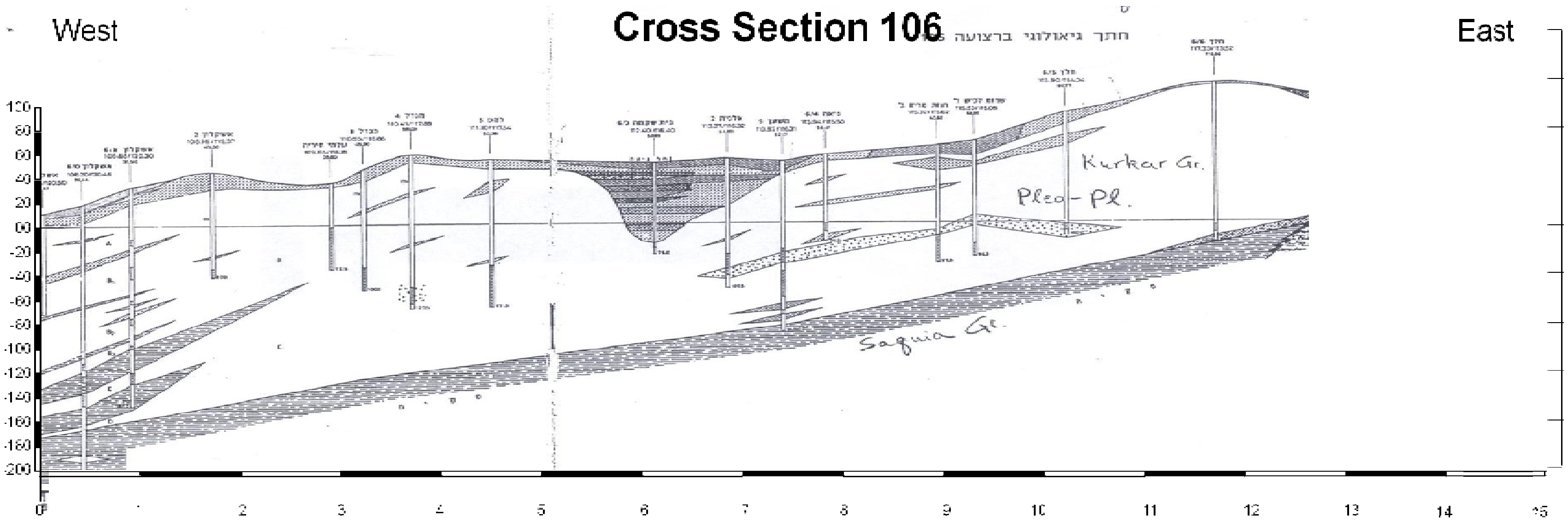


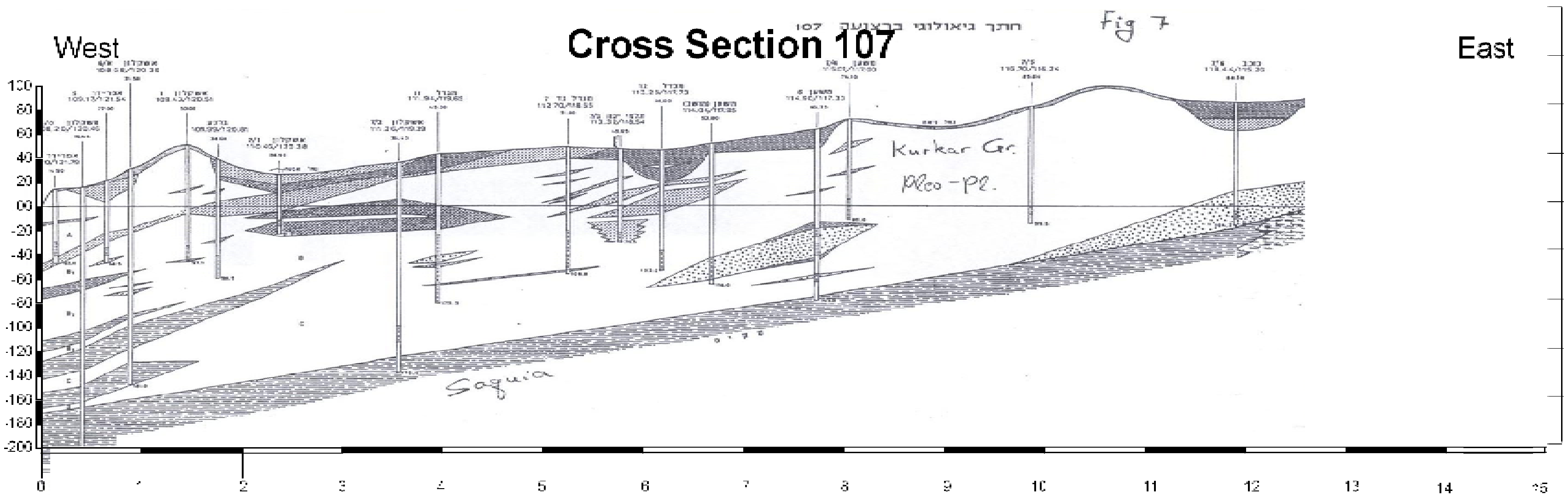
Appendix – B Lithology Cross Sections for Gaza Strip



