UNIVERSITY OF LILLE FOR SCIENCE AND TECHNOLOGY

LABORATORY OF MECHANICS

DISSERTATION

MODELLING INTERACTION OF LAND USE, URBANIZATION AND HYDROLOGICAL FACTORS FOR THE ANALYSIS OF GROUNDWATER QUALITY IN MEDITERRANEAN ZONE (EXAMPLE THE GAZA STRIP, PALESTINE)

BY

Mr. Khamis ALMAHALLAWI

Supervised by Professor Jacky MANIA

Lille, France

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Dedicated to

The Soul of My Father

My Kind-hearted and Sweet Mother

My Beloved Wife,

My Daughters Hifaa and Rima,

My Sons Mohammed, Hasan and Jamal

© 2005 Tous droits réservés.

Acknowledgements

I am extremely grateful to the Regional Initiative for Dryland Management (*RIDM*) for the financial assistance which enabled the realization of this research. RIDM is funded by the European Commission and World Bank and managed by the International Centre for Agricultural Research in Dry Areas (*ICARDA*).

I would like to express my sincere gratitude to my supervisor "*Professor Jacky Mania*" for his well-considered advice and priceless support during the period of my study.

I wish to acknowledge "*Dr. Yousif Abou Safia*" (The Minster of Palestinian Environmental Quality Authority) for his priceless support and encouragement in order to conduct my research study.

My deepest thanks to "*Professor Isam Shahrour*" (Vice Director of the School of Engineering Polytech' Lille, University of Lille1) for his co-operation, and support.

My greatest gratitude to "*Environmental Quality Authority*" for granting me the research to increase my knowledge in such favourable environment.

I wish to acknowledge the co-operation, and support of the entire staff members of the Palestinian Environmental Quality Authority, the Palestinian Water Authority, The Ministry of Agriculture. I gratefully acknowledge them for the materials and information given to me through the course of the research.

I am also indebted to many friends (*Especially Eng. Said Jalala and Eng. Mohammed Eila*) for their encouragement and support.

I would like to gratefully acknowledge my mother, sister and brothers for their prayers and support to pursue of this doctoral degree. Finally, I wish also to thank my wife for her unwavering support, patience and devotion, sharing both the disappointments of failure and the joys of success.

© 2005 Tous droits réservés.

Abstract

This study "Modelling interaction of land use, urbanization and hydrological factors for the analysis of groundwater chemical quality in Mediterranean zone (Example the Gaza Strip, Palestine)" aims at determining the main factors affecting groundwater pollution in the Gaza Strip. The research aims specifically at describing and quantifying the dominant transport processes involved in the movement of nitrate solute and the role of land use and environment in modifying temporal and spatial signals, determining all possible sources and sinks of nitrogen, predicting the impact of environmental and land use change on the groundwater quality at different spatial scales, and finding the relation among urban groundwater chemical quality (major cations and anions) and hydrological factors as well as land use factors in the Gaza Strip coastal aquifer.

All possible nitrogen sources and the dominant losses of nitrogen were studied based on mass balance approach at a regional scale. Correlation analyses were performed to analyze the relation among the nitrate concentration and explanatory variables. Visually appealing maps were produced by kriging method. Long term trends and seasonal fluctuations of nitrate were investigated using Mann-Kendall trend analysis and seasonal Kendall test. The Artificial Neural Networks (ANNs) were applied as a new type of modelling to predict nitrate contamination in agricultural and urban areas. A set of six explanatory variables for 189 sampled agricultural wells was used and those with significant influence were identified. The input variables are: nitrogen load, housing density in 500-m radius area surrounding wells, well depth, screen length, well discharge, and infiltration rate. Also, 9 input explanatory variables expected to have significant influence on groundwater chemical quality in urban areas were used. These 9 variables are total well depth, depth to initial water level, depth to the screen level, well screen length, population density in buffer zone of 250m and 500m radii, rainfall intensity, well discharge, and well distance from the seashore. In addition, multiple regression statistical tests were utilized and the results were compared with those of ANN models.

The study showed that agriculture activities and wastewater from urban areas are the two major contributors to the nitrogen load in the study area. The added nitrogen load from solid waste leachate, drinking water networks leakage and precipitation is considered minor compared to other sources. According to the N-balance calculation it is found that there is high pollution risks regarding nitrogen in most of the areas. Long term trends indicate that there are three dominant types of groundwater quality present in the Gaza Strip ranging from

© 2005 Tous droits réservés.

decreasing (2%), stable (67%) to increasing (31%) nitrate concentration. Seasonal Kendall test displayed a seasonal cycle, with higher concentrations in the and lower concentrations in summer.

In application of the ANN model to simulate nitrate groundwater pollution in agricultural areas, the best network was Multi Layer Preceptron (MLP) with the six used input variables and four hidden nodes. The best network found to have a good performance with a correlation of 0.9773, and an error of 8.4322. Studying the effects of urbanization and hydrological factors showed that the best network found to simulate the study area groundwater chemistry is the MPL model. The ANN model has a good performance for nitrate contamination prediction (correlation 0.936, and error 0.444) and a performance rated as positive (OK) for the other water quality parameters with correlation coefficients ranging from 0.644 to 0.866. The buffer zone of 250 meter radius gave a strong positive relation with nitrate rather than the larger buffers, indicating that the problem is mainly due to anthropogenic sources (urbanized activities). The bivariate statistical test revealed a considerable unexplained variation in nitrate concentration.

The study showed that the ANN model can be used as a management tool for the prediction of agricultural and urban groundwater quality by the water sector managers and planners aiming at management of water resources and pollution prevention. Also, since the stressed coastal aquifer areas are mostly typical throughout the world, this approach for groundwater modelling can be applied to other aquifers on the regional or international scale. Since intensive agriculture and livestock farming produces serious risks of nitrogen pollution, fertilization management is very essential to stop the degradation of groundwater quality. Increasing the percentage of sewer system networks coverage as much as possible and wastewater treatment with suitable treatment facilities is an important key factor to control the nitrate pollution due to urban activities.

Keywords: nitrate; coastal aquifer; bivariate statistical test; artificial neural network; multiple regression; major cations and anions, urban groundwater

© 2005 Tous droits réservés.

TABLE OF CONTENTS

Dedication .... **II**

Acknowledgments .... **III**

Abstract .... **IV**

Table of Contents .... **VI**

List of Symbols .... **XIII**

List of Abbreviations .... **XIV**

List of Tables .... **XV**

List of Figures .... **XVIII**

Chapter 1

Introduction

1.1 Water in the Euro-Mediterranean Countries 1

1.2 Water Quality 3

1.3 Nitrate contamination in groundwater - world-wide 3

1.4 Problem identification 5

1.5 Research objectives 7

1.6 Methodology 8

1.7 Selection of study area 9

- 1.7.1 Relative significance of the groundwater quality problem 9
- 1.7.2 Land use 9
- 1.7.3 Land-Usage 10
- 1.7.4 Environmental Factors 10

1.8 Report Format.. 12

Chapter 2

Literature Review

2.1 Integrated Water Planning and Management in the Mediterranean Region 14

2.2 Conclusions 15

2.3 Measures for Minimizing Harmful Fluxes from Land to Water 15

- 2.3.1 Urban sources 16
- 2.3.2 Industrial Sources... 17
- 2.3.3 Agricultural sources 17

© 2005 Tous droits réservés.

2.4 Threats to groundwater quality 17

2.5 Chemical properties of contaminants 18

2.6 Mechanisms of contamination 19

2.7 Overview of major chemical groundwater quality parameters 21

2.7.1 Electrical Conductivity 21

2.7.2 Chlorides 21

2.7.2.1 Seawater Intrusion 22

2.7.3 Sodium 23

2.7.4 Nitrate 23

2.7.5 Hardness 23

2.7.6 Calcium 24

2.7.7 Magnesium 24

2.7.8 Alkalinity 24

2.7.9 Fluoride 24

2.8 Land Use and environmental effects on Groundwater quality 25

2.9 Uses for Groundwater Vulnerability Assessment 27

2.9.1 Overlay and Index Methods 27

2.9.2 Mathematical Models 28

2.9.3 Statistical Methods 29

2.9.4 Checklists 29

2.10 Natural Sources of Soil Nitrogen 30

2.11 The Nitrogen Cycle 32

2.12 Nitrogen Transformations 32

2.12.1 Immobilization and Mineralization 33

2.12.2 Nitrification 35

2.12.2.1 Nitrification Environmental Impact 36

2.12.3 Denitrification 37

2.12.4 Ammonia Volatilization 38

2.12.5 Ammonium Fixation 39

2.12.6 Nitrogen Fixation 40

© 2005 Tous droits réservés.

2.13 Nitrate Leaching 41
2.14 Nitrogen inputs 42
  2.14.1 Effluent from sewer systems and septage 43
  2.14.2 Leachate from landfills 43
  2.14.3 Fertilizers 45
  2.14.4 Manure N inputs 46
  2.14.5 Irrigation water inputs 47
  2.14.6 Nitrogen fixation inputs 48
  2.14.7 Precipitation inputs 48
2.15 Losses of Nitrogen 49
  2.15.1 Losses through ammonia volatilization 49
  2.15.2 Losses through denitrification 50
  2.15.3 Plant Uptake 51
  2.15.4 Erosion and runoff 52
2.16 The fate and transport of nitrogen in wastewater effluents 52

Chapter 3

Description of the Study Area

3.1 Geographical Data 54
3.2 Climate and Rainfall 54
3.3 Geology and Hydro-geology 56
  3.3.1 Geology 56
    3.3.1.1 Tertiary Formation 56
    3.3.1.2 Quaternary Formation 56
  3.3.2 Hydrogeology 58
3.4 Aquifer System 59
3.5 Land use 61
  3.5.1 The present situation of land use 61
  3.5.2 Future land use 63
    3.5.2.1 Residential future needs 63
    3.5.2.2 Future Land Use Demand for Industries and Commerce 63
    3.5.2.3 Future agricultural land use 64
3.6 Domestic Wastewater Treatment and Disposal 64

© 2005 Tous droits réservés.

3.6.1 Gaza City Treatment Plant 65
3.6.2 Beit-Lahia Wastewater Treatment Plant 66
3.6.3 Rafah Wastewater Treatment Plant 66
3.7 Sludge Disposal and Treatment 67
3.8 Industrial Wastewater 68
3.9 Pesticides Use 69
3.10 Fertilizers 69
3.10.1 Chemical Fertilizers 69
3.10.2 Organic Fertilizers 70
3.11 Solid Waste Generation 71

Chapter 4

Urban and Agriculture Loads of Nitrogen

4.1 Objectives 72
4.2 Potential Sources of Nitrate to Groundwater 72
4.3 Wastewater 75
4.3.1 Effluents of the treatment plants 75
4.3.2 Leakage from sewer system 76
4.3.3 Unsewered areas 77
4.4 Solid waste 78
4.5 Agricultural areas 79
4.5.1 Chemical fertilizers addition 79
4.5.2 Organic fertilizer additions 81
4.5.3 Agricultural water 83
4.5.4 Nitrogen balance for agricultural areas 84
4.6 Drinking water distribution network 86
4.7 Precipitation 86
4.8 Settlements 87
4.9 Total nitrogen balance 88
4.10 Discussion 90

Chapter 5

Effect of Land Use and Environmental Factors on Nitrate Pollution

5.1 Objective 92

© 2005 Tous droits réservés.

5.2 Introduction …………………………………………………………… 92
5.3 Groundwater Data and Sampling History ……………………………….. 93
5.4 Critical analysis of the data …………………………………………… 95
  5.4.1 Normality …………………………………………………… 95
    5.4.1.1 Empirical distribution …………………………………. 96
    5.4.1.2 Skewness test ………………………………………….. 96
    5.4.1.3 Chi-square (χ^2) test ……………………………………. 97
5.5 Land Use Characteristics ……………………………………………… 97
5.6 Nitrate analytical methods …………………………………………….. 98
5.7 Statistical Analysis Procedures ……………………………………….. 99
5.8 Variations of nitrate concentration …………………………………… 99
  5.8.1 Spatial patterns in nitrate concentrations ……………………….. 100
    5.8.1.1 Mapping method ……………………………………….. 100
    5.8.1.2 Method of illustration …………………………………. 100
  5.8.2 Discussion of spatial patterns …………………………………... 107
5.9 Analysis of long-term trends in nitrate concentrations …………………….. 108
  5.9.1 Data Compilation ………………………………………….. 110
  5.9.2 Outlier values and creation of graphs …………………………... 110
  5.9.3 Result of calculation of trends and slopes ……………………… 111
    5.9.3.1 Decreasing Trends …………………………………….. 112
    5.9.3.2 No Trends …………………………………………… 112
    5.9.3.3 Some Examples ……………………………………….. 112
5.10 Seasonal Fluctuations in Nitrate Concentrations …………………………… 113
  5.10.1 Method of Analysis ………………………………………… 113
  5.10.2 Analysis Result …………………………………………….. 114
5.11 Application to the Case Study-Gaza Governorate ………………………….. 120
  5.11.1 Introduction ……………………………………………….. 120
5.12 Data Collection and Analysis ………………………………………….. 122
5.13 Correlation between variables ………………………………………….. 125
5.14 Nitrate Concentration and Well Depth ……………………………………... 126
5.15 Application of Bivariate Regression Test …………………………... 128
5.16 Multiple Regression Statistical Test ………………………………………... 129

© 2005 Tous droits réservés.

5.16.1 The Regression Equation ………………………………………... 130
5.16.2 Predicted and Residual Scores ………………………………….. 130
5.16.3 Residual Variance and R-square ………………………………... 130
5.16.4 Correlation Coefficient R ………………………………………. 131
5.16.5 Application of Multiple Regression Statistical Test ……………. 131
5.16.6 Forward and Backward Stepwise Linear regression …………… 132
5.16.7 Model Validation Using Validation Data Set ………………….. 135
5.17 Artificial Neural Network Modelling ………………………………………. 135
5.18 Background of artificial neural network ……………………………………. 136
5.19 One-neuron model ………………………………………………………….. 136
5.20 Solving Regression Problems by Using ANN ……………………………… 138
5.21 Functions …………………………………………………………………… 138
5.22 Cross verification …………………………………………………………… 138
5.23 Linear Networks ……………………………………………………………. 139
5.24 Radial Basis Function Network (RBF) ……………………………………… 139
5.25 Generalized Regression Neural Networks (GRNNs) ………………………. 139
5.26 Multilayer Perceptron ………………………………………………………. 139
5.26.1 Backpropagation Training Algorithm for Three-Layered Neural Networks ………………………………………………………… 140
5.27 Training with three-layer feed-forward back-propagation network ………... 141
5.28 Sensitivity analysis …………………………………………………… 144
5.29 Conclusions ………………………………………………………….. 145

Chapter 6

Effect of Urbanization and Hydrological Factors on Groundwater Chemical Quality

6.1 Objective ………………………………………………………….. 147
6.2 Introduction ……………………………………………………….... 147
6.3 Materials and methods ……………………………………………………… 148
6.3.1 Data origin and collection …………………………………….. 148
6.3.2 Water chemistry data and analytical methods …………………... 149
6.3.3 Analysis tools and methods 149
6.4 Overview of groundwater chemistry ……………………………………… 150
6.5 Correlation between variables ……………………………………………… 151

© 2005 Tous droits réservés.

6.6 Multivariate Statistical Test …………………………………………………… 158
  6.6.1 Factor analysis ………………………………………………….... 159
    6.6.1.1 R-mode Factor Analysis ……………………………….. 159
    6.6.1.2 Q-mode Factor Analysis ……………………………….. 162
6.7 Cluster analysis ……………………………………………………………….. 165
6.8 Principal Component Analysis (PCA) ……………………………………… 167
  6.8.1 Principal Component Analysis (PCA) Results ………………….. 167
6.9 Groundwater Chemistry and Explanatory Variables ……………………….. 171
  6.9.1 Bivariate Statistical Test ………………………………………….... 171
  6.9.2 Application of Multiple Regression Statistical Tests …………… 173
6.10 Neural network application ………………………………………………… 176
  6.10.1 Training with three-layer feed-forward back-propagation network 176
  6.10.2 Sensitivity Analysis ……………………………………………... 179
6.11 Conclusion ………………………………………………………………... 181

Chapter 7

General Conclusions and Recommendations

7.1 Conclusions ………………………………………………………………. 183
  7.1.1 Nature and overall understanding of the nitrate problem ……….... 183
  7.1.2 Understanding of risks and processes ……………………………. 184
  7.1.3 Principal features of the analysis and findings …………………... 184
  7.1.4 Deliverables of the research work ……………………………….. 186
  7.1.5 Limitations of the research work ………………………………… 187
7.2 Recommendations ………………………………………………………. 187
  7.2.1 Management and policy development …………………………… 187
  7.2.2 Confirmation of nitrate trends …………………………………… 188
  7.2.3 Research activities ……………………………………………….. 188
  7.2.4 Technical issues required for management ……………………… 189
REFERENCES 192

APPENDICES

Appendix I: Nitrogen Balance Calculations 204
Appendix II: Water quality of domestic and agricultural wells 223
About the Author 245

© 2005 Tous droits réservés.

List of Symbols

NH3	Ammonia
NH_4^+	Ammonium
ANN	Artificial Neural Network
HCO_3^-	Bicarbonate
BOD	Biochemical Oxygen Demand
Ca^{2+}	Calcium
CO_3^{2-}	Carbonate
COD	Chemical Oxygen Demand
CL^-	Chloride
EC	Electrical Conductivity
pH	Hydrogen Ion Concentration
Mg^{2+}	Magnesium
NO_2^-	Nitrogen Dioxide
N_2	Nitrogen Gas
K^+	Potassium
SO_4^{2-}	Sulphate
SSE	Sum Squared Error
TDS	Total Dissolved Solid
TH	Total Hardness
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TS	Total Solids
TSS	Total Suspended Solid
TVS	Total Volatile Salts

© 2005 Tous droits réservés.

List of Abbreviations

ANN	Artificial Neural Network
EQA	Environmental Quality Authority
GAD	Gaza Agricultural Department
GRNN	Generalized Regression Neural Network
GNP	Gross National Product
IPS	Intelligent Problem Solver
LPLN	Long-term potentially total N
LEKA	Lyonnaise Des Eaux Khatib and Alami
MAE	Mean Absolute Error
mm/y	Millimetres per year
Mm^3	Million cubic meter
MOA	Ministry of Agriculture
MOH	Ministry of Health
MOPIC	Ministry of Planning and International Cooperation
MLP	Multilayer Perceptrons
MAVWHO	Maximum Allowable Value by World Health Organization
PA	Palestinian Authority
PWA	Palestinian Water Authority
RBF	Radial Basis Function
RTD	Research and Technology Development
RMSE	Root Mean Square Error
PCBs	The Palestinian Central Bureau of Statistics
UNIDO	United Nations Industrial Development Organization’s
WWTP	Wastewater Treatment Plant
WHO	World Health Organization

© 2005 Tous droits réservés.

List of Tables

1.1 Frequency of nitrate concentration in groundwater wells in the Gaza Strip 6
2.1 Rates of nitrification by some heterotrophic and autotrophic nitrifiers 36
2.2 Composition of leachate from fresh and aged landfill 44
2.3 Typical composition of the leachate from domestic wastes in relation to age 44
2.4 Composition of various common N fertilizers 45
2.5 Moisture and nitrogen content of manure farm animals 47
2.6 Approximate N contents of livestock and poultry manure as produced values 47
2.7 Approximate percent of total plant N derived from N_2 fixation for various legumes and available soil N situations 48
2.8 Inorganic nitrogen content in precipitation for several locations in the USA 49
2.9 Approximate ammonia losses of land manure. 50
2.10 Characteristics of three different Jordanian soils 50
2.11 Studies on losses of N by denitrification following addition of manure or organic wastes to soil 51
2.12 Approximate N denitrification estimates for various soils 51
3.1 Geology and geological history of the Gaza Strip 57
3.2 Present land use distribution 62
3.3 Built-up areas per Governorate 63
3.4 Demand for industrial, trade and commercial land 63
3.5 Agriculture Production Areas in the Gaza Strip (ha) 64
3.6 Wastewater generation and treatment 65
3.7 Wastewater characteristic before/after plant rehabilitation in the Gaza City 66
3.8 Wastewater characteristics of the Gaza Strip 66
3.9 Quality of treated sludge at the GWWTP 68
3.10 Quantity of imported livestock from Israel to the Gaza Strip (No./year) 71
3.11 Proportion of Total Waste Generated by different sources in Gaza City 71
3.12 Composition of solid wastes 71
3.13 Projected solid waste production, 2000-2020 71
4.1 Wastewater characteristics of the Gaza Strip 75
4.2 Wastewater characteristics of Gaza WWTP 75
4.3 Wastewater characteristics of Beit-Lahia WWTP 76
4.4 Wastewater characteristics of Rafah Wastewater treatment plant 76

© 2005 Tous droits réservés.

4.5 Nitrogen balance for the Gaza Strip WWTPs 76
4.6 Nitrogen balance from leakage of sewer system 77
4.7 Average wastewater characteristics of cesspits in the study area. 78
4.8 Nitrogen balance for unsewered areas 78
4.9 Nitrogen production from solid waste generation 79
4.10 Agriculture Production Areas in the Gaza Strip (ha) 80
4.11 Nitrogen fertilizers applied for different types of crops in the Gaza Strip 80
4.12 Nitrogen fertilizer additions, losses and balance for Gaza Strip 81
4.13 Quantity of imported livestock from Israel to the Gaza Strip in 2000 81
4.14 Total quantity of livestock in the Gaza Strip in 2000 81
4.15 Total nitrogen production from livestock in Gaza areas (kg/y) 82
4.16 Nitrogen additions from imported manure 82
4.17 Manure application and nitrogen addition to different crops in the Gaza Strip 83
4.18 Actual water irrigation in the Gaza Strip (m^3) 84
4.19 Water quality of agricultural wells (Average concentrations) 84
4.20 Total nitrogen input from irrigated water (kg/y) 84
4.21 Total nitrogen balance for the agricultural lands 85
4.22 Nitrogen input through drinking water distribution networks leakage 86
4.23 Nitrogen input through precipitation (Rainfall) 87
4.24 Nitrogen additions and losses from the Agricultural Settlements 88
4.25 Nitrogen balance for Settlements 88
4.26 Nitrogen balance for Rafah area 88
4.27 Nitrogen balance for Khanyounis area 88
4.28 Nitrogen balance for middle area 89
4.29 Nitrogen balance for Gaza area 89
4.30 Nitrogen balance for Northern area 89
4.31 Nitrogen balance for the Gaza Strip 89
5.1 Skewness and standard error of groundwater chemical quality data 97
5.2 Critical values used in Mann-Kendall trend analysis 110
5.3 Mann-Kendall trend test and Kendall's S seasonal fluctuations test results 115
5.4 Descriptive statistics for the research data 123
5.5 Relation between nitrate concentration in groundwater and agriculture types 124
5.6 Bivariate correlation matrix of explanatory variables 126
5.7 Agricultural wells data sets used for model training and model validation 131

© 2005 Tous droits réservés.

5.8 Regression Summary (Forward stepwise) ; for Nitrate Conc. 133
5.9 Regression Summary (Backward Stepwise) ; for Nitrate Conc. 133
5.10 Regression Summary Coefficients (Forward stepwise) ; for Nitrate Conc. 133
5.11 Regression Summary Coefficients (Backward Stepwise); for Nitrate Conc. 134
5.12 Quick search for the best network 143
5.13 Medium search for an optimal network 144
5.14 Sensitivity analysis for the explanatory variables in the training and verification subsets 145
6.1 Univariate Statistical Overview of Water Quality Data Set 151
6.2 Correlation matrix of domestic groundwater chemical quality in the Gaza Strip 152
6.3 Hydro-geochemical signatures in the Gaza Strip 154
6.4 Correlations matrix between E_PCO_2 and major cations and anions 157
6.5 Factor loading matrix-varimax rotation 160
6.6 Eignvalues and variance of factor loading 161
6.7 Varimax rotated Q-mode factor analysis loading matrix 164
6.8 Factor load for groundwater chemical quality 169
6.9 Eigenvalues of correlation matrix, and related statistics 169
6.10 Bivariate Relation of Groundwater Chemistry and Explanatory Variables 173
6.11 Solving equation and R-square value for each model 174
6.12 Conduct Medium Search for an Optimal Network for Groundwater Chemistry 178
6.13 Sensitivity analysis for the explanatory variables in the verification subsets 180
6.14 Comparison of R-square between ANN networks and regression models 180

© 2005 Tous droits réservés.

List of Figures

1.1 Possible sources of groundwater contamination by nitrate 7
1.2 Schematic diagram of study methodology 11
1.3 Thesis Structure (Report Format) 13
2.1 Processes promoting contaminant attenuation in groundwater systems 21
2.2 Simplified Biological Nitrogen Cycle 33
2.3 Block diagram of N-fertilizer behaviour in the soil 46
3.1 Gaza Strip and West Bank Base Map 54
3.2 The rainfall variation in Beit Hanon and Rafah area 55
3.3 A typical cross section in the Gaza Strip 58
3.4 Schematic diagram across the Gaza Strip. 60
3.5 Gaza Strip Present Land Use Map 62
3.6 The agricultural land use in the Gaza Strip 64
3.7 Nitrogen, Phosphorus and Potassium fertilizers used annually in Gaza Strip 70
4.1 Sketch for nitrogen balance 72
4.2 Some Potential Sources of nitrate to groundwater 74
4.3 The nitrogen cycle in the soil and groundwater 74
4.4 Total nitrogen balance for agricultural lands 86
4.5 Nitrogen balance for different areas in the Gaza Strip 90
5.1 Methodology and procedures 93
5.2 Frequency histogram for nitrate (NO_3^-) data series 96
5.3 Number of monitoring wells and tests for agricultural wells 98
5.4 Number of monitoring agricultural and domestic groundwater wells 98
5.5 Median nitrate concentration in the Gaza Strip 101
5.6 Median nitrate concentration in the Northern Area (1987-2002) 102
5.7 Median nitrate concentration in the Gaza City (1987-2002) 103
5.8 Median nitrate concentration in the Middle Area (1987-2002) 104
5.9 Median nitrate concentration in the Khanyounis Area (1987-2002) 105
5.10 Median nitrate concentration in the Rafah Area (1987-2002) 106
5.11 Steady State of Nitrate Concentration of Well R/254. 112
5.12 Continuous Increase of Nitrate Concentration of Well L/43. 113
5.13 Nitrate concentration in the Gaza Governorate 125
5.14 Relationship between median nitrate concentration and well depth 128

© 2005 Tous droits réservés.

5.15 Scatter plot between nitrate concentration and explanatory variables 129
5.16 Stepwise Linear regression result 134
5.17 Observed vs. predicted nitrate concentration for model validation 135
5.18 A one-neuron model structure 136
5.19 Sigmoid transfer function 137
5.20 Typical three layered feed forward neural networks with a backpropagation 141
5.21 Actual vs. predicted nitrate concentration by using the three-layer feed-forward back-propagation network 143
6.1 Methodology and procedures 150
6.2 Plot of chemical variations of urban groundwater wells 155
6.3 Plots of EpCO2 level with pH in urban groundwater wells in the Gaza Strip 157
6.4 Representation of groundwater chemical data on a trilinear diagram 157
6.5 Factor 1 vs. factor 2 in R-mode factor analysis for 87 domestic wells (2002) 161
6.6 Factor 1 vs. factor 3 in R-mode factor analysis for 87 domestic wells (2002) 161
6.7 Plot of Eigen values 162
6.8 Plot of Eigen values 163
6.9 Dendogram of the R-mode cluster analysis 165
6.10 Dendogram of the Q-mode cluster analysis 166
6.11 Plot of PCA eigenvalue 170
6.12 Plot of variables contribution in each factor (absolute values) 170
6.13 Projection of the variables on the factor plan 170
6.14 Box plots of the scores of PCA according to the sampling location points. 171
6.15 Nitrate Concentration in the Gaza Governorates for the years 1987 and 2002. 173
6.16 Plot of the predicted concentration versus actual concentration 175
6.17 Observed versus predicted nitrate concentration (mg/L) 179

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Chapter 1

Introduction

1.1 Water in the Euro-Mediterranean Countries

Water is certainly at the centre of ecosystems and human development. But in the Mediterranean region, water is the most important because it is so scarce, fragile, unequally distributed and widely exploited. The hydro-graphic basins are broken up and also, several basins are crossed by national borders, making the resource common to several countries. Furthermore, some considerable water volumes stored in large deep aquifers in Libya, Tunisia, Egypt and Algeria are non-renewable resources and their use is consequently not sustainable.

Scarcity is often accompanied by *poor quality*, especially in the South, where water is often highly saline, reducing its utility. In Tunisia, 26% of the surface water, 90% of water pumped from water tables and 80% of that from deep aquifers have a salinity of more than 1.5 g/L. Over-pumping has caused seawater intrusion into Israel's coastal aquifer (a substantial freshwater source). Some 20% of the aquifer is now contaminated by salts and nitrates from urban and agricultural pollution, and water officials foresee that one fifth of the coastal wells may need to be closed over the next few years.

Natural and renewable water resources are *unequally distributed* among the Mediterranean countries. The four richer countries in water resources, France, Italy, Turkey and Yugoslavia, account for 825 km^3/yr, over 2/3 of the renewable water resources of the region (1179 km^3/yr). But within each country, water resources are also unequally distributed. In Spain, 81% of resources are located in the Northern half of the country; in Tunisia, the North (which covers 30% of the territory) provides 80% of the country's resources; in Algeria, 75% of renewable resources are concentrated in 6% of the land in the Mediterranean coastal border.

In terms of population (1995), the annual availability of water resources *per capita* is very imbalanced between the relatively rich and even overabundant North, and the poor to extremely poor South and East. While Albania and Yugoslavian countries have over 10,000 m^3/yr/capita, figures for Gaza, Malta and Libya total less than 100. Eight countries, with a total population of 115 million inhabitants, now lie below the desirable resource threshold of

© 2005 Tous droits réservés.

1,000 m^3/yr/capita. Naturally, tensions appear between needs and resources, particularly when irrigation is necessary. In six countries, with a population of 28 million (Israel, Jordan, Malta, Tunisia, Libya, Gaza and West Bank), water resources are below the *extreme poverty threshold* of 500 m^3/yr/capita.

With rapid population growth and possible re-allocations among countries in the region, the availability *per capita* is likely to be further reduced in the region. For Israel, the availability *per capita* will be reduced to 190 m^3/yr by 2030, including some 65 m^3 of recycled waste water. In many countries, water withdrawals exceed the limits of natural resource renewal and deplete the stock that cannot be renewed. Thus, Libya is making massive use of its "fossil" groundwater.

It is not only that the Mediterranean basin faces environmental problems of significant severity, but also that the ecological, economic and social changes are happening very rapidly. Increasingly, the challenge is one of how to accommodate *competing* and *conflicting* water demands in a rather "stressed" environment, and also to provide considerable improvements to the region.

A series of trends and developments are viewed as the backdrop to the crisis regarding water supplies and their utilization. Factors underlying this context of urgency include:

a. the high variance of water supply, resulting in dramatic fluctuations, exacerbated by periodic droughts or floods;

b. decreasing groundwater availability, coupled with contamination of a large number of aquifers;

c. deterioration of water quality, the result of intensive agricultural practices and of urban and industrial uses;

d. expanding agricultural uses and intensive irrigation developments;

e. increasing environmental concerns and ecosystem considerations, including natural changes and anthropogenic disturbances in the surrounding environment;

f. rapid population growth and significant consumption demands, especially as a result of shifts from rural to urban areas, and;

g. trans-frontier water dependencies, and challenging questions of overlapping and shifting political and administrative boundaries affecting shared water bodies.

© 2005 Tous droits réservés.

1.2 Water Quality

In industrialized countries, faecal contamination of surface water caused serious health problems (typhoid and cholera) in large cities in the mid-1800's. At the turn of the century, cities in Europe and North America began building sewer networks to route domestic wastes downstream of water intakes. While water-borne diseases have been virtually eliminated in the developed world, outbreaks of cholera and other gastro-enteric diseases still occur with alarming frequency in the developing countries. Since World War II and the dawn of the 'chemical age', water quality has been heavily impacted worldwide by industrial and agricultural chemicals. Eutrophication of surface waters from human and agricultural wastes, and nitrification of groundwater from agricultural practices have affected large parts of the world. Acidification of surface waters by air pollution is a recent phenomenon that threatens aquatic life in many areas.

1.3 Nitrate contamination in groundwater - world-wide

Nitrate has been reported above background concentrations in groundwater world-wide and it has been identified to be the most common and widespread chemical contaminant in groundwater (Spalding and Exner, 1993). Background levels of nitrate (as N) in natural groundwater are typically low. Concentrations between 0.45 and 2.0 mg/L have been reported in groundwater in Europe and the USA (Hallberg, 1989; Juergens-Gschwind, 1989) and from 1.15 to 2.3 mg/L in Australia (Lawrence, 1983).

Spalding and Exner (1993) refer to the work of Madison and Burnett, who in 1985 compiled a map of nitrate concentrations in groundwater from analytical data collected over 25 years from more than 87,000 wells. This represented the first comprehensive evaluation of the extent of nitrate contamination of groundwater in the USA. Madison and Burnett reported that the background level of nitrate in aquifers was greater than 3 mg/L ($NO3–N$) in 15 USA states.

In Europe there is a significant contamination of drinking water supplies which has been noted at levels of concern since the 1980s. In the UK this has resulted in the development of thirty *Nitrate Sensitive Areas* in which there is compensation provided for farmers who undertake improved management practices. In addition, groundwater management in the UK includes identification of groundwater protection zones around well heads to minimize groundwater contamination by nitrate and other contaminants, particularly those associated with agricultural practices.

© 2005 Tous droits réservés.

Groundwater contamination with nitrate is a world-wide problem especially in countries that have a high level of agriculture production. Agriculture activities, such as farming, which result in nitrate leaching into groundwater is a "non-point" source of pollution as opposed to effluent that is discharged through an outlet from a sewer system into stream, a "point source" of pollution. Non-point source pollution problems are very difficult to solve and the solution must come through an approach involving many individuals or groups. Once N from any of the various sources is added to the soil, it is subjected to chemical transformations that occur in the nitrogen cycle including transformations to nitrate. Since nitrate ion -in contrast to the ammonium ion- is highly soluble in water and not retained by humus and clay complexes, it is very mobile and easily leaches with percolating water. Nitrate not taken up by plants can get lost to deeper soil layers or after denitrification, to the atmosphere in the gas forms of N_2 or N_2O. The leaching nitrogen is most likely to be in the NO_3^- form, although certain levels of NH_4^+ have been detected in deep horizons.

Nitrate is a form of nitrogen found in soil and aquatic plants. Most plants take up soil nitrogen in the form of ammonium and nitrate in order to satisfy their nitrogen nutrient requirements. Nitrate is highly water-soluble and not strongly held on soil surface. These chemical characteristics of nitrate make it susceptible to leaching down through the soil and into ground water. Non-point source pollution of surface and groundwater has become a topic of increased controversy being fingered as a primary contributor. The threat of groundwater contamination increases under irrigation on sandy soils because mobile contaminants such as nitrate are more easily leached through sandy soils, compounded with possible excess water application. In an effort to reduce non-point source pollution from agricultural lands, producers are encouraged to adopt best management practices, i.e., farming practices capable of reducing nutrient contamination of surface and ground water.

It has been well documented that, in some countries, water supplies containing high levels of nitrate have been responsible for cases of infantile methamoglobinaemia and death. The extent of the worldwide problem has been reviewed by World Health Organization (WHO, 1996). It has been recommended that water supplies containing high levels of nitrate (more than 10 mg/L NO3-N) should not be used for the preparation of infant foods; alternative supplies having low nitrate content, even to the extent of using bottled water, have been recommended. The susceptibility of infants to nitrate has been attributed to their high intake relative to body weight, to the presence of nitrate-reducing bacteria in the upper gastrointestinal tract, and to the greater ease of oxidation of fetal haemoglobin (present in this form for the first few months

© 2005 Tous droits réservés.

of life). Increased sensitivity may also occur when infants suffer gastrointestinal disturbances, which increase the numbers of bacteria that can convert nitrate into nitrite. The stomach pH in infants, being about neutral, enables bacterial growth to occur in both the stomach and upper intestines. Infants, in contrast to adults, are also deficient in two specific enzymes that can convert met-haemoglobin back to haemoglobin (WHO, 1984). There is also a suggestion that pregnant women are at greater risk than the general adult population, but further work is needed to confirm this.

Since ingested nitrates can be readily converted to nitrites, either in the mouth or elsewhere in the body, where pH is high, it is possible that nitrosamines will be produced. It has been shown that the formation of nitrosamines may be increased in individuals with bladder infections and people suffering from achlorohydria (a condition of low stomach acidity). Most of N-nitroso compounds are carcinogenic at high doses in animal tests that make it reasonable to assume that exposure to these compounds might pose a risk of human cancer.

1.4 Problem identification

Gaza Strip is situated on the south west of Palestine. The total area of Gaza Governorates is 378 (km^2), 40 km long and average 7 –12 km wide. The estimated population in 2002 was around 1.3 million inhabitants (PCBs, 2002). That means the area is highly populated due to the high birth rate and Palestinians returning to their homeland. The Gaza Strip is located in a semi-arid zone. The annual rainfall rate in the area ranges from 200 mm in the south to 400 in the north. The District has very limited water resources. The groundwater is the main source for domestic, industrial and agricultural purposes. Salinity of the groundwater increases by time due to seawater intrusion and mobilization of incident deep brackish water, caused by over-abstraction of the groundwater. The groundwater is also contaminated by other pollutants like nitrate due to the use of nitrogen fertilizers and infiltration of disposed raw sewage and the commonly used cesspits where only about 60% of the population are served with sewage systems. The present estimation of the total water demand for all purposes is about 142 Mm^3/year. The main water consumer is the agricultural sector which consumes about 70% of the total water demand while the other 30% are used for domestic and industrial purposes. The sustainable amount of groundwater recharge is about 60 Mm^3/yr which leads to a water deficit of about 80 Mm^3/yr.

There are many anthropogenic activities and agricultural practices that pose a great probability of nitrate pollution of groundwater in the Gaza Strip. These practices and

© 2005 Tous droits réservés.

activities include the lack or inadequate sewage disposal methods, where about 40% of the population uses unprotected infiltration boreholes, and the rest of the population use inadequate sewage system characterized by flooded lagoons in the sandy dunes (naked areas) and streets all over the year. The heavy cultivation of the agricultural land and the need to increase the production lead to excessive use of fertilizers, pesticides, herbicides, and soil fumigants, which have drastic effects on the water quality in the Gaza Strip. Solid wastes (including manure) disposal practices, which mainly include crude dumping in any available open areas without controlling, monitoring, and studies also increase the severity of the water quality problems.

The concentrations of nitrate reach a level up to 600 mg/L, with typical values in the range of 100-200 mg/L; all these values exceed the WHO standard for drinking water (50 mg/L). Different studies and data reflected the severity of the nitrate problem in the majority of the groundwater wells. At present, different organizations monitor the groundwater quality in the shallow wells and wastewater influent and effluent quality. Table (1.1) shows nitrate concentration in groundwater wells in the Gaza Strip as mean values in the period from 1987 to 2002.

The nitrate concentrations in the areas without sewerage system like Khanyounis area is very high, also the nitrate concentration varies within the same area, due to the varying rainfall intensity and human activities in the different areas. The nitrate concentrations in the groundwater in agricultural areas are still substantially lower than in urban areas. The groundwater wells in the northern part of the Gaza Strip - where the soil is sandy and no sewerage system in the area of the wells - have gradual increase in nitrate in the water. On the other hand, nitrate content in the southern part of the Gaza Strip is up to 250 mg/L, where there is no sewerage system and rainfall is about 200 mm/year only. High values of more than 150 mg/L are found in wells inside the refugee camps.

Table (1.1): Frequency of nitrate concentration in groundwater wells in the Gaza Strip
(mean values from 1987 to 2002, 759 wells, and 6427 observation)

NO_3^- Range (mg/L)	No. of wells	Frequency %
0-50	71	9
50-100	293	39
100-150	213	28
150-200	92	12
More than 200	90	12
Total	759	100
Over WHO Limit (50 mg/L)	688	90.06%

© 2005 Tous droits réservés.

Nitrate pollution spreads approximately as fast as groundwater flow. In the present situation the groundwater flow in the shallow aquifer is mainly driven by the abstraction from more than 3500 wells. Each well has more or less its own "groundwater flow system" (EPD, MOPIC, vol.1-1996). According to the above information that describes the situations in Gaza Governorates, the following problems can be defined:

1. Deterioration of groundwater quality with regards to the nitrate pollution.
2. The contribution of each nitrogen source to the overall nitrogen pollution problem.
3. Lack of information and specialized studies about nitrogen sources, transformations and its fate.

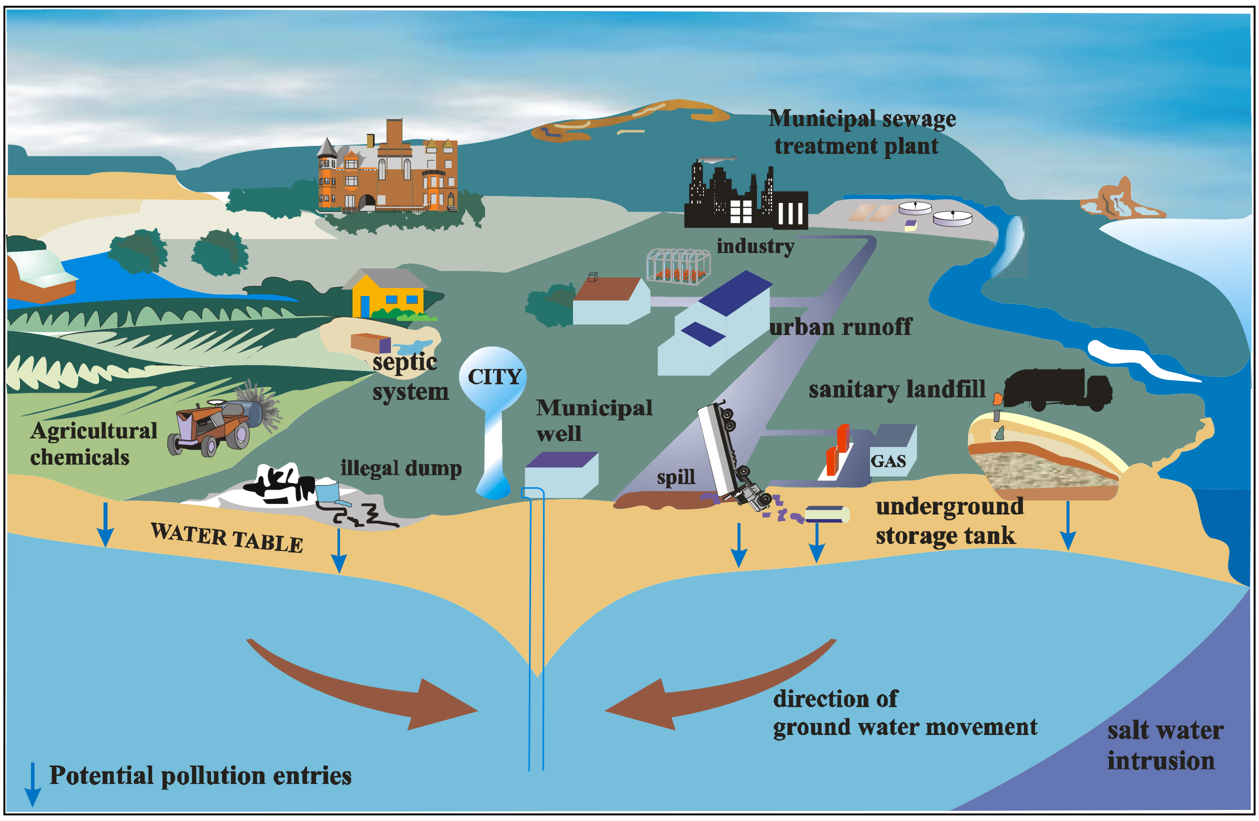

Figure (1.1): Possible sources of groundwater contamination with nitrate

1.5 Research objectives:

Water resources and land use planning can no longer be undertaken in isolation. The watershed or catchment is the appropriate spatial unit for the sustainable management of water. This requires an understanding of the implications of integrated policies with respect to land use, point and non-point source pollution regulation, and the consequences of trade-offs among production, environmental and social objectives. The overall objective of this research is to provide an overview of the current conditions of groundwater systems in the Gaza Strip especially nitrate contamination, and to evaluate the potential for ongoing problems of nitrate contamination. Also, the research aims at determining the factors

© 2005 Tous droits réservés.

affecting the quality of groundwater resources, from both point source and diffuse inputs; elucidating the spatial and temporal interactions with the environment that influence water resources; quantifying the groundwater consequences and interactions of pollutants.

Specifically the research will:

- Describe and quantify the dominant transport processes involved in the movement of nitrate solute in order to interpret the mechanisms controlling the production, consumption and transfer of nitrogen, and the role of land use and environment in modifying temporal and spatial signals.
- Determine all possible sources and sinks of nitrogen to quantify their contribution and effect.
- Define the extent of nitrate contamination within local groundwater systems and to further investigate the source(s) of elevated nitrate in groundwater.
- Predict the impact of environmental and land use change on the groundwater quality at different spatial scales.
- Find the relation among urban groundwater chemical quality (major cations and anions) and hydrological factors as well as land use factors in the Gaza Strip coastal aquifer
- Recommend further work on groundwater contamination processes, including generation of data, research and establishment of groundwater monitoring programs, and possible ways to improve the groundwater quality status.

1.6 Methodology

The first step in this study was applying the nitrogen balance approach since no study tackles this problem in the area. This approach requires a lot of data and information about many aspects concerning the sources and sinks of nitrogen in the study area. Most of these data are dispersed in different places and many are not available. If there were no data available, comparisons with similar situations were made, and if that was not possible assumptions were postulated. Also, a number of cases has been used to develop an appreciation of the key nitrate contamination processes and draw conclusions on the significance of the key factors for nitrate contamination of groundwater in the Gaza Strip. The factors that may have significant effects of groundwater contamination were studied. Statistical methods were used to model the factors that have influential effect on groundwater pollution problem. Since most of the data are not linearly related, the Artificial Neural Networks (ANN) modelling were used as new scientific tools to investigate the situation and analyze the system

© 2005 Tous droits réservés.

behaviour in order to draw the complete picture about the groundwater pollution and the fate of surplus uses of nitrogen compounds. Major groundwater chemical characteristics were studied by different methods of analysis including univariate, bivariate and multivariate statistical methods. The ANN model was also used to find the relation between groundwater chemical quality and urban and environmental factors.

1.7 Selection of the study area

The area of the Gaza Strip has been divided to five case studies to investigate a variety of different situations which potentially result in groundwater contamination. The approach taken has been to identify the most suitable factors to characterize the key issues for a type of contaminants sources. Information about land uses, aquifer conditions and environmental factors were used to understand the processes that lead to groundwater contamination. The following criteria were used to select the study area:

- Relative significance of nitrate contamination;
- Land use(s) in the study area;
- Hydro-geological setting; and
- Environmental factors with respect to the geographic location.

1.7.1 Relative significance of the groundwater quality problem

Initial screening of the study areas involved identifying areas where:

- The groundwater chemical quality and its concentration are known to likely exceed the world heath organization guideline (WHO limits);
- There was high demand for groundwater or a potential for major impacts of major chemical quality to contaminate groundwater.

1.7.2 Land use

Land use takes into account the nature of the contamination source (natural or/and anthropogenic) that may affect groundwater quality in the study area. It includes the typical loading of nitrate generated from the land use, and the distribution of the nitrate as either a point source or distributed source. The following pollution sources were considered in this research:

1. Wastewater (Sewer systems discharge - Leakage from sewer system - areas not served by sewer system - Industrial wastewater)
2. Solid waste
3. Organic and inorganic fertilizers

© 2005 Tous droits réservés.

4. Leakage from distribution networks
5. Precipitation
6. Sludge Disposal

The following land usage and environmental factors were considered:

1.7.3 Land-Usage:

- Conservation - Recreation - Agriculture - Residential - Industrial and commercial - Mixed land use

1.7.4 Environmental Factors:

- Hydrology: Water table – depth to water table – screen depth - well discharge – well location
- Soil permeability

© 2005 Tous droits réservés.

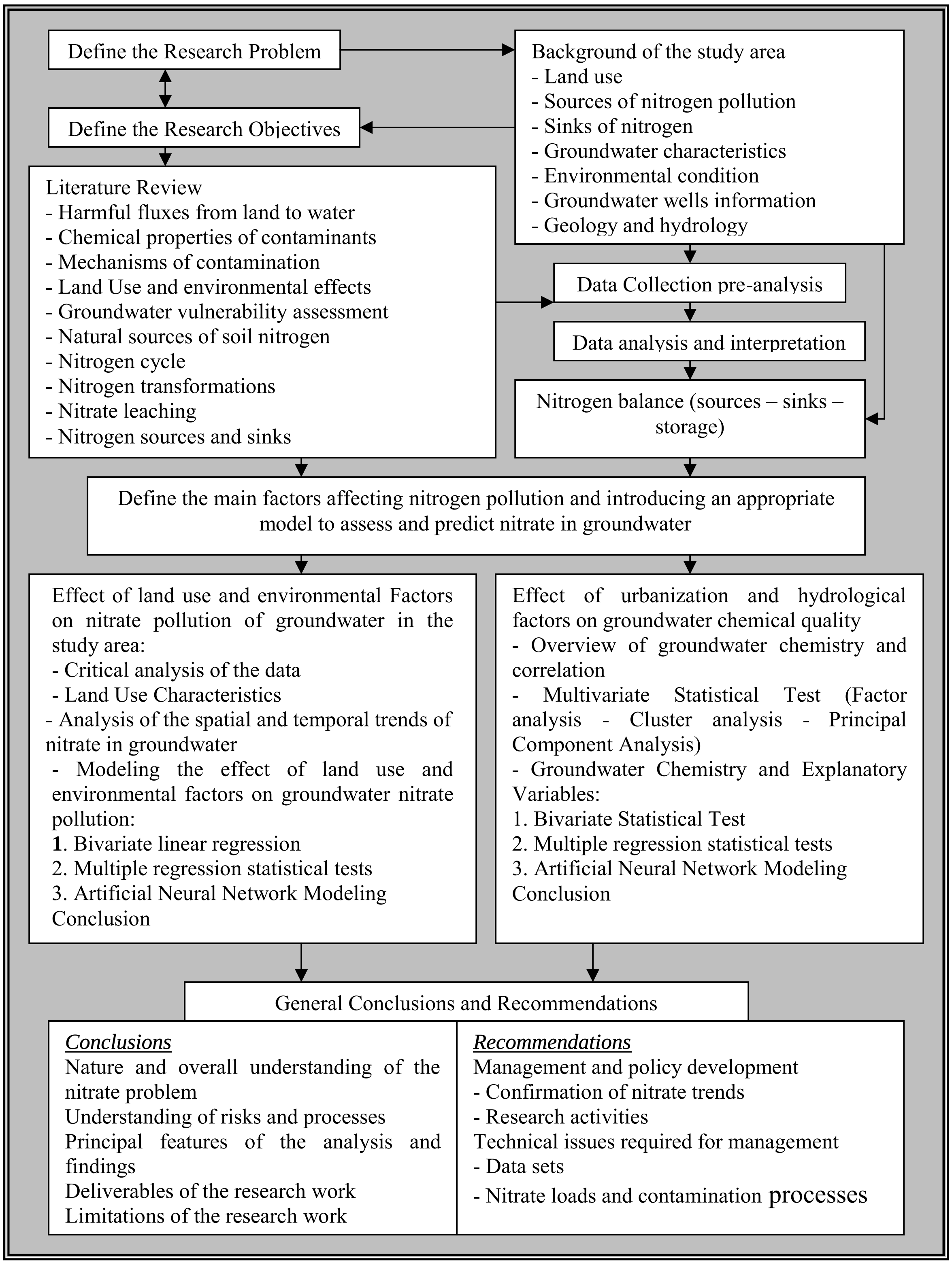

Figure (1.2): Schematic diagram of study methodology

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

1.8 Report Format

This study consists of seven chapters.

- Chapter one includes introduction on general information and view about groundwater pollution, problem identification, study objectives and methodology as well as materials used in order to tackle the study objectives and to find the possible ways to solve the problems were specified.

- Chapter two covers a general literature review on the nitrate pollution including nitrogen cycle, nitrogen balance, nitrogen sources and sinks, the possible ways for nitrate transport mechanisms and leaching.

- Chapter three describes the study area with respect to geology, hydro-geology and climate, agricultural activates, wastewater and solid waste treatment practices and finally water quality of the study area.

- Chapter four discuses major sources of nitrogen in the Gaza Strip, nitrogen transformation within each system, and the contribution of each source of nitrogen in nitrate pollution problem in the study area.

- Chapter five includes the results obtained and the analysis of the data collected in chapter four, statistical analysis and application of artificial neural networks regarding the significance of nitrate contamination in groundwater in Gaza aquifers; the factors affecting existing and future nitrate contamination of groundwater, the ranking of the most significant land use and site conditions affecting the concentration of nitrate in groundwater.

- Chapter six discusses the urban groundwater chemical quality with regards to major cations and anions, hydrochemical interpretation of the quality of groundwater, and modelling the effect of urbanization and hydrological factors on groundwater contamination as a prediction tool.

- The data and information gained from chapter four, five and six were utilized to conclude and recommend the possible ways to overcome groundwater chemical pollution problem in the Gaza Strip (Chapter Seven).

© 2005 Tous droits réservés.

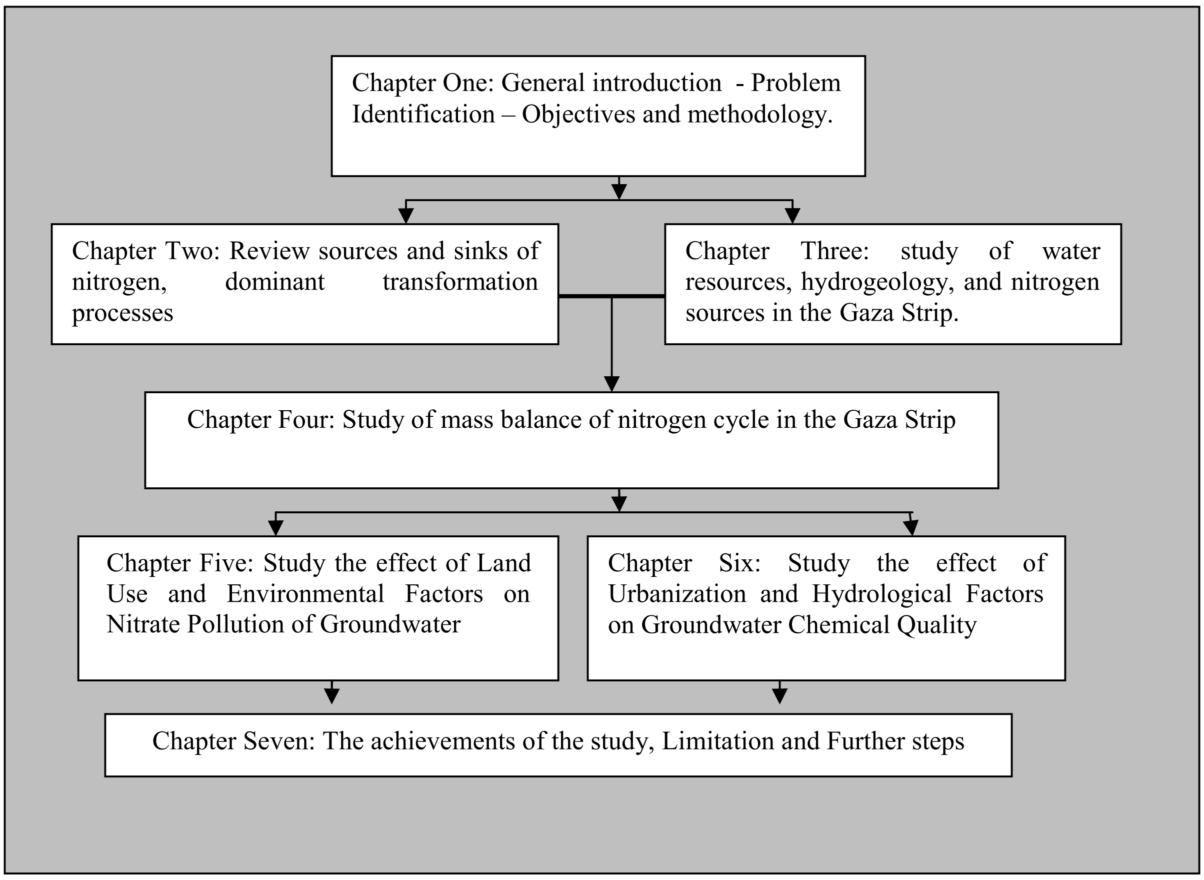

Figure (1.3): Thesis Structure (Report Format)

© 2005 Tous droits réservés.

Chapter 2

Literature Review

2.1 Integrated Water Planning and Management in the Mediterranean Region

Integrated Water Resources Management is becoming recognized as the only sustainable solution for water shortages. This holistic water resources approach, referred to as the Dublin-Rio principle (UNCED, Rio De Janeiro, 1992), highlights that fresh water is finite, vulnerable and that it is essential to sustain life, economic development and the environment. Water development and management should be based on participatory approach, involving users, planners and policy makers at all levels.

The 21 coastal states of the Mediterranean Sea have a total population of 427 million inhabitants. About 145 million live near the sea in addition to about 180 million tourists each year. By 2025 the population is expected to increase by 17-19% and the tourist population by 40%. Eleven countries in the Mediterranean region are predicted to have used more than 50% of their renewable water resources by 2010. In 2025 the percentage used is predicted to exceed 100% in 8 countries and more than 50% in the others (Bruce Durham, 1999).

The threat of recurrent critical water shortages led to many official regional declarations, such as the Genoa Declaration of the Mediterranean Action (1985) and the Mediterranean Charter for Water in Rome (1992). During the 1990s, at least two more ministerial conferences on water were held with the participation of all Mediterranean countries. More recently, other efforts include the coming together of the European Union in co-operation with its Mediterranean partners in Barcelona, in November 1995, establishing the "Euro-Mediterranean Partnership Policy". These principles and objectives are an extension of earlier Declarations at the European Council level (Lisbon, Corfu, Essen and Cannes), as well as part of the European Commission's programme of international co-operation through the Fourth and now Fifth Framework Programme for Research and Technology Development (RTD).

Water-related research and technology development has been a high priority, as expressed in scientific co-operation efforts in programmes. Three lines of action have emerged in the context of scientific and technological co-operation between the European Union and the

© 2005 Tous droits réservés.

Mediterranean Partner Countries, namely: capacity building, joint research projects, and technology transfer. Most of the RTD projects implemented in this context address comprehensive management approaches directly or indirectly. They would included a mixture of different considerations such as natural conditions (e.g. aridity, global change); variety of uses (irrigation, municipal uses, water quality, effluent control, etc.); sources of supply (surface, groundwater, mixed); technological considerations (wastewater treatment and reuse, desalination, use of renewable energies, etc.) and socio-demographic conditions (population growth, urbanization, industrialization, etc.).

RTD on the efficient use of water resources, as well as on the optimization of water uses by the different users, is largely promoted by these programmes. Important results have been achieved so far and more research is undoubtedly needed. At present, however, the main weakness in most countries of the region is not a lack of knowledge, but that of planning, education and training, transfer of new technologies and implementation of existing regulations.

2.2 Conclusions

Essentially, water resources planning and management should combine a space-time-quantity-quality balance. To simply repeat that the Mediterranean Basin is a water-stressed area requiring considerations of both natural and socio-economic factors which are no longer sufficient. What must be considered is a joint approach to the problems of water quantity and quality, as well as addressing the unique characteristics of arid or semi-arid climates, which make surrounding environments much more vulnerable to environmental assaults. In addition, integration should reflect the concern of trans-boundary water challenges and of policies and implementation mechanisms that transcend artificial administrative boundaries. No country in the region can be economically and socially stable without an adequate water supply. But supplies in the region are so tight *that only an equitable share of water resources will permit sustainable development*.

2.3 Measures for Minimizing Harmful Fluxes from Land to Water

The focus is on how to minimize harmful fluxes from human activities to air, land and water. These fluxes eventually reach groundwater aquifers and water bodies through fall-out, erosion, leaching and contamination from waste and wastewater, thereby threatening future water supplies, human health, aquatic ecosystems and fisheries. Understanding the spatial and temporal interactions of land use, the associated potential sources of contamination, and

© 2005 Tous droits réservés.

the intrinsic susceptibility of a ground-water resource are key to determining the geochemical system, and ultimately, the vulnerability of groundwater to contamination. The potential sources of anthropogenic contamination usually exist along the boundary of the ground-water system with contaminants entering the ground-water system with recharge water.

Sources of contamination such as poor well construction and underground point sources such as septic and storage tanks also can become significant issues on a local scale. In addition, the source area for a groundwater supply can change over time as stresses on the resource change. Natural sources of contamination depend on aquifer mineralogy and geochemical conditions, and can occur anywhere in an aquifer or water supply on local as well as regional spatial scales.

The source of contamination is usually classified in space as either a point source or a non-point source. A point source is a contaminant release at one specific location, whereas a non-point source is a release over a widespread area. The source of contamination is also classified in time as either a continuous source or an instantaneous (one time) source. A continuous source is a contamination that is released over a long period of time, whereas an instantaneous source is a contamination that is released at only one time. The type of contamination source in space and time (that is, point source, non-point source, continuous source, instantaneous source) is important in determining the resulting spatial and temporal distribution of concentrations within a ground-water system. In some cases, the cumulative effects of point sources in proximity with each other can have similar characteristics to one or more non-point sources of contamination.

2.3.1 Urban sources

The tremendous speed of the population growth in many developing country cities, often doubling in only 10-20 years, is much faster than the city authorities can ever manage to run. Growing cities often destroy their own water sources, while the new sources, further and further away, rapidly tend to get insurmountably costly. This makes water reuse within the city an interesting alternative. Another fundamental dilemma is that processes of wealth generate huge amounts of pollution load, which increases much quicker than the population and the GNP. While the population load doubles, the pollution load tends to increase 5-10 times, even more in some cases.

© 2005 Tous droits réservés.

2.3.2 Industrial Sources

The principal issue is how to minimize harmful fluxes from industrial activities to air, land and water. Such fluxes may emerge from different production phases: raw material treatment, production and refining, consumption and after-use of products. Industrial development is generally seen as a crucial key to economic development and income generation. A fundamental drawback is, however, the massive production of waste and the escalating toxification of fresh-water that tends to follow. The transfer of industrial models developed in temperate climate, with plenty of dilution water available in the rivers, to regions with a long dry season in tropics and subtropics has been a major mistake. In some developing countries, industry's output of some pollutants may grow five times more rapidly than its economic output. Moreover, the United Nations Industrial Development Organization’s (UNIDO) projections for Southeast Asia have suggested a ten-fold increase in certain pollution loads in the next 30 years. The Symposium questioned whether the main objective of business should really be pure profit or be broadened to be socially acceptable.

2.3.3 Agricultural sources

Here the focus is on how to demonstrate and discuss global exports and imports of nutrients, and how to reduce the enormous present-day losses of nutrients and agricultural chemicals from arable lands to groundwater aquifers and surface waters. Particular emphasis was placed on integrated land/water management with the aim, on the one hand, of protecting soil structure and fertility and, on the other, of avoiding water pollution by nutrients, herbicides and pesticides, and using scarce water resources rationally so as to minimize salinisation and water logging.

2.4 Threats to groundwater quality

The ‘looming water crisis’ is becoming a major issue on the world agenda for the twenty-first century. The World Water Council presented the ‘World Water Vision’ during the Second World Water Forum and Ministerial Conference at The Hague in March (Cosgrove, W. J.; and Rijsberman F.R. (2000). The Vision reported that 1.2 billion people or one fifth of the world population do not have access to safe drinking water, while half of the world population lack adequate sanitation. The Vision document further states that ‘rapidly growing cities, burgeoning industries, and rapidly rising use of chemicals in agriculture have undermined the quality of many rivers, lakes, and aquifers’ and also emphasizes that ‘the impacts of agriculture on water quality are less visible over time but at least as dangerous as

© 2005 Tous droits réservés.

industrial, because many of the fertilizers, pesticides, and herbicides used to improve agricultural productivity slowly accumulate in groundwater aquifers and natural ecosystems.

The term quality of groundwater refers to its physical, chemical, and biological characteristics as they relate to the intended use of water. Groundwater quality is threatened mainly by human activities, although harmful substances are sometimes introduced by natural processes such as flooding and earthquake. Sustainable groundwater management must be based not only on prevention of the overexploitation of groundwater resources but also on prevention of contamination, because unlike treatment at the point of use, prevention protects all of the resource.

2.5 Chemical properties of contaminants

Contaminants can be transformed by geochemical, radiological, and microbiological processes as they are transported through various environments within the groundwater system. Some chemical transformations can change harmful contaminants into less harmful chemical species, while other processes can produce compounds that are more harmful to ecosystems or human health than the parent compound. The natural decay of some radionuclides can produce daughter products with different transport properties and health effects than the parent product (Focazio and others, 2000).

In some cases, transformation products are found in the environment more often than parent compounds (Kolpin, and others, 1997). For example, groundwater remediation programs are increasingly focused on natural attenuation processes controlled by mixing, advection, and biodegradation as these processes serve to decrease concentrations and (or) viability of contaminants (Chapelle and others, 2000).

Similarly, some chemical transformations can change relatively immobile compounds into highly mobile compounds, and change parent compounds to transformation products. Knowledge of the path and timing of groundwater movement as well as the chemistry and biology relevant for the contaminant present is important in determining the fate and transport of a contaminant and its associated transformation products. This is important for contaminants that rapidly change to other chemicals in the environment particularly when transformation or daughter products are more persistent than the parent compound.

© 2005 Tous droits réservés.

In addition, the vulnerability of a groundwater supply to many contaminants is dependent on the solubility and subsequent mobility of the contaminant as influenced by the specific mineralogy and associated geochemical conditions within the aquifer and pumped well. For example, naturally occurring arsenic can be tightly bound to aquifer materials in certain geochemical conditions but can be subsequently released to the pore waters of the aquifer if those conditions are changed, Welch and others, (2000). The chemical properties of a contaminant are important in the unsaturated zone as well as the aquifer itself. For example, some (hydrophobic) compounds strongly attach to soils in the unsaturated zone (as well as the saturated zone) before reaching the water table, and these compounds are attached until released by geochemical or other changes such as when the binding capacity of the soil is exceeded.

2.6 Mechanisms of contamination

The contaminant introduced into the soil-rock-groundwater system will spread within the system only if a transport mechanism is available, for example, a flowing liquid. As soon as the contaminant reaches the subsurface water in the unsaturated or saturated zone, various processes determine its fate (Jackson, R.E., 1980):

- Physical processes: advection, dispersion, evaporation, filtration, and degassing;
- Geochemical processes: acid-base reactions, adsorption-desorption, ion exchange, oxidation-reduction, precipitation-dissolution, retardation, and complexation; and
- Biochemical processes: transpiration, bacterial respiration, decay, and cell synthesis.

Many of these processes are related to each other or interact. Some of them may attenuate the contaminants, some have a reverse effect. The soil zone is the most reactive part of the system due to the soil-water-air environment, the soil-plant behaviour, and the microbiological activity. Short-circuiting of this zone makes the soil-rock-groundwater system much more vulnerable. Because groundwater travel times are relatively slow, contaminants can persist for long times in groundwater environment (Walton R. et. al. 2000).

Contaminants are carried by moving groundwater (advection) and travel at the same rate as the average linear velocity of groundwater. The process of dispersion acts to dilute the contaminant and lower its concentration. For example, because of hydrodynamic dispersion, the concentration of a waste plume will decrease with distance from the source. Dispersion increases with increasing groundwater velocity and aquifer heterogeneity. However, for

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

removal of bacteria and viruses by filtration, a fine-grained and homogeneous material is needed. Volatile bacterial products, such as carbon dioxide, nitrogen, or methane, and volatile organic compounds may be removed by degassing.

Chemical reactions, such as adsorption-desorption and ion exchange can retard the rate of contaminant movement. Adsorption and desorption are characterized by the distribution coefficient, which expresses the ratio of the amount of contaminant adsorbed per gram of soil material to the amount of contaminant remaining in groundwater per millilitre. The distribution coefficient can be used to compute the retardation of the movement of the contamination front (Fetter, C. W., 1994). Bacteria use the reaction energy of oxidation-reduction (redox) reactions for their metabolism. After free oxygen is used up, anaerobic bacterial respiration may successfully reduce nitrate, Sulphate, and even carbon dioxide and decompose organic compounds. Recent research has given strong evidence that many toxic organic chemicals can undergo microbial decay to more simple compounds.

The mechanisms mentioned above are illustrated here with an example of nitrogen (nitrate and ammonium) contamination by fertilizers. Some of the nitrogen released from the fertilizers will be taken up by crops. Evaporation concentrates the leachate. Further, a part of the dissolved nitrogen will be removed, and another amount will be added to the soil water. Removal takes place by bacterial cell synthesis and further by nitrate respiration under anaerobic conditions, when bacteria break nitrate down to molecular nitrogen. Decay (mineralization) of litter by bacteria will add nitrate and ammonium to the system.

Ammonium ions will be adsorbed on clay particles, but are under aerobic conditions subsequently oxidized to nitrate, which is very mobile. The nitrate moves with the infiltrating water to the saturated zone (advective transport) and is diluted by dispersion. The dispersive capacity of the porous medium is directly proportional to the pore-water velocity and the heterogeneity of the aquifer materials. During residence in an anaerobic saturated zone, nitrate may be reduced by pyrite according to:

$2FeS_2\,(s) + 6NO_3^{\,-} + 4H_2O = 2Fe(OH)_3\,(s) + 3N_2\,(g) + 4SO4_{2}^{\,-} + 2H^{+}$, where

s = solid and g = gas.

During oxidation, pyrite may release heavy metals, e.g. bivalent Cd, Ni, or Zn, which become mobile under acidic conditions or by complexation with organic substances and may contaminate the groundwater. Figure 2.1 shows the processes that cause contaminant attenuation.

© 2005 Tous droits réservés.

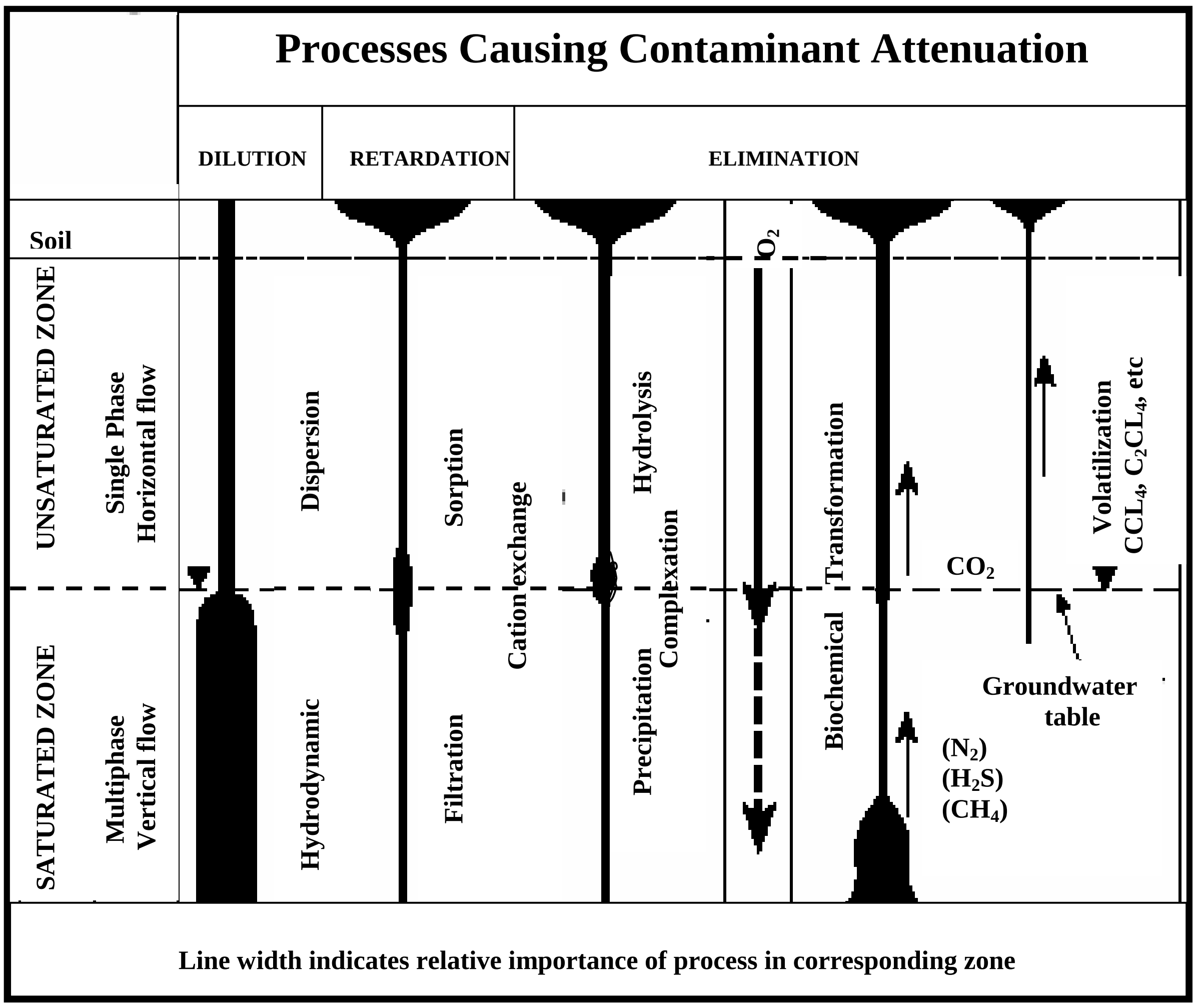

Figure (2.1): Processes promoting contaminant attenuation in groundwater systems (after Gowler, 1983).

2.7 Overview of major chemical groundwater quality parameters

2.7.1 Electrical Conductivity

Conductivity is the measurement of the ability of a solution to carry electric current. As this ability is dependent upon the presence of ions in solution, a conductivity measurement is an excellent indicator of total dissolved solids in water. The unit of conductivity is mS/cm (MilliSiemens per cm). For most waters a factor in the range of 0.55-0.70 multiplied by conductivity gives a close approximation to the total dissolved solids in mg/l. The values more than 2mS/cm (1000 mg/l total dissolved solid) is considered unsuitable for domestic purposes.

2.7.2 Chlorides

Chlorides, compounds of chlorine with another element or radical are present in nearly all natural waters and the range of concentrations can vary widely, but the most concentrations are with sodium (NaCl, “common salt”) and, to a lesser extent, with calcium and magnesium.

© 2005 Tous droits réservés.

They are one of the most stable components in water, with concentrations being unaffected by most of natural physiochemical or biological processes. The presence of chloride in natural waters in general can be attributed to dissolution of salt deposits, discharges of effluents for chemical industries, oil-well operations, sewage discharges, irrigation drainage, contamination from refuse leachate, and seawater intrusion in coastal areas. The WHO standard of chloride in the drinking water is 250 mg/L. The main sources of high salinity of groundwater and consequently the chloride concentration are seawater intrusion and salt water upconing.

2.7.2.1 Seawater Intrusion

Seawater Intrusion is defined as the migration of saltwater into fresh water aquifers under the influence of groundwater development (Freeze and Cherry, 1979). Saltwater intrusion becomes a problem in coastal areas where aquifers are hydraulically connected with seawater. When large amounts of fresh water are withdrawn from these aquifers, hydraulic gradient encourage the flow of seawater towards the pumped well or wells.

- **Saltwater intrusion can have natural causes or be due to human activities:**

  - Natural causes can be tectonic movement, sea level rise and climate changes resulting in a decrease of the natural recharge of the groundwater.

  - Human activities, such as groundwater abstraction, land reclamation and land drainage, result in drawdown of the groundwater tables and piezometric levels and inflow of saline groundwater, leading to a rise of the interface between fresh and saline groundwater, with its harmful consequence on wells and the occurrence of saline or brackish seepage, (Qahman, 1998).

- **Saltwater Upconing**

The term saltwater upconing is used to describe the local movement of saltwater from a deeper saltwater zone upward into the fresh groundwater in response to surface water abstractions or pumping. Due to the groundwater discharge, the underlying saltwater migrates vertically upward in the shape of a cone or mound. Pumping of wells from the freshwater zone can disturb the regional salt/freshwater equilibrium. A saline water cone develops in the underlying interface or transition zone, and the well discharge may become saline. This is governed by the discharge rate, hydrodynamic dispersion, and the duration of pumping and local hydrological condition.

© 2005 Tous droits réservés.

2.7.3 Sodium

The sodium ion is ubiquitous in water owing to the high solubility of its salts and the abundance of mineral deposits. Seawater contains about 10 g/l of sodium. The highest fresh water levels are found in groundwater. Elevated levels of sodium are associated with groundwater in areas where there is an abundance of sodium mineral deposits or where there has been contamination from seawater intrusion. The WHO standard limit of sodium in drinking water is 200 mg/l. Excessive intake of sodium chloride causes vomiting and elimination much of the salt. Acute effects may include convulsions, muscular twitching and rigidity, and cerebral and pulmonary oedema. Acute effects and death have been reported in cases of accidental overdoses of sodium chloride. Infants with severe gastrointestinal infections can suffer from fluid loss leading to dehydration and raised levels in the plasma (**Hypernatraemia**); permanent neurological damage is common under such conditions (WHO, 1996).

2.7.4 Nitrate

Water analysts in terms of nitrogen, i.e. mg/l N, usually express nitrite (NO_2^-) and Nitrate (NO_3^-) as the total oxidized nitrogen which is the sum of nitrite and nitrate nitrogen. Nitrite is an intermediate oxidation state of nitrogen in the biochemical oxidation of ammonia to nitrate and in the reduction of nitrates under conditions where there is a deficit of oxygen. The presence of nitrites in a groundwater may be a sign of sewage pollution; it may have no hygienic significance. Nitrates in groundwater can be reduced to nitrite, especially in areas of ferruginous sands, and new brickwork in the wells is also known to produce a similar effect. Nitrate is the final stage of oxidation of ammonia and mineralization of nitrogen from organic matter. Most of this oxidation in soil and water is achieved by nitrifying bacteria and can only occur in a well-oxygenated environment.

2.7.5 Hardness

Hardness enters a water supply when calcium and magnesium salts are dissolved by groundwater. It can be present in many forms including the bicarbonate, Sulphate, and chloride salts which are the most common. Each will cause its own form of trouble. Carbonate hardness is the result of rainwater dissolving limestone, i.e., calcium and magnesium carbonate. They are formed when water dissolves carbon dioxide gas to form carbonic acid. This weak acidic water is aggressive and tends to dissolve many minerals with which it comes in contact. When it dissolves limestone, it forms solutions of calcium and/or magnesium bicarbonate.

© 2005 Tous droits réservés.

2.7.6 Calcium

Calcium is found in most natural waters, and its level depends upon the type of rock through which the water has passed. It is usually present as carbonate or bicarbonate and Sulphate, although in waters of high salinity, calcium chloride and nitrate can also be found. Calcium contributes to the hardness of water with the bicarbonate forming temporary or carbonate hardness and sulphates, chlorides, and nitrates forming permanent or non-carbonate hardness. There is no health-base guideline value recommended by the WHO for water calcium. The taste threshold for the calcium ion is in the range of 100-300 mg/l depending on the associated anion.

2.7.7 Magnesium

Magnesium is one of the earth's most common elements that forms highly soluble salts. Magnesium contributes to both carbonate and non-carbonate hardness in water, usually at a concentration considerably lower than that of calcium component. Excessive concentrations of magnesium are undesirable in domestic water because of problems of scale formation and also because magnesium has a cathartic and diuretic effect, especially when associated with high levels of Sulphate.

2.7.8 Alkalinity

Alkalinity is one important natural parameter in the groundwater, and it is the sum of carbonates, bicarbonates, and hydroxide ions usually associated with calcium, magnesium and potassium. Analyses often quote alkalinity in terms of CaCO3 instead of carbonate and bicarbonate content. This is a convenient form of expression whereby the sum of the constituent salts is expressed in equivalent terms of calcium carbonate. The bicarbonate alkalinity is in equilibrium with carbon dioxide in the water between pH values 4.6 and 8.3. Above pH 8.3 free carbon dioxide ceases to exist and combines to give both carbonate and bicarbonate alkalinity. Between pH values 9.4 and 10 the alkalinity is all due to caustic or hydroxide alkalinity. No limits are set for alkalinity levels in water, although high concentrations of sodium bicarbonate can give rise to taste problems. The level of alkalinity is also important in chemical coagulation because of the buffering capacity it imparts to the water.

2.7.9 Fluoride

The natural fluoride content of water in different areas varies according to the source of water, the geological formation of the area, the amount of rainfall, and the quantity of the

© 2005 Tous droits réservés.

evaporation. The presence of fluoride bearing minerals (fluorspar, cryolite, fluorapatite etc.) and gases is essential for the occurrence of fluoride in water. The ultimate concentration of fluoride, however, depends also on climatological and geochemical conditions in the region (Schuiling, 1994). It is now generally accepted that fluoridation of water supplies to a level of 1mg/L F is both safe and effective in substantially reducing dental caries.

2.8 Land Use and environmental effects on Groundwater quality

Local land use alteration whose objective are usually based upon short-sighted economic benefit to owners, give little concern to integration with the regional unit of which the plots in question are a part. The euphemistic term "development", applied to land use alteration has largely taken the pragmatic form of engineering for short-term economic objectives losing sight of longer-term imaginative perspectives of ambient landscape architecture. The human quest to subdue nature has replaced the ability to integrate with natural realities and beauty (Naveh Z., 1977). The results of an imbalance situation of land use leads to adverse effects on human behaviour and the quality of life as well as on available quantity and quality of water resources.

The spread of cities and their attendant utilities over the landscape has encouraged the growth of urban blight. Parallel to this urbanization follows a sharp increase in demand for groundwater resources and a concomitant rise in anthropogenic pollution percolating to the water tables of phreatic aquifers (Lerner DN., 1997). Expansion of industrial and commercial, agricultural, and residential land-usage then demands matching expenditures for groundwater recharge and treatment. Over-exploitation of groundwater resources can result in a non-sustainable situation in which ‘mining’ ultimately leads to rapid depletion of groundwater levels. This can lead to deterioration of the aquifer matrix, subsidence of upper layers of the aquifer, and loss of water resources (Schultz GA, Hornbogen M. 1995).

Where salinity sources can subsequently intrude into the aquifer, an unbalanced situation could ensue, leading to a decline in groundwater quality and storage. This stressed situation that currently afflicts the environment, natural resources, and human quality of life results from inadequate planned land-use alterations and groundwater resource management. In urban areas this appears in an increase in concrete, tree-less with contaminated air and water, deplettion of natural resources for future needs.

© 2005 Tous droits réservés.

Because, accessing to groundwater in order to fulfil requisite usage needs is generally not significantly considered in the planning stages of land-use alterations, the pollution potential of such alteration upon region resource sustainability is often not a factor in such decision-making (Meybeck M, Chapman D, Helmer R. 1990; Howard K, Eyles WF, Livingstone S. 1996; Melloul AJ, Goldenberg LC. 1994). In consequence, humanity should extract itself from its artificial and utilitarian world by connecting planning of land-uses in accordance with the natural environment. Contributory natural environmental factors affect the limitation provided by protective shield of soil and rock above the water table of phreatic aquifers. These include low slopes, shallow water table, high recharge and hydraulic conductivity, permeable soils, low natural groundwater, high coefficient recharge, etc. Such natural aspects of the ambient environment can become un-sustainability factors with regard to maintenance of groundwater quality.

In the steady-state situation of coastal aquifers water drains towards the seashore. Excessive pumpage clearly has a severe detrimental effect upon groundwater reservoirs. Water tables drop, significantly alter groundwater flow directions. Where excessive pumpage situations apply, saline seawater inland reservoirs is a phenomenon that can make salinisation almost irreversible (Goldenberg, Mandel, & Magaritz, 1986). Improper aquifer management, characterized by insufficient long-term considerations, can thus have significantly adverse consequences. Urbanization in coastal regions is most often accompanied by a rise in anthropogenic pollution percolating to water tables of coastal phreatic aquifers. The magnitude of percolation and subsequent pollution potential in such areas can be assessed by empirical models such as DRASTIC models (Aller, Bennet, Lehr, & Petty, R. J. 1985; Andersen & Gosk, 1989; Van Stempvort, D., Ewart, L., & Wassenaar, L. 1933).

Groundwater quality deterioration is a function of many factors. These include the ability of the intervening unsaturated zone and soil media to transfer fluids from the ground surface to the water table of phreatic aquifers. However, an equally significant concern is the potential of any specific land-use to contribute to percolating pollutants. Ideally "time of arrival" as a numerical value, would be the ideal basis for vulnerability assessment with regard to the potential at any point for groundwater pollution. In fact, the unsaturated zone and soil act as the key factors determining percolation potential at any point.

In the saturated zone, hydraulic conductivity (k) values can provide key assumption. However, within the unsaturated zone, owing to the lack of meaningful conductivity (k)

© 2005 Tous droits réservés.

values in this zone, a theoretical time of arrival model is not presently workable. Only empirical extrapolation of field values can approximate time of arrival estimation. Therefore, the use of environmental and land-use impact consideration remains the most meaningful representation of true vulnerability of groundwater resources to potential anthropogenic pollution from ground surface.

So, effective land use and natural resource planning processes must ultimately be integrated. Sustainable development of groundwater is critical to urban planning. Integrated land use and natural resources planning must simultaneously consider social and economic concerns and amenities, ecological and esthetical requirements, in the context of sustainable groundwater development.

2.9 Uses of Groundwater Vulnerability Assessment

A groundwater vulnerability analysis identifies regions where groundwater is likely to become contaminated as a result of human activities. The objective of vulnerability analyses is to direct regulatory, monitoring, educational, and policy development efforts to those areas where they are most needed for the protection of groundwater quality. Fundamentally, this is an economic goal, rather than a scientific one. Vulnerability analysis should provide an answer to the question "Where groundwater protection efforts should be directed to gain the most environmental and public health benefits for the least cost?"

Comprehensive review of groundwater vulnerability assessment methods is presented in the USA National Research Council (NRC, 1993) report. The report divides groundwater vulnerability assessment methods into three categories: (1) overlay and index methods, (2) methods employing process-based simulation models, and (3) statistical models (4) checklists.

2.9.1 Overlay and Index Methods. Overlay and index methods or parameter weighting methods, combine maps of parameters considered to be influential in contaminant transport. Each parameter has a range of possible values, indicating the degree to which that parameter protects or leaves vulnerable the groundwater in a region. Depth of the groundwater, for example, appears in many such systems, with shallow water considered more vulnerable than deep.

The simplest overlay systems identify areas where parameters indicating vulnerability coincide, e.g. shallow groundwater and sandy soils. More sophisticated systems assign

© 2005 Tous droits réservés.

numerical scores based on several parameters. The most popular of theses methods, DRASTIC (Aller, et al. 1985) uses a scoring system based on seven hydrogeologic characteristics of a region. The acronym DRASTIC stands for the parameters included in the method: **D**epth to groundwater, **R**echarge rate, **A**quifer media, **S**oil media, **T**ransport, **I**mpact of vadose zone media, and hydraulic **C**onductivity of the aquifer.

DRASTIC is applied by identifying mappable units, called hydrogeologic settings, in which all seven parameters have nearly constant values. Each parameter in a hydrogeologic setting is assigned a numerical rating from 0–10 (0 meaning low risk; 10 meaning high risk) which is multiplied by a weighting factor varying from 1 to 5. Two sets of weights, one for general vulnerability, and another for vulnerability to pesticides can be used. A score for the setting is calculated as the sum of the seven products. DRASTIC scores are roughly analogous to the likelihood that contaminants released in a region will reach ground water, higher scores implying higher likelihood of contamination. DRASTIC is used to produce maps of large regions showing their relative vulnerability.

Several other overlay and index systems for groundwater vulnerability assessment exist. Typically, such systems include variables related to groundwater recharge rate, depth to the water table, and soil and aquifer properties. The relative importance of the variables and the methods for combining them vary from one method to another, but all share some common traits. In general, overlay and index methods rely on simple mathematical representations of expert opinion, and not on process representation or empirical data.

2.9.2 Mathematical Models. Process-based mathematical models such as PRZM, GLEAMS, and LEACHM can predict the fate and transport of contaminants from known sources with remarkable accuracy in a localized area by applying fundamental physical principles to predict the flow of water in porous media and the behaviour of chemical constituents carried by that water. In the hands of knowledgeable analysts with the appropriate site-specific information, such models allow threats to the safety of groundwater supplies to be recognized and can play an important role in planning remediation efforts. Unlike other groundwater quality prediction methods, mathematical models predict variations of water quality both in space and in time.

Although process models offer the most sophisticated and potentially most accurate predictions of water quality, they are not widely used for regional groundwater vulnerability analysis. The Federal Republic of Germany, however, has sponsored a modelling project to

© 2005 Tous droits réservés.

identify the regions most susceptible nitrate contamination of groundwater (Wendland et al. 1993). The data include five hydrologic themes, seven soil themes, three hydrogeologic themes, six themes describing regional groundwater flow, and five themes contributing to the nitrogen cycle. From this data, the model produces a map of "Denitrification Conditions" and three maps of potential nitrate concentrations under different flow assumptions. The quantity of data needed for this study, both in terms of characteristics mapped and detail of mapping, requires greater resources than any study presently devoted to groundwater vulnerability analysis.