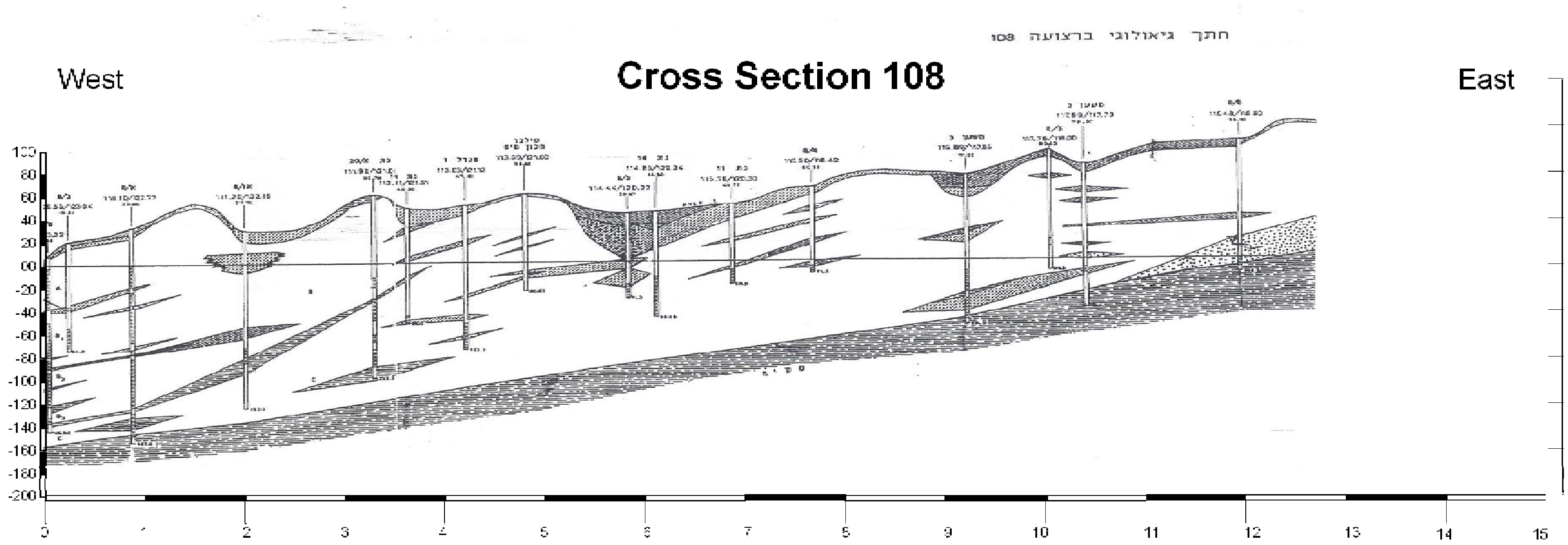


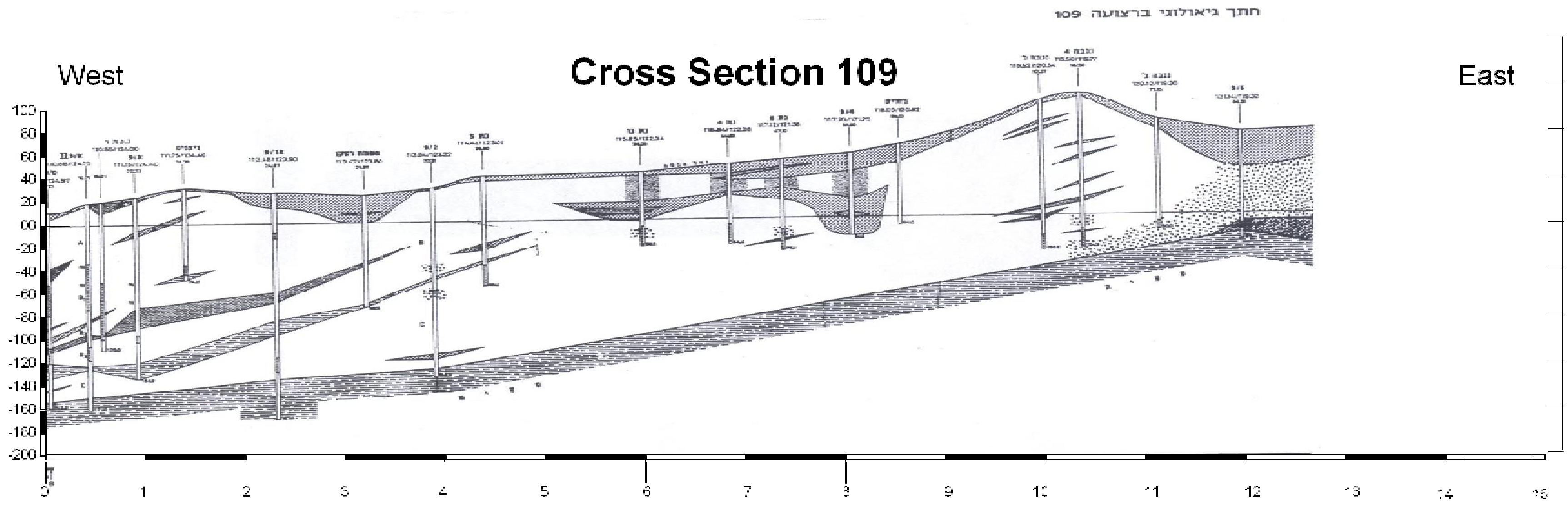
Appendix – B Lithology Cross Sections for Gaza Strip