2.9.3 Statistical Methods. Empirical or statistical methods are the least common vulnerability assessment methods in the literature. Although statistical studies are used as tests for other methods, and geostatistical methods such as kriging are frequently used to describe the distribution of water quality parameters, very few vulnerability assessment methods are directly based on statistical methods. In addition, some reports in the literature use empirical methods for assessing the vulnerability of groundwater to pesticide contamination, their methods are not published, and have not been verified.

2.9.4 Checklists. These methods provide a checklist or decision tree, based on well construction, geologic and soil factors, and the presence of chemical sources in the vicinity of the well. The assessment consists of the following steps in some literature (Blodgett 1993):

1. Determining the location of the water supply well.
2. Acquisition of well construction and material setting descriptions, and driller's logs for the well.
3. Verification of proper well construction, and identification of a *vulnerability point*, typically the bottom of a cemented well casing, the top of a gravel pack, or the top of the well's shallowest open interval. A well lacking cemented casing, or otherwise improperly constructed is considered susceptible to contamination.
4. Examination of driller's logs to determine geologic susceptibility.
5. Delineation of a zone of contribution for susceptible wells.
6. Review of contaminant use in the zone of contribution.
7. Using the results of the preceding steps, a list of contaminants to be tested for is generated.

The above procedure and a similar vulnerability assessment method rely on a process similar to the overlay and index methods described earlier. Like those methods, the checklist applies expert knowledge and opinion systematically to the problem of vulnerability assessment, but

© 2005 Tous droits réservés.

does not employ a specific process model or an empirical/statistical basis for its recommendations.

2.10 Natural Sources of Soil Nitrogen

This section presents a comprehensive review of nitrate in groundwater, relevant to the present study. In particular, the nitrate cycle is discussed, and important concentration values are identified. The nitrogen in soil that might eventually be used by plants has two sources - nitrogen-containing minerals and the vast storehouse of nitrogen in the atmosphere. The nitrogen in soil minerals is released as the mineral decomposes. This process is generally quite slow and contributes only slightly to nitrogen nutrition in most soils. On soils containing large quantities of NH_4^+ rich clays (either naturally occurring or developed by fixation of NH_4^+ added as fertilizer), however, nitrogen supplied by the mineral fraction may be significant in some years.

Atmospheric nitrogen is thought to be a major source of nitrogen in soils. In the atmosphere it exists in the very inert N_2 form and must be converted before it becomes useful in the soil. This conversion is accomplished by two ways. Some N_2 is oxidized to NO_3^- by lightning during thunderstorms. The NO_3^- dissolves in raindrops and falls into the soil. The quantity of nitrogen added to the soil in this manner is directly related to thunderstorm activity, but most areas probably receive no more than 22.4 kg nitrogen/hectare per year from this source.

Some microorganisms can utilize atmospheric N_2 to manufacture nitrogenous compounds for use in their own cells. This process, called biological nitrogen fixation, requires a great deal of energy; therefore, free-living organisms that perform the reaction, such as *Azotobacter*, generally fix little nitrogen each year (usually less than 22.4 kg nitrogen/hectare), because food energy is usually scarce. Most of this fixed nitrogen is released for use by other organisms upon death of the microorganism. Bacteria such as *Rhizobia*, that infect (nodulate) the roots of, and receive much food energy from; legume plants can fix much more nitrogen per year (over 1120 kg nitrogen/hectare). When the quantity of nitrogen fixed by *Rhizobia* exceeds that needed by the microbes themselves, it is released for use by the host legume plant. This is why well-nodulated legumes do not often respond to additions of nitrogen fertilizer. They are already receiving enough from the bacteria. There are three major forms of nitrogen in mineral soils:

1. Organic nitrogen associated with the soil humus,
2. Ammonium nitrogen by certain clay minerals, and

© 2005 Tous droits réservés.

3. Soluble inorganic ammonium and nitrate compounds.

Most of the nitrogen in surface soils is associated with organic matter. In this form it is protected from rapid microbial release, only 2-3% a year being mineralized under normal conditions. About half of the organic nitrogen is in the form of amino compounds. The form of the remainder is uncertain. Some of the clay minerals have the ability to fix ammonium nitrogen between their crystal units. The amount fixed varies depending on the nature and amount of clay present. Up to 80% of the total nitrogen in surface soils and 40% of that in sub-soils may be in the clay-fixed form. In most cases, however, both these figures would be considerably lower. Even so, the nitrogen so fixed is only slowly available to plants and microorganisms. The amount of nitrogen in the form of soluble ammonium and nitrate compounds is seldom more than 1-2% of the total present, except where large applications of inorganic nitrogen fertilizers have been made. This is fortunate since inorganic nitrogen is subject to loss from soils by leaching and volatilization.

Nitrate concentrations are usually reported in units of milligrams per litter (mg/L) with the mass representing either the total mass of nitrate ion in the water (nitrate-NO_3^-), or as the mass of only the nitrogen (nitrate-N). The molecular weight of nitrate is 62; the molecular weight of nitrogen is 14, so the ratio of a concentration measured as nitrate- NO_3^- to an equivalent concentration measured as nitrate-N is 4.43. The WHO recommendation of 11.3 mg/L nitrate-N is equivalent to 50 mg/L nitrate-NO_3^-. According to Hem (1989), nitrogen occurs in water as nitrate or nitrite anions, as ammonium cations, and in a variety of organic compounds. Nitrite and the organic species are unstable in aerated water. Ammonium cations are strongly adsorbed on mineral surfaces, but the anionic species are readily transported in water and are stable over a wide range of conditions. In their study of nitrate in the groundwater of the U.S., Madison and Brunett (1985) assigned the following interpretations to ranges of nitrate concentrations (in nitrate-N):

- Less than 0.2 mg/L - Assumed to represent natural background concentrations.
- 0.21 to 3.0 mg/L - Transitional; concentrations that may or may not represent human influence.
- 3.1 to 10 mg/L - May indicate elevated concentrations resulting from human activities
- More than 10 mg/L - Exceeds maximum concentration for US Primary Drinking-Water Regulations.

Their selection of 3.0 mg/L as a threshold to indicate human influence has been followed by many investigators, including Burkart and Kolpin 1993, and Baker et al, 1994.

© 2005 Tous droits réservés.

2.11 The Nitrogen Cycle

Madison and Brunett (1985) list the following as major anthropogenic sources of nitrate: "fertilizers, septic tank drainage, feedlots, dairy and poultry farming, land disposal of municipal and industrial wastes, dry cultivation of mineralized soils, and the leaching of soil as the result of the application of irrigation water." Natural sources include: "soil nitrogen, nitrogen-rich geologic deposits, and atmospheric deposition." In all soils the considerable intake and loss of nitrogen in the course of a year are accompanied by many complex transformations. Some of these changes may be controlled more or less by man, whereas others are beyond his command. This interlocking succession of largely biochemical reactions constitutes what is known the nitrogen cycle.

The nitrogen income of arable soils is derived from such materials as commercial fertilizers, crop residues, green and farm manure's, and ammonium and nitrate salts brought down by precipitation. In addition, there is the fixation of atmospheric nitrogen accomplished by certain micro-organisms. The depletion is due to crop removal, drainage, erosion, and to loss in a gaseous form. Much of the nitrogen added to the soil undergoes many transformations before it is removed. The nitrogen in organic combination is subjected to especially complex changes. Proteins are converted into various decomposition products, and finally some of nitrogen appears in nitrate form. Even then it is allowed no rest since it is appropriated by micro-organisms and higher plants, removed in drainage, or lost by volatilization. And so the cyclic transfer goes on and on. At any one time, great bulk of the nitrogen in a soil is in organic combinations protected from loss but largely unavailable to higher plants. The process of tying up nitrogen in organic forms is called immobilization; its slow release-specifically, organic to inorganic conversion- is called mineralization.

2.12 Nitrogen Transformations

High concentrations of nitrate (NO_3^-) in drinking water may cause the disease methemoglobinemea in young children (Hem, 1989). Because of this and other diseases linked to nitrate (and possibly because it is inexpensive to measure), its concentration in public water supplies is monitored by the PWA. The World Health Organization (WHO) set the maximum contaminant level for nitrate at 11.3 mg/L (measured as nitrogen). Figure (2.2) shows the following major transformations from the nitrogen cycle (Madison and Brunett, 1985).

© 2005 Tous droits réservés.

Yet the fate of the applied nitrogen is poorly known because of the lack of reliable methods to establish losses and accumulation of soil Nitrogen at a farm-scale level. The Nitrogen flow in and out of a farm is, in principle, easy to determine, by simply measuring the amount and the N-content of the products that enter (such as fertilizer, animal feed) and leave (cattle, milk) the farm. For a typical Dutch cattle farm, over 80% of the N-input is lost, entering the environment (by leaching, volatilization, or denitrification), or being immobilized in the soil (A. Th. Aerts-Bijma et. al. 1997*)*.

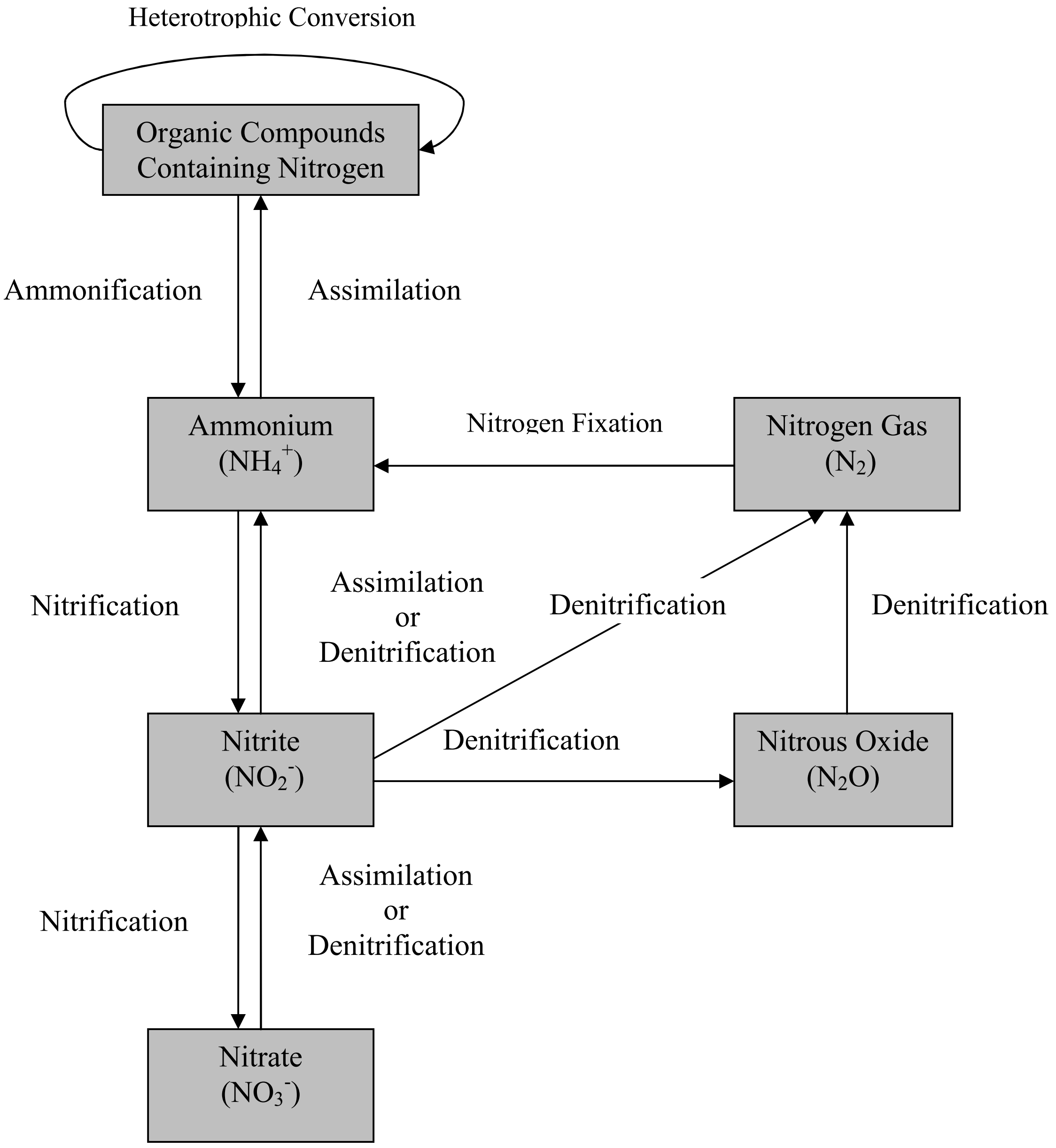

Figure (2.2): Simplified Biological Nitrogen Cycle [after Madison and Brunett (1985)]

2.12.1 Immobilization and Mineralization

Mineralization is the process by which organic compounds in the soil break down to release ammonium ion (NH_4^+), with the concurrent release of carbon.

© 2005 Tous droits réservés.

Immobilization is the reverse process by which there is a net incorporation of mineral nitrogen, usually NH_4^+, into organic forms (effectively into microbial tissue) during the decomposition process.

During the process of microbial decomposition of plant and animal residues, especially those low in nitrogen, the plant inorganic nitrogen as well as that in soil is converted to organic form primarily as microbial tissue. As the rate of microbial activity subsides, some of this immobilized nitrogen will be mineralized and ammonium and nitrate ions will again appear in the solution. However, most of immobilized nitrogen remains in organic form. The mechanism by which simple nitrogen compounds are changed to organic combinations that resist breakdown is still obscure. Somehow the immobilized nitrogen in the microbial tissue becomes an integral part of the soil organic matter. In this form it is only slowly mineralized to compounds usable by higher plants. Isotopically tagged nitrogen experiments have demonstrated that only about 2-3% of immobilized nitrogen is mineralized annually. Even so, this release of nitrogen to inorganic forms has long supplied a significant portion of crop needs and may be about 60 kg/ha of nitrogen per year for a representative mineral surface soil.

A major influence on the balance between mineralization and immobilization is the C:N ratio in the decomposing organic substance. A low C:N ratio (high nitrogen content) generally results in net mineralization and facilitates a high rate of decomposition. Although there is a general trend relating net mineralization / immobilization to the C:N ratio, there is no precise critical value, which marks the point at which reversal from immobilization occurs. This is because other aspects of substrate quality have a major impact on the rate of the decomposition (Vinten and Smith, 1993).

The rate of mineralization of nitrogen from soil organic matter generally increase with increasing moisture content between permanent wilting point (- 1.5 Mpa) and field capacity (-5 to -10 Kpa). This effect is well illustrated by the results of Stanford and Epstein (1974), who found 2.5 fold increase in the amount of mineral nitrogen accumulating over two weeks period of incubation, as the soil moisture content was increased from less than five to about 35 g/100g.

As the soil moisture content is raised above field capacity, however mineralization rates fall because of restricted aeration. The rate of decomposition by aerobic bacteria is much greater

© 2005 Tous droits réservés.

than that brought about by anaerobic bacteria. Decomposition by fungi and actinomycetes is also predominantly an aerobic process; this is inhibited by lack of oxygen. When organic residues of low N content undergo decomposition, net immobilization occurs over a period dependent upon the temperature, but the total amount of N incorporated into the organic form is not temperature dependent. The lower the temperature is the longer the period of net immobilization.

Mineralization and immobilization rates are usually highest in neutral or slightly alkaline range, which is optimum for most soil organisms. However, the rates are also affected by the inorganic N present and its relationship to soil pH. Soil organisms utilize ammonium preferentially over nitrate, unlike many higher plants. Since the ammonium ion is physiologically acidic, the amount of NH4-N immobilized increases with increasing pH. Conversely as soil becomes more acidic, there is a tendency for immobilization of nitrate to increase. Nitrogen can enter the soil from the application of wastewater, artificial fertilizers, plant and animal matter, precipitation, dust fall and nitrogen fixation. The identification of N sources to groundwater is usually difficult.

2.12.2 Nitrification

Nitrification is the biological oxidation of ammonium salt in soil to nitrite and then nitrates. Under favourable environmental conditions the nitrification process is carried out by bacterial population that sequentially oxidizes ammonium to nitrate with an intermediate formation of nitrite. The principle two genera of importance for carrying out this process are *Nitrosomonas* and *Nitrobacter.* Both of these groups are classified as autotrophic organisms because they derive energy for growth from the oxidation of inorganic nitrogen compounds.

1. Ammonium Oxidation: This step carried out by microorganisms known as ammonia oxidizers, where these bacteria oxidize ammonia to nitrate as follow:

$HN_4^+ + 1/2O_2 = NO_2^- + HOH + 2H^+$ 66 Kcal of energy are liberated per gram atom of ammonia oxidize.

2. Nitrite Oxidation: This step occurs by Nitrobacter as follows:

$NO_2^- + 1/2O_2 = NO_3^- +$ 18Kcal of energy is liberated per gram atom of nitrite oxidized

Nitrification is much more dependent on the environmental factors than ammonification or N mineralization. Nitrification depends largely on acidity and on O_2 supply. The nitrifiers are sensitive to H^+ in which their activity is reduced below pH 6.0 and become negligible below 5.0. Optimum pH is 6.6-8.0 or higher.

© 2005 Tous droits réservés.

All nitrifiers need O_2, and nitrification ceases in its absence. For this reason, nitrification is sensitive to soil structure and water content. In aerobic soils, optimum water content is generally 50% to 67% of the water holding capacity. Oxygen diffuses very slowly through water so that nitrification may be occurring in the outer part of an aggregate at the same time that there is denitrification in the interior. The nitrification and denitrification could take place at the same time (Kuenen and Robertson, 1994). Nitrification is temperature sensitive and occurs mostly in the range 5 - 40 degrees C. In summary, nitrification occurs rapidly in most well drained and moist agricultural soils with a pH of 6.0 or higher. Table (2.1) shows the rates of nitrification by some heterotrophic and autotrophic nitrifiers.

Table (2.1): Rates of nitrification by some heterotrophic and autotrophic nitrifiers

Organism	Substrate	Product	Rate of Formation (micro-g N/day/g dry cells)	Max. Product Accumulation (micro-g N/mL)
Arthrobacter/heterotroph	NH_4^+	Nitrite	375-9,000	0.2-1
Arthrobacter/heterotroph	NH_4^+	Nitrate	250-650	2-4.5
Aspergillis/heterotroph	NH_4^+	Nitrate	1,350	75
Nitrosomonas/autotroph	NH_4^+	Nitrite	1-30 million	2,000-4,000
Nitrobacter/autotrophy	NO_2^-	Nitrate	5-70 million	2,000-4,000

2.12.2.1 Nitrification Environmental Impact

(i) Nitrification aids in the decomposition of nitrogenous material and thus in the recycling of nitrogen atoms since the de-amination of organic nitrogen produces ammonia that is subsequently oxidized to nitrate by nitrification.

(ii) The microbes that perform nitrification are inefficient. Most of them are autotrophs that use the energy gained from oxidizing ammonia to fix carbon. Thus these bacteria have a dual ecological role - they are involved in recycling nitrogen and in fixing carbon into organic. Carbon fixation by this method is not very efficient. Therefore a lot of nitrogenous oxidation is required to acquire enough energy to fix carbon. The fixation of one mole of carbon requires the oxidation of 35 moles of ammonia to nitrite and of 100 moles of nitrite to nitrate.

(iii) The microbes that perform nitrification are fragile. These organisms are acid-sensitive even though they produce acid! If a large source of nitrogen is dumped into the environment, these organisms can potentially kill themselves by metabolizing it to nitric acid. Since they are also strict aerobes, they can be killed if introduction of wastes leads to excessive growth of other species that deplete oxygen (i.e. Eutrophication).

© 2005 Tous droits réservés.

2.12.3 Denitrification

Denitrification (the microbial reduction of nitrate to N_2, NO and N_2O) is the major biological process by which the nitrogen cycle is completed, and fixed nitrogen is returned to the atmosphere. Denitrification is the dissimilative pathway returns nitrogen atoms to the atmosphere by reducing nitrate to nitrogen gas. Several intermediates are involved:

NO_3^- -----> NO_2^- -----> NO -----> N_2O -----> N_2 gas

The diagnostic enzyme for denitrification is nitrate reductase. The best-studied nitrate reductase is from E. coli, although this organism only converts nitrate to nitrite and does not do the subsequent reaction steps. E. coli will only reduce nitrate under anaerobic conditions. Recall that oxygen is the favoured electron acceptor (because it has a higher reduction potential). When oxygen is not available, E. coli utilizes the next best electron acceptor available, i.e. nitrate.

Major Denitrifier's only microorganisms, usually facultative anaerobes, do denitrification. These bacteria normally used oxygen of the air as hydrogen acceptor (aerobically) but also possess the ability to use nitrates and nitrites in the place of oxygen (anaerobically) and predominantly in two genera:

- *Pseudomonas spp.*
- *Bacillus spp.*

Many soil bacteria like *Thiobacillus denitrificans*, which are known to oxidize sulfur chemoautotrophically also, reduce nitrate to nitrogen. The anaerobic conversion of nitrate into molecular of nitrogen is also known as nitrate respiration. The organisms capable of denitrification are isolated by enrichment cultures in anaerobic media containing excess of potassium nitrate (Subbarao, N.S., 1989). The environment in which the greatest quantities of nitrate, the essential substrate for denitrification, are likely to be found is agricultural land receiving substantial inputs of nitrogenous fertilizers or manure. Estimates of the quantities of nitrogen lost by denitrification from agricultural land differ widely. A review by Colbourn and Dowdell (1984) produced figures of 0-20 % of the applied fertilizer nitrogen from arable land and 0-0.7% from grassland.

The oxygen level is the dominant factor affecting denitrification in most agricultural soils. Low oxygen levels most frequently result from high soil water contents because the volume of soil air decreases as soil water increases and because oxygen diffuses through water

© 2005 Tous droits réservés.

10,000 times slower than through air (Firestone, 1982). However, even in well-drained soil, oxygen deficits can develop locally due to high oxygen uptake rates by soil microbes as they oxidize readily available carbon (Parkin, 1987) or due to long oxygen diffusion paths into the centre of soil aggregates.

Dissimilative denitrification is a nuisance to the agricultural industry. The reactions essentially reverse Nitrogen Fixation in that the nitrogen atoms in a salt are returned to the atmosphere as nitrogen gas rather than being incorporated into plants. Denitrification is detrimental to agriculture, because nitrogen is lost from soils. Denitrification, however, helps to prevent an excess of nitrate in the groundwater of irrigated valleys where high rates of nitrogen fertilizer have been used. Fallow soils flooded with water are more congenial for denitrification than well-drained and continuously cropped soils. In fact, the practice of continuous cropping, which provides the much-needed competition between plants and microorganisms for nitrate substrates, minimizes the hazards of denitrification.

2.12.4 Ammonia volatilization

Ammonia volatilization is a complex process involving chemical and biological reactions within the soil, and physical transport of N out of the soil. Ammonia losses from fertilizers is influenced by the method of N application, N source, soil pH, soil cation exchange capacity (CEC), and weather conditions. Conditions favouring losses are surface application, N sources containing urea, soil pH above 7, low CEC soils, and weather conditions favouring drying (Nelson, 1982). Figure (2.3) shows ammonia/ammonium percentages in aqueous solution at different temperature and pH values. The intensity of ammonia volatilization from solution is directly related to the concentration of dissolved ammonia in the water. The concentration of dissolved ammonia [NH3 (aq)] depends to great extent on the ammonical N level, pH, and carbonate status of the solution. An empirical equation for calculating ammonia/ammonium fraction in aqueous solution (Emerson et al, 1975):

$F=1/(I0^{pKa-pH}+1)$

f: the fraction of ammonia in aqueous solution

$pK_a = -\log K_a$ (the acid dissociation constant of the NH_4^+ ion). It can be calculated using the equation:

$pK_a = 0.09018 + 2729.92/T$

T: temperature (Kelvin)

© 2005 Tous droits réservés. http://www.univ-lille1.fr/bustl

Ammonia volatilization from acidic solutions is negligible (Velk and Stumpe, 1978). Velk and Stumpe have reported that the ammonia volatilization per second followed first order reaction kinetics. The rate of volatilization is severely restricted by limiting the movement of air above the water, as is often the case in the laboratory and field studies reported. Ammonia volatilization was enhanced by water turbulence and increased exponentially with temperature from almost nil at 0°C to approximately 20 mg N/100 cm^2/ 5 hours at 46 °C.

Yoram and Malka (1977) stated that the pH of the solution is the dominant factor controlling the extent of ammonia volatilization only when the soil's buffer capacity is high or when the concentration of ammonium in the soil is low. At high pH and high initial ammonium concentrations, the dominant factor controlling the reaction is the buffer capacity of the soil.

2.12.5 Ammonium Fixation

Inorganic NH_4^+-N in the soil environment may be divided into interrelated "pools" that are conventionally termed soluble, exchangeable and non-exchangeable. Soluble NH_4^+ is removed from soil with the soil solution or on extraction with distilled water. Exchangeable $NH_4^+$is extractable with neutral KCI, and non-exchangeable NH_4^+ is the portion of total inorganic NH_4^+that is not extractable with KCI solution but is extractable when stronger means are used. Non-exchangeable NH_4^+ may be further divided into natively fixed NH_4^+ and recently fixed NH_4^+. Natively fixed NH_4^+ is believed to be associated with illites and chlorites of the parent material and is released only on geologic weathering of these minerals (Smith et al. 1994). Recently fixed NH_4^+ refers to added NH_4^+ from fertilizers, mineralization of organic matter, or other sources that moved into non-exchangeable pool. Recently fixed NH_4^+ can be released and is available for uptake by plants and micro-organisms.

Soils typically have relatively small non-exchangeable NH_4^+ pools. The levels of non-exchangeable NH_4^+ in soils are influenced by many factors, including rate of nitrification, leaching, plant uptake and mineralization of organic matter. Liu et al. (1997) found that exchangeable NH_4^+ levels were slightly higher in soils receiving the highest rate of fertilization, but otherwise were unresponsive to N fertilization. In addition they conclude that nitrification of NH_4^+ prevents build up of either exchangeable or non-exchangeable NH_4^+ in soils. Stechouwer and Johnson (1991) reported that the predominance of mica, illite and vermiculite in the clay fraction of the Hytville soil resulted in the preferential fixation of NH_4^+ and reduced K^+ fixation when anhydrous ammonia and KCI were injected simultaneously.

© 2005 Tous droits réservés.

The similarity in ionic radius and energy of hydration of NH_4^+ and K^+ causes the ions to compete for fixation sites in micaceous minerals. The upper limit of fixation in field soils is about 1 to 2 meq/l00 g of soil. About 10 percent of the N in soils may be fixed, and its distribution in the soil profile parallels that of the clay. Just as with K^+, equilibrium for NH_4^+ exists between ions that are exchangeable and those that are in solution, and between ions that are exchangeable and those that are fixed. Although considerable fixed NH_4^+ may exist in soils, it is of minor importance in meeting the daily N needs of growing plants.

2.12.6 Nitrogen Fixation

There are two types of nitrogen fixation: Symbiotic and non-symbiotic. The symbiotic N_2 fixation converts atmospheric N_2 gas into plant N through symbiotic bacteria living in root nodules of certain plants, primarily legumes. Although the importance of N2 fixation has been known since ancient times, there are very few quantitative estimates of this process under natural conditions. The mass of symbiotic fixed N depends on many genetic and environmental factors. These include plant species, available soil N, crop management, soil water, type of fixing bacteria and soil chemical environment in which mineral factors affect nitrogen fixation i.e. molybdenum is a constituent of nitrogenase, and also of the reductase enzymes involved in the assimilation of nitrate and in denitrification. Nitrogen fixers also require cobalt and iron (National Academy of Science, 1978).

Nitrogen fixation is an adaptive process that occurs at significant rates only when the supply of fixed nitrogen is low and apparently growth-limiting. Fixation of nitrogen requires a considerable input of energy. In situations in which other forms of nitrogen are available, the energy requirements of nitrogen fixing results in a considerable competitive disadvantage to organisms that fix nitrogen compared to organisms that use ammonia or nitrate. Thus, all agents of fixation use ammonia or nitrate when they are available, and synthesis of nitrogenase in organisms that are capable of nitrogen fixation occurs only when sources of fixed nitrogen are depleted.

Non-symbiotic N fixation occurs in temperate agricultural soils, but there is a lack of quantitative data concerning it. Much of the available literature is not very useful, but sufficient data are available to suggest that none symbiotic fixation may be of agronomic significance under some circumstances. The optimum non-symbiotic N2 fixation in soil has not been clearly defined, but the presence of adequate energy materials, low soil N levels, and adequate mineral nutrients and moisture seem to be the major factors involved. The amount

© 2005 Tous droits réservés.

of non-symbiotic N-fixation will probably be between 0 and 30 kg N/ha.yr with the lesser amounts in N-fertilized soils where the soil surface is dry during long period of the time (Schepers and Fox, 1989).

2.13 Nitrate Leaching

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

A: Leaching of NO_3^- is affected by:

- Infiltration rate, that is related to soil slope, land use, stability of soil aggregates, the moisture content and all factors affecting size and continuity of soil pores.
- Interactions with soil constituents: Sandy, light textured soils generally have a fairly uniform porosity. They retain less water than clayey, heavily textured soils and nitrates can be leached with relatively small amount of rainfall. By contrast, finer textured homogeneous clayey soils favor chemical processes (exchange of anions and cations, absorption of dissolved organic substances, reactions between dissolved materials and those absorbed on the clay-humus complex) and retain more nitrate and water.
- The size of soil pores which is related to the soil texture, structure, cracks, worm holes, old root channels, and any restrictive pans of soil layers. Also the continuity of the pores that is affected by the tillage system plays an important role.

Rainfall and amount of nitrogen applied: As a general rule the greater the total winter rainfall, the greater the mount of nitrate being leached though average concentrations of nitrate in the leachate decline as winter progress and rainfall increases. Bergstrom and Brink (1986) found that the leaching of nitrate was moderate up to a rate of application of 100 kg N/ha.yr, but increase rapidly thereafter.

Movement of nitrate is generally considered to be more of a problem in light textured sandy soils, however it should not be understood that nitrate movement is not a serious problem in clay soils (Swoboda, 1977). Thomas and Swoboda (1969) have reported anion movement in clay soils as much as estimated faster than would be predicted if the water moved through the soil as (piston type) flow. Barraclough et al. (1983) found that the cumulative nitrate leaching over 3 years from isolated 0.4 ha grass land plots were equivalent to 1.5%, 5.4% and 16.7%

© 2005 Tous droits réservés.

of the fertilizer applied at 250, 500, and 900 kg/ha rates respectively. Vagstad et al. (1997) found that the major parts of the N lost by leaching apparently derive from soil organic matter rather than from recently applied fertilizers.

B: Nitrate transport mechanisms

Movement of any dissolved ion such as nitrate through soil is governed by two mechanisms: convection (or mass flow of the chemical with the moving soil solution) and diffusion of the chemical within the solution (Jury and Nielsen, 1989). Because the convection flow paths are never known exactly, a volume average expression is used to describe the mass flow. The extra three dimensional convection which has been averaged out of the mass flow expression is included as a separate solute transport mechanism called hydrodynamic dispersion, which is used to describe the movement of solute around solid obstacles.

The simplest representation of mass transport of solute by convection is given in the equation:

$J_{sc}=J_wC$ (1)

J_{sc} : The mass of solute per unit area per unit time

J_w : The water or soil solution flux (average over many pores)

C: Solute concentration in mass per solution volume.

Equation (1) is often used alone to give a rough estimate of solute movement. This called (piston-flow) model movement because it assumes that solution is displaced through the soil like a piston. Solute dissolved in solution spread out under the influence of molecular scale collisions, a process known as molecular diffusion. The diffusive flux of solute J_{SD} in one dimension is described by Fick's Law of diffusion, which in water is written as:

$J_{SD}= -D_{sw}\partial C/\partial Z$ (2)

D_{sw}: Binary diffusion coefficient

2.14 Nitrogen inputs

Most nitrate-related environmental impacts occur on local or regional scales, rather than on the national scale. The nature of those impacts is usually quite closely related to the nature and spatial distribution of the sources. For example, some point sources of nitrogenous wastewater streams can cause localized but intense pollution. Other inputs such as emissions of nitrogen oxides from combustion, may originate with point sources but can contribute to nitrate problems over large areas, because of the transport and transformation processes typically associated with such emissions. On the other hand, dispersed non-point sources,

© 2005 Tous droits réservés.

such as agriculture operations, are often responsible for pollution of groundwater or surface waters and nitrous oxides. The sources of nitrogen to be discussed are the effluents from sewer systems and septage, leachate from landfills, fertilizers and manure inputs, nitrogen fixation, irrigation water and precipitation.

2.14.1 Effluent from sewer systems and septage

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

Magdoff and Keeny, (1976) found that the removal of nitrogen in the septage by soil materials is nearly about 22%. This makes septage a major local source of nitrate. Figure (2.9) shows major transformations of septage. Significant denitrification is not likely if seepage for the effluent is built in deep sandy soils (Walker et al., 1973a). In the movement of nitrate through loamy sand soil beneath a septic tank disposal field; nitrate concentration increased, and ammonia concentration decreased with depth. Walker et al. (1973b) reported nitrate concentrations from 2 to 42 mg/L in groundwater around several non-sewered households in a sandy soil area of central Wisconsin; the highest concentrations were just down the flow gradient from the disposal field. As distance from the septic tank field increased, nitrate concentrations declined rapidly because of dilution groundwater. Contamination of groundwater by nitrate from septic tanks and cesspits is of little significance in sparsely population rural areas; however increased population density can produce high nitrate levels in groundwater supplies.

2.14.2 Leachate from landfills

Leachate from municipal solid waste landfills is characterized as a relatively low volume, high-strength wastewater. A survey of leachate characterized for many landfills shows ammonium values of 0 – 1160 mg/l and nitrate plus nitrite nitrogen of 0.2 – 10.2 mg/l (Scheible, 1994). Gracia Posadas et al., 1996 studied a landfill with an estimated daily leachate 20-200 m3/d and they found the ammonia nitrogen concentration ranged from 100 to 500 mg NH_4^--N/L. Depending on the landfill and the materials placed in it, typical values

© 2005 Tous droits réservés.

of nitrogen in the landfill leachate are 200 mg/l organic nitrogen, 200 mg/l ammonia nitrogen and 25 mg/l nitrate nitrogen (Rabah, 1997).

Poul et al. 1995, found that the leachate of the Grindsted landfill in Denmark contains lower ammonium concentration closer to the landfill and they related this to the cation exchange process that may attenuate ammonium in the anaerobic part of the plume. The leakage of organic and inorganic pollutants from old landfills without leachate collecting system may influence the groundwater quality and thereby be a risk for drinking water. The composition of leachate from landfills is dependent on the age of the landfill. Table (2.2) shows the composition of leachate from fresh and aged landfill. Table (2.3) shows the typical composition of leachates from recent and aged domestic wastes at various stages of decomposition (all results in mg/l except pH-value).

Table (2.2): Composition of leachate from fresh and aged landfill

Reference	Israel Ministry of Environment	Crawford <2 years old	Crawford <2 years old	Ehrig Acid phase	Ehrig methanogenic
Parameter mg/l	Range	Range	Range	Average	Average
PH (value)	6.1 – 8.7	5.0-6.5	6.5-7.5	6.1	8.0
TDS	8310 – 18685	8000-50000	1000-3000		
CL^-	1075 – 26500	500-2000	100-500	2119	
SO_4^{--}	0 – 15060	50-1000	<10	1745	884
NH4-N	12.5-2900			741	
NO3-N	0-3.4			3.3	
PO4-P	2.7-49.2	5-100	<5		
Total P		4000-30000		5.7	
BOD_5	74-2700	10000-60000	<100	13000	180
COD		1000-20000	50-500	22000	3000
TOC			<100		
Kj-N		100-1000			
Organic N	81-906		<100	592	

Table (2.3): Typical composition of the leachate from domestic wastes in relation to age, Westlake, 1995 (All results in mg/l except pH-value).

Parameter	Leachate from recent wastes	Leachate from aged wastes
pH-value	6.2	7.5
COD	23800	1160
BOD	11900	260
TOC	8000	465
Fatty acids (as C)	5688	5
Ammoniacal-N	790	370
Oxidized-N	3	1
O-phosphate	0.73	1.4
Chloride	1315	2080

© 2005 Tous droits réservés.

2.14.3 Fertilizers

Fertilizer N use is increasing worldwide and it is considered as a major source of nitrogen to the soil. Ludwick et al., (1976) sampled the 0-90 cm depth under a number of irrigated Colorado fields and showed a direct relationship of nitrate profile to fertilizer N use. On average, about 170 kg N/ha was in the upper layer. These levels were the result of build up of excess N over many years of excessive fertilizer use. Fertilizers are applied in different forms and it has different nitrogen concentration. Table (2.4) shows composition of various N fertilizers used. Figure (2.3) shows the transformation that occur after fertilization application.

Table (2.4): Composition of various common N fertilizers

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

© 2005 Tous droits réservés.

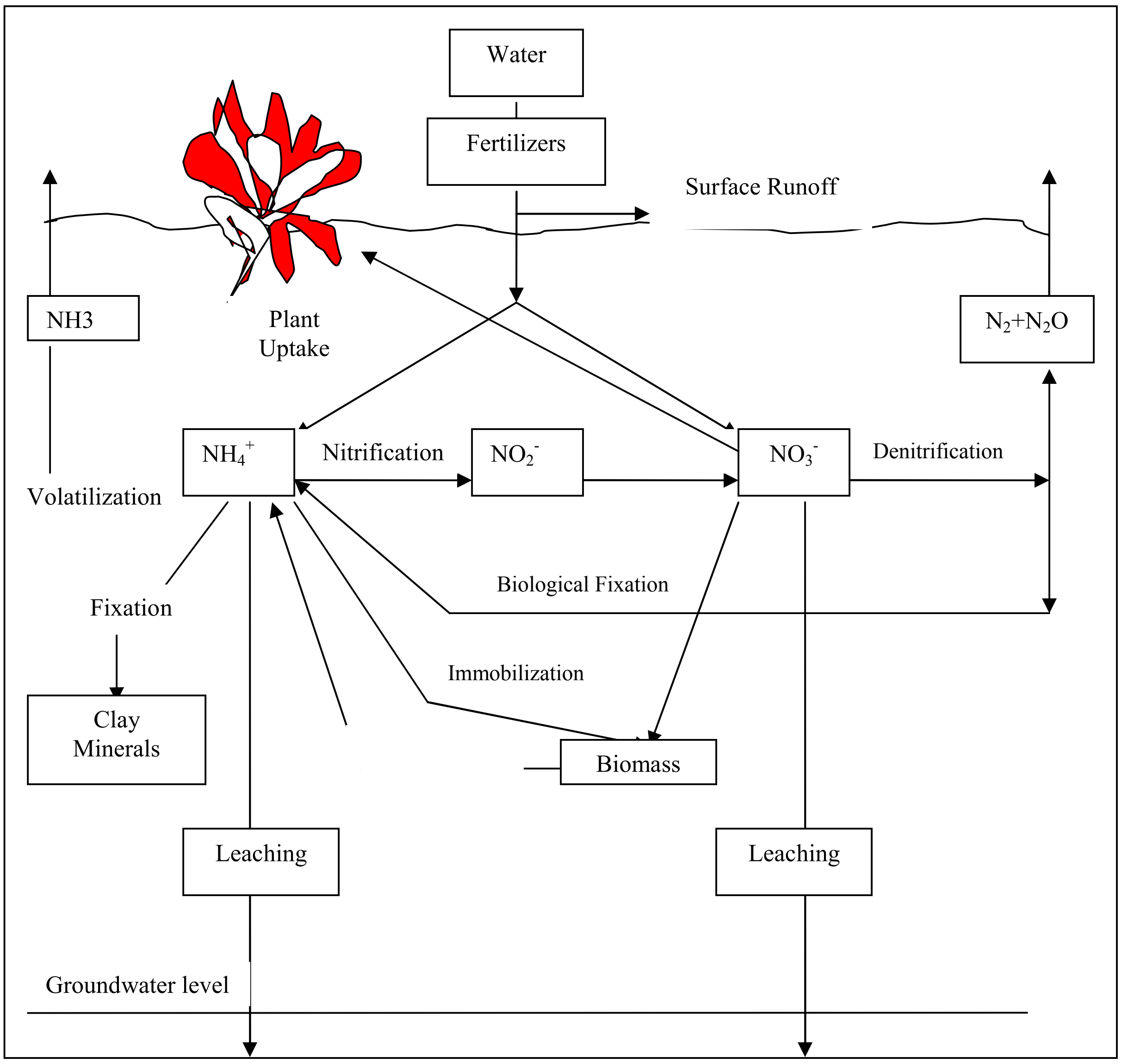

Figure (2.3): Block diagram of N-fertilizer behaviour in the soil (adapted from Alwneh, 1996).

2.14.4 Manure N inputs

Land application of animal wastes, especially concentrated wastes as poultry and cattle manure, can lead to nitrate accumulation in the profile and groundwater pollution. Manure N inputs are very difficult to estimate because of the variability in N composition, the uncertainty in loading rates, the spatial variability of manure application, and the many N losses that manure undergoes after excretion (ammonia volatilization and denitrification). According to the Agriculture Compendium (1989), N content of cattle manure is 2% of the dry weight of the manure applied while the N content in poultry is 5%. According to the same reference, the amount of manure needed to maintain the humus level of soil is 15 ton/ha, but the actual application of manure by farmers is much more this amount. Table (2.5) and (2.6) below show the approximate estimation of N content in manure.

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Table (2.5): Moisture and nitrogen content of manure farm animals[a]

Animal	Feces/Urea Ratio	H_2O %	Nutrients (kg/Mg)		
			N	P	K
Dairy cattle	18:20	85	5	0.6	3.1
Feeder cattle	80:20	85	6	1	3
Poultry	100:00	62	15	3.1	2.9
Swine	60:40	85	6.5	1.6	4.5
Sheep	67:33	66	11.5	1.6	8.6
Horse	80:20	66	7.5	1	5.5

a: Average values from a number of references (Brady, 1974)

Table (2.6): Approximate N contents of livestock and poultry manure

Livestock description		Approximate Kg of N excreted	
Type	**Common weight, kg**	**Common daily value**	**Common yearly**
Dairy cattle	67.5	0.027	9.9
	112.5	0.045	16.65
	225	0.09	33.75
	450	0.1845	67.5
	630	0.2565	94.5
Beef cattle	225	0.0765	27.9
	337.5	0.117	41.85
	450	0.153	55.8
	562.5	0.1935	64.8
Boar	157.5	0.0351	12.6
Sheep	45	0.02025	7.2
Horse	450	0.1215	44.55
Poultry			
Layers	1.8	0.130 (for 100 birds)	47.25 (for 100 birds)
Broilers	0.9	0.108 (for 100 birds)	38.24 (for 100 birds)
Turkeys	4.5	0.405 (for 100 birds)	148.5 (for 100 birds)

2.14.5 Irrigation water inputs

Nitrates in irrigation water abstracted from the aquifer or reused after wastewater treatment may provide a significant part of the nitrogen needed by a crop (Grander and Roth, 1984; Martine et al., 1982). Irrigated agriculture is the primary source of nitrate (Keeney, 1989). Nitrogen added in irrigation water can vary greatly from site to site with ranges from 10-145 kg/ha.yr (Legg and Meisinger, 1982). The inputs can be readily estimated from the quantity of water applied and its N content.

© 2005 Tous droits réservés.

2.14.6 Nitrogen fixation inputs

As indicated before nitrogen fixation is dependent on many factors, therefore the estimates of nitrogen fixation will be rather crude. Table (2.7) shows the approximate percent plant N derived for various legumes.

Table (2.7): Approximate percent of total plant N derived from N_2 fixation for various legumes and available soil N situations (Meisinger and Randoll, 1991).

Legume system		Total inorganic available to legume annually (kg/ha)			
Type	Example	56	56-112	112-224	>224
Annual legume, grain legume, cover crop	Crimson clover, pea, soybean, peanut, vetch	78.4-106.4	56-89.3	33.6-67.2	5.6-44.8
Perennial legumes, Forage legumes in established stands or seeding year	Alfalfa, red clover, birds foot trefoil	89.6-10.4	67.2-100.8	56-89.6	11.2-46

*Available soil N equal percent organic matter times 30. Also add fertilizer N applied (if any) plus one half of manure N (or three-fourth s of poultry manure N) plus residual NO_3-N from prior crop. For soils with > 3% organic matter, use values at the lower end of the range. Soils with < 3% organic matter, use upper end of range

2.14.7 Precipitation inputs

The atmosphere contains ammonia and compounds released from soil and plants as well as from the combustion of coal and petroleum products. The principal forms of N in precipitation are NH3, N-oxides and organic N (Legg and Meisinger, 1982). The effect of precipitated N for cropland is minor, but may be of major importance for forests, pastures and rangelands. There is little information available, however, to support specific quantitative assessment of N in the precipitation or of the influence of atmospheric movement and chemical transformations on the forms and amounts of N deposited in different localities.

The main sources of atmospheric N are combustion of fuels, volatilization of NH_3 from animal wastes and fertilizers, volcanoes, and lightening. The concentration of nitrogen in precipitation in most cases will contain between 1 and 4 mg/l total N (Meisinger and Randall, 1991). Combined N, consisting of NH_3, NO_2^-, NO_3^-, and organically bound N is a common constituent of atmospheric precipitation. Nitrites occur in trace amounts and are usually ignored or included with NO_3^- determination. The organically bound N is probably associated with cosmic dust and does not represent a new addition to landmasses of the world.

In many areas in the USA, and Europe the estimates for NH_4^+- N plus NO_3^--N ranged from 0.78 to 22 kg/ha per year (Brezonik, 1976; Stevenson, 1986). For the Netherlands, values of approximately 50 kg N/ha.yr have been observed and an average deposition of 30 kg N/ha.yr

© 2005 Tous droits réservés.

has been estimated for Europe (Arts and Middelkoop, 1990). Table (2.8) shows the mean inorganic nitrogen content in precipitation for several locations in the United State.

Table (2.8): Inorganic nitrogen content in precipitation for several locations in the United State (adapted from Scheper and Fox, 1989)

Location	Years	Amounts (mm)	MH4-N (kg/ha)	NO3-N (kg/ha)	Total inorganic-N (kg/ha)
Indiana					
Black Creek	1975	820	3	7.5	10.5
Iowa					
Treynor	1971-73	890	4.6	4.2	8.8
Ames	1971-73	NA	6	6.4	12.4
Minnesota					
Morris	1976-78	360	2.2	1.7	3.9
Waseca	1976-78	570	4.9	3.3	8.2
Wisconsin					
Marshfield	1970	NA	8.6	3.5	12.1
Madison	1971	NA	3.7	6.4	10.1
Nebraska					
Scottsbulff	1972-73	360	3	1.8	4.8

NA: Data not available

2.15 Losses of Nitrogen

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

2.15.1 Losses through ammonia volatilization

Volatilization losses from injected NH3 can be assumed to be minimal if the NH3 injected to a depth of at least 5 cm and if the furrow behind injector seals completely. Losses from unincorporated surface application of NH_4^+ sources on high pH (calcareous) soils or urea-containing sources on any soil can reach as high as 30 to 50% (Schepers and Fox, 1989). Ammonia volatilization from manure can be significant. Table (2.9) shows estimation of ammonia volatilization from land-applied manure.

© 2005 Tous droits réservés.

Table (2.9): approximate ammonia losses of land manure.

Manure application method	Type of manure	Short term fate (%N)		Long term fate (%N)	
		Lost	Retained	Lost	Retained
Broadcast no incorporation	Solid Liquid	15-30 10-25	70-85 75-90	25-45 20-40	55-75 60-80
Broadcast immediate incorporation	Solid Liquid	1-5 1-5	95-99 95-99	1-5 1-5	95-99 95-99
Knifed	Liquid	0-2	98-100	0-2	98-100
Sprinkler irrigated	Liquid	15-35	65-85	20-40	60-80

EI-Khatari and Kharabsheh in 1983 have studied ammonia volatilization from three different soils in Jordan (Table 2.10) and they found that the losses of ammonia are directly proportional with time after application, and the losses are doubled by doubling the amount of fertilizers applied.

Table (2.10): Characteristics of three different Jordanian soils.

Soil Location	Clay	$CaCO_3$ equivalent %	Organic matter %	ECE meq/100g	pH	EC mS/cm
Al-Jerm	41.6	56	5.3	21.7	7.8	2
Azraq	20.4	18	0.45	16.8	7.8	0.4
Hisban	64.4	6	1.24	63	8.2	136.7

2.15.2 Losses through denitrification

Dowdell and Webster (1984) have confirmed through laboratory studies in aerobic and anaerobic conditions in the presence of acetylene that 10-20% of the applied N could have been transformed to dinitrogen. Egginton and smith (1986) have found that the quantities of N lost from nitrate-treated soils were much greater than from slurry-treated areas, and ranged up to 20% of the N applied. Research has shown that denitrification losses are higher in manured soils than the non-manured soils and has shown that denitrification losses of soil NO3 occurred within hours of manure application (Paul and Beauchamp, 1989). However a survey by Hauck (1989) indicated losses of 20-40%. Some estimated denitrification losses during growth of crops in a number of different countries, compiled by Nieder, et al (1989) showed a range of losses from 2.5% to over 50% of the applied nitrogen. Table (2.11) is a summary of studies about losses of N by denitrification following addition of manure or organic wastes to soil.

© 2005 Tous droits réservés.

Table (2.11): studies on losses of N by denitrification following addition of manure or organic wastes to soil (adapted from Loro et al., 1997)

Reference	**Type of study**	**Study period**	**type of manure**	**App. rate (ton/ha)**	**N losses (kg/ha)**
Wallingford et al., 1975	Field. Irrigated	2 yr	Beef cattle	85-1043	700-2830*
Guenzi et al., 1978	Greenhouse	39 day	Dry cattle	45, 90	Up to 360**
Rolston et al., 1978	Field/ covers	30 day	NI***	34	218
Rice et al., 1988	Field/soil cores	37 day	Fermentation wastes	5.9, 9.7	270, 440
Webster & Goulding, 1989	Field/covers	60 day	Farmyard manure	35	29

* Part of this loss may have been due to leaching of NO3

** Extrapolated from pilot studies to field scale

*** No t indicated

Studies have shown that denitrification losses are usually small during much of the year with periodic major losses occurring when the soil is re-wetted by rainfall or irrigation (Sexstone et al., 1985a) these episodic losses occur because denitrification primarily requires a low soil oxygen status. Denitrification also requires an available energy source (organic matter) and a supply of NO3. Denitrification occurs most readily when soil temperature is above 10 ^{0}C and the soil pH is above 5 (Firestone, 1982). Table (2.12) shows approximate estimates for various soils.

Table (2.12): Approximate N denitrification estimates for various soils (Meisinger and Randall, 1991)

Soil drainage classification - % inorganic N denitrified					
Soil organic matter	Excessively well-drained	Well-drained	Moderately well-drained	Somewhat poorly drained	Poorly drained
<2	2-4	3-9	4-14	6-20	10-30
2-5	3-9	4-16	6-20	10-25	15-45
>5	4-12	6-20	10-25	15-35	25-55

2.15.3 Plant Uptake

The amount of N consumed by plants varies greatly from one species to another, and, for any given species; the amount varies with genotype and the environment. Also considerable variation exists in the relative amount of the N contained in the different plant parts (grains, stems, leaves, roots, etc,). Substantial variation can occur depending on soil N status, fertilization practice, and climate. In general, more N is contained in the harvested portion than in the stover, vines, straw, or roots. Nitrogen uptake by plants is very rapid during the period of rapid vegetative growth

© 2005 Tous droits réservés. http://www.univ-lille1.fr/bustl

2.15.4 Erosion and runoff

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

2.16 The fate and transport of nitrogen in wastewater effluents

The transport and fate of nitrogen in the subsurface effluent of wastewater is dependent upon the form of entering nitrogen and various biological conversions that may take place. The predominant form of nitrogen entering the soil from septage and untreated wastewater is the ammonium. Some organic nitrogen will also be introduced. The fate of the introduced nitrogen is dependent on its initial form as well as biological conversions in the soil and groundwater. Nitrification is dependent on the aeration of the soil, which, in turn, is dependent on soil characteristics, percolation rate, loading rate, distance to impervious strata, and distance to groundwater.

Denitrification is another important nitrogen transformation in subsurface environment underlying sewage effluent. It is the only mechanism by which NO_3^- concentration in the percolating (and oxidized) effluent can be decreased. Denitrification or the reduction of NO_3^- to N_2O or N_2 is a biological process performed primarily by ubiquitous facultative heterotrophs. In the absence of O_2, NO_3^- acts as an acceptor of electrons generated in the microbial decomposition of any energy source. However, in order for the denitrification to occur in soil beneath waste disposal, the nitrogen must usually be in the NO_3^- form and an energy source must be available. Therefore nitrification, as an aerobic reaction must occur before denitrification. Therefore, knowing the aeration conditions beneath seepage will provide information as to the probable nitrogen forms present (Bouma, 1979).

Based on the forms of nitrogen in the sewage effluents, and the biological transformations, which can occur in the subsurface environment, there are two forms of major concern relative to groundwater pollution, ammonium ions and nitrates. The transport and fate of ammonium ions may involve adsorption, cation exchange, incorporation into microbial biomass, or release to the atmosphere in the gaseous form. Adsorption is probably the major mechanism for removal in subsurface environment.

© 2005 Tous droits réservés.

Anaerobic conditions will normally prevail below the upper layers of soil beneath the soil adsorption system. Under these conditions, positively charged ions are readily adsorbed onto negatively charged soil particles. This adsorption is essentially complete in the first few inches of soil. After the adsorption capacity of the first few inches of soil is reached, the ammonia must travel through saturated soil to find unoccupied sites. Cation exchange may be involved along with adsorption in retention of ammonium ions in soil. However just as the adsorption capacity of the soil can be exceeded, the cation exchange capacity can also be exhausted.

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Chapter 3

Description of the Study Area

3.1Geographical Data

Geographically, the Gaza Strip is a part of Palestinian coastal plain in the south west of Palestine, where it forms a long and narrow rectangle. Its area is about 378 km^2 (UNEP, 2003) and its length is approximately 45 km (Figure 3.1). It shows desert characteristics, bounded by the Negev to the Southeast and the Sinai to the Southwest. The Gaza Strip consists of five Governorates, named as North, Gaza, Middle, Khanyounis, and Rafah.

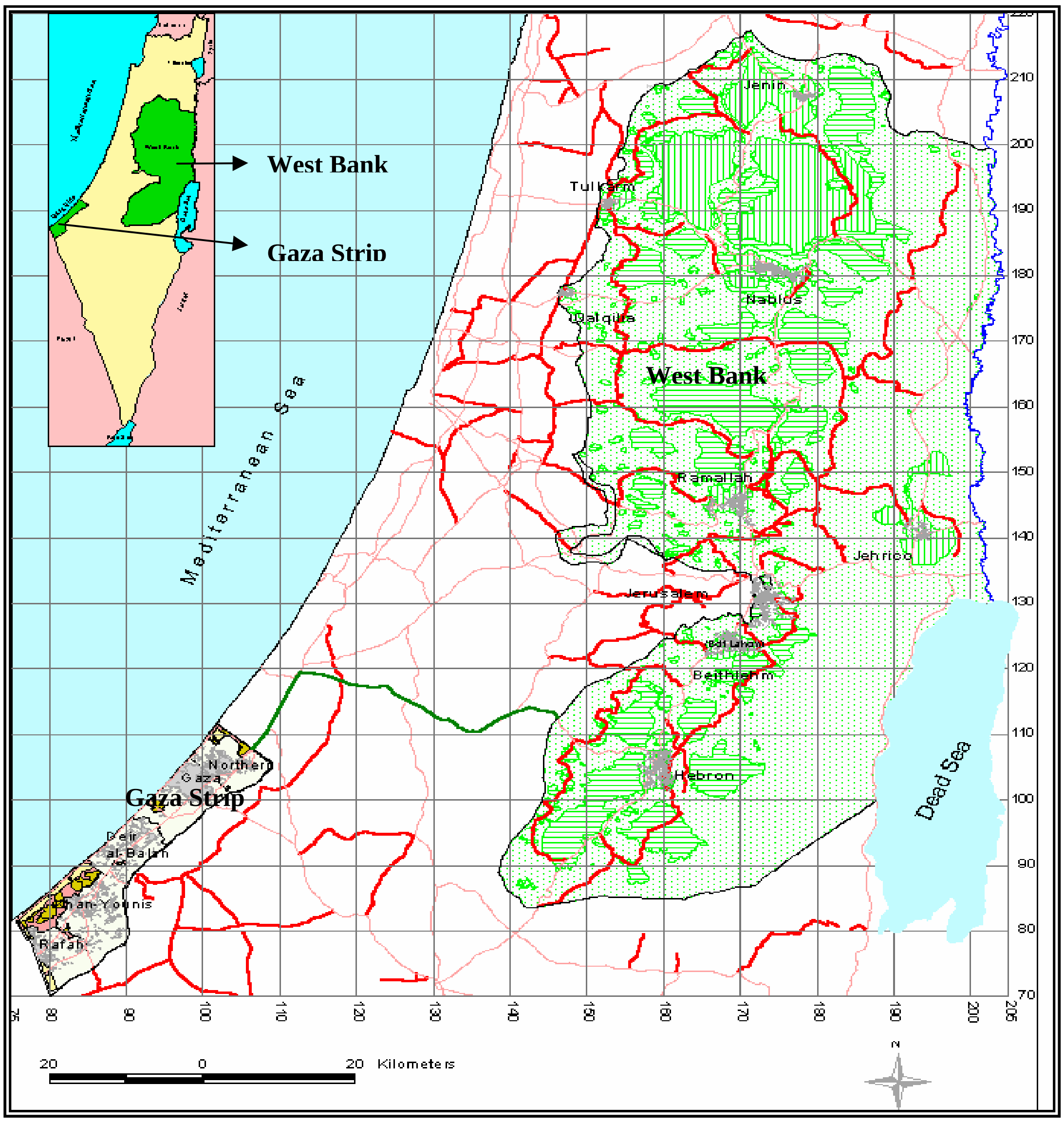

Figure (3.1): Gaza Strip and West Bank Base Map (MOPIC, 1994)

3.2 Climate and Rainfall

Gaza Strip has a characteristically semi-arid climate, and is located in a transitional zone between a temperate Mediterranean climate to the west and north, and the arid Negev and

© 2005 Tous droits réservés.

Sinai deserts to the east and south. There are two well-defined seasons: the wet season starting in October and extending through March, and the dry season from April to September. Peak months for rainfall are December and January as shown in figure (3.2).

Annual average rainfall varies considerably from more than 400 millimeters per year (mm/y) in the north to about 200 mm/y in the south near Rafah. Average annual rainfall for several Israeli stations surrounding Gaza Strip from 1961 to1990 varies between greater than 400 mm/y in the north to about 250 mm/y in the southeast. While a general north-south pattern of rainfall is apparent, a review of the existing rainfall data indicates that from one year to another, there can be significant variation in rainfall at any given station. The rainfall at any two stations located only few kilometers apart often show very different rainfall totals in any given year. Daily rainfall data have been available for 8 stations in Gaza Strip since August 1973, while one station (Station 10, the 'Meteorological Station' in Gaza City) has daily records dating back to 1968. The highest recorded one-day total in Gaza Strip was 138mm at the Beit Lahia Station on November 29, 1991.

The average mean daily temperature in Gaza ranges from 26 degrees centigrade (C^o) in summer to 12 ^oC in winter. Pan evaporation has been measured at the Gaza Meteorological Station (Station 10) for 1968 to 1997. Monthly evaporation varies significantly throughout the year. There is a five-month period in winter (November – March with a rainfall surplus). During the rest of the year, potential evaporation greatly exceeds rainfall). Fig (3.2) shows the rainfall variation in two cities, Beit Hanon in the North and Rafah in the South.

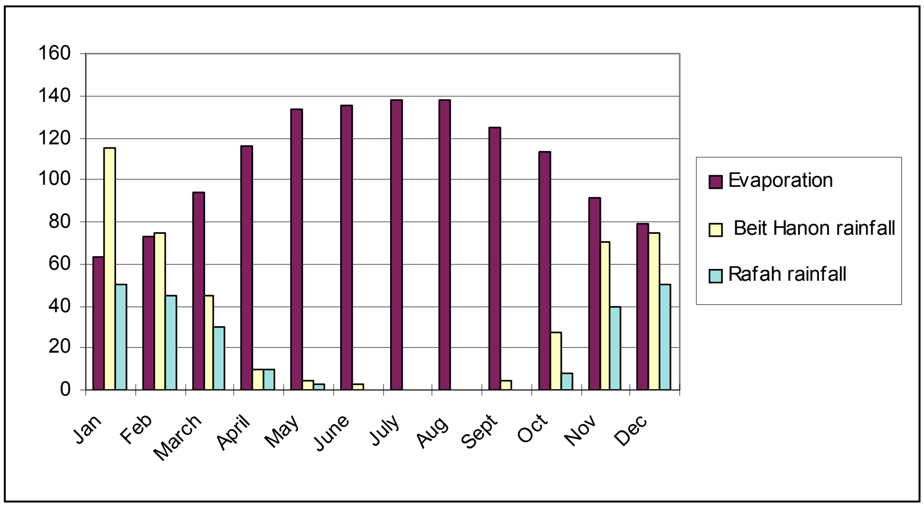

Figure (3.2): The rainfall variation in Beit Hanon and Rafah areas

© 2005 Tous droits réservés.

3.3Geology and Hydro-geology

3.3.1 Geology

The geology of the Gaza Strip consists of a series of geological formations sloping gradually westwards as shown in figure (3.3). These formations are mainly from the Tertiary and Quaternary ages. Table (3.1) summarizes the geological history of the area, which was obtained from oil exploitation logs up to 2000 m in depth.

3.3.1.1 Tertiary Formation

The Quaternary deposits throughout the Gaza Strip are underlain by the Saqiya formation of the Pliocene, which constitutes part of the Tertiary formations in the area. The Tertiary formation is composed mainly of shallow marine clays, shales and marls. The thickness of this formation is about 1200 m at the shoreline, and it decreases down rapidly to the east. Moreover, it is found in accordance to oil exploitation logs that there are other tertiary formations such as chalks, limestone, and sandstone at depths of over 2000 m.

3.3.1.2 Quaternary Formation

The Quaternary deposits in the area cover the Pliocene Saqiya and have a thickness of about 225m. The overlying Pleistocene deposits consist of the following formations (from bottom to the top):

1. **Marine Kurkar formation**

The constituents of this formation mainly consist of shell fragments and consolidated quartz sands with calcareous material. The thickness of the shell layer varies between 10 m in the east and increases to 100m westward. The marine Kurkar deposits form a good aquifer due to its high permeability and porosity.

2. **Continental Kurkar formation**

This formation is composed of calcareous sandstone with alternating red loamy sand beds. The thickness of this formation is about 100 m at most. The origin of this formation is marine sediments, which formed parallel to beach ridges.

3. **Recent deposits**

These deposits are found at the top of the Pleistocene formation with a thickness up to 25m. These deposits can be divided into four different types:

© 2005 Tous droits réservés.

a. Sand dunes:

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

b. Sand, loess and gravel beds:

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

c. Alluvial deposits:

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

d. Beach formation:

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

Table (3.1): Geology and geological history of the Gaza Strip

Era	**Epoch**	**Age 10^6 year BP**	**Formation**	**Environment of deposition**	**Lithology**	**Max. Thickness (m)**	**Water bearing character**
Quaternary	Holocene	0.01	Rocent	Terrestrial	Sand, loess, calcareous silt and gravel	25	Locally phreatic aquifer
	Pleistocene	1.8	Continental Kurkar Complex	Eolian Fluvial	Calcareous sandstone and loamy sand	100	Main aquifer
			Marine Kurkar	Near shore	Calcareous sandstone, Limestone (sandy and porus)	100	Main aquifer
Tertiary	Pliocene	12	Conglomerate	Near shore		20	Base of the coastal zone aquifer
			Saqiya	Shallow marine	Clay, marl, shale	1000	Aquiclude
	Miocene	25		Marine	Marl, limestone, sandstone and chalk	500	Aquiclude alternating permeable layers with saline water

Source: (Gaza Environmental Profile, 1994).

© 2005 Tous droits réservés.

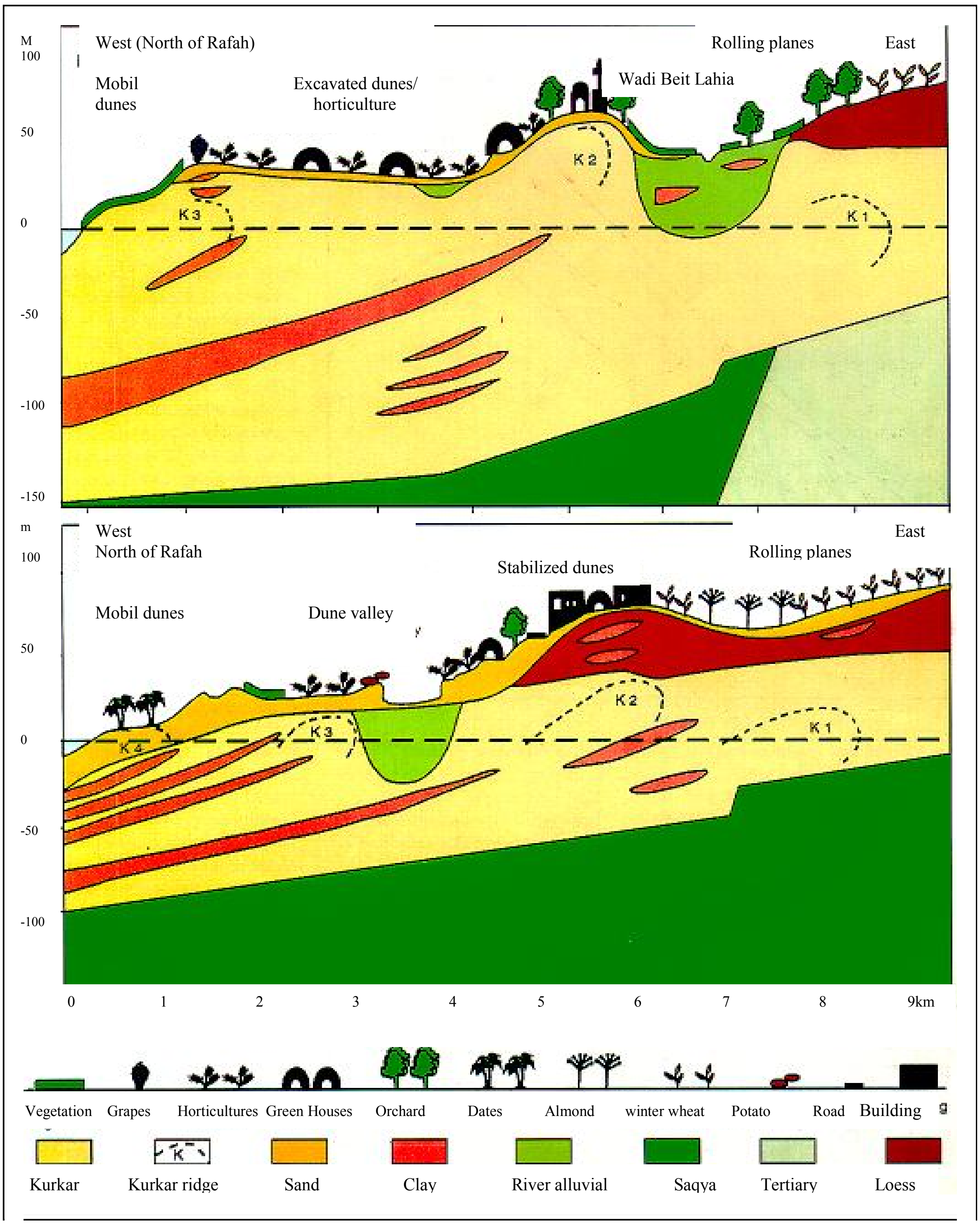

Figure (3.3): A typical cross section in the Gaza Strip (Gaza Environmental Profile, 1994)

3.3.2 Hydrogeology

The hydrogeology of the coastal aquifer consists of one sedimentary basin, the post-Eocene marine clay (Saqiya), which fills the bottom of the aquifer. Pleistocene sedimentary deposits of alluvial sand, graded gravel, conglomerates, pebbles and mixed soils constitute the

© 2005 Tous droits réservés.

regional hydrological system. Intercalated clay deposits of marine origin separate these deposits, and are randomly distributed in the area. Their thickness is decreasing to the east and basically they can be classified as aquitards. In the eastern plain the aquifer is semi-confined with an average thickness of 10 m clay, becoming phreatic 4 km from the sea.

The regional groundwater flow is mainly westward towards the Mediterranean Sea. Most of the recharge is at the adjacent uphill eastern aquifer boundary and from dune areas of the West Coast from dunes occurring in the coastal aquifer itself and from the adjacent uphill area in the east zone. The maximum saturated thickness of the aquifer range from 120 m near the sea to a few meters near the eastern aquifer boundary. Natural average groundwater heads decline sharply east of the Gaza Strip and then gradually decline towards the sea. In the Gaza Strip, the coastal aquifer can be divided into three sub-aquifers. These three sub-aquifers overlay each other and are separated by impervious and semi-pervious clayey layers. Schematization of hydro-geological cross section of the Gaza Strip aquifer is shown in the above figure (3.3).

3.4 Aquifer System

The aquifer system in the area extends along the coastal plain of the Gaza Strip. It is a continuation of the shallow sandy stone coastal aquifer of Palestine, which is of the Pliocene-Pleistocene geological age. The main aquifer consists of marine deposits of sandstone, calcareous siltstone and red loamy soils as shown in figure (3.4). The thickness of the aquifer is about 80 m at most near the sea and its thickness decreases considerably down to 10 m in the east. The aquifer is composed mainly from clastic sediments overlying impervious clay. It is more or less phreatic in the eastern half. In the western part, the aquifer is non-uniform since it divided by clay layers into sub-aquifers. These clay layers are somewhat in between aquitard and aquiclude. The unsaturated zone has a thickness varies between few meters to about 90 meters (Gaza Environmental Profile, 1994).

The main characteristics of this aquifer are that:

- It is composed of recent sandy dunes and calcareous sandstone
- At the shoreline, there are some clay layers, which subdivide the aquifer and fan out inland.
- There is a thin clay layer at the extreme east (at the border of Gaza Strip), which covers the aquifer and has a thickness of about 20m.
- Deeper aquifers are below the shale strata and are saline.

© 2005 Tous droits réservés.

The aquifer system can be divided into three sub-aquifers:

1. THE UPPER SUB-AQUIFER

The uppermost aquifer (classified as A-aquifer) extends from the shoreline to the east up to 2 km, whereas the lower sub-aquifer (C-aquifer) extends up to 5km. This aquifer is bounded from the top by the water table and at the bottom partly bounded by the first aquitard of silty clay. The thickness of this aquifer varies between 10 to 30 meters.

2. THE MIDDLE SUB-AQUIFER

This aquifer consists mainly from Kurkar and micro-conglomerate. It is considered as a partly confined-unconfined aquifer since the semi-permeable clay layer extends eastward up to about 5km. The semi-permeable layer consists of clay with chalk and silty sand. The average thickness of this aquifer ranges from 40 to 50 meter.

3. THE LOWER SUB-AQUIFER

This sub-aquifer is the deepest one in the shallow aquifer. It is partly bounded by the second semi-permeable layer at the top and by the Saqiya impervious formation at the bottom. This aquifer is considered as confined at the shoreline up to about 5km eastward. The main constituents of this aquifer are sand and chalk with some conglomerate in the middle.

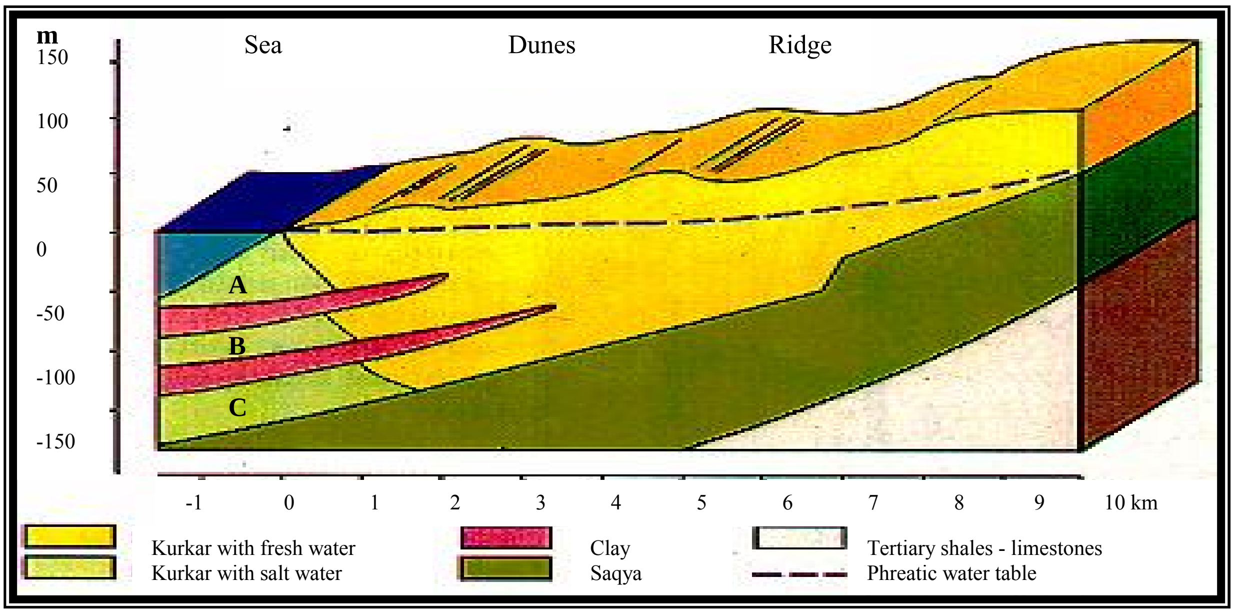

Figure (3.4): Schematic diagram across the Gaza Strip (Gaza Environmental Profile, 1994).

© 2005 Tous droits réservés.

3.5 Land Use

3.5.1 The present situation of land use

Land use of the Gaza Strip is based on a regional plan developed by the Ministry of Planning and International Co-operation for the West Bank and Gaza Strip (MOPIC. 1998). The land is scarce in the Gaza Strip. The pressure on land is increasing rapidly for all kinds of uses, such as urban use, industrial use, and most important the need for more agricultural land for people in order to make a living. The current situation may change rapidly if the political situation improves, because at present, the Israeli Occupation imposes restrictions on the development especially on the industrial development. Also the situation may change when Palestinians return from exile. Currently, nothing is known about land use within the area under the occupation of the Israeli colonies.

Agricultural land occupies about 170 km^2, which is close to 50% of the total area of the Gaza Strip. Agriculture is the largest single sector in the economy and contributes to 32% of the economic production. This sector employs approximately half of the active labour force (approximately 50.000 employees). Agriculture has passed through stages of expansion and land reduction. The cultivated area increased from 170 to 198 km^2 from 1966-1968. Ten years later, the cultivated area decreased to 179 km^2, mainly due to the increase in urban areas from 11% to 19% of the total area of Gaza Strip. Also, the forest areas and sand dunes have decreased from 32% to 22%. Green Houses are introduced and the traditional system of irrigation has been replaced by drip and sprinkler irrigation. Also traditional crops such as citrus are replaced by other crops such as strawberries, flowers and others. Agricultural land is mostly in private ownership, registered in the cadastre or owned by inheritance. Gaza experiences a fragmentation of agriculture land due to the traditional system of ownership by inheritance and parcellation of land to family members. Seventy three percent of the agricultural land consists of parcels of less than 9000 m^3.

Israeli settlements occupy about 15% of the total land area. The largest settlement is Gush Qatif in the Mawasi area in Southwest Gaza Strip. Settlements consist primarily of agricultural land, with intensive farming in greenhouses. Surrounding the settlements, Israeli authorities have established security zones, which further reduce access to surrounding land. The breakdown of land use by sector is provided in Figure (3.5). The table bellow shows the land use distribution in the Gaza Strip.

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Table (3.2): Present land use distribution

Type of use	Area (ha)	Area (%)
Cities, villages, municipal borders and village councils	11,7 00	32
Israeli settlements	5,7 00	15.6
Main and secondary roads	500	1.4
Agricultural land	17,000	46.5
Reserved areas for future plans	1,600	4.5
Total	36,500	100

Source: MOPIC, 1996

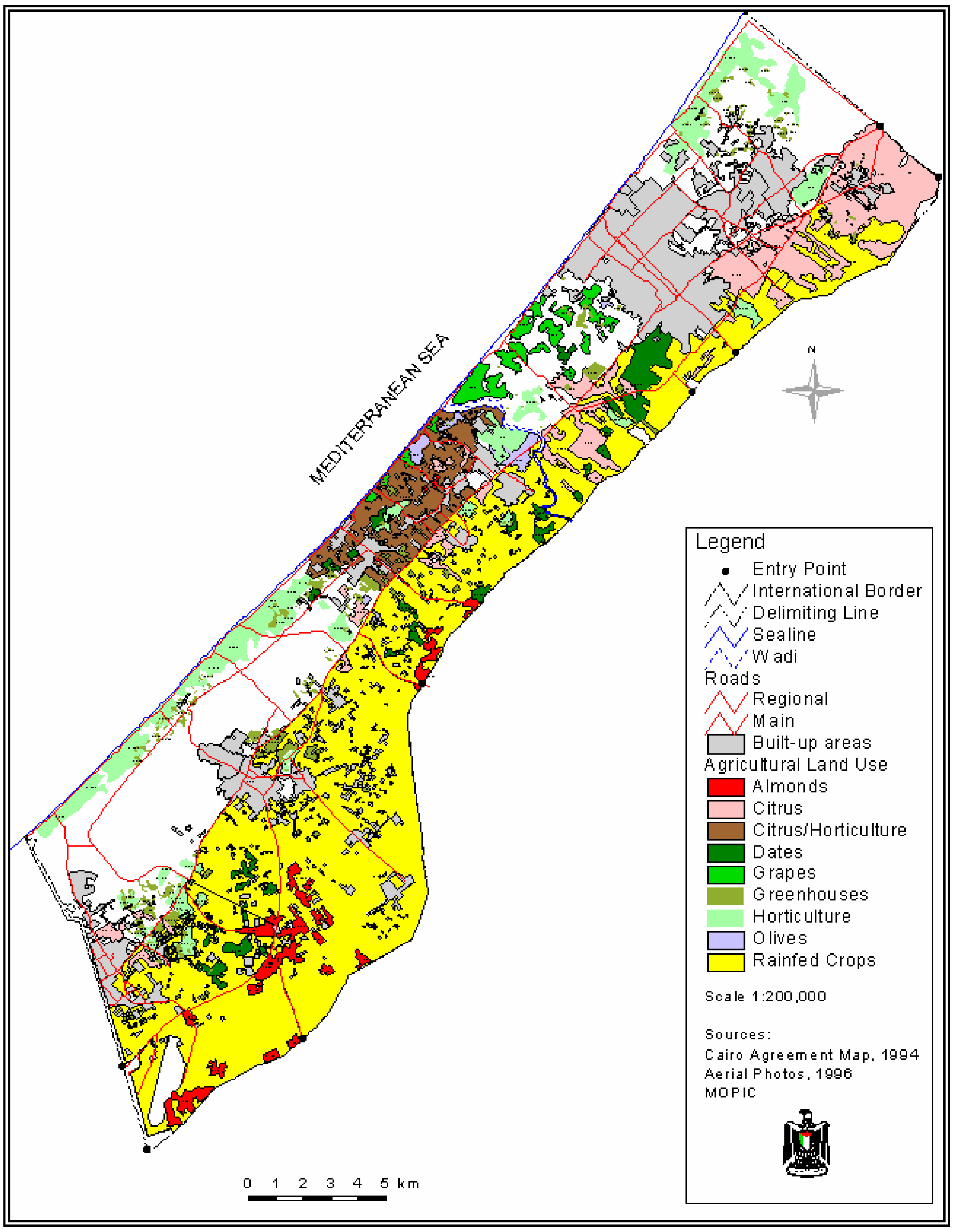

Figure (3.5): Gaza Strip Present Land Use Map

© 2005 Tous droits réservés.

3.5.2 Future land use

3.5.2.1 Residential future needs

Residential future needs for land use have been estimated without access to regional economic projections. They are therefore primarily based on population forecasts (MOPIC, 1996). According to the basic planning assumption and population projection from 1996-2025 (Table 3.3) and based on scenario one (Low rate of population growth), the projection is calculated for housing units demand in the five governorates and the future land use needs in terms of residential, roads and transportation, industry, commerce, services and recreation (MPOIC, 1996). So it is expected that the nitrogen pollution sources from the residential areas will increase according to the increases of residential lands.

Table (3.3): Built-up areas per Governorate

Area	1997		2005		2015		2025	
	ha	Person/ ha	ha	Person/ ha	ha	Person/ ha	ha	Person/ ha
North	1,356	10.96	1,672	11.86	2,16	11.98	2,564	12.43
Gaza	2,023	17.52	2,893	17.32	4,42	19.03	5,457	19.7
Middle	703	20.65	1,034	18.7	1,55	16.28	1,985	15.66
Kanyunis	1,081	18.62	1,545	19.45	3,47	21.45	4,469	21.68
Rafah	586	19.29	834	17.9	1,23	15.74	1,548	15.29
Total	5,750	16.74	7,980	16.83	12,8	17.85	16,024	18.16

Source: MOPIC, 1997

3.5.2.2 Future Land Use Demand for Industries and Commerce

The industries and the commerce now do not have designated land to perform their activities on. The future plans will designate certain areas as industrial zones. There are already some industrial zones under construction or proposed to be constructed in the near future.

- Almuntar industrial area; located in Gaza city.
- Deir El Balah Industrial Area; which is to the east of Deir El Balah.
- Rafah Industrial Area ; close to the Gaza International Airport in Rafah city

Table (3.4): Demand for industrial, trade and commercial land

Area	Industry (ha)	Trade and commerce (ha)
Northern Goverorate	115	92
Gaza Governorate	250	198
Deir El Balah Governorate	129	104
Khan Younis Governorate	222	178
Rafah Goverorate	127	102
Total	843	674

Source: MOPIC, 1997

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

3.5.2.3 Future agricultural land use

The current land use will not expand in the future. There is no much land in Gaza Strip left unused, so it is expected that the future expansion will be for the domestic use on the account of agricultural land already used. So it is expected that the nitrogen pollution sources from agricultural will be stable or decease according to the loss of agricultural lands. There will be some change in the crop pattern, because of the following reasons.

- Going for less water demanding crops, because the expected increase of water price
- The low return for the existing crops
- The increase of water salinity that will require more tolerant crops

Table (3.5): Agriculture Production Areas in the Gaza Strip (ha)

Item	Rafah	Khanyounis	Middle area	Gaza	Northern area	Total
Vegetable	1515.1	880.8	983.7	642.6	704.8	4727
Rainfed crops	985	2897	553	401	460.5	5296.5
Citrus	140	95.5	591.7	1195	1184.7	3206.9
Fruit	577	1356	957.2	1300	241	4431.2
Total	3217.1	5229.3	3085.6	3538.6	2591	17661.6

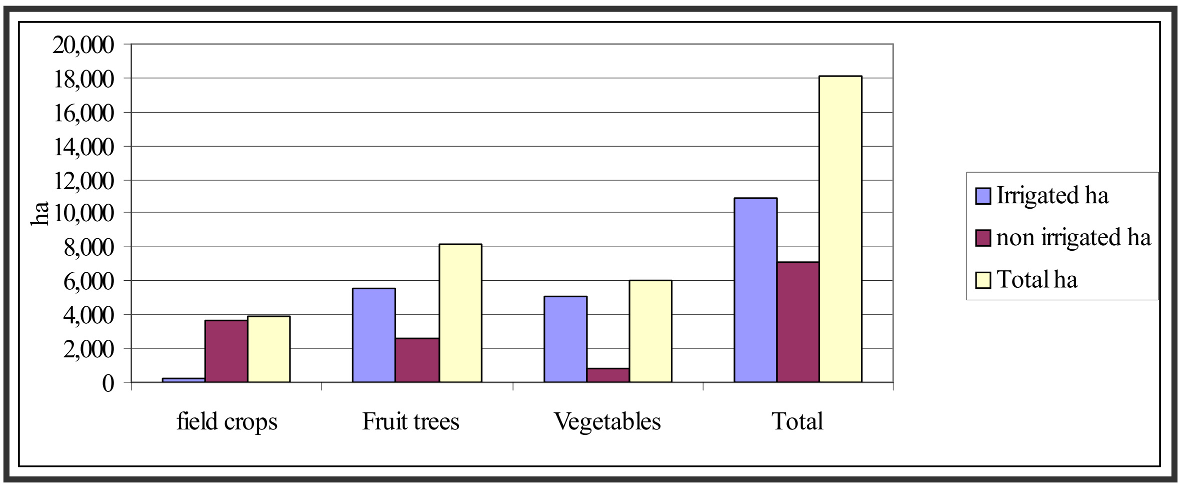

Figure (3.6): The agricultural land use in the Gaza Strip (MOPIC, 1997)

3.6 Domestic Wastewater treatment and Disposal:

Currently there are three treatment plants in the Gaza Strip namely, Beit-Lahia, Gaza City and Rafah. The effluents of the treatment plants are mostly discharged to the Mediterranean Sea and to the environment. The total annual wastewater production in the area is estimated to be about 40 Mm^3, from which 22 Mm^3 are disposed into the sewers and 18 Mm^3 into cesspits or pit latrines. Due to low water consumption in the Gaza Strip, the produced wastewater strength is high with an average BOD value of 560 mg/l. It was reported that

© 2005 Tous droits réservés. http://www.univ-lille1.fr/bustl

about 60% of the population in the area are connected to sewer networks. This percent is distributed as follows: Beit-Hanon 62%, Jabalia 77%, Gaza City 78%, Rafah 50%, Deir El-Balah area 50% and 0% for the remainder. Cesspits and boreholes are the other wastewater disposal systems in the area. About 75% of the industrial activities dispose their wastewater into the sewers while the rest use cesspits. The estimated annual industrial water consumption is 2 million cubic meter, most of it is disposed into the sewer systems. The following table summarizes wastewater generation and treatment in the Gaza Strip.

Table (3.6): Wastewater generation and treatment

#	Category	Unit	Quantity
1	Population connected to wastewater treatment	%	54
2	TOTAL number of wastewater treatment plants	number	3
3	TOTAL wastewater generated	1000 m^3/d	109.58
3.1	Non-treated wastewater	1000 m^3/d	50.17
3.2	Treated in public treatment plants	1000 m^3/d	59.42
4	Discharge to Environment (raw and treated)	%	60
5	Discharge to the Sea (raw and treated)	%	40

EQA, Land base Pollution Sources, 2001

3.6.1 Gaza City treatment plant

The Gaza City treatment plant is located to the Southwest of the Gaza City, newly rehabilitated, with influent flow rate of 42,000 m^3/d (300,000-population equivalent) and a total area of 130,000 m^2. The system comprises 2 sedimentation ponds, 1 anaerobic pond, 2 trickling filters, 1 aerated lagoon, disinfection chamber, 8 sludge drying beds and a pond for holding sludge. The effluent BOD is 30 mg/l, TSS is lower than 30 mg/L and Kj-N is lower than 50 mg/L.

Ten thousand cubic meters of the effluent is allowed to infiltrate through 2 infiltration basins to the east of the plant. Most of the produced effluent from Gaza City treatment plant is discharged to the Mediterranean Sea through an old pipeline. The plant now receives wastewater quantity more than its capacity. As a result of that the PWA in cooperation with Gaza Municipality prepared a study to expand the capacity of the plant to be able to receive around 70,000 m^3/d to cover the wastewater production in the next five years until establishment of the proposed central treatment plant. Table (3.7) shows the wastewater characteristics before and after rehabilitation of the Gaza City Wastewater Treatment Plant. The result indicates that a high improvement of performance of the plant has happened.

© 2005 Tous droits réservés.

Table (3.7): Wastewater characteristic before/after plant rehabilitation in the Gaza City

Parameter	Before Rehabilitation	After Rehabilitation
pH	7.24	6.5-8.5
Conductivity (mS/cm)	3243	2000-2600
Turbidity (NTU)	110	20-30
BOD (mg/L)	178	20-30
COD (mg/L)	339	46-85
Temperature (C^o)	18.9	11-18.7
TSS (mg/L)		14-30

Source: Gaza Municipality, 2001

3.6.2 Beit-Lahia wastewater treatment plant

The Beit-Lahia wastewater treatment plant comprises 2 anaerobic ponds, 2 aerated lagoons, 2 facultative lagoons and a maturation pond. The flow rate value is 10,000 m^3/d (120,000-population equivalent). The plant was rehabilitated in 1996 by adding additional ponds. The system is located on a permeable sandy soil above the aquifer (which has the best water quality in comparison with other aquifers in the Gaza Strip). The effluent of Beit-Lahia treatment plant is discharged to the area of the sand dunes around the plant.

3.6.3 Rafah Wastewater treatment plant

The Rafah wastewater treatment plant was designed for a capacity of 1800 m^3/d (21,000-population equivalent). At the present the plant is considered over loaded by receiving more than 4000 m^3/d. The plant includes inlet micro-screen 0.4 mm, one aerated pond, volume 31200 m3 fitted with surface aerators and horizontal mixers, one chlorination channel for disinfection (not in operation), and one pumping station containing two pumps to discharge the effluent to the sea. The aerators of the plant are only operated daytime and not on a 24 hour basis. The following table shows the raw and treated wastewater characteristics of the Beit Lahia, Gaza, and Rafah WWTPs

Table (3.8): Wastewater characteristics of the Gaza Strip

Parameter	Beit Lahia WWTP		Gaza WWTP		Rafah WWTP	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
PH	7.49	7.69	7.51	7.68	7.67	7.46
BOD (mg/L)	552.85	27.05	547.14	47.14	836.44	268.42
COD (mg/L)	1151.84	94.08	1106.92	144.21	1510.96	650.53
Temperature (C^o)	25.2	25.3	24.8	25.1	20.3	22
TSS (mg/L)	561.62	26.1	595	56.5	583.29	161.81
TDS (mg/L)	1600	1579	989	983.5	1596	1510

Source: Municipalities, 2001

© 2005 Tous droits réservés.

3.7 Sludge Disposal and Treatment

Three wastewater treatment plants exist in the Gaza Strip, the largest one of them which serves Gaza City use the activated sludge treatment method. In general, treatment plants which use the activated sludge method generate large quantities of sludge. Sewage sludge has beneficial plant nutrients and soil conditioning properties. Land application of raw or treated sewage sludge can provide a large part of nitrogen and phosphorus required for many crops because of its rich nutrient value on agricultural land. But in this case sewage sludge must be produced from domestic sewage only to avoid industrial effluents which contain, in addition to organic material, traces of many pollutants used in our society.

It is estimated that sludge quantities in the Gaza Strip reach many thousands of tons per day. In order to provide sludge as fertilizer for agricultural use, methods must be implemented to control and reduce metal concentrations to prevent damage to agricultural crops and public health and to prevent soil and groundwater pollution. Sewage sludge may contain pathogenic bacteria, viruses and protozoa along with other parasitic helminthes, which can give rise to potential hazards to the health of humans, animals and plants. The numbers of pathogenic and parasitic organisms in sludge can be significantly reduced before application to the land by appropriate sludge treatment and the potential health risk is further reduced by the effects of climate, soil micro-organisms and time after the sludge is applied to the soil.

Due to the lack of sludge treatment and non-acceptability of farmers for sludge use in agricultural land application, the municipal sludge is not used in the Gaza Strip till now. Use of treated sludge in land application needs approval of the relative ministries such as the Ministry of Environment and the Ministry of Health. If the farmers accept to use waste sludge in land application, there is a difficulty of assuring the long-term stable demand from farmers in Gaza Strip. Owing to non-using of treated sludge the disposal in a sanitary landfill has been established.

Beit Lahia WWTP sludge: The generated sludge mixed with sand, 27,000 m3/year, is disposed at solid waste dumping site by boldozers from the sedimentation ponds once every year. In year 2001, a sand trap and screeners were installed to reduce the huge amount of sand reaches the plants. Fourteen cubic meters of black sand produced weekly in the plant are disposed at Biet-Hanon landfill.

© 2005 Tous droits réservés.

Gaza WWTP sludge: This plant has been designed to receive about 35,000 m^3/d wastewater and 320 m^3 per day wet sludge (95% humidity), but in fact the plant receives 45,000 m^3 wastewater of which 450-500 m^3/d wet sludge. By settlement channel the sludge has been disposed from aerated ponds to the holding pond and then to drying ponds where the sludge stay about 8 days until dry (with thickness about 5-10 cm). This settlement channel with length about five meter do as imhoff where sediments settled at the bottom and the water passes over it. The pump exists at the bottom settlement channel to pump the sludge to the holding pond three times per day. The farmers are forbidden to use the treated sludge because Gaza Municipality is waiting the agreement of MOH and EQA, so the sludge is transferred daily from drying ponds to Gaza landfill. Owing to the small size of drying ponds, there is a new project to develop and increase the capacity of these ponds to become around 20 drying ponds. The size of each one will be about 1000 m^3, and the sludge will be treated and accumulated in the holding pond then drying. The following table shows the quality of treated sludge produced in the Gaza City WWTP.

Table (3.9): Quality of treated sludge at the GWWTP

Temp. C^o	pH	EC ms/cm	TS mg/L	TSS mg/L	TVS mg/L	COD mg/L	NO_3^- mg/L	NH3 mg/L	TKN mg/L	PO_4^{--} mg/L
21.8	7.2	2.56	28,440	25,060	14,400	25,860	0	114	672	9

Rafah WWTP sludge: No sludge treatment has been done in the city of Rafah. The waste sludge settle at the bottom of the collection bond mixed with sand without any separation. In 1998, a project of WWTP has been implemented with LEKA co-operation to clean the ponds from accumulated sludge. In this project all sludge quantities have been removed from the main ponds to other temporary small lagoons protected and coated with polyethylene sheets at the base. The quantity of the sludge produced daily is unknown but can be estimated according to the wastewater production.

3.8 Industrial Wastewater

Industrial wastewater constitutes about 5% of Palestinians wastewater, but its potential risk to the environment is especially significant. At present a significant portion of the industrial wastewater generated in Gaza Strip is similar to domestic wastewater. This is because most of industries in Gaza Strip are small-scale industries and several industries such as garment manufacturing, plastic, paper manufacturing, print shops, glass, wood, leather, asphalt, petrol

© 2005 Tous droits réservés.

stations and refrigeration don't use water as a row material in the production process but only for domestic purposes.

3.9 Pesticides Use

In the Gaza Strip, more than 125 different pesticides are used annually, mainly organochloronated, organophosphated, carbamates and pyrethroids. More than 900 metric tons of formulated pesticides are used annually in Gaza Strip. Most of these pesticides are used to protect the main cash crop products (citrus, vegetables, fruits and flowers) from pests and fungi. Moreover insecticides and rodenticides are also used in towns and cities to control household insects and pests.

The most common application methods are spraying with liquid formulations, dusting with powders and injection with gas. Spraying methods are used to apply more than 70% of the pesticides, a method that is particularly hazardous to the inhabitants of the crowded village lying within the spray zone. Moreover methyl bromide, which is considered the most dangerous fumigants, is applied directly to the soil.

Most of the pesticides are manufactured in Israeli and the others are imported from western companies through Israel. Nevertheless, several dangerous agricultural pesticides that are restricted, cancelled or banned in most of the developed countries, including Israel, are allowed to enter the Gaza Strip and still widely used.

3.10 Fertilizers

3.10.1 Chemical Fertilizers

Man-made fertilizers became widely available after World War II, and they came quickly into use across the world. Today, nitrogen fertilizers (commonly nitrate or ammonium compounds) and phosphorus fertilizers as well as potassium fertilizers are used in large quantities in most of agricultural settings in Gaza Strip. All Phosphorus and nitrogen and potassium fertilizers are applied to the soil before plantation to prepare and enrich the soil for seed grow up. The remaining quantity of these compounds is added to the plant during grow up campaigned with water to compensate the plant uptake of the nutrients.

Agrochemicals are increasingly important to improve crop yields needed to feed a growing population in the Gaza Strip. The estimated population will reach 1.6 million by 2010. Although the demand for food will increase as population increases, the area of cultivated

© 2005 Tous droits réservés.

land will not increase significantly. For this reason, methods of improving crop production must be found to satisfy the nutritional requirements of the expanding population. The use of pesticides and fertilizers are one way of increasing food supply.

The extent and intensity of agriculture in the Gaza Strip produce high annual rates of fertilizers application (28,100 Tons/ year). This has particular influence on water and land quality. Nitrogen fertilizers used in agriculture make up 70% of the nitrate load in the Gaza ground water resources, since nitrogen fertilizers constitute 50% of the fertilizers use. Most of chemical fertilizers are imported from Israeli companies and a little quantity comes to Gaza Strip as a donation from Egypt or Japan Government. The lack of equipped laboratories in the Gaza Strip makes it difficult to test the quality or components of these chemicals. Figure (3.7) shows the quantity of Nitrogen, Phosphorus and Potassium fertilizers used annually in Gaza Strip.

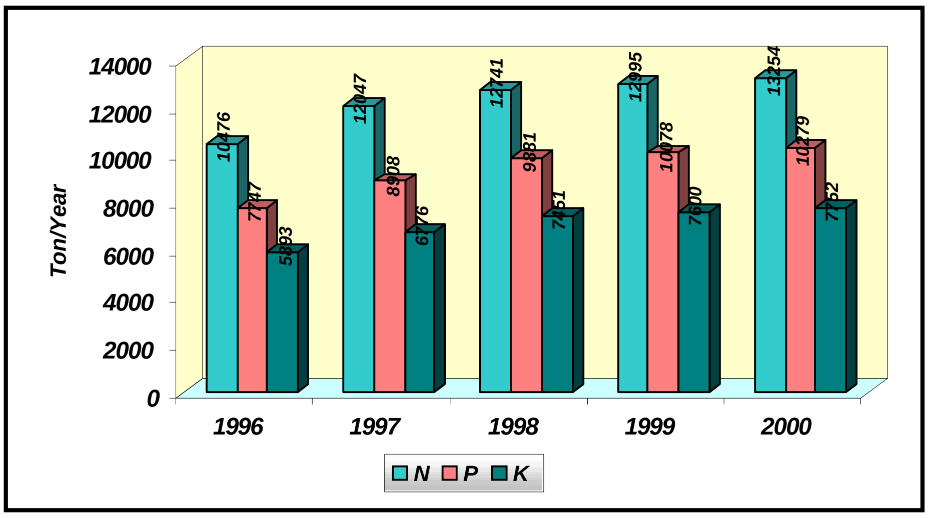

Figure (3.7): Nitrogen, Phosphorus and Potassium fertilizers used annually in Gaza Strip

3.10.2 Organic Fertilizers

More than 370,000 ton of organic fertilizers are used annually in the Gaza Strip, 40% of these quantities are imported from Israel, and the other quantities are produced by the animal farms in the Gaza Strip. The imported organic fertilizer from Israel is not checked for the quality or the chemical components to find out whether it is mixed with industrial waste or not. Table 3.10 below shows the quantity of imported livestock from Israel to the Gaza Strip in 2000.

© 2005 Tous droits réservés.

Table (3.10): Quantity of imported livestock from Israel to the Gaza Strip (No./year)

Type	Cows & Calfs	Sheep	Layers chicken	Duck chicken	Turkey chicken	Geese chicken	Alive Turkey	Broilers hatching eggs	Layers Hatching eggs	Layers Hens
Total	16823	4154	93050	77290	110300	19340	10270	5954750	364000	108105

3.11 Solid Waste Generation

Solid waste in Gaza consists mainly of household waste, building debris, agricultural waste, industrial waste (workshops), medical waste, and car workshops. A solid waste generation rate varies between 0.35 Kg/capita to 1.0 Kg/capita. The total solid waste generated in Gaza Strip varies between 500 to 550 tons per day for all cities and village councils and from 200 to 220 ton per day for all refugee camps. It is estimated that more than (65%) of the household solid waste consists of organic materials, while sand is the second major component (23%). This implies that the density of the household solid waste ranges between 250 to 600 kg per m^3. Table (3.11) shows the proportion of total waste generated by different sources in the Gaza City and table (3.12) shows the composition of solid wastes in the Gaza Strip. Table (3.13) shows the projected solid waste production, 2000-2020.

Table (3.11): Proportion of Total Waste Generated by different sources in Gaza City

Item	Percent	Item	Percent
Households	49%	Schools and universities	2%
Shops and markets contribute	8%	Hospitals, clinics, pharmacies	2%
Butchers, restaurants, hotels	4%	Construction sector	10%
Offices, banks, institutions	4%	Other industries	10%
Army, police camps	4%	Litter, sand and crash cleaning	7%

Table (3.12): Composition of solid wastes

Composition	% by Wet Weight	Composition	% by Wet Weight
Organic materials	67	Cloth	1.5
Paper	1.5	Plastic	2
Metal	1.5	Sand	23
Glass	1.5		

Table (3.13): Projected solid waste production, 2000-2020

Year	Tons per day
2000	1144
2010	1883
2020	2777

Source: MOPIC, Solid waste urgent action plan, 1995.

© 2005 Tous droits réservés.

Chapter 4

Urban and Agriculture Nitrogen Load

4.1 Objectives

1. To determine all possible sources of nitrogen in the study area and to quantify their contribution.
2. To determine all possible sinks of nitrogen in the study area and to quantify their effect.
3. To formulate a clear picture about nitrogen pollution at the present and the possibility for contamination in the future.

4.2 Potential Sources of Nitrate in Groundwater

There are a number of complex numerical models, which have been developed to predict pollutant flow within and impact upon aquifers. In general, these models demand a high level of mathematical competence, computer access, and often require a more detailed knowledge of aquifer characteristics than is available (e.g. values for coefficient of storage, dispersivity). The nitrogen balance is used as a useful tool to identify the nitrate pollution sources and to asses the contributions of each source to pollution load in order to be able to recommend the possible ways for management of point and non-point pollution sources regarding nitrogen compound. The general nitrogen balance equation is: N inputs – N outputs = change in total N (organic plus inorganic) stored within the system. This equation can be solved for long-term potentially leachable N (LPLN).

LPLN = N inputs – N outputs – (ΔN_{st}), where

LPLN: Long-term potentially leachable total N that may leach from the system during drainage events and thus it may potentially affect groundwater quality (N-Balance).

N inputs: Nitrogen additions.

N Outputs: Nitrogen sinks (losses) excluding Leaching.

ΔN_{st}: the change in the storage within the system.

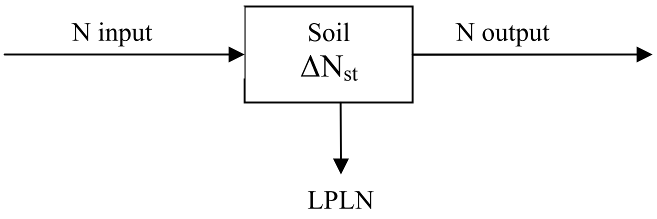

Figure (4.1): Sketch for nitrogen balance

© 2005 Tous droits réservés.

In dry areas the LPLN may not reach the groundwater for many years or decades. The extent that LPLN affects groundwater quality will therefore depend heavily on hydrologic conditions. Another noteworthy aspect of LPLN is that it is the total N (inorganic N plus organic N) estimated to be an excess and thus potentially available for leaching. This is obviously a simplification since only NO3-N is mobile in the soil and organic N is immobile. If viewed over the long term, however, the organic N component can certainly be subject to potential leaching as it mineralizes over time. The impact of LPLN on groundwater quality may be affected by N transformation in the vadose zone. Thus, the fact that LPLN may be high does not necessarily mean that groundwater quality will be affected. On the other hand, if LPLN is high it does mean that the potential for significant leaching is present.

The N balance or budget can be simplified by assuming that the soil organic matter content, and consequently soil N content, remains constant on yearly basis for monoculture system. Fried et al. (1976) stated that any continued agricultural practice will result in the soil N content reaching a steady state level. The transfer of N to groundwater should then equal to the difference between N inputs and N outputs. So in this chapter the nitrogen balance will be based on the assumption of steady state condition in which there is no change in nitrogen storage within the system.

The ΔN_{st} is equal to zero since most of the lands in the study area have monoculture and is subjected to the same continued agricultural practice. There are many different sources of nitrogen in the study area which should be discussed through this chapter. Figure (4.1) shows the different nitrogen sources in the study area and figure (4.2) shows the nitrogen cycle in soil and groundwater. Within the scope of this study the main sources of nitrogen will be determined. These sources are:

1. Wastewater application, leakage from sewer system, and septic system.
2. Decaying of organic mater (solid waste).
3. Manure and fertilizers.
4. Leakage from drinking water distribution networks.
5. Natural precipitation & atmospheric deposition.

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

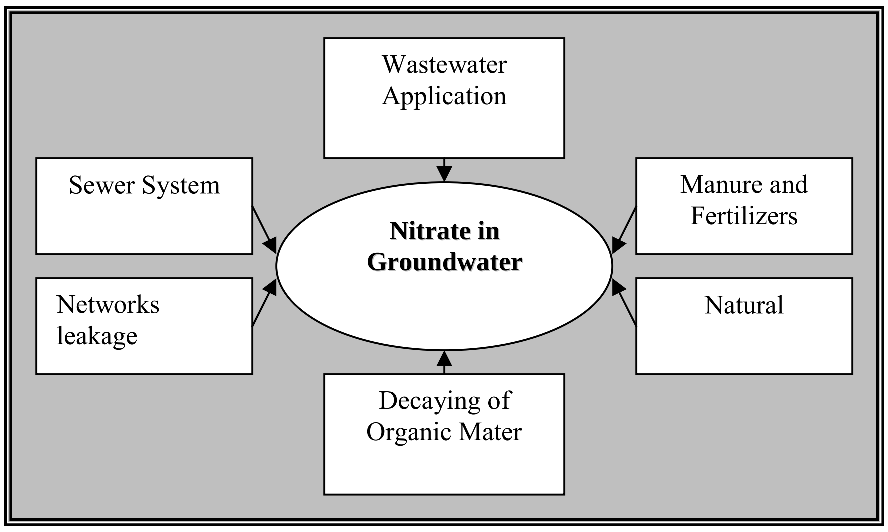

Figure (4.2) Some Potential Sources of Nitrate to Groundwater

The possible sinks of nitrogen in the study area:

1. Plant uptake.
2. Denitrification from fertilizers, manure, irrigation water and wastewater
3. Ammonia volatilization from fertilizers and manure.

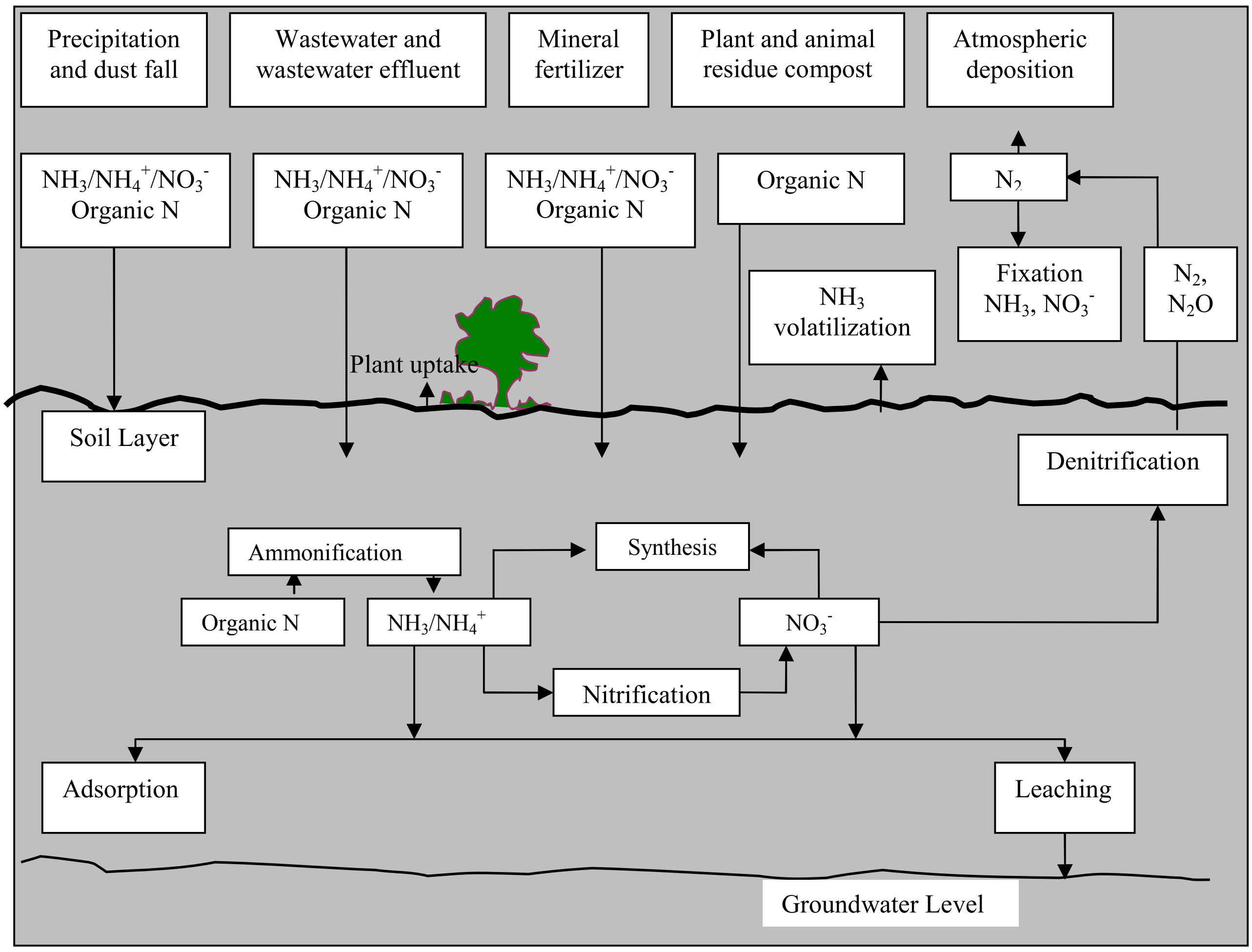

Figure (4.3): The nitrogen cycle in the soil and groundwater (after Scheible, 1994)

© 2005 Tous droits réservés.

4.3 Wastewater

4.3.1 Effluents of the treatment plants

The effluents of the treatment plants are mostly discharged to the Mediterranean Sea and to the environment. The total annual wastewater production in the area is estimated to be about 40 Mm^3, from which 22 Mm^3 are disposed into the sewers and 18 Mm^3 into cesspits or pit latrines.

- **Gaza City treatment plant:** The Gaza City treatment plant influent flow rate is 42,000 m^3/d (300,000-population equivalent). Most of the produced effluent (32,000 m3/d) from the Gaza City treatment plant is discharged to the Mediterranean Sea through an old pipeline.

- **Beit-Lahia wastewater treatment plant:** The flow rate value of the Beit-Lahia wastewater treatment plant is 10,000 m^3/day (120,000-population equivalent). The plant is located on a permeable sandy soil above the aquifer (which has the best water quality in comparison with other aquifers in the Gaza Strip). The effluent of Beit-Lahia treatment plant is discharged to the area of the sand dunes around the plant.

- **Rafah Wastewater treatment plant:** The Rafah wastewater treatment plant was designed for a capacity of 1800 m^3/d (21,000-population equivalent). At the present the plant is considered over loaded by receiving more than 4200 m^3/d. Tables 4.1, 4.2, 4.3 and 4.4 show the wastewater characteristics in the three treatment plants.

Table (4.1): Wastewater characteristics of the Gaza Strip

Parameter	**Jabalia WWTP**		**Gaza WWTP**		**Rafah WWTP**	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
pH	7.49	7.69	7.51	7.68	7.67	7.46
BOD (mg/l)	552.85	27.05	547.14	47.14	836.44	268.42
COD (mg/l)	1151.84	94.08	1106.92	144.21	1510.96	650.53
Temperature (C°)	25.2	25.3	24.8	25.1	20.3	22
TSS (mg/l)	561.62	26.1	595	56.5	583.29	161.81
TDS (mg/l)	1600	1579	989	983.5	1596	1510
Kj-N	103	93.3	109	68	98	95
NH4-N	62.2	69	54	45	54	68
NO3-N	0.0	0.0	0.0	0.0	0.0	0.0

Source: Fieldwork, 2002

Table (4.2): Wastewater characteristics of Gaza WWTP

Parameter	Run 1		Run 2		Run 3		Average	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	9.98	8.1	8.05	7.59	7.73	8.05	8.6	7.9
Kj-N	95	67	196	84	154	77	148.3	76.0
NO3	4	2.4	0	0	0	0	1.3	0.8
NH3-N	34.2	56	84	53.2	41	36	53.1	48.4

Source: Fieldwork, 2002

© 2005 Tous droits réservés.

Table (4.3): Wastewater characteristics of Beit-Lahia WWTP

Parameter	Run 1		Run 2		Run 3		Average	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	7.98	7.54	8.06	7.59	7.74	7.67	7.9	7.6
KjN	196	106	196	84	175	87.5	189.0	92.5
NO3	1.2	2	0	0	0	0	0.4	0.7
NH3-N	112	68	84	53.2	71	61	89.0	60.7

Source: Fieldwork, 2002

Table (4.4): Wastewater characteristics of Rafah Wastewater treatment plant

Parameter	Run 1		Run 2		Run 3		**Average**	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	8.24	7.67	8.08	7.56	7.96	7.56	8.1	7.6
Kj-N	308	218	210	114	196	126	238.0	152.7
NO3	0	0	0	0	0	0	0.0	0.0
NH3-N	140	79.5	100	64	100	63	113.3	68.8

Source: Fieldwork, 2002

In order to calculate the nitrogen balance for the Gaza Strip treatment plants there must be some assumptions as:

1. The flow rate of influent equals the outflow (negligible evaporation and leakage from the ponds),
2. Since the pH is less than 8, there is no ammonia volatilization from the WWTP.
3. Nitrification will occur along the wastewater stream, a denitrification loss of 20% of the nitrogen is estimated (Section 2.15.2).
4. The table below shows the nitrogen balance (production-losses) in the three treatment plants in the Gaza Strip.

Table (4.5): Nitrogen balance for the Gaza Strip WWTPs

Location	Area affected (ha)	Flow rate (m3/d)	TN (kg/m3)	N input (kg/y)	N losses (kg/y)	N-balance kg/y	N-balance kg/ha.y
North	1514	10000	0.0925	337625	67525	270100	178
Gaza	2458	42000*	0.067	244500	48910	195590	80
Middle area	869	There is no treatment plant exist					
Khanyounis	1313	There is no treatment plant exist					
Rafah	710	4200	0.1527	234,089	46,818	187,271	264
Total	6864			816,214	163,253	652,961	139

* About 32,000 m3/d are disposed to the Sea

4.3.2 Leakage from sewer system

It was reported that about 60% of the population in the area are connected to sewer networks. This percent is distributed as follows: Beit-Hanon 62%, Jabalia 77%, Gaza City 78%, Rafah 50%, Deir El-Balah area 50% and 0% for the remainder. Leakage from sewer system is considered as non point source pollution. There are no estimations for the leakage from the sewer systems, so 20% leakage from the total flow was made according to Rabah, F., 1996.

© 2005 Tous droits réservés. http://www.univ-lille1.fr/bustl

This percentage is considered very high compared with other areas but the pipes age, malfunction of pumping system, size of the pipes, and soil type are the main reasons to assume 20% of wastewater leakage from the sewer systems. The nitrogen concentration in the leakage is considered to be similar to that in the influent. By assuming that nitrification will occur with time during percolation, 20% loss of nitrogen through denitrification (Section 2.15.2), and no significant nitrogen loss from leakage through ammonia volatilization, the nitrogen balance were calculated. The table below shows the nitrogen balance for the leakage from the sewer systems.

Table (4.6): Nitrogen balance from leakage of sewer system

Location	Area (ha)	leakage (m^3/y)	N Input (kg/y)	N loss (kg/y)	N-balance (kg/y)	N-balance kg/ha.y
Northern area	1514	730,000	137,970	27,594	110,376	73
Gaza area	2458	3,066,000	454,687	90,937	363,750	148
Middle area	869	251,120	46,206	9,241	36,965	43
Khanyounis	1313	There is no sewer system exist			***	***
Rafah	710	306,600	72,970	14,594	58,377	82
Total	6864	4,353,720	711,835	142,367	459,092	103

4.3.3 Unsewered areas

In the unsewered areas, using of cesspits is the common practice for wastewater collection. These cesspits serve one house or a number of houses. This system lets water to percolate through soil to the groundwater. After some years of construction the soil permeability decreases and these systems must be excavated two to three times per year that depends on water consumption. When these systems become filled they are pumped by vacuum tankers and discharged manly into uncontrolled areas and sometimes to the near wastewater treatment plant. As mentioned before about 60% of the population in the area are connected to sewer networks. The percentage of unsewered areas is estimated at about 40% of the total areas of the Gaza Strip (EQA, 200l). The table below (4.7) shows the average wastewater characteristics of cesspits taken from different areas in the Gaza Strip.

In order to calculate the nitrogen balance it is assumed that the people are distributed evenly in the residential areas, total water supply is 145 litter/capita/day (L/c/d), non-physical water losses is 13%, water consumption is 126 L/c/d according to PWA estimation with physical losses, there is no significant loss of nitrogen in the cesspits through ammonia volatilization since the pH is around 7, the average concentration which was calculated in the table (4.8) below is representative for the total average concentration.

© 2005 Tous droits réservés.

Table (4.7): Average wastewater characteristics of cesspits in the study area.

Area	NH4-N (mg/l)	TKN (mg/l)
Northern	145	310
Gaza	165	267
Middle	89	184
Khanyounis	219	370
Rafah	145	238
Average	152.6	273.8

Table (4.8): Nitrogen balance for unsewered areas

Location	Area affected ha	Population	Unserved Population	TN kg/m3	N Input kg/y	N-balance kg/y	N-balance kg/ha.y
Northern	1514	209412	52353	0.31	559792.9	559792.9	370
Gaza	2458	419557	83911	0.267	772781.1	772781.1	314
Middle	869	168875	32086	0.184	750251.3	750251.3	863
Khanyounis	1313	229204	229204	0.37	2925149	2925149	2228
Rafah	710	140312	68753	0.238	564405.8	564405.8	795
Gaza Strip	6864	1,167,359	466,307		5,572,380	5,572,380	812

Note: The N loss was assumed to be equals zero

4.4 Solid waste

Solid waste in Gaza consists mainly of household waste, building debris, agricultural waste, industrial waste (workshops), medical waste, and car workshops. The daily generation rates of solid waste vary between 0.35 Kg per capita to 1.0 Kg per capita. The total Solid waste generated in the Gaza Governorates varies between 500 to 550 tons per day in the cities and village council's and from 200 to 220 tons per day in refugee camps. It is estimated that more than (65%) of the household solid waste consists of organic material, while sand is the second major component (23%). This implies that the density of the household solid waste ranges between 250 to 600 kg/m^3.

The municipal landfill areas lack the infrastructure such as soil conditioning, isolation material and a drainage system for the run off rain and leachate water. As a result, the solid waste dumping sites are posing additional pressure on the groundwater quality through the infiltration of leachate. The Deir El-Balah landfill is the only sanitary dumping site in the Gaza Strip. The nitrogen concentration in the leachate is adapted from Weslake (1995), which is 370 mg/l, mainly as ammonia. The table below shows the nitrogen balance for solid waste in the study area. It was assumed that there is no significant nitrogen loss through ammonia volatilization since the main form of nitrogen is the ammonium and the leachate is not alkaline. Also it was assumed that the composition and the production of the waste from the Israeli settlements are the same as the Palestinian communities in the area.

© 2005 Tous droits réservés.

Table (4.9): Nitrogen production from solid waste generation

Location	Population	Area ha	waste amount ton/y	Leachate m3/y	N-produced kg/y	N-produced kg/ha.y
Northern	209412	6169.9	64970	6497	2404	0.39
Gaza	419557	7368.7	130167	13017	4816	0.65
Middle	168875	5735.8	52394	5239	1939	0.34
Khanyounis	229204	11232.6	71110	7111	2631	0.23
Rafah	140312	5993.0	43532	4353	1611	0.27
Gaza Strip	1167359	36500	362173	36217	13400	0.37

4.5 Agricultural areas:

Agricultural land occupies about 170 km^2, which is close to 50% of the total area of the Gaza Strip. Agriculture is considered as one of the largest non-point sources of nitrogen to the groundwater. The agricultural areas in the Gaza Strip are distributed randomly and many residential areas are suited there. The average area per farm is estimated to be 0.8 to 1.1 hectare. There is no clear data regarding farm area distribution in the Gaza Strip except the last study prepared by the planning department in the ministry of planning in 1996. The irrigated land forms about 70% of the total agricultural area. Table 4.10 shows the agriculture production areas in the Gaza Strip (ministry of agriculture, 2001).

4.5.1 Chemical fertilizers addition:

The amount of nitrogen fertilizers added in the Gaza Strip was adapted from the ministry of agriculture. The extent and intensity of agriculture in the Gaza Strip produce high annual rates of fertilizers application (28,157 Tons/ year). Nitrogen fertilizers constitute about 50% of the fertilizers use. There is no differentiation between the quantity and the type of chemical nitrogen fertilizers imported to the Gaza Strip.

The main types of chemical fertilizers used in the Gaza Strip include potassium nitrate, ammonium Sulphate, and compound fertilizer. The main form of nitrogen used is in ammonia form. The estimated percentage of nitrogen content in the chemical nitrogen fertilizers used is about 20% of the total composition. In order to estimate the fertilizer quantities used in the Gaza Strip field visits to the farmers were conducted at farmlands and meetings with agricultural engineers also were done. According to information, which was collected through the farmers meetings and field visits by the auther, the quantity of chemical nitrogen fertilizers was calculated as it is shown in table 4.11.

© 2005 Tous droits réservés.

Table (4.10): Agriculture Production Areas in the Gaza Strip (ha)

Crop / Area	**Area cultivated (ha)**					
	Rafah	**Khanyounis**	**Middle**	**Gaza**	**North**	**Total**
Vegetables						
Tomatoes	415	292	148	114.2	50.1	1019.3
Watermelon	98	157	20.5	17.5	17	310
Cucumbers	320	36.2	95.5	49.5	28.1	529.3
Beans	208.9	134.3	22.3	38.7	72.7	476.9
Peppers	48	25.9	45	53	28.6	200.5
Potatoes	560	548	42	30	230.3	1410.3
Eggplants	42	20	67	40	61.7	230.7
Cauliflower	106	23.5	224	57	31.1	441.6
Molokhia	45	21.5	46	31.2	95.4	239.1
Corn	9	4.5	60	13	73	159.5
Gumbo	9	42	32	20	15	118
Others	214.2	123.9	223.4	208.5	232.1	1002.1
Cereals						
Barley	40	150	20	50	40	300
Wheat	250	2055	420	300	160	3185
Others	135	144	71	21	30.2	401.2
Trees						
Citrus	140.05	95.5	591.7	1195	1185	3207.025
Olives	305	792	540	950	102.2	2689.2
Palms	19	64.5	165	15	***	263.5
Almonds	165	166.5	100	15	3.7	450.2
Guava	50	317	50	***	33	450
Grapes	2	0.4	93.4	260	40	395.8
Others	36	15.8	8.8	60	62.1	182.7
Total	3217.2	5229.5	3085.6	3538.6	2591.1	17661.9

Table (4.11): Nitrogen fertilizers applied for different types of crops in the Gaza Strip - average values), (Ministry of agriculture, 2001).

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

The following table shows the nitrogen fertilizer additions, losses and balance for Gaza Strip. Fertilizer losses due to volatilization of ammonia or denitrification, calculated on the basis of the total losses is equal on average 25% of the applied fertilizers (Balba, 1980).

© 2005 Tous droits réservés.

Table (4.12): Nitrogen fertilizer additions, losses and balance for Gaza Strip

Area	Cultivated areas	Nitrogen chemical fertilizers added (kg/y)	N input kg/y	N loss kg/y	N-balance Kg/y
Rafah	3217	3601150	678659	169665	508994
Khanyounis	5230	3933415	771497	192874	578623
Middle Area	3086	2723460	533781	133445	400336
Gaza	3539	2490950	500414	125103	375310
Northern Area	2591	2174370	426239	106560	319679
Total	17662	14,923,345	2,910,590	727,647	2,182,942

4.5.2 Organic fertilizer additions

More than 370,000 tons of organic fertilizers are used annually in the Gaza Strip, about 40% of these quantities are imported from Israel, and the other quantities are produced by the animal farms which exist in the Gaza Strip. Typically 40–60 % of the N manure is present either as ammonical N or as urea and uric acid N that can be readily hydrolyzed to ammonical N (Bouldine et al., 1984). The table below shows the numbers of cows, chickens, sheep and goats imported from Israel in the year 2000 to the Gaza Strip.

Table (4.13): Quantity of imported livestock from Israel to the Gaza Strip in 2000

Cows & Calfs	Sheep	Layers chicken	Duck chicken	Turkey chicken	Geese chicken	Alive Turkey	Broilers hatching eggs	Layers Hatching eggs	Layers Hens
16823	4154	93050	77290	110300	19340	10270	5954750	364000	108105

Source: Ministry of Agriculture, 2000

Table (4.14): Total quantity of livestock in the Gaza Strip in 2000 (imported and existed) and amount of nitrogen produced

Area/Type	Cows and Camels	Sheep and Goat	Chicken (10^3)	
			Layers	Broilers
Rafah	2635	9796	38	947
Khanyounis	4547	8924	110	1977
Middle Area	4547	9263	114	935
Gaza	4392	14564	396	1167
Northern Area	4916	9348	124	929
Total	21038	51896	782.4	5954.8

Source: Ministry of Agriculture, 2000

To calculate the nitrogen additions from livestock (imported and existed) in the Gaza Strip the following assumptions were set according to Meisinger and Randall, 1991:

1. The quantity of manure produced is distributed evenly in the areas according to the size of agricultural areas,

2. The approximate kilograms of N generated by:

- Layers chicken is 47.7/year/100 birds
- Broilers Chicken is 38.6/year/100 birds
- Cows and Camels is 47/year/head
- Sheep and Goat is 7.2/year/head

© 2005 Tous droits réservés.

Table (4.15): Total nitrogen production from livestock in Gaza areas (kg/y)

Location	Cows and Camels	Sheep and Goat	Layers Chicken	Broilers Chicken	**Total N additions kg/y**
Rafah	123862	70532	18204	365461	578060
Khanyounis	213709	64255	52337	763124	1093425
Middle Area	213709	66697	54612	360864	695883
Gaza	206437	104859	188867	450513	950676
Northern Area	231069	67308	59163	358571	716111
Total	988,786	373,651	3,73,183	2,298,534	4,034,154

The estimated quantity of manure imported from Israel is around 40% of the total manure used in the Gaza Strip. So for calculation of the quantity of manure uses in different areas it was assumed that:

- The quantity of manure imported is distributed in the areas according to the size of agricultural areas.
- One cubic meter of manure equals 650 kg.
- The amount imported from Israel (ea. 200,000 cubic meters, 130,000 tons) are both cattle and poultry manure with 1:1 ratio (ministry of agriculture, 2000).
- N content of cattle manure is 2% of the dry weight (dry weight is 50% of the manure applied). Also N content in poultry is 5% of the dry weight (dry weight 50%) according to the Agriculture Compendium (1989).

Table (4.16): Nitrogen additions from imported manure

Location	Cultivated area (ha)	Imported manure kg/y	N input kg/y
Rafah	3217.1	23680	414396
Khan-Younis	5229.3	38491	673589
Middle Area	3085.6	22712	397458
Gaza	3538.6	26046	455809
Northern Area	2591	19071	333748
Total	17661.6	130000	2,275,000

© 2005 Tous droits réservés.

Table (4.17): Manure application and nitrogen addition to different crops in the Gaza Strip

Crop type	Areas (ha)	Manure application rate (ton/ha)	Total applied manure ton/y	N manure addition kg/y	N addition kg/ha.y
Vegetables					
GH Tomatoes	657.8	50	32890	575575	875
Tomatoes	361.5	20	7230	126525	350
Watermelon	310	20	6200	108500	350
Cucumbers	529.3	50	26465	463138	875
Beans	476.9	20	9538	166915	350
Peppers	200.5	20	4010	70175	350
Potatoes	1410.3	50	70515	1234013	875
Eggplants	230.7	20	4614	80745	350
Cauliflower	441.6	20	8832	154560	350
Molokhia	239.1	20	4782	83685	350
Corn	159.5	20	3190	55825	350
Gumbo	118	20	2360	41300	350
Others	1002.1	20	20042	350735	350
Cereals					
Barley	300	15	4500	78750	262.5
Wheat	3185	15	47775	836063	262.5
Others	401.2	15	6018	105315	262.5
Trees					
Citrus	3207.0	15	48105	841844	262.5
Olives	2689.2	15	40338	705915	262.5
Palms	263.5	15	3953	69169	262.5
Almonds	450.2	15	6753	118178	262.5
Guava	450	15	6750	118125	262.5
Grapes	395.8	15	5937	103898	262.5
Others	182.7	15	2741	47959	262.5
Total	17661.9		373,537	6,536,904	

4.5.3 Agricultural water

The cropping pattern in Palestine is classified into irrigated agriculture and rain-fed agriculture; each has three main crop vegetables, fruit trees, and field. In addition, more land is devoted to vegetable production than any other type of agriculture. Potatoes and tomatoes are the most widely cultivated vegetables, followed by watermelon, cucumber, beans, and eggplant. Vegetables are grown using efficient drip or sprinkler irrigation. Many vegetables are grown in greenhouses, particularly tomatoes, cucumber, squash, and peppers. By using different varieties and/or intensive agricultural practices, these crops can be harvested four times a year. Trees, particularly olive, almond, guava, grape, and date, also contribute significantly to agricultural production. The sophistication of irrigation for fruit and citrus trees generally lags behind that for other crops.

© 2005 Tous droits réservés.

Surface irrigation is still routinely employed for a significant portion of these crops. Surface irrigation method is much less efficient than either sprinkler or drip irrigation systems. In the year 2000, the ministry of agriculture calculated the actual quantity of water irrigation for each type of crops in the five areas of the Gaza Stripe. This calculation is shown in the following tables.

Table (4.18): Actual water irrigation in the Gaza Strip (m^3)

Crop/Area	**North**	**Gaza**	**Middle**	**Khanyounis**	**Rafah**
Olive	276,000	1,520,000	1,440,800	938,000	784,000
Citrus	11,110,500	12,537,000	7,813,800	1,762,200	1,728,000
Fruits	693,500	4,326,300	1,020,300	2,578,300	356,250
Field Crops	774,000	4,125,000	1,852,500	1,248,750	660,750
GH Vegetable	1,440,000	928,000	1,836,000	2,906,400	1,979,200
Vegetable	8,085,200	2,759,950	3,127,150	7,445,150	6,650,400
Total	22,379,200	26,196,250	17,090,550	16,878,800	12,158,600
Summation	**94,703,400**				

Source: Ministry of agriculture, 2000

Table (4.19): Water quality of agricultural wells (Average concentrations)

Area	EC (mS/cm)	CL^- (mg/L)	NO_3^- (mg/L N-NO3)
Beit Hanon	1.5	251.6	59.7
Beit Lahia	1.2	182.0	102.0
Jabalia	1.7	290.4	160.4
Gaza	3.1	679.5	97.6
Middle Area	3.8	843.1	99.7
Khanyounis	3.2	649.0	137.4
Estern Villages	5.0	1099.6	86.2
Rafah	2.3	479.8	137.9
Average	2.7	559.4	110.1

Table (4.20): Total nitrogen input from irrigated water (kg/y)

Crop/Area	North	Gaza	Middle	Khanyounis	Rafah	Total N input
Olive	6624	33440	33138	23450	24304	120956
Citrus	266652	275814	179717	44055	53568	819806
Fruits	16644	95179	23467	64458	11044	210791
Field Crops	18576	90750	42608	31219	20483	203636
GH Vegetable	34560	20416	42228	72660	61355	231219
Vegetable	194045	60719	71924	186129	206162	718979
Total	537,101	576,318	393,083	421,970	376,917	2,305,388

4.5.4 Nitrogen balance for agricultural areas

The main sources of nitrogen in the Gaza Strip area are chemical fertilizers, manure, irrigation water, precipitation and symbiotic N-Fixation. Losses of nitrogen in the agricultural areas are mainly due to plant uptake, ammonia volatilization, and denitrification. In order to calculate the nitrogen balance for agricultural areas the following assumptions were assumed:

© 2005 Tous droits réservés.

- All manure produced in the area is distributed evenly on the agricultural lands in the area and the animals also are distributed evenly throughout the area.
- Losses of fertilizers through ammonia volatilization adapted from El-Khattari and Kharabsheh.
- Loss of manure through denitrification was adapted from section 2.15.2 which accounts 20% of the remainder manure after volatilization.
- Percent of nitrogen in the harvested crop was adapted from Meisinger and Randall (1991) and Benton et al. (1991). The plant uptake was calculated according to the yield and percent of nitrogen in the harvested crop.
- Losses of manure fertilizers through storage within the soil were adapted from chapter 2 and are estimated to account for 33% of the remainder after volatilization and denitrification.
- Losses of nitrogen fertilizers through volatilization or denitrification were adapted from chapter 2 and are estimated to account for 25% of the total nitrogen fertilizer addition.
- Losses through erosion and runoff are negligible since the soil in the study area is mainly dependent on artificial nitrogen sources and the organic matter content in the soil is very small.
- Nitrogen addition through non-symbiotic fixation in the study area is negligible based on Schepers and Fox (1989) since the conditions there are not favourable for it.
- Symbiotic N-fixation was estimated to be 10% of the plant uptake in the study area (Chapter 2 section 2.12.6) since it depends on the soil available nitrogen.
- Nitrogen balance through precipitation was calculated according to the rainfall intensity and nitrogen content equals 1.5 mg/l.
- The total nitrogen balance for the agricultural lands of different areas in the Gaza Strip can be summarized as shown in the following table and figure.

Table (4.21): Total nitrogen balance for agricultural lands

Site	**Area (ha)**	**Additions (kg/y)**	**Losses (kg/y)**	**N-Balance (kg/ y)**	**N-Balance (kg/ha.y)**
Northern area	2591.1	1,834,216	852,688	981,528	379
Gaza	3538.6	2,014,383	954,810	1,059,574	299
Middle area	3085.6	2,021,104	1,047,462	973,642	316
Khanyounis	5229.5	3,238,268	1,782,867	1,455,402	278
Rafah	3217.2	2,947,470	1,412,377	1,535,093	477
Gaza Strip	**17662**	**12,055,441**	**6,050,204**	**6,005,239**	**340**

© 2005 Tous droits réservés.

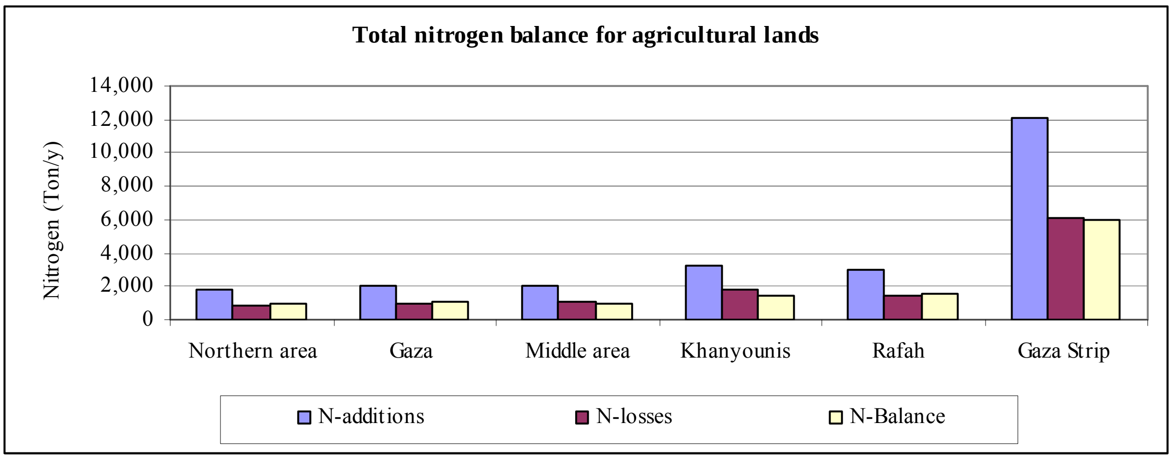

Figure (4.4): Total nitrogen balance for agricultural lands

The results from the above table show that the total additions of nitrogen from the agricultural lands are around 12 million-kg annually and the total losses within the system are around half of the total quantity added. The excesses of nitrogen are nearly equal of the total losses in each area of the Gaza Strip. The approximate total additions of nitrogen from agricultural lands in each area of the Gaza Strip are the same except Khanyounis and Rafah areas which is 1.5 times the other areas.

4.6 Drinking water distribution network

Most of the houses are served from indoor taps, and they depend on the municipal wells as the main source of water for the domestic use except in the Middle and the eastern part of Khanyounis Governorate, where they depend mainly on Mekoroth Water Company. According to the LEKA reports in 2001, the service coverage percentage in the Gaza Strip is estimated to be 95%, which is, mean that most of the population is served by indoor tap. Table (4.22) shows the nitrogen input through drinking water distribution networks leakage.

Table (4.22): Nitrogen input through drinking water distribution networks leakage

Area	Area affected ha	Water supply m3/y	Physical losses %	Water losses m3/y	N Conc. mg/l	N input kg/y	N input kg/ha.y
Northern area	1514	11,968,522	29	3,470,871	24	84,186	56
Gaza	2458	28,098,804	25	7,024,701	22	154,884	63
Middle area	869	6,274,965	25	1,568,741	23	35,333	41
Khanyounis	1313	9,470,434	23	2,178,200	25	55,013	42
Rafah	710	4888482	25	1,222,120	31	38,072	54
Total	6864	60,701,207	24	15,464,634		367,488	54

4.7 Precipitation (Rainfall)

The rainfall in the Gaza Strip varies from North to South. In the North the rain reach up to 450 mm/y and it can be as low as 200 mm/y in southern area. The nitrogen concentration in

© 2005 Tous droits réservés.

the precipitation is about 0.4 mg/L. The estimated annual amount of precipitation on the Gaza Strip is 90 Mm^3. The following table shows the balance for nitrogen added through precipitation based on average concentration of nitrogen of 1.5 mg/L and 20% loss through denitrification.

Table (4.23): Nitrogen input through precipitation (rainfall)

Area	**Rafah**	**Khanyounis**	**Middle**	**Gaza**	**North**	**Total**
Total area (ha)	5993	11233	5736	7369	6170	36500
Build up area	710	1,313	868.5	2,458	1,514	6863.5
Agricultural area	3217	5230	3086	3539	2591	17662
Settlements area	1225	3417	70	233	755	5700
Unused land						6275
Precipitation mm/y	247	321	366	378	474	
Precipitation Mm^3/y	14,803	36,057	20,993	27,854	29,245	128,951
Precipitation m3/ha.y	2,470,000	3,210,000	3,660,000	3,780,000	4,740,000	
N addition to the agricultural lands kg/y	11920	25180	16971	20170	18397	92637
N losses from the agricultural lands kg/y	2384	5036	3394	4034	3679	18527
N addition to the other lands kg/y	10285	28905	14519	21611	25472	100790
N losses from the other lands kg/y	2057	5781	2904	4322	5094	20158
Total N-addition kg/y	22204	54085	31489	41781	43868	193427
Total N-loss kg/y	4441	10817	6298	8356	8774	38685
Total N-balance kg/y	17763	43268	25191	33425	35095	154742
Total N-balance kg/ha.y	3	4	4	5	6	4

4.8 Settlements

There are 18 Israeli Settlements in the Gaza Strip, 3 in the Northern area, one in the Gaza area, one in the middle area, 8 in Khanyounis area and 5 in Rafah area. Some of these settlements are urban in nature and the others agricultural. There is no information about the urban and the agricultural activities in the Settlements. In order to calculate the nitrogen balance in the Settlements the following assumption were assumed:

- The nitrogen production per capita per day in the settlements is 18 g/capita.day (Keeney, 1989)
- The nitrogen losses from urban activity equal 20% of the nitrogen addition
- The nitrogen additions rate (kg/ha.y) from agricultural activity at the Israeli settlements is the same of the nitrogen additions rate of the agricultural activity in the Gaza Strip, which equals in average of 340 kg/ha.y.
- 60% of the lands of the settlements are used for agricultural activity except the settlement in the middle area, which is used for urban purpose only.

The tables bellow show the nitrogen additions, losses and balance from the Settlements in the Gaza Strip.

© 2005 Tous droits réservés.

Table (4.24): Nitrogen additions and losses from the Agricultural Settlements

Location	Population (Capita)	Area (ha)	Nitrogen additions kg/y		Nitrogen losses kg/y	
			Urban	Agricultural	Urban	Agricultural
Northern	920	228	6044	46471	1209	23236
Gaza	220	220	1445	44880	289	22440
Middle	200	31.7	1314	***	263	***
Khanyounis	3571	1157.4	23461	236110	4692	118055
Rafah	1025	627.1	6734	127928	1347	63964
Gaza Strip	5936	2264	39000	455389	7800	227695

Table (4.25): Nitrogen balance for Settlements

Location	N-addition kg/y	N-loss kg/y	N-balance kg/y	N-balance kg/ha.y
Northern	52516	24444	28071	123
Gaza	46325	22729	23596	107
Middle	1314	263	1051	33
Khanyounis	259571	122747	136824	118
Rafah	134663	65311	69352	111
Gaza Strip	494389	235495	258894	114

4.9 Total nitrogen balance

For each area of the Gaza Strip and for the overall study area, the nitrogen balance and the relative contribution of each source are shown in the following tables and graph.

Table (4.26): Nitrogen balance for Rafah area (total area = 5993 ha)

Source	Additions Kg/y	Losses Kg/y	N-balance Kg/y	N-balance kg/y.ha	% Contribution
WWTP discharge	234,089	46,818	187,271	31.2	6.7
Sewer system Leakage	72,970	14,594	58,377	9.7	2.1
Unsewered areas	564405	0	564405	94.2	20.1
Solid waste	1611	0	1611	0.3	0.1
Agricultural areas excluding precipitation	2947470	1412377	1535093	256.1	54.8
Drinking water leakage	367,488	0	367,488	61.3	13.1
Precipitation	22204	4441	17763	3.0	0.6
Settlements	134663	65311	69352	11.6	2.5
Total	4344900	1543541	2,801,360	467.4	100

Table (4.27): Nitrogen balance for Khanyounis area (total area = 11233 ha)

Source	Additions Kg/y	Losses Kg/y	N-balance Kg/y	N-balance kg/y.ha	% Contribution
WWTP discharge	***	***	***	***	***
Sewer system Leakage	***	***	***	***	***
Unsewered areas	2925149	0	2925149	260.4	63.6
Solid waste	2631	0	2631	0.2	0.1
Agricultural areas excluding precipitation	3238268	1782867	1455402	129.6	31.6
Drinking water leakage	38,072	0	38,072	3.4	0.8
Precipitation	54085	10817	43268	3.9	0.9
Settlements	259571	122747	136824	12.2	3.0
Total	6517776	1916431	4601346	409.6	100

© 2005 Tous droits réservés.

Table (4.28): Nitrogen balance for middle area (total area = 5736 ha)

Source	Additions Kg/y	Losses Kg/y	N-balance Kg/y	N-balance kg/y.ha	% Contribution
Wastewater discharge	***	***	***	***	***
Sewer system Leakage	46,206	9,241	36,965	6.4	1.89
Unsewered areas	750251	0	750251	130.8	38.68
Solid waste	1939	0	1939	0.3	0.09
Agricultural areas excluding precipitation	2021104	1047462	973642	169.7	50.18
Drinking water leakage	55,013	0	154,884	27.0	7.98
Precipitation	31,489	6298	25,191	4.4	1.30
Settlements	1314	263	1051	0.2	0.06
Total	2861110	1054023	1906958	332.5	100

Table (4.29): Nitrogen balance for Gaza area (total area = 7369 ha)

Source	Additions Kg/y	Losses Kg/y	N-balance Kg/y	N-balance kg/y.ha	% Contribution
WWTP discharge	244500	48910	195590	26.5	7.84
Sewer system Leakage	454,687	90,937	363,750	49.4	14.62
Unsewered areas	772781	0	772781	104.9	31.05
Solid waste	4816	0	4816	0.7	0.21
Agricultural areas excluding precipitation	2,014,383	954,810	1,059,574	143.8	42.57
Drinking water leakage	35,333	0	35,333	4.8	1.42
Precipitation	41781	8356	33425	4.5	1.33
Settlements	46325	22729	23596	3.2	0.95
Total	2915419	985895	1929525	261.8	100

Table (4.30): Nitrogen balance for Northern area (total area = 6170 ha)

Source	Additions Kg/y	Losses Kg/y	N-balance Kg/y	N-balance kg/y.ha	% Contribution
WWTP discharge	337625	67525	270100	43.8	12.62
Sewer system Leakage	137,970	27,594	110,376	17.9	5.16
Unsewered areas	559792	0	559792	90.7	26.12
Solid waste	2404	0	2404	0.4	0.12
Agricultural areas excluding precipitation	1,834,216	852,688	981,528	159.1	45.82
Drinking water leakage	154,884	0	154,884	25.1	7.23
Precipitation	43868	8774	35095	5.7	1.64
Settlements	52516	24444	28071	4.5	1.30
Total	2647680	885906	1761774	285.5	100

Table (4.31): Nitrogen balance for the Gaza Strip (total area = 36500 ha)

Source	Additions Kg/y	Losses Kg/y	N-balance Kg/y	N-balance kg/y.ha	% Contribution
WWTP discharge	816,214	163,253	652,961	17.9	4.9
Sewer system Leakage	711,835	142,367	459,092	12.6	3.5
Unsewered areas	5,572,380	0	5,572,380	152.7	42.2
Solid waste	13400	0	13400	0.4	0.1
Agricultural areas excluding precipitation	12055441	6050204	6005239	164.5	45.5
Drinking water leakage	84,186	0	84,186	2.3	0.6
Precipitation	193427	38685	154742	4.2	1.2
Settlements	494389	235495	258894	7.1	2.0
Total	18413223	6324384	12088841	331.2	100

© 2005 Tous droits réservés.

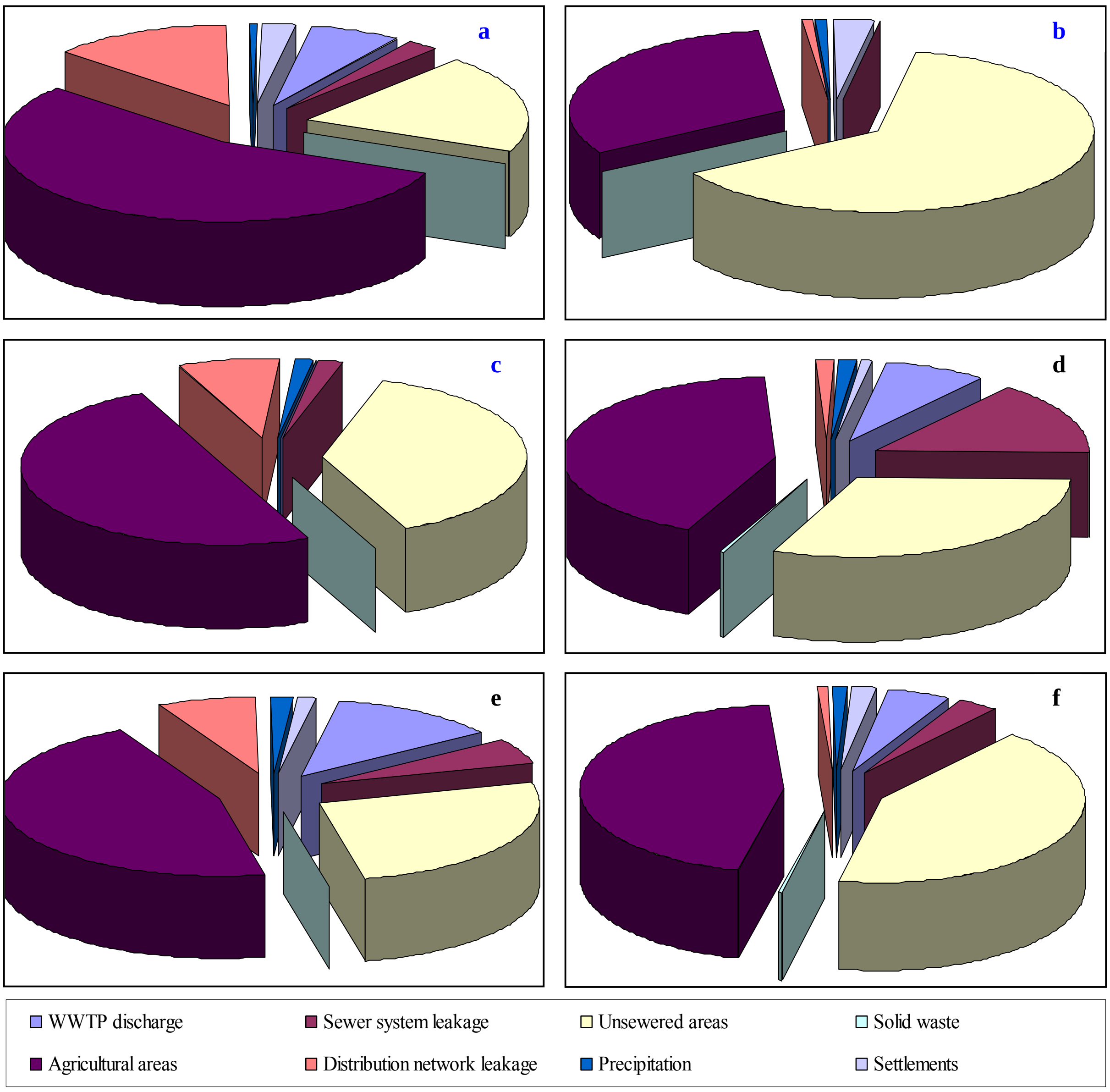

Figure (4.5): Nitrogen balance for different areas in the Gaza Strip a) Rafah, b) Khanyounis, c) Middle area, d) Gaza, e) Northern area, and (f) The Gaza Strip.

4.10 Discussion

Sources of nitrogen that can be related to water quality issues are those that will produce nitrate-nitrogen, a form that can potentially leach or runoff but also a form of nitrogen necessary for plant uptake. An analysis of the location of nitrogen sources, losses, immobilization, and the resulting excess is an important step in identifying where solutions to excess agricultural and urban nitrogen may be most successfully attempted. The excess of nitrogen in the soil means that the movement towards the groundwater is very possible. The results of groundwater analysis in the study area show that nitrogen pollution in the Gaza Strip groundwater is very high and exceeding the WHO guideline.

© 2005 Tous droits réservés.

Sources were found to include inorganic fertilizers, manure, mineralized soil organic matter, legume fixation, atmospheric deposition, wastewater flow, sewer system leakage, drinking network leakage, and solid waste of locally derived problem. Principal losses of nitrogen include crop harvesting, and denitrification in soil. Immobilization of nitrogen (conversion to microbial bio-mass) is a critical process that affects the nitrogen available for leaching and runoff.

The total nitrogen sources clearly shows that excessive amounts in the Gaza Strip are used for crop production. Inorganic fertilizer and manure are considered the dominant sources of nitrogen associated with agriculture. Also, water irrigation is considered one main source of nitrogen because of high concentration of nitrate compound in water. Crop losses harvest less than half of nitrogen additions from inorganic fertilizer sources in most areas and consume only about 15% of the total sources and equals only about 27% of the total losses. Manure may be considered the first largest direct source of nitrogen due to the large quantity used in the agricultural areas but much of it is lost to the atmosphere (52%) during storage and application. The total nitrogen removed by harvesting is smaller than either inorganic fertilizer or mineralization of soil organic matter. Also, losses through the total harvest are only nominally smaller than manure applied.

Manure nitrogen addition represents around 50 to 60% of the total applied nitrogen. The applied nitrogen through irrigation water represents the same quantity of the plant uptake. For some irrigated crops in the areas where nitrogen content in irrigation water is very high, the total nitrogen addition by irrigation water may be equal to the plant uptake. In the areas where there is no available wastewater treatment plant such as Khanyounis area, the nitrogen load through wastewater contributes the largest source of nitrogen in comparison of other sources and the agricultural nitrogen balance is the second source. The added nitrogen load from solid waste leachate, drinking water networks leakage and precipitation is considered minor compared to other sources such as wastewater and agricultural.

© 2005 Tous droits réservés.

Chapter 5

Effect of Land Use and Environmental Factors on Nitrate Pollution

5.1 Objective

The objective of this chapter is to address the following questions based on a review of existing groundwater nitrate data held by the Ministry of Health, the Ministry of Agriculture and the Palestinian Water Authority database:

- What is the range of nitrate concentrations found in the Gaza Strip groundwater?
- Are there any spatial patterns to the concentrations, and if so, how can these patterns be interpreted?
- What seasonal variations in nitrate concentrations are observed?
- Are there any discernible long-term trends in the data?
- How do concentrations vary with land use and environmental factors?

5.2 Introduction

Wise management, development, protection, and allocation of water resources is based on sound data regarding the location, quantity, quality, and use of water and how these characteristics are changing over time. The quantity and quality of available water varies over space and time, and is influenced by multifaceted natural and man-made factors including climate, hydro-geology, management practices, pollution, etc. As a foundation for water-resources decision-making, sound data must be continuous over space and time. Computer systems now offer the possibility of handling and manipulating very large databases in ways which were not previously a practical option. The quality of water resources is a subject of ongoing concern. The assessment of long-term water quality changes is also a challenging problem. During the last decades, there has been an increasing demand for monitoring water quality by regular measurements of various water quality variables. The result has been the gradual accumulation of reliable long-term water quality records. Accordingly, some of the necessities of water quality monitoring are the following: 1) to provide a system-wide synopsis of water quality, 2) to monitor long-range trends in selected water quality parameters, 3) to detect actual or potential water quality problems; if such problems exist 3a) to determine specific causes and 3b) to assess the effect of any convective action and 4) to

© 2005 Tous droits réservés.

enforce standards. Figure 5.1 shows the methodology and procedure implemented in this chapter.

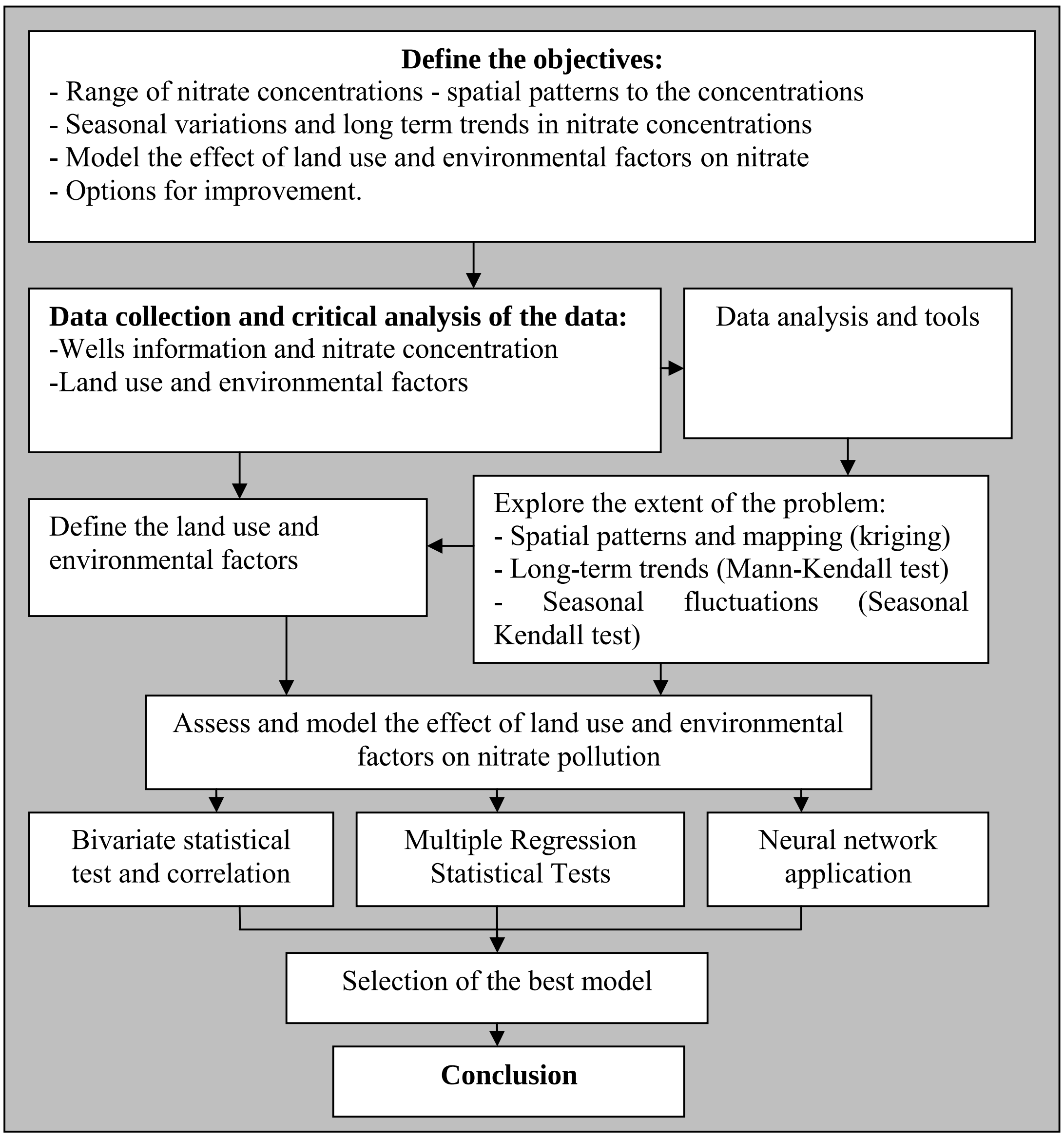

Figure (5.1): Methodology and procedures

5.3 Groundwater Data and Sampling History

Over the last century, areas of the West Bank and Gaza Strip have been under Turkish, British, Jordanian, Egyptian, and Israeli occupation. Although this has resulted in inconsistent hydrologic monitoring for water resources management, a significant data base has nonetheless been built by efforts made under different administrations.

Surveys of hydrologic characteristics began under the British occupation of Palestine (1917–1948), and regular monitoring throughout the region began in the early 1930s. Between October 1934 and September 1935 a survey of chloride concentration and water level in wells

© 2005 Tous droits réservés.

was conducted throughout the region. This survey included 397 wells in the coastal aquifer in the vicinity of the Gaza Strip. Unfortunately, station identification numbers used in the British report are not consistent with modern identifiers, and definite association with current wells is usually not possible.

In the Gaza Strip under the Egyptian administration (1948–1967) the Department of Municipal and Rural Affairs was responsible for water supply and wells. Records of regular hydrologic monitoring in the Gaza Strip from this period have not been found. In 1967 the Israeli Civil Administration established the Gaza Agricultural Department (GAD) for hydrologic monitoring and water supply management. The GAD conducted an extensive survey of existing wells in 1969, and beginning of 1970, where hundreds of new wells were constructed throughout the Gaza Strip for monitoring and for production. Lithological logs and basic construction data (well depth, screened interval, *etc*.) were recorded for most of these wells, providing valuable information for aquifer characterization. Agricultural production wells were typically constructed as large diameter (about 2.5 to 3 meters) excavated holes, supported by caissons, to the water table, where drilled holes (typically 6 to 10 inches in diameter) were sunk to the total well depth. Most of these agricultural wells extend less than 10 meters below the groundwater table in the coastal aquifer.

The GAD licensed and placed pumping meters on most of the production wells in the Gaza Strip, and cumulative pumped withdrawal volume was estimated at 6 month intervals for about 1,600 wells until 1994. Water-level measurements and water-quality sampling of a network of about 200 wells began in 1970. These monitoring sites include discontinued (abandoned) production wells, operational production wells, and piezometers (wells installed for monitoring only). Samples from these wells were analyzed for electrical conductivity and concentrations of chloride. Beginning in 1987, about 80 domestic wells were sampled for several additional cations and anions. Water-quality samples were analyzed in the laboratories of the GAD, and results were reported to the Gaza Department of Health.

In May 1994, civil administration of the Gaza Strip and Jericho area became the responsibility of the Palestinian Authority (PA). In 1995 the Gaza Water Department prepared a summary data report of available water resources information in the Gaza Strip. This data report consisted of 6 volumes and provided site information and parameter plots of data in the Gaza Strip through 1995 for water levels, water quality, lithology, and

© 2005 Tous droits réservés.

meteorology. After continued quality-assurance work on existing data, and collection of new information, a second edition of this data summary was published in 1998 to 1999.

Each summer and winter the Ministry of Agriculture collects water samples from about 370 agricultural water-use wells. The samples are analyzed to measure electrical conductance and concentrations of chloride and nitrate. Each summer and winter the Ministry of Health also collects samples from about 90 domestic water-use wells (most owned by municipalities), and analyzes them for major anions and cations. Pumped withdrawal volume is measured monthly by the Ministry of Health for about 90 municipal water-use wells. Some of these wells have recently been constructed. Also, municipal withdrawal volume data were not available for the period from 1994 to 1996. Monitoring of pumped withdrawal in agricultural wells was interrupted in 1994 and has not yet resumed. All data on water levels, water quality, and withdrawals are transferred to the PWA, Water Resources Department, Gaza Water Data Bank Section, for quality assurance and entry into the hydrologic database.

5.4 Critical analysis of the data

5.4.1. Normality

Of all the commonly used probability distributions, normal distribution is most widely used because of its performance as a base distribution for comparison and error analysis. Parametric statistics rely on the assumption of a normal population distribution. Slight deviations from normality typically don't have significant effects. Large departures from normality, particularly in the form of skewness, or lack of symmetry, can invalidate results, result in serious errors in the analysis and incorrect conclusions. Transformations (for example, log transformation) of non-normal data are often used to remove skewness and produce normally distributed values. Signs of non-normal distribution are:

1. Skewness or kurtosis greater than 3.
2. Mean and median differ by a factor of 2 or more.
3. The coefficient of variation is greater than 100%.
4. The maximum or minimum is more than five standard deviation from the mean.
5. Q25 or Q75 are more than one standard deviation from the mean.

If any of the above conditions apply, the data transformation should be considered.

In this study, in addition to the above mentioned signs the data were examined for normality by several alternative methods, such as fitting empirical distribution and chi-square goodness-of-fit test.

© 2005 Tous droits réservés.

5.4.1.1. Empirical distribution

Empirical distribution of observations is usually represented by frequency histograms, which provides a visual indication of the symmetry of probability distributions. Histograms were constructed for original and log-transformed data sets for all the parameters. Histogram for nitrate concentration of 266 sampled wells by the MOA (domestic and agricultural wells in the Gaza Governorates) in the period 2002 is presented in order to perform a visual inspection for normality as shown in Figure (5.2).

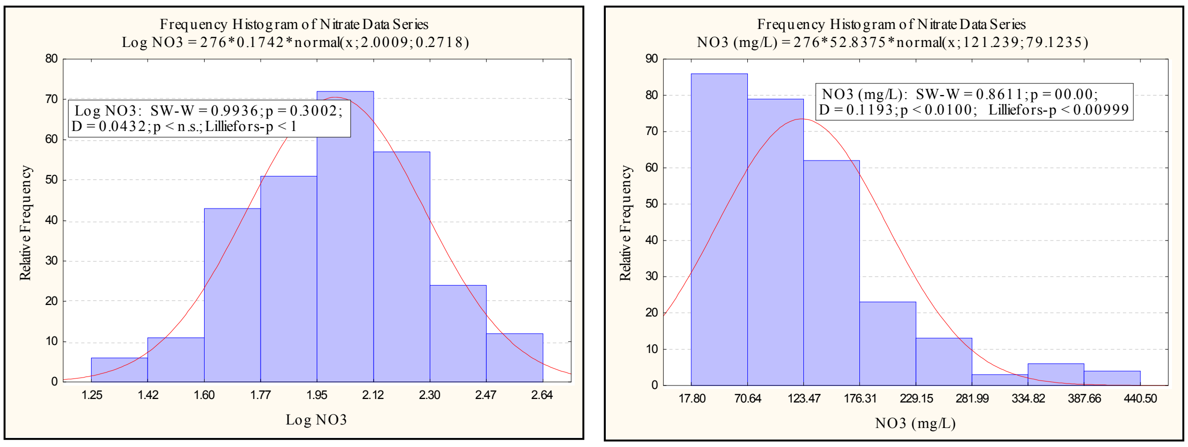

Figure (5.2): Frequency histogram for nitrate (NO_3^-) data series

Relative frequency provides an estimate of the probability of parameter concentration falling in the indicated range or class interval. Frequency distribution of all the parameters appeared to be skewed to the right. Qualitatively it can be stated that the degree of skewness varied considerably for the other parameters (major cations and major anions), some of it contains values that are significantly larger than the average values. These values may arise from measurement errors or from groundwater contamination, in which case the high values may belong to a “population” different from that of the remaining sample values. However, the groundwater quality variables were found lognormally distributed.

5.4.1.2 Skewness test

Skewness is a measure of symmetry of the distributions and can be a conclusive indicator of non-normality. The skewness coefficients (C_s) for original and log-transformed data were calculated following the procedure given by McCuen (1993). Results revealed that skewness of all the parameters have positive value where negative skewness is not as common as positive skewness in groundwater quality. Theoretical values of skewness for normal and lognormal distributions are reported by Law and Kelton (1991) as 0.00 and 6.18 respectively. Comparing the computed values with these values for normal and lognormal distribution, all water quality parameters were appeared to be log-normally distributed. However, most of the

© 2005 Tous droits réservés.

skewness for log-transformed data shows negative value, which is usually expected for non-normal data set (Haan, 1977). The table bellow shows the skewness of the observed groundwater quality data and the log-transformed data for 87 samples of domestic groundwater wells in 2002.

Table (5.1): Skewness and standard error of groundwater chemical quality data

Parameter	**Skewness**	**Std.Err.**	**Log value**	**Skewness**	**Std.Err.**
EC	0.980	0.258	**log EC**	0.132	0.258
TDS	0.965	0.258	**Log TDS**	0.101	0.258
pH	0.064	0.258	**Log pH**	-0.035	0.258
Ca^{2+}	1.833	0.258	**Log Ca^{2+}**	0.201	0.258
Mg^{2+}	1.627	0.258	**Log Mg^{2+}**	-0.117	0.258
Na^{+}	1.054	0.258	**Log Na^{+}**	-0.130	0.258
K^{+}	3.496	0.258	**Log K^{+}**	-0.184	0.258
F^{-}	0.804	0.258	**Log F^{-}**	-2.734	0.258
CL^{-}	1.121	0.258	**Log CL^{-}**	-0.115	0.258
NO_3^{-}	1.588	0.258	**Log NO_3^{-}**	-0.078	0.258
SO_4^{2-}	1.622	0.258	**Log SO_4^{2-}**	-0.011	0.258
HCO_3^{-}	0.371	0.258	**Log HCO_3^{-}**	-2.714	0.258
Hardness	1.256	0.258	**Log Hardness**	0.020	0.260

5.4.1.3 Chi-square (χ^2) test

The Chi-square goodness of fit test was used to test for a significant difference between the distribution suggested by a data sample and a selected probability distribution. Here the test assumed the data drawn from a normal population; chi-square test checked the validity of this assumption. The hypothesis of χ^2-test was performed at 5% significance level and the computed χ^2 was compared with critical χ^2 value (McCuen, 1993). The results revealed that the computed χ^2 values for the groundwater quality parameters are larger than the critical χ^2 values, which indicates that the parameters were not normally distributed.

5.5 Land Use Characteristics

Digitized land use data are available in geographic information system (GIS) format for the Gaza Governorates areas. Land uses map were developed by the Ministry of Planning in 1996 and modified by the Environmental Quality Authority 1998 (Figure 3.5). Land use categories include cropland, trees, urban, rural …etc. There is no surface water in the study area so it was not included in the analyses addressing land use factors. Most of the Gaza Strip areas are categorized as urban but since it includes small industry located on the site, most of the area can be considered as urban/industrial. The agricultural land is considered to be about 50% of the total area and mostly contains mixed agricultural pattern (see chapter 3 section 3.5).

© 2005 Tous droits réservés.

5.6 Nitrate analytical methods

There are many different methods for analysis of nitrate-nitrogen in the different standard methods books. Two methods of analysis were used in the Gaza Strip laboratories. Nitrate nitrogen was analyzed primarily by Ion Selective Electrode method and in the later the ultraviolet spectrophotometer, with a detection limit generally around 0.1 mg/L. There should be essentially no difference in the overall results between the two methods, so analysis of long term trends should not be affected by the different analytical techniques. However, Ion Selective Electrode method was less reliable than the ultraviolet methods, so errors were more likely in the older samples. Figure 5.3 and Figure 5.4 show a number of groundwater monitoring wells and a number of tests for each well in the Gaza Strip.

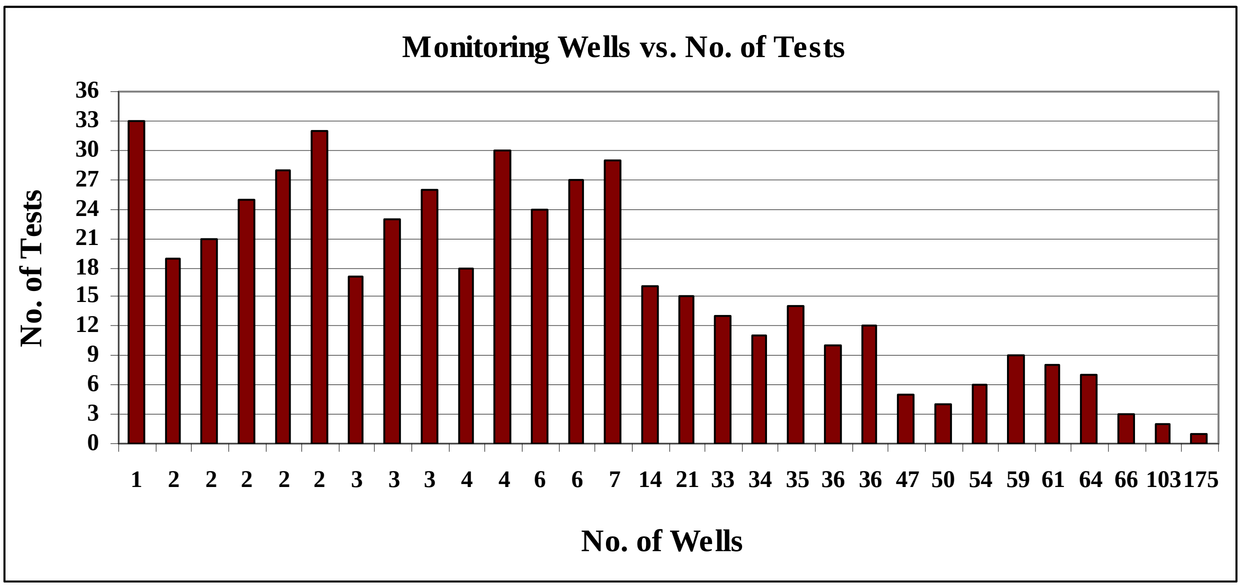

Figure (5.3): Number of monitoring wells and tests for agricultural wells

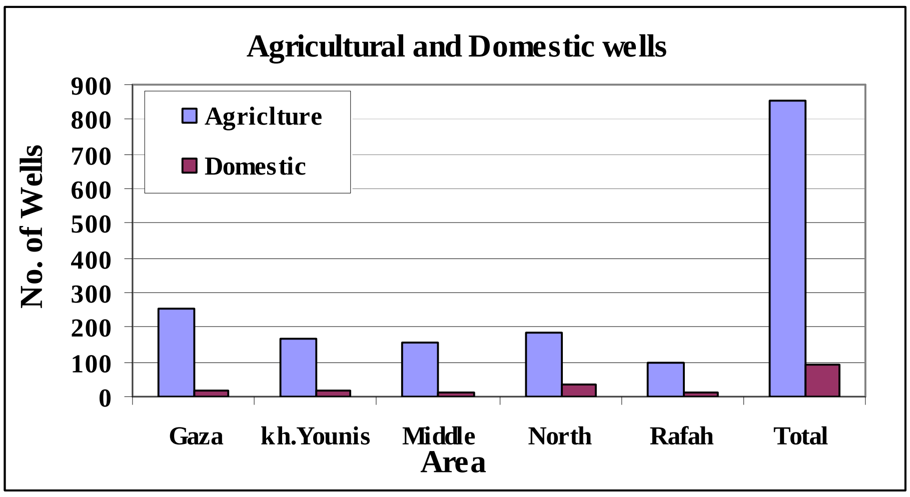

Figure (5.4): Number of monitoring agricultural and domestic groundwater wells in the Gaza Strip

© 2005 Tous droits réservés.

5.7 Statistical Analysis Procedures

In planning control and management program of groundwater, the statistical and trend analysis as well as the relations between concentrations and land usage and environmental factors are important steps for understanding the behaviour and the variation of water quality parameters. This variation is affected by many factors. These factors may be formed by the different substances in the land surface due to activities in the area and may be further obscured by random events.

Basic data statistics for each well were obtained by performing a univariate procedure using Statistica computer program version 6 (Statsoft, 2002). Basic statistics including mean, median, standard deviation; number of samples, skewness, kurtosis, minimum value, and maximum value were done for each well with two water quality tests and more. Correlation analyses were performed on the data to determine whether relationships exist at $\propto$=0.05 between NO_3^- means and the various land uses and environmental factors. Analytical results including a Pearson correlation coefficient (R), which indicates the direction of the relationship, with higher absolute values of the coefficient indicate stronger relationships. The Pearson product moment correlation coefficient, (R), a dimensionless index that ranges from -1.0 to 1.0 inclusive reflects the extent of a linear relationship between two data sets.

As mentioned before, the correlation coefficient (r) represents the linear relationship between two variables. If the correlation coefficient is squared, then the resulting value (r^2, the coefficient of determination will represent the proportion of common variation in the two variables (i.e., the "strength" or "magnitude" of the relationship). In order to evaluate the correlation between variables, it is important to know this "magnitude" or "strength" as well as the significance of the correlation.

5.8 Variations of nitrate concentration

In Environmental Research, there is an increasing interest in the analysis of time series in relation to environmental degradation, which is one of the most important concerns of regulatory agencies that are responsible for the management of water resources. A prime question is whether or not the quality of water has changed over time or space. Nitrate-nitrogen concentrations in the wells were reviewed in relation to site geology (or soil type), development density, and well characteristics, such as type, depth, location, and yield. The broad goals of the study were to assess the effect of land use and environmental factors on groundwater quality, and to identify site factors that exert the greatest influence on its quality.

© 2005 Tous droits réservés.

Parametric and Non-parametric statistical testing were applied to the NO_3^- analysis results. Findings of the study are as follows:

5.8.1 Spatial patterns in nitrate concentrations

5.8.1.1 Mapping method:

In this study, kriging method was utilized to describe the spatial variations of nitrate concentration in the Gaza Strip. Kriging is a geo-statistical griding method that has proven useful and popular in many fields. This method produces visually appealing maps from irregularly spaced data. Kriging is a method commonly used in groundwater quality analysis. This method produces a statistical uncertainty in estimates of unmeasured sites as functions of distance between measurement location and determines a best estimate at unmeasured locations by the averages of the values at known points weighted inversely to their uncertainty at the unknown point by minimizing the kriging variance. Kriging can be applied to network design by finding the point with the maximum uncertainty based on the assumed statistical uncertainty functions, the semivariograms (Cooper and lstoc, 1988).

5.8.1.2 Method of illustration

The spatial distribution of nitrate concentrations in the Gaza Strip groundwater is illustrated on the maps in Figures (5.5) to (5.10). The maps were created by calculating a single, median nitrate concentration for each well in the database, then plotting these median values on the maps as colour-coded contours lines. The median of a data set is less affected by skewed data and outlier values than the mean, and it is therefore a better indicator of the central tendency of the data (Gilbert, 1987). The median concentration for each well was calculated using all available data, regardless of whether the well was sampled once, twice, or many times between 1987 and 2002.

© 2005 Tous droits réservés.

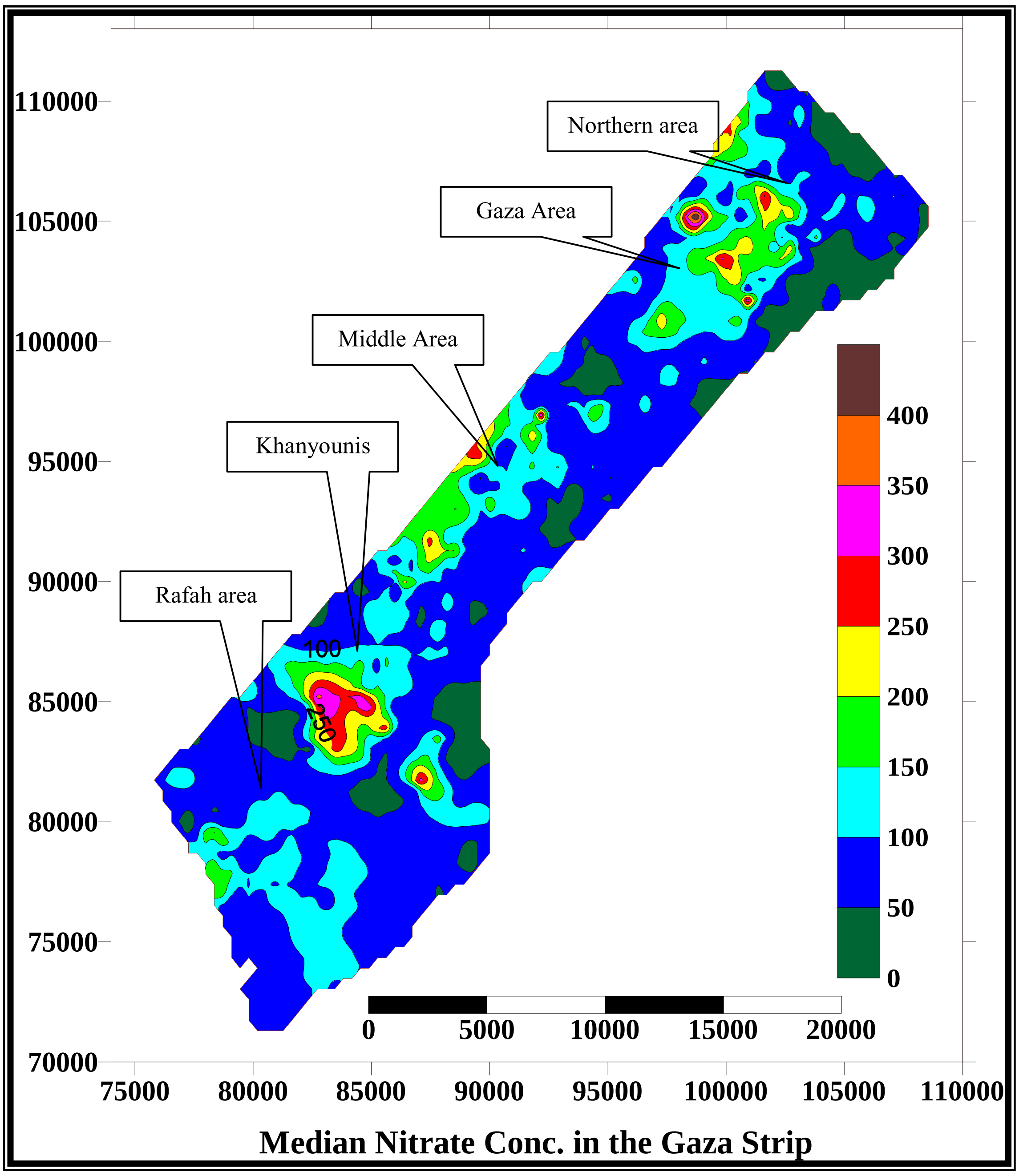

Figure (5.5): Median nitrate concentration in the Gaza Strip

© 2005 Tous droits réservés.