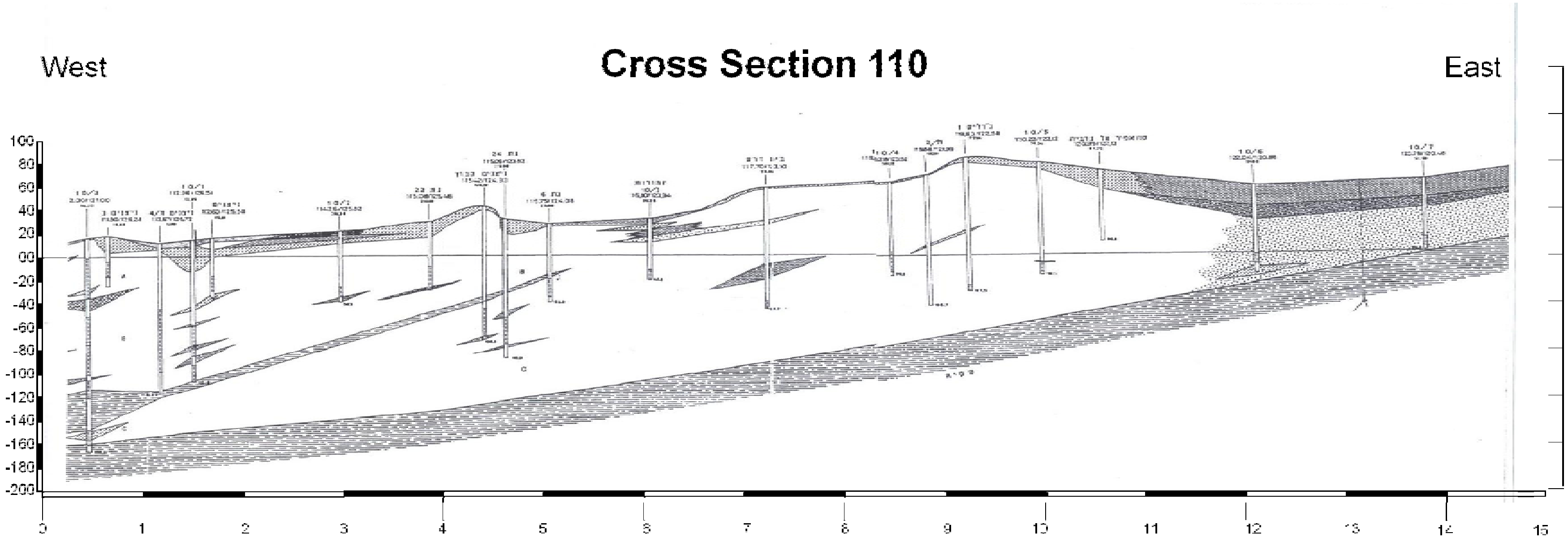


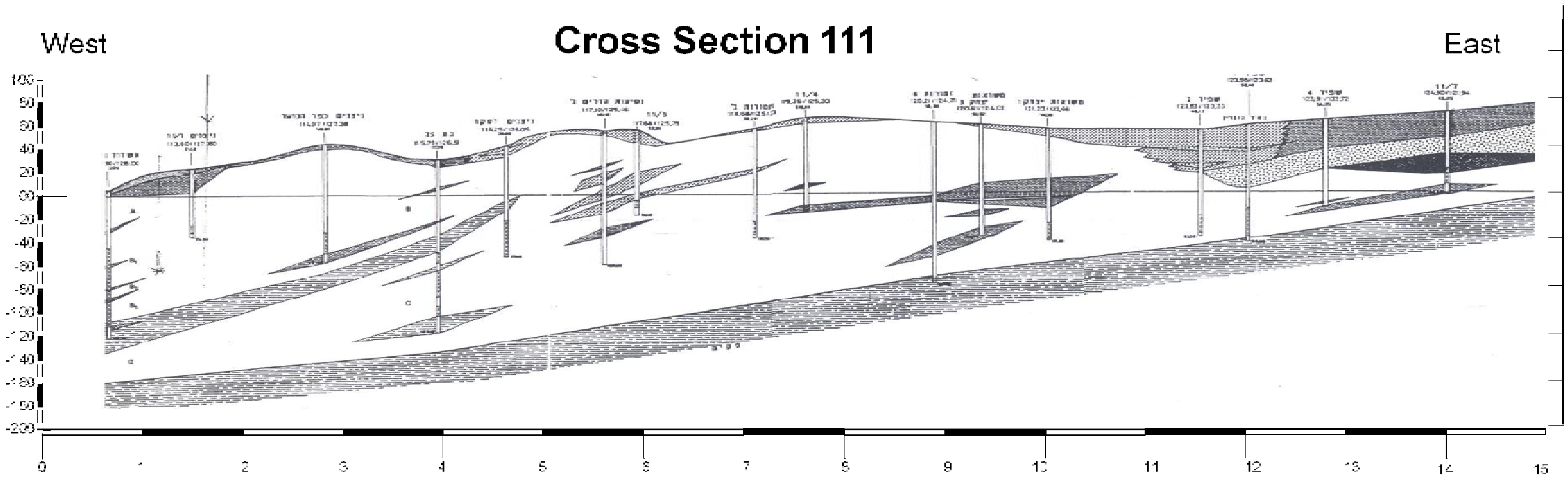
Appendix – B Lithology Cross Sections for Gaza Strip