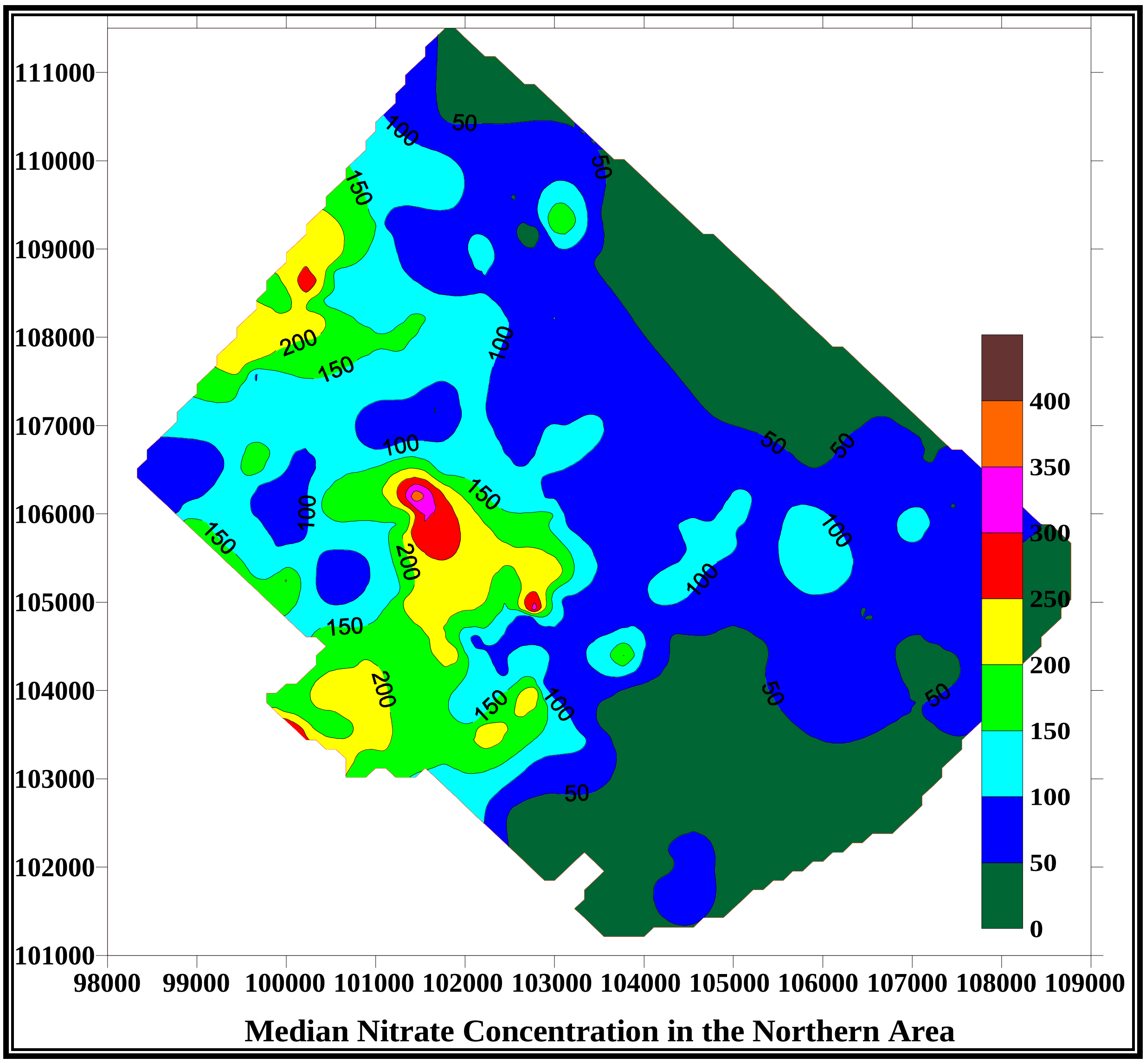

Figure (5.6): Median nitrate concentration in the Northern Area (1987-2002)

© 2005 Tous droits réservés.

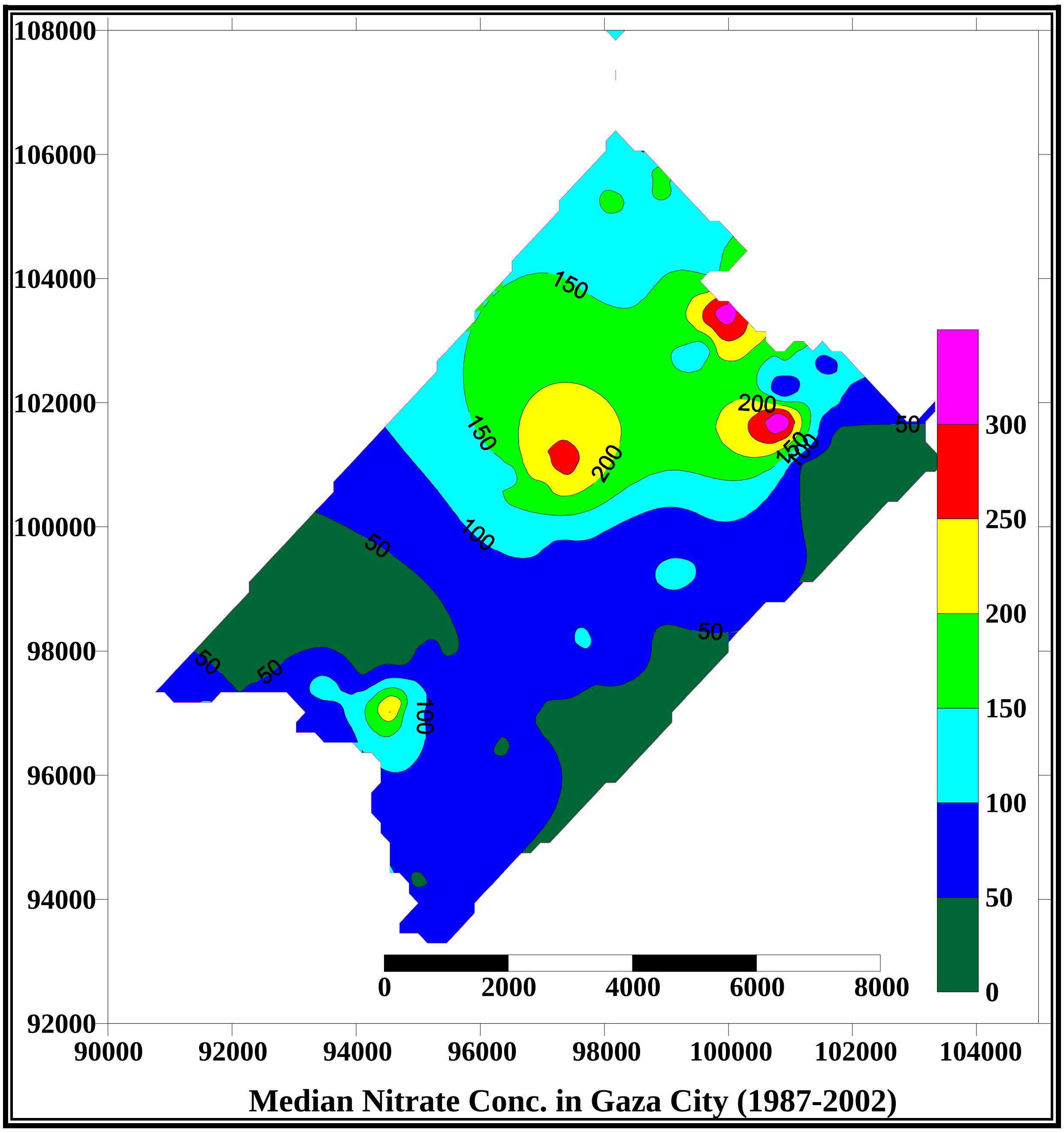

Figure (5.7): Median nitrate concentration in the Gaza City (1987-2002)

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

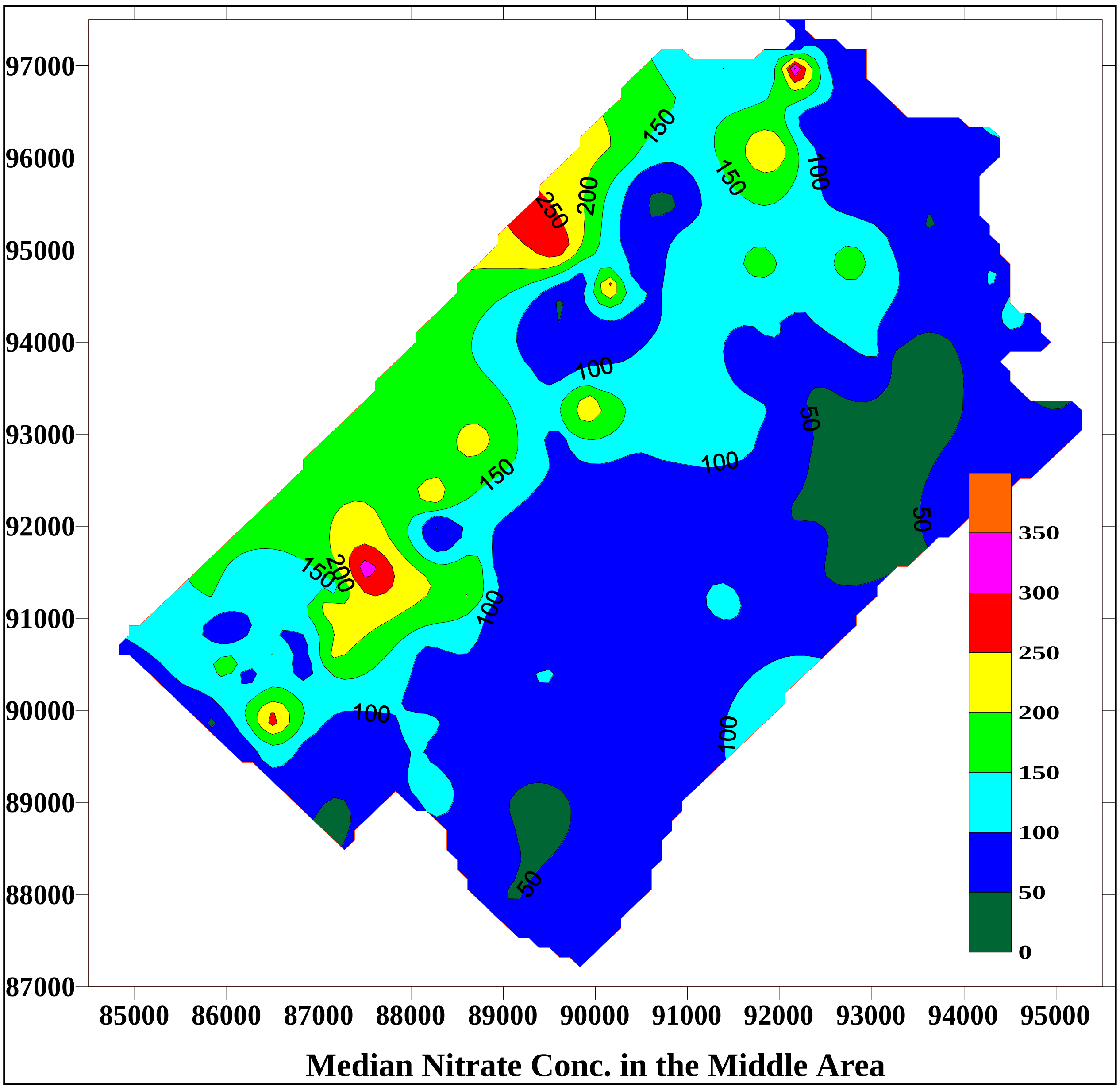

Figure (5.8): Median nitrate concentration in the Middle Area (1987-2002)

© 2005 Tous droits réservés.

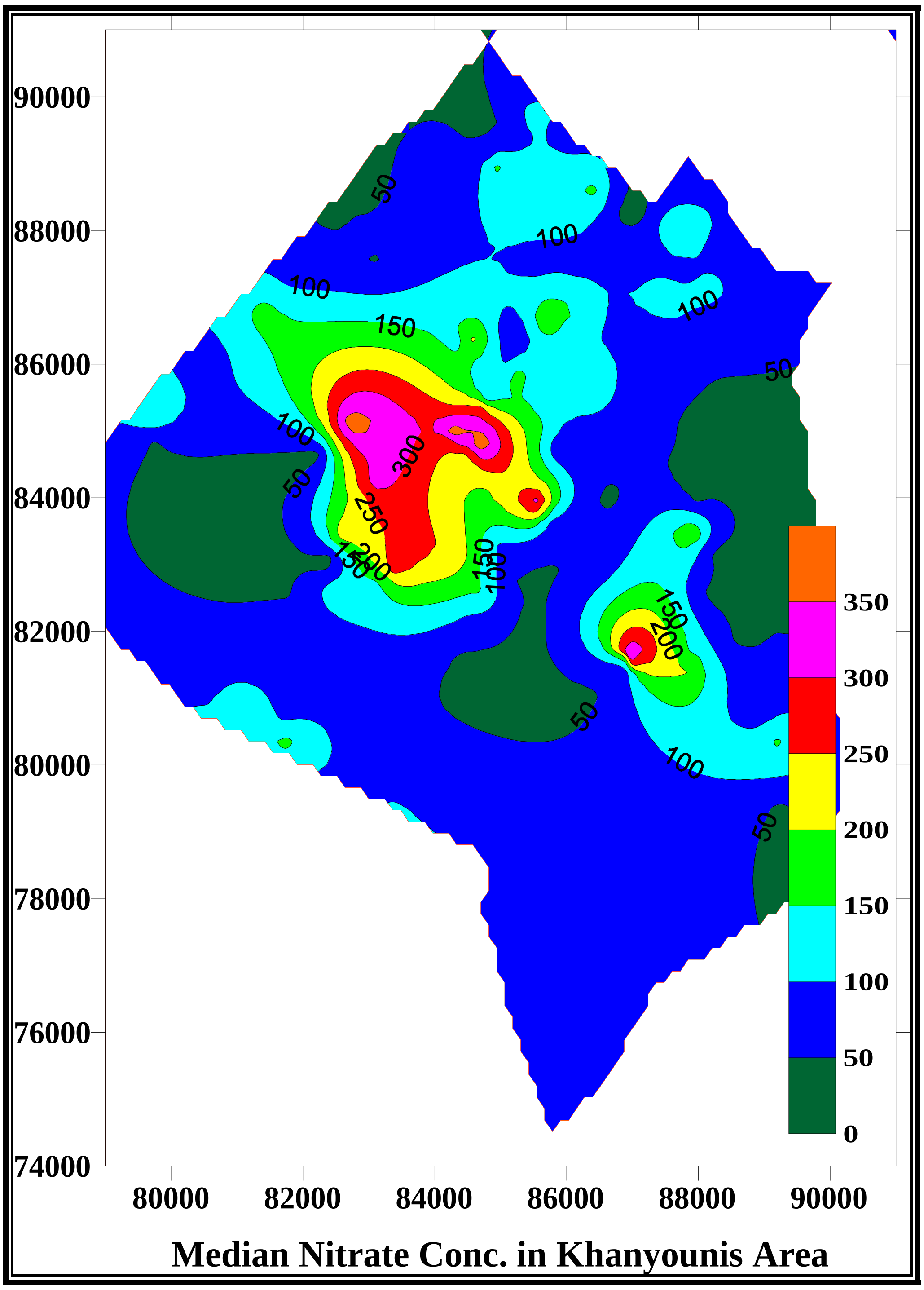

Figure (5.9): Median nitrate concentration in the Khanyounis Area (1987-2002)

© 2005 Tous droits réservés.

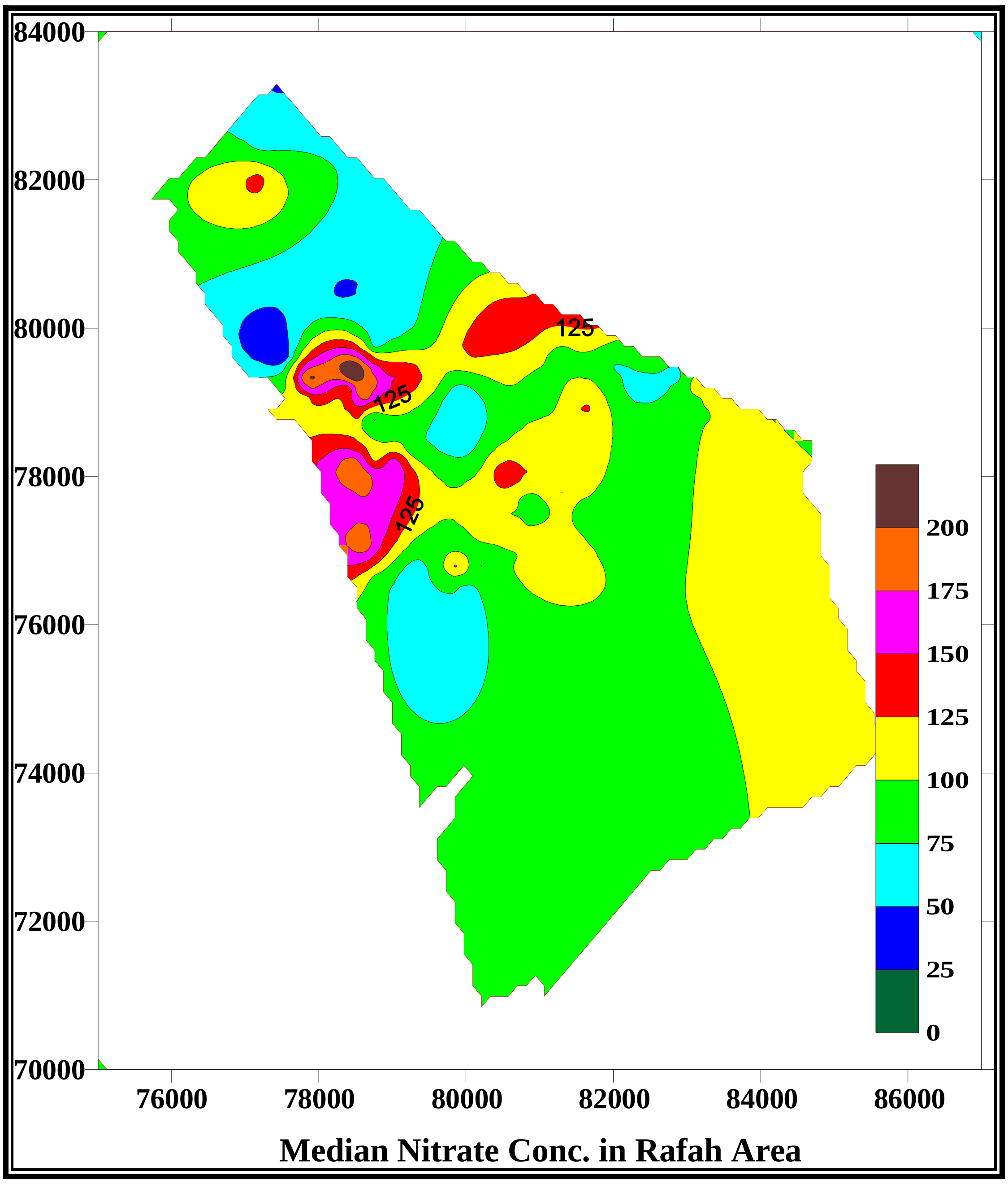

Figure (5.10): Median nitrate concentration in the Rafah Area (1987-2002)

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

5.8.2 Discussion of spatial patterns

Maps, in Figures (5.5) to (5.10), show that the median nitrate concentrations are generally more than 50 mg/L in groundwater. In some areas along the boarder of the Gaza Strip and near the coastal area, nitrate concentration is near 50 mg/L. This is because most of the urban and agricultural activities have been kept outside those areas. Outside of those areas, in the middle of the Gaza Strip, the concentrations vary considerably but are generally greater than 50 mg/L up to the level of 400 mg/L or more. In some areas, nitrate concentrations can be observed to increase with the distance from the boarder. For example, in the northern area, the nitrate concentrations decrease in a north-eastward direction. The water flow direction is from north-eastward to south-westward. This means that water comes from outside the Gaza Strip especially in the northern part has almost nitrate concentration less than 50 mg/L. Since this water mixed with the local aquifer the quality of water regarding nitrate contamination increases. There are several reasons for the nitrate concentration less than 50 mg/L compared to the high concentration in the rest of the areas of the Gaza Strip. First, parts of these areas are kept low by dilution as discussed above. Second, large parts of this aquifer are deep in depth in the range of 50-120 meter.

The high nitrates concentrations in the coastal aquifer are a result of high oxidation potential. Under oxidizing conditions, ammonia and nitrogen gas can be converted to nitrate under different processes. Oxidation potential is commonly high in unconfined aquifers because groundwater has direct contact with the atmosphere and therefore there is a possibility to replenish oxygen that is consumed through microbiological activity. The nitrate form of nitrogen is the dominant part in all wells tapping these aquifers in the area. Ammonia nitrogen concentrations exceed those of nitrate nitrogen at a few individual well locations, in small cases, owing to septic tank or boreholes discharges or land disposal of effluent. In such cases, the groundwater may not actually be reduced; it may instead be the discharge from a waste disposal system which simply had not yet been oxidized at the time and location of sample collection.

The concentrations are highly variable in the study area with clear spatial pattern and specific sources can be identified for many of the highest concentrations. Areas with high oxidation potential and areas dominated by wastewater recharge (e.g. Beit Lahia and Gaza area infiltration beds), nitrate nitrogen concentrations in groundwater are generally very high and more than 10 mg/L, suggesting influence from direct discharge and land disposal of wastewater effluent from the two wastewater treatment plants that exist in those areas. The

© 2005 Tous droits réservés.

solid waste landfill site located in the north east of the northern area also contributes to high concentrations of nitrate. Some wells have high concentrations of nitrates more than the WHO recommendation don't have a clear source of contamination. Boreholes and surface runoff that may enter the wells through a poorly protected well head could be the main reason for such elevated nitrate concentration.

Generally, four big areas have very high nitrate concentrations in groundwater (150-500 mg/L) more than the others as clearly shown in Figure (5.5). The concentration of nitrate gradually increases toward the centres of these areas to reach the level of 500 mg/L. By making overlay of the big four cites in the Gaza Strip (Gaza with Jabalia, Khanyounis, Dier-alBalah, and Rafah) and the four spots areas with high nitrate concentration, a complete overlay can be achieved. Also, there is a high level of nitrate concentrations in groundwater aquifer located to the east of the Khanyounis city as shown in the Figure (5.9). This aquifer is located under a five small towns without sewer system (Khanyounis eastern villages). In fact, there are several areas other than the areas mentioned above that have median nitrate concentrations from 100 to 150 mg/L (two to three times the WHO limit). The concentrations in these areas reflect the land uses, which include agriculture, irrigation, fertilizer application, cultivation practices and small communities.

5.9 Analysis of long-term trends in nitrate concentrations

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

The broad question in this subject: is there an evidence of increasing or decreasing nitrate concentration in groundwater in the region's wells within the period of the already implemented water quality program from 1987 till 2002? In statistical terms this is a determination of whether the probability distribution from which they arise has changed over

© 2005 Tous droits réservés.

time. We would also like to describe the amount or rate of that change, in terms of changes in some central value of the distribution such as a mean or median.

To answer this question a long term trends in the data from individual wells were investigated using a Mann-Kendall trend analysis, a non-parametric test that does not depend on the data being drawn at random from a normally-distributed population (Gilbert, 1987). This is appropriate for the available groundwater quality data, where the number of samples is generally small. The Mann-Kendall test does not calculate the magnitude of a trend. It simply determines whether or not a trend is present, based on the frequency with which the concentrations observed in later samples are greater or less than those observed in earlier samples. The Mann–Kendall Test can be used with a minimum of 4 rounds of sampling results; however, the Mann–Kendall Test is not valid for data that exhibit seasonal behavior. The Mann-Kendall statistic is calculated using the following equation:

$$\boxed{S = \sum_{i=2}^{k} \sum_{j=1}^{i=1} sign\left(x_k - x_j\right)}$$

where n is the total number of samples, x_j is the concentration in sample number j, x_k is the concentration in sample number k, and j and k are ordinal numbers where j is greater than k, indicating a sample collected at a later date. The sign function determines whether the concentration in sample j is greater or less than the concentration in sample k. If x_j is greater, the function returns a positive 1, if x_k is greater it returns a negative 1, and if they're equal it returns a zero. The greater the magnitude of the Mann-Kendall statistic, is the greater the number of instances in which a later concentration is higher (or, in the case of a decreasing trend, lower) than earlier concentrations, and the greater the probability that the values represent a real trend rather than random chance.

The null hypothesis: H_0 is that there is no trend. However, any given test brings with it a precise mathematical definition of what is meant by "no trend", including a set of background assumptions usually related to type of distribution and serial correlation. The outcome of the test is a "decision" either H_0 is rejected or not rejected. Failing to reject H_0 does not mean that it was "proven" that there is no trend. Rather, it is a statement that the evidence available is not sufficient to conclude that there is a trend. The Mann-Kendall statistic for each well was compared to a "critical value" corresponding to the number of years of data for that well (Table 5.2). The critical values were taken from IDT (1998), using an "alpha" confidence level of 0.05. If the absolute value of the Mann-Kendall statistic was greater than the critical

© 2005 Tous droits réservés.

value, then the trend was considered significant. The sign of the statistic indicated whether the trend was increasing or decreasing. If no trend exists, then *S* is expected to be zero and has variance equal:

$\mathrm{Var}(S) = n(n-1)(2n+5)/18$

If $n>10$, compare the test statistic $Z = S/SE(S)$ against the critical values from the Standard Normal Table.

Table (5.2): Critical values used in Mann-Kendall trend analysis

Years of Data	Critical value	Years of Data	Critical value	Years of Data	Critical value
4	6	9	17	14	32
5	8	10	20	15	35
6	10	11	23	16	38
7	13	12	26	17	42
8	15	13	29	18	45

5.9.1 Data Compilation

Long-term trend analyses were done on two sets of data (Domestic wells data and agricultural wells data). The data was divided to two groups named winter and summer group. The criteria for the data used in the tests were:

- The well was sampled in the period between 1987 and 2002
- The sample was collected in the summer months from April to June or the sample was collected in the winter months from September to November
- The well had data from at least 4 calendar years

There were 65 wells that met the criteria for the application of statistical tests. All groundwater nitrate data from 1987 to 2002 were collected and from these 65 wells were extracted and copied into a Microsoft Excel spreadsheet. The data for the summer period was copied in one column and the data for the winter season was copied in other column.

5.9.2 Outlier values and creation of graphs

Outlier values were identified and removed from the trend analyses through the following procedure in the Excel spreadsheet:

- For each site, all values collected outside the winter or summer time was identified and moved to two separate columns
- For each well, using only the winter and summer data, identify all values that are outside two standard deviations from the median and move them to a third column
- Create graphs of the data for each, with date on the x-axis and three series on the y-axis, using the three separate columns of data (1: winter data; 2: summer data; 3: data outside two standard deviations of the median).

© 2005 Tous droits réservés.

- Visually each graph with outlier data was examined; based on the range and variations in the data, make a subjective decision as to whether the points that fall outside two standard deviations of the median are actually outliers; where there is reasonable doubt that a point is not an outlier, go back to the data worksheet page and move the value back to the "winter" or "summer" data column so that it is included in the trend analyses.

5.9.3 Result of calculation of trends

Through the monitoring program, which was run from 1987 to 2002 by MOA, indicates that there are three dominant types of groundwater quality present in the Gaza Strip ranging from decreasing, constant to increasing nitrate concentration. The analysis of long-term trends in nitrate concentrations was conducted at a confidence level of 95% (alpha = 0.05), the results show the following:

1. for data set of winter season:
    - Increasing trend was identified in 20 (31%) of the 65 wells tested
    - Decreasing trend was identified in 1 (1.5%) of the wells tested
    - No trend was identified in 44 (67.5%) of the wells tested
2. The test was done for the summer season data for the same wells and the results were as follows:
    - Increasing trend was identified in 19 (29.5%) of the 65 wells tested
    - Decreasing trend was identified in 2 (3%) of the wells tested
    - No trend was identified in 44 (67.5%) of the wells tested

The wells with increasing trends are distributed across the Gaza Strip but are primarily at the centre of the residential areas. There are also some wells with increasing trends in the agricultural areas. The land use activities in the area surrounding each well are summarized in appendix (II). Increasing trends were identified in a total of 65 groundwater wells between the two sets of test (summer and winter case) but 20 wells showed an increasing trend in both sets. Fourteen groundwater wells showed increase in nitrate concentration around the urban areas but only 5 wells showed increasing trends in both sets of tests around the agricultural areas. Seven of the 20 wells were associated with land disposal of wastewater effluent from treatment plants. The wells with increasing trends in the agricultural lands are associated with the type of agricultural pattern, nitrogen load and agricultural activities like effluent spreading, dairy farming, and horticulture.

© 2005 Tous droits réservés.

5.9.3.1 Decreasing Trends

Decreasing trends were identified in a total of 65 groundwater wells between the two sets of tests, but only two wells showed a decreasing trend in both sets. Well number E/40, is a 50 meter deep well located in northern area. Based on its bore log, the well is screened in the second confined aquifer. Its median nitrate concentration is 145 mg/L. The concentrations fluctuated considerably between 110 and 200 mg/L through the 1987 and early 1995, but they have been consistently less than 70 mg/L since1994.

5.9.3.2 No Trends

Twenty two wells showed no trends in the two data sets. Inspection of the data for these wells shows that in most of them, the concentrations were decreasing during the late 1987 to early 1990, but the trends levelled off in the late 1990s.

5.9.3.3 Some Examples:

Class (1): Steady state of nitrate concentration in groundwater

In this type the nitrate concentration represent more or less a constant state, which is found mainly in the protected area, and there is a little chance for contaminate transport from the ground to aquifer. Some wells are well protected, and their distribution in the Gaza Strip depends on the location, construction of the wells, and also on the depth in the clayey areas. This stable situation, reflect either good protection conditions and flushing of the aquifer with fresh infiltrating rainwater. The following figure shows the time series for well number (R/254) in the northern area in the clayey areas with little agriculture and urban activities.

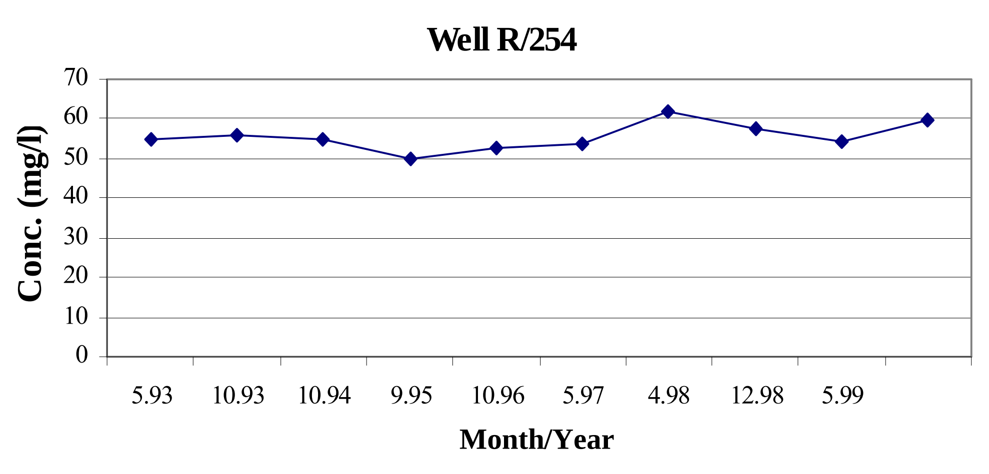

Figure (5.11): Steady State of Nitrate Concentration of Well R/254.

© 2005 Tous droits réservés.

Class 2: Continuous increase of nitrate concentration in groundwater

This type represents the situation in the Jabalia and Khanyounis areas of the Gaza Strip. Figure (5.12) presents the situation in well number (L/43) located in Khanyounis. The gradual build up of nitrate could result as well from urban activities and/or through recharge of wastewater or irrigation return flow.

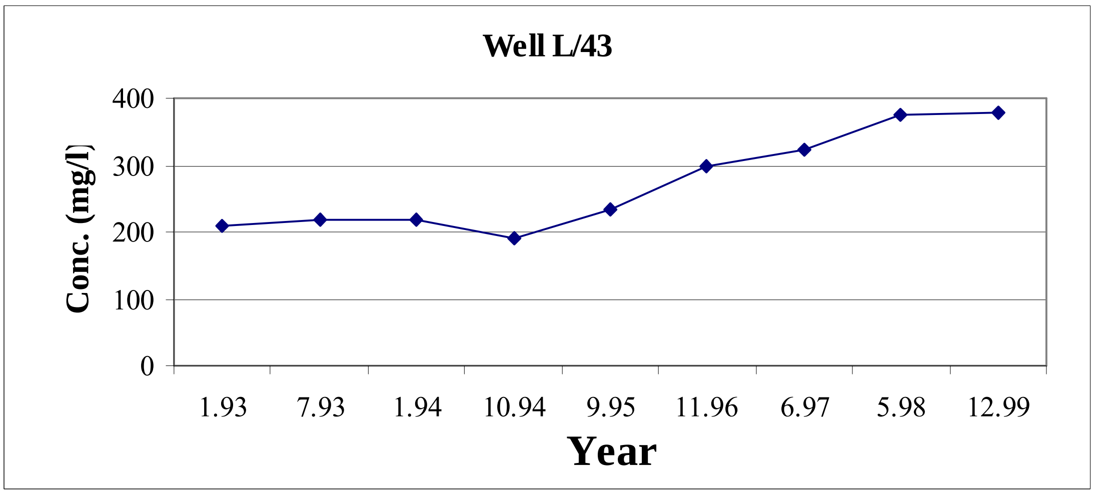

Figure (5.12): Continuous Increase of Nitrate Concentration of Well L/43.

5.10 Seasonal Fluctuations in Nitrate Concentrations

5.10.1 Method of Analysis

The seasonal Kendall test (Hirsch et al., 1984) accounts for seasonality by computing the Mann-Kendall test on each of m seasons separately, and then combining the results. So, for this research the data is divided into two groups based on the monitoring program (winter season and summer season), winter data are compared only with winter data for the well, summer data only with summer data. No comparisons are made across season boundaries. Kendall's S statistics S_i for each season are summed to form the overall statistic S_k.

$$S_k = \sum_{i=1}^{m} S_i$$

When the product of number of seasons and number of years is more than about 25, the distribution of S_k can be approximated quite well by a normal distribution with expectation equal to the sum of the expectations (zero) of the individual S_i under the null hypothesis, and variance equal to the sum of their variances. S_k is standardized by subtracting its expectation $\mu_k = 0$ and dividing by its standard deviation σ_{Sk}. The result is evaluated against a table of the standard normal distribution.

© 2005 Tous droits réservés.

$$Z_{sk} = \begin{cases} \dfrac{S_k - 1}{S_{sk}} & if\ S_k \supset 0 \\ 0 & if\ S_k = 0 \\ \dfrac{S_k + 1}{S_{sk}} & if\ S_k \subset 0 \end{cases} \qquad \text{where } \mu_{sk} = 0$$

$$\boxed{S_{sk} = \sqrt{\sum_{i=1}^{m} (n_i/18) * (n_i - 1) * (2n_i + 5)}} \qquad \text{, and}$$

n_i = number of data in the i_{th} season

The null hypothesis is rejected at significance level α if $|Z_{Sk}| > Z_{crit}$ where Zcrit is the value of the standard normal distribution with a probability of exceedance of α/2.

5.10.2 Analysis Result

In addition to the long-term trends discussed in the previous section, nitrate concentrations in groundwater may display seasonal fluctuations. Nitrate concentrations at a given location are variable over time, and they commonly display a seasonal cycle, with higher concentrations in the winter and lower concentrations in the summer. The reason for the seasonal fluctuations is interpreted to be that during the winter, when rainfall is greater and evaporation rates and plant activity are lower, there is available soil moisture to percolate downward through the soil profile and carry nitrates to the groundwater. Nitrate concentrations then decline over the summer when there is little available soil moisture, so they are generally lowest in the summer. Table 5.3 shows Mann-Kendall trend test and Kendall's S seasonal fluctuations test results.

© 2005 Tous droits réservés.

Table (5.3): Mann-Kendall trend test and Kendall's S seasonal fluctuations test results

Well No. A/185	
Outliers	2
Season	Winter
S =	48.0
N =	15.0
Var(S) =	408.3
SE(S) =	20.2
Z =	2.4
Trend	Increase
Season	Summer
S =	39.0
N =	15.0
Var(S) =	408.3
SE(S) =	20.2
Z =	1.9
Trend	Increase

Well No. A/11	
Outliers	0.0
Season	Winter
S =	-12.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	-1.3
Trend	none
Season	Summer
S =	-27.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	-2.8
Trend	Decrease

Well No. A/32	
Outliers	0.0
Season	Winter
S =	0.0
N =	7.0
Var(S) =	44.3
SE(S) =	6.7
Z =	0.0
Trend	none
Season	Summer
S =	0.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	0.0
Trend	None

Well No. C/79	
Outliers	1.0
Season	Winter
S =	4.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	1.4
Trend	none
Season	Summer
S =	4.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	0.8
Trend	None

Well No. C/127	
Outliers	4
Season	Winter
S =	60.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	3.3
Trend	Increase
Season	Summer
S =	37.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.5
Trend	Increase

Well No. C/128	
Outliers	4.0
Season	Winter
S =	43.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.9
Trend	Increase
Season	Summer
S =	32.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	2.5
Trend	Increase

Well No. D/2	
Outliers	0.0
Season	Winter
S =	0.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.0
Trend	None
Season	Summer
S =	8.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	1.5
Trend	None

Well No. D/60	
Outliers	3.0
Season	Winter
S =	6.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	1.5
Trend	None
Season	Summer
S =	7.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	1.3
Trend	None

Well No. D/67	
Outliers	0
Season	Winter
S =	56.0
N =	15.0
Var(S) =	408.3
SE(S) =	20.2
Z =	2.8
Season	Summer
S =	33.0
N =	15.0
Var(S) =	408.3
SE(S) =	20.2
Z =	1.6
Trend	None

Well No. D/68	
Outliers	5.0
Season	Winter
S =	45.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	3.5
Season	Summer
S =	40.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	3.1
Trend	Increase

Well No. D/69	
Outliers	0.0
Season	Winter
S =	-2.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	-0.5
Season	Summer
S =	4.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	1.4
Trend	None

Well No. D/70	
Outliers	0.0
Season	Winter
S =	-3.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	-0.6
Season	Summer
---	---
---	---
---	---
---	---
---	---
---	---

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Table (5.3): Continued

Well No. D/73	
Outliers	0
Season	Winter
S =	2.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.7
Trend	None
Season	Summer
---	---
---	---
---	---
---	---
---	---
---	---

Well No. D/74	
Outliers	0.0
Season	Winter
S =	-2.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	-0.7
Trend	None
Season	Summer
S =	-4.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	-1.4
Trend	None

Well No. E-11A	
Outliers	0.0
Season	Winter
S =	-15.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	-0.8
Trend	None
Season	Summer
S =	9.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	0.5
Trend	None

Well No. E-11B	
Outliers	0.0
Season	Winter
S =	-5.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	-0.3
Trend	None
Season	Summer
S =	-9.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	-0.6
Trend	None

Well No. E-138	
Outliers	0
Season	Winter
S =	-2.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	-0.7
Trend	None
Season	Summer
S =	-14.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	-1.1
Trend	None

Well No. E-154	
Outliers	3.0
Season	Winter
S =	59.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	3.2
Trend	Increase
Season	Summer
S =	8.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	0.6
Trend	None

Well No. E-156	
Outliers	1.0
Season	Winter
S =	-6.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	-0.4
Trend	None
Season	Summer
S =	-15.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	-1.2
Trend	None

Well No. E-157	
Outliers	5.0
Season	Winter
S =	37.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	2.9
Trend	Increase
Season	Summer
S =	14.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	1.5
Trend	None

Well No. A-180	
Outliers	0
Season	Winter
S =	62.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	3.4
Trend	Increase
Season	Summer
S =	75.0
N =	15.0
Var(S) =	408.3
SE(S) =	20.2
Z =	3.7
Trend	Increase

Well No. T-15	
Outliers	0.0
Season	Winter
S =	5.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	0.9
Trend	None
Season	Summer
S =	11.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	2.1
Trend	Increase

Well No. E-4	
Outliers	3.0
Season	Winter
S =	-17.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	-1.8
Trend	Decrease
Season	Summer
S =	-35.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	-2.4
Trend	Decrease

Well No. E-6	
Outliers	0.0
Season	Winter
S =	0.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.0
Trend	None
Season	Summer
S =	0.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.0
Trend	None

© 2005 Tous droits réservés.

Table (5.3): Continued

Well No. E-90	
Outliers	3
Season	Winter
S =	13.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	1.2
Trend	None
Season	Summer
S =	6.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	0.3
Trend	None

Well No. E-92	
Outliers	3.0
Season	Winter
S =	18.0
N =	8.0
Var(S) =	65.3
SE(S) =	8.1
Z =	2.2
Trend	Increase
Season	Summer
S =	-2.0
N =	8.0
Var(S) =	65.3
SE(S) =	8.1
Z =	-0.2
Trend	None

Well No. J-146	
Outliers	4.0
Season	Winter
S =	6.0
N =	8.0
Var(S) =	65.3
SE(S) =	8.1
Z =	0.7
Trend	None
Season	Summer
S =	-3.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	-0.3
Trend	None

Well No. J-32	
Outliers	2.0
Season	Winter
S =	5.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	0.9
Trend	None
Season	Summer
S =	-2.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	-0.5
Trend	None

Well No. L-127	
Outliers	4.0
Season	Winter
S =	82.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	4.5
Trend	Increase
Season	Summer
S =	13.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	1.0
Trend	None

Well No. L-159	
Outliers	3.0
Season	Winter
S =	42.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	2.6
Trend	Increase
Season	Summer
S =	31.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	2.8
Trend	Increase

Well No. L-176	
Outliers	5.0
Season	Winter
S =	34.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.3
Trend	Increase
Season	Summer
S =	34.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	3.0
Trend	Increase

Well No. L-178	
Outliers	1.0
Season	Winter
S =	4.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	1.0
Trend	None
Season	Summer
S =	4.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	0.8
Trend	None

Well No. L-41	
Outliers	0.0
Season	Winter
S =	20.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	1.1
Season	Summer
S =	-14.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	-0.8
Trend	None

Well No. L-43	
Outliers	4.0
Season	Winter
S =	39.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.7
Season	Summer
S =	11.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	1.0
Trend	None

Well No. L-86	
Outliers	0.0
Season	Winter
S =	14.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	1.0
Season	Summer
S =	-10.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	-0.9
Trend	None

Well No. L-87	
Outliers	4.0
Season	Winter
S =	18.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	1.4
Season	Summer
S =	31.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.1
Trend	Increase

© 2005 Tous droits réservés.

Table (5.3): Continued

Well No. L-179	
Outliers	1.0
Season	Winter
S =	14.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	1.1
Trend	None
Season	Summer
S =	-16.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	-1.0
Trend	None

Well No. L-M2a	
Outliers	0.0
Season	Winter
---	---
---	---
---	---
---	---
---	---
Trend	
Season	Summer
S =	1.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.3
Trend	None

Well No. M-2b	
Outliers	0.0
Season	Winter
S =	4.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	1.4
Trend	None
Season	Summer
S =	22.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	2.3
Trend	Increase

Well No. N-9	
Outliers	4.0
Season	Winter
S =	4.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	1.0
Trend	None
Season	Summer
S =	1.0
N =	8.0
Var(S) =	65.3
SE(S) =	8.1
Z =	0.1
Trend	None

Well No. N-22	
Outliers	0.0
Season	Winter
S =	0.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.0
Trend	None
Season	Summer
S =	7.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	1.3
Trend	None

Well No. P-10	
Outliers	4.0
Season	Winter
S =	7.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	1.3
Trend	None
Season	Summer
S =	67.0
N =	14.0
Var(S) =	333.7
SE(S) =	18.3
Z =	3.7
Trend	Increase

Well No. P-15	
Outliers	3.0
Season	Winter
S =	34.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.3
Trend	Increase
Season	Summer
S =	48.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	2.9
Trend	Increase

Well No. P-124	
Outliers	3.0
Season	Winter
S =	58.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	3.5
Trend	Increase
Season	Summer
S =	18.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	1.4
Trend	None

Well No. P-138	
Outliers	0.0
Season	Winter
S =	0.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.0
Trend	None
Season	Summer
S =	8.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	2.0
Trend	Increase

Well No. P-138old	
Outliers	0.0
Season	Winter
S =	-9.0
N =	7.0
Var(S) =	44.3
SE(S) =	6.7
Z =	-1.4
Trend	None
Season	Summer
S =	-1.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	-0.2
Trend	None

Well No. P-144	
Outliers	0.0
Season	Winter
S =	-11.0
N =	7.0
Var(S) =	44.3
SE(S) =	6.7
Z =	-1.7
Trend	None
Season	Summer
S =	-13.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	-1.4
Trend	None

Well No. P-145	
Outliers	0.0
Season	Winter
S =	2.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.7
Trend	None
Season	Summer
S =	-2.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	-0.7
Trend	None

© 2005 Tous droits réservés.

Table (5.3): Continued

Well No. R-25a	
Outliers	
Season	Winter
S =	22.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	1.3
Trend	None
Season	Summer
S =	17.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	1.3
Trend	None

Well No. R-25b	
Outliers	3.0
Season	Winter
S =	12.0
N =	11.0
Var(S) =	165.0
SE(S) =	12.8
Z =	0.9
Trend	None
Season	Summer
S =	0.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	0.0
Trend	None

Well No. R-25C	
Outliers	
Season	Winter
S =	20.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	1.4
Trend	None
Season	Summer
S =	10.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	1.0
Trend	None

Well No. R-25D	
Outliers	4.0
Season	Winter
S =	21.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	1.9
Trend	Increase
Season	Summer
S =	8.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	0.8
Trend	None

Well No. R-74	
Outliers	2.0
Season	Winter
S =	5.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	1.7
Trend	None
Season	Summer
S =	2.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.7
Trend	None

Well No. R-75	
Outliers	2.0
Season	Winter
S =	3.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	0.7
Trend	None
Season	Summer
S =	-2.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	-0.5
Trend	None

Well No. R-112	
Outliers	4.0
Season	Winter
S =	2.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	0.1
Trend	None
Season	Summer
S =	-10.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	-0.9
Trend	None

Well No. R-254	
Outliers	4.0
Season	Winter
S =	23.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	1.6
Trend	None
Season	Summer
S =	-5.0
N =	13.0
Var(S) =	268.7
SE(S) =	16.4
Z =	-0.3
Trend	None

Well No. R-162F	
Outliers	0.0
Season	Winter
S =	-4.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	-1.0
Trend	None
Season	Summer
S =	5.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	0.9
Trend	None

Well No. S-69	
Outliers	4.0
Season	Winter
S =	-5.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	-0.5
Trend	None
Season	Summer
S =	-10.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	-0.9
Trend	None

Well No. T-44	
Outliers	0.0
Season	Winter
S =	6.0
N =	5.0
Var(S) =	16.7
SE(S) =	4.1
Z =	1.5
Trend	None
Season	Summer
S =	6.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	2.0
Trend	None

Well No. S-19	
Outliers	1.0
Season	Winter
S =	1.0
N =	4.0
Var(S) =	8.7
SE(S) =	2.9
Z =	0.3
Trend	None
Season	Summer
S =	21.0
N =	8.0
Var(S) =	65.3
SE(S) =	8.1
Z =	2.6
Trend	Increase

© 2005 Tous droits réservés.

Table (5.3): Continued

Well No. R-162C	
Outliers	0.0
Season	Winter
S =	34.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.3
Trend	Increase
Season	Summer
S =	15.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	1.6
Trend	None

Well No. R-162B	
Outliers	5.0
Season	Winter
S =	40.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.7
Trend	Increase
Season	Summer
S =	7.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	0.6
Trend	None

Well No. R-162E	
Outliers	1.0
Season	Winter
S =	1.0
N =	6.0
Var(S) =	28.3
SE(S) =	5.3
Z =	0.2
Trend	None
Season	Summer
S =	26.0
N =	8.0
Var(S) =	65.3
SE(S) =	8.1
Z =	3.2
Trend	Increase

Well No. R-162L	
Outliers	3.0
Season	Winter
S =	16.0
N =	10.0
Var(S) =	125.0
SE(S) =	11.2
Z =	1.4
Trend	None
Season	Summer
S =	10.0
N =	7.0
Var(S) =	44.3
SE(S) =	6.7
Z =	1.5
Trend	None

Well No. R-162H	
Outliers	3.0
Season	Winter
S =	31.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.1
Trend	Increase
Season	Summer
S =	16.0
N =	9.0
Var(S) =	92.0
SE(S) =	9.6
Z =	1.7
Trend	None

Well No. R-162G	
Outliers	5.0
Season	Winter
S =	69.0
N =	15.0
Var(S) =	408.3
SE(S) =	20.2
Z =	3.4
Trend	Increase
Season	Summer
S =	37.0
N =	12.0
Var(S) =	212.7
SE(S) =	14.6
Z =	2.5
Trend	Increase

5.11 Application to the Case Study-Gaza Governorate:

5.11.1 Introduction

Nitrate has been reported above background concentrations in groundwater world-wide and it has been identified to be the most common and widespread chemical contaminant in groundwater (Spalding and Exner, 1993) and is commonly associated with diffuse sources such as intensive agriculture, high density housing with unsewered sanitation, and point sources such as discharge of sewage effluent onto land (Keeney, 1986; Eckhardt and Stackelburg, 1995). Background levels of nitrate (as N) in natural groundwater are typically low. Concentrations between 0.45 and 2.0 mg/L have been reported in groundwater in Europe and the USA (Hallberg, 1989; Juergens-Gschwind, 1989) and from 1.15 to 2.3 mg/L in Australia (Lawrence, 1983). Some studies show that groundwater concentrations exceeding

© 2005 Tous droits réservés.

an arbitrary threshold of 3 mg/L may be indicative of contamination of natural groundwater as a result of human activities (referred to as the human affected value; HAV; Burkart and Kolpin, 1993; Echardt and Stackelberg, 1995).

Elevated concentrations of nitrate in drinking water are a cause for concern as it may represent a loss of fertility from overlaying soil, cause Eutrophication when the groundwater discharge into surface water, and can potentially cause health problems to animals and humans. Ingestion of excessive amounts of nitrates causes ill health effects in infants less than six months old and susceptible adults. It causes "blue baby syndrome" or methemoglobinemia in infants, which can lead to brain damage and sometimes death (WHO, 1998).

The extent of the worldwide problem has been reviewed in a world health organization document. The maximum allowable concentration of NO3-N used for potable water varies considerably worldwide, although the two most commonly used values are 10 mg/L used in the USA and 11.3 mg/L recommended by the World Health Organization (MAVWHO). It has been recommended that water supplies containing high levels of nitrate (more than 11.3 mg/l NO3-N) should not be used for the preparation of infant foods; alternative supplies having low nitrate content, even to the extent of using bottled water, have been recommended. There is also a suggestion that pregnant women are at greater risk than the general adult population, but further work is needed to confirm this. The MAVWHO is used in Palestine as a public health standard.

Predicting where contamination will occur is very difficult, especially in areas with a mixture of land uses. Numerous studies over the world of 'potential' groundwater contamination with NO3-N have been reported from solute leaching and the groundwater is suggested to be at risk of contamination due to the overlying land use or management activity. Many solute leaching models exist in the literature (for a review, see Addiscott and Wagenet, 1985). However, many leaching models are constrained by the need for stringent boundary conditions to be satisfied, which is not possible in areas of mixed land use. Further, many models need intensive on-site calibration, and do not cope well with non-uniform strata and the numerous biological and chemical processes can affect the fate of nitrate in the vadose zone between the soil and an underlying aquifer.

© 2005 Tous droits réservés.

An alternative approach for predicting groundwater NO3-N contamination has been at a broader scale by correlating the dominant land use in an area with nitrate concentrations actually measured in underlying aquifers in some countries (e.g. Barringer et al., 1990; Burkart and Kolpin, 1993; Eckhardt and Stackelburg, 1995). Recently, many research projects have examined the relationship between specific land-use patterns, corresponding pollutant emissions and the resulting groundwater quality (Trauth and Xanthopoulos 1997; Hong and Rosen 2001; Lasserre and others 1999).

Land use is suggested to influence groundwater quality because the land use commonly influences the nitrogen flow in the surface soil. However, contamination of groundwater with NO3-N has been reported in all areas of the Gaza Strip and within all land uses (Khairy Al-Jamal and M. Shoblack, 2000). The most severely contaminated groundwater that are reported in rural and agricultural areas associated with vegetable production, orchards and horticulture land uses due to the greater amount of N fertilizer used than other agricultural land uses, and also with land uses where wastes are frequently applied to soils (Palestinian Hydrology Group, 2002).

The primary goal of this study is to analyze and model the relationship between land uses and hydrological factors and the well-known contaminant in urban and agricultural groundwater wells, NO3-N. In other words, the study aims to propose the basis for the development predictive tools for the assessment of nitrate contamination and use the best-fit model as a management tool for nitrate prediction to be used by the water sector managers and planners advance towards the management of water resources and pollution prevention.

5.12 Data Collection and Analysis

This study was carried out in three steps: firstly, data was collected for database construction using a Geographic Information System (GIS) for graphical presentation, data storage and retrieves. Secondly, the data collected was used to construct the database for 139 groundwater wells in the Gaza Governorate. The data includes well depth, location, screen length, and nitrate concentration. A total of 975 observations were collected by the PWA data base for the period 1987 to 2002. The data on infiltration rates and land-use such as housing density in 500-m radius area surrounding wells, agricultural pattern and estimated nitrogen loads were obtained from references, reports, related GIS data and site visits, and calculated nitrogen loads from chapter four.

© 2005 Tous droits réservés.

In this study, the relation between groundwater nitrate concentration and potential explanatory variables were analyzed in simple bivariate fashion statistical analysis to investigate the characteristics of NO3-N according to the well depth, screen length, infiltration rate and land uses. Thirdly, different types of artificial neural networks were applied. STATISTICA software (StatSoft Inc. version 6, 2002) has been used for the bivariate statistical analysis. The P values for testing the results of statistical analysis were calculated at the 95% significance level. The Intelligent Problem Solver (IPS) under STATISTICA Software was used for building the ANN models.

To estimate the extent of contamination in the area, maps of nitrate were generated by using the available data for the years 1987, and 2002 as well as the median nitrate concentration from the period 1987 to 2002. The median of a data set is less affected by skewed data and outlier values than the mean, and it is therefore a better indicator of the central tendency of the data (Gilbert, 1987). The maps show high increase of nitrate concentration from the year 1987 to the year 2002 (Figure 5.13a, b, and c).

The mean nitrate concentration for the 139 agricultural wells out of 189 wells, wells used for domestic and agricultural purposes were excluded, was 90.81 mg/L. Large variations in nitrate concentrations were observed among samples, with a high coefficient of variation exceeding 100%. The large ranges of dependent variable correspond to the large variations in hydrological parameters, soil characteristics and land use. Among these wells, 114 wells (82%) exceeded the drinking water quality standard (50 mg/L). Table 5.5 shows the number of wells located in various land uses, the number of contaminated wells with nitrate more than 50 mg/L in addition to the maximum and minimum nitrate concentration. Most of groundwater wells contains NO_3^- concentration exceeding 50 mg/L depending on the land uses. The field crops represent the highest ratio of nitrate in groundwater. This is due to the high amount of nitrogen fertilizer used for crops.

Table (5.4): Descriptive statistics for the research data (975 observations, 1987-2002)

Variable	Mean	Median	Min.	Max.	Variance	Std.Dev.	Skewness	Kurtosis
Nitrate (mg/L)	90.8	88	30	208	1576.53	39.71	0.58	-0.30
Well Depth (m)	35.4	36	8	91	324.33	18.01	0.48	-0.22
Screen Length (m)	16.2	10	5	44	87.54	9.36	1.38	0.94
Nitrogen Load (kg/h/y)	340.5	335	129	640	13663.80	116.89	0.40	-0.80
Housing Density	51.8	50	47	64	16.36	4.04	1.24	0.79
Infiltration Rate	15.3	15	2	33	79.75	8.93	0.20	-1.06
Discharge (m3/d)	192.9	187	100	423	2865.33	53.53	1.33	3.42

© 2005 Tous droits réservés.

Table (5.5): Relation between nitrate concentration in groundwater (mg/L) and agriculture types in the Gaza Governorate

	No. of wells	no. of observation	contaminated wells 1987	contaminated wells 2002	Min NO_3^- 1987	Max NO_3^- 1987	Min NO_3^- 2002	Max NO_3^- 2002
Palms	4	20	3	4	37	50	57	100
Beans	7	43	4	7	47	85	51	203
Citrus	15	86	9	15	32	162	55	225
Olives	12	91	2	12	11	85	100	266
Gumbo	4	14	4	4	55	140	114	275
Cauliflower	7	42	4	7	45	110	70	283
Peppers	3	28	1	3	40	145	91	284
Almonds	15	120	10	15	25	75	55	290
Cereals	6	51	4	6	13	83	68	296
Green houses	11	71	10	11	35	135	165	301
Mixed trees	15	88	4	14	36	106	40	309
Tomato	11	89	5	11	40	105	90	311
Grapes	15	114	4	14	3	92	44	315
Corn	5	34	4	5	40	111	137	315
Potatoes	2	14	2	2	131	173	173	332
Watermelon	7	70	4	7	20	124	115	425

© 2005 Tous droits réservés.

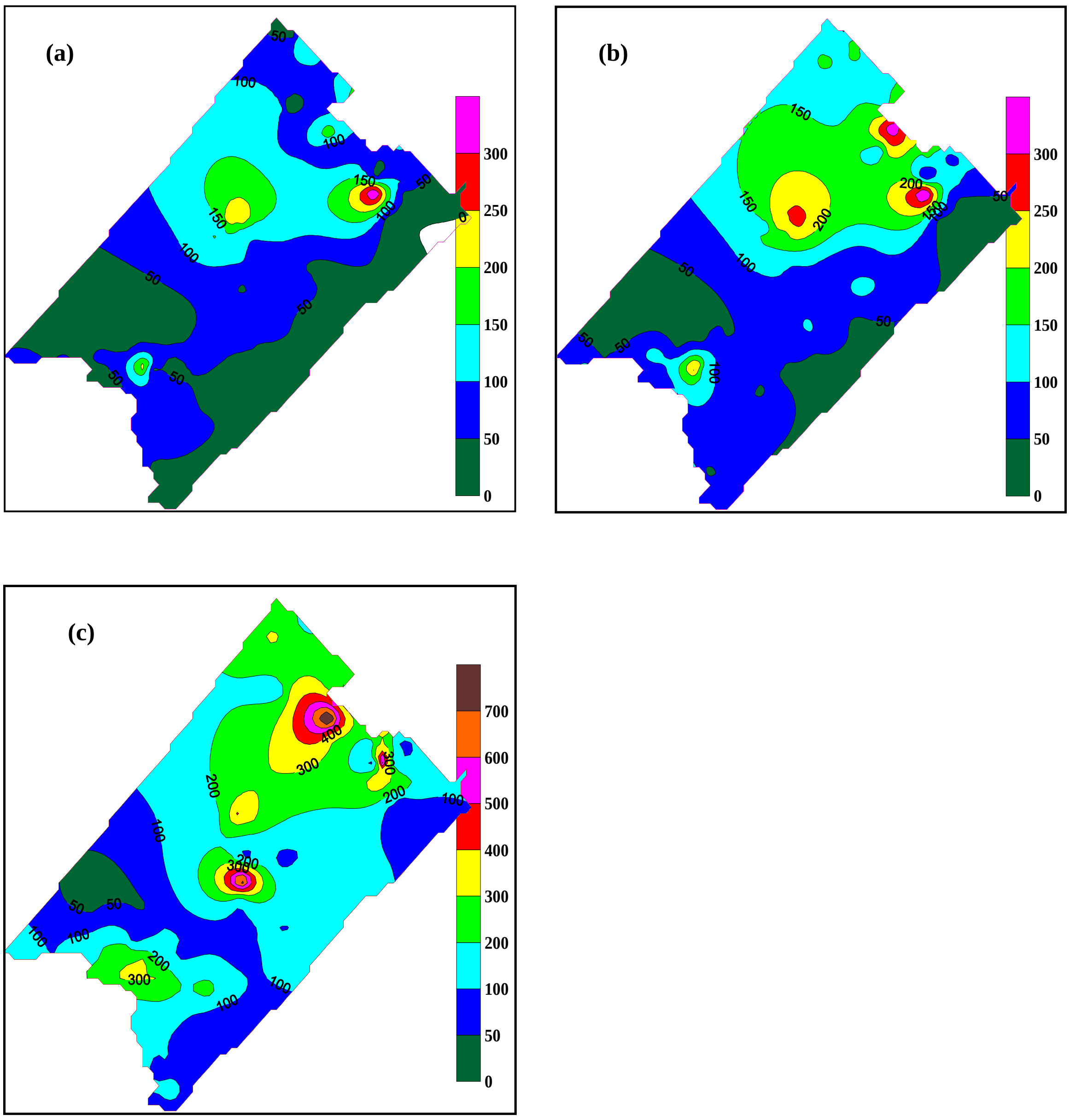

Fig (5.13): Nitrate concentration in the Gaza Governorate a) Nitrate Conc. in the 1987. b) Median Nitrate Conc. from 1987 to 2002. C) Nitrate Conc. in 2002

5.13 Correlation between variables:

A correlation describes the strength of an association between variables. An association between variables means that the value of one variable can be predicted, to some extent, by the value of the other. A correlation is a special kind of association: there is a linear relation between the values of the variables. A non-linear relation can be transformed into a linear one before the correlation is calculated. For a set of variable pairs, the correlation coefficient gives the strength of the association. The square of the size of the correlation coefficient is the fraction of the variance of the one variable that can be explained from the variance of the other variable.

© 2005 Tous droits réservés.

Table (5.6) shows the correlation matrix of the variables. Usually, significant correlations (at a P =0.05 level) are searched for but because of the high number of degrees of freedom, $r_{critical}$ is low at P = 0.05, so the number of statistically significant correlations (with $r > r_{critical}$) is high. The real usefulness of this test is questionable since it simply proves that r is significantly different from zero.

Nitrate concentration in groundwater versus nitrogen loading from fertilizer, manure, and atmospheric sources showed generally increasing nitrate response to N loading with (r=0.52). There are strong positive relation between nitrate concentration and number of houses as well as infiltration rate. Also the table shows strong positive relation between nitrogen load and infiltration rate. We observe negative correlation between nitrate concentration and well depth. Increase number of houses means increase nitrogen load which leads to increase nitrate concentration. Also, the increase of infiltration rate will allow nitrogen compounds to move easily from the top soil and increase the chance of nitrogen leaching to the groundwater. There is a positive correlation is existed between wells discharge and number of houses with correlation ratio of 0.23. This ratio is considered low due to the limited number of houses existing in agricultural areas.

Table (5.6): Bivariate correlation matrix of explanatory variables (Marked correlations are significant at p < .05000 N=189, Log data for normalization)

Variables	Nitrate Conc.	Well Depth	Screen Length	nitrogen load	No. of Houses	Infiltration Rate	Discharge
Nitrate Conc.	1.00						
Well Depth	-0.14	1.00					
Screen Length	0.03	-0.04	1.00				
nitrogen load	**0.52**	**0.84**	-0.04	1.00			
No. of Houses	**0.67**	-0.06	0.09	**0.31**	1.00		
Infiltration Rate	**0.68**	**0.66**	-0.02	**0.89**	**0.46**	1.00	
Discharge	0.09	-0.11	-0.04	0.02	**0.23**	-0.01	1.00

5.14 Nitrate Concentration and Well Depth

Numerous studies worldwide have shown that groundwater nitrate concentrations decrease with depth (Freeze and Cherry, 1979; Hallberg, 1989; Close *et al.*, 2001). In many cases, this occurs because oxidation potential decreases with depth and distance from the groundwater recharge source (Fetter, 1988), and nitrate is reduced to nitrogen gas or ammonia. In other cases, it may be that nitrates from human activities have not yet penetrated to the deeper water. Depth may be considered in three ways: the depth of the water table below the ground

© 2005 Tous droits réservés.

surface, the depth of a well screen below the water table, and the total depth of a well below ground surface.

The depth of the water table below the ground surface may influence the attenuation of the nitrate concentrations in the soil drainage that reaches the water table. Nitrate is a conservative contaminant that does not decay in the unsaturated zone and is not adsorbed to the sediment (Close *et al.*, 2001; Freeze and Cherry, 1979), so the primary effect of a deeper water table would be to reduce peak concentrations and the magnitude of seasonal variations in concentration, rather than reducing the overall nitrate loading to the groundwater. The depth of a well screen below the water table is also likely to influence the nitrate nitrogen concentrations observed in a well because of the dilution that occurs as the soil drainage water mixes with the groundwater. The depth to which nitrates penetrate the saturated zone is not well understood. The total depth of the well below ground surface is a combination of the first two depth values, and it does not itself directly affect the nitrate concentration in the groundwater. However, it is the most commonly available value of the three. Accurate water level measurements are often not made at the time of sample collection, and in the case of deep wells, the water level measurements that are made may not reflect a true water table.

In the Gaza Strip, the deep aquifer is mixed with the shallow aquifer in some areas due to the screen construction of some wells which is opened between the deep and shallow aquifer. So the water quality in some wells is not representative of the quality for one aquifer but a mixture of the aquifers where the well is located. Median nitrate concentrations were plotted against total well depth in Figure (5.14). The graph shows no correlation in wells below 40 meters deep. Few shallow wells have low concentrations, and several wells less than 40 meters deep have median concentrations between 35-400 mg/L. In wells deeper than 40 meters, nitrate concentrations fall down and the median concentrations between 30-150 mg/L. However, most of the wells exceed the WHO Limit (45 mg/L).

© 2005 Tous droits réservés.

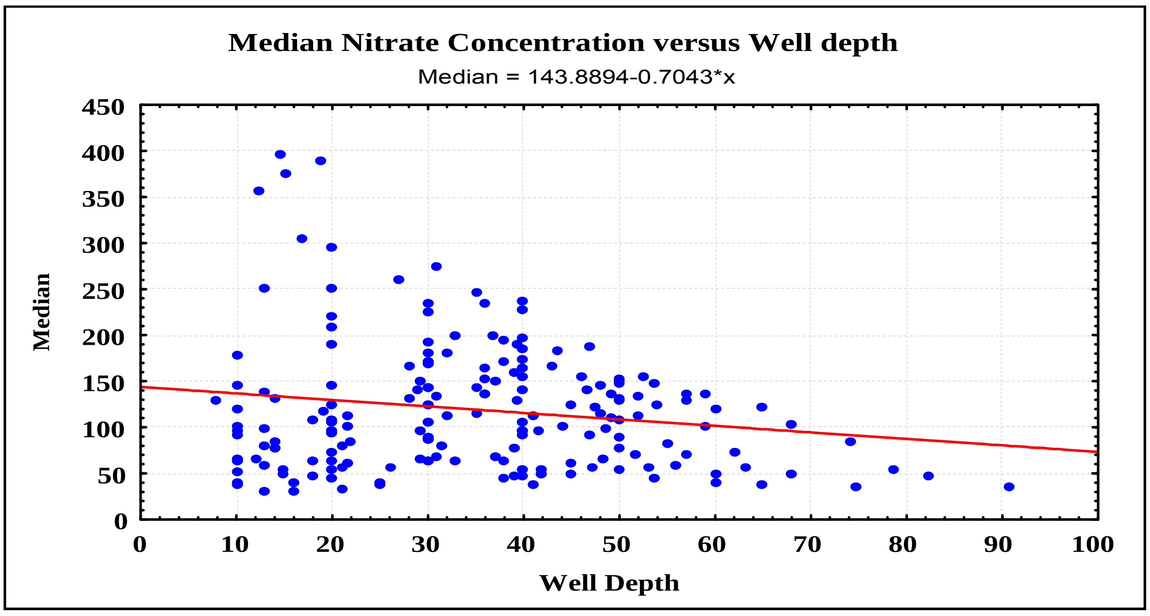

Figure (5.14): Relationship between median nitrate concentration and well depth

5.15 Application of Bivariate Regression Test

The bivariate linear regression test is a measure of linear association that investigates a straight-line relationship between independent or predictor variable and a dependent variable. In general, bivariate linear regression procedures will estimate a linear equation of the form:

Y = a + bX, where

Y is the dependent variable,

X is the independent variable, and

a and b are two constants to be estimated.

The relation between groundwater nitrate concentration and potential explanatory variables were analyzed in simple bivariate fashion, resulting in considerable unexplained variation in nitrate concentration. For example, a plot of nitrate concentration of groundwater wells versus screen length showed considerable scatter with correlation (r = 0.03396). Nitrate concentration in relation to groundwater well depth showed a decrease in concentration with an increasing of well depth in general but with very low correlation factor (r = -0.0028).

The data shows no correlation in wells below 40 meters deep. Few shallow wells have low concentrations, and several wells less than 40 meters deep have nitrate concentrations between 35-400 mg/L. In wells deeper than 40 meters, the concentrations fall down to between 30-150 mg/L. This may occur because oxidation potential decreases with depth and distance from the groundwater recharge source, and nitrate is reduced to nitrogen gas or

© 2005 Tous droits réservés.

ammonia (denitrification process) or nitrogen not penetrated to the high depth till the present. A plot of nitrate concentration in groundwater versus nitrogen loading from fertilizer, manure, and atmospheric sources showed generally increasing nitrate response to N loading with (r=0.6). Figure 5.15 shows the relation between nitrate concentration of agricultural wells and different explanatory variables.

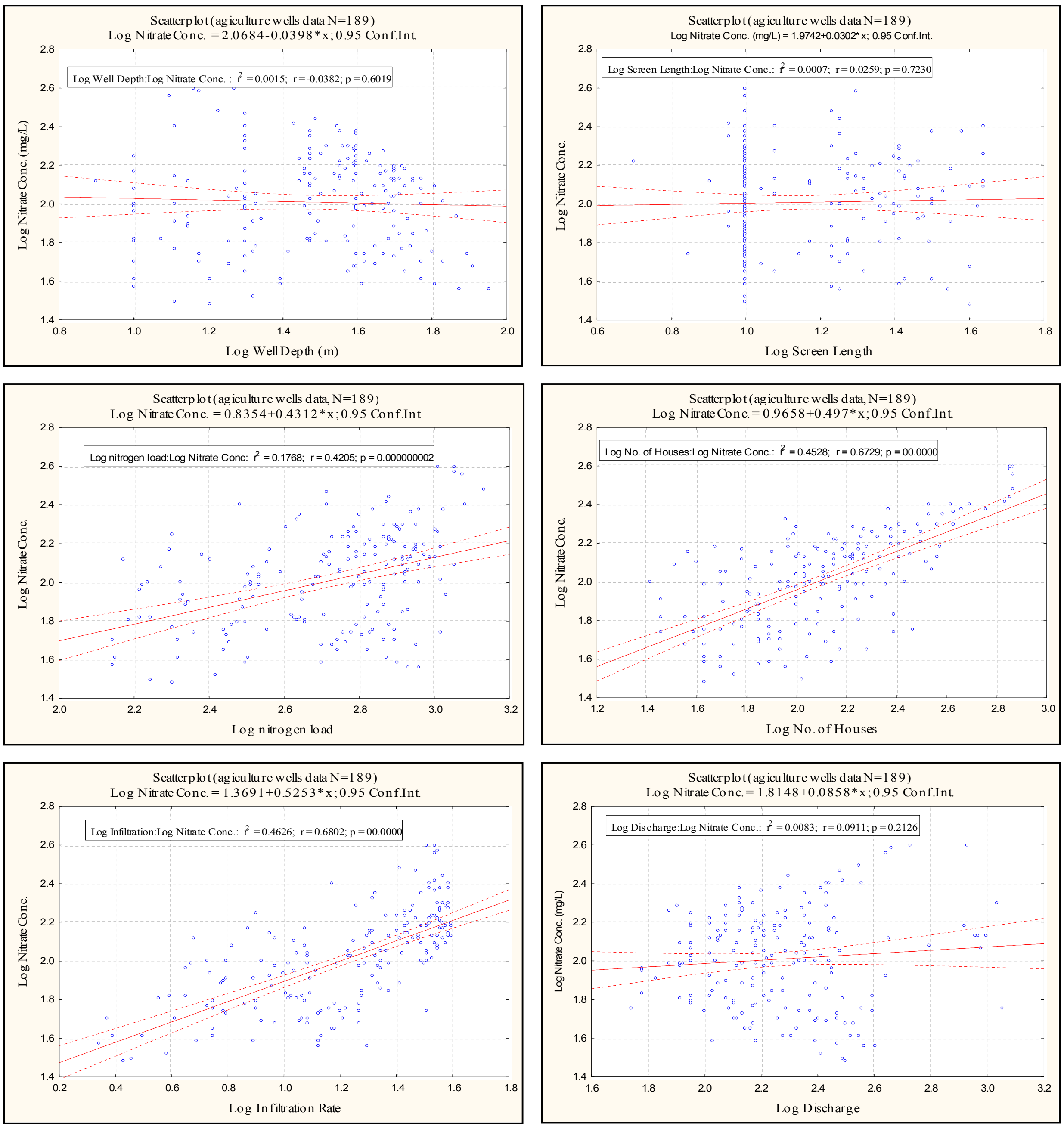

Figure (5.15): Scatter plot between nitrate concentration and explanatory variables

5.16 Multiple Regression Statistical Test

The general purpose of multiple regression (the term was first used by Pearson, 1908) is to analyze the relationship between several independent or predictor variables and a dependent

© 2005 Tous droits réservés.

or criterion variable. The computational problem that needs to be solved in multiple regression analysis is to fit a straight line (or plane in an n-dimensional space, where n is the number of independent variables) to a number of points. In the simplest case - one dependent and one independent variable - one can visualize this in a scatter plot (scatter plots are two-dimensional plots of the scores on a pair of variables). It is used as either a hypothesis testing or exploratory method.

5.16.1 The Regression Equation

A line in a two dimensional or two-variable space is defined by the equation $Y=a+b*X$; in full text: the *Y* variable can be expressed in terms of a constant (*a*) and a slope (*b*) times the *X* variable. The constant is also referred to as the intercept, and the slope as the regression coefficient or B coefficient. In the multivariate case, when there is more than one independent variable, the regression line cannot be visualized in the two dimensional space, but can be computed just as easily (via ***multiple regression***; the computations are actually quite complex). In general then, multiple regression procedures will estimate a linear equation of the form: $Y = a + b_1*X_1 + b_2*X_2 + ... + b_p*X_p$

5.16.2 Predicted and Residual Scores

The regression line expresses the best prediction of the dependent variable (*Y*), given the independent variables (*X*). However, nature is rarely (if ever) perfectly predictable, and usually there is substantial variation of the observed points around the fitted regression line. The deviation of a particular point from the regression line (its predicted value) is called the residual value.

5.16.3 Residual Variance and R-square

The smaller the variability of the residual values around the regression line relative to the overall variability, the better is our prediction. For example, if there is no relationship between the *X* and *Y* variables, then the ratio of the residual variability of the *Y* variable to the original variance is equal to 1.0. If *X* and *Y* are perfectly related then there is no residual variance and the ratio of variance would be 0.0. In most cases, the ratio would fall somewhere between these extremes, that is, between 0.0 and 1.0. One minus this ratio is referred to as R-square or the coefficient of determination. This value is immediately interpretable in the following manner. If we have an R-square of 0.4 then we know that the variability of the *Y* values around the regression line is 1-0.4 times the original variance; in other words we have explained 40% of the original variability, and are left with 60% residual

© 2005 Tous droits réservés.

variability. Ideally, we would like to explain most if not all of the original variability. The R-square value is an indicator of how well the model fits the data (e.g., an R-square close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model).

5.16.4 Correlation Coefficient R

Customarily, the degree to which two or more predictors (independent or *X* variables) are related to the dependent (*Y*) variable is expressed in the correlation coefficient R, which is the square root of R-square. In multiple regression, R can assume values between 0 and 1. To interpret the direction of the relationship between variables, one looks at the signs (plus or minus) of the regression or β coefficients. If a β coefficient is positive, then the relationship of this variable with the dependent variable is positive; if the β coefficient is negative then the relationship is negative. Of course, if the β coefficient is equal to 0 then there is no relationship between the variables.

5.16.5 Application of Multiple Regression Statistical Test

Regression analyses were performed on the data using nitrate median concentrations mg/L as the dependent (response) variable and a set of explanatory variables which are: nitrogen load, housing density in 500-m radius area surrounding wells, well depth, screen length, well discharge, and infiltration rate. Stepwise procedures were used to identify the set of explanatory variables that could best estimate the nitrate concentration in groundwater. The regression models were compared based on their R-squared values, and plots of residuals. The data set of 189 agricultural wells was divided into two sets. For model building purposes, 129 observations (70% of data set) were used. Also, 60 observations (30% of data set) were used for model validation purposes (table 5.7).

Table (5.7): Agricultural wells data sets used for model training and model validation

Wells for model training (N=129) data 2002
F/76A - F/97 - R/67 - A/76 – F/78 - S/14 - A/131 - F/141 - S/23 - F/43 - R/46 - F/131 - E/56 - S/45 – F/30A - F/156 - F/15 - F/136 - R/94 - H/14 - E/88 - S/19 - F/17 - S/55 - A/106 - F/46 - F/9 - R/90 - F/29 - F/71 - S/17 - J/143 - S/7 - F/82 - F/127 - S/43 - F/99 - F/34 - R/30 - E/53 - F/21 - F/76 - R/270 - F/22 - F/70 - E/62 - S/6 - E/35 - R/249 - S/18- G/27 - F/32 - F/143 - F/88 - S/36 - H/19 - E/65 - G/19 - H/20 - S/13 - H/16 - F/163 - F/5 - E/43 - E/149 - R/197 - F/68B - E/142 - F/52 - R/33 - R/134 - E/67 - D/9 - S/49 - E/144 - A/125 - R/23 - A/159- G/12 - A/90 - R/88 - D/71 - H/24 - R/28 - E/37 - R/162La - D/43 - A/79 - E/79 - D/6 - E/85 - E/109 - E/41 - D/58 - H/25 - R/26A - R/8B - R/20 - E/78 - A/112 - R/8A - R/160 - R/135 - A/85 - G/26 - D/55 - E/31 - G/16 - R/170 - A/93 - R/3 - R/6 - E/74 - E/110 - E/127 - E/92 - R/129 - E/73 - R/199 - R/147 - R/131 - R/185 - G/13 - R/128 - A/89 - E/158 - R/189 - R/66B - G/17
Wells for model validation (N=60)
G/24C - F/47 - S/27 - H/61 – S/9 - S/32 - S/21 - R/52 - F/128 - S/41 - F/24 - S/10 - R/42 - S/44 - F/157 - R/60 - G/18 - F/36 - F/198 - F/73 - F/30B - F/62 - F/77 - A/181 - F/148 - S/25 - E/30 - F/7 - F/35 - R/253 - R/87 - R/16A - S/34 - A/114 - H/15 - S/30 - A/58 - G/20 - H/58 - E/42 D/60 - R/162L - S/12 - R/240 - R/101 - F/37 - E/89 - E/28 - R/5 - E/107 - E/111 - E/113 - E/63 - E/94 - A/86 - R/146 - A/92 - E/102 - A/151 - F/53

© 2005 Tous droits réservés.

5.16.6 Forward and Backward Stepwise Linear regression

The R-square value was 0.9327. This value of R-square shows that 93.27% of the variation in NO_3^- can be explained by the model. At a 5% significance level and df=124, the F-value for the model was 207.2. As the p-value was less than 0.0001, the regression model was statistically significant.

Log {NO_3^-} = 1.576 + 0.060 Log (No. of Houses) + 0.735 Log (Infiltration Rate) - 0.888 Log (Well Depth) + 0.269 Log (nitrogen load)

The significance value of the F statistic is less than 0.05, which means that the variation explained by the model is not due to chance. The Variation Inflatation Factor (VIF) was less than 10 for all explanatory variables and also the Condition Index from the Collinearity Diagnostics was less than 30 for all explanatory variables. Thus multicollinearity was not a problem. The coefficient for number of houses was 0.06, which implies that with a unit increase in number of houses, there will be a 6% increase of nitrate concentration. The model result shows positive relation with the explanatory variables (no. of houses, infiltration rate, and nitrogen load) and negative relation to the well depth. That is the increase of number of houses, infiltration rate, and nitrogen load or decrease in well depth values will lead to increase of nitrate concentration according to their relative coefficients. Two variables, screen length and discharge, were excluded from the model due to their low contribution to improve R-Square.

From the scatter plot of the regression standardized residual versus predicted and observed nitrate concentration (Figure 5.16c and d) we see that there is no special pattern or trend in this distribution. They are randomly distributed about zero. From the plot of the predicted nitrate concentration versus actual concentration (Figure 5.16a), we can see that one cluster of points around the correlation line. Also, a paired t-test was done to check if any statistically significant difference existed between the actual nitrate concentration and predicted concentration for the data set. The probability of the actual t-value was less than the tabulated t-value at $\alpha = 0.05$ and df = 124. Thus, no statistically significant difference exists between the actual nitrate concentration and predicted values for the data set. Tables 5.8, 5.9, 5.10 and 5.11 show the summary results of application of forward and backward stepwise linear regression models.

© 2005 Tous droits réservés.

Table (5.8): Regression Summary (Forward stepwise) for Nitrate Conc.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.702[a]	0.493	0.489	0.170	0.493	123.398	1	127	0.000
2	0.8098[b]	0.656	0.650	0.141	0.163	59.670	1	126	0.000
3	0.9294[c]	0.864	0.861	0.089	0.208	191.002	1	125	0.000
4	0.9327	0.870	0.866	0.087	0.006	5.735	1	124	0.018

[a] Predictors: (Constant), Log No. of Houses

[b] Predictors: (Constant), Log No. of Houses, Log Infiltration

[c] Predictors: (Constant), Log No. of Houses , Log Infiltration, Log Well Depth

[d] Predictors: (Constant), Log No. of Houses , Log Infiltration , Log Well Depth, Log Nitrogen Load

Table (5.9): Regression Summary (Backward Stepwise) for Nitrate Conc.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.9335[a]	0.871	0.865	0.087	0.871	137.730	6	122	0.000
2	0.9332[b]	0.871	0.866	0.087	0.000	0.436	1	124	0.510
3	0.9327[c]	0.870	0.866	0.087	-0.001	0.983	1	125	0.323

[a] Predictors: (Constant), Log Discharge, Log Screen Length, Log Well Depth, Log No. of Houses, Log Infiltration, Log nitrogen load

[b] Predictors: (Constant), Log Screen Length, Log Well Depth, Log No. of Houses, Log Infiltration, Log nitrogen load

[c] Predictors: (Constant), Log Well Depth, Log No. of Houses, Log Infiltration, Log Nitrogen Load

Table (5.10): Regression Summary Coefficients (Forward stepwise) for Nitrate Conc.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1(Constant)	0.967	0.096		10.026	0.000	0.776	1.158		
Log No. of Houses	0.502	0.045	0.702	11.108	0.000	0.413	0.592	1.000	1.000
2(Constant)	0.814	0.082		9.902	0.000	0.651	0.977		
Log No. of Houses	0.343	0.043	0.479	8.035	0.000	0.258	0.427	0.767	1.304
Log Infiltration	0.388	0.050	0.461	7.725	0.000	0.289	0.488	0.767	1.304
3(Constant)	1.939	0.097		20.083	0.000	1.748	2.131		
Log No. of Houses	0.079	0.033	0.111	2.405	0.018	0.014	0.145	0.511	1.956
Log Infiltration	0.844	0.046	1.002	18.440	0.000	0.753	0.935	0.369	2.709
Log Well Depth	-0.758	0.055	-0.666	-13.82	0.000	-0.867	-0.649	0.469	2.133
4(Constant)	1.576	0.179		8.797	0.000	1.221	1.930		
Log No. of Houses	0.060	0.033	0.084	1.788	0.076	-0.006	0.126	0.480	2.082
Log Infiltration	0.735	0.064	0.872	11.477	0.000	0.608	0.861	0.182	5.501
Log Well Depth	-0.888	0.076	-0.780	-11.62	0.000	-1.039	-0.737	0.233	4.294
Log nitrogen load	0.269	0.112	0.235	2.395	0.018	0.047	0.490	0.109	9.156

© 2005 Tous droits réservés.

Table (5.11): Regression Summary Coefficients (Backward Stepwise); for Nitrate Conc.

Model	Unstandardized		Standardized	t	Sig.	95% Confidence Interval		Collinearity	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1(Constant)	1.547	0.184		8.396	0.000	1.182	1.912		
Log Well Depth	-0.898	0.077	-0.789	-11.594	0.000	-1.051	-0.744	0.228	4.390
Log Screen Length	0.037	0.039	0.032	0.968	0.335	-0.039	0.114	0.982	1.019
Log nitrogen load	0.290	0.116	0.254	2.499	0.014	0.060	0.520	0.102	9.776
Log No. of Houses	0.062	0.034	0.087	1.800	0.074	-0.006	0.130	0.454	2.202
Log Infiltration	0.722	0.066	0.857	10.903	0.000	0.591	0.853	0.171	5.861
Log Discharge	-0.021	0.032	-0.023	-0.660	0.510	-0.084	0.042	0.845	1.184
2(Constant)	1.537	0.183		8.390	0.000	1.175	1.900		
Log Well Depth	-0.890	0.076	-0.782	-11.648	0.000	-1.041	-0.739	0.233	4.298
Log Screen Length	0.038	0.039	0.032	0.991	0.323	-0.038	0.115	0.982	1.018
Log nitrogen load	0.271	0.112	0.237	2.416	0.017	0.049	0.493	0.109	9.160
Log No. of Houses	0.057	0.034	0.080	1.700	0.092	-0.009	0.123	0.477	2.096
Log Infiltration	0.733	0.064	0.870	11.443	0.000	0.606	0.860	0.182	5.505
3(Constant)	1.576	0.179		8.797	0.000	1.221	1.930		
Log Well Depth	-0.888	0.076	-0.780	-11.623	0.000	-1.039	-0.737	0.233	4.294
Log nitrogen load	0.269	0.112	0.235	2.395	0.018	0.047	0.490	0.109	9.156
Log No. of Houses	0.060	0.033	0.084	1.788	0.076	-0.006	0.126	0.480	2.082
Log Infiltration	0.735	0.064	0.872	11.477	0.000	0.608	0.861	0.182	5.501

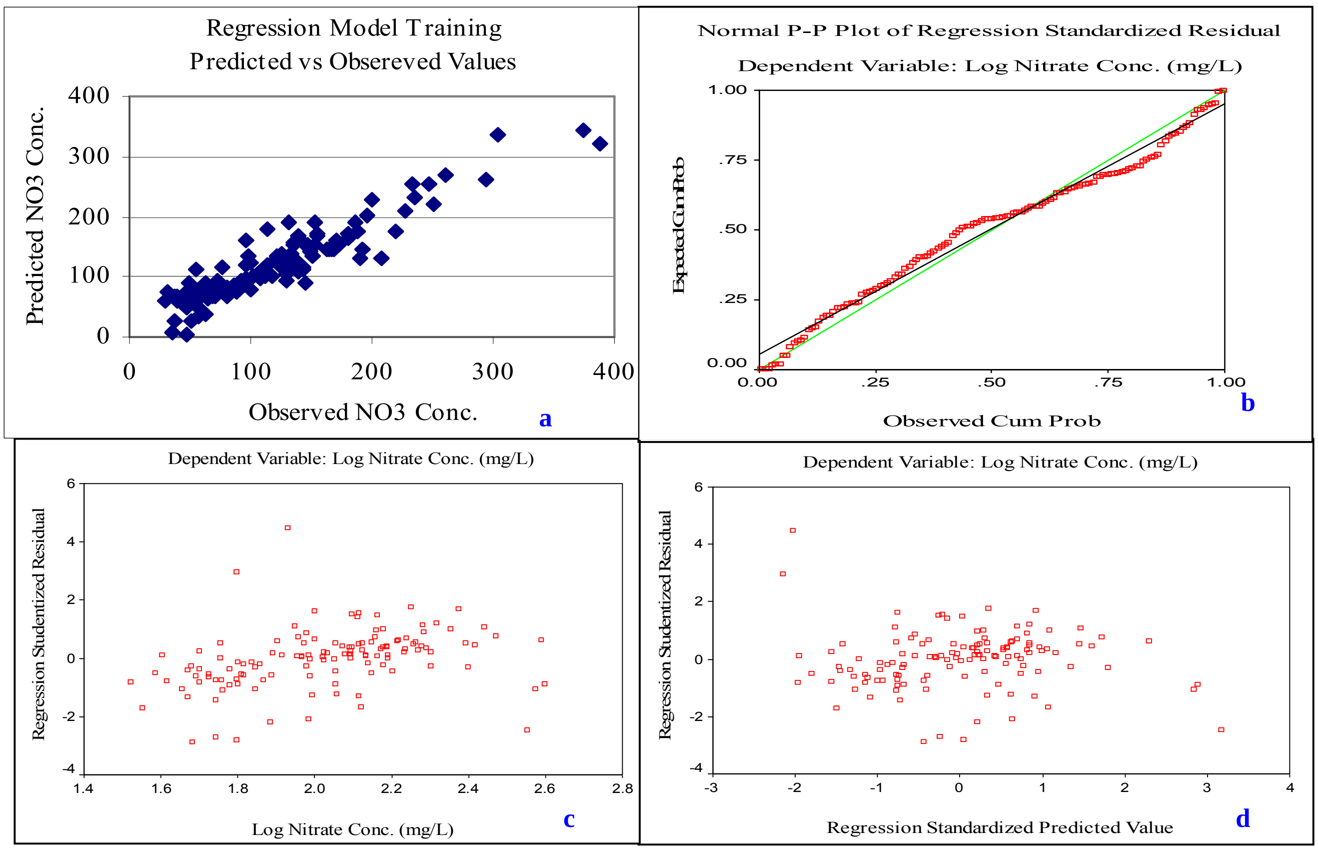

Figure (5.16): Stepwise Linear regression result

© 2005 Tous droits réservés.

5.16.7 Model Validation Using Validation Data Set

For model validation purposes, 60 observations (30% of data set) were used. The mean sum squared errors (mean SSE) calculated for the validation data set and compared with the mean SSE of the training data set. The mean SSE for the validation data set is less than that of the training data set, implying that the predictions are better for the validation data set than the training data set. Plot of the predicted nitrate concentration versus observed concentration for the validation data set (Figure 5.17) shows one cluster of points around the correlation line with straightforward relationship with R-square 0.9525. A paired t-test was done to check if any statistically significant difference between the observed nitrate concentration and predicted concentration for the validation data set. The probability of the actual t-value was less than the tabulated t-value at α = 0.05. Thus, no statistically significant difference exists between the observed nitrate concentration and predicted concentration for the validation data set.

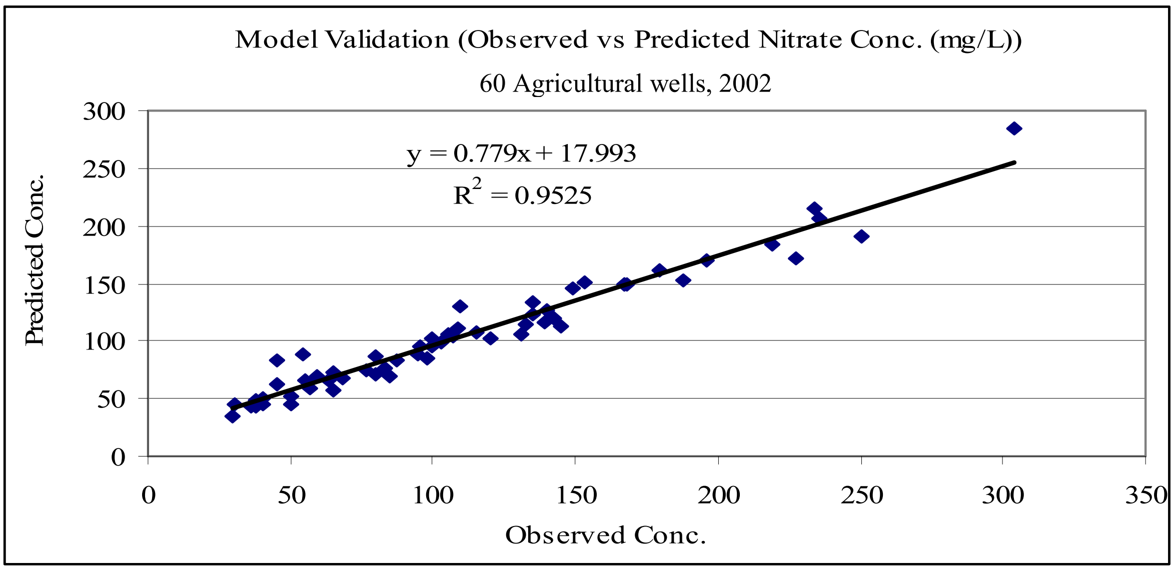

Figure (5.17): Observed vs. predicted nitrate concentration for model validation

5.17 Artificial Neural Network Modeling

In the previous section, multivariate techniques have been used to investigate how environment variables are related to explain the dependent variable, including several methods of univariate, bivariate or multivariate linear regressions. Most statistical methods, used, assume that relationships are smooth, continuous and either linear or simply lognormal. As nitrate concentration and environment parameters show nonlinear or nonmonotonous relationships, the use of techniques based on correlation coefficients is often inappropriate.

As a neural network provides a non-linear function mapping of a set of input variables into the corresponding network output, without the requirement of having to specify the actual

© 2005 Tous droits réservés.

mathematical form of the relation between the input and output variables, it has the versatility for modelling a wide range of complex non-linear phenomena. ANNs have been used to model groundwater, assess quality of water, forecast precipitation, predict stream-flow, and support other hydrologic applications. Leket et al., 1999 applied ANNs to predict the concentration of nitrogen in streams from watershed features. Wen and Lee, 1998 addressed the multi-objective optimization of water pollution control and river pollution planning, for the Tou-Chen river basin in Taiwan. Rogers and Dowla, 1994 employed an ANN, trained by a solute transport model, to perform optimization of groundwater remediation.

5.18 Background of artificial neural network

Neural networks are applicable in virtually every situation in which a relationship between the predictor variables (independents, inputs) and predicted variables (dependents, outputs) exists, even when that relationship is very complex and not easy to articulate in the usual terms of "correlations" or "differences between groups." An artificial neural network (ANN) is a biologically inspired computational system that relies on the collective behaviour of a large number of processing elements (called neurons), which are interconnected in some information-passing settings (Hassan, 2001). The basic idea of an ANN is that the network learns from the input data and the associated output data, which is commonly known as the generalization ability of the ANN.

5.19 One-neuron model

By starting with a one-neuron model, it may be much easier to understand the neural network structure. A neuron is defined as an information-processing unit that is fundamental to the operation of a neural network. Fig. 5.18 shows a simple one-neuron model to illustrate the neural network structure.

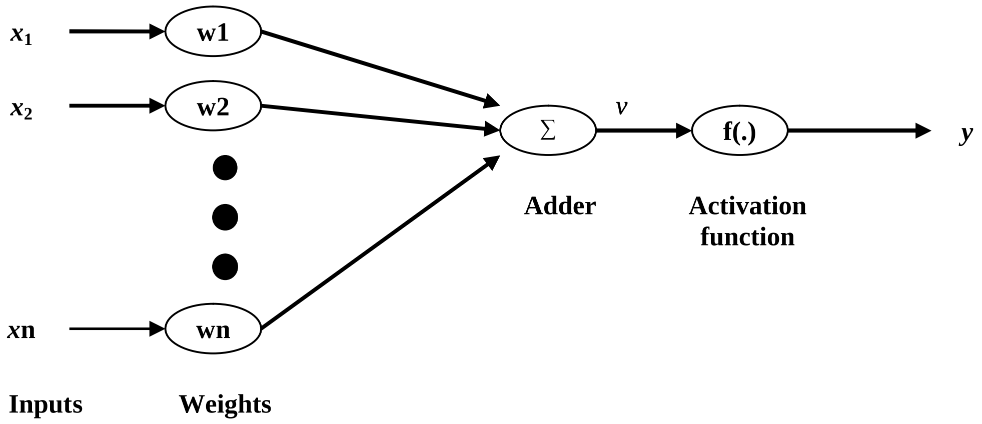

Figure (5.18): A one-neuron model structure

© 2005 Tous droits réservés.

As shown in figure 5.18, there are three basic elements in a neural network model given as follows:

(a) A set of connecting links, 'w', each of which is characterized by a weight of its own. The weights on the connections from the input $x_1, x_2, \ldots, x_n$ to the neuron y are w_1; $w_2, \ldots, w_n$; respectively.

(b) An adder, '∑' for summing the weighted input signals; the operation constitutes a linear combiner, 'v':

$$v = w_1 x_1 + w_2 x_2 + \ldots + w_n x_n$$

(c) An activation function, F(.), for limiting the amplitude of the output of a neuron. The output from the neuron model can be described by

$$y = F(v)$$

There are several types of activation functions. Examples of activation functions related to this study are given below:

(i) Linear function: $F(v) = v$

(ii) Non-linear sigmoid function: The sigmoid function is usually used as the activation function because of the convenient mathematical expression of its derivation. The sigmoid function is expressed as following: $F(v) = 1/(1 + \exp(-av))$

where 'v' is the input, F(v) is the output and 'a' is the slope parameter (Hassoun, 1995). It can be derived that F'(v) = F(v)(1-F(v)). This function allows simplification in deriving training algorithms. The graph of sigmoid function is as shown as in figure 5.19.

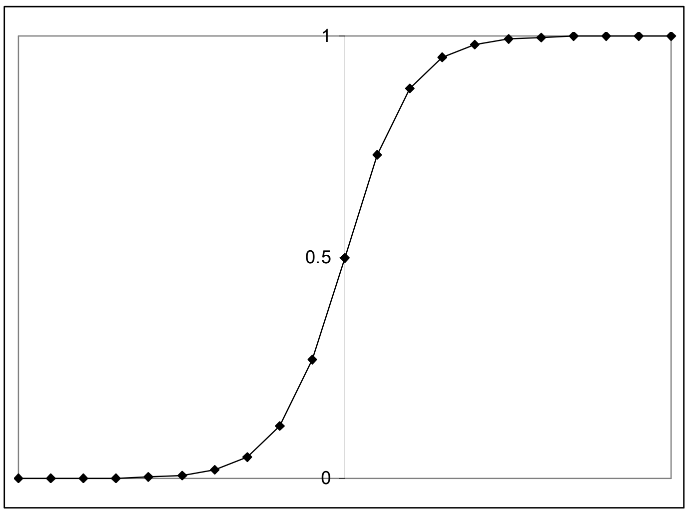

Figure (5.19): Sigmoid transfer function

© 2005 Tous droits réservés.

5.20 Solving Regression Problems by Using ANN

In regression problems, the objective is to estimate the value of a continuous output variable, given the known input variables. Regression problems can be solved using the following network types MLP, RBF, GRNN, and Linear. The performance of a regression network can be examined in a number of ways:

- The output of the network for each case can be submitted to the network. If part of the data set, the residual errors can also be generated.
- Summary statistics such as the mean and standard deviation of both the training data values and the prediction error, the Pearson-R correlation coefficient between the network's prediction and the observed values. A view of the response surface can be generated. The network's actual response surface is, of course, constructed in (N+1) dimensions, where N is the number of input units, and the last dimension plots the height.

5.21 Functions

The Neural Networks model we used is supported by two main post synaptic potential (PSP) functions (Linear and Radial). Linear PSP units perform a weighted sum of their inputs, biased by the threshold value. In vector terminology, this is the dot product of the weight vector with the input vector, plus a bias value. Linear PSP units have equal output values along hyperplanes in pattern space. Radial PSP units calculate the square of the distance between the two points in N dimensional space (where N is the number of inputs) represented by the input pattern vector and the unit's weight vector. Radial PSP units have equal output values lying on hyperspheres in pattern space. The squared distance calculated by the radial unit is multiplied by the threshold (which is, therefore, actually a deviation value in radial units) to produce the input value of the unit. Linear PSP units were used in multilayer perceptron and linear networks, and in the final layers of radial basis function, and regression networks. Radial units were used in the second layer of radial basis function, and regression networks.

5.22 Cross verification

For building our models we used the cross verification option to generalize and to validate the network's performance against the third set of data which has not been used in the training process at all - not even for verification of results. This is the test set.

© 2005 Tous droits réservés.

5.23 Linear Networks

Linear networks have only two layers: an input and output layer, the latter having linear PSP and activation function. Many problems cannot be solved (or solved well) by linear techniques; however, many others can, and it is a poor practice to neglect a simple technique in favour of more complex ones without comparison. A linear network was trained as a standard of comparison for the more complex non-linear one.

5.24 Radial Basis Function Network (RBF)

Like the back-propagation network, the RBF neural network has a feed-forward architecture, which consists of three layers: one input layer, one hidden layer and one output layer with a number of neurons in each layer. However, the structure of an RBF network is one of self-organized characteristics, which allow for adaptive determination of the hidden neurons during training of the network (Zhang and Kushwaha, 1999).

Each input neuron is completely connected to all hidden neurons, and hidden neurons and output neurons are also interconnected to each other by a set of weights. Information fed into the network through input neurons is transmitted to hidden neurons. The radial layer has exponential activation functions; and the output layer has linear units with linear activation functions (Haykin, 1994; Bishop, 1995). In a radial basis function network (Broomhead and Lowe, 1988; Moody and Darkin, 1989; Haykin, 1994) units respond (non-linearly) to the distance of points from the centre represented by the radial unit. The response surface of a single radial unit is therefore a Gaussian (bell-shaped) function, peaked at the centre, and descending outwards.

5.25 Generalized Regression Neural Networks (GRNNs)

Generalized regression neural networks, or GRNNs have exactly four layers: input, a layer of radial centres, a layer of regression units, and output. The radial layer units represent the centres of clusters of known training data. This layer was trained by a clustering algorithm such as sub-sampling. The regression layer contains linear units.

5.26 Multilayer Perceptron

Multilayer Perceptrons is perhaps the most popular network architecture in use today. The units each perform a biased weighted sum of their inputs and pass this activation level through a transfer function to produce their output, and the units are arranged in a layered feed-forward topology. The network thus has a simple interpretation as a form of input-output

© 2005 Tous droits réservés.

model, with the weights and thresholds (biases) the free parameters of the model. Multilayer Perceptrons (MLPs) use a linear PSP function, and a (usually) non-linear activation (transformation) function.

Due to the advantages of ANNs in modelling, they have become extremely popular for the prediction and forecasting of water resources variables. As shown in Fig. 5.20, three-layered feed forward neural networks (FFNNs), which have been used in this research for the prediction of nitrate concentration in groundwater wells, provide a general framework for representing nonlinear functional mapping between a set of input and output variables. Three-layered FFNNs are based on a linear combination of the input variables, which are transformed by a nonlinear activation function. The explicit expression for an output value of network model is given by:

$$\boxed{\hat{y}_k = f_o\left(\sum_{j=1}^{M} w_{kj} \bullet f_h\left(\sum_{i=1}^{N} w_{ji} x_i + w_{jo}\right) + w_{ko}\right)}$$

where w_{ji} is a weight in the hidden layer connecting the ith neuron in the input layer and the jth neuron in the hidden layer, w_{jo} is the bias for the jth hidden neuron, f_h is the activation function of the hidden neuron, w_{kj} is a weight in the output layer connecting the jth neuron in the hidden layer and the kth neuron in the output layer, w_{ko} is the bias for the kth output neuron, and f_o is the activation function for the output neuron. The weights are different in the hidden and output layer, and their values can be changed during the process of network training.

5.26.1 Backpropagation Training Algorithm for Three-Layered Neural Networks

Because there are no physical rules between inputs and outputs in designing ANNs, the relationship of the available input variables and output variables is generated by the training process. In this study, the process of training ANNs is accomplished by a backpropagation algorithm, as shown in Fig. (5.20), which has been applied successfully to solve difficult and diverse problems. The weights are adjusted so as to make the actual response ($\hat{y}_k$) of the network closer to the desired response (y_k). The objective of the backpropagation training process is to adjust the weights of the network to minimize the sum of square errors of the network as seen in the next equation, which approximates the model outputs to the target values with a selected error goal.

$$\boxed{E(n) = \frac{1}{2}\sum_{k=1}^{k}\left[y_k(n) - \hat{y}_k(n)\right]^2}$$

© 2005 Tous droits réservés.

where $y_k(n)$ is the desired target responses and $\hat{y}_k$ is the actual response of the network for the *k*th neuron at the *n*th iteration. The error function is used in training the network, and in reporting the error. The error function used can have a profound effect on the performance of training algorithms (Bishop, 1995). This is the standard error function used in neural network training, and is certainly the most appropriate for most regression problems.

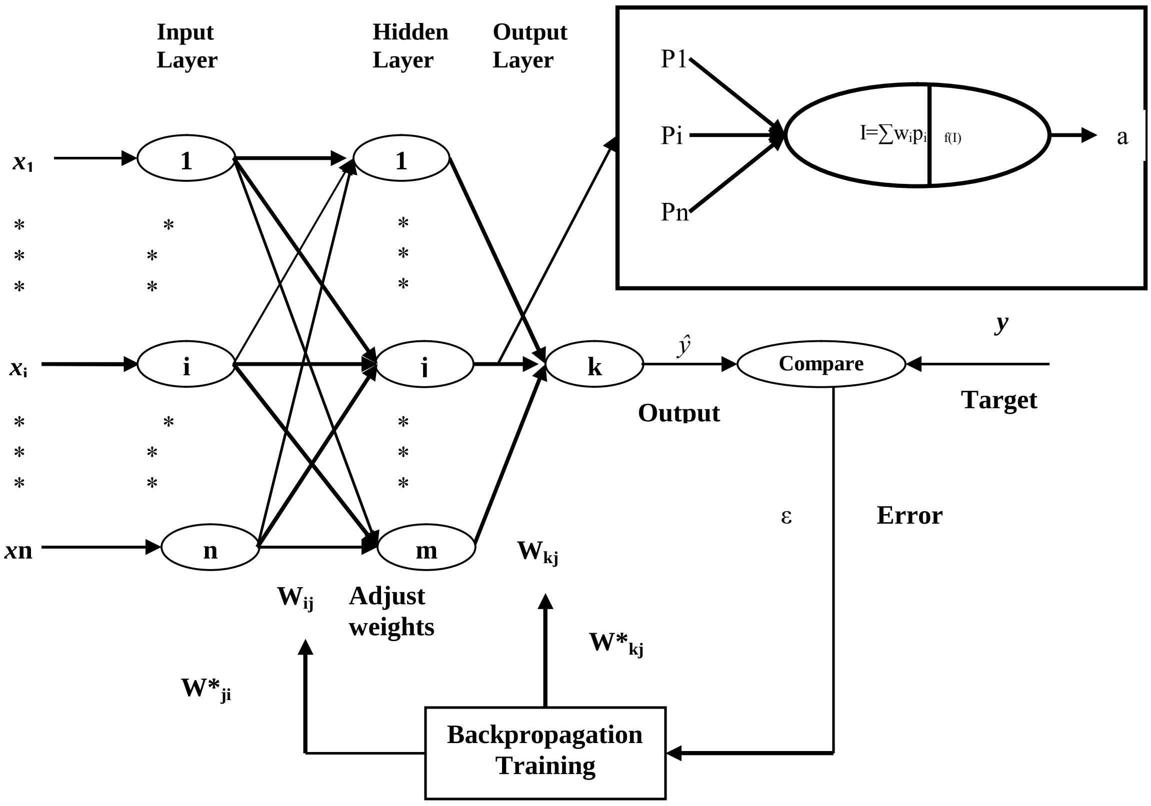

Figure (5.20): Typical three layered feed forward neural networks with a backpropagation training algorithm

5.27 Training with three-layer feed-forward back-propagation network

In this research, we used the standard three-layer feed-forward back-propagation network [MLP] with a non-linear differentiable log-sigmoid transfer function in the hidden layer. In parallel to the MLP network, we used also the GRNN, Linear and RBF networks for the comparison and to find the optimal network for the prediction of nitrate concentration in Groundwater.

As mentioned by (Florentina M. et., 1999), the number of neurons in the hidden layers cannot be achieved from a universal formula but in this research for running the MLP network we used the formula recommended by Fletcher and Goss, 1993 to the estimate number of

© 2005 Tous droits réservés.

neurons, to prevent over-fitting. Fletcher and Goss suggested that the appropriate number of neurons in a hidden layer ranges from $(2n^{1/2}+m)$ to (2n+1), where n is the number of input nodes and m is the number of output nodes. Running the model shows an increase of the training time as the number of hidden neurons increases. We applied a trial and error approach to select the best ANN architecture.

A sensitivity analysis was conducted in this study to examine the effect of the network size on the model performance. In our case we started to learn the model with one neuron up to ten, until the optimal result is achieved. For different network size, the network was trained using the first data set, and then it was validated with the second data set. ANNs were trained by using the backpropagation algorithm with an initial learning rate of 0.01 and momentum of 0.3 to reach an error goal of 0.0. The conjugate gradient descent method was used also to improve the network training and performance.

Two types of searching were chosen in building the model. The first search was done by using a quick searching (a minimal search) because this way gives a very rapid feel for what neural networks may be able to achieve with a data set. After several searching we tried to do the medium search to find the optimal neural networks. Tables 5.12 and 5.13 show the result of different searching methods for the optimal network found. Also the tables show the differences between using of MLP, GRNN, Linear and RBF models. The optimal network size was selected from the one which resulted in minimum error and best correlation in the verification data set. The test error was used to diagnose training problems and as a final check of the performance of the network.

The MLP network showed the best result in each searching trials to find the optimal network. By using the backpropagation algorithm the optimal network discovered during that run was selected (for "best" and "lowest verification error") and was found on the 50th epoch. The Conjugate Gradient Descent algorithm was also used, and the best network discovered during that run was selected and was found on the 213th epoch.

In the model-training phase, model predictions of nitrate calculated in terms of well depth, screen length, nitrogen load, infiltration rate, well discharge, and housing density were compared to the observations. The parameters of weights in the model were then adjusted until the root mean square (RMS) error between model predictions of nitrate and the

© 2005 Tous droits réservés.

observations was reduced to an acceptable level. In model validation phase, the trained matrices of weight were directly used to calculate nitrate concentration from the above mentioned input variables. The neural network model simulation required no iterative computation once the model was satisfactorily trained. Beside the observed-predicted plots, the root mean square errors are used for the validation of the models in this work as it is one of the most common measures for the quality of model and performance.

During the training period, the model fits well with observations showing a correlation coefficient above 0.96. Compared to the validation data set, the correlation coefficients range between 0.96 to 0.98 and the RMS error is between 7.2407 and 17.0396 depending on the number of neurons used in the model. The network with a four neuron hidden layer was found to have the best performance with the best correlation (R= 0.9835) and error (7.2407). The comparison of the nitrate concentration from model predictions and observations is presented in figures 5.21 for the 4 neuron network. The model predictions of nitrate matched well with the observations in training and verification sets. The model predictions also show reasonable correlation value (0.92) with test data set.

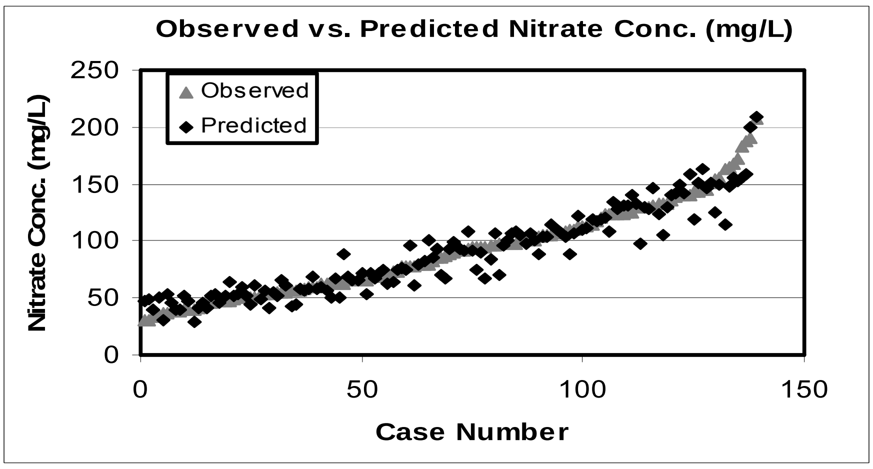

Figure (5.21): Actual vs. predicted nitrate concentration by using the three-layer feed-forward back-propagation network

Table (5.12): Quick search for the best network

Network Index	Network type	Inputs variables	Hidden layer	Hidden layer (2)	Training error	Verification error	Training Performance	Verification Performance	Training
150 *	MLP	6	4	-	9.014	7.241	0.253	0.188	BP50,CG225b
142	RBF	6	14	-	11.239	10.381	0.315	0.272	KM,KN,PI
139	Linear	6	-	-	12.714	12.361	0.356	0.322	PI
138	GRNN	6	70	2	3.318	14.397	0.093	0.368	SS

* The optimal network

© 2005 Tous droits réservés.

Table (5.13): Medium search for an optimal network

Network Index	Network type	Inputs variables	Hidden layer	Hidden layer (2)	Training error	Verification error	Training Performance	Verification Performance	Training
160 *	MLP	6	4	-	8.794	8.432	0.246	0.216	BP50,CG326b
142	RBF	6	14	-	11.239	10.381	0.315	0.272	KM,KN,PI
139	Linear	6	-	-	12.714	12.361	0.356	0.322	PI
138	GRNN	6	70	2	3.318	14.397	0.093	0.369	SS

* The optimal network

5.28 Sensitivity analysis

In this research we conducted a sensitivity analysis on the inputs for each neural network model in order to find which input variables are considered most important by that particular neural network. Sensitivity analyses can give important insights into the usefulness of individual variables. It often identifies variables that can be safely ignored in subsequent analysis, and key variables that must always be retained. Sensitivity analysis rates variables according to the deterioration in modelling performance that occurs if the variable is no longer available to the model.

The sensitivity analysis of the best model we have through running different neural network trials is shown in table 5.14. The analysis is reported separately for training and verification subsets and in three rows – the Rank, Error, and Ratio. The basic sensitivity figure is the Error, which indicates the performance of the network if that variable is "unavailable". Important variables have a high error, indicating that the network performance deteriorates badly if they are not present. The “Ratio” reports the ratio between the Error and the Baseline Error (i.e. the error of the network if all variables are "available"). A ratio of 1.0 indicates that the variable has no positive effect on the model at all, and can definitely be removed. A ratio below 1.0 indicates that the model actually performs better if the variable is removed. The Rank simply lists the variables in order of importance (i.e. order of descending Error), and is provided for convenience in interpreting the sensitivities.

From the error figures in the training data subset, it is seen that the model will perform badly if the infiltration rate is unavailable followed by nitrogen load, housing density, screen length, well depth then discharge. Also there is conformity in both training and verification subset in the importance of infiltration rate and nitrogen load. The data shows that the well depth variable has more sensitivity in the verification subset than the training. The groundwater wells discharge is the less important in the two subsets but there is no need to remove it since

© 2005 Tous droits réservés.

the ratio in the two subsets is more than one. However, it is clear from the sensitivity figures that all variables have a significant importance in building the neural network model.

Table (5.14): Sensitivity analysis for the explanatory variables in the training and verification subsets

Data Subsets		Well	Screen	Nitrogen	Houses	Infiltration	Discharge
Training	Rank	5	4	2	3	1	6
	Error	20.969	23.492	34.764	24.284	55.823	9.659
	Ratio	2.326	2.606	3.857	2.694	6.193	1.072
Verification	Rank	3	4	2	5	1	6
	Error	28.803	22.372	30.671	20.229	57.016	8.128
	Ratio	3.978	3.090	4.236	2.794	7.874	1.122

5.29 Conclusions

Nitrate is an important factor for drinking water quality. We have presented in this study a successful application of multiple regression and neural network models to simulate groundwater contamination by nitrate responding to multiple explanatory variables of the Gaza Strip aquifer.

Application of stepwise forward and backward multiple regression model showed no statistically significant difference between predicted and observed nitrate concentration with RMS=0.9327. The model includes four explanatory variables (nitrogen load, housing density in 500-m radius area surrounding wells, water table, and infiltration rate), that have significant effects on model prediction. Two explanatory variables were excluded from the model since they have no significant effect on the model prediction.

The Multilayer Perceptrons (MLP), Radial Basis Function **(**RBF), Generalized Regression Neural Network (GRNN), and Linear Networks were used in the ANN model. The best network found to simulate nitrate was the MLP network with six input nodes and four hidden nodes. The input variables are: nitrogen load, housing density in 500-m radius area surrounding wells, water table, well discharge, and infiltration rate. The best network found with good performance is MLP (regression ratio 0.2158, correlation 0.9773, and error 8.4322).

Results indicate that the back-propagation neural network model can be trained to provide satisfactory estimations of nitrate concentration responding to the changes of: nitrogen load, housing density in 500-m radius area surrounding wells, screen length, water table, well

© 2005 Tous droits réservés.

discharge, and infiltration rate. On other hand, the Radial Basis Function **(**RBF), Generalized Regression Neural Network (GRNN), and Linear Networks show lower performance than the MLP network. The development of a neural network model only requires field observations of nitrate data, and the implementation of a neural network model requires no iterative computation. Therefore, a neural network can be developed with much less effort than that required for the development of hydrodynamic models.

Bivariate statistical test was used. The bivariate test showed week correlation between the input variables and nitrate concentration to provide reasonable predictions. The test, resulted in a considerable unexplained variation in nitrate concentration and the explanatory variables analyzed. ANN and regression models which have been built to predict nitrate concentration in groundwater as a function of different explanatory variables are come off the planed study. Based on ANN and regression models, groundwater contamination by nitrate depends not on any single factor but on the combination of them. Infiltration rate followed by nitrogen load show the most significant factors affecting the prediction of nitrate concentration in the two models.

The R-square values for neural networks are higher than the R-square in the regression model. This is the first evidence showing that the ANN models work in better performance than the regression models. The Mean Absolute Error (MAE) was calculated to compare the predictions of regression and neural networks. For both data sets, MAE is less for neural network than for regression, implying that the predictions of neural networks are better.

The neural network model can be easily used as a basis for the development of predictive tools for engineers to assess the potential impact of land use activities and hydrological factors on the nitrate contamination of groundwater. Also the Artificial Neural Network model can be used as a management tool for the prediction of nitrate contamination in groundwater to be used by the water sector managers and planners as a basis for an efficient management of water resources and pollution prevention.

© 2005 Tous droits réservés.

Chapter 6

Effect of Urbanization and Hydrological Factors on Groundwater Chemical Quality

6.1 Objective

To develop options for the integrated management of urban groundwater quality in the Gaza Strip. The study specifically aims:

1. To suggest explanations for the variation in groundwater chemical quality in the Gaza Strip, on the basis of, amongst other factors, urbanization and hydrological factors.
2. To identify point and non-point sources of groundwater contamination.
3. To model the relationship between urbanization and hydrological factors and the chemical contaminations of urban groundwater.
4. To recommend options for the control of pollution of groundwater in the Gaza Strip.

6.2 Introduction

Urban groundwater (or groundwater that underlies urban areas) is a distinct sub-domain of hydrogeology (Lerner, 1996). In contrast to rural areas, urban groundwater shows some specific features. For example, the recharge of urban groundwater is heavily affected by extensive sealing of surfaces, leaking water mains, sewers, and storm water recharge. Beside this, urban groundwater is also affected by geotechnical interactions such as deep basements. The quality of urban groundwater is mainly affected by input of the municipality of urban features. Urban groundwater quality is strongly influenced by population density, water shortages, and pollution (Hongguage et al., 2003). The tremendous speed of the population growth in many cities of the developing countries, often doubling in only 10-20 years, is much faster than the city authorities can ever manage to run. Growing cities often destroy their own water sources, while the new sources further and further away rapidly tend to get insurmountably costly. While the population load doubles, the pollution load tends to increase 5-10 times, even more in some cases. This is due to the tremendous possible sources of pollution for urban groundwater contamination when the population density increases.

© 2005 Tous droits réservés.

Numerous publications over the world have discussed the chemistry of "mature" urban groundwater (Eckhardt, D.A.V., 1995; Bruce and McMahon, 1996; Custodio, 1997; Eiswith and Hotzl, 1997). Land use is suggested to influence groundwater quality because the land use commonly influences the contaminants flow in the surface soil. However, contamination of groundwater with chemicals has been reported in all areas of the Gaza Strip and within all land uses (Almahallawi kh, et. al, 2001). The most severely contaminated groundwater that is reported in urban areas are those associated with domestic and industrial wastewater, and landfills. Such pollution sources are abundant in the Gaza Strip and groundwater quality may be largely affected by it. However, to overcome these problems related to the urban water pollution, effective control of water pollution is an important part for protecting the urban environment.

6.3. Materials and methods

6.3.1 Data origin and collection

Water quality data were collected from several sources, primarily from the Palestinian Water Authority. Many problems and errors were found in some of the data sets; for example, duplications due to incomplete information in one of the duplicate records, mistyped numbers, and incorrect locations or depths. Errors were corrected to the extent possible by referring to the original printed version of the data in publications if they could be found. The data collected were used to construct the database for 87 domestic groundwater wells in the Gaza Governorate. The data includes: total well depth, depth to initial water level, depth to the screen level, well location, well screen length, physical and chemical characteristics of groundwater wells for the reference year 2002, population density in 250m and 500m radius circle, rainfall intensity, well discharge (m3/d), and distance of the well from seashore. Digitized land use data were available in geographic information system (GIS) format for the Gaza Governorates areas. Land use map were developed by the Ministry of Planning in 1996 and modified by the Environmental Quality Authority 1998.

The information on land use plan and urbanization in the Gaza Strip area is cited from the report on the regional plan for Gaza Governorates (MOPIC, 1998). Population density is used as a measure of urbanization based on census density data and geographic information system (GIS). It is calculated as the number of people per unit area in a given region. The population density based on population data from 2002 and distance of the well from seashore are calculated from the existed GIS data and transferred to the study data base file.

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

6.3.2 Water chemistry data and analytical methods

The water samples were analyzed for the major ion-chemistry, employing the standard methods (APHA, 1992): hydrogen ion concentration (pH) and electrical conductivity (EC) were measured using pH and EC meters. Total dissolved solids (TDS) were analyzed by evaporation method at 105 C^o and dried at 180 C^o. Carbonate (CO_3^-) and bicarbonate (HCO_3^-) were estimated by titrating with HCL. Total hardness (TH) as $CaCO_3$ and calcium (Ca^{2+}) were analyzed by titration method with standard EDTA. Magnesium (Mg^{2+}) was calculated from total hardness and Ca^{2+}. Sodium (Na^+) and potassium (K^+) were measured by a flame photometer. Chloride (CL^-) was estimated by standard AgNO3 titration. Sulphate (SO_4^{2-}), Nitrate (NO_3^-) and Fluoride (F^-) were analyzed using a spectrophotometer. All parameters are expressed in milligrams per litter (mg/L), except pH (Units) and EC (µS/cm). The analytical precision for the measurements of cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and anions (CL^-, SO_4^{2-}, NO_3^- , HCO_3^-) is indicated by the ionic balance error, which is observed to be within the stipulated limit of ±5%.

6.3.3 Analysis tools and methods

In this study the relations between groundwater chemistry and potential explanatory variables were analyzed in simple bivariate fashion statistical analysis to investigate the characteristics of water chemistry. STATISTICA software (StatSoft, Inc. version 6) has been used for the bivariate statistical analysis. The p-values for testing the results of statistical analyses were calculated at the 95% significance level. Different types of artificial neural networks were applied. This study introduces the back-propagation feed-forward multilayer perceptrons (MLP) and other common types of ANNs models for the purposes of comparison. These types include Radial Basis Functions (RBF), General Regression Neural Networks (GRNN), and Linear relation. Details about these ANN types can be found in the literature (see Haykin, 1994; Bishop, 1995; Broomhead and Lowe, 1988; Moody and Darkin, 1989; Zhang and Kushwaha, 1999). The Intelligent Problem Solver (IPS) under STATISTICA Software was used for building the ANN models. Figure 6.1 shows the methodology and procedures implemented in this chapter.

© 2005 Tous droits réservés.

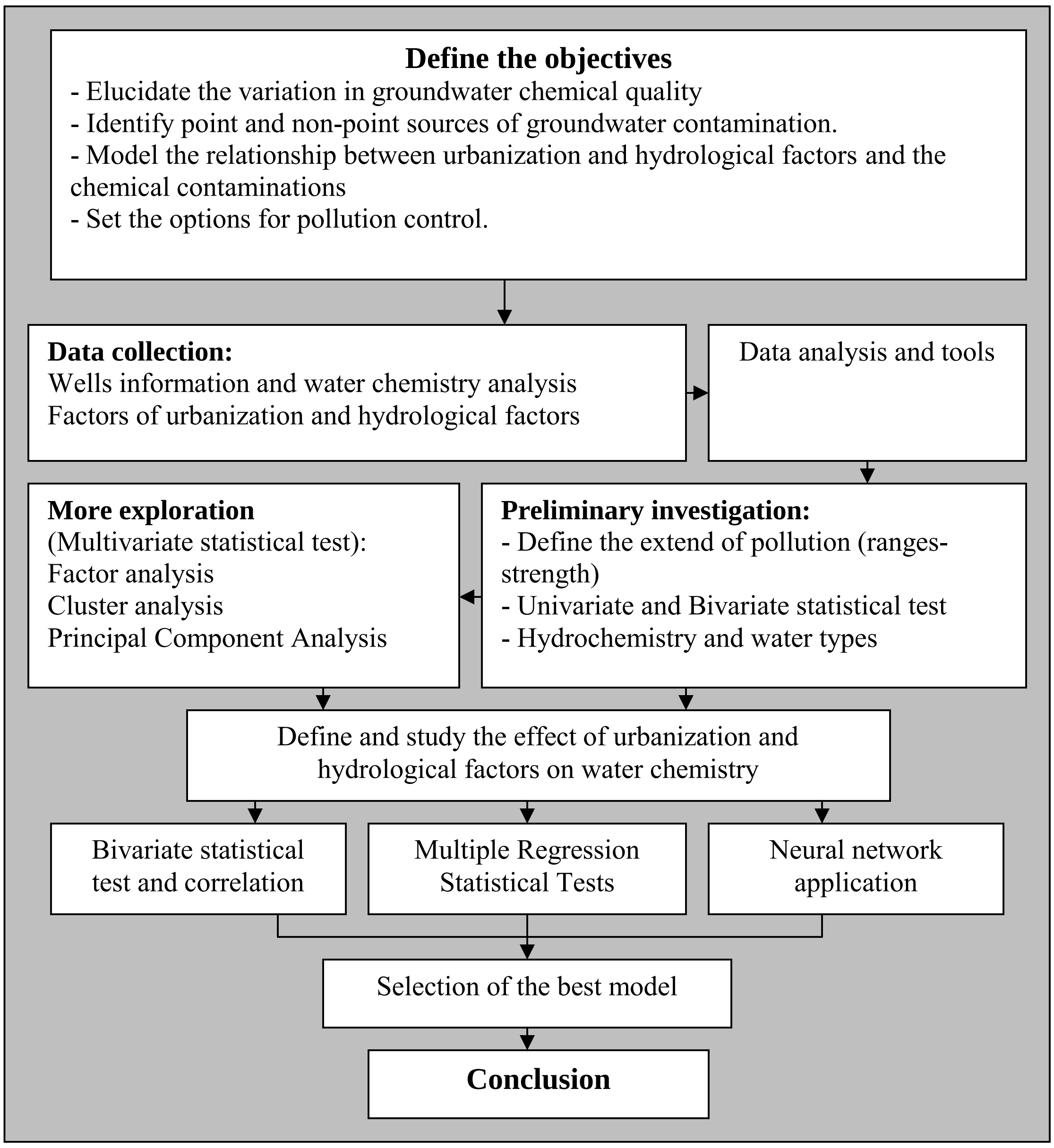

Figure (6.1): Methodology and procedures

6.4 Overview of groundwater chemistry

Table (6.1) presents a univariate overview of groundwater chemistry, seawater and rainwater quality. The pH of groundwater varies from 7.0 to 8.2 with an average of 7.56 indicating an alkaline nature. Concentration of TDS, a measure of quality, ranges from 274 to 3532 mg/L with a mean of 1263.9 mg/L. According to the TDS classification, 49.4 % of the samples of groundwater belonged to the brackish type (TDS > 1000 mg/L). The remaining samples were fresh water (TDS < 1000 mg/L).

Among the cations, the concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} ions ranged from 28.2 to 289.7, 6.9 to 154.3, 32 to 950, and 0.5 to 28.2 mg/L with a mean of 88.7, 46.6, 283.5 and 4.4 respectively. Their ionic concentrations (on the basis of mmole/L) were 74.4, 13.4, 11.6, and

© 2005 Tous droits réservés.

0.60 %. The order of abundance is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. The dissolved anions, HCO_3^-, CL^-, SO_4^{2-}, and NO_3^- ions (mg/L) lie in between 22.8 and 512.4, 42.5 and 1648, 7.5 and 616.3, 17.8 and 440.5 (mg/L) with a mean of 278.4, 427, 129.6 and 125.4 respectively. The order of their abundance (mmol/L) is $CL^- > HCO_3^- > NO_3^- > SO_4^{2-}$. The CO_3^{--} is almost zero and the alkalinity is due to the existence of HCO_3^-.

The reduced form of NO_3^- ions such as NO_2^-, and NH_4^+ is almost zero which means that the water in Gaza aquifer is in the oxidized form in case there is no direct contact between wastewater and shallow groundwater. All of the data shows skewness for all water quality distribution with right-hand tails. This pattern is common for water quality data as negative concentrations don’t exist.

Table (6.1): Univariate Statistical Overview of Water Quality Data Set (Rainwater, Groundwater, and Seawater Samples).

Parameter	Groundwater								Seawater	Rainwater
	Mean	Median	Min.	Max.	Variance	Std.Dev.	Skew.	Kurtosis	Mean=2	Mean =2
EC (µS/cm)	2135.7	1514	463	5837	1962266	1400.8	0.98	-0.049	---	2
TDS	1263.9	929	274	3532	684754	827.4	0.965	-0.024	---	17
pH	7.56	7.56	7.0	8.2	0	0.294	0.063	-0.294	---	5.2
Ca	88.7	80.4	28.2	289.7	2397	48.9	1.833	4.79	461	0.3
Mg	46.64	40.7	6.9	154.3	680	26.06	1.627	3.61	1474.5	0.2
Na	283.54	221	32	950	57205	239.1	1.054	0.271	12636	0.2
K	4.376	3.4	0.5	28.2	14	3.79	3.495	18.15	499.5	0.1
F	1.117	1.02	0.01	2.9	0	0.589	0.803	0.902	22670	0.1
Cl	427.4	285.7	42.5	1648	121702	348.8	1.12	0.807	---	6.1
NO3	125.4	100.5	17.8	440.5	9439	97.15	1.587	2.199	---	0.2
NO2	0.001	0	0	0.015	0	0.003	3.238	11.57	---	N.D.
SO4	129.6	75	7.53	616.3	18064	134.4	1.622	2.345	3103.5	0.6
HCO3	278.4	264	22.8	512.4	7701	87.7	0.37	1.156	148	8.7
Hard	409.3	370.2	0	1262	42016	204.9	1.256	2.646	---	
NH_4^+	0.006	0	0	0.061	0	0.015	2.52	5.25	---	N.D.

All values in mg/L unless otherwise indicated (N.D. = not detected. Std.Dev. = standard deviation. Min. = Minimum. Max. = Maximum. Skew. = Skewness).

6.5 Correlation between variables

The correlation analysis was initially performed before conducting the factor analysis in order to modify the interpretation obtained from the factor analysis. The most widely-used type of correlation coefficient is Pearson r (Pearson, 1896), also called linear or product-moment

© 2005 Tous droits réservés.

correlation was used. The correlation coefficient determines the extent to which values of two variables are "proportional" to each other. The value of the correlation (i.e., correlation coefficient) does not depend on the specific measurement units used. Proportional means linearly related; that is, the correlation is high if it can be approximated by a straight line (sloped upwards or downwards). This line is called the regression line or least squares line, because it is determined such that the sum of the squared distances of all the data points from the line is the lowest possible. Pearson correlation assumes that the two variables are measured on at least interval scales.

Table (6.2): Correlation matrix of domestic groundwater chemical quality in the Gaza Strip (year 2002)

	Correlations of water chemistry data for domestic wells, 2002 Marked correlations are significant at p < .05000 N=87 (Casewise deletion of missing data)												
Variable	log EC	Log TDS	Log pH	Log Ca	Log Mg	Log Na	Log K	Log F	Log CL	Log NO3	Log SO4	Log HCO3	Log Hardness
log EC	1.00												
Log TDS	**0.99**	1.00											
Log pH	-0.11	-0.08	1.00										
Log Ca	0.47	0.48	-0.34	1.00									
Log Mg	**0.58**	**0.59**	-0.41	**0.61**	1.00								
Log Na	**0.75**	0.74	0.08	0.18	**0.50**	1.00							
Log K	0.39	0.46	0.03	0.35	0.40	0.34	1.00						
Log F	0.08	0.12	0.33	-0.13	-0.02	0.25	0.36	1.00					
Log CL	**0.80**	**0.80**	-0.05	0.40	**0.63**	**0.95**	0.39	0.17	1.00				
Log NO3	0.49	0.49	-0.18	**0.52**	**0.53**	0.39	0.30	0.04	0.44	1.00			
Log SO4	**0.69**	**0.68**	0.12	0.18	0.43	**0.76**	0.36	0.22	**0.72**	0.35	1.00		
Log HCO3	0.26	0.27	-0.19	0.11	0.29	0.35	0.26	0.01	0.33	0.10	0.26	1.00	
Log Hardness	**0.51**	**0.51**	-0.40	**0.72**	**0.83**	0.43	0.35	-0.06	**0.57**	**0.50**	0.24	0.29	1.00

Table (6.2) shows the correlation matrix of the variables. Usually, significant correlations (at a P =0.05 level) are searched for, but because of the high number of degrees of freedom, $r_{critical}$ is low at P = 0.05, so the number of statistically significant correlations (with $r > r_{critical}$) is very high. The real usefulness of this test is questionable since it simply proves that r is significantly different from zero. As uniquely really stronger correlations will be of utility, only those with r values higher than 0.500 have been considered, and are highlighted in the correlation matrix.

We can observe strong and positive correlations with the major cations and anions in groundwater in the study area: EC and TDS (r =0.99), chloride and sodium (r =0.95). Sulphate with EC, TDS, sodium and chloride (r =0.69, 0.68, 0.76, and 0.72 respectively), hardness with calcium and magnesium (r = 0.72 and 0.83 respectively), calcium and

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

magnesium (r= 0.61). Most of these associations can be explained in terms of the hydrochemical characteristics of the Gaza aquifer. Taking into account the high agricultural activity in the area and population density, the behaviour of groundwater chemistry can be somehow attributed, partially, to man-made pollution, i.e. fertilizers and/or industrial wastes. This can be shown through the positive relation between nitrate and the major concentration of water quality parameters.

As a general rule, the mineral contents found in groundwater samples are closely related to dissolution processes of materials predominant in the soils of the study area. In our case, the presence of gypsum and carbonates can explain the correlations found for Sulphate, calcium, and magnesium. The correlation between sodium and chloride can be attributed to dissolution of halite, or it could be due to some non-natural processes, such as leakages from municipal sanitary systems, or leachates derived from disposal of industrial wastes. The strong positive correlation of electrical conductivity with the most abundant ions, Sulphate, chloride, calcium, magnesium, sodium and potassium (with r values ranking from 0.80 to 0.26), is reasonable.

The major exchangeable ions, Na^+–Ca^{2+} and Na^+–Mg^{2+}, correlate positively with a strong correlation with magnesium and week with calcium. It can therefore be postulated that the concurrent increase/decrease in the cations is the result mainly of dissolution/precipitation reactions and concentration effects. The pH has a negative correlation with some variables and a weak correlation with all variables which can be explained by the higher aggressiveness of acidic media towards soil and host rocks that increase the concentrations of the rest of the ions.

To determine the relationship between different parameters of the carbonate systems, the carbonate species were subjected to product linear correlations to determine the correlation coefficient with other variables. These relationships show that HCO_3^- correlates directly with Ca^{2+} and Mg^{2+}, which means an increase in carbonate concentration results from increasing calcium and magnesium concentrations. The source of calcium and magnesium in the water is believed to be calcite, dolomite, gypsum and anhydrite formations. The inverse relationship between Ca^{2+} and HCO_3^- with the pH value could be attributed to the decrease of these two ions at high pH values due to the precipitation of calcite (CO_3^{--} exist in case of pH more than 8.3).

© 2005 Tous droits réservés.

The plot of (Ca^{2+}+ Mg^{2+}) versus HCO_3^- in Fig (6.2a) shows that most of the data fall below the equiline (1:1), although some points approach this line. It suggests that an excess of alkalinity of the water have been balanced by alkalies (Na^+ and K^+). The excess of alkaline earth elements (Ca^{2+} + Mg^{2+}) over HCO_3^- in some samples reflects an extra source of Ca^{2+} and Mg^{2+} ions. It might have been balanced by CL^- and SO_4^{2-}. Further, Ca^{2+} + Mg^{2+} versus TC (total cations) shows that the data lie far below the theoretical line (1:1; Fig 6.2b), depicting an increasing contribution of alkalies to the major ions. Significantly, the increase in alkalies corresponds to a simultaneous increase in (CL^- + SO_4^{2-}; Fig 6.2c), suggesting a common source for these ions and the presence of Na_2SO_4 and K_2SO_4 in the soil. Also, the observed excess of Na^+ over K^+ is because of greater resistance of K^+ to chemical reaction such as weathering and its fixation in the formation of clay minerals.

Most of water samples have high Na^+/CL^- ratios and mostly above the marine ratio. The dominance of Na^+, suggests that ions result from dissolution of evaporatic constituent (e.g. halite), or weathering of the bearing rock. Sporadic gypsum deposits, which beds sodium, are known to exist within the Kurkar Group, and have been described in the coastal aquifer near the Gaza boarder (PWA, 2000). Low Na^+/CL^- ratios are found in some water samples throughout the Gaza Strip, most frequently in the middle and northern areas. Whereas the excess of Na^+ over CL^- in many water samples suggest that the higher concentration of alkalies is from sources such as anthropogenic interaction other than precipitation. However, groundwater in the area has a higher ratio (0.5) of (Na^+ + K^+) versus TC, depicting the contribution of cations via soil ion exchange.

Molar Na^+: Ca^{2+} ratios (Table 6.3) are more than one unit (6.38), indicating a deficiency of Ca^{2+}. This may be caused by precipitation of $CaCO_3$ and/or ion exchange process. In many groundwater samples, the concentration of Mg^{2+} is more than that of Ca^{2+}. As the solubility of $CaCO_3$ is much lower (less than that of $MgCO_3$), the Ca^{2+} appears to have precipitated as $CaCO_3$, resulting in a decline of Ca^{2+} values.

Table (6.3): Hydro-geochemical signatures in the Gaza Strip (87 domestic wells – 2002)

Chemical Parameter	Na/CL[a]	Na/K[a]	Mg/Ca[a]	Na/Ca[a]	CA1[b]	CA2[c]	EpCO2
Average	1.026694	148.3304	0.93414	6.381563	-0.04212	-0.01743	26.28622
Minimum value	0.414	10.71	0.172	0.253	-1.28	-2.11	2.366
Maximum value	2.26	836.7	2.18	28.17	0.584	3.75	85.98

[a] mmoL/L
[b] CA1 = CL^--Na^++K^+ : CL^- meq/L
[c] CA2 = CL^--Na^++K^+ : CO_3^{2-} + HCO_3^-

© 2005 Tous droits réservés.

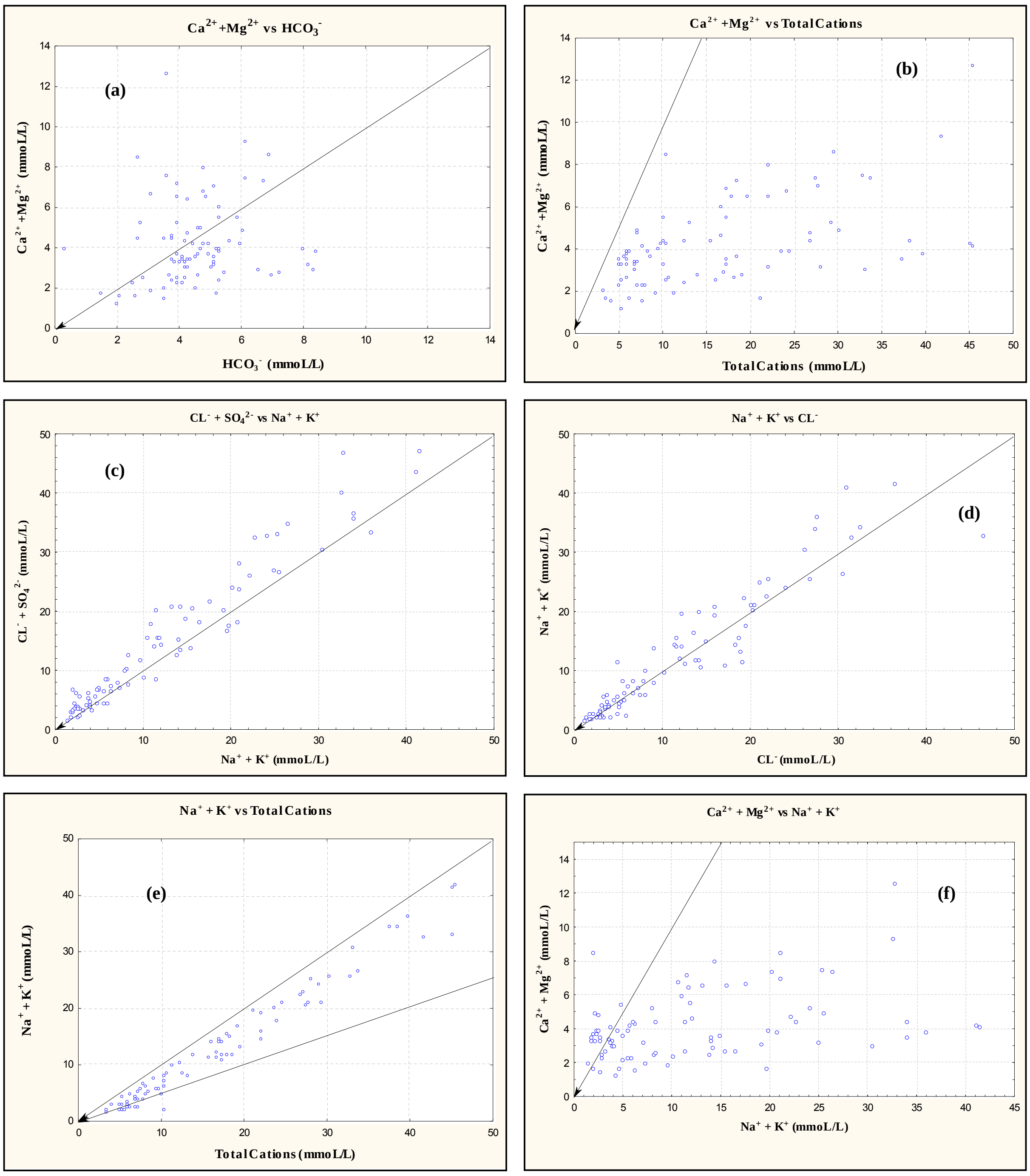

Fig (6.2): Plot of chemical variations of urban groundwater wells

The concentration of HCO_3^- in groundwater ranges from 126 to 430 mg/L. Relatively high HCO_3^- concentration exists in eastern part of the Gaza Strip. Groundwater of relatively low HCO_3^- content, below 150 mg/L is dominant in western part of the Gaza Strip especially in Rafah and Jabalia areas. Natural processes such as the dissolution of carbonate minerals and dissolution of atmospheric and soil CO_2 gas could be a mechanism which supplies HCO_3^- to the groundwater:

$$CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2\,HCO_3^-$$

$$CO_2 + H_2O = H^+ + HCO_3^-$$

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

In addition, anthropogenic CO_2 gas should be considered as a potential source of bicarbonate in urban groundwater. Potential sources of CO_2 gas are: (a) CO_2 gas from municipal wastes within unlined landfill sites, (b) CO_2 gas due to oxidation of organic materials leaking from old latrines and sewage systems, (c) CO_2 gas from Sulphate reduction of organic materials in the aquifer (Clark and Fritz, 1997)

$$\mathbf{CH_2O + O_2 = CO_2 + H_2O}$$

$$\mathbf{2CH_2O + SO_4^{2-} = H_2S + 2HCO_3^-}$$

E_pCO_2 that is the CO_2 content of a water sample relative to pure water was computed using the equation proposed by Neal et. al. (1998a,b):

$$\mathbf{E_PCO_2 = (Alk_{\mu Eq/l} + 10^{(6-pH)} - 10^{(6-pHendpoint)})10^{(6-pH)}/6}$$

Where, pH endpoint is the pH from the endpoint of the alkalinity measurement. The endpoint pH is usually 4.5; hence the $10^{(6-pHendpoint)}$ term is 31.6 µEq/l. The E_PCO_2 of the groundwater samples in the Gaza Strip area ranges from 1 to 85 times atmospheric equilibrium (=CO_2 pressure of $10^{-3.5}$ atmosphere). Typical E_PCO_2 levels of groundwater samples are listed in (appendix II). The minimum, maximum and average CO_2 are 2.399, 85.98 and 25.87 respectively. CO_2 pressures of $10^{-1.5} - 10^{-2.5}$ atmosphere are commonly found in open system soil layer.

The CO_2 is generated in soils by the decay of organic materials and by root respiration. Land use and biological productivity are therefore important in determining CO2 pressure in soils. Figure (6.3) shows strong negative relationship between E_PCO_2 and the pH. This relates to the reaction involving the supply and consumption of CO2 and carbonic acid in the evolution process of groundwater. Rough positive relationships exist between the E_PCO_2 and the inorganic components in groundwater from urbanized area (Table 6.4). This indicates that organic polluted groundwater in urbanized area is related to increase of inorganic components in groundwater. However, a few groundwater show no relationship between the E_PCO_2 and inorganic components.

Furthermore, the water types in the study area are identified by using a Piper diagram, which is a trilinear plot that permits the classification of water samples into seven types according to Langguth, 1966 (Qasem Abdul-Jaber and others, 1999). The samples were plotted on the diagram (Figure 6.4) using AuqaChem software (Waterloo hydrogelogic version 3.6.2). The trilinear plot of all samples shows that the large group of the wells is located on the area of alkaline water type with prevailing Sulphate. Some groups of water wells are located in an

© 2005 Tous droits réservés.

area of earth alkaline water with prevailing bicarbonate, sulphate and chloride chemicals. Only one domestic well of 87 wells is located in the area of normal earth alkaline water with prevailing chloride.

Table (6.4): Correlations matrix between E_PCO_2 and major cations and anions in groundwater (Marked correlations are significant at p < .05000) N=87

	pH	EC	TDS	Na	K	Mg	Ca	F	CL	SO4	NO3	HCO3	Hardness
$EpCO_2$	**-0.86**	0.18	0.16	0.10	**0.26**	**0.46**	**0.24**	-0.18	0.16	-0.03	0.17	**0.54**	**0.41**

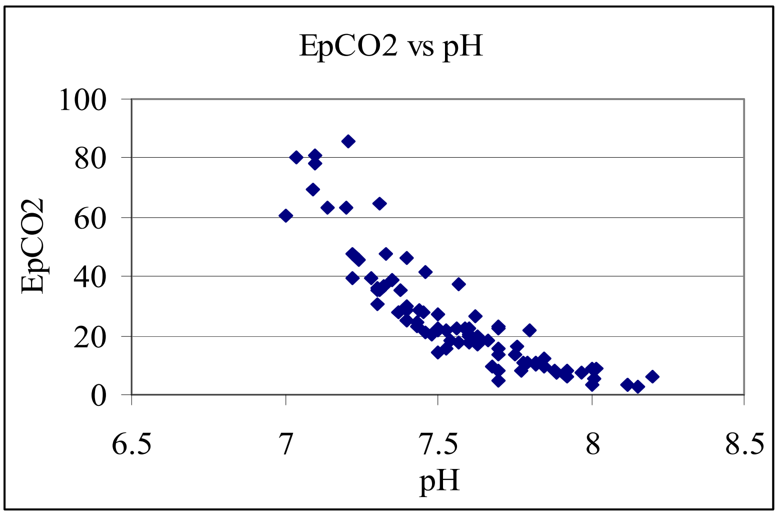

Figure (6.3): Plots of EpCO2 level with pH in 87 urban groundwater wells in the Gaza Strip (year 2002)

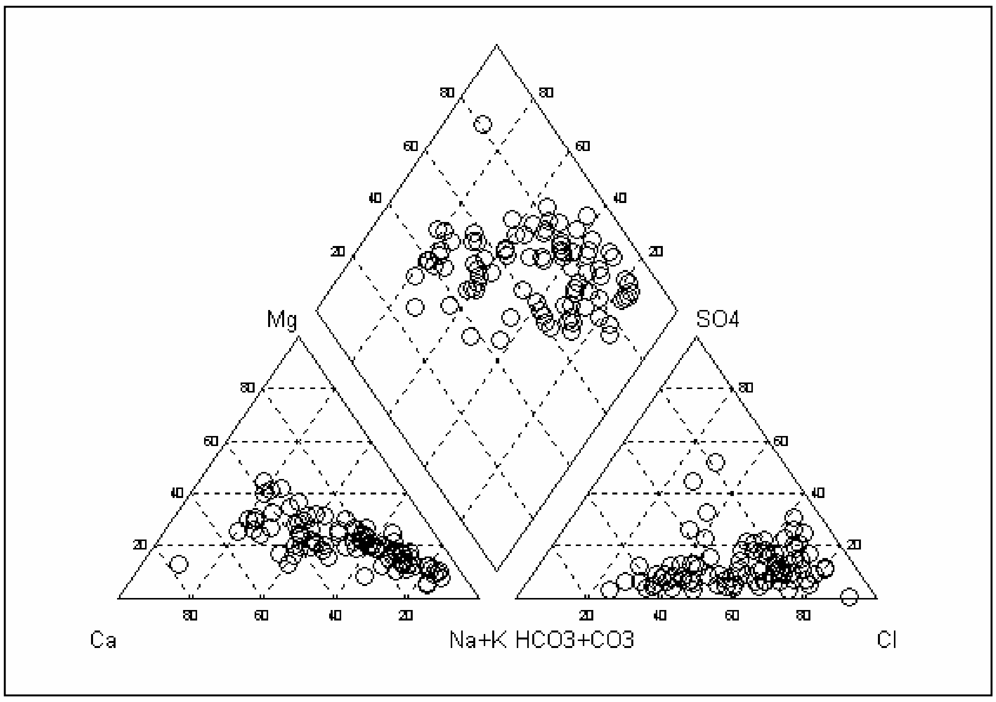

Figure (6.4): Representation of groundwater chemical data on a trilinear diagram (year 2002)

© 2005 Tous droits réservés.

6.6 Multivariate Statistical Test

The chemistry of groundwater is an important factor determining its use for domestic, irrigation or industrial purposes. The quality of groundwater is controlled by several factors, including climate, soil characteristics, manner of circulation of groundwater through the rock types, topography of the area, saline water intrusion in coastal areas, human activities on the ground, etc. The ionic constituents Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CL^{-}, HCO_3^{-}, NO_3^{-}, and SO_4^{2-} and the non-ionic constituents pH, electrical conductivity (EC), total dissolved solids (TDS) and hardness were subjected to multivariate analytical techniques such as factor, cluster and principal component analysis.

The univariate statistical analysis, generally used to treat environmental data such as water quality data, could cause misunderstanding and error both in the interpretation and in those to whom the conclusions are presented (Ashley and Lloyd, 1978). In order to avoid this problem, multivariate statistical techniques can be used instead, as they are unbiased methods which can help indicate natural associations between samples and/or variables (Wenning and Erickson, 1994) thus highlighting information not available at first glance.

The multivariate treatment of environmental data is widely used to characterize and evaluate surface and freshwater quality, and it is useful for detecting temporal and spatial variations caused by natural and human factors linked to seasonality (Andrade et al., 1992; Reisenhofer et al., 1998; Vega et al., 1998). However, these statistical methods have not attained a comparable diffusion in the case of groundwater studies to date (Aruga et al., 1993; Ashley and Lloyd, 1978). Multivariate techniques can help to simplify and organize large data sets and to make useful generalizations that can lead to meaningful insight (Laaksoharju M, et. al, 1999).

Cluster and factor analyses are efficient ways of displaying complex relationships among many objects (Davis JC, 1973). The two methods in cluster and factor analyses, i.e., Q- and R- mode analyses have been conducted for the data generated. R-mode analysis reveals the interaction among the variables studied and the Q-mode analysis reveals the interrelation among the samples studied. In this research, Principal Component Analysis (PCA) also was used, which made it possible to reduce the dimensionality of a highly dimensioned data set by explaining the correlation amongst a large number of variables in terms of a smaller number of underlying factors (principal components or PCs) without losing much information (Jackson, 1991). Varimax rotation has also been applied in order to find more clearly defined

© 2005 Tous droits réservés.

factors (called varifactors or VFs) which could be more easily interpreted. The computer package Statistica 6 Package has been used to carry out the analysis. The data have been standardized by using standard statistical procedures.

6.6.1 Factor analysis

The usual procedures of interpretation of chemical quality of groundwater with the help of plots of different ions and pairs of ions do not define the simultaneously the similarities between all ions or samples (Dalton MG, 1978). Factor analysis offers a powerful means of detecting such similarities among the variables or samples. Factor analysis is an exploratory technique designed to reduce the number of variables and to detect structure in the relationships between variables that is to classify variables. Therefore, factor analysis is applied as a data reduction or (exploratory) structure detection method.

The purpose of factor analysis is to interpret the structure within the variance–covariance matrix of a multivariate data collection. The technique used is extraction of the eigen values and eigen vectors from the matrix of correlations or covariances (Davis JC, 1973). Thus, factor analysis is a multivariate technique designed to analyze the interrelationships within a set of variables or objects. The factors are constructed in a way that reduces the overall complexity of the data by taking advantage of inherent inter-dependencies. As a result, a small number of factors will usually account for approximately the same amount of information as do the much larger set of original observations. The interpretation is based on rotated factors, rotated loadings and rotated eigen values.

6.6.1.1 R-mode Factor Analysis

Factor analysis of different chemical constituents for the year 2002 of 87 domestic groundwater wells of the Gaza Strip aquifer has been carried out. All cations and anions, TDS, EC, pH and Hardness have been considered for the present analysis. The analysis generated 12 factors which together account for 99.98% of variance. The rotated loadings, eigen values, percentage of variance and cumulative percentage of variance of all 12 factors are given in Table 6.5 and Table 6.6. The first eigen value is 6.076 which accounts for 46.74% of the total variance and this constitutes the first and main factor. The second and third eigen values are 2.098 and 1.0964 and these account for 16.13% and 8.43%, respectively, of the total variance. The rest of the eigen values each constitute about 10% of the total variance.

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

The first factor (which accounts for 46.74% of the total variance) is characterized by very high loadings of Na^+, Cl^-, TDS and EC and moderate loading of Sulphate. This factor reveals that the EC and TDS in the study area are mainly due to Na^+ and Cl^-, though Sulphate also plays a substantial role in determining EC and TDS. This factor also can explain the mineralization behaviour of groundwater chemistry. The second factor (which accounts for 16.13% of the total variance) is mainly associated with moderate to high loadings of Mg^{2+} and hardness. This factor accounts for the temporary hardness of the water.

Factors 3 to 8 are characterized by the dominance of only one variable each, such as F^- (factor 3), HCO_3^- (factor 4), K^+ (factor 5), NO_3^- (factor 6), pH (factor 7) and Ca^{2+} (factor 8) and together these six factors account for 33.42% of the total variance. The single dominance of variables in each factor indicates non-mixing or partial mixing of different types of water. The 7th factor, with high negative loading only on pH, possibly implies biogenic or organic controls on the pH value of water or the major contribution towards pH is not from the ions analyzed in this study. The remaining factors (from 9 to 12) are characterized by low to very low loading of all variables and hence can be considered as irrelevant for describing the factor model of the groundwater chemistry of the Gaza Strip aquifer. The first eight factors which explain 94.8% of the total variance of the data could be considered as representative of the factor model.

Table (6.5): Factor loading matrix-varimax rotation

	Factor Loadings (transfered and standarized data for 87 domestic wells, 2002) (Marked loadings are >.700000)												
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13
EC'	0.923	0.108	-0.021	0.036	0.089	0.117	0.064	0.163	-0.031	-0.283	-0.005	0.012	0.035
TDS'	0.913	0.110	0.013	0.039	0.156	0.118	0.045	0.168	-0.038	-0.285	0.016	-0.005	-0.036
pH'	0.011	-0.217	0.165	-0.090	0.025	-0.061	-0.949	-0.107	0.028	0.008	-0.004	0.000	-0.000
Ca'	0.261	0.380	-0.100	-0.008	0.149	0.210	0.157	0.828	-0.013	-0.016	0.009	-0.001	0.000
Mg'	0.465	0.747	-0.030	0.082	0.136	0.171	0.229	0.134	0.092	-0.016	0.303	-0.001	-0.000
Na'	0.901	0.139	0.120	0.141	0.028	0.074	-0.084	-0.114	0.048	0.311	-0.025	0.090	0.000
K'	0.296	0.139	0.194	0.105	0.907	0.079	-0.026	0.116	0.034	-0.004	0.004	-0.000	0.000
F'	0.122	-0.038	0.964	-0.008	0.160	0.004	-0.157	-0.065	0.023	0.007	-0.001	0.000	-0.000
'CL	0.904	0.233	0.059	0.100	0.064	0.065	0.002	0.079	0.004	0.301	0.007	-0.097	-0.001
'NO3	0.351	0.211	0.007	-0.006	0.082	0.889	0.074	0.170	0.028	-0.002	0.005	0.000	-0.000
SO4'	0.758	0.013	0.081	0.076	0.098	0.076	-0.091	-0.033	0.623	0.013	0.014	0.000	0.000
HCO3'	0.224	0.099	-0.008	0.961	0.088	-0.004	0.088	-0.001	0.022	0.006	0.002	-0.000	-0.000
Hard'	0.364	0.807	-0.035	0.115	0.093	0.153	0.188	0.294	-0.063	0.022	-0.210	0.001	0.000
Expl.Var	4.582	1.572	1.031	1.002	0.960	0.940	1.073	0.924	0.409	0.351	0.137	0.017	0.003
Prp.Totl	0.352	0.121	0.079	0.077	0.074	0.072	0.083	0.071	0.031	0.027	0.011	0.001	0.000

© 2005 Tous droits réservés.

Table (6.6): Eigen values and variance of factor loading

	Eigenvalues (transfered data for domestic wells)			
Value	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	6.0768	46.7444	6.0768	46.7444
2	2.0982	16.1398	8.1749	62.8842
3	1.0964	8.4335	9.2713	71.3178
4	0.9944	7.6494	10.2657	78.9671
5	0.5924	4.5567	10.8581	83.5238
6	0.5547	4.2668	11.4128	87.7906
7	0.5136	3.9509	11.9264	91.7414
8	0.3973	3.0560	12.3237	94.7974
9	0.2951	2.2697	12.6187	97.0671
10	0.2481	1.9086	12.8668	98.9757
11	0.1140	0.8770	12.9809	99.8527
12	0.0167	0.1281	12.9975	99.9808
13	0.0025	0.0192	13.0000	100.0000

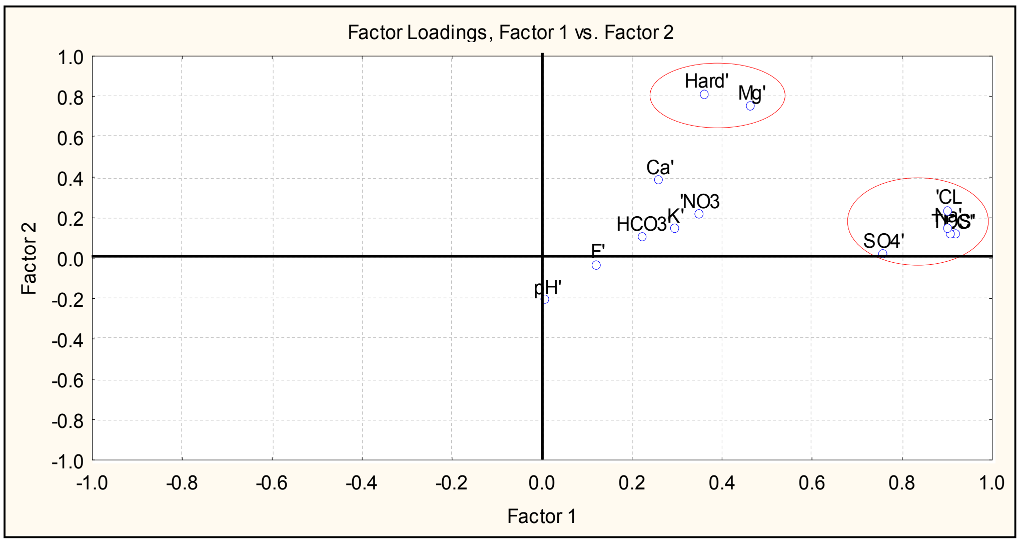

Figure (6.5): Factor 1 vs. factor 2 in R-mode factor analysis for 87 domestic wells (2002)

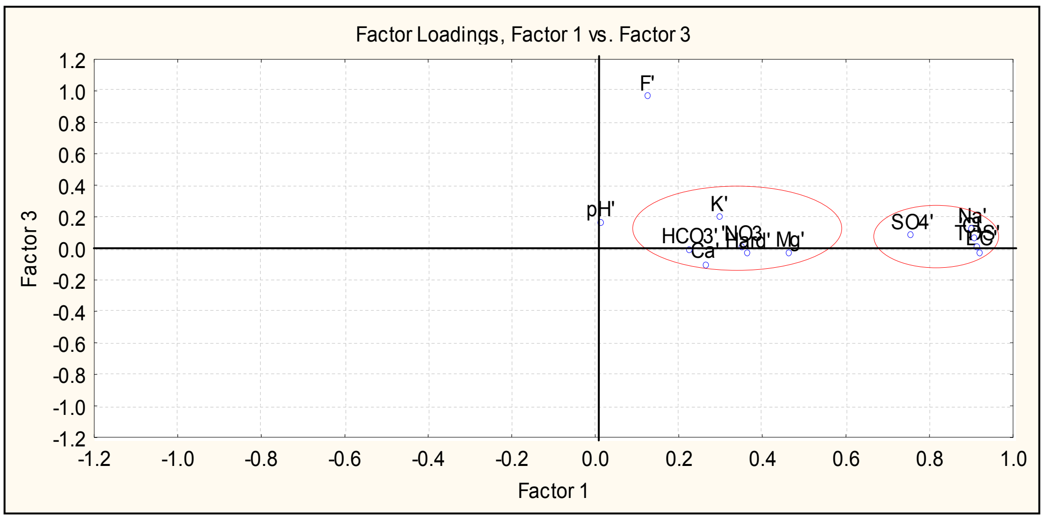

Figure (6.6): Factor 1 vs. factor 3 in R-mode factor analysis for 87 domestic wells (2002)

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

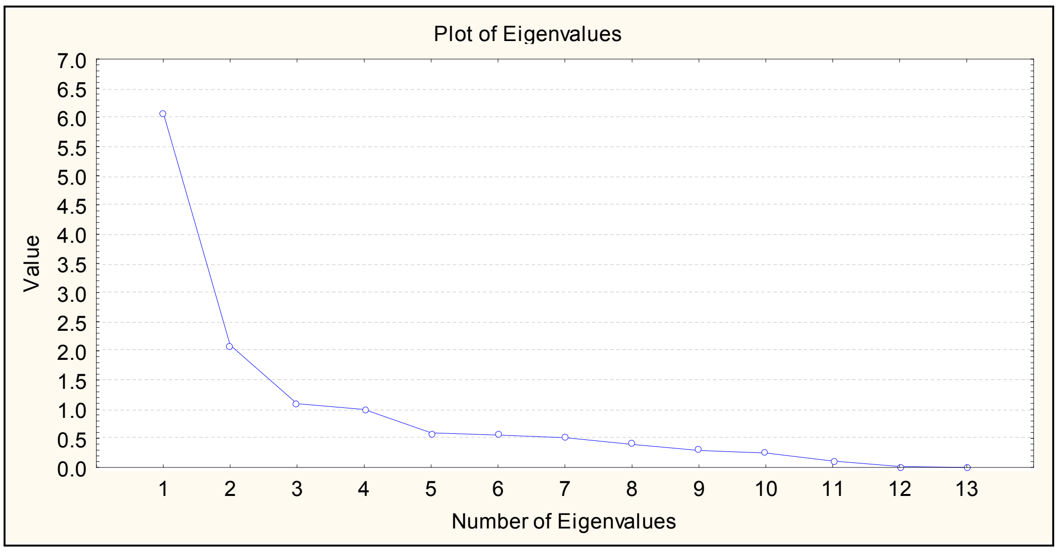

Fig (6.7): Plot of Eigen values

6.6.1.2 Q-mode Factor Analysis

Q-mode factor analysis of the water samples of the Gaza Strip aquifer has been carried out. All the 87 samples were considered for this analysis. The analysis has generated six factors which together account for 99.9% of the variance. The first three factors (which constitute for 99.1% of the variance) are considered as representative of the factor model and have been taken for interpretation. The rotated loadings, eigen values, percentage of variance and cumulative percentage of variance of the first three factors are given in table (6.7). Plot 6.8 shows the eigen values of the model result.

The first factor which accounted for 95.5% of the variance consists of high loadings of samples k/19, J/1, R/162BA, R/192/CA, A/185, E157, E/61, E/156, D/74, D/68, D/69, D/76, D/75, E/90, R/280, D/70, D/67, E/11A, E/11C, E/11B, E/154, A/180, E/138, E/8, E/4, E/1, A/40, A/6, C/127, C/128, C/48. The second factor which accounted for 2.029% of the variance consists of high loadings of samples P/139, P/124, P/15, P/144, P/10, P/138, P/145, P/153, P/147, L/184, L/187, L/176, L/86A, L/86B, L/159, L/159A, L/127, L/87, L/43, L/41, L/178, L/14, L/179, J/2, G/45, Q/569, J/146, G/30, S/69, S/37, S/71, R/265, R/112, R/254, R/254, R/271, R/162E, R/162LA, R/162D, R/162C, R/162EA, R/162G, R/162H, R/75, D/68, R/25A, R/25C, R/25B, R/25D, Q/68, C/76, C/79. Factor 3 which accounted for 1.522% of the variance consists of high loadings of samples D/71 and R/270.

The distribution of wells explained by factor 3 does not conform to any kind of spatial pattern. Samples in Northern area fall within factor one while the majority of the samples

© 2005 Tous droits réservés. http://www.univ-lille1.fr/bustl

within factor 2 fall on the Rafah, Khanyounis, middle area and Gaza city. This strongly suggests that there is a seawater intrusion towards groundwater and we have two different types of water chemistry in the study area. The high variance of factor one (95.5% out of 99.1%) suggests that seawater intrusion plays a dominant role in the hydrochemical evolution of groundwater in the Rafah, Khanyounis, middle area and Gaza city and explains the recharge that happens in the Northern area.

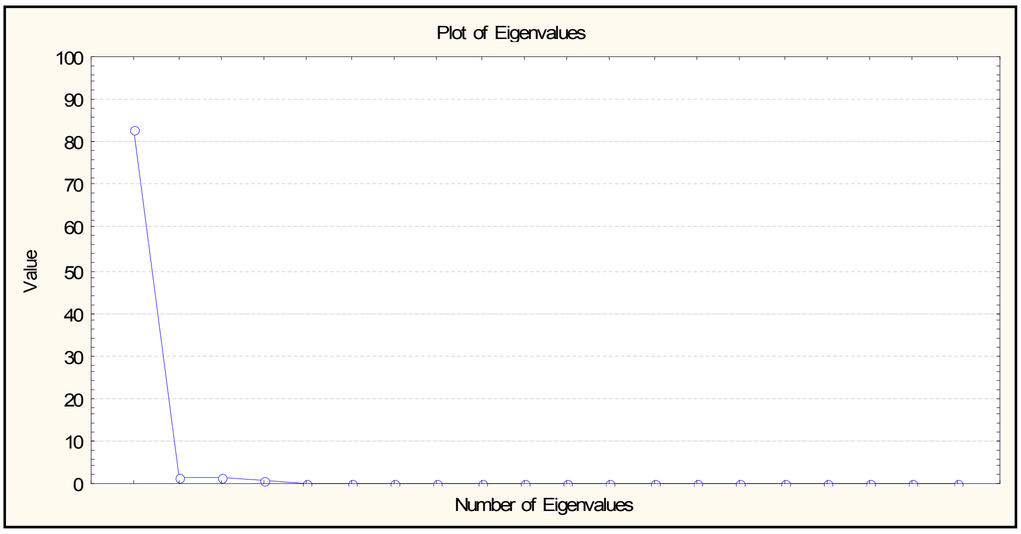

Figure (6.8): Plot of Eigen values

© 2005 Tous droits réservés.

Table (6.7): Varimax rotated Q-mode factor analysis loading matrix

SampleID	Location	Factor1	Factor2	Factor3	SampleID	Location	Factor1	Factor2	Factor3
C/76	BeitHanon	**0.661**	0.311	0.675	R/25C	Gaza	0.613	0.178	**0.769**
C/128	BeitHanon	**0.710**	0.278	0.644	R/25D	Gaza	0.533	0.335	**0.773**
A/6	BeitHanon	**0.781**	0.241	0.570	R/25B	Gaza	0.612	0.255	**0.746**
C/79	Beit-Hanon	**0.676**	0.292	0.675	R/25A	Gaza	0.600	0.248	**0.756**
C/127	Beit-Hanon	**0.830**	0.228	0.507	R/271	Gaza	0.594	0.242	**0.766**
E/1	BeitLahia	**0.763**	0.240	0.597	R/112	Gaza	0.592	0.290	**0.750**
E/8	BeitLahia	**0.795**	0.165	0.578	R/75	Gaza	0.501	0.372	**0.780**
E/4	BeitLahia	**0.842**	0.207	0.495	R/162D	Gaza	0.529	0.313	**0.781**
D/68	BeitLahia	**0.778**	0.230	0.584	Q/68	Gaza	0.667	0.215	**0.704**
D/69	BeitLahia	**0.758**	0.208	0.615	R/162E	Gaza	0.623	0.122	**0.770**
D/70	BeitLahia	**0.816**	0.189	0.545	R/162H	Gaza	0.617	0.216	**0.755**
C/48	BeitLahia	**0.737**	0.272	0.613	R/162LA	Gaza	0.628	0.285	**0.721**
D/74	BeitLahia	**0.809**	0.185	0.557	R/162B	Gaza	0.647	0.241	**0.718**
E/61	BeitLahia	**0.762**	0.217	0.609	R/254	Gaza	0.647	0.345	**0.673**
D/72	BeitLahia	**0.742**	0.372	0.525	R/254b	Gaza	0.625	0.282	**0.718**
D/76	BeitLahia	**0.857**	0.186	0.480	L/184	Khanyounis	0.688	0.240	**0.679**
D/75	BeitLahia	**0.822**	0.200	0.532	L/187	Khanyounis	0.609	0.071	**0.789**
A/180	BeitLahia	**0.827**	0.207	0.521	L/41	Khanyounis	0.542	0.253	**0.801**
D/67	BeitLahia	**0.861**	0.211	0.453	L/176	Khanyounis	0.538	0.291	**0.786**
E/157	BeitLahia	**0.778**	0.232	0.583	L/43	Khanyounis	0.637	0.225	**0.736**
A/40	BeitLahia	**0.807**	0.253	0.525	L/127	Khanyounis	0.617	0.233	**0.747**
R/162BA	Jabalia	**0.634**	0.464	0.588	L/87	Khanyounis	0.588	0.262	**0.763**
R/265	Jabalia	**0.635**	0.480	0.590	L/86A	Khanyounis	0.637	0.212	**0.738**
R/280	Jabalia	**0.795**	0.252	0.525	L/159	Khanyounis	0.657	0.189	**0.723**
A/185	Jabalia	**0.821**	0.209	0.529	L/159A	Khanyounis	0.680	0.175	**0.705**
R/162EA	Jabalia	**0.660**	0.262	0.698	L/14	Khanyounis	0.548	0.266	**0.788**
R/162CA	Jabalia	**0.749**	0.217	0.625	L/178	Khanyounis	0.532	0.269	**0.802**
R/162G	Jabalia	**0.692**	0.270	0.661	L/179	Khanyounis	0.558	0.289	**0.770**
R/162C	Jabalia	**0.712**	0.242	0.654	Q/569	Middle	0.615	0.287	**0.733**
E/11A	Jabalia	**0.746**	0.253	0.599	J/146	Middle	0.580	0.273	**0.766**
E/11B	Jabalia	**0.790**	0.181	0.566	S/69	Middle	0.607	0.260	**0.743**
E/11C	Jabalia	**0.783**	0.206	0.578	S/71	Middle	0.596	0.277	**0.753**
E/138	Jabalia	**0.779**	0.209	0.588	S/37	Middle	0.577	0.273	**0.769**
E/90	Jabalia	**0.762**	0.184	0.616	G/45	Middle	0.596	0.291	**0.742**
E/154	Jabalia	**0.736**	0.247	0.627	G/30	Middle	0.579	0.286	**0.758**
E/156	Jabalia	**0.771**	0.225	0.594	J/2	Middle	0.683	0.234	0.689
D/68	Jabalia	**0.781**	0.234	0.572	P/10	Rafah	0.531	0.271	**0.797**
K/19	Qarara	**0.733**	0.228	0.635	P/15	Rafah	0.644	0.261	**0.717**
J/1	Qarara	**0.735**	0.229	0.634	P/124	Rafah	0.642	0.257	**0.720**
D/71	BeitLahia	0.265	**0.814**	0.471	P/138	Rafah	0.668	0.253	**0.699**
R/270	Jabalia	0.119	**0.968**	0.159	P/145	Rafah	0.626	0.261	**0.735**
					P/153	Rafah	0.674	0.251	**0.691**
					P/147	Rafah	0.637	0.254	**0.726**
					P/144	Rafah	0.622	0.281	**0.730**
					P/139	Rafah	0.684	0.123	**0.714**

Factor	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative Variance
1	82.41081	95.82652	82.41081	95.82652
2	1.78259	2.07278	84.19341	97.89931
3	1.17338	1.36439	85.36678	99.26370

© 2005 Tous droits réservés.

6.7 Cluster analysis

Cluster analysis comprises a series of multivariate methods which are used to find true groups of data or stations. In clustering, the objects are grouped such that similar objects fall into the same class (Danielsson A, et. al, 1999). The hierarchical method of cluster analysis, which is used in this study, has the advantage of not demanding any prior knowledge of the number of clusters, which the non-hierarchical method does. A review by Sharma [Sharma S. 1996] suggests Ward's clustering procedure to be the best, because it yields a larger proportion of correct classified observations than do most other methods. Hence, Ward's clustering procedure is used in this study. As a distance measure, the squared euclidean distance was used, which is one of the most commonly adopted measures (Fovell R, 1993). The outputs of the Q-mode and R-mode cluster analysis are given as a dendrogram (Figures 6.10 and 6.11).

According to the R-mode cluster analysis; there are two major clusters as shown in Figure 6.9. Cluster one corresponds to the total dissolved solids, electrical conductivity and water mineralization components. This cluster contains all cations and anions in different subgroups. Chloride and sodium are in one group with the same weight to bicarbonate and hardness. Calcium and magnesium are corresponding to one group. This analysis confirms the explanation done through factor analysis. According to Q-mode cluster analysis; there are three major clusters as shown in Fig. 6.10. Clusters 1, 2 and 3 correspond to the factors 1, 2 and 3, respectively, of the Q-mode factor analysis except for small number of sampled wells. The similarity of the Q-mode cluster analysis to the Q-mode factor analysis confirms the interpretations made using the Q-mode factor analysis.

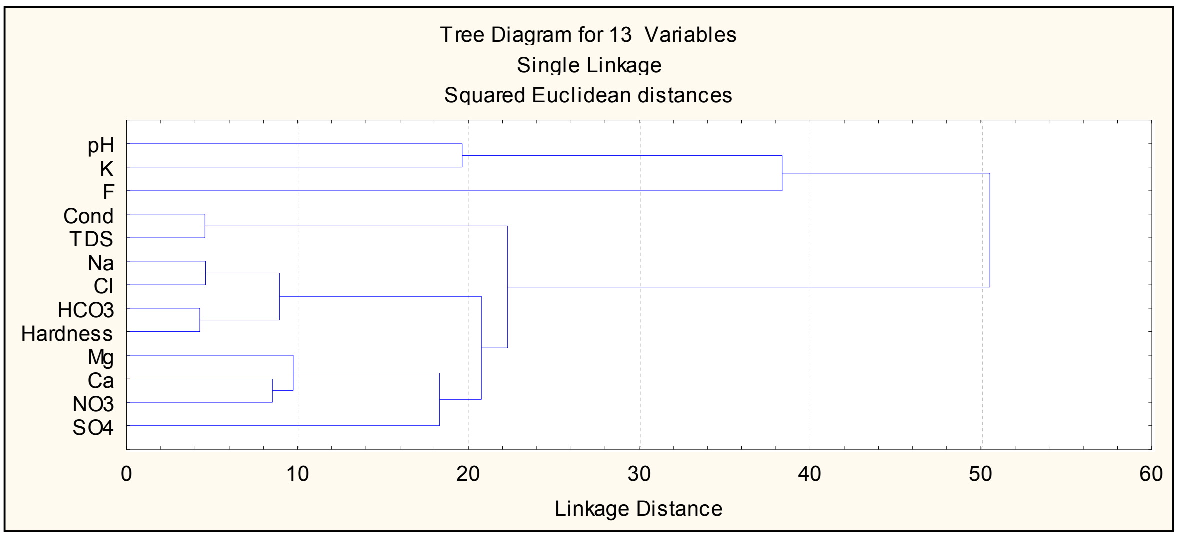

Fig (6.9): Dendogram of the R-mode cluster analysis

Hierarchical cluster analysis using Ward Method-Squared Euclidean distances

© 2005 Tous droits réservés.