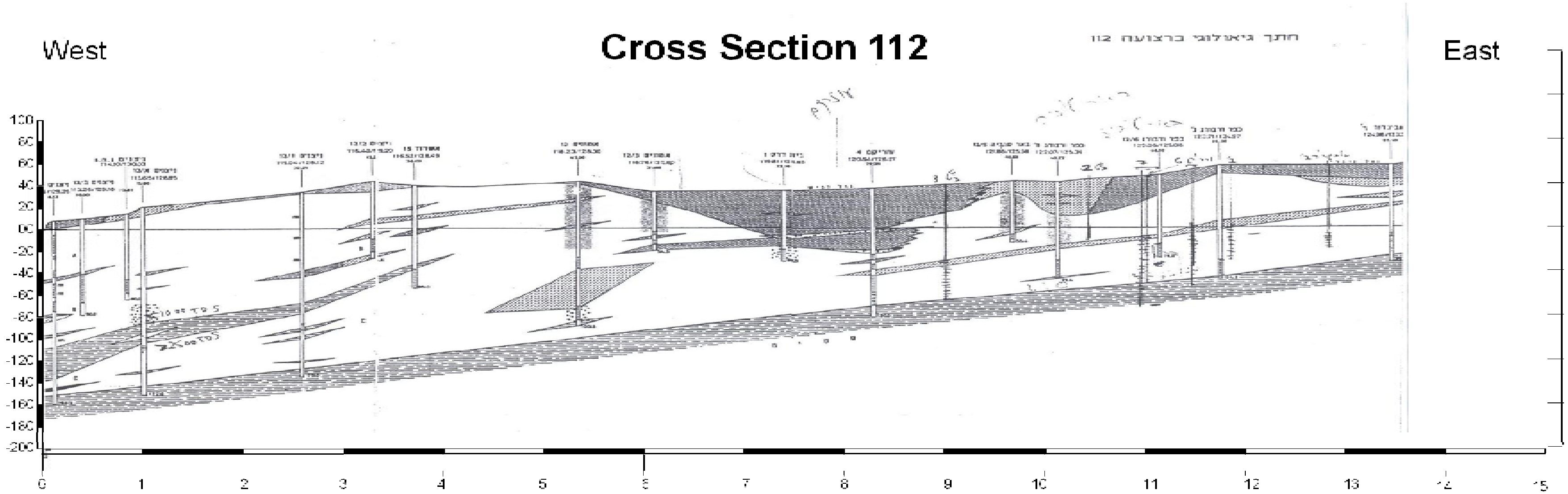


Appendix – B Lithology Cross Sections for Gaza Strip

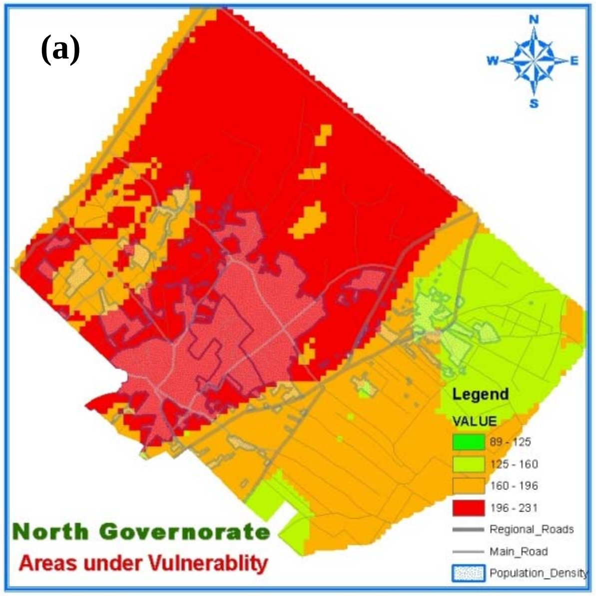


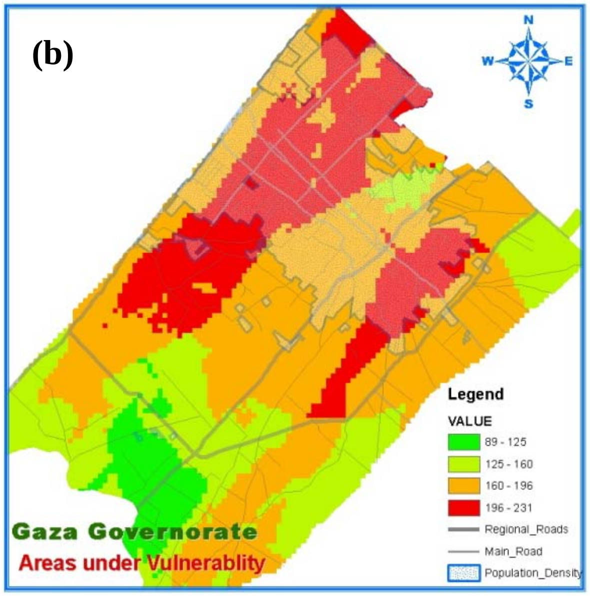


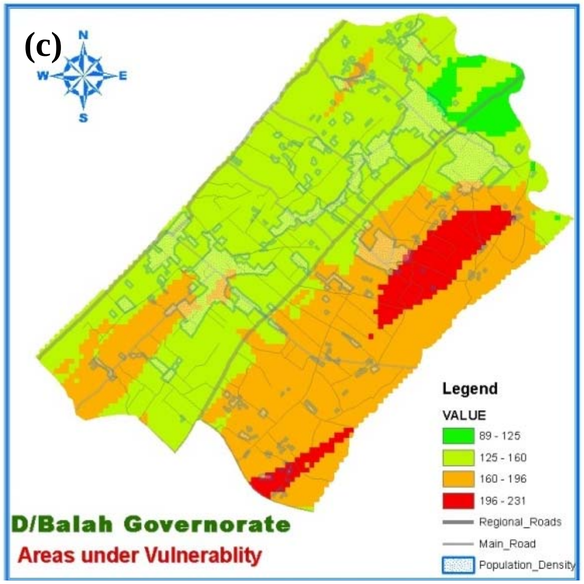
Appendix – B Lithology Cross Sections for Gaza Strip



Appendix C Areas under Vulnerability to Pesticides Contamination in Gaza Governorates