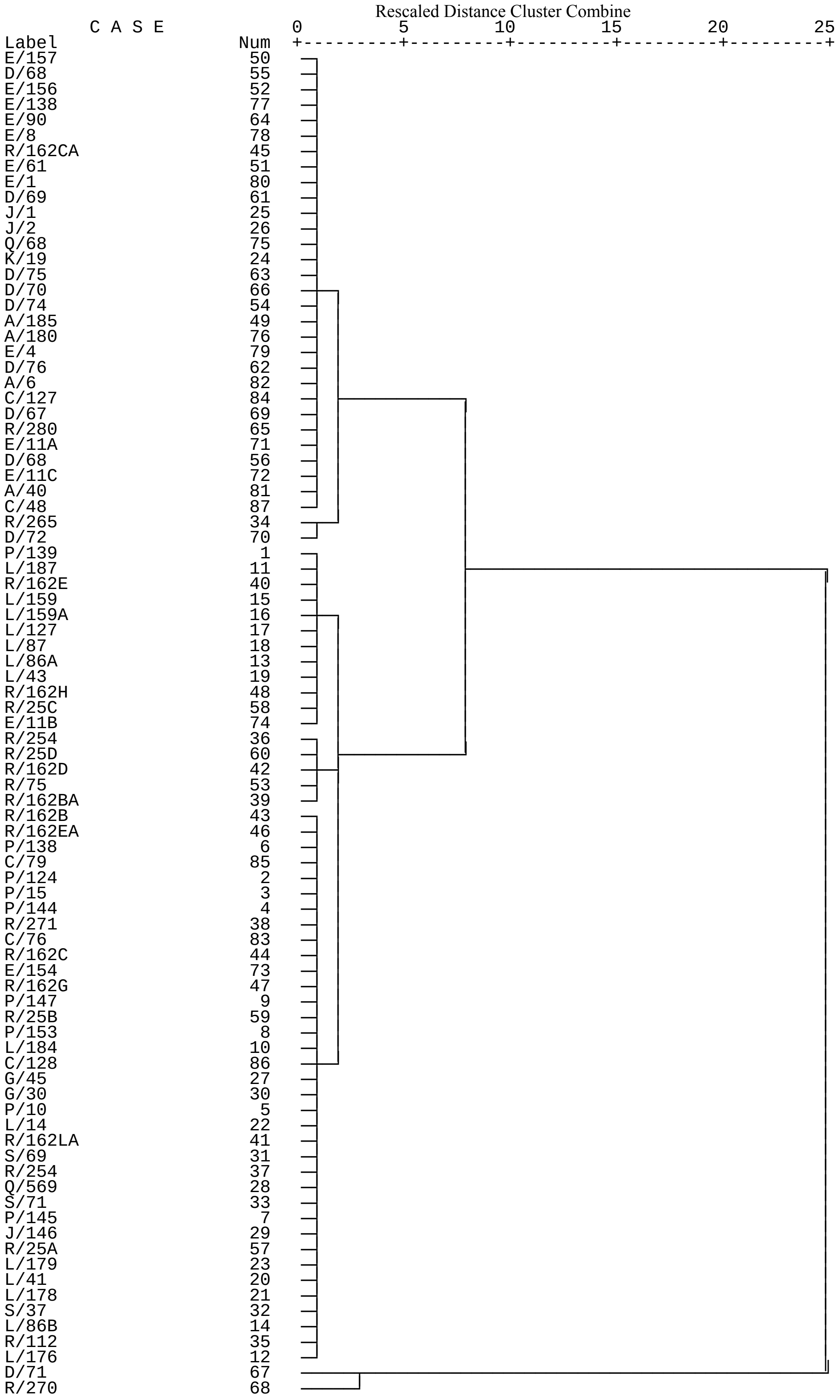

Figure (6.10): Dendogram of the Q-mode cluster analysis (the axis shown at the top indicates the relative similarity of the different cluster groups. Lesser the distance, greater the similarity between objects)

6.8 Principal Component Analysis (PCA)

© 2005 Tous droits réservés.

Principal component analysis (PCA) is a statistical technique that can help explain variation in large data sets of multiple components, such as the groundwater chemistry of the study area. Principal component analysis will allow for the grouping of variables that may help to explain a process that is controlling the particular grouping observed. Principal component analysis allowed finding out associations among variables, thus reducing the dimensionality of the data set. The following constituents were selected to represent the variables for principal component analysis for this study: electrical conductivity, total dissolved solids, pH, sodium, potassium, calcium, magnesium, chloride, Sulphate, fluoride, bicarbonate, nitrate, and hardness. These constituents were measured in the 87 domestic groundwater wells of all study area. Principal component analysis may provide reasons for the variation observed for these constituents.

The work is accomplished by diagonalization of the correlation matrix of the data, which transforms the 13 original variables into 13 uncorrelated (orthogonal) ones (weighed linear combinations of the original variables) called principal components (PCs). The eigen values of the PCs are a measure of their associated variance, the participation of the original variables in the PCs is given by the loadings, and the individual transformed observations are called scores. A varimax rotation allows to `clean up' the PCs by increasing the participation of the variables with higher contribution, and by simultaneously reducing that of the variables with lesser contribution. In that way, the number of original variables contributing to each VF is reduced at the cost of a loss of orthogonality.

6.8.1 Principal Component Analysis (PCA) Results

PCA is based on the diagonalization of the correlation matrix. The observation of that matrix is useful because it can point out associations between variables that can show the global coherence of the data set and will evidence the participation of the individual chemical parameters in several influence factors, a fact which commonly occurs in hydrochemistry. The PCA was carried out by a diagonalization of the correlation matrix, so the problems arising from different measurement scales and numerical ranges of the original variables are avoided, since all variables are automatically autoscaled to mean zero and variance unit. Two important points in interpreting the results of principal component analysis are the absolute values of the loadings and the positive or negative value of the results relative to one another. Table 6.8 summarizes the PCA results including the loadings (participation of the original variables in the new ones) and the eigenvalue of each PC.

© 2005 Tous droits réservés.

The amount of variance (i.e. information) spanned by each PC (also shown in table 6.9) depends on the relative value of its eigenvalue with respect to the total sum of eigenvalues. There are several criteria to identify the number of PCs to be retained in order to understand the underlying data structure (Jackson, 1991). A screen plot (see Fig. 6.11) was used, which shows a change of slope after the second eigenvalue.

Following the criteria of Cattell and Jaspers (1967), which suggest using all the PC's up to and including the first one after the break, we have retained three PCs, having eigenvalues greater than one unit and explaining 70.7% of the variance or information contained in the original data set. Incidentally, the fact that a PC has an eigenvalue higher than one unit means that it contains more information than one original variable, so the decrease of dimensionality is ensured. The absolute value of the loadings (their actual sign depends on the calculation algorithm used) is an indicator of the participation of the chemical variables in the PCs (Fig 6.12). PC1 explains 44.845% of the variance and is contributed by conductivity, TDS, calcium, magnesium, chloride, sodium, nitrate, sulphate and hardness. PC 2 explains 17.648 % of the variance and is mainly participated by pH and fluoride. This factor is positively correlated with NO_3^- and F^- and negatively correlated with pH, Ca^{2+}, and Mg^{2+}. The high negative of pH with the positive relation with NO_3^- indicates nitrification to be taking place according to the equation:

$$\mathbf{NH_4^+ + 1.5O_2 = NO_2^- + 2H^+ + H_2O}$$

Then, NO_3^- is formed through the oxidation of NO_2^- according to the following equation:

$$\mathbf{NO_2^- + 0.5O_2 = NO_3^-}$$

PC 3 (8.208% of the variance) includes alkalinity. We can see that PCs 1 and 3 contain classical hydrochemical variables originating, from mineralization of the geological components of soils, and that can be attributed to human action: nitrate may originate from fertilizers and wastewater.

A bivariate plot of the scores of the chosen PCs will display more information than any bivariate plot of the original variables. Box plots (also called box-and-whisker plots) of the scores were used to identify the most useful PCs to visualize differences between samples. The degree of overlapping between boxes corresponding to different categories will give a good visual impression of the difference or similarity between them. The criteria of differentiation were assayed to show the effect of location of groundwater wells. Figure 6.14a shows box plots for the scores of PCs 1 and 2 according to the location. The box plot of PCs shows the existence of a pattern of differential behaviour of the different areas within the

© 2005 Tous droits réservés.

Gaza aquifer. However, the distribution of the scores in PC 1 follows the sequence Khanyounis < Middle area < Gaza < North = Rafah. In the case of PC 2 (Figure 6.14b) the sequence is not the same but the North is always the zone with highest scores.

Table (6.8): Factor load for groundwater chemical quality

Factor coordinates of the variables, based on correlations			
	Factor 1	**Factor 2**	**Factor 3**
pH	0.13651	**0.712193**	-0.40158
EC	**-0.88278**	0.222747	0.060636
TDS	**-0.87669**	0.223204	0.045169
Na^+	**-0.84923**	0.420825	0.125042
K^+	**-0.39961**	-0.02643	0.222177
Mg^{2+}	**-0.79599**	-0.36609	-0.03525
Ca^{2+}	-0.5039	**-0.5962**	-0.41511
F^-	-0.19523	**0.559086**	-0.24569
CL^-	**-0.89568**	0.243696	0.02147
SO_4^{2-}	**-0.70013**	0.457881	0.043876
NO_3^-	**-0.63945**	-0.27945	-0.30203
HCO_3^-	-0.41609	-0.23422	**0.666553**
Hardness	**-0.76312**	**-0.55292**	-0.25145

Table (6.9): Eigenvalues of correlation matrix, and related statistics

Eigenvalues of correlation matrix, and related statistics				
	Eigenvalue	**% Total variance**	**Cumulative Eigenvalue**	**Cumulative variance**
1	**5.830**	**44.845**	**5.830**	**44.845**
2	**2.294**	**17.648**	**8.124**	**62.493**
3	**1.067**	**8.208**	**9.191**	**70.700**
4	0.898	6.910	10.089	77.610
5	0.795	6.113	10.884	83.723
6	0.648	4.985	11.532	88.709
7	0.507	3.901	12.039	92.610
8	0.397	3.058	12.437	95.668
9	0.326	2.504	12.762	98.171
10	0.220	1.695	12.983	99.867
11	0.014	0.106	12.996	99.973
12	0.004	0.027	13.000	100.000

© 2005 Tous droits réservés.

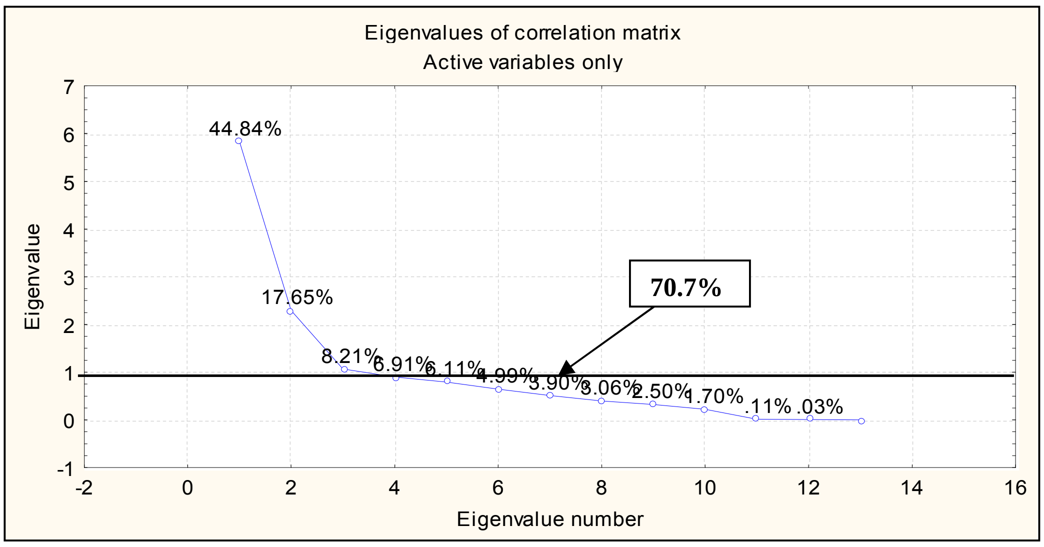

Figure (6.11): Plot of PCA eigenvalue

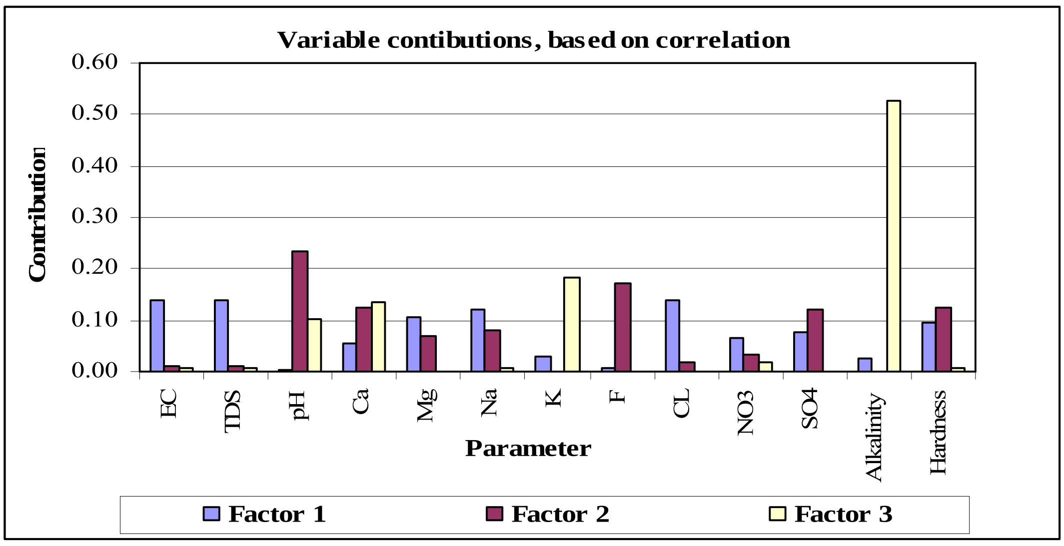

Fig (6.12): Plot of variables contribution in each factor (absolute values)

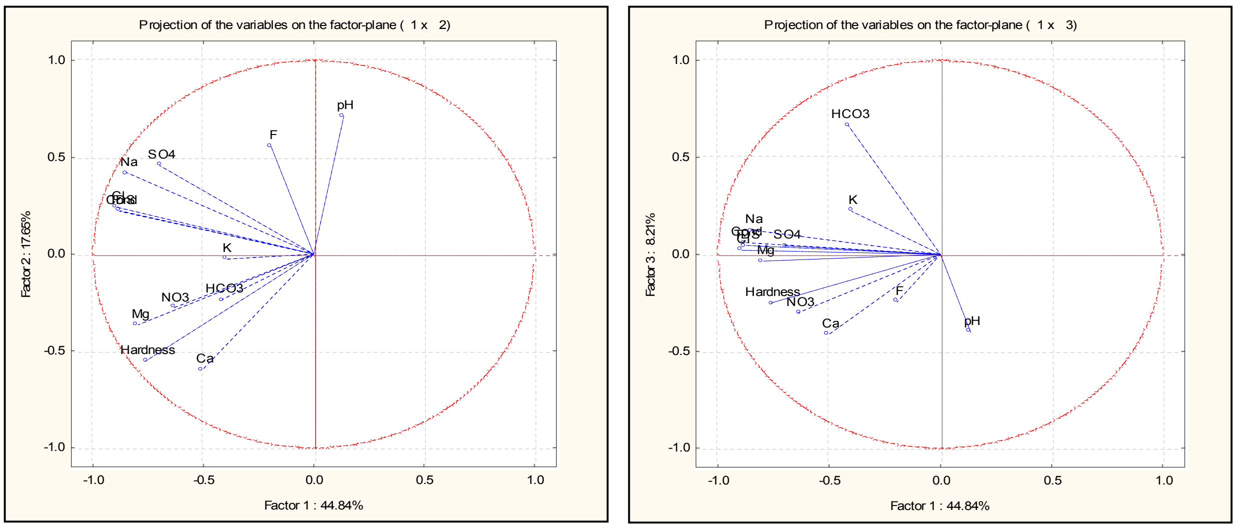

Figure (6.13): Projection of the variables on the factor plan

© 2005 Tous droits réservés.

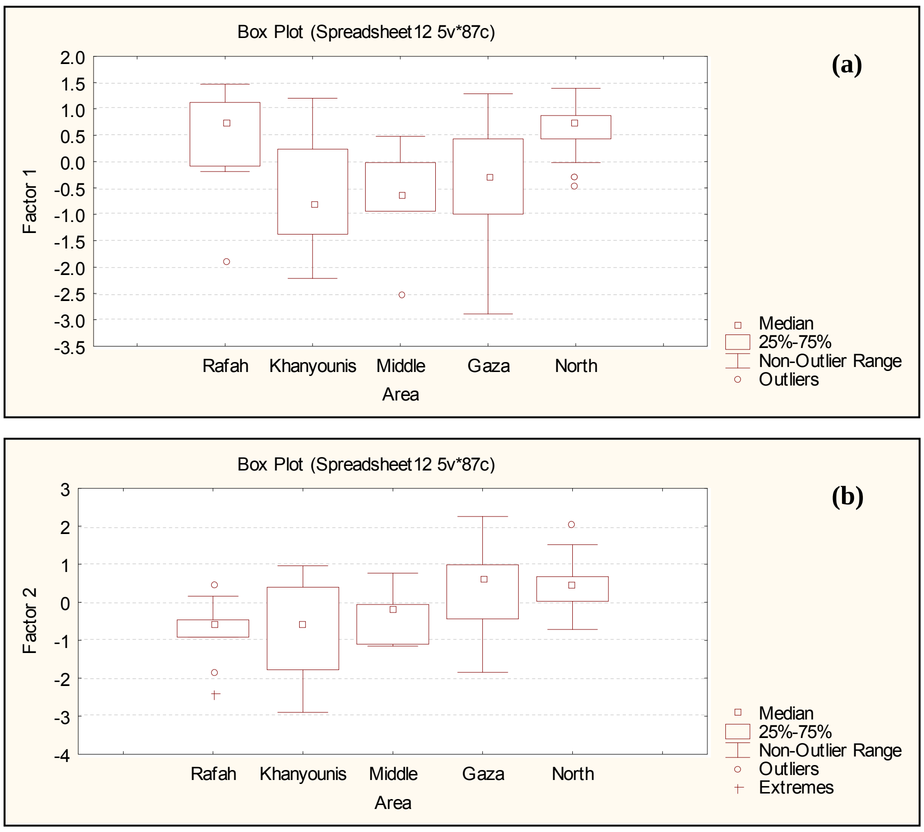

Figure (6.14): Box plots of the scores of PCA according to the sampling point's location: (a) PC 1; (b) PC 2. The line across the box represents the median. The bottom and top of the box show the locations of the first and third quartiles (Q1 and Q3). The whiskers extend to the lowest and highest observations inside the region defined by Q1-1.5(Q3-Q1) and Q3+1.5(Q3-Q1). Individual points with values outside these limits (outliers) are plotted with asterisks.

6.9 Groundwater Chemistry and Explanatory Variables

6.9.1 Bivariate Statistical Test

Table (6.10) presents the simple bivariate relation between groundwater chemistry and potential explanatory variables. The bivariate statistical test was done in order to analyze and investigate the characteristics of water chemistry according to different explanatory variables. TDS shows inversely proportional relationship to the rainfall and the distance of the wells from the seashore, and positive relationship with well depth and discharge. This may be considered the first evidence related to seawater intrusion of the coastal aquifer. The salinity of water increases with the increase of water depth and decreases with distance from the sea, which could be due to the influence of water interface. Calcium, magnesium, potassium and nitrate show an inverse association with well depth, screen depth, screen length and distance from the sea. Chlorides and sodium indicate positive relations with well depth, screen depth and length, well discharge, and population density. This indicates that the pollution includes natural and anthropogenic sources.

© 2005 Tous droits réservés.

The pH is affected negatively with the rainfall intensity. The increase of the rainfall intensity decreases the pH values of groundwater due to the low pH values of the rainwater (mean = 5.2) compared to the groundwater pH values (mean = 7.56). The buffer zone of 250m radius gives a strong relationship with nitrate rather than the larger zones, indicating the localized nature of the problem. On the other hand, the buffer zone of 500 meter radius gave strong relation with TDS, CL^-, Na^+, and SO_4^{2-} rather than 250 meter buffer zone which reveals the regional nature of the contaminants. The sulphate is positively influenced by the water depth, distance from the sea and population density, which indicates that the sources of pollution could be attributed to the seawater intrusion and the leakage from the sewerage system.

To estimate the extent of contamination in the area, maps of the most important water quality parameter, nitrate, were generated by using the available data for the years 1987 and 2002, and compared with the urban locations in each area of the Gaza Strip. The nitrate maps (Fig. 6.15) show large increase of nitrate concentration in groundwater located under the urban areas which reveals the anthropogenic nature of the problem. The mean nitrate concentration for the 87 wells was 125.4 mg/L while the mean value for agricultural wells for the 139 wells in the same period was 90.81 mg/L. Large variations in nitrate concentrations were observed among the samples, with a very high coefficient of variation exceeding 100%. The large ranges of the dependent variable correspond to the large variations in hydrological parameters, and land use. Among the 87 wells, 73 (84%) exceeded the WHO drinking water quality standard (50 mg/L) for nitrate.

© 2005 Tous droits réservés.

Table (6.10): Bivariate Relation of Groundwater Chemistry and Explanatory Variables

	Correlations (domestic wells 2002) Marked correlations are significant at p < .05000 N=87 (Casewise deletion of missing data)								
Variable	SCR.Dep	DWT	TWD	D.S.	Disch.	Scr.L	P.250m	P.500M	Rainfall
pH	0.01	0.08	0.12	0.19	-0.02	0.11	-0.06	-0.05	-0.41
Cond	0.16	0.01	-0.05	-0.14	0.31	-0.18	0.38	0.34	-0.32
TDS	0.15	0.02	-0.03	-0.14	0.31	-0.18	0.37	0.32	-0.34
Na	0.24	0.01	-0.01	-0.05	0.15	-0.03	0.21	0.21	-0.28
K	-0.06	-0.04	0.01	-0.10	0.23	0.07	0.20	0.17	-0.23
Mg	-0.04	-0.15	-0.16	-0.17	0.29	-0.02	0.39	0.33	0.11
Ca	-0.12	-0.15	-0.10	-0.13	0.28	0.08	0.34	0.25	0.10
F	0.06	0.07	0.10	0.11	0.05	0.03	0.05	0.01	-0.22
Cl	0.25	-0.02	-0.02	-0.08	0.19	-0.04	0.26	0.25	-0.24
SO4	0.11	-0.03	-0.03	-0.05	0.12	-0.00	0.13	0.11	-0.31
NO3	-0.22	-0.15	-0.18	-0.12	0.58	-0.06	0.66	0.57	-0.23
HCO3	0.08	-0.05	-0.04	-0.03	0.06	0.06	0.10	0.14	0.46
Hardness	-0.07	-0.17	-0.15	-0.20	0.33	0.02	0.44	0.34	0.12

(Scr.Dep = Depth to Screen, D.W.T = Depth to water table, T.W.D = Total well depth, D.S = Distance from seashore, Disch. = will discharge, Scr.L = Screen length, P.250m = Population within 250m buffer zone, P.500m = Population within 500m buffer zone).

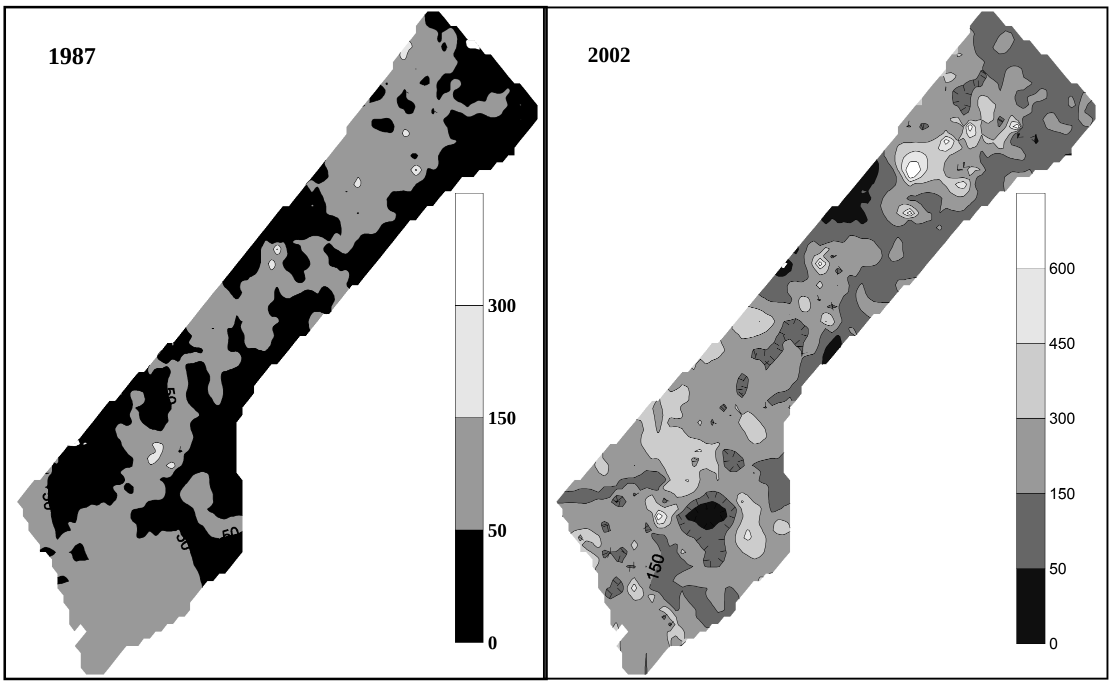

Figure (6.14): Nitrate Concentration in the Gaza Governorates for the years 1987 and 2002.

6.9.2 Application of Multiple Regression Statistical Tests

Regression analyses were performed for groundwater chemical quality data of major cations and anions (Ca^{2+}, Mg^{2+}, Na^{+}, CL^{-}, SO_4^{2-}, and NO_3^{-}) concentrations in mg/L as dependent (response) variable and a set of explanatory variables which are: total well depth, depth to

© 2005 Tous droits réservés.

initial water level, depth to the screen level, well screen length, population density in buffer zone of 250m and 500m radii, rainfall intensity, well discharge (m^3/d), and well distance from the seashore. Forward stepwise procedure was used to identify set of explanatory variables that could best estimate the chemical quality characteristics of groundwater. The regression models were compared based on their R-squared values, and plots of residuals. The data set was divided into two sets. For model building purposes, 57 observations (67% of data set) were used. Also, 29 observations (33% of data set) were used for model validation purposes. The R-square value for each model and solving equation are shown in table (6.11). The R-square in the training and validation data sets for the major cations and anions is low except for modelling nitrate ion.

A t-test was performed to confirm that the observed data does not differ significantly from the validation data. The null hypothesis H_0 for this test is that there is no significant difference between the observed and the validation data. The null hypothesis is rejected if at the given 5% significance level, p-value of the calculated t-value is less than the 0.05. Rejection of the null hypothesis would mean that the validation data are not from the same population as the actual data. R-squared value would determine the closeness of fit. The p-value of the calculated t-value was > 0.05 except for carbonate and calcium. Hence, we fail to reject the null hypothesis. This implies that the validation data are in accordance with the observed data.

Table (6.11): Solving equation and R-square value for each model (Log variable)

Prediction Equation	R-square Training	R-square Validation
{Na} = 4.476 - 1.9608 (Rainfall) + 0.752 (Z-depth) + 0.4 (Discharge)	0.456884	0.49
{Mg} = -0.0861 + 0.866426 (Pop-250m) - 0.216 (Distance-sea-line) - 0.2229 (Pop-500m) + 0.224645 Screen-Length)	0.28182	0.63
{Ca} = 1.0333 - 0.221 (Distance-sea-line) + 0.634 (Rainfall)	0.177118	0.32
{CL} = 7.406 -1.989 (Rainfall) + 0.616 (Z-Depth) -0.26 (Distance-sea-line)	0.21776	0.45
{SO4} = 9.228 + 0.523 (Z-Depth) -0.259 (Distance-sea-line) + 0.801(Screen-Length) – 3.184 (Rainfall)	0.210159	0.27
{NO3} = -5.100 + 1.656(Pop-250m) + 0.416 (Screen-Length) - 0.1374 (Distance-sea-line) - 0.656 (Pop-500M) + 1.0149 (Discharge) + 0.330 (Z-Depth)	0.234635	0.82
{HCO3} = 0.2452 + 0.7651 (Rainfall) + 0.14607 (Discharge) - 0.0637 (Distance-sea-line)	0.196865	0.41

*P_250= Population density at 250m circle radii, and P_500= Population density at 500m circle radii

The Variation Inflation Factor (VIF) was less than 10 for all explanatory variables and also the Condition Index from the Collinearity Diagnostics was less than 30 for all explanatory variables. Thus multicollinearity was not a problem. The model result for nitrate shows

© 2005 Tous droits réservés.

positive relation with the explanatory variables (population density, and screen length) and negative relation to distance from the sea and rainfall. Increase in population density will lead to increase in nitrate concentration. Increase in distance of the wells from the sea will decrease nitrate concentration. This is due to the existence of urban density mostly near the sea and sandy soil. Nitrate model has the highest R-square (0.82) than the other models for the major cations and anions. R-square measures the proportion of variation in the dependant variables explained jointly by the independent variables. For chloride concentration the increase of the distance from the sea line and rainfall will lead to decrease of the concentration while well discharge will lead to increase of the concentration. From the plot of the predicted concentration versus actual concentration (Figure 6.16), we can see that the prediction values follow the sequences of observed values.

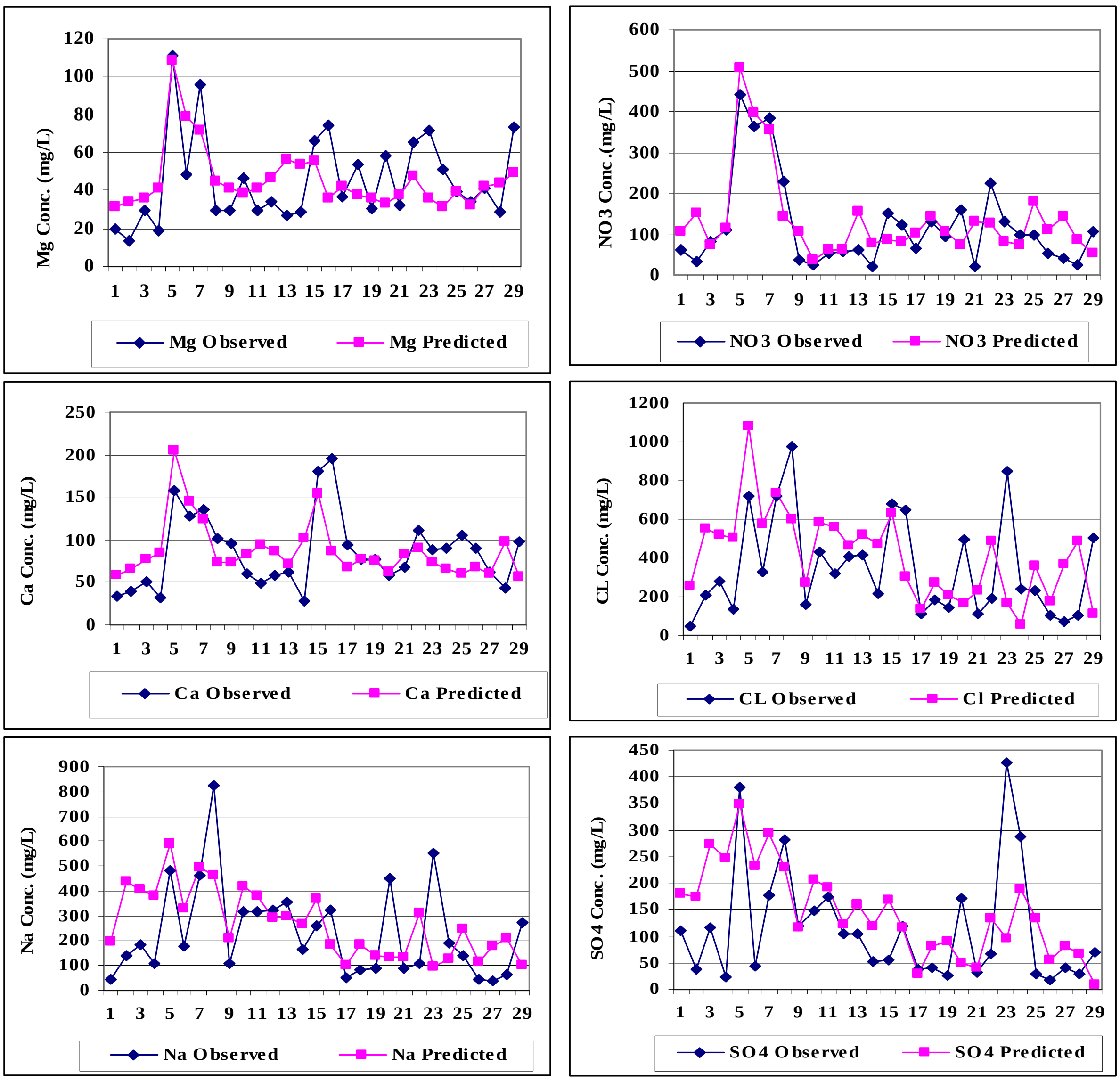

Fig (6.16): Plot of the predicted concentration versus actual concentration

© 2005 Tous droits réservés.

6.10 Neural network application

6.10.1 Training with three-layer feed-forward back-propagation network

In this research, we used the standard three-layer feed-forward back-propagation network [MLP] with a non-linear differentiable log-sigmoid transfer function in the hidden layer. In parallel to the MLP network, The GRNN Linear and, RBF networks for the comparison and finding the optimal network for the prediction of Groundwater hydrochemistry were used. As mentioned by (Florentina M. et., 1999), the number of neurons in the hidden layers cannot be achieved from a universal formula. In this study, to run the MLP network, the formula recommended by Fletcher and Goss, 1993 was used in order to estimate the number of neurons, and to prevent over-fitting. Fletcher and Goss (1993) suggested that the appropriate number of neurons in a hidden layer ranges from $(2n^{1/2}+m)$ to (2n+1), where n is the number of input nodes and m is the number of output nodes.

Running the models shows an increase of the training time as the number of hidden neurons increases. A trial and error approach is incorporated to select the best ANNs architectures. A sensitivity analysis was conducted in this study to examine the effect of the networks sizes on the model performance. In our case we started to train the models with one neuron up to ten, until the optimal results were achieved. For different network sizes, the networks were trained using the first data sets, and then they were validated with the second data sets. ANNs were trained by using the backpropagation algorithm with an initial learning rate of 0.01 and a momentum of 0.3 to reach an error goal of 0.00. The conjugate gradient descent method was used also to improve the networks training and performance. Two types of searching were chosen in building the models. The first search was performed using a quick searching (a minimal search) because this way gives a very rapid feel for what neural networks may be able to achieve with a data set. After several searching trails we tried to do the medium search to find the optimal neural networks. Table 6.12 shows the results of the medium searching method for the optimal networks found for each water quality parameter. Also the table shows the differences between using MLP, GRNN, Linear and RBF models.

The optimal network size for each water quality parameter was selected as one which gave a minimum error and a best correlation in the verification data set. The test error was used to diagnose training problems and as the final check of the performance of the network. The MLP network showed the best result in each searching trail to find the optimal network for each water quality parameter except for potassium where the GRNN network gave a better

© 2005 Tous droits réservés.

performance than the other types of networks. By using the backpropagation algorithm, the optimal networks discovered during that run were selected (for "best" and "lowest verification error"). The Conjugate Gradient Descent algorithm was also used, and the best networks discovered during that run were selected.

In the model-training phase, the model predictions of water quality parameters calculated in terms of total well depth, depth to initial water level, depth to the screen level, well screen length, population density in buffer zone of 250m and 500m radii, rainfall intensity, well discharge, and well distance from the seashore were compared to the observations. The parameters of weights in the models were then adjusted until the root mean square (RMS) errors between model predictions of water quality parameters and the observations were reduced to an acceptable level. In model validation phase, the trained matrices of weight were directly used to calculate the concentration of water quality parameters from the above mentioned input variables. The neural network model simulation requires no iterative computation once the model is satisfactorily trained. Besides the observed-predicted plots, the root mean square errors were used for the validation of the models in this work as it represents the most common measures for the quality and performance of model.

During the training period for the cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), the models showed the correlation coefficients of 0.445, 0.736, 0.606, and 0.653 respectively. Compared with the validation data set for cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), the correlation coefficients were 0.812, 0.988, 0.866, and, 0.999 and the RMS errors were 0.574, 0.643, 5.641, and 0.0730 respectively depending on the number of neurons used in the model. For the anions (HCO_3^-, CL^-, SO_4^{2-}, and NO_3^-), the models showed correlation coefficients of 0.144, 0.714, 0.705, and 0.858 respectively, through the training period. Compared with the validation data set for the anions (HCO_3^-, CL^-, SO_4^{2-}, and NO_3^-), the correlation coefficients were 0.6438, 0.720, 0.866, and 0.936 and the RMS errors were 1.083, 5.94, 0.848, and 0.444 respectively.

The network with eight neurons in the hidden layer for groundwater nitrate modelling was found to have the best performance with correlation of r^2 equal 0.936 and, an error of 0.444. Comparison of the nitrate concentration from model predictions and observations are presented in figure 6.17 for the eight neuron network. The model predictions of nitrate matched good relation with the observations in training and verification sets. The model predictions also showed a reasonable correlation value of 0.845 with test data set. For the other water quality parameters (major anions and cations), the model showed lower

© 2005 Tous droits réservés.

performance than the nitrate model. But in general the selected best network found for each parameter had positive (OK) performance with correlation rages from 0.65 to 0.812 for the major cations and from 0.644 to 0.866 for the anions.

Table 6.12: Conduct Medium Search for an Optimal Network for Groundwater Chemistry

Parameter	Network index	Network type	Inputs variables	Hidden layer (1)	Hidden layer (2)	Training error	Verification error	Training Performance	Verification Performance
pH	1950*	MLP	9	8	-	1.673	1.083	1.038	0.771
	1947	Linear	9	-	-	1.496	1.328	0.946	0.954
	1946	RBF	9	8	-	1.465	1.348	0.927	0.969
	1943	GRNN	9	44	2	1.208	1.410	0.762	0.997
Calcium	880*	MLP	9	8	-	1.160	0.574	0.895	0.607
	877	GRNN	9	44	2	0.935	0.760	0.790	0.710
	874	RBF	9	14	-	0.925	0.817	0.782	0.821
	871	Linear	9	-	-	0.988	0.821	0.835	0.842
Sodium	1190*	MLP	9	3	-	8.533	5.642	0.796	0.508
	1187	RBF	9	13	-	7.765	7.091	0.726	0.684
	1186	GRNN	9	44	2	3.042	7.360	0.284	0.698
	1183	Linear	9	-	-	8.846	8.460	0.827	0.791
Potassium	1800 *	GRNN	9	45	2	0.367	0.065	0.079	0.791
	1796	MLP	9	1	-	4.694	0.078	1.000	0.980
	1791	Linear	9	-	-	3.959	2.170	0.853	27.11
	1782	RBF	9	1	-	4.670	0.787	0.995	2.901
Magnesium	980 *	MLP	9	5	-	0.718	0.703	0.153	0.700
	979	GRNN	9	44	2	3.990	0.751	0.850	0.750
	974	RBF	9	1	-	4.646	0.958	0.991	0.853
	971	Linear	9	-	-	3.787	2.654	0.808	2.551
Chloride	1790	MLP	9	5	-	7.767	6.213	0.745	0.685
	1787	GRNN	9	44	2	5.166	6.781	0.496	0.739
	1784	RBF	9	16	-	6.636	6.898	0.637	0.761
	1782	Linear	9	-	-	8.501	7.400	0.816	0.806
Nitrate	2350 *	MLP	9	8	-	0.821	0.445	0.513	0.352
	2347	RBF	9	17	-	0.674	0.583	0.421	0.454
	2346	GRNN	9	44	2	0.645	0.597	0.403	0.474
	2341	Linear	9	-	-	0.765	0.952	0.478	0.715
Sulphate	1850 *	MLP	9	12	-	0.955	0.848	0.710	0.534
	1847	RBF	9	18	-	0.869	1.254	0.685	0.792
	1844	GRNN	9	44	2	0.625	1.481	0.493	0.934
	1841	Linear	9	-	-	1.215	1.914	0.959	1.209
Bicarbonate	1950 *	MLP	9	8	-	1.673	1.083	1.038	0.771
	1947	Linear	9	-	-	1.496	1.328	0.946	0.954
	1946	RBF	9	8	-	1.465	1.348	0.927	0.969
	1943	GRNN	9	44	2	1.208	1.410	0.762	0.997

* The optimal network found

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

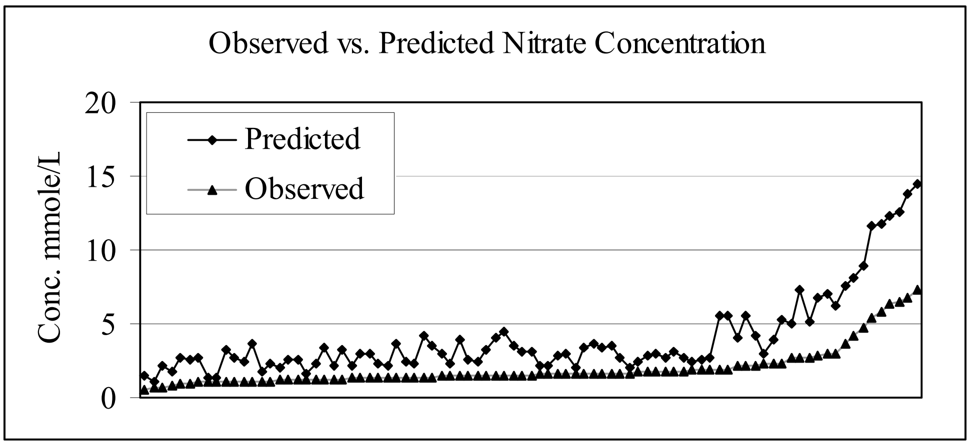

Figure (6.17): Observed versus predicted nitrate concentration (mmole/L) using a three-layer feed-forward back-propagation network

6.10.2 Sensitivity Analysis

In this study, sensitivity analysis on the inputs for each neural network model were conducted in order to find which input variables are considered most important by that particular neural network. Sensitivity analyses can give important insights into the usefulness of individual variables. It often identifies variables that can be safely ignored in subsequent analysis, and key variables that must always be retained. Sensitivity analysis rates variables according to the deterioration in modelling performance that occurs if that variable is no longer available to the model. Table 6.13 shows the sensitivity analyses of the best models found through running different neural network trails for each water quality parameter. The analysis is reported for verification subsets and in two rows – Error, and Ratio. The basic sensitivity figure is the Error. This indicates the performance of the network if that variable is "unavailable". Important variables have a high error, indicating that the network performance deteriorates badly if they are not present.

The Ratio row reports the ratio between the Error and the Baseline Error (i.e. the error of the network if all variables are "available"). A ratio of 1.0 indicates that the variable has no positive effect on the model at all, and can definitely be removed. A ratio below 1.0 indicates that the model actually performs better if the variable is removed. From the error figures in the verification data subset, it is seen that the models will perform badly if the population density on 250 m is unavailable followed by rainfall. The figures show the importance of population density in 250 m for all water quality parameters with strong influence on the nitrate and potassium. For magnesium and sulphate, it is clear from the sensitivity figures that all variables have a significant importance in building the neural network model. Also,

© 2005 Tous droits réservés.

rainfall and screen depth of the wells show significant relation with all water quality parameters. The screen length should be removed from the calcium, sodium, and potassium models and they will actually perform better if the variable is removed. The well discharge, distance from the sea, and population density have strong influence in building the chloride model.

Table (6.13): Sensitivity analysis for the explanatory variables in the verification subsets

Parameter	Index	Scr.Dep.	D.W.T	T.W.D	D.S	Disch.	Scr.L	P.250m	P.500m	Rainfall
Ca^{2+}	Error	0.58	0.58	0.60	0.62	0.60	0.56	0.82	0.56	0.61
	Ratio	1.01	1.01	1.05	1.07	1.05	0.97	1.43	0.98	1.06
Mg^{2+}	Error	0.91	0.78	0.91	0.89	0.99	0.90	1.92	0.77	0.77
	Ratio	1.30	1.11	1.30	1.27	1.41	1.27	2.74	1.10	1.10
Na^{+}	Error	9.17	5.64	5.93	6.29	6.53	5.61	6.59	6.41	6.41
	Ratio	1.63	1.00	1.05	1.11	1.16	0.99	1.17	1.14	1.14
K^{+}	Error	1.31	0.10	0.11	0.11	0.07	0.07	0.46	0.11	0.11
	Ratio	17.98	1.34	1.55	1.55	1.02	0.93	6.28	1.48	1.44
CL^{-}	Error	6.47	5.91	5.90	7.25	11.96	5.99	6.31	8.11	7.13
	Ratio	1.09	0.99	0.99	1.22	2.01	1.01	1.06	1.36	1.20
NO_3^{-}	Error	0.48	0.44	0.45	0.44	0.44	0.45	1.55	0.62	0.45
	Ratio	1.07	0.98	1.01	0.99	0.98	1.01	3.48	1.40	1.01
SO_4^{2-}	Error	1.09	0.91	0.91	0.93	1.42	0.99	0.94	0.97	1.13
	Ratio	1.29	1.07	1.07	1.10	1.67	1.17	1.11	1.14	1.33
HCO_3^{-}	Error	1.17	1.08	1.07	1.17	1.10	1.10	1.12	1.12	1.18
	Ratio	1.08	1.00	0.99	1.08	1.02	1.02	1.04	1.03	1.09

The R-square values for neural networks are higher than the R-square in the regression model as shown in table (6.14). This is the first evidence shows that the ANN models perform better than the regression models.

Table (6.14): Comparison of R-square between ANN networks and regression models

Parameter	Regression ANN models		R-square Regression	
	Training	Validation	Training	Validation
NO_3^{-}	0.858	0.936	0.234635	0.82
CL^{-}	0.714	0.720	0.21776	0.45
SO_4^{2-}	0.705	0.866	0.210159	0.27
Ca^{2+}	0.445	0.812	0.177118	0.32
Mg^{2+}	0.736	0.988	0.28182	0.63
Na^{+}	0.606	0.866	0.456884	0.49
HCO_3^{-}	0.144	0.6438	0.196865	0.41

© 2005 Tous droits réservés.

6.11 Conclusion

The chemical characteristics and contamination of groundwater in the Gaza strip were investigated in relation to land use, urbanization, and hydrological factors. The groundwater shows a very variable chemical composition, e.g. electrical conductivity ranges from 463 to 5837 µS/cm. The chemical composition of groundwater in the Gaza Strip is highly influenced by population density factors. Application of forward stepwise multiple regression models for major cations and anions in groundwater showed no statistically significant difference between predicted and observed values concentration with R-square for model training ranges from 0.177 to 0.456 while R-square for model validation ranges from 0.27 to 0.82. The best model was for prediction of nitrate contamination which includes five explanatory variables (Screen-Length, housing density in 250m and 500m radius area surrounding wells, Distance-sea-line, depth to water table, and well Discharge), which have significant effects on model prediction. Two explanatory variables were excluded from the model since they have no significant effect on the model prediction.

Also in this study, we have presented a successful application of the neural network model to simulate groundwater contamination for the major cations and anions responding to multiple explanatory variables of the Gaza Strip aquifer. The Multilayer Perceptrons (MLP), Radial Basis Function (RBF), Generalized Regression Neural Network (GRNN), and Linear Networks were used. The MLP network gave the best result in each searching trial to find the optimal network for each water quality parameter except for potassium where the GRRN network gave a best performance than the other types of networks. Comparison of ANN modelling via multiple regression shows that the ANN models have better performance than multiple regression in modelling groundwater chemistry parameters. This is due to the lack of strong explanatory variables in the study for water chemistry except for nitrate parameter. This indicates that one or more important variables were not included in the present analysis. In general modelling water chemistry parameters (major cations and anions) has less performance than nitrate modelling. Also, the lack of previous data on water chemical quality did not permit the prediction on time in most of the cases.

Application of ANN modelling shows that the best networks model for water quality parameters was that for nitrate. The buffer zones of 250 meter radius gave strong relation rather than the larger buffers, indicating the local nature of the nitrate problem. The best network found to simulate groundwater contamination by nitrate was the MPL network. For the other water quality parameters the models showed positive (OK) performance. The input

© 2005 Tous droits réservés.

variables are: total well depth, depth to initial water level, depth to the screen level, well screen length, population density in buffer zone of 250m and 500m radii, rainfall intensity, well discharge (m3/d), and well distance from the seashore. The bivariate test showed weak correlation between the input variables and urban groundwater to provide reasonable predictions. The test resulted in considerable unexplained variation in groundwater quality parameters due to the explanatory variables analyzed. But, based on ANN model, groundwater quality with respect to the major cations and anions, depends on a combination of the factors and not on individual factors.

The results indicate that the back-propagation neural network model can be trained to provide satisfactory estimations of urban groundwater chemistry responding to the explanatory variables mentioned above. On the other hand, the Radial Basis Function **(**RBF), Generalized Regression Neural Network (GRNN), and Linear Networks showed lower performance than the MLP network. The development of a neural network model only requires field observations of groundwater quality data, and the implementation of a neural network model requires no iterative computation. Therefore, a neural network can be developed with much less effort than that required for the development of hydrodynamic models. The neural network model can be easily used as a basis for the developing a predictive tool for engineers to assess the potential impact of land use activities and hydrological factors on urban groundwater. Also the Artificial Neural Network model can be used as a management tool for the prediction of urban groundwater chemical quality to be used by the water sector managers and planners aiming at the management of water resources and pollution prevention. However, since the stressed coastal aquifer areas are mostly typical throughout the world, this approach for urban groundwater modelling for major cations and anions can be applied to other aquifers on the regional or international scale.

© 2005 Tous droits réservés.

Chapter 7

General Conclusions and Recommendations

7.1 Conclusions

7.1.1 Nature and overall understanding of the nitrate problem

Contamination of groundwater by nitrate in the Gaza Strip is widespread and occurs over regional and local scales. In many areas the concentration is greater than the WHO level of 50 mg NO_3^-/L (11.3 mg N-NO_3^-/L) which makes the groundwater resource in these areas unfit for drinking. This research have clearly indicated that in the Gaza Strip a variety of land uses and situations in both urban and agricultural environments often result in high nitrate concentrations in the underling groundwater aquifer and the local area surrounding the particular land use. The impacts are mainly on the quality of groundwater resources where there is a potential for the situation to become worse.

Current water management practices have not recognized the implications and complexities of nitrate contamination and the means of minimizing nitrate inputs to groundwater. There is a significant probability that with a continuation of current farming practices in the Gaza Strip it is unlikely to get a significant reduction in environmental nitrate loads available to migrate to the water table. The ongoing clearing of land for both urban and rural development represents a potentially increasing source of nitrates from a variety of both diffuse and point sources. In addition under particular circumstances, a time lag exists between the surface release of nitrate and entry into the aquifer. Therefore there is a potential that nitrate stored in the unsaturated zone has not yet reached the water table, and currently unaffected aquifers are at risk of contamination or increased concentrations could result. However there is a range of technical problems and data deficiencies in relation to the understanding and management of nitrate contamination. This does not relate only to identifying the current or future extent and the long-term trends in groundwater concentrations, but it relates to the recognition of the extent of major impacts, community education programs, planning of development, and research works.

© 2005 Tous droits réservés.

7.1.2 Understanding of risks and processes

There is a wide variability in the conditions which yield high nitrate concentrations in the groundwater. The highest concentrations are found in the shallow unconfined aquifers which are most susceptible to contamination, but migration to depths of 50 m or more does occur. The potential layering of nitrate concentrations means that in areas of thick aquifers multiple observation wells are likely to be required. It appears that, wherever a source of nitrogen exists there will be a potential for nitrate to reach the groundwater beneath the source. However the concentration of leachate that reaches the groundwater depends on local conditions at the source. That is, certain areas are at greater risk of being contaminated by nitrate than others. The key factors which influence the ultimate load of nitrates to the groundwater are:

- Variations in soil type and recharge rate which controls the rate of leachate migration through the soil zone;
- The conditions in the soil zone and the unsaturated zone which may prevent the production of nitrate or denitrify nitrate; and
- The conditions in the aquifer that allow denitrification or attenuation to occur by other means such as dilution.

7.1.3 Principal features of the analysis and findings

In this study, spatial and temporal variations of nitrate trends were examined by kriging and nonparametric statistical techniques. The mass balance approach for nitrogen cycle in the Gaza Strip was calculated. Hydrochemical evolution of groundwater parameters and nature of contamination were considered. Prediction of groundwater nitrate contamination in agricultural areas was studied by using the Artificial Neural Networks (ANNs) newly applied models. The models depict the most significant factors related to nitrate contamination. Modelling the effect of urbanization and hydrological factors on groundwater chemical quality (major cations and anions) was done by using classical statistical techniques and ANN modelling. The main findings of these analyses and modelling procedures are:

- Wastewater from urban centres is the major contributor to the nitrogen load followed by agriculture activities.
- Inorganic fertilizers and manure are considered the dominant sources of nitrogen associated with agriculture.

© 2005 Tous droits réservés.

- Solid waste leachate, drinking water networks leakage and precipitation are considered minor sources of nitrogen compared to wastewater and agricultural practices.
- There are three dominant types of groundwater quality with nitrate concentrations ranging from decreasing (2%), constant (67%) to increasing (31%).
- According to stepwise forward and backward multiple regression model, the main factors that having strong influences on nitrate rising level in groundwater in agricultural areas are nitrogen load, housing density in 500-m radius area surrounding wells, water table, and infiltration rate with RMS=0.8479 between predicted and observed nitrate concentration. Two explanatory variables (screen length and well discharge) were excluded from the model since they have no significant effect on the model prediction.
- According to the ANN model, the best network found to simulate nitrate was the MLP network with six input nodes and four hidden nodes. The input variables are: nitrogen load, housing density in 500-m radius area surrounding wells, water table, well discharge, and infiltration rate. The best MLP network found had good performance (correlation 0.9773, and error 8.4322).
- The order of abundance of major cations is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ where the abundance of the major anions is $CL^- > HCO_3^- > NO_3^- > SO_4^{2-}$.
- Strong and positive correlations with the major cations and anions in groundwater in the study area e.g. EC and TDS (r =0.99), chloride and sodium (r =0.95).
- Higher ratio (>0.5) of $(Na^+ + K^+)$ versus TC, depicting the contribution of cations via soil ion exchange.
- Molar Na^+: Ca^{2+} ratios are more than one unit (6.38), indicating a deficiency of Ca^{2+} in groundwater samples.
- The concentration of HCO_3^- in groundwater ranges from 126 to 430 mg/L. Relatively high HCO_3^- concentrations exist in eastern part of the Gaza Strip where relatively low HCO_3^- content, below 150 mg/L, is dominant in western part of the Gaza Strip especially in Rafah and Jabalia areas. Natural processes such as the dissolution of carbonate minerals and dissolution of atmospheric and soil CO_2 gas could be a mechanism which supplies HCO_3^- to the groundwater.
- The large group of groundwater wells are located in the area of alkaline water type with prevailing sulphate. Some group of water wells are located in the area of earth alkaline water type with prevailing bicarbonate, sulphate and chloride while only one

© 2005 Tous droits réservés.

well of the 87 wells is located in the area of normal earth alkaline water with prevailing chloride.

- The R-mode factor analysis reveals that the EC and TDS in the study area are mainly due to Na^+ and Cl^-, though sulphate also plays a substantial role in determining EC and TDS. This second factor accounts for the temporary hardness of the water. The other factors (3-8) are characterized by the dominance of only one variable each, such as bicarbonate, K^+, Fluoride, NO_3^-, $Ca^{2+}$and pH and together these six factors account for 33.42% of the total variance. The single dominance of variables in each factor indicates non-mixing or partial mixing of different types of water.
- The high variance of factor one of Q-mode factor analysis (95.5% out of 99.1%) suggests that seawater intrusion plays a dominant role in the hydrochemical evolution of groundwater in the Rafah, Khanyounis, middle area and Gaza city and explains the recharge that happens in the Northern area.
- The similarity of the Q-mode cluster analysis to the Q-mode factor analysis confirms the interpretations made using the Q-mode factor analysis.
- The high negative of pH with the positive relation with NO_3^- indicates nitrification to be taking place.
- The best ANN model (MLP network) for groundwater quality parameters was found for nitrate (correlation 0.936, and error 0.444).
- The ANN models showed better performance than multiple regression models for the prediction of groundwater chemical parameters (major cations and anions).
- The buffer zones of 250 meter radius gave strong relation rather than the larger buffers, indicating the local nature of the nitrate problem.

7.1.4 Deliverables of the research work:

The main deliverables produced by this research work are:

- Production of mass balance of nitrogen loads and finding the most potential significant factors to be managed in the future in each area of the Gaza Strip.
- Prediction model for the relationship between groundwater nitrate and land use and environmental factors.
- Defining the extent of nitrate contamination within local groundwater systems and investigating the main source(s) of elevated nitrate in groundwater.
- Elucidation of the spatial and temporal interactions of groundwater resources quality with the environment.

© 2005 Tous droits réservés.

- Investigation and defining the hydrochemistry evolution of the Gaza Strip coastal aquifer.
- Prediction model for the relationship between groundwater chemical quality of the Gaza Strip aquifer (major cations and anions) and urbanization and hydrological factors.

7.1.5 Limitations of the research work

The understanding of nitrate contamination and the processes causing it has been developed in the Gaza Strip from a collected set of data available from 1987 to 2002. There is a limited routine monitoring of nitrate in groundwater and there are numerous uncertainties regarding the nature of the data available. Time series data are typically inadequate to establish seasonal and other variability in groundwater nitrate contamination. Some of the nitrate analyses available have been obtained from water samples taken at the initial construction of a groundwater well. There are also concerns regarding the quality of the early analyses and the manner in which results are reported. There is still no consistent way of reporting nitrate concentration although most workers report concentrations of NO3 as NO3 rather than NO3 as N. Insufficient data about land use and environmental factors. Routine groundwater monitoring programs doesn’t have consistent sampling periods. The integrity of the data on nitrate concentrations is not consistent with the land use and hydrological factors. Some wells are closed and others opened in each year which interruptions in the statistical and ANN applications. The lack of previous data on water chemical quality did not permit the prediction on time in most of the cases.

7.2 Recommendations

This study has identified a broad range of issues associated with the existing and future management of nitrate in groundwater in the Gaza Strip. The following recommendations are put forward to establish management actions, and to reduce gaps in our existing knowledge.

7.2.1 Management and policy development

- Change the focus of policy and research on nitrate contamination in groundwater from point sources of nutrients (which can be managed) to broad area diffuse sources (which require more complex management);
- Develop guidelines for groundwater protection zones around major potable water supply areas specifically focusing on nitrate sources;

© 2005 Tous droits réservés.

- Develop programs for land management which improve nutrient applications in broad farming area; and
- Encourage the Palestinian Water Authority to more actively include water quality (particularly nitrate) in developing future policy decisions.

7.2.2 Confirmation of nitrate trends

- Develop suitable groundwater monitoring networks in key areas where nitrate contamination from existing land use is already known. This will need to be conducted in association with all relevant agencies;
- An emphasis should be placed on fully categorizing the extent of nitrate pollution laterally and vertically; and
- Evaluate any long-term urban water supply monitoring data on nitrate concentrations to establish nitrate trends. This must incorporate information in the areas which are outside the study areas in this research.

7.2.3 Research activities

In general there is little detailed understanding of the groundwater conditions and the nitrate contamination processes, so that the interpretation of the limited data is likely to be inconclusive. It is important that, particularly in risk areas, the characteristics of the groundwater system including the soil and unsaturated zones, are carefully understood to enable an evaluation of nitrate contamination to be undertaken. Future investigations and research should focus on obtaining a clearer understanding of the nature and extent of nitrate contamination. The key issues are to:

- Develop a comprehensive set of reliable data on which to base interpretations and conclusions;
- Undertake detailed research of the key processes of nitrate contamination to obtain greater understanding of the relationship between nitrate release and downwards migration and resulting groundwater contamination and impact.
- Establish techniques for identifying risk to groundwater from nitrate pollution around key industries which can produce high nutrient loads. Two major tasks are proposed:
  a. Risk mapping in areas where there is extensive area nutrient loading; and
  b. Development of a ‘pollution index’ for more localized nitrate source management, e.g. point sources, taking into consideration factors such as water table depth, lithology, groundwater flow system, and groundwater beneficial use.

© 2005 Tous droits réservés.

- Establish research into denitrification of nitrate, including determination of the key processes and conditions allowing denitrification. The relationship of denitrification to climate is an important issue.
- Establish trial sites in areas where land management is changing and monitor impacts on nutrients in both soils and groundwater.

7.2.4 Technical issues required for management

The major technical issues relate to developing both an adequate data set to identify the spatial and temporal patterns of nitrate contamination and an understanding of the major processes affecting nitrate behaviour in the soil and groundwater system.

A. Data sets

1. Establishment of routine monitoring programs using consistent sampling periods agreed sampling protocols and analyses, recovering samples from representative wells which provide a suitable aquifer thickness is necessary. Likewise it would be preferred to have consistent reporting of nitrate concentrations (preferably NO3 as N mg/L);
2. Consolidation of the data base on nitrate concentrations commenced for this study could provide greater focus on the key areas for future investigation and research; and
3. The development of statistical techniques to refine the definition of nitrate source areas in localities where there is mixed land use and no clear relationship between nitrate concentration and land use.

B. Nitrate loads and contamination processes

The importance of the local conditions on the ultimate nitrate concentrations in groundwater means that future works should be focused on areas at risk of groundwater contamination. This requires identifying the areas to be targeted for detailed studies and improved management of various land use activities. For each area at risk, the factors needing to be addressed relate to the nitrogen loading and the resultant leaching of nitrate to the water table and the behaviour of nitrate within a groundwater plume. These are:

1. For the soil and unsaturated zones, an integrated approach to land planning, both rural and urban, is needed from soil scientists, agronomists and hyrdrogeologists to develop techniques to minimize nitrate loads from particular activities. There is a need to understand the soil and unsaturated zone processes and the generation of nitrate leachate and its migration to the water table. There is a need to develop an understanding of:

© 2005 Tous droits réservés.

- Processes contributing to leaching for strategic land uses in risk areas and the effects of changes in land management practices on leaching;
- The key drivers of nitrate loads through soil to the water table and a quantitative assessment of leaching potential for different soils, land uses and management practices. This includes better understanding of nitrogen uptake by plants in particular soil and climatic regimes; and
- The kinetics of nitrate migration through the unsaturated zone and the likely flux of nitrate to reach the water table. This may include verification of existing and development of new modelling tools, including instrumented monitoring sites.

2. In the saturated zone there is limited predictive capability for the longer-term attenuation processes within a groundwater plume.
    - Groundwater samples from individual bores may record lower concentrations than others in the same area, which may reflect conditions in an aquifer system and the pathways by which nitrate may migrate within the aquifer system;
    - There is a need to fully understand the groundwater flow system in the vicinity of any of the types of nitrate sources so that the data generated on the nitrate loads and the monitoring that has been or may be introduced is able to be interpreted effectively;
    - It is generally assumed that once a nitrate plume is generated, it will continue to migrate down gradient toward a receiving environment with no loss of nitrate. From a site management perspective this can have implications for the sitting of nitrate generating developments;
    - An understanding of nitrate dilution, dispersion and attenuation, as well as appropriate modelling techniques and monitored study sites, is needed. In addition data is required to identify the impacts on receiving waters and to asses the health risk which may result in potable aquifers with nitrate concentrations above drinking water standards; and
    - Such an understanding will include detailed understanding of denitrification processes, and establishing guidelines for identifying sites where denitrification may occur.
3. The vertical extent of nitrate contamination within an aquifer is not well understood. More detailed documentation of vertical as well as lateral and temporal conditions would assist in understanding the distribution and potential migration of high nitrate groundwater within aquifer systems. Leakage of nitrate to deeper groundwater systems and the factors which may allow this to occur need to be considered.

© 2005 Tous droits réservés.

4. Detailed understanding of the variation in groundwater nitrate concentrations, including the relationship of recharge to nitrate concentration is currently inadequate. This has implications in understanding the behaviour of nitrate plume migration and the ability to utilize nitrate affected resources;
5. In urban areas there is a need to identify the impact of sewers on nitrate sources in groundwater.

© 2005 Tous droits réservés.

References

1 A. Th. Aerts-Bijma, H.G Jansen, H.A.J. Meijer, 1997. SO-02 Nitrogen balance of an agro-ecosystem, Scientific Report 1995-1997, Center of isotope research, The Netherlands.

2 Adamus C. L. and Bergman M. J., Estimating non-point-source pollution loads with a GIS screening model. Water Res. Bull. (1996) 31, 647-655.

3 Addiscott, T.M., Wagenet, R.J., 1985. Concepts of solute leaching in soils: a review of modeling approaches. Journal of Soil Science 36, 411-424.

4 Alawneh M., 1996. Nitrate formation and transport through sandy soils, MSc. Thesis EE 235, IHE, Delft, The Netherlands.

5 Aller, Bennet, Lehr, & Petty, R. J. (1985) DRASTIC: a standardized system for evaluating groundwater potential using hydrogeological settings. Environmental Research Laboratory, US EPA, Ada Oklahoma, EPA/600-2-85/018.

6 Almahallawi kh. Abou Daya N., Groundwater Quality in the Gaza Strip. Palestinian Hydrology Group (PHG), (2001) Gaza-Palestine.

7 Andersen & Gosk, (1989). Applicability of vulnerability maps in environmental geology Water Science, 13(1), 39-43

8 Andrade J. M., Padra D., Muniategui S., GonzaA lez E. And Alonso E. (1992) Multivariate analysis of environmental data for two hydrographic basins. Anal. Lett. 25, 379±399.

9 APHA (1992), Standard methods for the examination of water and wastewater: American Public Heath Association, Washington, DC.

10 Aruga R., Negro G. and Ostacoli G. (1993) Multivariate data analysis applied to the investigation of river pollution. Fresenius. J. Anal. Chem. 346, 968±975.

11 Ashley R. P. and Lloyd J. W. (1978). An example of the use of factor analysis and cluster analysis in groundwater chemistry interpretation. J. Hydrol. 39, 355±364.

12 Baker, D., L. Wallrabenstein, and R. Richards 1994. "Well Vulnerability and Agricultural Contamination: Assessments from a Voluntary Well Testing Program," Procedings of the Fourth National Conference on Pesticides: New Directions in Research, Development and Policy. D. Weigmann, ed. Blacksburg, Virginia: Virginia Water Resources Center.

13 Barrchlough, D., M. J. Hyden and G.P. Davies, 1983. Fate of fertilizer nitrogen applied to grassland. I.Field leaching results. J. Soil Sci. 34:483-497.

14 Barringer, T., Dunn, D., Battaglin, W., and Vowinkel, E., 1990. Problems and Methods involved in relating land use to groundwater quality. Water Resources Bulletin 26, 1-9.

15 Benton J. Jones, Benjamin Wolf and Harry A. Mills, 1991. Plant Analysis Handbook. Micro-macro Publishing, Inc

© 2005 Tous droits réservés.

16 Bergstrom, L. and Brink, N., 1986. Effects of differentiated applications of fertilizer N on leaching losses and distribution of inorganic N in the soil. Plant and Soil. 93:333-345.

17 Bishop, C. (1995). Neural Networks for Pattern Recognition. Oxford: University Press.

18 Blodgett, R. 1993. "Drinking Water Vulnerability Assessments in Texas," Proceedings—1993 Annual Conference, American Water Works Association.

19 Bouldin. D.R., Klausner, S.D. and Reid, W.S., 1984. Use of nitrogen from manure. Pp.221-284. In R.D. Hauk (ed.). Nitrogen in crop production. Amer. Soc. Agron., Madison, WI.

20 Bouma J., 1979. Subsurface Application of Sewage Effluent. In Planning the Uses and Management of Land. ASA-CSSA-SSSA, Madison, Wisconsin. pp 665-703.

21 Brady, N.C. 1974. The Nature and Properties of Soils. 8th Edition. *Macmillan* Publishing Co., Inc., New York.

22 Brezonik, P.L., 1976. Nutrients and other biologically active substances in atmospheric pricipitation. J. Great lakes Res. 2, suppl. 1:166-186.

23 Broomhead, D.S. and Lowe, D. (1988). Multivariable functional interpolation and adaptive networks. Complex Systems 2, 321-355.

24 Bruce Durham, Stephanie Rinck-Pfeiffer, Dawn Guendert, Integrated Water Resources Management-through reuse and aquifer recharge.

25 Bruce, B. W. and P. B. McMahon, Shallow groundwater quality beneath a major urban center: Denver, Colorado, USA. J. Hydrol. (1996) 186:129-151.

26 Burkart, M.R., Kolpin, D.W., 1993. Hydrologic and land use factors associated with herbicides and nitrates in near-surface aquifers. Journal of Environmental Quality 22, 646-656.

27 Cattell, R. B., & Jaspers, J. A. (1967). A general plasmode for factor analytic exercises and research. Multivariate Behavioral Research Monographs.

28 Chapelle, F.H., 2000, Ground-water microbiology and geochemistry: New York, John Wiley and Sons, 468 p.

29 Clark, I., Fritz, P., 1997. Environmental Isotopes in Hydrology. Lewis Boca Ratopn/NewYourk.

30 Close M.E., Rosen, M.R., and Smith, V.R., 2001. Fate and transport of nitrates and pesticides in New Zealand's aquifers. In: *Groundwater of New Zealand*, edited by M.R. Rosen and P.A. White. New Zealand Hydrological Society Inc., Wellington. Pages 185-220.

31 Colbourn, P. and Dowdell, R.J., 1984. Denitrification in field soil. Plant and Soil. 76:213-226.

32 Cooper, R.M.,and Istok, J.D., 1988, Geo-statistics applied to groundwater

© 2005 Tous droits réservés.

contamination, 1, methodology: Journal of environmental Engineering, v, 114, no. 2 p.270-285.

33 Cosgrove, W.J. and F.R. Rijsberman (2000) World Water Vision: Making Water Everybody’s Business. London: Earthscan Publications.

34 Custodio, E., (1997); Groundwater quantity and quality changes related to land and water management around urban areas: blessing and misfortunes. In: Chilton, J. (Ed.). Proc. of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, Vol. 1, problems, Processes and Management, 21-27 Sept., (1997). Gallard Publ. Ltd., Great Yarmouth, UK, pp. 11-22.

35 Dalton MG, Upchurch SB. Interpretation of hydrochemical facies by factor analysis. Groundwater 1978; 16:228–33.

36 Danielsson A, Cato I, Carman R, Rahm L. Spatial clustering of metals in the sediments of the Skagerrak/Kattegat. Appl Geochem 1999; 14:689–706.

37 Davis JC. Statistics, data analysis in geology. New York: Wiley, 1973. 550pp.

38 Dowdell, R. J. and C. P. Webster, 1984. A lysimeter study of the fate of fertilizer nitrogen in spring barely crops grown on a shallow soil overlying chalk; denitrification losses & the nitrogen balance. J. of soil science. 35:183-190.

39 Dowdell, R.J., Colbroun, P. and Cannel, R.Q., 1987. A study of mole drainage with simplified cultivation for autumn-sown crop on a clay soil. 5. Losses of nitrate-N in surface run-off and drain water. Soil and Tillage research. 9:317-331.

40 Eckhardt, D.A.V., Stackelberg, P.E., Relation of groundwater quality to land use on Long Island, New York. Groundwater (1995) 33, 1019-1033.

41 Egginton, G.M. and Smith, K.A., 1986. Nitrous oxide emission from a grassland soil fertilized with slurry and calcium nitrate. Journal of Soil Science. 37:59-67.

42 Eiswirth. M & Hotzl. H. (1994). Groundwater contamination by leaky sewerage systems. Proceedings of the 15th Congress of the International Association of Hydro-geologists, “Water Down under 94”. Adelaide (Australia) 21-25 November (1994). Vol. A. p. 111-114.

43 Eiswith. M and Hotzl, (1997). The impact of leaking sewers on urban groundwater. In: Chilton, J. (Ed.). proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Vol. 1, problems, Processes and Management, 21-27 September (1997). A.A. Balkema, Rotterdam/Brookfield, pp. 399-404.

44 El-Khattari S. and N. Kharabsheh, 1983. Ammonia loss from surface applied ammonium Sulphate and urea in some Jordanian soils. Dirasat, vol. X, no. 1 University of Jordan.

45 Emerson, K, R, E, Lund and R. V. Thurston, 1975. Aqueous ammonia equilibrium calculations: Effect of pH and Temperature. J. Fish. Res. Board Can. 32:2379-383.

46 Fetter, C. W., (1994) Applied Hydrogeology (Third ed.) Macmillan College

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Publishing Company, New York, NY, USA, 691 pp.

47 Fetter, C.W., 1988. Applied Hydrogeology. Second edition. Merrill Publishing Company, Columbus, Ohio, USA. 592 pages.

48 Firestone, M.K., 1982. Biological denitrification. In F.J. Stevenson (ed.). Nitrogen in agricultural soils. Agron. Monogr.22. ASA, CSSA, and SSSA, Madison, WI., pp. 298-326.

49 Fletcher, D., Goss, E., 1993. Forecasting with neural networks: an application using bankruptcy data. Inf Management 24, 159–167.

50 Florentina M. et., 1999. pH modeling by neural networks. Application of control and validation data series in the Middle Loire River, Ecological modeling 120, 141-156.

51 Focazio, M.J., Z. Szabo, T.F. Kraemer, A.H. Mullin, T.H. Barringer, and V.T. de Paul, 2000, Occurrence of selected radionuclides in ground water used for drinking water in the United States: A reconnaissance survey, 1998. U.S. Geological Survey Water-Resources Investigations Report 00-4273. 40 p.

52 Fovell R, Fovell MY. Climate zones of the conterminous United States defined using cluster analysis. J Climate 1993; 6:2103–35.

53 Freeze R.A. and Cherry, J.A., 1979. Ground water, Prentice-Hall, Inc., Englewood cliffs, New Jersey.

54 Fried, M., K.K. Tanji, and R.M. Van de Pol, 1976. Simplified long term concept for evaluating leaching of nitrogen from agricultural land. J. Environ. Qual. 5:197-200.

55 Gaza Municipality, Water quality Monitoring Laboratory, Wastewater Characteristic.

56 Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, NewYork. 320 pages.

57 Goldenberg, Mandel, & Magaritz, 1986. Water-rock interaction at the mixing zone between chemically different bodies of groundwater: Implications for management of sand aquifers. Hydrological Sciences Journal, 31, 413.

58 Gowler, A. 1983 Underground purification capacity. In: *Groundwater in Water Resources Planning,* Proceedings of the Koblenz symposium. IAHS Publication 142, Volume 2, International Association of Hydrological Sciences, Wallingford, UK, 1063-1072.

59 Gracis Posadas H., J. L. Rico Gutierrez and P. A. Gracia Encina, 1996. Aerobic treatment of leachates. J. Environ. Sci. Health, A31 (6):1255-1262.

60 Haan, C. T., 1977, Statistical methods in hydrology, The Iowa State University Press.

61 Hallberg, G.R. (1989) Nitrate in groundwater in the United States. *In:* Nitrogen Management and Groundwater Protection. Ed. Follett, R.F. Elsevier, Amsterdam. pp. 35–74.

© 2005 Tous droits réservés.

62 Hassan, A. E., 2001. Prediction of plume migration in heterogeneous media using artificial neural networks. Water Resources Research 37 (3), 605–623.

63 Hassoun, M.H., (1995). Fundamentals of Artificial Neural Networks. The MIT Press, Cambridge.

64 Hauk, R.D., 1986, Field Measurement of denitrification over view. In Hauk, R.J. and Weaver, R.W. (eds), Field Measurements of Dinitrogen Fixation and Denitrification, special Publication No. 18, Soil Sci Soc. Amer., Maison, Wisconsin, pp. 59-72.

65 Haykin, S. (1994). Neural Networks: A Comprehensive Foundation. New York: Macmillan Publishing.

66 Heikkinen, K., Raimo Ihme and Esko Lakso, 1995. Contribution of cation exchange property of the overflow wetland peat to removal of NH_4^+ discharged from some finishing peat mines. Applied Geochemistry 10:207-214.

67 Hem, J. D. 1989. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water-Supply Paper 2245. Washington, D. C.

68 Hirsch, R.M. and J. R. Slack, 1984, a nonparametric trend test for seasonal data with serial dependence: *Water Resources Research 20*, 727-732.

69 Hong YS, Rosen MR., Intelligent characterization and diagnosis of the groundwater quality in an urban fractured-rock aquifer using an artificial neural network. Urban Water (2001) 3:217-228.

70 Hongguage Cheng, Zhifeng Yang, Christine W, Chen, (2003). An expert system for decision support of municipal water pollution control, Engineering Application of Artificial Intelligence.

71 Howard K, Eyles WF, Livingstone S. Municipal landfilling practice and its impact on groundwater resources in and around urban Toronto, Canada. Hydrogeol. J 1996;4(1):64–78.

72 IDT (Intelligent Decisions Technologies), 1998. WQStat Plus. Intelligent Decisions Technologies Ltd., Longmont, Colorado, USA.

73 Jackson J. E. (1991). A User's Guide to Principal Components. Wiley, NewYork.

74 Jackson, R.E. (1980). Aquifer Contamination and Protection. UNSCO, Paris, France, 440 PP.

75 Juergens-Gschwind, S., (1989). Groundwater nitrates in other developed countries (Europe)-relationships to land use patterns. *In* Nitrogen Management and Groundwater Protection. Ed. Follett, R.F. Elsevier, Amsterdam. pp. 75-138.

76 Jury, A. William and Donald R. Nielsen, 1989. Nitrate transport and leaching Mechanisms. In R. F. Follett. Nitrogen management and ground water protection. P. 139-155.

© 2005 Tous droits réservés.

77 Kayamanidou, N.M., & Siccardi, F., Water in the Mediterranean: Collaborative Euro-Mediterranean Research, Forthcoming, European Commission.

78 Keeney D., 1986. Sources of nitrate to groundwater. CRC Critical Reviews in Environmental Control. 16:257-304.

79 Keeney D.R., 1989. Sources of nitrate to groundwater. In R.F. Follett (ed.). Nitrogen Management and Grounwater Protection. pp: 23-33.

80 Khairy Al-Jamal and M. Shoblack, 2000, Institutional reforms towards sustainable water sector.

81 Kolpin, D.W., Kalkhoff, S.J., Goolsby, D.A., Sneck-Fahrer, D.A., and Thurman, E.M., 1997, Occurrence of selected herbicides and herbicide degradation products in Iowa's ground water, 1995. Ground Water, v. 35, no. 4, p. 679- 688.

82 Kuenen J. G. and Robertson L.A., 1994. Combined nitrification denitrification process. FEMS Microbiology Reviews 15:109-117.

83 Laaksoharju M, Skarman C, Skarman E. Multivariate mixing and mass balance (M3) calculation, a new tool for decoding hydrogeochemical information. Appl Geochem 1999; 14:861–71.

84 Lasserre F., Razack M., Banton O., A GIS-linked model for the assessment of nitrate contamination in groundwater. J Hydrol 224 (1999) 81-90.

85 Law, A. M. and Kelton, W. D., 1991, Simulation modeling and analysis, McGraw Hill Inc., NewYork.

86 Lawrence, C.R. 1983. Nitrate rich groundwater of Australia, AWRC Tech Paper 79. AGPS, Canberra, 110p.

87 Legg. J.O. and J.J. Meisinger, 1982. Soil Nitrogen Budgets. In F.J. Stevenson (ed.). Nitrogen in agricultural soils.Agron Monogr22. ASA, CSSA, and SSSA, and Madison, WI, pp503-566.

88 LEKA; Lyonnaise Des Eaux Khatib and Alami. "Monthly reports", 2000/2001.

89 Leket, Guiresse M, Giraudel JL, Predicting stream nitrogen concentration from watershed features using neural networks. Water Res; 33(16) (1999) 3469–78.

90 Lerner DN. Too much or too little: recharge in urban areas. In: Chilton J, Hemings S, Kimbling R, Tellem J, Aldous P, Nash H, Puri S, Morris B, Younger P, Hiscock K, editors. Groundwater in Urban Environments. 1997. p. 41–8.

91 Lerner. D.N. 1996. Guest Editor's Preface to the theme Issue: Urban groundwater. Hydrogeological Journal v.4 (1): 4-5.

92 Liu. Y.J., D. a. Laird, and P. Barak, 1997. Release & Fixation of Ammonium and Potassium under Long-Term Fertility Management. Soil. Sci. Sco. Amer. J. 61:310-314.

© 2005 Tous droits réservés.

93 Loro P.J., D. W. Bergstrom, and E.G. Beauchamp, 1997. Intensity and duration of denitrification following application of manure and fertilizer to soil J. Environ. Qua 26:706-713.

94 Ludwick, A. E., Reuss, J. O., and Langin, E.J., 1976. Soil nitrates following four years contious corn and as surreyed in irrigated field of central and eastern colorado. J. Environ. Qual., 5:82-84.

95 Madison, R. and J. Brunett 1985. "Overview of the Occurrence of Nitrate in Ground Water of the United States," National Water Summary 1985-Hydrologic Events, Selected Water-Quality Trends and Ground-Water Resources. Water-Supply Paper 2275. Reston, Virginia: U.S. Geological Survey.

96 Magdoff F. R., Keeney D.R., 1975. Nutrient mass balance in columns representing fill systems for disposal of septic tank effluents. Environmental Letters, 10(4):285-294.

97 Margat, J., L'EAU dans le bassin Méditerranéen, Plan Bleu, Economica, 1992.

98 McCuen, R. H., 1993, Microcomputer applications in statistical hydrology, PTR, Prentice Hall, Englewood Chiffs, New Jersey.

99 Meisinger J. J and G.W. Randall, 1991. Estimating Nitrogen Budgets for Soil-Crop Systems. In Managing Nitrogen for Groundwater Quality and Farm Profitability. Soil Science Society of America, 677 S. Seoge Rd., Madison, WI 53711, USA, pp 85-124.

100 Melloul AJ, Goldenberg LC. Groundwater pollution by airborne toxic contaminants: a factor to be considered in groundwater management. In: Kovar, Soveri, editors. GQM 93, vol. 220. IAHS Publication Walling ford, UK; 1994. p. 95–105.

101 MEnA 2000, Palestinian Environmental Strategy. Palestinian National Authority, Ministry of Environmental Affair, (2000) Gaza.

102 Metcalf & Eddy. Inc., 1990. Waste water Engineering. 3rd edition. NewYork: McGraw-Hill.

103 Meybeck M, Chapman D, Helmer R. Global fresh water quality: a first assessment. W.H.O. and U.N.E.P 1990, Blackwell Ltd, Oxford, 306p.

104 Ministry of Agriculture, Statistics Directorate, Yearly reports, 2000.

105 Ministry of Environmental Affairs, Land base pollution sources report, 2001.

106 Ministry of Environmental Affairs, Palestinian Environmental Strategy, 1998.

107 Ministry of Environmental Affairs, State of Environment, 2000.

108 Mitchell, J.G. 1996. Our Polluted Runoff. *National Geographic*. 189(2): 106-125.

109 Moody, J. and Darkin, C.J., Fast learning in networks of locally-tuned processing units. Neural Computation 1 (2) (1989) 281-294.

© 2005 Tous droits réservés.

110 MOPIC (1994), "Gaza Environmental Profile, Part 1" Environmental Planning Directorate (EPD), Ministry of Planning and International Co-operation (MOPIC), Palestine.

111 MOPIC (1996), "Gaza Environmental Profile, Part 2" Environmental Planning Directorate (EPD), Ministry of Planning and International Co-operation (MOPIC), Palestine.

112 MOPIC (1996), "Gaza Land Resources, Land Use Planning and Resources Protection" Environmental Planning Directorate (EPD), Ministry of Planning and International Co-operation (MOPIC), Palestine.

113 MOPIC, Regional plan for Gaza Governorates Volume, ministry of Planning and International Cooperation, (1998) Gaza, Palestine.

114 National Academy of Science-Panel on Nitrates of the Coordinating Committee for Scientific and Technical Assessment of Environmental Pollutants, Environmental Studies Board, Commission on Natural Resources and National Research Council., 1978. Nitrates: An Environmental Assessment. National Academy of Science. Washington, D.C.

115 Naveh Z. The value of open landscape as life-supporting system. Isr. Environ Bull 1977;20(4):21-4

116 Neal, C., House, W.A., Down, K., 1998. An assessment of excess carbon dioxide partial pressures in natural waters based on pH and alkalinity measurements. The Science of Total Environmental 210/211, 173-185.

117 Neal, C., House, W.A., Jarive, H.P., Eatherall, A., 1998. The significance of dissolved carbon dioxide in major lowland rivers entering the North Sea. The Science of Total Environmental 210/211, 187-203.

118 Nelson, D.W., 1982. Gaseous losses of nitrogen other than through denitrification. In F.J Stevenson (ed.) Nitrogen in agricultural soils. Agron Monogr. 22. ASA, CSSA, and SSSA, Madison, WI., pp.327-363.

119 Nider, R., Schollmayer, G. and Richter, J., 1989. Denitrification in the rooting zone of cropped soils with regard to methodology and climate: A review. Biology and Fertility in soils. 8:219-226.

120 NRC (National Research Council) 1993. Ground Water Vulnerability Assessment: Predicting Relative Contamination Potential Under Conditions of Uncertainty. Washington, D.C.: National Academy Press.

121 Palestinian Hydrology Group, (PHG), 2002. Nitrogen sources and sinks in the Gaza Strip, Gaza-Palestine.

122 Palestinian Hydrology Group, Drinking Water Quality in the Gaza Strip, 1999.

123 Palestinian water authority (PWA), 2000. Integrated Aquifer Management Plan (Task 3) Appendix A.

© 2005 Tous droits réservés.

124 Palestinian water authority, Data base division, agricultural water quality, 2000.

125 Parkin, T.B and Tiedje, J.M., 1984. Application of soil core method to investigate the effect of oxygen concentration on denitrification. Soil Biology and Biochemistry. 16331-334.

126 Paul, J.W. and Beauchamp, E.G., 1989. Effect of carbon constituents in manure on denitrification in soil. Can. J. Soil Sci. 69:49-61.

127 PCBS 2000, Population, Housing and Establishment Census 1997. Palestinian National Authority, Palestinian Central Bureau of Statistics, Ramallah.

128 Pearson, K. (1896). Regression, heredity, and panmixia. Philosophical Transactions of the Royal Society of London, Ser. A, 187, 253-318.

129 Pearson, K. (1908). On the generalized probable error in multiple normal correlation. Biometrika, 6, 59-68.

130 Peavy H.S., D.R Rowe., and G. Tchobanoglous, 1985. Environmental Engineering. Mc Graw-Hill.

131 Poul, L.B, Rugge, K. and Pedesen, J., 1995. Irrigation and drainage. Distribution of redox sensitive groundwater quality parameters down gradient of a landfill. Environmental science and technology, 29:1387-1394.

132 Qahman, K. (1998), Monitoring of Seawater Intrusion in the Gaza Strip, Palestine, MSc. Thesis, HH 330, IHE, Delft, The Netherlands.

133 Qasem Abdul-Jaberm Alfred Abed Rabbo, David Scarpa, Ziad Qannam, Paul Younger, 1999. Wells in the West Bank, Water Quality and Chemistry.

134 Rabah, F.K., 1997. Quantification of nitrate pollution to groundwater resources of Rafah (Gaza Strip). MSc. Thesis S.E.E. 10, IHE, Delft, the Netherlands.

135 Reisenhofer E., Adami G. and Barbieri P. (1998) Using chemical and physical parameters to define the quality of karstic freshwaters (Timavo River, North-eastern Italy): A chemometric approach. Wat. Res. 32, 1193±1203.

136 Rogers LL, Dowla FU., Optimization of groundwater remediation using artificial neural networks with parallel solute transport modeling. Water Resour Res; 30(2) (1994) 457–81.

137 Scheible, O. K. (ed)/ US Environmental protection Agency, office of research & development comp, 1994. Nitrogen ontrol. Technomic, Basel.

138 Schepers, J.S. and R.H. Fox, 1989. Estimation of N budgets for crops. In R. F. Follett (ed.) Nitrogen management and groundwater protection. Elsevier, New York. p221-242.

139 Schuiling, R. D. (1994) Introduction to Geochemistry, Department of Geochemistry, Institute of Earth Sciences, University of Utrecht, Utrecht, The Netherlands.

© 2005 Tous droits réservés.

140 Schultz GA, Hornbogen M. Sustainable development of water resources systems with regard to long changes of design variables. Modeling and management of sustainable basin-scale water resource systems. In: Proceedings of a Boulder Symposium, IAHS, 231. 1995. p. 31–40.

141 Sexstone, A. J., T. B. Parkin, and J. M. Tiedje, 1985a. Temporal response of soil denitrification rates to rainfall and irrigation. Soil Sci. Soc. Am. J. 49:99-103.

142 Sharma S. Applied multivariate techniques. New York: Wiley, 1996.

143 Smith J. R. M., Breedveld L. W., Derksen M. W. J., Kateman G., Balfoort H. W., Snoek J. and Hofstraat J. W., Pattern classification with artificial neural networks: classification of algae, based upon flow cytometer data. Anal. Chim. Acta 258 (1992) 11-25.

144 Smith, S. J., J. F. Power. And W.D. Kemper, 1994. Fixed ammonium and nitrogen availability indexes. Soil Science 158:132-140.

145 Spalding, R.F. and Exner, M.E. (1993) Occurrence of nitrate in groundwater—a review. *Journal of Environmental Quality*. 22:392–402.

146 Stanford, G. and Epstien, E., 1974. Nitrogen Mineralization-Water relations in soils. Soil Science Society of American Proceedings. 38:103-107.

147 Stehouwer R.C. and J. W. Johnson, 1991. Soil Adsorption Interactions of Band-Injected Anhydrous Ammonia and Potassium Chloride Fertilizers. Soil. Sci. Soc. Amer. J., 55:1374-1381.