Areas under Vulnerability to Pesticides Contamination in Gaza Governorates

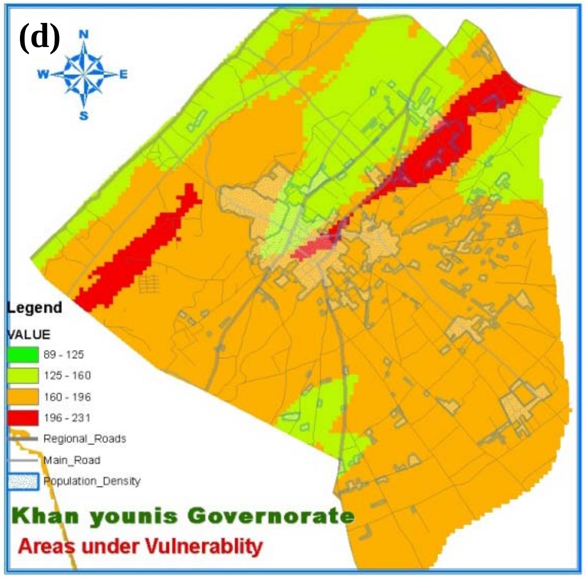
a: North Governorate

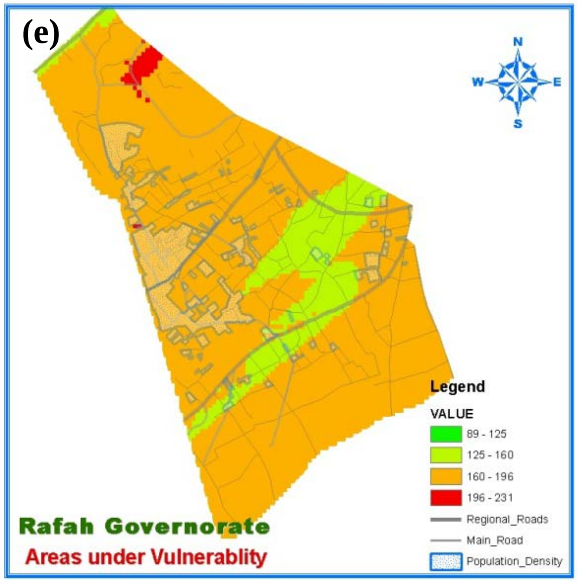
b: Gaza Governorate

c: D/Balah Governorate

d: Khan younis Governorate

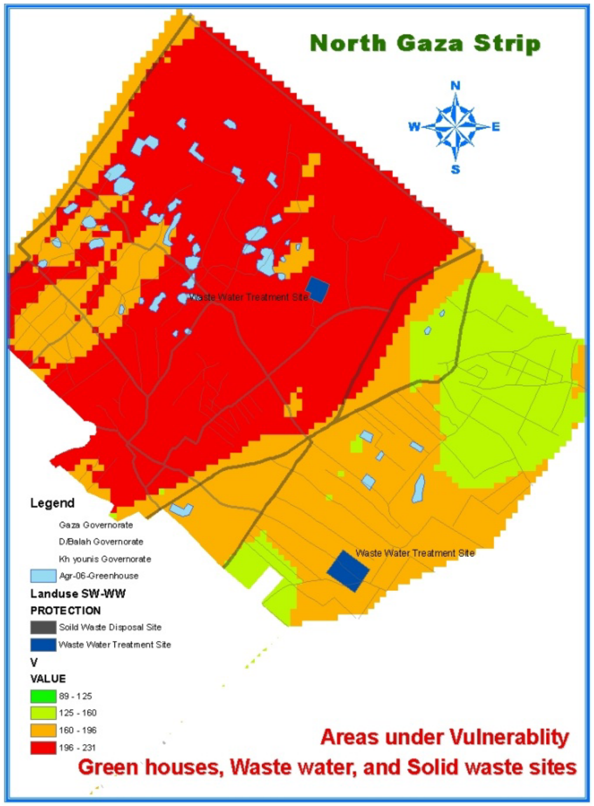