148 Stevenson, F. J., 1986. Cycles of soil carbon, nitrogen; Phosphorous, Sulphur & Micronutriants. John Wiley & Sons, NewYork.

149 Subbarao, N.S. 1989. Soil Microorganisms and Plant Growth 2nd edition. Oxford and IBH Publishing Co., PVT Ltd., New Delhi, Bombay & Calcutta.

150 Subbarao,N.S., Soil Microorganisms And Plant Growth.3rd Edition.

151 Swoboda, A.R., 1977. Nitrate movement in clay soils and methods of pollution control, Nitrogen in return flow. Proceeding of national conference irrigation return flow quality management. pp: 19-25.

152 Thomas, G. W., and Swoboda, A. R., 1969. Anion exclusion effects on chloride movement in soils. Soil Sci. 110:163-166.

153 Trauth R, Xanthopoulos C., Non-point pollution of groundwater in urban areas. Water Resour Res 31(1997) 2711-2718.

154 UNCED, Rio de Janeiro, 1992, Annex I, RIO DECLARATION ON ENVIRONMENT AND DEVELOPMENT, The United Nations Conference on Environment and Development, Rio de Janeiro 3-14 June 1992.

155 Vagstad Nils, Hans Olav Eggestad and Tyra R. H yns, 1997. Mineral nitrogen in agricultural soils and nitrogen losses: Relation to soil properties, weather conditions and farm practices. AMBIO, A journal of the human and environment,

© 2005 Tous droits réservés.

26(5):266-272.

156 Van Stempvort, D., Ewart, L., & Wassenaar, L. (1933). Aquifer vulnerability index a GIS-compatible method for groundwater vulnerability mapping. Canadian Water Resources Journal, 18(1), 25-32.

157 Vega M., Pardo R., Barrado E. and Deban L. (1998) Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Wat. Res. 32, 3581±3592.

158 Velk, P.L.G., and J. M. Stumpe, 1978. Effect of solution chemistry and environmental conditions on ammonia volatilization losses from aqueous systems. Soil Sci. Soc. Am. J. 42:416-421.

159 Vinten, A.J.A. and K.A. Smith, 1993. Nitrogen cycling in agricultural soils. In burt, T.P, A.L. Heathwaite and S.t. Trudgill (eds). Nitrate: Processes, Paterns and Management. John Wiley and sons, pp: 39-73.

160 Walker, W.G, Bouma, J., Keeney, D.R. and Magdoff, F.R. 1973a. Nitrogen transformation during subsurface disposal of septic tank effluent on sands. I. Soil transformations. J. Environ. Qual., 2:475-480.

161 Walker, W.G, Bouma, J., Keeney, D.R. and Olcott, P.G., 1973b. Nitrogen transformation during subsurface, disposal of septic tank effluent on sands. II Ground water quality. J. Environ. Qual., 2:521-525.

162 Walton R. and Steven D. Wilson, 2000. Temporal Changes in Shallow Groundwater Quality in Northeastern Illinois. Groundwater Section Illinois State Water Survey, Champaign, IL 61820.

163 Water Resources Management, A World Bank Policy Paper, 1993.

164 Welch, A.H., Westjohn, D.B., Helsel, D.R., and Wanty, R.B., 2000, Arsenic in ground water of the United States Occurrence and geochemistry. Ground Water, v. 38, no. 4, p. 589.

165 Wen CW, Lee CS., A neural network approach to multi-objective optimization for water quality management in a river basin. Water Resour Res. 34 (3) (1998) 427–36.

166 Wendland, F., H. Albert, M. Bach and R. Schmidt 1993. Atlas zum Nitratstrom in der Bundersrepublik Deutschland. Berlin: Springer-Verlag.

167 Wenning R. J. and Erickson G. A. (1994) Interpretation and analysis of complex environmental data using chemometric methods. Trends in Anal. Chem. 13, 446±457.

168 Westlake K., 1995. Landfill waste pollution and control, Albion Publishing, England.

169 WHO, (1998). Guidelines for Drinking Water Quality. Volume 2, Second Edition, Health Criteria and Other Supporting Information (WHO/EOS/98.1), World Health Organization, Geneva.

© 2005 Tous droits réservés.

170 World health organization, Guidelines for drinking water quality, vol.2, WHO, 1984.

171 Yoram, A. and L., Malka, 1977. Ammonia Volatilization From Soils. Equilibrium considerations. Soil Sci Soc. Amer. J. 41:1080-1084.

172 Zhang, Z.X., Kushwaha, R.L., Applications of neural networks to simulate soil-tool interaction and soil behavior. Can. Agric. Eng. 41 (1999) 119–125.

© 2005 Tous droits réservés.

APPENDIX I

Nitrogen Balance Calculations

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

1. Calculation of nitrogen input through un-sewered areas

a. basic data for calculation

Location	Population	Unconnected Population	TKj N kg/m3	amount of water consumed m3/d	amount of wastewater produced m3/y
Northern area	209412	52353	0.31	6596.469	1805783
Gaza area	419557	83911	0.267	10572.83	2894311
Middle area	168875	118213	0.184	14894.8	4077453
Khan-Younis	229204	229204	0.37	28879.67	7905808
Rafah area	140312	68753	0.238	8662.842	2371453
Gaza Strip	1167359	552433		69606.61	19054809

b. Unsewered area of Northern area:

Percentage of population not connected to sewer system = 25%

No. of population not connected to sewer system = 0.25 * 209412 = 52353 cap.

Average water consumption with losses = 93 l/c/d

Average water supply = 145 l/c/d

Non physical losses = 13%

Average water consumption with physical losses = 126.15 l/c/d

Amount of water consumed = 52353 * 0.126 = 6596.469 m3/d

Amount of wastewater produced = 6596.469 m3/d * 0.75 = 1,805,783 m3/y

Average conc. of nitrogen in cesspits = 310 mg/l = 0.31 kg/m3

Nitrogen production = 0.31 kg/m3 * 1,805,783 m3/y = 559792.9 kg/y

c. Unsewered area of Gaza area:

Percentage of population not connected to sewer system = 20%

No. of population not connected to sewer system = 0.20 * 419557 = 83911 cap.

Average water consumption with losses = 93 l/c/d

Average water supply = 145 l/c/d

Non physical losses = 13%

Average water consumption with physical losses = 126.15 l/c/d

Amount of water consumed = 83911 * 0.126 = 10572.83 m3/d

Amount of wastewater produced = 10572.83 m3/d * 0.75 = 2,894,311 m3/y

Average conc. of nitrogen in cesspits = 267 mg/l = 0.267 kg/m3

Nitrogen production = 0.267 kg/m3 * 2,894,311 m3/y = 772781.1 kg/y

d. Unsewered area of middle area:

Percentage of population not connected to sewer system = 70%

No. of population not connected to sewer system = 0.70 * 168875 = 118213 cap.

Average water consumption with losses = 93 l/c/d

Average water supply = 145 l/c/d

Non physical losses = 13%

Average water consumption with physical losses = 126.15 l/c/d

Amount of water consumed = 118213 * 0.126 = 14894.8 m3/d

Amount of wastewater produced = 14894.8 m3/d * 0.75 = 4077453 m3/y

Average conc. of nitrogen in cesspits = 184 mg/l = 0.184 kg/m3

Nitrogen production = 0.184 kg/m3 * 4077453 m3/y = 750251.3 kg/y

© 2005 Tous droits réservés.

e. Unsewered area of Khan-Younis area:

Percentage of population not connected to sewer system = 100%
No. of population not connected to sewer system = 1.0 * 229204 = 229204 cap.
Average water consumption with losses = 93 l/c/d
Average water supply = 145 l/c/d
Non physical losses = 13%
Average water consumption with physical losses = 126.15 l/c/d
Amount of water consumed = 229204 * 0.126 = 28879.67 m3/d
Amount of wastewater produced = 28879.67 m3/d * 0.75 = 7905808 m3/y
Average conc. of nitrogen in cesspits = 370 mg/l = 0.370 kg/m3
Nitrogen production = 0.370 kg/m3 * 7905808 m3/y = 2,925,149 kg/y

f. Un-sewered area of Rafah area:

Percentage of population not connected to sewer system = 49 %
No. of population not connected to sewer system = 0.49 * 140312 = 552433 cap.
Average water consumption with losses = 93 l/c/d
Average water supply = 145 l/c/d
Non physical losses = 13%
Average water consumption with physical losses = 126.15 l/c/d
Amount of water consumed = 552433 * 0.126 = 8662.842 m3/d
Amount of wastewater produced = 8662.842 m3/d * 0.75 = 2371453 m3/y
Average conc. of nitrogen in cesspits = 238 mg/l = 0.238 kg/m3
Nitrogen production = 0.238 kg/m3 * 2371453 m3/y = 564405.8 kg/y

2. Amount of nitrogen produced from sewer system leakage

a. Northern area:

Amount leaked from Northern area = 2000 m3/d = 730000 m3/y
Nitrogen production = 365000 * 0.189 = 137970 kg/y
About 20% of the nitrogen is lost through denitrification
Nitrogen lost = 137970 kg/y * 0.2 = 27594 kg/y

b. Gaza area:

Amount leaked from Gaza area = 8400 m3/d = 3,066,000 m3/y
Nitrogen production = 3,066,000 * 0.1483 = 454687.8 kg/y
About 20% of the nitrogen is lost through denitrification
Nitrogen lost = 454687.8 kg/y * 0.2 = 90937.6 kg/y

c. Rafah area:

Amount leaked from Rafah area = 840 m3/d = 306600 m3/y
Nitrogen production = 306600 * 0.238 = 72970.8 kg/y
About 20% of the nitrogen is lost through denitrification
Nitrogen lost = 72970.8 kg/y * 0.2 = 14594.2 kg/y

d. Middle area:

Amount leaked from Middle area = 688 m3/d = 251120 m3/y
Nitrogen production = 251120 * 0.184 = 46206 kg/y
About 20% of the nitrogen is lost through denitrification
Nitrogen lost = 46206 kg/y * 0.2 = 9241.2 kg/y

3. Addition of nitrogen through wastewater treatment plant

a. Gaza wastewater treatment plant

Flow rate = 42,000 m3/d
Discharge to the sea = 32,000 m3/d
Discharge to the land = 10,000 m3/d
Average total nitrogen concentration = 67.0 mg/l = 0.067 kg/m3
Nitrogen production = 0.067 kg/m3 * 3,650,000 m3/y = 244550 kg/y
About 20% of total nitrogen load is lost through denitrification
Nitrogen losses = 244550 kg/y * 20%= 48910 kg/y

© 2005 Tous droits réservés.

b. Beit Lahia wastewater treatment plant

Flow rate = 10,000 m3/d

Discharge to the land = 10,000 m3/d = 3,650,000 m3/y
Average total nitrogen concentration = 92.5 mg/l = 0.0925 kg/m3
Nitrogen production = 0.0925 kg/m3 * 3,650,000 m3/y = 337625 kg/y
About 20% of total nitrogen load is lost through denitrification
Nitrogen losses = 337625 kg/y * 20%= 67525 kg/y

c. Rafah wastewater treatment plant

Flow rate = 10,000 m3/d

Discharge to the land = 4200 m3/d = 1533000 m3/y
Average total nitrogen concentration = 152.7 mg/l = 0.1527 kg/m3
Nitrogen production = 0.1527 kg/m3 * 1533000 m3/y = 234089 kg/y
About 20% of total nitrogen load lost through denitrification
Nitrogen losses = = 234089 kg/y * 20%= 46818 kg/y

4. Amount of nitrogen input through solid waste:

Example Calculation: Nitrogen production through solid waste in the northern area

Northern area
Average waste production = 0.85 kg/c/d
Population number = 209412 capita
Waste produced = 209412 * 0.85 = 178000 kg/d = 64970 ton/y
Amount of leachate produced = 64970 * 0.1 = 6497 m3/y
Concentration of nitrogen in the leachate = 0.37 kg/m3
Amount of N produced = 0.37 * 6497 = 2404 kg/y = 0.39 kg/ha/y

5. Amount of Nitrogen input though drinking water distribution network

1. Water quality

Area	EC (mS/cm)	Cl- (mg/L)	NO3 (mg/L N-NO3)
Beit Hanon	1.5	251.6	60
Beit Lahia	1.2	182	102
Jabalia	1.7	290.4	160
Northern area average concentration			**107**
Gaza	3.1	679.5	**98**
Middle Area	3.8	843.1	**100**
Khanyounis	3.2	649	137
Estern Villages	5	1099.6	86
Khanyounis area average concentration			**112**
Rafah	2.3	479.8	**138**
Average (Gaza Strip)	2.7	559.4	110

2. Calculation of nitrogen addition through drinking water network leakage

Area	Total water supply m3/y	Physical losses %	water losses m3/y	conc. as Nitrogen	N input kg/y	Area affected	N input kg/ha.y
Northern area	11968522	29	3470871	24.25	84186	1514	56
Gaza	28098804	25	7024701	22.05	154884	2458	63
Middle area	6274965	25	1568741	22.52	35333	869	41
Khanyounis	9470434	23	2178200	25.26	55013	1313	42
Rafah	4888482	25	1222120	31.15	38072	710	54
Total	60701207	24	15464634		367488	6864	54

Sample calculation for drinking water nitrogen addition in the Northern area through drinking water network leakage:

1. total water supply for Northern area = 11968522 m3/y
2. physical losses = 29%
3. water losses = 11968522 m3/y * 0.29 = 3470871 m3/y
4. nitrogen input = 3470871 * 0.02425 = 84186 kg/y = 56 kg/ha.y

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

6. Agriculture activities:

6.1 Nitrogen chemical fertilizers calculation:

1. Amounts and types of nitrogen fertilizers applied for different types of crops in the Gaza Strip (Average)

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

Fertilizer application for tomato

Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Compound fertilizer 20-20-20	600	20	120
Ammonium sulphate	200	21	42
Potassium Nitrate	400	13	52
Total applied N (kg/ha.y)	1200		214

Fertilizer application for greenhouse tomato

Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Compound fertilizer 20-20-20	1500	20	300
Ammonium Sulphate	500	21	105
Potassium Nitrate	1000	13	130
Total applied N (kg/ha.y)	3000		535

Fertilizer application for greenhouse cucumber

Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Compound fertilizer 20-20-20	1000	20	200
Ammonium Sulphate	600	21	126
Potassium Nitrate	600	13	78
Total applied N (kg/ha.y)	2200		404

Fertilizer application for potatoes

Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Compound fertilizer 20-20-20	--	20	---
Ammonium Sulphate	600	21	126
Potassium Nitrate	300	13	39
Total applied N (kg/ha.y)	900		165

Fertilizer application for eggplant and pepper

Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Compound fertilizer 20-20-20	250	20	50
Ammonium Sulphate	1000	21	210
Potassium Nitrate	400	13	52
Total applied N (kg/ha.y)	1650		312

Fertilizer application for cauliflower

Type of fertilizers	Quantity (kg/ha)	% nitrogen	N added (kg/ha)
Compound fertilizer 20-20-20	---	20	---
Ammonium Sulphate	1000	21	210
Potassium Nitrate	---	13	---
Total applied N (kg/ha.y)	1000		210

© 2005 Tous droits réservés.

Fertilizer application for beans

Type of fertilizers	**Quantity (kg/ha)**	**% nitrogen**	**N added (kg/ha)**
Compound fertilizer 20-20-20	---	20	---
Ammonium Sulphate	600	21	126
Potassium Nitrate	---	13	---
Total applied N (kg/ha.y)	600		126

Fertilizer application for barely

Type of fertilizers	**Quantity (kg/ha)**	**% nitrogen**	**N added (kg/ha)**
Compound fertilizer 20-20-20	---	20	---
Ammonium Sulphate	500	21	105
Potassium Nitrate	---	13	---
Total applied N (kg/ha.y)	500		105

Fertilizer application for citrus

Type of fertilizers	**Quantity (kg/ha)**	**% nitrogen**	**N added (kg/ha)**
Compound fertilizer 20-20-20	---	20	---
Ammonium sulphate	600	21	126
Potassium Nitrate	---	13	---
Total applied N (kg/ha.y)	600		126

Fertilizer application for olives

Type of fertilizers	**Quantity (kg/ha)**	**% nitrogen**	**N added (kg/ha)**
Compound fertilizer 20-20-20	---	20	---
Ammonium sulphate	500	21	105
Potassium Nitrate	---	13	---
Total applied N (kg/ha.y)	500		105

6.2. Nitrogen fertilizers compound use in the Gaza Strip (kg/y)

Crop Type/area	Rafah	Khanyounis	Middle	Gaza	Northern	Summation
Vegetables						
GH Tomatoes	675000	720000	420000	42600	115800	1973400
Tomatoes	228000	62400	9600	120000	13800	433800
Watermelon	137200	219800	28700	24500	23800	434000
Cucumbers	704000	79640	210100	108900	61820	1164460
Beans	125340	80580	13380	23220	43620	286140
Peppers	79200	42735	74250	87450	47190	330825
Potatoes	504000	493200	37800	27000	207270	1269270
Eggplants	69300	33000	110550	66000	101805	380655
Cauliflower	106000	23500	224000	57000	31100	441600
Molokhia	63000	30100	64400	43680	133560	334740
Corn	12600	6300	84000	18200	102200	223300
Gumbo	12600	58800	44800	28000	21000	165200
Others	299880	173460	312760	291900	324940	1402940
Cereals						
Barley	20000	75000	10000	25000	20000	150000
Wheat	125000	1027500	210000	150000	80000	1592500
Others	67500	72000	35500	10500	15100	200600
Trees						
Citrus	84030	57300	355020	717000	710865	1924215
Olives	152500	396000	270000	475000	51100	1344600
Palms	9500	32250	82500	7500		131750
Almonds	82500	83250	50000	7500	1850	225100
Guava	25000	158500	25000		16500	225000
Grapes	1000	200	46700	130000	20000	197900
Others	18000	7900	4400	30000	31050	91350
Total	3601150	3933415	2723460	2490950	2174370	14923345

Assumptions for calculation of nitrogen additions and losses for nitrogen chemical fertilizers

- Nitrogen addition according to the fertilizer application rate as shown in the above tables
- Fertilizer losses due to volatilization of ammonia or denitrification were calculated based on the total loss is equal on average 25% of the applied fertilizers (Balba, 1980).

© 2005 Tous droits réservés.

6.3. Nitrogen additions and losses for different crops for Rafah area

Crop type	Area	Nitrogen chemical	N input	N loss	N-balance
Vegetables					
GH Tomatoes	225	675000	120375	30094	90281
Tomatoes	190	228000	40660	10165	30495
Watermelon	98	137200	25186	6297	18890
Cucumbers	320	704000	129280	32320	96960
Beans	208.9	125340	26321	6580	19741
Peppers	48	79200	14976	3744	11232
Potatoes	560	504000	92400	23100	69300
Eggplants	42	69300	13104	3276	9828
Cauliflower	106	106000	22260	5565	16695
Molokhia	45	63000	11565	2891	8674
Corn	9	12600	2313	578	1735
Gumbo	9	12600	2313	578	1735
Others	214.2	299880	55049	13762	41287
Cereals					
Barley	40	20000	4200	1050	3150
Wheat	250	125000	26250	6563	19688
Others	135	67500	14175	3544	10631
Trees					
Citrus	140.05	84030	17646	4412	13235
Olives	305	152500	32025	8006	24019
Palms	19	9500	1995	499	1496
Almonds	165	82500	17325	4331	12994
Guava	50	25000	5250	1313	3938
Grapes	2	1000	210	53	158
Others	36	18000	3780	945	2835
Total	3217.2	3601150	678659	169665	508994

6.4 Nitrogen additions and losses for different crops for Khanyounis area

Crop type	Area (ha)	Nitrogen chemical fertilizers addition (kg/y)	N input kg/y	N loss kg/y	N-balance Kg/y
Vegetables					
GH Tomatoes	240	720000	128400	32100	96300
Tomatoes	52	62400	11128	2782	8346
Watermelon	157	219800	40349	10087	30262
Cucumbers	36.2	79640	14625	3656	10969
Beans	134.3	80580	16922	4230	12691
Peppers	25.9	42735	8081	2020	6061
Potatoes	548	493200	90420	22605	67815
Eggplants	20	33000	6240	1560	4680
Cauliflower	23.5	23500	4935	1234	3701
Molokhia	21.5	30100	5526	1381	4144
Corn	4.5	6300	1157	289	867
Gumbo	42	58800	10794	2699	8096
Others	123.9	173460	31842	7961	23882
Cereals					
Barley	150	75000	15750	3938	11813
Wheat	2055	1027500	215775	53944	161831
Others	144	72000	15120	3780	11340
Trees					
Citrus	95.5	57300	12033	3008	9025
Olives	792	396000	83160	20790	62370
Palms	64.5	32250	6773	1693	5079
Almonds	166.5	83250	17483	4371	13112
Guava	317	158500	33285	8321	24964
Grapes	0.4	200	42	11	32
Others	15.8	7900	1659	415	1244
Total	5229.5	3933415	771497	192874	578623

© 2005 Tous droits réservés.

6.5 Nitrogen additions and losses for different crops for Middle area

Crop type	Area (ha)	Nitrogen chemical fertilizers addition (kg/y)	N input kg/y	N loss kg/y	N-balance Kg/y
Vegetables					
GH Tomatoes	140	420000	74900	18725	56175
Tomatoes	8	9600	1712	428	1284
Watermelon	20.5	28700	5269	1317	3951
Cucumbers	95.5	210100	38582	9646	28937
Beans	22.3	13380	2810	702	2107
Peppers	45	74250	14040	3510	10530
Potatoes	42	37800	6930	1733	5198
Eggplants	67	110550	20904	5226	15678
Cauliflower	224	224000	47040	11760	35280
Molokhia	46	64400	11822	2956	8867
Corn	60	84000	15420	3855	11565
Gumbo	32	44800	8224	2056	6168
Others	223.4	312760	57414	14353	43060
Cereals					
Barley	20	10000	2100	525	1575
Wheat	420	210000	44100	11025	33075
Others	71	35500	7455	1864	5591
Trees					
Citrus	591.7	355020	74554	18639	55916
Olives	540	270000	56700	14175	42525
Palms	165	82500	17325	4331	12994
Almonds	100	50000	10500	2625	7875
Guava	50	25000	5250	1313	3938
Grapes	93.4	46700	9807	2452	7355
Others	8.8	4400	924	231	693
Total	3085.6	2723460	533781	133445	400336

6.6 Nitrogen additions and losses for different crops for Gaza area

Crop type	Area (ha)	Nitrogen chemical fertilizers addition (kg/y)	N input kg/y	N loss kg/y	N-balance Kg/y
Vegetables					
GH Tomatoes	14.2	42600	7597	1899	5698
Tomatoes	100	120000	21400	5350	16050
Watermelon	17.5	24500	4498	1124	3373
Cucumbers	49.5	108900	19998	5000	14999
Beans	38.7	23220	4876	1219	3657
Peppers	53	87450	16536	4134	12402
Potatoes	30	27000	4950	1238	3713
Eggplants	40	66000	12480	3120	9360
Cauliflower	57	57000	11970	2993	8978
Molokhia	31.2	43680	8018	2005	6014
Corn	13	18200	3341	835	2506
Gumbo	20	28000	5140	1285	3855
Others	208.5	291900	53585	13396	40188
Cereals					
Barley	50	25000	5250	1313	3938
Wheat	300	150000	31500	7875	23625
Others	21	10500	2205	551	1654
Trees					
Citrus	1195	717000	150570	37643	112928
Olives	950	475000	99750	24938	74813
Palms	15	7500	1575	394	1181
Almonds	15	7500	1575	394	1181
Guava	***		0		
Grapes	260	130000	27300	6825	20475
Others	60.0	30000	6300	1575	4725
Total	3538.6	2490950	500414	125103	375310

© 2005 Tous droits réservés.

6.7 Nitrogen additions and losses for different crops for Northern area

Crop type	Area (ha)	Nitrogen chemical fertilizers addition (kg/y)	N input kg/y	N loss kg/y	N-balance Kg/y
Vegetables					
GH Tomatoes	38.6	115800	20651	5163	15488
Tomatoes	11.5	13800	2461	615	1846
Watermelon	17	23800	4369	1092	3277
Cucumbers	28.1	61820	11352	2838	8514
Beans	72.7	43620	9160	2290	6870
Peppers	28.6	47190	8923	2231	6692
Potatoes	230.3	207270	38000	9500	28500
Eggplants	61.7	101805	19250	4813	14438
Cauliflower	31.1	31100	6531	1633	4898
Molokhia	95.4	133560	24518	6129	18388
Corn	73	102200	18761	4690	14071
Gumbo	15	21000	3855	964	2891
Others	232.1	324940	59650	14912	44737
Cereals					
Barley	40	20000	4200	1050	3150
Wheat	160	80000	16800	4200	12600
Others	30.2	15100	3171	793	2378
Trees					
Citrus	1184.775	710865	149282	37320	111961
Olives	102.2	51100	10731	2683	8048
Palms	***		0		
Almonds	3.7	1850	389	97	291
Guava	33	16500	3465	866	2599
Grapes	40	20000	4200	1050	3150
Others	62.1	31050	6521	1630	4890
Total	2591.075	2174370	426239	106560	319679

6.8 Nitrogen chemical fertilizers additions and losses for different crops for Gaza Strip

Crop type	Area (ha)	fertilizers addition (kg/y)	N input kg/y	N loss kg/y	N-balance Kg/y
Vegetables					
GH Tomatoes	657.8	1973400	351923	87981	263942
Tomatoes	361.5	433800	77361	19340	58021
Watermelon	310	434000	79670	19918	59753
Cucumbers	529.3	1164460	213837	53459	160378
Beans	476.9	286140	60089	15022	45067
Peppers	200.5	330825	62556	15639	46917
Potatoes	1410.3	1269270	232700	58175	174525
Eggplants	230.7	380655	71978	17995	53984
Cauliflower	441.6	441600	92736	23184	69552
Molokhia	239.1	334740	61449	15362	46087
Corn	159.5	223300	40992	10248	30744
Gumbo	118	165200	30326	7582	22745
Others	1002.1	1402940	257540	64385	193155
Cereals					
Barley	300	150000	31500	7875	23625
Wheat	3185	1592500	334425	83606	250819
Others	401.2	200600	42126	10532	31595
Trees					
Citrus	3207.025	1924215	404085	101021	303064
Olives	2689.2	1344600	282366	70592	211775
Palms	263.5	131750	27668	6917	20751
Almonds	450.2	225100	47271	11818	35453
Guava	450	225000	47250	11813	35438
Grapes	395.8	197900	41559	10390	31169
Others	182.7	91350	19184	4796	14388
Total	17661.9	14923345	2910590	727647	2182942

© 2005 Tous droits réservés.

7. Calculations of nitrogen addition and loss through irrigation water

Assumption: The nitrogen losses from irrigated water accounts 20% of the total nitrogen addition through irrigated water

1. Total actual irrigation (m3/year)

Crop/Area	Rafah	Khanyounis	Middle	Gaza	North	Total
Olive	784000	938000	1440800	1520000	276000	4958800
Citrus	1728000	1762200	7813800	12537000	11110500	34951500
Fruits	356250	2578300	1020300	4326300	693500	8974650
Field Crops	660750	1248750	1852500	4125000	774000	8661000
GH Vegetable	1979200	2906400	1836000	928000	1440000	9089600
Vegetable	6650400	7445150	3127150	2759950	8085200	28067850
Total	12158600	16878800	17090550	26196250	22379200	94703400

Rafah area

Crop type	area (ha)	irrigation rate m3/ha.y	irrigation water m3/y	N addition kg/y	N addition kg/ha.y	N loss kg/ha.y	N loss kg/y
Vegetables							
GH Tomatoes	225	10000	2250000	69750	310	62	13950
Tomatoes	190	8000	1520000	47120	248	50	9424
Watermelon	98	8000	784000	24304	248	50	4861
Cucumbers	320	10000	3200000	99200	310	62	19840
Beans	208.9	3000	626700	19428	93	19	3886
Peppers	48	8000	384000	11904	248	50	2381
Potatoes	560	8000	4480000	138880	248	50	27776
Eggplants	42	8000	336000	10416	248	50	2083
Cauliflower	106	8000	848000	26288	248	50	5258
Molokhia	45	8000	360000	11160	248	50	2232
Corn	9	8000	72000	2232	248	50	446
Gumbo	9	5000	45000	1395	155	31	279
Others	214.2	8000	1713600	53122	248	50	10624
Cereals							
Barley	40	1000	40000	1240	31	6	248
Wheat	250	1000	250000	7750	31	6	1550
Others	135	1000	135000	4185	31	6	837
Trees							
Citrus	140.05	9000	1260450	39074	279	56	7815
Olives	305	2000	610000	18910	62	12	3782
Palms	19	4500	85500	2651	140	28	530
Almonds	165	4500	742500	23018	140	28	4604
Guava	50	4500	225000	6975	140	28	1395
Grapes	2	4500	9000	279	140	28	56
Others	36	4500	162000	5022	140	28	1004
Total	3217.2		20138750	624301			124860

© 2005 Tous droits réservés.

Khanyounis area

Crop type	**area (ha)**	**irrigation rate m3/ha.y**	**irrigation water m3/y**	**N addition kg/y**	**N addition kg/ha.y**	**N loss kg/ha.y**	**N loss kg/y**
Vegetables							
GH Tomatoes	240	10000	2400000	60000	250	50	12000
Tomatoes	52	8000	416000	10400	200	40	2080
Watermelon	157	8000	1256000	31400	200	40	6280
Cucumbers	36.2	10000	362000	9050	250	50	1810
Beans	134.3	3000	402900	10073	75	15	2015
Peppers	25.9	8000	207200	5180	200	40	1036
Potatoes	548	8000	4384000	109600	200	40	21920
Eggplants	20	8000	160000	4000	200	40	800
Cauliflower	23.5	8000	188000	4700	200	40	940
Molokhia	21.5	8000	172000	4300	200	40	860
Corn	4.5	8000	36000	900	200	40	180
Gumbo	42	5000	210000	5250	125	25	1050
Others	123.9	8000	991200	24780	200	40	4956
Cereals							
Barley	150	1000	150000	3750	25	5	750
Wheat	2055	1000	2055000	51375	25	5	10275
Others	144	1000	144000	3600	25	5	720
Trees							
Citrus	95.5	9000	859500	21488	225	45	4298
Olives	792	2000	1584000	39600	50	10	7920
Palms	64.5	4500	290250	7256	113	23	1451
Almonds	166.5	4500	749250	18731	113	23	3746
Guava	317	4500	1426500	35663	113	23	7133
Grapes	0.4	4500	1800	45	113	23	9
Others	15.8	4500	71100	1778	113	23	356
Total	5229.5		18516700	462918			92584

Middle area

Crop type	**area (ha)**	**irrigation rate m3/ha.y**	**irrigation water m3/y**	**N addition kg/y**	**N addition kg/ha.y**	**N loss kg/ha.y**	**N loss kg/y**
Vegetables							
GH Tomatoes	140	10000	1400000	32200	230	46	6440
Tomatoes	8	8000	64000	1472	184	37	294
Watermelon	20.5	8000	164000	3772	184	37	754
Cucumbers	95.5	10000	955000	21965	230	46	4393
Beans	22.3	3000	66900	1539	69	14	308
Peppers	45	8000	360000	8280	184	37	1656
Potatoes	42	8000	336000	7728	184	37	1546
Eggplants	67	8000	536000	12328	184	37	2466
Cauliflower	224	8000	1792000	41216	184	37	8243
Molokhia	46	8000	368000	8464	184	37	1693
Corn	60	8000	480000	11040	184	37	2208
Gumbo	32	5000	160000	3680	115	23	736
Others	223.4	8000	1787200	41106	184	37	8221
Cereals							
Barley	20	1000	20000	460	23	5	92
Wheat	420	1000	420000	9660	23	5	1932
Others	71	1000	71000	1633	23	5	327
Trees							
Citrus	591.7	9000	5325300	122482	207	41	24496
Olives	540	2000	1080000	24840	46	9	4968
Palms	165	4500	742500	17078	104	21	3416
Almonds	100	4500	450000	10350	104	21	2070
Guava	50	4500	225000	5175	104	21	1035
Grapes	93.4	4500	420300	9667	104	21	1933
Others	8.8	4500	39600	911	104	21	182
Total	3085.6		17262800	397044			79409

© 2005 Tous droits réservés.

Gaza area

Crop type	area (ha)	irrigation rate m3/ha.y	irrigation water m3/y	N addition kg/y	N addition kg/ha.y	N loss kg/ha.y	N loss kg/y
Vegetables							
GH Tomatoes	14.2	10000	142000	3124	220	44	625
Tomatoes	100	8000	800000	17600	176	35	3520
Watermelon	17.5	8000	140000	3080	176	35	616
Cucumbers	49.5	10000	495000	10890	220	44	2178
Beans	38.7	3000	116100	2554	66	13	511
Peppers	53	8000	424000	9328	176	35	1866
Potatoes	30	8000	240000	5280	176	35	1056
Eggplants	40	8000	320000	7040	176	35	1408
Cauliflower	57	8000	456000	10032	176	35	2006
Molokhia	31.2	8000	249600	5491	176	35	1098
Corn	13	8000	104000	2288	176	35	458
Gumbo	20	5000	100000	2200	110	22	440
Others	208.5	8000	1668000	36696	176	35	7339
Cereals							
Barley	50	1000	50000	1100	22	4	220
Wheat	300	1000	300000	6600	22	4	1320
Others	21	1000	21000	462	22	4	92
Trees							
Citrus	1195	9000	10755000	236610	198	40	47322
Olives	950	2000	1900000	41800	44	9	8360
Palms	15	4500	67500	1485	99	20	297
Almonds	15	4500	67500	1485	99	20	297
Guava	***	4500					
Grapes	260	4500	1170000	25740	99	20	5148
Others	60	4500	270000	5940	99	20	1188
Total	3538.6		19855700	436825			87365

Northern area

Crop type	area (ha)	irrigation rate m3/ha.y	irrigation water m3/y	N addition kg/y	N addition kg/ha.y	N loss kg/ha.y	N loss kg/y
Vegetables							
GH Tomatoes	38.6	10000	386000	9264	240	48	1853
Tomatoes	11.5	8000	92000	2208	192	38	442
Watermelon	17	8000	136000	3264	192	38	653
Cucumbers	28.1	10000	281000	6744	240	48	1349
Beans	72.7	3000	218100	5234	72	14	1047
Peppers	28.6	8000	228800	5491	192	38	1098
Potatoes	230.3	8000	1842400	44218	192	38	8844
Eggplants	61.7	8000	493600	11846	192	38	2369
Cauliflower	31.1	8000	248800	5971	192	38	1194
Molokhia	95.4	8000	763200	18317	192	38	3663
Corn	73	8000	584000	14016	192	38	2803
Gumbo	15	5000	75000	1800	120	24	360
Others	232.1	8000	1856800	44563	192	38	8913
Cereals							
Barley	40	1000	40000	960	24	5	192
Wheat	160	1000	160000	3840	24	5	768
Others	30.2	1000	30200	725	24	5	145
Trees							
Citrus	1184.7	9000	10662975	255911	216	43	51182
Olives	102.2	2000	204400	4906	48	10	981
Palms	***	***	***	***	***	***	***
Almonds	3.7	4500	16650	400	108	22	80
Guava	33	4500	148500	3564	108	22	713
Grapes	40	4500	180000	4320	108	22	864
Others	62.1	4500	279450	6707	108	22	1341
Total	2591.1		18927875	454269			90854

© 2005 Tous droits réservés.

Gaza Strip

Crop type	area (ha)	irrigation rate m3/ha.y	irrigation water m3/y	N addition kg/y	N addition kg/ha.y	N loss kg/ha.y	N loss kg/y
Vegetables							
GH Tomatoes	657.8	10000	6578000	160174	244	49	32035
Tomatoes	361.5	8000	2892000	70420	195	39	14084
Watermelon	310	8000	2480000	60388	195	39	12078
Cucumbers	529.3	10000	5293000	128885	244	49	25777
Beans	476.9	3000	1430700	34838	73	15	6968
Peppers	200.5	8000	1604000	39057	195	39	7811
Potatoes	1410.3	8000	11282400	274726	195	39	54945
Eggplants	230.7	8000	1845600	44940	195	39	8988
Cauliflower	441.6	8000	3532800	86024	195	39	17205
Molokhia	239.1	8000	1912800	46577	195	39	9315
Corn	159.5	8000	1276000	31071	195	39	6214
Gumbo	118	5000	590000	14367	122	24	2873
Others	1002.1	8000	8016800	195209	195	39	39042
Cereals							
Barley	300	1000	300000	7305	24	5	1461
Wheat	3185	1000	3185000	77555	24	5	15511
Others	401.2	1000	401200	9769	24	5	1954
Trees							
Citrus	3207.025	9000	28863225	702820	219	44	140564
Olives	2689.2	2000	5378400	130964	49	10	26193
Palms	263.5	4500	1185750	28873	110	22	5775
Almonds	450.2	4500	2025900	49331	110	22	9866
Guava	450	4500	2025000	49309	110	22	9862
Grapes	395.8	4500	1781100	43370	110	22	8674
Others	182.7	4500	822150	20019	110	22	4004
Total	17661.9		94701825	2305989			461198

8. Calculation of nitrogen addition, loss, and balance through rain water

Nitrogen balance through precipitation was calculated according to the rainfall intensity and nitrogen content equals 1.5 mg/l and 20% loss through denitrification

Area	Rafah	Khanyounis	Middle	Gaza	North	total
Total area ha	5993	11233	5736	7369	6170	36500
build up area	710	1313	869	2458	1514	6864
Agricultural area	3217	5230	3086	3539	2591	17662
Settlements area	1225	3417	70	233	755	5700
unused land						6275
Precipitation mm/y	247	321	366	378	474	
Precipitation amount MCM/y	14,803	36057	20993	27854	29245	128951
Precipitation amount m3/ha.y	2,470,000	3210000	3660000	3780000	4740000	
N addition for agricultural lands kg/y	11920	25180	16971	20170	18397	92637
N losses for agricultural lands kg/y	2384	5036	3394	4034	3679	18527
N addition for other areas	10285	28905	14519	21611	25472	100790
N losses for other areas	2057	5781	2904	4322	5094	20158
Total N-addition kg/y	22204	54085	31489	41781	43868	193427
Total N-loss kg/y	4441	10817	6298	8356	8774	38685
Total N-balance kg/y	17763	43268	25191	33425	35095	154742
Total N-balance kg/ha.y	3	4	4	5	6	4

Calculation of nitrogen addition and loss through manure

Assumptions: To calculate the nitrogen input produces from livestock (imported and existed) in the Gaza Strip the following assumptions were set according to (Meisinger and Randall, 1991):

1. the quantity of manure produced is distributed evenly in the areas according to the size of agricultural areas,
2. The approximate kilograms of N exerted by:

© 2005 Tous droits réservés.

- Layers chicken is 47.7 per day per 100 birds
- Broilers Chicken is 38.6 per day per 100 birds
- Cows and Camels is 47 per day per head
- Sheep and Goat is 7.2 per day per head

8.1. Numbers of livestock exist in the Gaza Strip

Area/Type	Cows and Camels	Sheep and Goat	Chiken (103)	
			Layers	Broilers
Rafah	2635	9796	38	947
Khanyounis	4547	8924	110	1977
Middle Area	4547	9263	114	935
Gaza	4392	14564	396	1167
Northern Area	4916	9348	124	929
Total	21038	51896	782.4	5954.8

8.2 Nitrogen additions from local livestock

Location	Cows and Camels	Sheep and Goat	Layers Chicken	Broilers Chicken	Total N input kg/y
Rafah	123862	70532	18204	365461	578060
Khanyounis	213709	64255	52337	763124	1093425
Middle Area	213709	66697	54612	360864	695883
Gaza	206437	104859	188867	450513	950676
Northern Area	231069	67308	59163	358571	716111
Total	988786	373651	373183	2298534	4034154

The estimated quantity of manure imported from Israel is around 40% of the total manure uses

8.3 Calculation of the manure quantity uses and addition in different areas (assumption):

- The quantity of manure imported is distributed evenly in the areas according to the size of agricultural areas,
- Cubic meter of manure equals 650 kg,
- The amount imported from Israel (ea. 200,000 cubic meter, 130,000 ton) are both cattle and poultry manure with 1:1 ratio.
- N content of cattle manure is 2% of the dry weight (dry weight 50%) of the manure applied. Also N content in poultry is 5% of the dry weight (dry weight 50%) according to the Agriculture Compendium (1989)

8.4 Calculation of manure losses

- Losses of manure through volatilization accounts 3% of nitrogen manure input
- Loss of manure through denitrification accounts 26% of the remainder manure after volatilization.
- Losses of fertilizers through storage within the soil were adapted from chapter 2 and are estimated to be accounts for 33% of the remainder after volatilization and denitrification

Sample calculation for Greenhouse Tomatoes:
Area cultivated in the Gaza Strip = 657.8 ha
Application rate = 50 Ton/ha.y
Dry matter = 50%,
Manure type (25 ton/ha.y Dairy cattle & 25 ton/ha.y Poultry)= 1:1 ratio
N content % of dray matter = (2% for Dairy cattle and 5% for Poultry)
Nitrogen Applied = (25000*0.5*0.02) + (25000*0.5*0.05) = 875 kg/ha.y = 575575 kg/y
Losses through ammonia volatilization = 875 * 0.03 = 26 kg/ha.y
Losses through denitrification = (875-26)*0.26 = 221 kg/ha.y
Remained = 875 – 247.25 = 628 kg/ha.y
Losses through storage within the soil = 628 * 0.33 = 207 kg/ha/y
Total losses = 26 + 221 + 207 = 454 kg/ha/y
Nitrogen balance = 875 – 454 = 421 kg/ha.y

© 2005 Tous droits réservés. http://www.univ-lille1.fr/bustl

Total nitrogen addition based in application rate of manure for different types of crops

Crop type	Areas (ha)	application ton/ha	total applied manure Ton/y	N manure addition kg/y	N addition kg/ha.y
Vegetables					
GH Tomatoes	657.8	50	32890	575575	875
Tomatoes	361.5	20	7230	126525	350
Watermelon	310	20	6200	108500	350
Cucumbers	529.3	50	26465	463138	875
Beans	476.9	20	9538	166915	350
Peppers	200.5	20	4010	70175	350
Potatoes	1410.3	50	70515	1234013	875
Eggplants	230.7	20	4614	80745	350
Cauliflower	441.6	20	8832	154560	350
Molokhia	239.1	20	4782	83685	350
Corn	159.5	20	3190	55825	350
Gumbo	118	20	2360	41300	350
Others	1002.1	20	20042	350735	350
Cereals					
Barley	300	15	4500	78750	262.5
Wheat	3185	15	47775	836063	262.5
Others	401.2	15	6018	105315	262.5
Trees					
Citrus	3207.025	15	48105	841844	262.5
Olives	2689.2	15	40338	705915	262.5
Palms	263.5	15	3953	69169	262.5
Almonds	450.2	15	6753	118178	262.5
Guava	450	15	6750	118125	262.5
Grapes	395.8	15	5937	103898	262.5
Others	182.7	15	2741	47959	262.5
Total	17661.9		373537	6536904	370.11277

Total nitrogen losses of manure for different types of crops

Crop type	Areas (ha)	N manure addition kg/y	losses through (kg/ha.y)		remained kg/ha.y	losses through storage within the soil	Total loss kg/ha.y
			ammonia volatilization	denitrification			
Vegetables							
GH Tomatoes	657.8	575575	26	221	628	207	454
Tomatoes	361.5	126525	11	88	251	83	182
Watermelon	310	108500	11	88	251	83	182
Cucumbers	529.3	463138	26	221	628	207	454
Beans	476.9	166915	11	88	251	83	182
Peppers	200.5	70175	11	88	251	83	182
Potatoes	1410.3	1234013	26	221	628	207	454
Eggplants	230.7	80745	11	88	251	83	182
Cauliflower	441.6	154560	11	88	251	83	182
Molokhia	239.1	83685	11	88	251	83	182
Corn	159.5	55825	11	88	251	83	182
Gumbo	118	41300	11	88	251	83	182
Others	1002.1	350735	11	88	251	83	182
Cereals							
Barley	300	78750	8	66	188	62	136
Wheat	3185	836063	8	66	188	62	136
Others	401.2	105315	8	66	188	62	136
Trees							
Citrus	3207.0	841844	8	66	188	62	136
Olives	2689.2	705915	8	66	188	62	136
Palms	263.5	69169	8	66	188	62	136
Almonds	450.2	118178	8	66	188	62	136
Guava	450	118125	8	66	188	62	136
Grapes	395.8	103898	8	66	188	62	136
Others	182.7	47959	8	66	188	62	136
Total	17661.9	6536904	11	93	266	88	192

© 2005 Tous droits réservés.

9. Plant uptake:

Sample calculation of plant uptake:

1. Greenhouse tomatoes (Vegetables) cultivated area in Rafah = 225 ha
2. Water content 94%, N content 2.7%, Yeild 150000 kg/ha.y
3. **N harvested (N removal) = 0.06 * 150000 * 0.027 = 243 kg/ha.y = 54674 kg/y**

1. Nitrogen content for different type of crops

crop type	**water content %**	**N content %**	**crop type**	**water content %**	**N content %**
GH Tomatoes	94	2.7	Other vegetables	92	2.3
Tomatoes	94	2.7	Barley	14	2.1
Watermelon	95	2.4	Wheat	14	2.4
Cucumbers	95	2.4	Others Cereals	50	2
Beans	87	3	Citrus	86	1.3
Peppers	92	2.3	Olives	25	2
Potatoes	92	2.3	Palms	15	3.3
Eggplants	85	4.5	Almonds	15	3.3
Cauliflower	92	2.3	Guava	70	2
Molokhia	92	2.3	Grapes	80	0.6
Corn	92	2.3	Other Trees	50	2
Gumbo	92	2.3			

Rafah area:

crop type	cultivated area ha	Yield kg/ha	water content %	Average N content %	N removal kg/ha	N removal kg/y
Vegetables						
GH Tomatoes	225	150000	94	2.7	243	54675
Tomatoes	190	40000	94	2.7	65	12312
Watermelon	98	28622	95	2.4	34	3366
Cucumbers	320	100000	95	2.4	120	38400
Beans	208.9	6474	87	3	25	5275
Peppers	48	26667	92	2.3	49	2355
Potatoes	560	28080	92	2.3	52	28934
Eggplants	42	60000	85	4.5	405	17010
Cauliflower	106	35377	92	2.3	65	6900
Molokhia	45	23444	92	2.3	43	1941
Corn	9	25000	92	2.3	46	414
Gumbo	9	6056	92	2.3	11	100
Others	214.2	25196	92	2.3	46	9930
Cereals						
Barley	40	4500	14	2.1	81	3251
Wheat	250	5000	14	2.4	103	25800
Others	135	19851	50	2	199	26800
Trees						
Citrus	140.05	22431	86	1.3	41	5717
Olives	305	3025	25	2	45	13838
Palms	19	8421	15	3.3	236	4488
Almonds	165	1500	15	3.3	42	6942
Guava	50	31500	70	2	189	9450
Grapes	2	7500	80	0.6	9	18
Others	36	17222	50	2	172	6200

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Khanyounis

crop type	cultivated area ha	Yield kg/ha	water content %	Average N content %	N removal kg/ha	N removal kg/y
Vegetables						
GH Tomatoes	240	150000	94	2.7	243	58320
Tomatoes	52	40000	94	2.7	65	3370
Watermelon	157	23535	95	2.4	28	4434
Cucumbers	36.2	94406	95	2.4	113	4101
Beans	134.3	6951	87	3	27	3641
Peppers	25.9	25927	92	2.3	48	1236
Potatoes	548	29288	92	2.3	54	29532
Eggplants	20	54000	85	4.5	365	7290
Cauliflower	23.5	36170	92	2.3	67	1564
Molokhia	21.5	22907	92	2.3	42	906
Corn	4.5	25000	92	2.3	46	207
Gumbo	42	5917	92	2.3	11	457
Others	123.9	27599	92	2.3	51	6292
Cereals						
Barley	150	4500	14	2.1	81	12191
Wheat	2055	5000	14	2.4	103	212076
Others	144	8954	50	2	90	12894
Trees	0					
Citrus	95.5	24200	86	1.3	44	4206
Olives	792	3648	25	2	55	43335
Palms	64.5	9302	15	3.3	261	16830
Almonds	166.5	1498	15	3.3	42	6997
Guava	317	32792	70	2	197	62370
Grapes	0.4	10000	80	0.6	12	5
Others	15.8	19620	50	2	196	3100

Middle area

crop type	**cultivated area ha**	**yield kg/ha**	**water content %**	**Average N content %**	**N removal kg/ha**	**N removal kg/y**
Vegetables						
GH Tomatoes	140	150000	94	2.7	243	34020
Tomatoes	8	40000	94	2.7	65	518
Watermelon	20.5	26402	95	2.4	32	650
Cucumbers	95.5	96497	95	2.4	116	11059
Beans	22.3	8430	87	3	33	733
Peppers	45	27667	92	2.3	51	2291
Potatoes	42	29762	92	2.3	55	2300
Eggplants	67	61642	85	4.5	416	27878
Cauliflower	224	34018	92	2.3	63	14021
Molokhia	46	23696	92	2.3	44	2006
Corn	60	25000	92	2.3	46	2760
Gumbo	32	4719	92	2.3	9	278
Others	223.4	24999	92	2.3	46	10276
Cereals						
Barley	20	4500	14	2.1	81	1625
Wheat	420	6000	14	2.4	124	52013
Others	71	17107	50	2	171	12146
Trees						
Citrus	591.7	23754	86	1.3	43	25580
Olives	540	4062	25	2	61	32900
Palms	165	8964	15	3.3	251	41486
Almonds	100	1500	15	3.3	42	4208
Guava	50	35000	70	2	210	10500
Grapes	93.4	9454	80	0.6	11	1060
Others	8.8	18864	50	2	189	1660

© 2005 Tous droits réservés.

Gaza area

crop type	cultivated area ha	yield kg/ha	water content %	Average N content %	N removal kg/ha	N removal kg/y
Vegetables						
GH Tomatoes	14.2	150000	94	2.7	243	3451
Tomatoes	100	40000	94	2.7	65	6480
Watermelon	17.5	22286	95	2.4	27	468
Cucumbers	49.5	48889	95	2.4	59	2904
Beans	38.7	8811	87	3	34	1330
Peppers	53	25000	92	2.3	46	2438
Potatoes	30	30000	92	2.3	55	1656
Eggplants	40	60500	85	4.5	408	16335
Cauliflower	57	28772	92	2.3	53	3018
Molokhia	31.2	24968	92	2.3	46	1433
Corn	13	25000	92	2.3	46	598
Gumbo	20	4500	92	2.3	8	166
Others	208.5	24209	92	2.3	45	9287
Cereals						
Barley	50	5000	14	2.1	90	4515
Wheat	300	6000	14	2.4	124	37152
Others	21	8390	50	2	84	1762
Trees						
Citrus	1195	23423	86	1.3	43	50943
Olives	950	3316	25	2	50	47250
Palms	15	3333	15	3.3	94	1403
Almonds	15	1500	15	3.3	42	631
Guava	***		***	***	***	***
Grapes	260	9231	80	0.6	11	2880
Others	60	13333	50	2	133	8000

Northern area

crop type	cultivated area ha	Yield kg/ha	water content %	Average N content %	N removal kg/ha	N removal kg/y
Vegetables						
GH Tomatoes	38.6	150000	94	2.7	243	9380
Tomatoes	11.5	40000	94	2.7	65	745
Watermelon	17	24265	95	2.4	29	495
Cucumbers	28.1	54911	95	2.4	66	1852
Beans	72.7	8160	87	3	32	2313
Peppers	28.6	16993	92	2.3	31	894
Potatoes	230.3	29993	92	2.3	55	12710
Eggplants	61.7	60543	85	4.5	409	25215
Cauliflower	31.1	36849	92	2.3	68	2109
Molokhia	95.4	23800	92	2.3	44	4178
Corn	73	25000	92	2.3	46	3358
Gumbo	15	4500	92	2.3	8	124
Others	232.1	28710	92	2.3	53	12261
Cereals						
Barley	40	5000	14	2.1	90	3612
Wheat	160	5500	14	2.4	114	18163
Others	30.2	13467	50	2	135	4067
Trees					0	0
Citrus	1184.775	25493	86	1.3	46	54971
Olives	102.2	3954	25	2	59	6062
Palms	***	***	***	***	***	***
Almonds	3.7	1500	15	3.3	42	156
Guava	33	31818	70	2	191	6300
Grapes	40	9800	80	0.6	12	470
Others	62.1	15105	50	2	151	9380

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Gaza Strip

crop type	cultivated area ha	Yield kg/ha	Water content %	Average N content %	N removal kg/ha	N removal kg/y
Vegetables						
GH Tomatoes	657.8	150000	94	2.7	243	159845
Tomatoes	361.5	40000	94	2.7	65	23425
Watermelon	310	25302	95	2.4	30	9413
Cucumbers	529.3	91812	95	2.4	110	58315
Beans	476.9	7147	87	3	28	13292
Peppers	200.5	24975	92	2.3	46	9214
Potatoes	1410.3	28953	92	2.3	53	75132
Eggplants	230.7	60189	85	4.5	406	93727
Cauliflower	441.6	33981	92	2.3	63	27611
Molokhia	239.1	23785	92	2.3	44	10464
Corn	159.5	25000	92	2.3	46	7337
Gumbo	118	5182	92	2.3	10	1125
Others	1002.1	26058	92	2.3	48	48047
Cereals						
Barley	300	4650	14	2.1	84	25194
Wheat	3185	5251	14	2.4	108	345204
Others	401.2	14374	50	2	144	57668
Trees						
Citrus	3207.025	24229	86	1.3	44	141418
Olives	2689.2	3555	25	2	53	143384
Palms	263.5	8687	15	3.3	244	64206
Almonds	450.2	1499	15	3.3	42	18934
Guava	450	32822	70	2	197	88620
Grapes	395.8	9333	80	0.6	11	4433
Others	182.7	15512	50	2	155	28340

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Appendix II

Water quality of domestic and agricultural wells

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

Table (II.1): Water quality and descriptive statistics of monitoring wells data from 1987-2002

Well No.	Well type	Area	X	Y	Well depth	NO_3^{--} Mean	NO_3^{--} Median	STD	NO_3^{--} Min	NO_3^{--} Max	# Samples
sahel-5	Domestic	Gaza	84900	88970	15.36	170.5	161.0	98.0	55.0	312.0	6
Sahel-4	Domestic	Gaza	85250	89300	14.56	102.3	83.0	55.5	50.0	190.0	6
Sahel-3	Domestic	Gaza	85650	89800	11.1	167.0	167.0	137.2	70.0	264.0	2
Sahel2	Domestic	Gaza	86000	90050	15.41	127.6	120.0	122.8	8.8	254.0	3
S/19	Domestic	Gaza	93660	94910	25.6	61.6	57.0	47.1	9.4	202.0	13
R/66B	Domestic	Gaza	100840	101730	50.3	388.0	388.0	17.0	376.0	400.0	2
R/271	Domestic	Gaza	96558	102589	41	54.0	67.9	24.6	25.5	68.5	3
R/270	Domestic	Gaza	101530	102670	50.2	83.1	82.0	8.4	74.8	93.6	4
R/162La	Domestic	Gaza	98320	104020	59	275.0	140.0	167.9	130.0	500.0	9
R/162L	Domestic	Gaza	98442	104037	56.9	180.1	135.0	119.9	16.5	460.0	21
R/113	Domestic	Gaza	96180	102500	27	199.6	216.0	105.9	92.0	328.0	5
E/92	Domestic	Gaza	100850	104250	33.4	271.5	220.0	203.3	95.0	909.0	19
E/142	Domestic	Gaza	99980	105260	47.57	250.4	210.0	175.8	73.0	460.0	6
D/71	Domestic	Gaza	101458	106193	28	287.8	400.0	162.2	90.0	410.0	5
D/60	Domestic	Gaza	101286	105112	36	201.1	139.5	140.9	90.0	537.0	14
S/9	Agriculture	Gaza	94850	94350	25	39.3	37.8	3.0	36.7	43.8	7
S/7	Agriculture	Gaza	95190	94600	30	71.8	65.2	19.4	50.0	104.0	6
S/68	Agriculture	Gaza	93800	91480	19.4	61.3	50.0	29.5	40.0	105.0	4
S/6	Agriculture	Gaza	94360	95450	10	90.5	90.5	10.6	83.0	98.0	2
S/55	Agriculture	Gaza	95110	93740	20	73.4	60.0	41.0	40.0	141.0	5
S/49	Agriculture	Gaza	91440	91090	53.8	128.7	123.6	45.1	85.0	252.0	11
S/45	Agriculture	Gaza	92000	91230	60.9	53.3	50.0	20.2	35.0	75.0	3
S/44	Agriculture	Gaza	92000	91460	50	63.4	55.5	30.6	40.0	139.9	9
S/43	Agriculture	Gaza	92330	91800	57.2	83.0	70.0	41.1	50.0	129.0	3
S/41	Agriculture	Gaza	92180	92130	50	59.5	45.0	29.9	40.0	115.0	6
S/36	Agriculture	Gaza	91780	92740	40	117.5	96.9	70.8	50.0	258.0	7
S/34	Agriculture	Gaza	91820	93270	30	116.8	105.5	71.0	45.0	211.0	4
S/32	Agriculture	Gaza	92410	93400	65	41.1	38.0	21.8	13.3	77.0	11
S/30	Agriculture	Gaza	93090	93860	50	129.3	110.0	84.3	45.0	283.0	6
S/27	Agriculture	Gaza	93700	93260	70	38.2	36.0	19.1	7.5	68.0	7
S/25	Agriculture	Gaza	94610	92840	30	87.0	87.0	17.0	75.0	99.0	2
S/23	Agriculture	Gaza	93900	93420	70	52.9	47.5	27.5	17.5	99.0	6
S/21	Agriculture	Gaza	93560	94000	10	49.6	40.0	28.1	30.0	106.0	7
S/18	Agriculture	Gaza	93750	94740	20.1	93.6	93.6	2.8	91.6	95.5	2
S/17	Agriculture	Gaza	94000	94430	30	78.8	64.5	44.1	45.0	141.0	4
S/14	Agriculture	Gaza	94250	94560	20	56.6	45.0	20.1	45.0	79.8	3
S/13	Agriculture	Gaza	94260	94620	30	112.5	105.0	57.5	55.0	185.0	4
S/12	Agriculture	Gaza	94550	94310	12.8	139.0	139.0	90.5	75.0	203.0	2
S/10	Agriculture	Gaza	95000	93580	10	47.0	50.5	12.6	30.0	57.0	4
R/94	Agriculture	Gaza	99100	99810	42.3	64.7	55.0	19.4	45.0	103.0	14
R/90	Agriculture	Gaza	98350	99650	38.4	62.5	62.5	10.6	55.0	70.0	2
R/8B	Agriculture	Gaza	101980	103070	50	130.3	150.8	48.4	75.0	165.0	3
R/8A	Agriculture	Gaza	101810	103270	39.7	166.3	154.9	50.1	120.0	301.0	10
R/88	Agriculture	Gaza	99100	99300	57.2	130.0	130.0	77.8	75.0	185.0	2
R/87	Agriculture	Gaza	99370	99460	58.6	104.2	100.0	31.6	20.4	168.0	15
R/67	Agriculture	Gaza	100860	102160	41.3	38.3	38.3	3.0	36.2	40.5	2
R/60	Agriculture	Gaza	101061	99499	56	66.7	59.7	27.5	44.0	113.0	7
R/6	Agriculture	Gaza	101620	103450	40.2	189.0	189.0	70.7	139.0	239.0	2
R/52	Agriculture	Gaza	101200	101000	60	45.7	40.0	18.1	27.5	90.0	15
R/5	Agriculture	Gaza	101850	103570	40	178.3	167.0	55.5	130.7	332.0	12
R/46	Agriculture	Gaza	101600	101260	45	51.1	48.9	11.9	32.0	70.0	8
R/42	Agriculture	Gaza	101640	101700	70	93.4	54.4	89.5	40.0	301.1	14
R/33	Agriculture	Gaza	101650	101970	59.9	119.5	119.5	29.0	99.0	140.0	2
R/30	Agriculture	Gaza	101060	102240	39	133.2	76.8	200.2	50.0	766.0	12
R/3	Agriculture	Gaza	102020	103450	40	194.2	185.9	80.8	75.0	419.0	15
R/28	Agriculture	Gaza	101300	102240	52	129.4	133.0	37.3	83.4	165.3	5
R/26A	Agriculture	Gaza	100890	102600	37.3	166.7	150.0	125.8	50.0	300.0	3
R/253	Agriculture	Gaza	97200	99800	44.16	100.0	100.0	0.1	99.9	100.0	3
R/249	Agriculture	Gaza	97390	99700	40	92.5	92.5	3.5	90.0	95.0	2
R/247	Agriculture	Gaza	93520	100160	16.1	42.5	42.5	3.5	40.0	45.0	2
R/240	Agriculture	Gaza	96580	100770	40	140.0	140.0	63.6	95.0	185.0	2
R/236	Agriculture	Gaza	93180	99800	10	115.2	103.7	71.1	59.5	336.0	13
R/23	Agriculture	Gaza	100780	102630	30	120.0	125.0	27.8	90.0	145.0	3

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

R/211	Agriculture	Gaza	95080	102160	9.9	115.5	115.5	7.8	110.0	121.0	2
R/20	Agriculture	Gaza	101380	103050	35.5	153.5	153.5	30.4	132.0	175.0	2
R/199	Agriculture	Gaza	99800	102890	30	207.2	225.0	82.9	69.0	339.0	9
R/197	Agriculture	Gaza	99660	102890	20	170.0	113.0	123.9	51.7	338.0	7
R/189	Agriculture	Gaza	100000	103520	24.5	281.7	367.5	148.7	110.0	367.5	3
R/185	Agriculture	Gaza	99600	103300	20	297.8	250.0	199.0	190.0	885.0	11
R/170	Agriculture	Gaza	99880	102380	30	182.8	179.9	32.6	105.0	255.9	16
R/16A	Agriculture	Gaza	101980	102350	68.1	100.0	102.5	14.7	80.0	115.0	4
R/160	Agriculture	Gaza	98520	103050	40	182.4	159.0	81.2	82.7	373.0	10
R/147	Agriculture	Gaza	97500	100770	40	243.0	236.1	62.8	119.0	328.0	8
R/146	Agriculture	Gaza	97300	100650	40	220.4	227.5	54.8	115.0	298.0	8
R/135	Agriculture	Gaza	96460	100570	36	163.4	163.4	2.3	161.7	165.0	2
R/134	Agriculture	Gaza	96500	100830	69	122.5	122.5	46.0	90.0	155.0	2
R/131	Agriculture	Gaza	96870	100970	69	247.0	247.0	29.7	226.0	268.0	2
R/129	Agriculture	Gaza	97130	100860	40	239.6	200.0	88.3	185.0	432.0	7
R/128	Agriculture	Gaza	97310	100960	31.3	275.0	275.0	50.0	225.0	325.0	3
R/101	Agriculture	Gaza	98360	100550	35	143.8	142.5	36.4	110.0	180.0	4
J/143	Agriculture	Gaza	90780	90800	44.5	83.7	65.0	55.4	40.0	146.0	3
H/61	Agriculture	Gaza	90820	95500	10	44.6	37.5	21.9	25.4	92.0	9
H/58	Agriculture	Gaza	90960	95070	13.9	132.8	130.9	15.2	119.9	149.4	4
H/25	Agriculture	Gaza	90940	93830	30	182.0	150.0	133.9	60.0	566.0	11
H/24	Agriculture	Gaza	91050	94030	30	132.0	133.0	43.1	85.0	203.0	6
H/20	Agriculture	Gaza	92240	94400	20	108.0	100.0	72.3	40.0	184.0	3
H/19	Agriculture	Gaza	91980	94180	30	103.0	97.1	43.1	50.0	221.0	14
H/16	Agriculture	Gaza	91950	94080	20	122.5	105.3	67.9	70.0	315.0	14
H/15	Agriculture	Gaza	91870	94100	19	118.1	109.0	47.5	65.0	201.0	8
H/14	Agriculture	Gaza	91680	93930	20	56.6	56.7	5.3	50.1	62.7	4
G/8	Agriculture	Gaza	91030	96250	9.5	121.9	125.0	28.4	80.0	160.0	8
G/43	Agriculture	Gaza	93300	98640	13.7	62.8	65.0	17.4	45.0	82.0	5
G/42	Agriculture	Gaza	92440	98940	2.37	144.4	145.0	24.6	100.0	170.0	8
G/27	Agriculture	Gaza	92200	94970	10	93.9	95.0	35.3	45.0	135.0	8
G/26	Agriculture	Gaza	91880	94850	38	179.2	170.2	91.9	65.0	442.0	12
G/24C	Agriculture	Gaza	93150	98300	15.6	34.0	30.0	9.9	25.0	50.8	6
G/24A	Agriculture	Gaza	92930	98550	14.1	84.0	75.0	22.5	65.0	115.0	5
G/23	Agriculture	Gaza	90920	96600	6.1	155.5	150.5	21.6	135.0	185.9	4
G/20	Agriculture	Gaza	91600	97040	10	131.4	120.0	47.7	85.0	221.0	7
G/19	Agriculture	Gaza	91700	96850	10	107.0	100.0	36.8	50.0	173.0	8
G/18	Agriculture	Gaza	92140	97180	10	72.2	63.0	14.9	56.8	99.0	10
G/17	Agriculture	Gaza	92140	96960	10	395.5	395.5	29.0	375.0	416.0	2
G/16	Agriculture	Gaza	92050	96920	10	161.0	177.4	50.0	85.0	205.7	6
G/13	Agriculture	Gaza	91928	96100	27	333.7	261.1	196.5	225.0	808.7	8
G/12	Agriculture	Gaza	91590	95330	40	130.0	130.0	7.1	125.0	135.0	2
F/99	Agriculture	Gaza	98440	98000	62.3	72.1	72.1	25.4	54.1	90.0	2
F/97	Agriculture	Gaza	98980	98270	70	57.4	35.5	48.6	31.6	172.0	8
F/9	Agriculture	Gaza	93460	95280	20	80.4	62.5	33.9	50.0	132.8	8
F/88	Agriculture	Gaza	97240	99170	40	157.3	96.5	224.1	40.0	819.0	11
F/82	Agriculture	Gaza	96050	97830	30	68.4	68.4	0.0	68.4	68.4	2
F/78	Agriculture	Gaza	95450	97950	25	44.7	41.1	17.7	2.6	76.0	15
F/77	Agriculture	Gaza	95200	97920	21	74.8	80.0	23.3	35.0	108.9	9
F/76A	Agriculture	Gaza	94940	98480	20.5	36.6	33.1	10.5	23.4	54.0	12
F/76	Agriculture	Gaza	95450	97700	30	83.9	80.0	20.2	57.6	120.0	12
F/73	Agriculture	Gaza	95720	97430	36.9	68.2	68.2	0.0	68.2	68.2	2
F/71	Agriculture	Gaza	95510	97200	32.7	63.1	63.0	18.8	40.0	90.9	9
F/70	Agriculture	Gaza	95450	97100	30	85.0	88.3	24.7	40.0	135.0	11
F/7	Agriculture	Gaza	93250	95250	20	103.5	96.0	39.2	41.3	170.0	13
F/68B	Agriculture	Gaza	94940	96700	32.3	138.6	113.4	65.9	80.0	311.0	10
F/62	Agriculture	Gaza	93850	96650	13	97.2	80.0	73.5	33.2	297.0	13
F/53	Agriculture	Gaza	94650	97070	17.2	308.2	303.8	45.0	256.5	353.8	5
F/52	Agriculture	Gaza	94750	97030	19	125.3	117.5	73.8	45.0	221.0	4
F/5	Agriculture	Gaza	93030	95110	20	121.0	107.5	35.5	80.0	177.9	8
F/47	Agriculture	Gaza	94740	97850	13	44.5	30.8	22.1	29.8	77.6	6
F/46	Agriculture	Gaza	94300	97620	18	62.5	62.5	17.7	50.0	75.0	2
F/43	Agriculture	Gaza	94120	97550	17.7	93.8	48.1	67.6	40.3	205.0	10
F/37	Agriculture	Gaza	93440	97340	10.3	149.4	145.0	54.4	61.0	225.0	9
F/36	Agriculture	Gaza	93440	97100	10	90.6	65.0	67.0	45.0	251.0	8
F/35	Agriculture	Gaza	93300	97300	13	97.0	98.2	24.2	55.0	135.0	15
F/34	Agriculture	Gaza	92580	96970	20	91.5	73.2	54.0	45.0	265.0	14

© 2005 Tous droits réservés.

F/32	Agriculture	Gaza	92920	96230	20	122.3	95.0	84.4	55.0	290.0	6
F/30B	Agriculture	Gaza	92650	96060	13.9	85.5	77.0	46.0	40.0	212.0	11
F/30A	Agriculture	Gaza	92300	96400	20	62.8	53.0	33.2	35.7	99.8	3
F/29	Agriculture	Gaza	92600	95850	30	73.8	62.9	35.2	40.0	159.0	14
F/24	Agriculture	Gaza	93000	95730	15	55.0	50.0	21.0	37.0	78.0	3
F/22	Agriculture	Gaza	94200	96000	96	94.0	85.0	36.9	55.0	150.0	8
F/21	Agriculture	Gaza	94056	95965	14.2	88.3	77.3	70.3	11.1	266.0	9
F/198	Agriculture	Gaza	94030	95910	12.1	65.3	65.3	66.9	18.0	112.5	2
F/17	Agriculture	Gaza	93760	95740	13	81.8	57.5	70.9	30.0	221.0	6
F/163	Agriculture	Gaza	97700	98030	40.2	105.5	105.5	0.0	105.5	105.5	2
F/157	Agriculture	Gaza	96310	95550	51.6	56.3	57.1	1.4	54.7	57.1	3
F/156	Agriculture	Gaza	96010	95540	49.6	53.1	53.1	2.2	51.6	54.6	2
F/15	Agriculture	Gaza	93850	95650	15	82.2	55.0	57.6	50.0	184.0	5
F/148	Agriculture	Gaza	92770	96480	14.1	78.5	85.0	25.3	50.6	100.0	3
F/143	Agriculture	Gaza	97200	98700	40	96.6	96.0	16.5	80.4	113.4	3
F/141	Agriculture	Gaza	98510	97460	40	61.7	46.6	33.9	29.5	132.0	7
F/136	Agriculture	Gaza	97800	97670	40	61.3	55.0	26.1	40.0	109.0	7
F/131	Agriculture	Gaza	97110	97250	42	55.3	50.0	18.6	40.0	76.0	3
F/128	Agriculture	Gaza	96350	96350	38	80.6	45.0	76.9	44.0	252.7	7
F/127	Agriculture	Gaza	96500	96160	50	76.8	70.0	29.4	40.0	127.9	7
E/94	Agriculture	Gaza	100770	104280	40	204.8	196.5	79.0	100.0	380.0	8
E/89	Agriculture	Gaza	100320	106700	58.8	148.8	148.8	9.5	142.1	155.5	2
E/88	Agriculture	Gaza	100270	106660	59.8	55.9	56.8	30.5	25.0	86.0	3
E/85	Agriculture	Gaza	99900	106700	30	136.6	143.8	43.0	66.0	216.0	16
E/79	Agriculture	Gaza	99660	106940	50	167.3	140.0	61.7	125.0	301.0	7
E/78	Agriculture	Gaza	99600	107000	50	169.9	153.9	106.0	50.0	425.0	10
E/74	Agriculture	Gaza	99700	107680	20.3	181.7	190.0	43.1	135.0	220.0	3
E/73	Agriculture	Gaza	99490	107600	20	207.5	207.5	95.5	140.0	275.0	2
E/67	Agriculture	Gaza	99350	106860	50	123.3	122.7	48.1	66.0	212.0	11
E/65	Agriculture	Gaza	99340	106570	50	130.8	98.1	73.4	85.0	315.0	9
E/63	Agriculture	Gaza	99600	106520	50	193.4	187.5	47.1	123.6	301.0	10
E/62	Agriculture	Gaza	99740	106350	50	89.4	90.0	36.9	40.0	159.0	10
E/56	Agriculture	Gaza	100080	106060	60	61.3	50.0	20.3	40.0	90.0	7
E/53	Agriculture	Gaza	99830	106030	50	86.2	77.0	37.6	40.0	150.0	9
E/43	Agriculture	Gaza	99690	105830	50	130.1	112.5	57.7	50.0	239.0	8
E/42	Agriculture	Gaza	99600	105610	50	120.9	132.4	40.3	60.0	168.0	10
E/41	Agriculture	Gaza	99440	105570	50	149.0	145.0	32.3	110.0	212.0	7
E/37	Agriculture	Gaza	99200	106100	50	140.9	135.0	25.8	100.0	195.0	9
E/35	Agriculture	Gaza	99150	106730	50	86.0	92.5	29.4	40.0	141.0	11
E/31	Agriculture	Gaza	98820	105890	39.9	172.7	172.7	0.0	172.7	172.7	2
E/30	Agriculture	Gaza	98760	105920	39.9	96.4	95.0	53.7	35.0	212.0	13
E/28	Agriculture	Gaza	98100	105390	50	151.9	153.1	45.6	75.0	319.7	29
E/158	Agriculture	Gaza	99670	107560		344.8	356.1	46.9	288.5	388.1	5
E/149	Agriculture	Gaza	99350	105780	41.3	112.6	112.6	10.4	105.3	120.0	2
E/144	Agriculture	Gaza	99750	106400	44.8	124.0	124.0	18.1	111.2	136.8	2
E/127	Agriculture	Gaza	101230	103120	38	202.6	195.0	114.2	50.0	428.0	7
E/113	Agriculture	Gaza	100450	103680	32	176.3	180.0	28.9	100.0	203.3	13
E/111	Agriculture	Gaza	100220	103750	30	168.0	168.0	45.3	136.0	200.0	2
E/110	Agriculture	Gaza	100170	103700	30	192.5	192.5	10.6	185.0	200.0	2
E/109	Agriculture	Gaza	99690	104030	20	144.5	145.0	59.0	70.0	258.0	8
E/107	Agriculture	Gaza	100030	103800	28.3	167.5	167.5	3.5	165.0	170.0	2
E/102	Agriculture	Gaza	100380	103900	30.2	241.4	235.5	25.5	200.0	284.0	8
D/9	Agriculture	Gaza	101350	105930	30	137.4	123.7	38.0	103.8	217.5	7
D/6	Agriculture	Gaza	101140	105610	30	139.0	142.9	16.9	106.4	155.2	6
D/58	Agriculture	Gaza	101350	107500	50	145.6	147.9	11.4	127.9	164.3	7
D/55	Agriculture	Gaza	100460	104630	30	180.4	171.2	16.0	171.2	198.9	3
D/43	Agriculture	Gaza	101040	104980	36	150.8	137.0	33.5	130.5	225.3	7
A/93	Agriculture	Gaza	100300	108320	50	201.8	182.5	50.8	145.0	283.6	10
A/92	Agriculture	Gaza	100350	108220	50	214.4	234.0	78.6	91.0	321.2	8
A/90	Agriculture	Gaza	100400	108380	50	122.3	130.0	36.3	75.0	175.0	8
A/89	Agriculture	Gaza	100270	108580	20	298.4	295.0	43.5	240.0	350.0	8
A/86	Agriculture	Gaza	100550	108900	20	214.7	219.3	23.0	180.0	259.0	16
A/85	Agriculture	Gaza	100980	109250	39.5	167.0	165.0	40.9	100.0	248.5	13
A/79	Agriculture	Gaza	101720	109800	29.3	139.2	140.0	19.6	110.0	165.0	6
A/76	Agriculture	Gaza	101820	110500	16	39.2	40.0	11.1	25.0	55.0	6
A/58	Agriculture	Gaza	102000	107250	35	110.8	115.1	38.8	40.0	208.8	18
A/181	Agriculture	Gaza	101130	109300	22.3	81.8	83.4	10.6	69.8	90.7	4

© 2005 Tous droits réservés.

A/159	Agriculture	Gaza	99840	108430	8.4	121.3	128.7	31.7	72.8	155.0	5
A/151	Agriculture	Gaza	99750	108280	12.8	230.9	250.0	81.0	125.0	304.9	5
A/131	Agriculture	Gaza	101780	108880	39.1	47.6	46.6	1.7	46.5	50.7	6
A/125	Agriculture	Gaza	100580	108720	20.1	139.5	125.0	89.0	53.0	308.9	6
A/114	Agriculture	Gaza	101620	108450	50	107.0	107.0	9.9	100.0	114.1	2
A/112	Agriculture	Gaza	101530	108300	50	148.8	154.6	39.6	85.7	211.1	9
A/106	Agriculture	Gaza	101070	106970	44.6	68.4	60.0	21.9	48.2	125.1	14
N/9	Domestic	khanyounis	87833	81624	76.4	259.5	155.0	196.4	88.0	682.0	17
N/22	Domestic	khanyounis	86900	81552	69.5	368.5	375.0	126.7	132.0	543.0	10
N/16	Domestic	khanyounis	88941	81123	89.9	69.3	65.4	23.5	33.0	109.0	14
M/2B	Domestic	khanyounis	85767	83687	87.4	127.4	95.0	102.2	20.0	355.0	13
M/2a	Domestic	khanyounis	85555	83909	67.4	328.4	330.0	53.0	266.0	413.0	7
L/87	Domestic	khanyounis	83040	84201	52.7	319.4	310.0	153.6	35.0	714.0	29
L/86B	Domestic	khanyounis	82237	84664	74.9	35.7	35.7	5.7	30.0	41.3	3
L/86a	Domestic	khanyounis	82237	84664	48.3	202.3	100.0	153.6	35.0	387.0	9
L/86	Domestic	khanyounis	82237	84664	74.9	450.6	532.5	202.8	40.0	709.0	24
L/43	Domestic	khanyounis	83063	83461	59.9	296.7	230.0	180.9	88.6	709.0	26
L/41	Domestic	khanyounis	84346	83161	61.6	252.5	234.0	94.6	53.2	451.0	28
L/189	Domestic	khanyounis	81850	87300	9.9	79.3	79.3	23.4	62.8	95.9	2
L/184	Domestic	khanyounis	80630	85650	10	184.2	90.5	199.7	48.7	413.5	3
L/179	Domestic	khanyounis	85572	87461	28.5	99.2	85.2	65.0	44.3	365.0	26
L/178A	Domestic	khanyounis	84367	86334	22.8	164.9	134.5	140.8	29.5	400.0	6
L/176	Domestic	khanyounis	82187	83277	38.4	116.6	70.0	137.3	22.0	640.0	33
L/159A	Domestic	khanyounis	82678	85082	45.1	370.6	379.0	173.5	118.4	580.0	7
L/159	Domestic	khanyounis	82605	85047	42.8	348.2	325.5	169.2	37.5	709.0	26
L/127	Domestic	khanyounis	82851	83935	53	299.2	220.0	193.4	22.5	817.0	29
Y/3	Agriculture	khanyounis	83420	78250	60	115.0	120.0	22.9	90.0	135.0	3
T/8	Agriculture	khanyounis	88080	87840	40	104.0	100.0	44.3	45.0	175.0	7
T/6	Agriculture	khanyounis	88322	88117	44.6	108.5	96.0	44.1	83.5	223.2	9
T/4	Agriculture	khanyounis	88090	88780	50	117.0	84.0	63.8	65.0	221.0	5
T/39	Agriculture	khanyounis	87250	87560	36.7	88.0	65.0	66.8	35.0	230.0	7
T/37	Agriculture	khanyounis	90800	89900	49.1	80.2	69.5	37.8	40.0	146.0	6
T/34	Agriculture	khanyounis	87620	88040	34.8	155.8	148.1	100.4	30.0	398.0	9
T/29	Agriculture	khanyounis	89300	89010	44.7	66.5	43.5	58.5	32.0	185.0	6
T/26	Agriculture	khanyounis	87081	85664	65.8	71.4	52.9	46.0	43.0	191.4	9
T/24	Agriculture	khanyounis	87500	84840	75	106.0	56.0	106.1	47.0	265.0	4
T/23	Agriculture	khanyounis	87560	85650	75	109.0	62.0	117.5	40.0	345.0	6
T/22	Agriculture	khanyounis	88338	85644	82.2	73.4	43.5	99.9	25.2	337.6	9
T/20	Agriculture	khanyounis	87470	86320	50	108.1	83.8	96.9	40.0	371.0	10
T/2	Agriculture	khanyounis	89000	88980	41	86.1	52.0	100.1	33.0	332.0	8
T/19	Agriculture	khanyounis	87300	86570	48	122.7	75.0	137.2	40.0	430.0	7
T/18	Agriculture	khanyounis	86940	86680	41	98.9	79.0	100.4	35.0	361.0	9
T/16	Agriculture	khanyounis	87360	86860	45	152.2	123.3	141.5	45.0	520.0	9
T/15	Agriculture	khanyounis	87279	87445	35.3	91.5	90.5	32.0	37.0	135.1	12
T/14	Agriculture	khanyounis	87740	87440	45	82.6	90.4	29.1	40.0	135.0	9
T/12	Agriculture	khanyounis	88250	87100	55	105.0	105.0	84.9	45.0	165.0	2
P/51	Agriculture	khanyounis	81750	80350	70	139.6	163.0	49.9	65.0	219.0	11
P/50	Agriculture	khanyounis	81175	80833	67.2	148.4	147.5	59.8	70.0	247.9	10
P/29	Agriculture	Khanyounis	77860	83660	10	70.4	40.0	47.7	32.0	125.0	5
O/3	Agriculture	Khanyounis	89230	79400	70	66.9	43.0	57.5	26.9	223.0	14
O/1	Agriculture	Khanyounis	89210	80320	90	164.7	160.5	92.6	85.0	438.7	12
N/7	Agriculture	Khanyounis	89263	83503	92.8	35.0	27.1	19.9	26.5	80.0	7
N/6	Agriculture	Khanyounis	88198	83205	83.6	47.5	47.5	3.5	45.0	50.0	2
N/5	Agriculture	Khanyounis	87922	83467	77.3	197.2	197.2	209.5	49.0	345.3	2
N/3	Agriculture	Khanyounis	88130	83950	88	58.6	55.0	29.0	30.0	115.0	7
N/24	Agriculture	Khanyounis	88270	82900	85.7	52.9	47.0	39.6	23.6	185.0	16
N/23	Agriculture	Khanyounis	86899	81551	69.5	67.2	61.0	37.9	31.4	135.0	6
N/21	Agriculture	Khanyounis	87450	82450	10	173.7	170.0	28.6	125.0	206.8	10
N/20	Agriculture	Khanyounis	88070	82520	80	64.0	50.0	50.3	32.0	196.0	9
N/2	Agriculture	Khanyounis	88000	84050	80.3	42.8	29.2	31.8	26.0	123.9	9
N/19	Agriculture	khanyounis	88450	82450	90.3	53.8	40.0	45.3	29.8	210.0	15
N/18	Agriculture	Khanyounis	89120	82270	91	51.4	45.0	17.9	35.1	88.0	9
N/17	Agriculture	Khanyounis	89030	82150	91	52.6	50.0	17.7	30.0	79.0	9
N/15	Agriculture	khanyounis	88570	81850	80	58.5	45.0	45.9	27.0	168.0	8
N/14	Agriculture	khanyounis	87350	79750	80	149.7	80.0	180.2	26.7	541.0	7
N/13	Agriculture	khanyounis	88010	80490	82	175.7	125.0	128.7	80.0	322.0	3
N/12	Agriculture	khanyounis	88701	80357	92.5	121.4	128.6	26.8	80.0	159.9	12

© 2005 Tous droits réservés.

N/11	Agriculture	khanyounis	88800	80730	90.4	76.0	62.5	51.1	33.1	190.0	8
N/10	Agriculture	khanyounis	87850	81500	70	255.2	211.1	143.5	41.5	477.9	9
N/1	Agriculture	khanyounis	88000	83950	80	42.3	45.0	9.3	32.0	50.0	3
M/9	Agriculture	khanyounis	86490	84540	70	75.1	67.5	24.5	50.0	117.0	8
M/8	Agriculture	khanyounis	86608	84010	85.2	43.1	41.6	8.3	33.2	59.0	9
M/7	Agriculture	khanyounis	86480	83000	69.5	71.8	60.0	43.4	41.9	220.0	17
M/4	Agriculture	khanyounis	85480	82120	70	48.1	40.4	17.4	36.1	85.0	12
M/3	Agriculture	khanyounis	85580	83300	80	100.7	73.7	95.1	50.0	398.0	12
M/10	Agriculture	khanyounis	85880	84720	61	65.4	58.0	18.8	42.6	91.8	12
M/1	Agriculture	khanyounis	85440	84240	62.6	200.8	221.2	61.8	76.3	340.0	15
L/95	Agriculture	khanyounis	82810	87850	10	67.2	70.0	16.5	45.0	90.0	5
L/94	Agriculture	khanyounis	83066	88152	5.7	53.9	51.8	9.3	40.0	65.0	7
L/93	Agriculture	khanyounis	82650	88240	10	46.0	46.0	26.9	27.0	65.0	2
L/91	Agriculture	khanyounis	81910	87450	10	90.0	70.0	62.4	40.0	160.0	3
L/9	Agriculture	khanyounis	86420	85750	50	151.8	159.4	57.5	73.0	268.0	18
L/88	Agriculture	khanyounis	81404	86784	5.5	146.7	167.0	41.2	100.0	205.0	7
L/84	Agriculture	khanyounis	80630	85650	10	102.3	80.0	43.1	75.0	152.0	3
L/81	Agriculture	khanyounis	79750	85130	6.7	149.3	146.0	15.6	135.0	170.0	4
L/80	Agriculture	khanyounis	79740	84920	9.8	50.0	50.0	0.0	50.0	50.0	2
L/8	Agriculture	khanyounis	86254	86212	41.6	94.9	99.8	17.6	51.9	112.3	9
L/73B	Agriculture	khanyounis	78400	83800	10	106.5	106.5	44.5	75.0	138.0	2
L/72	Agriculture	khanyounis	81700	80750	70	87.7	83.8	26.2	60.0	147.8	9
L/71	Agriculture	khanyounis	81870	80730	60	194.9	94.3	267.8	65.0	942.0	11
L/70	Agriculture	khanyounis	82300	81600	69.1	65.0	65.0	14.1	55.0	75.0	2
L/7	Agriculture	khanyounis	85950	86420	40	143.1	105.0	61.8	75.0	225.7	9
L/69	Agriculture	khanyounis	82700	81380	70	93.1	69.3	79.7	45.0	376.3	16
L/68	Agriculture	khanyounis	83150	81250	70	96.9	66.8	84.3	50.0	376.3	14
L/67	Agriculture	khanyounis	83160	80900	60	62.1	55.9	17.4	40.0	104.0	11
L/65	Agriculture	khanyounis	82960	79350	50	96.3	70.5	84.5	52.5	377.9	14
L/64	Agriculture	khanyounis	83100	79250	60	108.0	120.0	34.7	50.0	140.0	5
L/62	Agriculture	khanyounis	83200	78700	60	104.0	100.0	31.2	75.0	137.0	3
L/61	Agriculture	khanyounis	83310	78720	59.4	128.6	99.0	106.2	70.0	409.0	9
L/6	Agriculture	khanyounis	85750	86630	35	187.1	217.2	73.2	75.0	268.0	16
L/57	Agriculture	khanyounis	84369	81663	70.2	47.5	47.5	10.6	40.0	55.0	2
L/53	Agriculture	khanyounis	82980	82550	70	122.0	125.5	93.7	5.3	428.4	16
L/52	Agriculture	khanyounis	82680	81960	59.5	95.0	91.0	14.5	82.9	111.0	3
L/51	Agriculture	khanyounis	82040	82140	55	94.0	74.0	61.5	45.0	163.0	3
L/50	Agriculture	khanyounis	81800	82540	60	45.0	45.0	7.1	40.0	50.0	2
L/49	Agriculture	khanyounis	81880	82560	50	62.5	62.5	3.5	60.0	65.0	2
L/48	Agriculture	khanyounis	82420	82650	50	138.2	123.0	92.4	70.0	428.4	13
L/47	Agriculture	khanyounis	82610	82589	62.7	139.2	119.7	116.9	42.9	414.0	8
L/46	Agriculture	khanyounis	82400	83050	50	32.0	23.0	15.6	23.0	50.0	3
L/45	Agriculture	khanyounis	82600	83450	50	223.2	232.3	66.2	100.0	371.0	11
L/4	Agriculture	khanyounis	86220	86760	50	128.7	136.4	32.7	75.0	185.0	16
L/39	Agriculture	khanyounis	84500	82250	76	108.7	100.0	46.7	70.4	258.0	14
L/35	Agriculture	khanyounis	85120	82780	80	87.0	54.2	63.7	30.0	236.0	12
L/34	Agriculture	khanyounis	84950	83360	70	93.0	97.5	44.4	42.0	135.0	4
L/32	Agriculture	khanyounis	84780	84120	50	190.3	195.4	78.7	110.0	435.0	14
L/31	Agriculture	khanyounis	84210	84080	37.9	213.9	213.9	54.9	175.0	252.7	2
L/30	Agriculture	khanyounis	84700	84770	35	346.0	393.9	93.8	180.0	435.1	14
L/3	Agriculture	khanyounis	86100	87450	32.3	87.5	87.5	3.5	85.0	90.0	2
L/29	Agriculture	khanyounis	84560	84730	35	302.3	302.3	228.1	141.0	463.5	2
L/27	Agriculture	khanyounis	84230	84900	30	314.0	275.0	149.8	115.0	529.9	7
L/26	Agriculture	khanyounis	84250	84930	50	362.3	392.1	106.2	200.0	619.0	15
L/24	Agriculture	khanyounis	84260	85400	28	212.3	237.9	59.2	110.0	290.8	15
L/23	Agriculture	khanyounis	84820	85550	30	99.5	90.0	20.2	84.3	132.0	5
L/22	Agriculture	khanyounis	85090	85560	32.4	139.7	135.0	27.3	115.0	169.0	3
L/21	Agriculture	khanyounis	85050	85600	30	142.5	143.5	22.0	115.0	168.0	4
L/20	Agriculture	khanyounis	85050	85750	30	142.3	140.0	45.3	75.0	224.0	9
L/1B	Agriculture	khanyounis	86920	86900	39.5	124.7	100.0	39.8	75.0	169.3	11
L/19	Agriculture	khanyounis	85190	85670	50	172.0	155.0	29.2	152.0	221.0	5
L/18	Agriculture	khanyounis	85277	85822	32.2	167.2	171.6	10.4	145.0	178.6	12
L/174	Agriculture	khanyounis	86570	86900	35.8	101.3	102.5	8.5	90.0	110.0	4
L/173	Agriculture	khanyounis	86680	87500	30	113.3	85.3	104.1	45.0	409.0	15
L/172	Agriculture	khanyounis	81570	81440	60	110.1	66.6	120.6	50.2	382.8	7
L/171	Agriculture	khanyounis	86340	80600	67.3	52.5	52.5	3.5	50.0	55.0	2
L/17	Agriculture	khanyounis	85100	86070	29	95.2	85.4	49.7	45.0	212.0	10

© 2005 Tous droits réservés.