e: Rafah Governorate

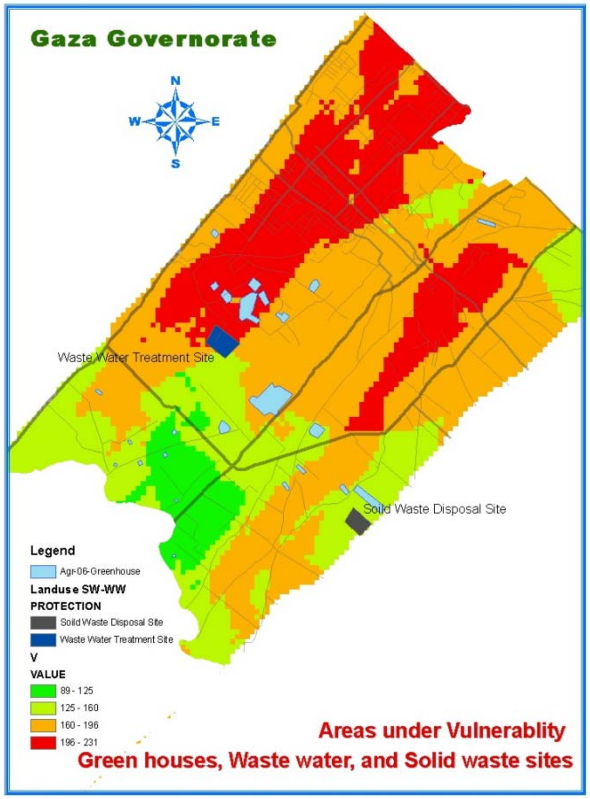


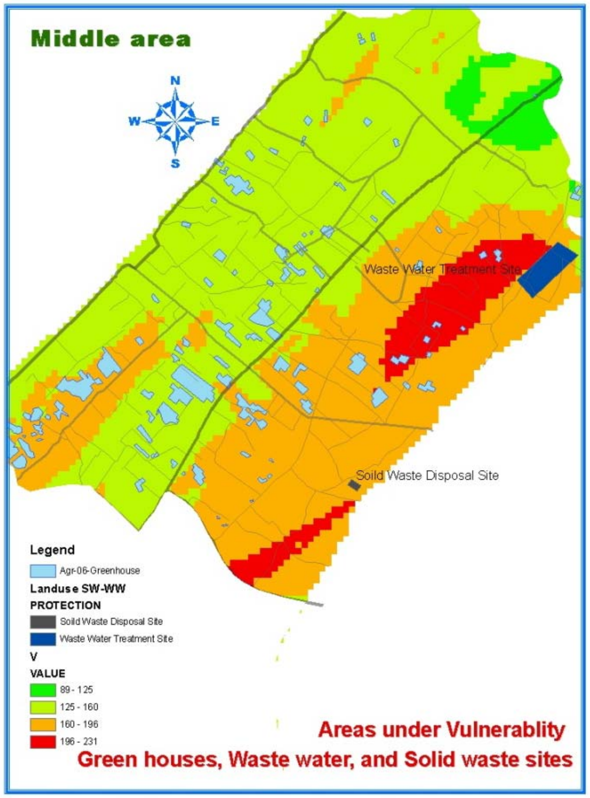


Appendix D **Areas under Vulnerability to Pesticides Contamination in Gaza Governorates and close to Green houses, Waste Water and Solid Waste sites (a, b, c, d, & e)**

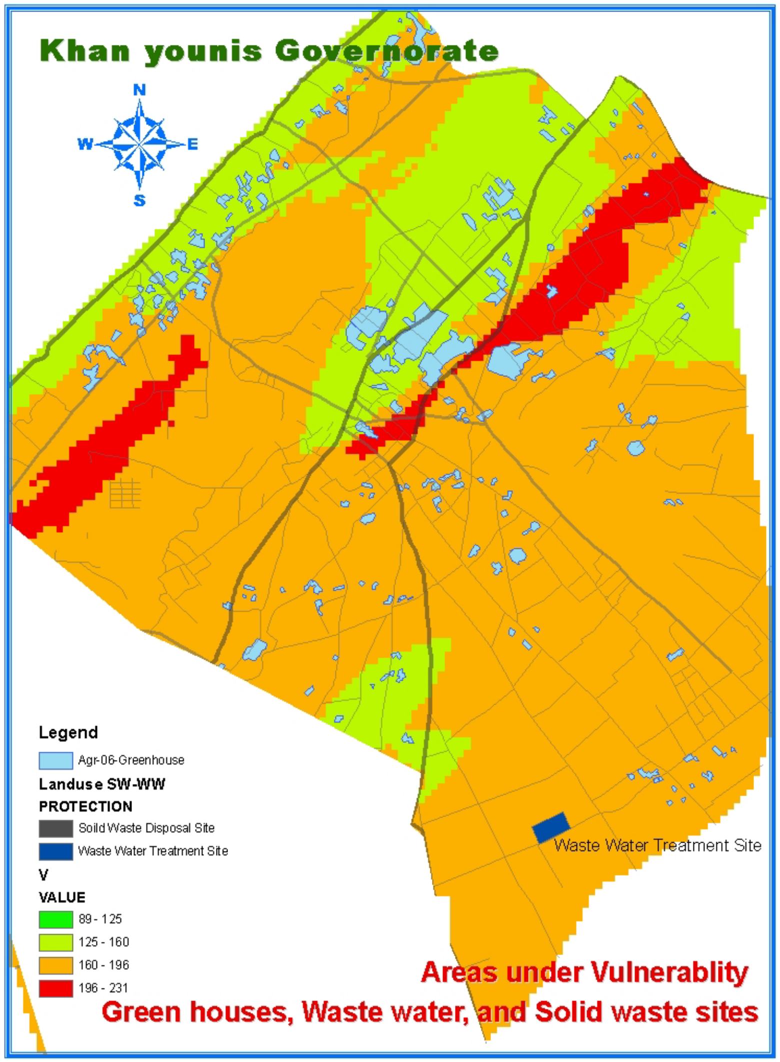
.