L/168	Agriculture	khanyounis	85120	89440	10	47.7	50.0	19.5	12.7	70.0	6
L/166	Agriculture	khanyounis	79800	85050	9.3	86.0	100.0	57.3	23.0	135.0	3
L/164	Agriculture	khanyounis	85870	78800	60	85.0	85.0	9.5	70.0	100.0	6
L/156	Agriculture	khanyounis	85150	86520	30	69.0	55.0	26.1	50.0	110.0	5
L/150	Agriculture	khanyounis	84760	82580	80	145.5	148.4	19.1	110.0	170.0	11
L/15	Agriculture	khanyounis	85450	86370	41	93.4	100.0	31.8	47.0	135.0	5
L/142	Agriculture	khanyounis	83620	81080	62.5	55.0	57.5	4.3	50.0	57.5	3
L/141	Agriculture	khanyounis	83840	82720	61.3	199.6	198.9	94.5	100.0	475.8	14
L/139	Agriculture	khanyounis	81800	82000	60	116.7	95.0	96.9	45.0	416.7	13
L/136	Agriculture	khanyounis	84700	85340	30	256.5	261.9	37.5	165.0	317.6	12
L/134	Agriculture	khanyounis	84480	84580	40.2	222.5	222.5	3.5	220.0	225.0	2
L/133	Agriculture	khanyounis	84000	84900	30	272.7	289.0	102.2	100.0	460.0	14
L/129	Agriculture	khanyounis	82800	81080	61	149.3	87.6	138.9	65.0	357.0	4
L/126	Agriculture	khanyounis	83070	87520	14.6	36.1	45.0	18.0	10.0	52.3	5
L/121	Agriculture	khanyounis	84520	88880	10	54.0	61.3	42.6	10.0	100.0	7
L/12	Agriculture	khanyounis	85670	85060	50	158.0	149.5	66.9	100.0	371.0	14
L/119	Agriculture	khanyounis	84460	89660	9.9	37.5	37.5	3.5	35.0	40.0	2
L/115	Agriculture	khanyounis	83200	82780	60.5	190.3	158.7	99.2	112.0	332.0	4
L/112	Agriculture	khanyounis	82720	87840	10	55.4	53.0	11.7	40.0	69.0	5
L/109	Agriculture	khanyounis	80540	86050	10	75.8	70.0	45.0	23.0	149.0	7
L/108	Agriculture	khanyounis	84600	86380	30	215.8	217.1	109.4	45.0	393.0	14
L/106	Agriculture	khanyounis	83370	82940	55	254.6	276.6	92.2	105.0	438.7	13
L/103	Agriculture	khanyounis	84630	89500	10	42.5	42.5	3.5	40.0	45.0	2
L/101	Agriculture	khanyounis	84806	89100	4.5	96.6	88.3	21.9	80.6	129.0	4
L/100	Agriculture	khanyounis	84140	89300	9.4	67.5	67.5	3.5	65.0	70.0	2
L/10	Agriculture	khanyounis	85660	85630	40	125.2	100.0	48.7	75.0	210.0	9
T/46	Domestic	Middle	91984	90273	78.5	159.1	152.0	138.6	32.5	300.0	4
T/44	Domestic	Middle	89231	87642	86.5	93.7	80.0	54.9	40.0	172.0	9
S/71	Domestic	Middle	92676	91700	71.5	35.0	35.0	8.1	29.2	40.7	2
S/69	Domestic	Middle	91768	90703	67.7	88.5	60.0	80.5	30.0	279.0	23
K/19	Domestic	Middle	86462	88592	24.1	170.8	165.0	94.2	69.9	313.0	5
J/35	Domestic	Middle	88270	92040	13.8	65.8	39.0	61.6	9.8	155.0	7
J/32	Domestic	Middle	88304	91767	28.3	109.5	75.0	84.9	40.0	311.0	13
J/2	Domestic	Middle	88440	89640	28.9	79.1	54.6	44.7	52.0	130.7	3
J/146	Domestic	Middle	91200	90460	60.9	103.0	70.0	84.3	40.0	296.0	23
T/7	Agriculture	Middle	89100	87950	61	51.3	46.6	21.8	25.0	85.0	5
T/3	Agriculture	Middle	88000	89000	30	111.7	65.0	77.1	40.0	224.0	7
T/1	Agriculture	Middle	89693	89350	46.4	70.9	55.0	40.0	35.0	188.2	13
S/60	Agriculture	Middle	93657	91961	54.7	66.2	51.0	47.0	35.0	189.7	9
S/50	Agriculture	Middle	91342	90668	61.4	61.6	46.2	41.6	31.8	185.9	12
S/42	Agriculture	Middle	93032	91935	74.8	51.1	50.0	17.9	33.0	87.0	7
S/40	Agriculture	Middle	92319	92188	53.5	78.9	45.0	103.4	29.4	352.7	9
S/37	Agriculture	Middle	92220	92756	42.9	50.9	55.0	8.4	32.0	55.3	8
S/29	Agriculture	Middle	93179	93846	45.6	49.7	45.0	18.5	30.0	77.0	6
S/28	Agriculture	Middle	93307	92856	58.6	49.7	44.8	15.2	31.0	85.0	10
S/15	Agriculture	Middle	94278	94367	19.8	76.3	63.6	51.2	33.0	205.7	9
S/11	Agriculture	Middle	94970	93543	19	62.8	30.0	98.5	22.0	358.5	11
K/9	Agriculture	Middle	87120	88240	50	40.0	40.0	0.0	40.0	40.0	2
K/8	Agriculture	Middle	87020	88750	28.1	41.1	37.5	8.8	34.2	58.0	6
K/7	Agriculture	Middle	86200	89570	20.7	61.0	60.5	21.4	32.0	115.0	11
K/7	Agriculture	Middle	85970	89690	20	58.6	55.0	26.9	32.0	115.0	7
K/4	Agriculture	Middle	86500	89900	20.5	290.0	290.0	155.6	180.0	400.0	2
K/3	Agriculture	Middle	86848	89605	21.6	85.1	83.4	28.8	45.0	168.0	13
K/2	Agriculture	Middle	87280	89750	23	68.4	64.0	30.0	40.0	154.0	11
K/14	Agriculture	Middle	86560	88580	26.63	107.1	121.5	53.0	43.0	221.0	11
K/10	Agriculture	Middle	86850	88280	30	45.4	38.1	27.1	26.2	119.0	10
K/1	Agriculture	Middle	87730	89130	28.2	82.2	71.4	41.1	40.0	180.0	9
J/99	Agriculture	Middle	88120	92800	10	211.0	160.0	164.5	72.0	478.0	5
J/94	Agriculture	Middle	88790	92490	20	223.5	155.0	143.7	145.0	439.0	4
J/93	Agriculture	Middle	88880	92180	20	139.0	115.0	96.7	50.0	276.0	4
J/92	Agriculture	Middle	88260	92250	15	210.6	227.4	113.2	40.0	397.0	11
J/85	Agriculture	Middle	88940	91600	25	82.7	74.0	38.2	45.0	148.0	6
J/73	Agriculture	Middle	86950	91290	13.1	116.6	123.9	26.7	87.0	138.8	3
J/68A	Agriculture	Middle	85986	90837	12.2	53.3	50.0	15.3	40.0	70.0	3
J/67	Agriculture	Middle	85650	89920	30	75.3	68.5	20.8	60.0	115.0	6
J/65	Agriculture	Middle	86030	90490	19.7	172.4	199.3	98.1	55.0	286.0	6
J/62	Agriculture	Middle	86210	90370	17.4	72.5	62.5	41.7	35.0	130.0	4

© 2005 Tous droits réservés.

J/60	Agriculture	Middle	87110	90610	19.9	181.7	215.0	71.1	100.0	230.0	3
J/6	Agriculture	Middle	88700	90350	28.2	101.3	101.3	44.5	69.8	132.8	2
J/59	Agriculture	Middle	86560	90650	18.1	156.3	168.1	66.8	65.0	336.0	13
J/58	Agriculture	Middle	86640	90760	16.6	102.2	80.0	66.3	40.0	210.0	5
J/57	Agriculture	Middle	86780	90950	16.5	157.4	131.5	83.2	75.0	286.0	8
J/56	Agriculture	Middle	86830	90910	17.9	160.9	106.0	98.2	40.0	314.9	14
J/55	Agriculture	Middle	86850	90440	21.5	64.5	64.5	7.8	59.0	70.0	2
J/54E	Agriculture	Middle	86880	90700	19.1	95.2	92.5	29.9	45.0	131.0	6
J/54D	Agriculture	Middle	86960	90670	19.8	114.7	114.0	5.0	110.0	120.0	3
J/54B	Agriculture	Middle	87080	91080	17.6	168.8	215.7	81.3	75.0	215.8	3
J/53	Agriculture	Middle	87140	91240	19.3	208.3	234.2	47.4	123.0	241.5	6
J/52	Agriculture	Middle	87160	91260	18.1	108.3	100.0	23.6	90.0	135.0	3
J/47	Agriculture	Middle	87510	91530	11.3	337.5	337.5	198.7	197.0	478.0	2
J/44	Agriculture	Middle	87740	91800	10	256.7	213.0	158.1	125.0	432.0	3
J/4	Agriculture	Middle	88160	90050	30	92.3	84.7	39.7	65.0	188.0	8
J/3	Agriculture	Middle	88170	89860	40	130.8	119.5	66.1	65.0	219.0	4
J/29	Agriculture	Middle	88120	91490	20	172.3	205.0	58.3	105.0	207.0	3
J/27	Agriculture	Middle	88640	91260	24.1	172.3	205.0	58.3	105.0	207.0	3
J/24	Agriculture	Middle	88920	91020	30	71.7	61.4	29.3	40.0	132.8	8
J/23	Agriculture	Middle	88780	90870	27	98.0	98.0	45.3	66.0	130.0	2
J/21	Agriculture	Middle	88160	90640	23.8	71.3	85.0	27.2	40.0	88.9	3
J/18	Agriculture	Middle	89950	91250	30	96.0	95.0	38.7	45.0	196.0	13
J/16	Agriculture	Middle	90030	90810	34.2	100.9	90.0	50.5	45.0	205.0	8
J/15	Agriculture	Middle	90370	90810	38.5	94.7	70.0	57.1	45.0	199.0	7
J/147	Agriculture	Middle	85820	91260	3.1	156.4	156.4	93.9	90.0	222.9	2
J/144	Agriculture	Middle	90430	91020	37.1	73.3	65.0	18.9	60.0	95.0	3
J/142	Agriculture	Middle	88720	91030	24.3	127.5	127.5	109.6	50.0	205.0	2
J/14	Agriculture	Middle	90220	90280	38	61.7	49.8	30.5	40.0	155.0	13
J/13	Agriculture	Middle	89440	90430	30.8	116.3	110.1	45.3	75.0	219.0	11
J/126	Agriculture	Middle	85800	89860	17.1	37.4	30.0	17.9	21.8	56.6	5
J/12	Agriculture	Middle	89370	90570	30.8	70.0	70.0	21.2	55.0	85.0	2
J/115	Agriculture	Middle	88700	91600	23.1	175.9	180.0	14.7	156.3	187.1	4
J/112	Agriculture	Middle	88440	89660	29.1	73.0	77.8	14.1	45.0	83.8	6
J/108	Agriculture	Middle	89380	93410	10	155.5	118.0	104.6	95.0	390.0	7
J/103	Agriculture	Middle	88733	92931	6.6	218.7	223.2	32.6	170.0	268.5	6
J/10	Agriculture	Middle	89260	91140	29	66.4	58.6	28.1	40.0	123.9	10
J/1	Agriculture	Middle	88150	89100	30	130.0	148.0	45.2	65.0	194.6	9
H/9	Agriculture	Middle	90440	92600	30	72.0	75.0	10.7	55.0	81.9	6
H/8	Agriculture	Middle	90000	93400	10	170.0	170.0	19.1	150.0	202.0	7
H/7	Agriculture	Middle	89960	93350	20	251.0	251.0	120.2	166.0	336.0	2
H/69	Agriculture	Middle	89750	93060	30	182.8	178.0	95.6	45.0	410.0	10
H/62	Agriculture	Middle	90480	95180	10	51.5	52.3	1.3	50.0	52.3	3
H/52	Agriculture	Middle	90380	94680	10	123.0	96.5	70.7	55.9	280.0	8
H/51	Agriculture	Middle	90180	94650	20	215.5	202.5	89.9	120.0	337.0	4
H/50	Agriculture	Middle	90160	94620	10	287.7	307.9	91.5	116.0	399.3	8
H/5	Agriculture	Middle	89613	92965	33.8	72.9	65.2	19.4	50.0	110.0	7
H/49	Agriculture	Middle	89900	94680	10	70.2	70.0	29.2	31.1	120.0	6
H/48	Agriculture	Middle	89870	94800	10	101.3	110.0	47.6	50.0	144.0	3
H/45	Agriculture	Middle	89650	95000	10	291.7	278.4	55.3	240.0	370.0	4
H/44	Agriculture	Middle	89490	94900	10	255.4	250.0	56.2	195.0	402.0	11
H/43	Agriculture	Middle	89590	94480	10	46.7	43.9	26.2	23.3	90.9	5
H/41	Agriculture	Middle	90450	94220	20	91.2	70.0	51.7	50.0	181.0	5
H/40	Agriculture	Middle	90200	94060	17	84.7	69.5	42.4	50.0	199.0	10
H/4	Agriculture	Middle	89350	92750	30	123.6	130.1	53.5	50.0	221.0	9
H/39	Agriculture	Middle	90000	94060	15	77.8	64.0	32.4	45.0	120.0	5
H/38	Agriculture	Middle	89960	93900	15	77.5	77.5	10.6	70.0	85.0	2
H/35	Agriculture	Middle	89510	93830	10	51.3	50.0	2.5	50.0	55.0	4
H/33	Agriculture	Middle	88210	93600	10	164.5	164.5	48.8	130.0	199.0	2
H/30	Agriculture	Middle	89270	93650	9.5	115.0	115.0	35.4	90.0	140.0	2
H/29	Agriculture	Middle	89520	93600	10.1	98.6	83.4	51.0	50.0	205.0	7
H/28	Agriculture	Middle	90440	93600	30	130.8	120.0	46.0	85.0	227.0	7
H/27	Agriculture	Middle	90630	93720	30	162.0	135.0	96.7	85.0	376.0	7
H/2	Agriculture	Middle	89820	92250	25	63.9	58.0	13.7	52.8	84.1	5
H/11	Agriculture	Middle	90660	92785	24.5	124.0	105.5	53.0	70.0	230.0	12
H/10	Agriculture	Middle	90500	92920	30	113.7	110.0	60.9	45.0	223.0	7
G/4A	Agriculture	Middle	90280	96050	14.8	198.1	193.2	49.5	110.0	309.0	13
G/24B	Agriculture	Middle	92377	98909	14	143.9	124.5	54.0	86.1	240.0	8

© 2005 Tous droits réservés.

G/21	Agriculture	Middle	91399	96975	7.9	126.8	99.0	78.2	54.8	293.2	10
G/2	Agriculture	Middle	90520	95710	10	61.0	61.4	13.8	46.2	82.8	5
G/10	Agriculture	Middle	91189	96149	8.3	141.3	139.6	43.9	45.0	210.0	9
F/84	Agriculture	Middle	96384	98212	37.9	77.3	70.0	22.7	57.9	132.8	12
F/83	Agriculture	Middle	96160	97870	30	66.1	63.5	21.2	40.0	92.0	8
F/68A	Agriculture	Middle	94888	96729	25.1	102.1	102.6	29.7	70.0	168.0	9
F/20	Agriculture	Middle	94020	95870	10	116.4	77.0	88.2	50.0	308.0	7
F/16	Agriculture	Middle	93820	95690	10	81.3	60.0	44.2	40.0	166.0	7
F/138	Agriculture	Middle	98065	96896	64.3	68.5	71.7	30.2	25.0	118.0	9
F/134	Agriculture	Middle	97720	97923	44.6	45.3	37.2	18.5	33.2	81.0	6
F/121	Agriculture	Middle	96218	95435	48.6	87.7	80.0	26.2	60.0	154.0	11
F/120A	Agriculture	Middle	96135	95435	38.77	32.0	32.0	0.0	32.0	32.0	2
F/120	Agriculture	Middle	96130	95430	50	40.0	40.0	7.1	35.0	45.0	2
F/12	Agriculture	Middle	93670	95460	10	60.4	52.5	27.8	35.0	130.0	10
F/114	Agriculture	Middle	95850	95170	10	87.4	73.9	28.9	65.0	162.0	12
F/113	Agriculture	Middle	95500	95000	40	73.7	73.7	0.0	73.7	73.7	2
F/111	Agriculture	Middle	95290	94680	35	60.6	56.6	17.3	40.0	100.0	15
F/11	Agriculture	Middle	93430	95420	15	115.4	100.0	45.8	70.0	209.0	9
F/109	Agriculture	Middle	95130	95530	25	62.8	52.2	21.3	45.7	103.0	12
F/108	Agriculture	Middle	95920	96500	30	66.0	60.0	23.7	40.0	114.0	8
F/106	Agriculture	Middle	96331	97455	26.5	78.0	72.1	21.4	50.0	110.0	6
F/105	Agriculture	Middle	96450	97420	30	168.7	168.0	69.0	100.0	238.0	3
F/103	Agriculture	Middle	97550	98510	40	125.9	125.9	0.0	125.9	125.9	2
F/10	Agriculture	Middle	93530	95350	20	55.8	47.5	19.1	33.0	94.4	12
F/1	Agriculture	Middle	92780	94900	20	224.9	182.5	85.8	150.0	360.0	8
R/75	Domestic	North	100417	101299	42.1	100.0	83.5	64.2	50.0	258.0	12
R/74	Domestic	North	100661	101543	44.7	105.2	83.5	69.3	50.0	258.0	10
R/265	Domestic	North	95809	101708	39.1	120.4	56.7	109.8	21.4	260.0	7
R/25D	Domestic	North	100820	102496	34.5	110.4	79.0	84.5	15.0	290.9	29
R/25C	Domestic	North	100775	102456	34.4	216.2	195.0	126.4	24.7	606.0	23
R/25b	Domestic	North	100779	102527	33.1	273.3	240.0	154.2	30.0	678.0	24
R/25a	Domestic	North	100759	102581	32.3	220.3	230.0	110.4	15.0	380.0	24
R/254	Domestic	North	96542	102056	36.1	102.5	60.7	88.7	10.0	322.0	30
R/162Ha	Domestic	North	99030	103700	32	342.0	195.0	208.5	164.6	584.0	7
R/162H	Domestic	North	99055	103668	33	234.9	200.0	130.6	20.0	580.0	25
R/162G	Domestic	North	99166	103952	35.7	180.0	126.5	149.7	15.0	580.0	32
R/162E	Domestic	North	98248	104479	40	113.0	60.0	122.1	15.0	474.0	15
R/162d	Domestic	North	98638	104990	39.9	438.3	599.0	279.1	116.0	600.0	3
R/162D	Domestic	North	98638	104990	39.9	176.7	176.7	95.5	109.2	244.2	2
R/162C	Domestic	North	98866	104595	50.5	85.0	82.0	106.4	7.0	189.0	21
R/162B	Domestic	North	98725	104402	53.5	212.3	132.0	212.1	11.5	683.0	27
R/112	Domestic	North	96061	102650	20.7	164.6	105.0	159.3	66.6	709.0	27
Q/68	Domestic	North	102221	103530	42.3	232.3	240.0	67.8	161.0	296.0	3
Q/40b	Domestic	North	102769	103963	55	222.0	254.0	98.3	65.0	312.0	7
Q/40B	Domestic	North	102769	103963	55	53.1	55.0	7.2	42.9	59.6	4
Q/39	Domestic	North	103040	109300	53.5	211.0	226.5	92.0	85.0	306.0	4
E/90	Domestic	North	101278	104583	46.2	193.9	160.0	104.9	64.0	522.0	29
E/9	Domestic	North	102719	104844	33.9	26.7	27.4	4.1	22.2	30.4	3
E/8	Domestic	North	102740	104910	40	357.8	377.0	159.7	181.3	496.0	4
E/61	Domestic	North	99737	106339	44.8	87.7	90.0	29.2	39.0	129.6	12
E/6	Domestic	North	103013	105334	35.2	215.4	241.5	151.4	34.0	490.0	8
E/4	Domestic	North	103034	105064	37.9	130.1	95.0	87.9	42.6	344.0	24
E/157	Domestic	North	99670	107560	17.26	136.4	81.0	121.7	48.0	426.0	25
E/156	Domestic	North	100156	104670	26.2	139.3	130.0	55.4	90.0	372.0	24
E/154	Domestic	North	102067	104589	27.2	104.5	70.0	88.4	20.0	336.0	29
E/15	Domestic	North	104047	104047	36.7	43.1	43.1	4.9	39.6	46.5	2
E/138	Domestic	North	102720	104398	41.3	155.6	135.0	91.5	19.6	428.0	19
E/11C	Domestic	North	101971	105190	33.9	240.4	222.5	108.8	38.9	444.0	18
E/11B	Domestic	North	102165	105095	28.4	216.9	230.0	93.4	54.1	360.0	27
E/11A	Domestic	North	101845	104415	35.8	243.0	250.0	138.8	54.0	564.0	27
E/10	Domestic	North	102523	105106	28.2	143.1	134.6	36.8	100.0	230.0	11
E/1	Domestic	North	103274	104899	54.3	73.3	81.2	35.3	26.8	109.2	5
D/74	Domestic	North	100504	106104	40	206.1	188.5	144.5	67.2	380.0	8
D/73	Domestic	North	101037	106827	37.2	135.9	70.0	123.0	45.0	330.0	7
D/72	Domestic	North	101739	106462	21.6	175.6	135.0	120.9	97.0	390.0	5
D/70	Domestic	North	101440	105833	24.9	258.3	301.0	153.8	90.0	491.0	9
D/69	Domestic	North	100835	105466	27.5	88.2	90.0	34.3	20.0	149.3	9

© 2005 Tous droits réservés.

D/68	Domestic	North	100514	105179	22.8	94.9	50.0	97.7	18.0	340.0	27
D/67	Domestic	North	101716	107218	22.9	41.8	35.5	24.0	2.5	80.0	30
D/2	Domestic	North	101379	105028	40.2	307.5	236.0	176.3	90.0	550.0	11
C/79	Domestic	North	105349	105095	42.1	79.0	73.4	16.5	55.0	106.9	10
C/76	Domestic	North	104667	104337	41.1	189.6	46.0	219.5	26.6	522.0	9
C/128	Domestic	North	106477	104891	66	86.0	42.5	108.5	4.0	391.0	27
C/127	Domestic	North	104778	106154	57.2	75.0	44.0	81.2	4.0	291.0	30
A/32	Domestic	North	102584	106271	40	108.7	115.0	42.2	17.5	170.0	14
A/185	Domestic	North	102530	106252	40.6	109.2	90.0	85.3	8.0	430.0	32
A/180	Domestic	North	102459	107033	24.1	51.3	50.0	19.5	3.5	85.0	30
R/84	Agriculture	North	99419	98988	73.8	75.0	75.0	14.1	65.0	85.0	2
R/62	Agriculture	North	100470	101080	41	270.1	220.5	195.9	90.0	730.0	8
R/38	Agriculture	North	102027	101783	56.3	60.9	60.9	8.6	54.8	67.0	2
R/255	Agriculture	North	96200	10080	-9999	57.9	56.6	14.8	40.0	85.0	12
R/243	Agriculture	North	96720	101140	40	100.0	100.0	21.2	85.0	115.0	2
R/219	Agriculture	North	97500	100880	30	145.0	145.0	28.3	125.0	165.0	2
R/216	Agriculture	North	101523	101059	65.1	51.4	47.9	25.5	29.2	100.0	6
R/212	Agriculture	North	95400	102300	16.9	126.8	115.0	29.1	100.0	185.0	7
R/210	Agriculture	North	94911	101914	16.7	98.6	91.1	12.5	89.0	121.0	7
R/16B	Agriculture	North	102070	102420	67.6	130.1	127.2	39.1	75.0	247.0	13
R/133	Agriculture	North	96773	101064	45.4	95.9	99.0	28.6	40.0	139.0	10
R/130	Agriculture	North	96910	100950	40	147.1	150.0	26.9	110.0	195.0	7
R/13	Agriculture	North	102580	102480	51.8	34.2	29.7	9.1	28.0	55.0	9
R/125	Agriculture	North	97350	101420	40	288.0	170.0	268.3	125.0	901.0	8
R/12	Agriculture	North	102580	102580	56.3	29.0	29.0	0.0	29.0	29.0	2
R/108	Agriculture	North	93374	100136	14.9	129.7	103.2	79.9	75.0	309.0	7
Q/8	Agriculture	North	105250	103350	58	23.1	13.7	16.2	12.9	50.0	7
Q/58	Agriculture	North	102480	100600	53.3	53.8	47.8	12.9	35.0	75.0	11
Q/57	Agriculture	North	102240	100910	50.8	48.1	49.0	2.7	45.0	50.2	3
Q/56	Agriculture	North	103384	101365	51.6	77.0	41.2	77.4	8.2	265.0	10
Q/55	Agriculture	North	103200	101620	50	44.5	39.3	9.1	39.3	55.0	3
Q/54D	Agriculture	North	102830	101770	58.61	59.0	50.0	26.4	40.0	96.0	4
Q/54B	Agriculture	North	103940	101950	58	50.0	47.5	13.5	34.0	76.0	8
Q/54A	Agriculture	North	102730	102040	52	40.8	37.1	10.3	30.0	60.0	8
Q/5	Agriculture	North	104640	103800	46.6	40.0	40.0	10.0	30.0	50.0	3
Q/48	Agriculture	North	102850	103130	55.7	139.2	76.6	136.2	36.9	421.0	14
Q/41	Agriculture	North	103100	103900	55	120.5	86.5	124.0	22.8	422.3	8
Q/40A	Agriculture	North	102910	104020	60	85.0	67.5	53.1	45.0	160.0	4
Q/4	Agriculture	North	104420	103900	43	56.7	42.5	45.8	26.1	190.0	12
Q/33	Agriculture	North	103520	103880	50	91.0	50.0	78.2	25.0	206.0	6
Q/31	Agriculture	North	103839	103994	42.6	35.0	33.7	7.2	25.7	50.0	8
Q/3	Agriculture	North	104000	104350	42.6	88.7	85.0	63.1	40.0	221.0	7
Q/28	Agriculture	North	103520	103660	49.9	39.0	39.0	22.6	23.0	55.0	2
Q/26	Agriculture	North	103310	103420	50.9	112.4	112.4	52.9	75.0	149.8	2
Q/21	Agriculture	North	104700	102870	60	28.0	25.0	6.9	20.0	38.0	6
Q/20	Agriculture	North	103760	102767	44.4	66.2	40.0	61.0	20.0	237.0	13
Q/2	Agriculture	North	103800	104390	5	303.6	209.7	295.6	46.7	1048.6	11
Q/18	Agriculture	North	104440	102350	57.3	70.0	50.0	53.6	30.0	175.0	6
Q/17	Agriculture	North	104470	102300	60	73.8	60.0	50.9	30.0	160.0	5
Q/16	Agriculture	North	104640	101760	70	73.8	60.0	50.9	30.0	160.0	5
Q/15	Agriculture	North	104380	102000	64	64.2	47.5	36.5	40.0	160.0	12
Q/14	Agriculture	North	104470	101980	70	70.0	80.0	26.5	40.0	90.0	3
Q/12	Agriculture	North	104914	101958	72	42.6	38.0	19.3	22.9	85.0	8
Q/10	Agriculture	North	105310	102600	80	48.2	35.0	35.0	23.1	155.0	13
Q/1	Agriculture	North	103610	104780	60	125.3	62.5	170.4	40.0	541.0	8
E/45	Agriculture	North	99823	105405	44.1	92.0	93.0	21.5	50.0	117.0	12
E/32	Agriculture	North	99053	106225	28.3	102.2	90.7	37.4	75.4	204.0	11
E/26	Agriculture	North	102090	103730	35	103.8	102.3	10.4	85.0	123.0	16
E/24B	Agriculture	North	102180	104740	39.3	236.8	176.3	141.2	162.5	489.2	5
E/23	Agriculture	North	102480	104170	40.1	92.5	92.5	24.7	75.0	110.0	2
E/12	Agriculture	North	101590	104298	39.1	165.4	170.2	40.8	100.0	256.0	15
E/114	Agriculture	North	100380	103600	30	177.4	175.0	28.1	125.0	212.0	7
C/93	Agriculture	North	105710	105870	40	121.7	121.7	0.0	121.7	121.7	2
C/92	Agriculture	North	105540	105680	40	110.9	108.5	11.3	100.0	125.0	6
C/91	Agriculture	North	105220	105720	45	33.6	35.9	9.9	13.3	45.6	7
C/9	Agriculture	North	105160	105670	40	93.7	93.7	0.1	93.6	93.7	2
C/78	Agriculture	North	104931	104934	39.6	55.7	55.1	17.4	30.0	94.8	14

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

C/77	Agriculture	North	104340	104580	42.3	41.8	42.1	1.9	39.6	43.7	5
C/70	Agriculture	North	106520	103200	75	50.2	40.0	14.0	40.0	66.0	5
C/7	Agriculture	North	106100	106380	40	71.0	74.5	30.5	32.0	103.0	4
C/69	Agriculture	North	106980	102720	87	30.5	31.0	2.8	25.9	32.7	5
C/61	Agriculture	North	105984	104040	60.1	91.3	92.0	23.7	55.0	143.0	10
C/56B	Agriculture	North	105720	103760	60	66.5	60.1	23.6	30.0	111.9	12
C/54	Agriculture	North	105050	104260	48.3	44.4	44.4	9.4	37.8	51.0	2
C/51	Agriculture	North	105350	104450	50	55.7	46.2	30.0	30.0	146.0	13
C/49	Agriculture	North	106028	105245	45	133.1	137.1	16.3	113.5	148.6	6
C/48	Agriculture	North	106501	105843	54.6	77.4	74.6	15.4	50.0	100.0	12
C/47A	Agriculture	North	105700	104760	50	88.3	71.8	47.8	40.0	237.0	15
C/43	Agriculture	North	106040	105010	54	85.4	80.0	40.0	30.0	132.8	5
C/3C	Agriculture	North	107626	105586	70.6	97.3	85.9	22.9	68.0	135.0	14
C/3B	Agriculture	North	107540	105800	70	74.5	58.2	33.5	40.0	132.8	8
C/3A	Agriculture	North	107230	105770	65	87.7	79.9	36.2	40.0	178.5	15
C/38	Agriculture	North	106130	104680	58.4	98.6	85.9	58.0	25.0	211.0	13
C/35	Agriculture	North	107030	103110	81	45.7	33.8	22.8	25.0	99.0	9
C/34	Agriculture	North	107490	103700	60	61.7	56.9	25.2	35.0	109.8	8
C/33	Agriculture	North	106960	104250	72	58.3	46.2	38.1	32.0	194.8	16
C/25	Agriculture	North	107490	104460	78.6	51.0	50.5	12.0	28.6	71.0	11
C/24	Agriculture	North	107160	104520	70	44.1	32.5	32.1	20.1	123.9	10
C/23	Agriculture	North	107220	104600	72.2	86.5	65.1	63.3	37.0	178.8	4
C/21	Agriculture	North	107270	104680	70.9	62.1	60.5	4.2	57.8	70.3	7
C/20	Agriculture	North	106780	104850	65	61.8	64.8	17.8	37.0	92.0	8
C/2	Agriculture	North	107100	105880	50	133.9	128.6	48.8	42.0	217.8	10
C/17B	Agriculture	North	108400	105350	59.8	26.3	24.2	4.5	23.7	33.1	4
C/17A	Agriculture	North	108370	105270	60	50.0	40.0	30.1	26.6	123.9	9
C/16B	Agriculture	North	108400	105070	70	42.5	34.3	24.3	23.0	118.6	15
C/16A	Agriculture	North	108280	105240	60	56.2	45.0	33.3	30.0	119.5	6
C/15B	Agriculture	North	107970	105470	63.5	59.1	45.4	31.1	32.0	123.9	8
C/15A	Agriculture	North	108040	105280	60.4	62.1	60.4	17.7	42.3	85.3	4
C/14	Agriculture	North	107870	105840	60	92.7	77.6	61.5	35.0	292.0	14
C/12C	Agriculture	North	107740	104780	70.1	120.3	84.5	92.7	56.1	281.0	5
C/12B	Agriculture	North	107900	104890	70.1	72.8	54.9	57.1	33.0	239.0	11
C/12A/1	Agriculture	North	107411	105175	69.4	70.8	68.8	33.2	30.0	146.0	10
C/113	Agriculture	North	105060	106050	4	152.1	169.2	64.1	58.7	237.0	14
C/111	Agriculture	North	105220	106020	36	88.1	72.5	57.4	35.0	210.0	8
C/106	Agriculture	North	105620	106400	35	92.5	85.0	40.9	45.0	168.0	9
C/104	Agriculture	North	105892	106624	31.9	37.1	30.1	13.0	27.3	65.0	12
B/5	Agriculture	North	106600	106650	39	88.6	85.5	12.9	70.0	115.1	10
B/4	Agriculture	North	106615	106740	35	110.0	101.8	30.6	70.0	190.4	14
B/3	Agriculture	North	106940	106870	45	58.6	55.0	25.1	20.0	110.0	9
B/21	Agriculture	North	106440	106940	35	61.0	52.5	27.5	39.0	100.0	4
B/2	Agriculture	North	106970	106820	60	62.2	58.3	16.1	40.0	110.0	16
B/18	Agriculture	North	107420	106080	64.8	47.5	47.5	17.7	35.0	60.0	2
B/17	Agriculture	North	107290	106170	50	81.2	80.0	25.5	45.0	132.8	9
B/15	Agriculture	North	106900	106380	40	68.5	65.0	20.0	40.0	110.0	14
B/12	Agriculture	North	107190	106590	45	49.4	45.0	18.1	35.0	106.3	16
B/11	Agriculture	North	107350	106570	50	63.4	60.4	18.4	30.0	95.0	14
B/10	Agriculture	North	108550	105550	61.6	45.2	46.1	18.0	25.0	70.0	7
B/1	Agriculture	North	106900	107050	40	45.0	44.8	9.3	30.2	54.7	6
A/95	Agriculture	North	100234	108116	23.1	193.5	209.7	55.9	100.0	274.0	11
A/74	Agriculture	North	102530	109580	45	52.8	45.0	28.1	25.0	110.0	13
A/72	Agriculture	North	102800	109180	47.4	55.4	21.8	67.3	9.2	239.0	12
A/70	Agriculture	North	103600	109400	30	41.4	25.1	45.4	10.0	141.3	8
A/7	Agriculture	North	104300	105170	45	139.5	130.7	45.8	65.0	247.9	13
A/68	Agriculture	North	103350	108880	30	59.0	53.7	19.0	32.0	95.0	13
A/65	Agriculture	North	103070	108250	30	102.3	102.3	10.4	95.0	109.7	2
A/59	Agriculture	North	102100	107400	30	116.0	117.0	5.5	110.0	120.9	3
A/57	Agriculture	North	102550	107350	30	60.7	67.0	18.3	40.0	75.0	3
A/53	Agriculture	North	102191	106917	23.7	158.2	138.8	52.8	90.0	315.0	15
A/52	Agriculture	North	103420	107020	30	120.0	111.0	46.8	65.0	195.0	8
A/48	Agriculture	North	102940	107000	30	100.8	104.0	39.6	45.0	173.0	8
A/47	Agriculture	North	103100	107080	30	95.1	91.4	29.5	51.3	155.0	13
A/46	Agriculture	North	103300	107500	30	75.5	68.3	42.4	35.0	203.0	15
A/36	Agriculture	North	103080	106680	30	114.0	118.7	25.7	50.0	155.8	15
A/31	Agriculture	North	102800	106050	50	144.8	142.0	40.1	95.1	256.8	12

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

A/28	Agriculture	North	103200	106000	26	58.2	55.0	19.2	27.7	115.0	18
A/27	Agriculture	North	103200	106040	30	80.0	50.0	49.9	40.0	223.0	15
A/26	Agriculture	North	103080	105980	50	139.4	120.0	76.4	55.0	263.0	8
A/25	Agriculture	North	103000	105930	30	122.9	116.0	41.8	75.0	203.0	16
A/24	Agriculture	North	102950	105980	26	180.7	193.2	46.1	100.0	247.9	10
A/21	Agriculture	North	103205	105476	32.7	160.5	150.5	51.1	100.3	295.0	10
A/17	Agriculture	North	104550	105900	45	118.7	111.2	48.4	45.0	215.1	14
A/14	Agriculture	North	104280	105850	70.3	95.0	95.0	63.6	50.0	140.0	2
A/123	Agriculture	North	102900	106100	30	104.3	104.3	0.0	104.3	104.3	2
A/115	Agriculture	North	102172	108994	44.8	124.6	125.7	10.2	106.0	140.7	7
A/107	Agriculture	North	101218	107482	57.5	120.8	129.2	47.8	30.3	240.9	17
A/10	Agriculture	North	104180	105650	59.9	54.1	56.5	6.9	44.1	59.3	4
A/1	Agriculture	North	103830	104600	50	110.0	125.0	47.0	30.0	150.0	5
P/15	Domestic	Rafah	77927	78904	22	153.3	118.0	122.4	16.7	510.0	29
P/146	Domestic	Rafah	80947	81867	43	68.6	68.6	68.5	20.1	117.0	2
P/145	Domestic	Rafah	79369	79856	48.2	111.8	83.0	59.9	50.0	205.0	8
P/144	Domestic	Rafah	78302	80376	32.2	65.1	48.2	43.9	32.7	171.5	16
P/139	Domestic	Rafah	77167	82011	9.8	114.5	135.5	59.6	27.0	160.0	4
P/138old	Domestic	Rafah	78773	79765	47.7	65.9	65.0	10.7	44.3	80.0	13
P/138	Domestic	Rafah	78773	79765	47.7	91.3	87.5	37.9	39.0	159.0	10
P/124	Domestic	Rafah	77598	79414	24.2	136.3	108.0	102.1	18.0	421.0	28
P/10	Domestic	Rafah	78613	77039	81.8	230.3	192.5	135.3	27.0	559.0	24
P/99	Agriculture	Rafah	78681	78385	50.3	122.6	123.1	9.6	110.3	133.9	4
P/97	Agriculture	Rafah	79190	79380	60	165.6	149.0	41.5	125.0	219.0	5
P/96	Agriculture	Rafah	79660	77650	60	117.5	105.0	43.5	80.0	180.0	4
P/94	Agriculture	Rafah	80942	76960	59	113.3	125.0	20.2	90.0	125.0	3
P/93	Agriculture	Rafah	80760	76970	60	129.0	100.0	73.5	85.0	260.0	5
P/91	Agriculture	Rafah	80510	77490	70	97.5	97.5	17.7	85.0	110.0	2
P/90	Agriculture	Rafah	80220	77300	70	134.1	116.6	69.0	90.0	336.0	11
P/88	Agriculture	Rafah	80290	76720	60	190.8	95.0	244.6	73.8	828.0	9
P/87	Agriculture	Rafah	80000	76490	60	67.5	67.5	3.5	65.0	70.0	2
P/86C	Agriculture	Rafah	79920	77030	60	98.8	82.5	60.6	50.0	180.0	4
P/86A	Agriculture	Rafah	80190	76790	60	70.0	70.0	21.2	55.0	85.0	2
P/85	Agriculture	Rafah	79500	76970	60	76.3	75.0	11.1	65.0	90.0	4
P/83	Agriculture	Rafah	79230	76720	60	70.6	63.0	31.9	47.8	168.0	13
P/79	Agriculture	Rafah	80630	77610	70	105.8	107.5	19.1	75.0	125.0	6
P/78	Agriculture	Rafah	80160	78120	70	104.6	94.0	52.5	50.0	262.0	12
P/76	Agriculture	Rafah	79950	78600	60	63.9	62.7	11.9	40.0	85.0	14
P/75	Agriculture	Rafah	79900	79110	50	65.9	54.6	32.1	35.0	155.2	11
P/74	Agriculture	Rafah	80010	78880	70	55.0	55.0	0.0	55.0	55.0	2
P/72	Agriculture	Rafah	80540	78590	70	112.2	92.5	68.1	60.0	247.9	6
P/70	Agriculture	Rafah	80650	78150	70	125.9	127.9	56.3	70.0	265.0	12
P/69	Agriculture	Rafah	80880	77640	70	110.1	75.0	70.5	70.0	265.0	7
P/68	Agriculture	Rafah	81330	77750	55	141.2	127.0	77.7	85.0	336.0	9
P/67	Agriculture	Rafah	82080	77620	60	89.4	90.0	8.6	78.8	100.0	5
P/66	Agriculture	Rafah	82374	77844	56.2	101.7	90.0	20.2	90.0	125.0	3
P/65	Agriculture	Rafah	82750	78200	70	84.2	82.5	16.2	65.0	104.2	6
P/64	Agriculture	Rafah	83010	78300	60	93.8	90.0	15.5	80.0	115.0	4
P/63	Agriculture	Rafah	83060	79080	60	90.0	90.0	10.0	80.0	100.0	3
P/61	Agriculture	Rafah	81113	79150	63.7	101.4	89.0	38.0	40.0	168.7	11
P/60	Agriculture	Rafah	81030	79270	60	104.8	90.2	45.2	65.0	221.0	9
P/6	Agriculture	Rafah	78770	76630	60	101.3	92.5	30.9	75.0	145.0	4
P/59	Agriculture	Rafah	81210	79510	70	102.1	99.0	31.8	70.0	198.0	13
P/58	Agriculture	Rafah	81610	78960	70	143.8	134.6	64.5	85.0	336.0	13
P/55	Agriculture	Rafah	82220	79110	60	72.9	71.6	7.1	65.0	85.0	8
P/54	Agriculture	Rafah	82020	79510	70	74.5	72.5	18.5	48.4	100.0	8
P/53	Agriculture	Rafah	82530	79700	70	92.0	90.0	7.6	85.0	100.0	5
P/49	Agriculture	Rafah	80650	80120	70	145.1	153.0	51.1	70.0	250.0	9
P/48A	Agriculture	Rafah	80067	79696	62	136.7	133.9	9.5	125.4	152.8	6
P/47	Agriculture	Rafah	79550	79240	60	121.7	111.0	60.5	60.0	262.0	8
P/45	Agriculture	Rafah	79240	79070	55	130.9	120.0	59.0	49.3	276.0	13
P/44	Agriculture	Rafah	78400	78780	50	113.4	105.0	39.6	50.0	200.0	15
P/43	Agriculture	Rafah	78700	78780	48.1	65.0	65.0	35.4	40.0	90.0	2
P/42	Agriculture	Rafah	79280	78330	60	83.8	85.0	36.8	40.0	125.0	4
P/41	Agriculture	Rafah	79030	78170	40	171.6	176.6	64.5	87.0	300.0	14
P/39	Agriculture	Rafah	78760	78270	55.7	97.5	97.5	38.9	70.0	125.0	2
P/38	Agriculture	Rafah	78490	78120	50	208.0	210.0	101.0	85.0	360.0	5

© 2005 Tous droits réservés.

P/37	Agriculture	Rafah	78460	78800	40	137.5	143.7	53.7	60.0	230.0	14
P/34	Agriculture	Rafah	78450	79430	31	201.9	246.5	112.6	40.0	380.0	12
P/33	Agriculture	Rafah	78370	79180	40	168.0	122.5	123.3	55.0	426.0	8
P/32	Agriculture	Rafah	78180	78970	40	126.0	117.5	41.7	85.0	196.0	6
P/31	Agriculture	Rafah	77840	79280	40	218.4	222.8	76.5	110.0	389.0	14
P/24	Agriculture	Rafah	77319	82292	10.3	79.0	85.0	33.1	32.0	132.0	9
P/23	Agriculture	Rafah	77200	82500	5	62.5	62.5	60.1	20.0	105.0	2
P/22	Agriculture	Rafah	76420	81830	15	92.9	105.0	30.4	55.0	125.0	7
P/18	Agriculture	Rafah	77620	79280	40	140.8	105.0	77.4	70.0	290.0	9
P/17	Agriculture	Rafah	77780	79090	40	105.0	105.0	84.9	45.0	165.0	2
P/16B	Agriculture	Rafah	77290	79120	42	103.3	107.5	20.9	70.0	125.0	6
P/142	Agriculture	Rafah	80540	78060	61.79	121.7	147.3	47.6	40.0	163.5	10
P/141	Agriculture	Rafah	80920	77900	60.34	111.3	119.0	52.9	55.0	160.0	3
P/135	Agriculture	Rafah	81520	77600	60	112.5	95.0	45.7	80.0	180.0	4
P/134	Agriculture	Rafah	80800	80650	60.9	108.5	100.0	24.1	80.0	148.0	6
P/130	Agriculture	Rafah	81400	78820	62.1	105.8	105.7	18.5	75.0	135.0	14
P/13	Agriculture	Rafah	77865	78429	34.8	160.8	129.7	120.0	50.0	520.0	12
P/127	Agriculture	Rafah	80500	79020	69.7	154.5	95.0	137.2	85.0	432.0	6
P/125	Agriculture	Rafah	78600	79080	41.2	189.9	198.9	35.0	135.0	265.0	13
P/12	Agriculture	Rafah	78300	77680	61	138.7	151.6	47.5	80.6	230.0	12
P/118	Agriculture	Rafah	79970	78440	65.5	60.0	60.0	35.4	35.0	85.0	2
P/110	Agriculture	Rafah	80160	77740	73.8	112.5	112.5	3.5	110.0	115.0	2
P/108	Agriculture	Rafah	80620	77340	68.5	135.3	108.0	101.7	50.0	247.9	3
P/106	Agriculture	Rafah	79890	76820	60	140.0	140.0	77.8	85.0	195.0	2
P/102	Agriculture	Rafah	77510	79600	36.5	26.3	21.9	17.7	8.7	60.0	10
P/101	Agriculture	Rafah	81259	79615	73.4	96.1	85.0	37.8	65.0	138.2	3

© 2005 Tous droits réservés.

Table (II.2): Nitrate concentration of agricultural wells and explanatory variables data

Well Code	Nitrate Conc. (mg/L)	Well Depth (m)	Screen Length (m)	nitrogen load (ton/ha.y)	No. of Houses (no.)	Infiltration (cm/h)	Discharge (m3/d)
G/24C	30	16	40	202	43	3	320
F/47	30.76	13	10	175	106	3	312
F/76A	33.12	21	10	264	57	4	259
F/97	35.49	90.6	18	919	50	20	370
S/27	36	74.8	35	850	90	13	400
H/61	37.47	10	17	139	71	2	295
S/9	37.83	25	26	315	140	5	251
S/32	38	65	10	800	79	13	107
R/67	38.32	41	10	504	43	8	152
S/21	40	10	32	142	50	2	330
A/76	40	16	27	207	43	3	350
R/52	40	60	10	754	43	14	203
F/78	41.07	25	10	322	110	6	189
S/14	45	20	10	274	86	6	141
F/128	45	38	21	552	191	15	145
S/41	45	53.6	12	666	151	15	213
A/131	46.62	39	10	500	57	9	335
F/141	46.63	40	10	541	36	12	150
S/23	47.5	82.3	40	902	43	19	317
F/43	48.12	18	10	284	133	8	269
R/46	48.87	45	11	582	71	12	247
F/24	50	15	10	209	79	4	128
F/131	50	42	10	554	86	12	132
E/56	50	60	10	740	71	12	181
S/45	50	67.9	18	790	71	16	255
S/10	50.5	10	10	140	71	2	299
F/30A	52.99	20	17	281	79	6	136
F/156	53.08	50	10	650	115	13	297
R/42	54.42	78.8	14	1046	141	33	391
F/15	55	15	10	231	86	6	216
F/136	55	40	7	602	249	18	100
R/94	55.04	42	19	574	39	14	240
S/44	55.49	47.2	10	676	29	16	55
H/14	56.74	21.1	10	274	50	6	123
E/88	56.84	63.2	10	785	43	17	360
S/19	57	26	10	358	295	8	1145
F/157	57.11	53.2	10	684	61	15	194
F/17	57.5	13	10	202	78	5	150
R/60	59.74	56	17	765	57	19	128
S/55	60	21.6	10	292	100	7	154
A/106	60	45	10	622	123	15	90
F/46	62.5	18	10	317	79	12	90
F/9	62.5	20	15	299	61	8	128
R/90	62.5	38	10	454	71	6	172
F/29	62.89	30	31	429	180	11	83
F/71	63	33	19	452	111	10	120
G/18	63.03	10	23	155	153	4	312
S/17	64.5	30	10	437	36	12	90
F/36	65	10	26	165	43	5	163
J/143	65	48.3	10	657	29	19	105
S/7	65.21	29.3	19	426	36	11	238
F/198	65.25	12	10	177	36	4	396
F/73	68.15	37	10	514	71	13	60
F/82	68.35	30.8	10	421	249	10	107
F/127	70	51.7	10	711	64	19	189
S/43	70	57	10	826	123	24	176
F/99	72.07	62	10	862	66	22	274
F/34	73.18	20	10	311	155	9	150
R/30	76.77	39	9	671	70	26	251
F/30B	77	14	10	219	71	6	136
E/53	77	50	17	735	100	22	112

© 2005 Tous droits réservés.

F/21	77.33	14	10	221	51	6	120
F/62	80	13	36	213	176	6	189
F/77	80	21	24	307	126	8	68
F/76	80	31.4	10	445	29	13	148
R/270	81.95	55.1	21	727	200	21	440
A/181	83.45	22	29	329	101	9	106
F/148	85	14	30	214	71	5	163
F/22	85	74.1	10	1080	66	10	286
S/25	87	30	25	450	107	13	60
F/70	88.31	30	10	447	64	11	60
E/62	89.97	50	10	743	86	22	60
S/6	90.5	10	9	165	150	5	286
E/35	92.48	47	10	734	93	22	83
R/249	92.5	40	10	605	149	19	130
S/18	93.58	20	10	313	100	9	163
G/27	95	10	42	167	125	5	207
F/32	95	20	10	343	43	12	136
E/30	95	40	10	613	50	19	84
F/143	95.98	40	10	613	129	19	75
F/7	96.02	20	26	324	173	10	176
F/88	96.52	40	23	737	228	31	152
S/36	96.89	41.7	23	656	189	24	83
H/19	97.14	29.1	10	475	107	15	83
E/65	98.06	48.7	10	848	114	33	90
F/35	98.18	13	17	213	160	6	216
G/19	100	10	18	174	93	5	247
H/20	100	21.6	32	328	86	8	225
R/253	100	44	25	680	270	22	109
R/87	100	59	18	918	26	31	280
R/16A	102.5	68	10	1040	66	34	167
S/13	105	30	32	489	136	17	260
H/16	105.31	20	10	343	129	12	176
F/163	105.49	40	10	631	129	21	90
S/34	105.5	30	22	496	107	18	90
A/114	107.04	50	29	788	107	27	105
F/5	107.5	20	24	342	100	12	213
H/15	109	18	10	323	171	11	229
S/30	110	49.2	10	844	244	32	150
E/43	112.5	52	23	846	50	33	165
E/149	112.65	41	10	661	53	23	129
R/197	113	21.6	12	392	193	17	195
F/68B	113.36	32	10	563	129	22	300
E/142	114.06	48	20	857	350	36	960
A/58	115.15	35	34	564	220	19	90
F/52	117.5	19	21	330	129	12	154
R/33	119.5	60	11	979	107	36	627
G/20	120	10	29	187	70	7	229
R/134	122.5	64.8	40	1134	114	38	221
E/67	122.75	47.4	44	829	33	31	83
D/9	123.65	30	10	527	143	21	90
S/49	123.65	54	10	909	80	35	132
E/144	124.01	45	10	750	143	28	90
A/125	125	20	10	361	40	11	113
R/23	125	30	15	501	330	18	152
A/159	128.73	8	15	149	143	5	240
G/12	130	39.3	10	792	171	37	105
A/90	130	50	44	826	143	31	113
R/88	130	57	8	851	186	26	243
H/58	130.93	14	10	254	61	9	181
D/71	131.8	28	21	593	368	29	450
E/42	132.4	50	27	823	107	30	165
H/24	133	31	19	519	257	20	165
R/28	133	52	12	878	171	34	114
D/60	135	36	10	620	157	24	1000
E/37	135	49.2	10	874	100	35	228
R/162L	135	57	10	982	164	39	933

© 2005 Tous droits réservés.

R/162La	135	59	10	1005	219	39	915
D/43	137.02	36	27	653	284	27	150
S/12	139	13	20	242	186	9	295
A/79	140	29	10	513	171	20	165
R/240	140	40	10	701	104	28	280
E/79	140	46.6	10	940	143	39	180
R/101	142.5	35	19	623	37	25	113
D/6	142.85	30	10	530	133	21	120
E/85	143.77	30	10	526	80	20	135
F/37	145	10	10	196	61	7	277
E/109	145	20	10	366	154	12	150
E/41	145	48.1	26	894	121	37	158
D/58	147.89	50	10	886	179	36	280
E/89	148.77	53.8	10	1051	193	39	180
H/25	149.99	29.1	18	596	94	27	185
R/26A	150	37	10	701	48	31	839
R/8B	150.8	50	10	847	120	33	90
E/28	153.07	50	36	902	380	38	160
R/20	153.5	36	28	658	241	28	90
E/78	153.89	52.6	10	947	157	39	105
A/112	154.57	46.2	22	894	179	37	120
R/8A	154.94	40	10	755	257	33	240
R/160	159	39.1	23	787	320	36	152
R/135	163.36	36	5	676	143	29	194
A/85	165	40	10	756	94	33	105
R/5	167	42.9	29	779	147	36	289
E/107	167.5	28	26	537	214	23	120
E/111	168	30	10	574	184	25	165
G/26	170.22	38	19	743	243	34	135
D/55	171.17	30	10	593	243	27	229
E/31	172.65	40	10	768	99	35	90
G/16	177.35	10	25	203	134	8	181
R/170	179.92	30	20	597	271	27	194
E/113	180	32	10	625	316	28	138
A/93	182.5	43.6	44	1028	200	36	75
R/3	185.87	40	12	811	243	39	222
E/63	187.5	46.8	10	1006	186	36	137
R/6	189.6	39.3	26	801	229	38	80
E/74	190	20	10	404	171	18	120
E/110	192.5	30	10	612	101	29	274
E/127	195	38	10	788	257	38	135
E/94	196.5	40	26	833	370	36	150
E/92	200	33	10	741	429	39	1100
R/129	200	36.8	17	903	307	37	240
E/73	207.5	20	10	431	90	21	135
A/86	219.34	20	9	438	386	21	229
R/199	225	30	10	634	343	31	269
R/146	227.5	40	18	864	429	35	160
A/92	234.02	36	38	1059	457	38	135
E/102	235.54	30	10	686	237	36	188
R/147	236.14	40	32	910	576	33	260
R/131	247	35.2	44	1214	341	39	280
A/151	250	13	10	304	494	15	270
R/185	250	20	12	523	419	33	363
G/13	261.08	27	9	746	686	35	312
R/128	275	31	18	761	714	37	200
A/89	295	20	17	523	740	30	303
F/53	303.84	17	10	1357	749	26	351
E/158	356.1	12.5	10	1200	734	34	440
R/189	375	15.1	20	1127	723	35	458
R/66B	388	18.8	10	1026	750	33	850
G/17	395.5	14.5	10	1126	730	34	532

© 2005 Tous droits réservés.

Table (II.3): Groundwater chemistry of domestic wells (mg/L, except pH value) for the year 2002.

SampleID	Location	pH	EC	TDS	Na	K	Mg	Ca	F	Cl	SO4	NO3	NO2	HCO3	Hardness
P/10	Rafah	7.6	5500	2750	942.6	1.9	28.6	119.6	2.5	1096	616.3	257.4	0	292.5	416.3
P/15	Rafah	7.43	2038	1263	270	14.1	56	91.1	1	425.1	117	151.1	0	233	457.9
P/124	Rafah	7.4	2096	1268	250	15.3	54.3	86.9	0.99	444	82.2	144.3	0.006	232.5	440.4
P/138	Rafah	7.7	1018	616	112.5	2.6	22	51.5	1.5	204.4	44.6	77.6	0	156.7	219.1
P/145	Rafah	7.77	1402	848	185	2.9	29.7	49.9	1.2	281.9	117	80.13	0.004	174.4	246.8
P/153	Rafah	8.15	628	380	96	2	6.9	36	0.78	112.7	8.8	51.6	0	126	118.3
P/147	Rafah	7.88	1500	929	230	2.4	29.7	47.2	0.96	283.4	37.5	85.8	0	232	240.1
P/144	Rafah	8	919	556	142.5	2.9	13.8	39.4	2.9	204.4	37.7	33.2	0.008	129	155.2
P/139	Rafah	7.7	1021	633	43	2.9	20	34	0.8	49	90	62	0	130	167.2
L/184	Khanyounis	8.12	760	460	106	1.6	19.2	32.3	1.6	134	24.1	111.2	0	159	159.7
L/187	Khanyounis	7.68	5580	3459	42	5.7	30.3	28	0.36	149	120	118.4	0	164	194.6
L/41	Khanyounis	7.85	4786	2896	780	5	45.8	63.14	1.24	972	402.6	200	0	315.8	346.1
L/176	Khanyounis	8.12	3200	1984	517.6	5.5	53.6	87.8	1.43	774.2	527.4	106.7	0	166	439.8
L/43	Khanyounis	7.7	4065	2460	460	6.2	95.6	135.5	1.12	718.9	178	383.4	0	412	731.7
L/127	Khanyounis	7.92	3424	2072	400	4.4	80.5	134	1.1	690.7	106.5	371.7	0	189.5	665.9
L/87	Khanyounis	7	4160	2579	580	5.6	99	135.8	1.26	949.4	301.5	376.4	0	223	746.5
L/86A	Khanyounis	7.7	4520	2820	480	5.4	110.7	158.5	1.04	722.7	380	440.5	0	423	851.3
L/159	Khanyounis	7.97	3120	1888	265	7.34	53.3	168	1.71	486	82.6	433.6	0	260.2	638.8
L/159A	Khanyounis	7.78	2353	1424	180	4.62	48.6	128.6	0.92	324.2	42.2	363	0	240	521.1
L/14	Khanyounis	7.6	4900	2450	826.4	1.7	29.5	101.6	1	977.7	280.3	228.3	0	324.2	375.1
L/178	Khanyounis	8.2	5837	3532	950	8.5	57.3	70	1.7	1290	527.4	61.3	0	366	410.6
L/179	Khanyounis	8	2082	1295	450	3	21	32.1	2	433.4	225	85.2	0	319.5	166.6
Q/569	Qarara	7.63	2010	1216	320	3.2	46.7	60.45	1.51	431.7	148.8	23.61	0	269	343.1
K/19	Qarara	7.85	921	573	125	1.7	32.7	35.4	1.3	120.7	55	106	0	251	223.0
J/1	Qarara	7.92	1223	740	110	5.02	29.3	96.7	0.87	162.8	120.1	38.7	0	243.4	362.0
J/2	Qarara	7.75	1349	816	190	2.1	30.7	52.4	1.58	198.2	92.6	130.7	0	281.8	257.2
J/146	Qarara	7.63	2651	1604	440	3.02	38.4	58.8	1.6	566.2	203.9	130.7	0	307.4	304.8
S/69	Middle	7.3	2000	1000	317.5	1.2	29.3	49.1	0.8	319.2	174	52.2	0	258.3	243.2
S/71	DeirAlBa	7.7	2393	1448	340	3.4	40.7	75.7	2.2	528.6	188.3	40.7	0	252.7	356.5
S/37	DeirAlBa	7.7	3623	2192	580	8.7	55.5	104.7	2.1	782.3	227.3	64	0	283	489.8
G/45	Middle	7.1	5100	2550	746	2.7	154.3	116.5	1.3	1119	423.1	244.8	0	374.8	925.8
G/30	Middle	7.4	3300	1650	508	1.5	65.5	80.4	0.4	684.3	336.3	103.4	0	263.4	470.3
R/162BA	Gaza	7.37	1477	918	300	4.2	50.2	177.6	0.52	672	84	74.5	0	240	650.0
R/75	Gaza	7.89	3330	2060	780	6.2	63	71.5	2.36	1148	207	57.7	0	215.3	437.8
R/265	Gaza	7.62	1064	644	325	3.8	33.7	58.8	1.37	407	103.6	56.7	0	402	285.5
R/254	Gaza	7.6	2188	1324	356	4.2	74.8	137	0.5	664.3	83.6	173.1	0	299.8	649.9
R/254	North	7.4	2200	1100	354.9	1.3	27	61.2	0.1	413.7	105.8	59.6	0	400	263.9
R/280	Gaza	8.01	543	274	60	1.1	17.6	28.6	0.5	64	16.9	17.8	0	218	143.8
R/25C	Gaza	7.31	4357	2636	450	7.6	58.3	58.8	1.45	500	172.7	159.3	0	410	386.7
R/25D	Gaza	7.57	3134	1896	695	6	45	43	1.6	928.6	208	290.9	0	420	292.5
R/25B	Gaza	7.21	2856	1728	460	28.2	53	65	1.1	564	113.4	245.9	0	405	380.4
R/25A	Gaza	7.46	2691	1628	374	7.2	29	60.45	1.22	483	223	53.8	0	380	270.3
R/271	Gaza	7.53	1818	1100	221	1.1	16.2	48.1	0.53	363.6	73	67.85	0	192	186.8
R/112	Gaza	7.33	4230	2700	600	13	98	133	0.5	1079	221.4	100.5	0	375	735.4
R/270	Gaza	7.8	463	280	570	3.7	46.6	48.3	1.5	750	281	85.7	0	430	312.4
A/185	Gaza	7.45	985	596	48.5	6.23	36.8	93.5	0.75	113.2	36.6	66.2	0.015	287	384.9
Q/68	Jabalia	8.02	1620	1000	260	3.4	36	48	0.18	177	177	161	0	334	268.0
R/162EA	Gaza	7.24	3017	1872	325	5	74.4	195.8	2.5	646.5	120	124	0	292	795.1
R/162CA	Gaza	7.35	1380	855	125	5	51	73.4	0.95	177.6	75	103.4	0	322	393.1
R/162G	Gaza	7.22	2208	1336	240	4.1	57	178	0.73	507	63.3	257	0	292	679.0
R/162H	Gaza	7.5	2640	1640	320	2.5	43	58.5	1.2	411	175	142.3	0	314.4	323.0
R/162LA	Gaza	7.38	3300	1751	480	5	86	137	0.2	710	175	186.4	0	314.4	696.0
C/76	BeitHanon	7.14	2235	1352	250	3.2	82.8	102	1.03	608.6	37.5	42.6	0.003	322	595.4
E/138	Jabalia	7.4	987	592	80	4.1	35.5	75.8	0.97	127.4	27.24	121	0	232.3	335.4
R/162B	Gaza	7.43	3206	1940	260	5.1	66	179.7	0.6	678.6	55	150.8	0	240.8	720.3
E/11A	Jabalia	7.59	1040	520	135.8	0.7	30.53	41.43	0.45	134.2	29.6	54.6	0	324.2	229.1
R/162E	Gaza	7.28	3391	2052	166	2.6	29.1	28.2	1.36	214.3	51.5	22.4	0	279	190.2
E/90	Jabalia	7.04	1675	1038	106	3.5	65	110	1.02	191	67.21	223	0	322.9	542.1
E/154	Jabalia	7.82	1350	820	140	5.4	39.7	104.8	0.75	235.7	27.7	96.2	0	258.7	425.1

© 2005 Tous droits réservés.

R/162C	Gaza-She	7.48	1514	916	135	2.6	23.4	137	0.53	285.7	25.8	112.3	0	230.6	438.4
E/156	Jabalia	7.53	1203	728	85	2.8	53.5	76.5	1.1	184.6	41.2	129.2	0.006	274.1	411.2
C/128	BeitHanon	7.09	1302	788	162.5	2.5	43.1	56.4	0.9	261.8	29.3	59.3	0.004	315.1	318.2
E/1	BeitLahia	7.54	1018	616	60	2.6	30.4	81.4	0.76	176.9	23.9	47.6	0.006	238.3	328.4
E/8	BeitLahia	7.44	1355	820	48	2.1	64.7	89.4	1.04	120	56.1	181.3	0	289.5	489.5
R/162D	Gaza	7.3	5012	3200	750	5.3	134	28.4	0.96	1648	15.5	244.2	0	223.1	622.3
E/4	BeitLahia	7.5	774	468	39.8	2.5	41.56	61.3	0.96	70.77	41.4	42.6	0	256.2	324.1
E/11B	Jabalia	7.22	1090	545	56.96	0.8	52.5	69.6	0.32	113.6	31.15	208	0	222	389.8
C/79	BeitHanon	7.1	2141	1296	270	3.2	73.7	97.5	0.9	502.5	68.5	106.9	0.01	361.2	546.7
D/68	Sh-Radwan	7.31	980	480	90.38	0.7	24.34	82.1	0.23	124.1	28.53	87	0	253.2	305.2
D/68	BeitLahia	7.82	985	596	90	2.6	30.8	77.4	0.95	142.8	25.7	94	0	263.9	320.0
E/11C	Jabalia	7.46	890	445	72.8	0.7	25.5	64.47	1.59	101.5	12.11	123.7	0	227.9	265.9
A/6	BeitHanon	7.79	754	456	64	2.7	28.7	42.7	1.14	106.1	28.8	23.2	0.006	243.4	224.7
D/69	BeitLahia	7.6	1071	648	90	3.9	32	67	2.8	114.3	31.5	20	0	256	299.0
D/70	BeitLahia	7.32	998	604	48	6.8	34.1	91	0.64	107.1	31.5	123.9	0	281.8	367.5
C/48	BeitLahia	7.56	1450	725	131.5	0.9	27.8	122.5	0.62	268.2	50.6	64.5	0	303.9	420.2
D/74	BeitLahia	7.5	939	568	45	4.5	27.4	84.6	0.82	92	18	85.9	0	258.8	324.0
C/127	BeitHanon	7.37	668	404	63	1.9	26.9	55.6	1.01	77.8	10.4	58.7	0.002	243.7	249.5
D/71	BeitLahia	7.5	873	540	550	4.9	71.7	88.6	1.6	850.2	426	131.8	0	169	516.3
E/61	BeitLahia	7.57	1046	649	81.5	5.2	20.9	94.35	0.77	141	56.63	70.8	0	246	321.6
D/72	BeitLahia	7.76	1003	624	190	2.8	51	90	1.7	238	286	97	0	343.4	434.6
D/76	BeitLahia	7.3	793	480	37.7	6	26.6	94	1.26	63.45	19.9	75.58	0	264	344.2
D/75	BeitLahia	7.4	919	556	55	7.4	27.6	92.7	1.18	100	33.99	100.7	0	279.3	345.0
A/180	BeitLahia	7.66	965	584	43.5	1.4	33.6	90.3	0.66	106.1	16.5	51.6	0.008	304.8	363.7
D/67	BeitLahia	7.89	502	304	32	1.5	21.2	44.33	0.78	42.5	7.53	18.5	0.004	217.7	197.9
E/157	BeitLahia	7.35	1190	720	100	5.2	43.61	83.8	1.56	178.6	29.5	109.8	0	317.7	388.7
A/40	BeitLahia	7.2	1300	650	55.7	0.5	57.9	95.3	0.01	207.4	18.8	47.5	0	369.8	476.2

© 2005 Tous droits réservés.

Table (II.4): Explanatory variables used for domestic wells modelling

Sample ID	Location	Y	X	Z-Depth	Scr-Depth	T-well depth	Dist-sea	Disch	Scr-Length	Pop-250m	Pop-500M	Rainfall mm/y
P/10	Rafah	77039	78613	55	67	77	5680	2882	10	6127	31600	295
P/15	Rafah	78904	77927	22	18	38	3734	2970	20	5906	34208	248
P/124	Rafah	79414	77598	24	48	58	3107	2835	10	5789	34208	244
P/138	Rafah	79765	78773	48	67	85	3570	1344	18	3156	4887	240
P/145	Rafah	79856	79369	48	75	81	3951	1277	6	2200	3500	241
P/153	Rafah	80166	80133	60	63	84	4205	1173	21	2300	2932	245
P/147	Rafah	80230	81200	46	71	79	4889	896	8	2500	2932	250
P/144	Rafah	80376	78302	32	80	90	2847	2203	10	3932	19547	229
P/139	Rafah	82011	77167	10	30	40	833	1564	10	2450	2550	220
L/184	Khanyounis	82373	81361	42	68	78	3519	1590	10	3281	8695	260
L/187	Khanyounis	82928	81859	53	76	86	3469	1297	10	3003	3650	260
L/41	Khanyounis	83161	84346	55	47	65	5059	3020	17.7	6339	36000	290
L/176	Khanyounis	83277	82187	38	110	120	3514	1362	10	2736	4348	265
L/43	Khanyounis	83461	83063	31	50	60	3906	3216	10	10782	38200	280
L/127	Khanyounis	83935	82851	23	30	40	3457	3478	10	12837	45700	275
L/87	Khanyounis	84201	83040	36	65	75	3373	3544	10	13303	47800	280
L/86A	Khanyounis	84664	82237	41	44	54	2517	3222	10	15221	47000	265
L/159	Khanyounis	85047	82605	20	19	55	2473	2876	35.9	14308	43800	270
L/159A	Khanyounis	85082	82678	14	31	41	2473	2891	10	11805	41700	275
L/14	Khanyounis	85150	85550	49	40	65	4586	2275	25	4027	20900	300
L/178	Khanyounis	86334	84367	67	115	125	2966	2339	10	3642	21600	290
L/179	Khanyounis	87461	85572	29	86	96	3041	2464	10	4249	24844	300
Q/569	Qarara	88500	89600	70	71	81	5100	950	10	1500	2650	310
K/19	Qarara	88592	86462	24	45	55	2796	1395	10	3098	3500	300
J/1	Qarara	89100	88150	30	35	45	3511	1504	10	3379	7500	305
J/2	Qarara	89640	88440	29	34	44	3366	1371	10	3011	4500	305
J/146	Qarara	90460	91200	61	62	72	4821	1013	10	2500	2760	310
S/69	Middle	90703	91768	68	73	83	5081	826	10	2430	2890	315
S/71	DeirAlBa	91700	92676	72	72	84	5137	943	12	2984	3300	320
S/37	DeirAlBa	92756	92220	43	37	58	4068	1165	20.9	2858	3267	320
G/45	Middle	95520	89500	39	35	45	203	2572	10	8480	43200	305
G/30	Middle	95976	91479	16	11	21	1438	1592	10	2821	4356	315
R/162BA	Gaza	100770	97500	40	23	55	2912	1417	32	2250	2500	325
R/75	Gaza	101299	100417	66	86	96	4914	1925	10	3363	16604	345
R/265	Gaza	101708	95809	39	39	66	1001	1769	27	1150	2000	320
R/254	Gaza	102056	96542	36	46	72	1356	1678	26	2739	6300	320
R/254	North	102056	96542	36	46	72	1092	1962	26	3901	20679	320
R/280	Gaza	102240	101300	65	60	72	4998	1102	12	2450	4500	370
R/25C	Gaza	102456	100775	34	45	55	4495	1300	10	2874	6500	355
R/25D	Gaza	102496	100820	35	50	60	4481	2645	10	5915	27600	360
R/25B	Gaza	102527	100779	33	52	62	4481	2856	10	6313	30900	355
R/25A	Gaza	102581	100759	32	85	95	4402	1144	10	3049	4236	350
R/271	Gaza	102589	96558	41	40	47	1062	1656	7	3256	8000	325
R/112	Gaza	102650	96061	51	66	75	658	1919	9	3020	12600	320
R/270	Gaza	102670	101530	50	38	59	4976	867	21	2756	3500	375
A/185	Gaza	103300	99600	20	15	27	3014	1632	12	3377	8471	340
Q/68	Jabalia	103530	102221	42	73	97	4653	1528	24	3683	13738	385
R/162EA	Gaza	103668	99055	33	90	100	2351	1468	10	2695	2832	335
R/162CA	Gaza	103700	99030	32	85	95	2351	1491	10	2450	2683	335
R/162G	Gaza	103952	99166	36	90	100	2291	2907	10	10092	45800	340
R/162H	Gaza	103952	99166	36	90	100	2291	1703	10	3010	8000	340
R/162LA	Gaza	104020	98320	59	56	66	1611	1750	10	2815	8300	330
C/76	BeitHanon	104337	104667	46	43	55	6488	852	12	3036	4591	400
E/138	Jabalia	104398	102720	41	39	53	4860	2791	14	5253	29438	390
R/162B	Gaza	104402	98725	54	70	80	1688	1617	10	2683	4690	330
E/11A	Jabalia	104415	101845	36	49	59	4098	2675	10	4660	27475	380
R/162E	Gaza	104479	98248	40	45	55	1230	1615	10	2300	2981	325
E/90	Jabalia	104583	101278	46	70	80	3532	2110	10	4252	18086	370
E/154	Jabalia	104589	102067	27	70	80	4196	3090	10	5746	34933	385

© 2005 Tous droits réservés.

http://www.univ-lille1.fr/bustl

R/162C	Gaza-She	104595	98866	51	67	77	1664	1611	10	3066	5680	335
E/156	Jabalia	104670	100156	26	38	85	2591	1965	47	3578	14468	345
C/128	BeitHanon	104891	106477	66	110	120	7662	824	10	2450	2800	405
E/1	BeitLahia	104899	103274	54	51	63	4993	2281	12	4155	22057	395
E/8	BeitLahia	104910	102740	40	45	55	4552	2658	10	5426	27572	390
R/162D	Gaza	104990	98638	45	50	60	1241	2620	10	7647	41400	330
E/4	BeitLahia	105064	103034	38	34	57	4686	2592	23	4566	26193	395
E/11B	Jabalia	105095	102165	28	83	93	3965	2518	10	5304	25513	385
C/79	BeitHanon	105095	105349	48	69	79	6649	851	10	2936	4591	405
D/68	Sh-Radwan	105179	100514	23	72	82	2579	1803	10	3418	11029	345
D/68	BeitLahia	105179	100514	23	72	82	2629	1543	10	2000	3300	350
E/11C	Jabalia	105190	101971	34	25	40	3754	2639	15	4956	27475	380
A/6	BeitHanon	105270	104130	70	59	86	5454	947	27	3332	4591	400
D/69	BeitLahia	105466	100835	28	40	85	2659	1640	45	3515	8271	360
D/70	BeitLahia	105833	101440	25	42	90	2954	1785	48	3412	11029	370
C/48	BeitLahia	105843	106501	55	60	70	7197	803	10	3129	4136	405
D/74	BeitLahia	106104	100504	40	81	91	2027	1505	10	3219	4136	345
C/127	BeitHanon	106154	104778	57	75	85	5568	1015	10	3375	7652	400
D/71	BeitLahia	106193	101458	28	50	71	2797	1561	21	2667	5514	375
E/61	BeitLahia	106339	99737	45	43	51	1239	1662	8	3390	8271	345
D/72	BeitLahia	106462	101739	22	46	70	2877	1410	24	2480	2757	380
D/76	BeitLahia	106827	101036	37	77	87	2076	1495	10	3272	4136	365
D/75	BeitLahia	106827	101037	37	79	89	2076	1690	10	3317	8271	365
A/180	BeitLahia	107033	102459	24	82	92	3129	2060	10	3792	16543	390
D/67	BeitLahia	107218	101716	23	79	89	2414	1461	10	2650	2757	375
E/157	BeitLahia	107560	99670	17	22	32	582	1668	10	2100	3560	345
A/40	BeitLahia	107660	103520	30	40	50	3682	1354	10	3263	5514	395

© 2005 Tous droits réservés.

Table (II.5): Calculation of water chemistry relation for domestic wells (2002)

Sample ID	**Ca+Mg**^{a}	**Na+K**^{a}	**TC**^{a}	**CL+SO4**^{a}	**NO3**^{a}	**Na/CL**^{a}	**Na/K**^{a}	**Mg/Ca**^{a}	**Na/Ca**^{a}	**CA1**^{b}	**CA2**^{c}	**EpCO2**
P/10	4.16	41.05	45.21	43.49	4.15	1.33	836.76	0.39	13.74	-0.33	-2.11	19.94
P/15	4.58	12.11	16.68	14.38	2.44	0.98	32.53	1.01	5.17	-0.01	-0.03	23.45
P/124	4.40	11.27	15.67	14.20	2.33	0.87	27.81	1.03	5.02	0.10	0.33	25.07
P/138	2.19	4.96	7.15	6.68	1.25	0.85	74.14	0.70	3.81	0.14	0.31	8.43
P/145	2.47	8.12	10.59	10.34	1.29	1.01	108.74	0.98	6.46	-0.02	-0.06	8.00
P/153	1.18	4.23	5.41	3.36	0.83	1.31	81.88	0.32	4.65	-0.33	-0.51	2.40
P/147	2.40	10.07	12.47	8.76	1.38	1.25	164.00	1.04	8.49	-0.26	-0.54	8.28
P/144	1.55	6.27	7.82	6.53	0.54	1.08	83.76	0.58	6.31	-0.09	-0.24	3.47
P/139	1.67	1.95	3.62	3.22	1.00	1.35	25.27	0.97	2.21	-0.41	-0.38	4.80
L/184	1.60	4.65	6.25	4.27	1.79	1.22	112.46	0.98	5.72	-0.23	-0.33	3.25
L/187	8.48	1.97	10.45	6.65	1.91	0.43	12.51	0.17	0.25	0.53	0.83	9.25
L/41	3.46	34.06	37.52	35.63	3.23	1.24	265.06	1.20	21.54	-0.24	-1.28	12.11
L/176	4.40	22.66	27.05	32.60	1.72	1.03	159.67	1.01	10.28	-0.04	-0.30	3.40
L/43	7.31	20.17	27.48	23.91	6.18	0.99	125.84	1.16	5.92	0.01	0.02	22.35
L/127	6.66	17.51	24.17	21.65	5.99	0.89	153.97	0.99	5.20	0.10	0.63	6.16
L/87	7.46	25.37	32.83	32.93	6.07	0.94	176.43	1.20	7.45	0.05	0.38	60.39
L/86A	8.51	21.02	29.53	28.14	7.10	1.02	151.30	1.15	5.28	-0.03	-0.09	22.95
L/159	6.39	11.72	18.10	15.39	6.99	0.84	61.31	0.52	2.75	0.15	0.47	7.56
L/159A	5.21	7.95	13.16	10.01	5.85	0.86	66.36	0.62	2.44	0.13	0.30	10.79
L/14	3.75	35.99	39.74	33.30	3.68	1.30	835.95	0.48	14.18	-0.31	-1.58	22.11
L/178	4.11	41.54	45.65	47.14	0.99	1.14	190.43	1.35	23.65	-0.14	-0.86	6.27
L/179	1.67	19.65	21.32	16.81	1.37	1.60	254.21	1.08	24.44	-0.61	-1.42	8.67
Q/569	3.43	14.00	17.43	15.21	0.38	1.14	169.74	1.27	9.23	-0.15	-0.41	17.10
K/19	2.23	5.48	7.71	4.53	1.71	1.60	126.44	1.52	6.16	-0.61	-0.50	9.61
J/1	3.62	4.91	8.53	7.04	0.62	1.04	37.38	0.50	1.98	-0.07	-0.08	7.93
J/2	2.57	8.32	10.89	7.48	2.11	1.48	153.06	0.97	6.32	-0.49	-0.59	13.59
J/146	3.05	19.22	22.26	20.13	2.11	1.20	248.56	1.08	13.05	-0.20	-0.64	19.56
S/69	2.43	13.84	16.27	12.55	0.84	1.53	445.48	0.98	11.27	-0.54	-1.14	35.10
S/71	3.56	14.88	18.44	18.75	0.66	0.99	169.99	0.89	7.83	0.00	0.01	13.67
S/37	4.90	25.45	30.35	26.70	1.03	1.14	113.13	0.87	9.66	-0.15	-0.73	15.32
G/45	9.26	32.52	41.77	40.19	3.95	1.03	470.28	2.18	11.16	-0.03	-0.16	80.90
G/30	4.70	22.14	26.84	26.16	1.67	1.14	581.50	1.34	11.02	-0.15	-0.66	28.43
R/162BA	6.50	13.16	19.65	20.67	1.20	0.69	121.95	0.47	2.94	0.31	1.47	27.74
R/75	4.38	34.09	38.46	36.60	0.93	1.05	213.38	1.45	19.02	-0.05	-0.48	7.51
R/265	2.85	14.23	17.09	13.59	0.91	1.23	145.74	0.95	9.64	-0.24	-0.42	26.21
R/254	6.50	15.59	22.09	20.44	2.79	0.83	144.72	0.90	4.53	0.17	0.64	20.44
R/254	2.64	15.47	18.11	13.83	0.96	1.32	467.79	0.73	10.11	-0.33	-0.55	46.06
R/280	1.44	2.64	4.08	2.15	0.29	1.45	93.21	1.01	3.66	-0.46	-0.23	5.77
R/25C	3.87	19.77	23.63	17.63	2.57	1.39	100.90	1.64	13.34	-0.40	-0.71	64.87
R/25D	2.92	30.38	33.31	30.44	4.69	1.15	197.59	1.73	28.17	-0.16	-0.50	37.13
R/25B	3.80	20.73	24.53	18.22	3.97	1.26	27.75	1.34	12.34	-0.30	-0.57	85.98
R/25A	2.70	16.45	19.15	18.17	0.87	1.19	88.41	0.79	10.79	-0.21	-0.39	41.49
R/271	1.87	9.64	11.51	11.75	1.09	0.94	343.32	0.56	8.01	0.06	0.20	15.32
R/112	7.35	26.43	33.78	34.95	1.62	0.86	78.61	1.21	7.86	0.13	0.65	47.67
R/270	3.12	24.89	28.01	26.89	1.38	1.17	260.99	1.59	20.58	-0.18	-0.46	21.43
A/185	3.85	2.27	6.12	3.94	1.07	0.66	13.27	0.65	0.90	0.29	0.20	27.63
Q/68	2.68	11.40	14.08	8.60	2.60	2.26	129.99	1.24	9.44	-1.28	-1.17	8.66
R/162EA	7.95	14.27	22.21	20.68	2.00	0.78	110.45	0.63	2.89	0.22	0.83	45.60
R/162CA	3.93	5.57	9.49	6.54	1.67	1.09	42.48	1.15	2.97	-0.11	-0.11	39.05
R/162G	6.79	10.54	17.33	15.59	4.15	0.73	99.42	0.53	2.35	0.26	0.78	47.75
R/162H	3.23	13.98	17.21	15.16	2.30	1.20	217.48	1.21	9.53	-0.21	-0.46	26.99
R/162LA	6.96	21.01	27.96	23.60	3.01	1.04	163.12	1.04	6.11	-0.05	-0.19	35.58
C/76	5.95	10.96	16.91	17.93	0.69	0.63	132.61	1.34	4.27	0.36	1.18	63.33
E/138	3.35	3.59	6.94	4.15	1.95	0.97	33.14	0.77	1.84	0.00	0.00	25.05
R/162B	7.20	11.44	18.64	20.26	2.43	0.59	86.99	0.61	2.52	0.40	1.95	24.24
E/11A	2.29	5.93	8.22	4.39	0.88	1.56	328.17	1.21	5.71	-0.56	-0.40	22.63
R/162E	1.90	7.29	9.19	7.10	0.36	1.19	109.41	1.70	10.26	-0.21	-0.27	39.71
E/90	5.42	4.70	10.12	6.76	3.60	0.86	51.23	0.97	1.68	0.13	0.13	79.96
E/154	4.25	6.23	10.48	7.21	1.55	0.92	44.13	0.62	2.33	0.06	0.10	10.62
R/162C	4.38	5.94	10.32	8.59	1.81	0.73	88.97	0.28	1.72	0.26	0.56	20.68
E/156	4.11	3.77	7.88	6.05	2.08	0.71	51.35	1.15	1.94	0.28	0.32	21.94
C/128	3.18	7.13	10.31	7.98	0.96	0.96	110.44	1.26	5.02	0.03	0.05	69.53
E/1	3.28	2.68	5.96	5.48	0.77	0.52	39.55	0.62	1.29	0.46	0.59	18.62
E/8	4.89	2.14	7.04	4.53	2.92	0.62	38.67	1.19	0.94	0.37	0.26	28.52
R/162D	12.60	32.76	45.36	46.80	3.94	0.70	239.88	0.78	4.60	0.30	3.75	30.28
E/4	3.24	1.80	5.04	2.84	0.69	0.87	27.05	1.12	1.13	0.10	0.05	21.96

© 2005 Tous droits réservés.

E/11B	3.90	2.50	6.40	3.84	3.36	0.77	123.90	1.24	1.43	0.22	1.89	39.50
C/79	5.47	11.83	17.29	15.57	1.72	0.83	143.22	1.25	4.83	0.17	0.40	77.96
D/68	2.93	3.98	6.91	4.61	1.52	0.97	59.32	0.52	2.03	0.01	0.01	35.05
D/68	3.32	3.95	7.27	4.02	1.40	1.12	218.39	0.62	1.92	-0.13	-0.11	10.39
E/11C	2.66	3.19	5.84	3.11	2.00	1.11	175.94	0.65	1.97	-0.11	-0.09	21.40
A/6	2.25	2.85	5.10	3.58	0.37	0.93	40.35	1.11	2.61	0.05	0.04	10.70
D/69	2.99	4.02	7.00	3.87	0.32	1.21	39.15	0.79	2.34	-0.25	-0.19	17.43
D/70	3.67	2.26	5.94	3.66	2.00	0.69	12.00	0.62	0.92	0.25	0.16	36.59
C/48	4.20	5.74	9.94	8.60	1.04	0.76	248.61	0.37	1.87	0.24	0.37	22.72
D/74	3.24	2.07	5.31	2.96	1.39	0.75	17.02	0.53	0.93	0.20	0.12	22.19
C/127	2.49	2.79	5.28	2.41	0.95	1.25	55.92	0.80	1.98	-0.27	-0.15	28.17
D/71	5.16	24.05	29.21	32.67	2.13	1.00	191.39	1.33	10.82	0.00	-0.02	14.43
E/61	3.21	3.68	6.89	5.13	1.14	0.89	26.65	0.37	1.51	0.08	0.07	17.95
D/72	4.34	8.34	12.68	12.55	1.56	1.23	114.79	0.93	3.68	-0.24	-0.29	16.21
D/76	3.44	1.79	5.23	2.20	1.22	0.92	10.72	0.47	0.70	0.00	0.00	35.88
D/75	3.45	2.58	6.03	3.51	1.62	0.85	12.66	0.49	1.03	0.08	0.05	30.16
A/180	3.64	1.93	5.56	3.33	0.83	0.63	52.56	0.61	0.84	0.36	0.21	18.10
D/67	1.98	1.43	3.41	1.35	0.30	1.16	36.63	0.79	1.26	-0.19	-0.06	7.59
E/157	3.89	4.48	8.37	5.64	1.77	0.86	32.71	0.86	2.08	0.11	0.11	38.53
A/40	4.76	2.44	7.20	6.23	0.77	0.41	186.38	1.00	1.02	0.58	0.56	63.41

[a] mmoL/L

[b] CA1 = CL^--Na^++K^+ : CL^- meq/L

[c] CA2 = CL^--Na^++K^+ : CO_3^{2-} + HCO_3^-

© 2005 Tous droits réservés.

About the Author

Khamis Mohammed ALMAHALLAWI was born in Jabalia Refugee Camp (Gaza, Palestine) on October 27th, 1966. He received his degree in Chemistry from the Faculty of Science of the Gar-Younis University (Benghazi, Libya), in 1991. In September 1999, he received his Master of Science degree in Water and Environmental Resources Management/Water Quality Management from IHE, Delft, The Netherlands.

In August 1991, he worked with Dr. Yousif Abou Safia as researcher assistance for water quality researches. In August 1993, he worked with the Palestinian Hydrology Group (PHG) as responsible for water laboratory testing, and in 2001 he worked with the PHG as researcher and project responsible. He worked as water quality expert with the TEAM group (Consultant Company) for different water projects in 1996 and 1997. He has been working since April 2001 till the present with the Environmental Equality Authority (Palestine) as a General Director of Environmental Awareness and Education.

In 2002, he was admitted to the doctoral research programme (Ph.D.) at the University of Lille1 (France) under the supervision of Prof. Jacky Mania (School of Engineering Polytech' Lille, University of Lille1). He conducted his PhD research on groundwater quality management with special emphasis to the nitrate problem.

Email: khamis1966@yahoo.com
Gaza, Palestine

© 2005 Tous droits réservés.