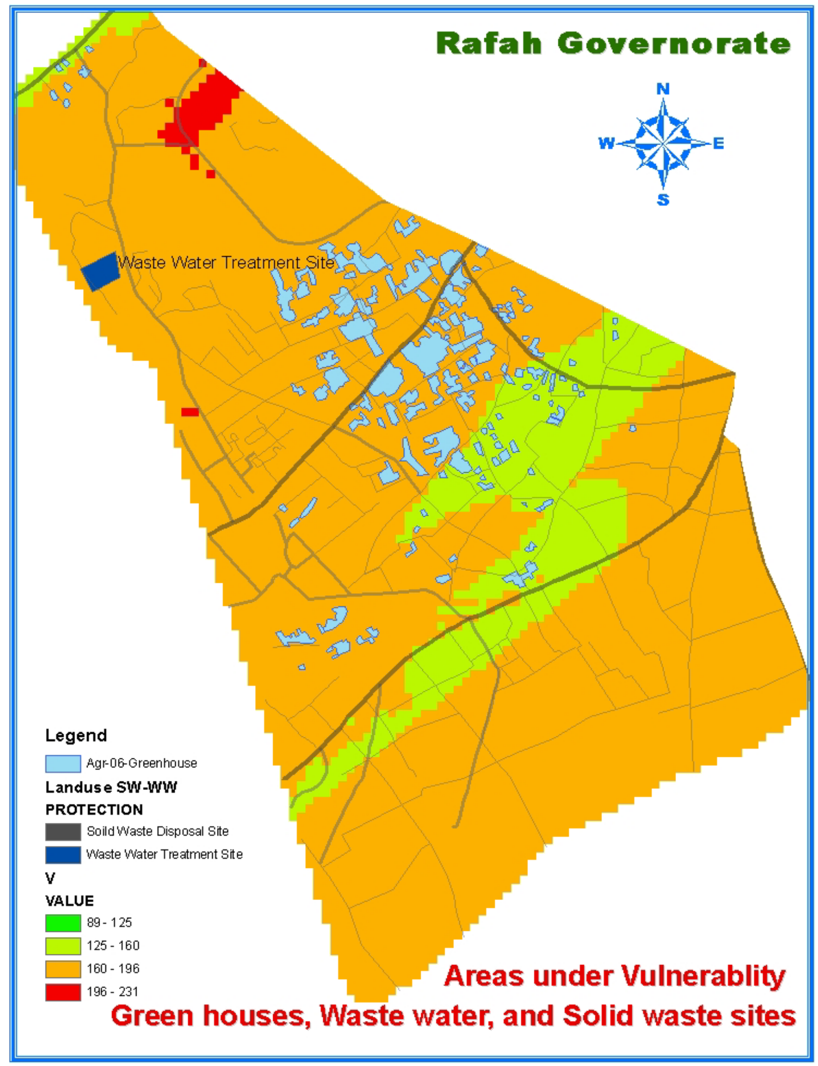




a: North Governorate **b: North Governorate** **c: D/Balah Governorate**



d: Khan younis Governorate



e: RafahGovernorate

Appendix E Calculation of Spearman's Correlation Coefficient

Computations 1

Ranking data

Computations 2 : Rank Order Correlation - Not corrected

$D = \sum_{i=1}^{n} d_i^2$, d = difference between data

$$r_s = \frac{6D}{n(n-1)(n+1)}$$

Computations 3 : Rank Order Correlation - Corrected

$\sum T_x = \frac{t^3-t}{12}$ $\sum T_y = \frac{t^3-t}{12}$

$\sum x^2 = \frac{n^3-n}{12} - \sum T_x$ $\sum y^2 = \frac{n^3-n}{12} - \sum T_y$

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum d^2}{2\sqrt{\sum y^2 \times \sum y^2}}$$

Computations 4 : t-Test Statistic

$t = r_s \sqrt{\frac{n-2}{1-r_s^2}}$ P (t ≥...) =

Computations 5 : z-Test Statistic

$E(D) = \frac{n(n-1)(n+1)}{6}$ $V(D) = \frac{n^2(n-1)(n+1)^2}{36}$

$z = \frac{D-E(D)}{\sqrt{V(D)}}$ P (z ≥...)

Appendix E (Cont'ed) **Calculation of Spearman's Correlation Coefficient**

#	Relation	Correlation (not corrected)	Correlation (Corrected)	t - test (n>10)	DOF	Critical 2-sided T-value (5%)	Critical 1-sided T-value (5%)	D-square value (calculated)	D-square value (expected)	SD	z-Test	Probability	Observation
1	D-R	-0.960606	-0.990811	-20.72036	8	2.306	1.86	323.5	165	55	2.8818	0.0038	10
2	D-A	0.948485	0.946943	8.333333	8	2.306	1.86	8.5	165	55	-2.845	0.0044	10
3	D-S	-0.969697	-0.993884	-25.455844	8	2.306	1.86	325	165	55	2.9091	0.0036	10
4	D-T	0.99697	0.996947	36.11094	8	2.306	1.86	0.5	165	55	-2.991	0.0026	10
5	D-I	0.972727	0.972253	11.755271	8	2.306	1.86	4.5	165	55	-2.918	0.0036	10
6	D-C	-0.833333	-0.946753	-8.317239	8	2.306	1.86	302.5	165	55	2.5	0.012	10
7	R-A	-0.833333	-0.927053	-6.993546	8	2.306	1.86	302.5	165	55	2.5	0.012	10
8	R-S	0.99697	0.996909	35.888717	8	2.306	1.86	0.5	165	55	-2.991	0.0026	10
9	R-T	-0.957576	-0.993846	-25.377155	8	2.306	1.86	323	165	55	2.8727	0.004	10
10	R-I	-0.921212	-0.981269	-14.407308	8	2.306	1.86	317	165	55	2.7636	0.0056	10
11	R-C	0.957576	0.955533	9.165151	8	2.306	1.86	7	165	55	-2.873	0.004	10
12	A-S	-0.854545	-0.943242	-8.033264	8	2.306	1.86	306	165	55	2.5636	0.0102	10
13	A-T	0.951515	0.949843	8.590736	8	2.306	1.86	8	165	55	-2.855	0.0042	10
14	A-I	0.954545	0.952099	8.806526	8	2.306	1.86	7.5	165	55	-2.864	0.0042	10
15	A-C	-0.715152	-0.886844	-5.428571	8	2.306	1.86	283	165	55	2.1455	0.0316	10
16	S-T	-0.966667	-0.996928	-36	8	2.306	1.86	324.5	165	55	2.9	0.0036	10
17	S-I	-0.924242	-0.978236	-13.334566	8	2.306	1.86	317.5	165	55	2.7727	0.0054	10
18	S-C	0.954545	0.952579	8.854377	8	2.306	1.86	7.5	165	55	-2.864	0.0042	10
19	T-I	0.975758	0.975231	12.470533	8	2.306	1.86	4	165	55	-2.927	0.0034	10
20	T-C	-0.830303	-0.949653	-8.573214	8	2.306	1.86	302	165	55	2.4909	0.0124	10
21	I-C	-0.81818	-0.961524	-9.899495	8	2.306	1.86	300	165	55	2.4545	0.0138	10