



UNIVERSITI PUTRA MALAYSIA

***GROUNDWATER QUALITY ASSESSMENT AND OPTIMIZATION OF
MONITORED WELLS USING MULTIVARIATE GEOSTATISTICAL
TECHNIQUES IN AMOL-BABOL PLAIN, IRAN***

TAHOORA SHEIKHY NARANY

FPAS 2015 11



**GROUNDWATER QUALITY ASSESSMENT AND OPTIMIZATION OF
MONITORED WELLS USING MULTIVARIATE GEOSTATISTICAL
TECHNIQUES IN AMOL-BABOL PLAIN, IRAN**

By

TAHOORA SHEIKHY NARANY

**Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

March 2015

COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



DEDICATION

This work is dedicated to my sweet and loving family, specially my

Mother & Father

Whose affection, love, encouragement and prays of day and night make me able to get such success and hono



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

**GROUNDWATER QUALITY ASSESSMENT AND OPTIMIZATION OF
MONITORED WELLS USING MULTIVARIATE GEOSTATISTICAL
TECHNIQUES IN AMOL-BABOL PLAIN, IRAN**

By

TAHOORA SHEIKHY NARANY

March 2015

Chairman : Mohammad Firuz Ramli, PhD

Faculty : Environmental Studies

Groundwater plays an essential role for human, animal, and plant life as well as an indispensable resource for the economy, especially in arid and semi-arid region. Appropriate monitoring strategies are required to assess the conditions of groundwater quality in the aquifer system, prevention of a potential threat to human health, and measurement of the efficiency of water protection. The main aim of this study is to assess and redesign the information-cost-effective groundwater monitoring network using geostatistical techniques in Amol-Babol Plain, Iran. The integration of multivariate statistical methods with geostatistical interpolation techniques revealed that salinity and total and faecal coliforms as time independent variables and hardness as a time dependent variable influenced the groundwater quality in the study area. The graphical geochemical analyses justified that the groundwater types vary from fresh water type in the west and south sides, to brackish-saline water type in central and eastern sides, and to saline water on the north-eastern area. Hydrogeochemical investigation revealed that evaporation/precipitation and dissolution of carbonate minerals as dominant factors, which control groundwater salinity and hardness in the study area, respectively. Since the agricultural lands cover more than 80% of the plain, the newly devised GIS-Index integration approach was proposed in order to identify the suitability of groundwater for irrigation usage and to determine suitable zones for irrigation activities based on the irrigation water quality index (IWQ) and hydrogeological factors. The index approach shows that more than 90% of the total study area has good to excellent suitability condition for irrigation purpose. Groundwater quality assessment based on the data obtained from arbitrary sampling wells might be presented redundant or shortage of information. Therefore, monitoring network wells should be optimized in information-cost-effective way, based on the current groundwater quality data and vulnerability of aquifer to contamination. DRASTIC model was applied as a vulnerability assessment method based on the physical environmental aquifer parameters for assessing potential risk zone of aquifer to contamination, which showed more than 88% of the total area was classified as low to

moderate risk to pollutant. A new optimization approach was proposed for redesign monitoring network wells using optimization algorithm based on the vulnerability of aquifer to contaminations, estimation error of sampling wells, nearest distance between wells, and source of contamination in the study area. Application of mass estimation error revealed that 100 and 74 sampling wells are suitable scenarios for monitoring natural and anthropogenic contaminant, respectively. Combination of the selected scenarios in GIS showed that contaminant mass detection capacity of around 86% can be obtained from 114 sampling wells, instead of 154 initial sampling wells.



Abstrak thesis yang dikemukakan kepada senate Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENILAIAN KUALITI AIR BAWAH TANAH DAN PENGOPTIMUMAN
TELAGA PEMANTAUAN MENGGUNAKAN TEKNIK MULTIVARIAT
GEOSTATISTIK DI DATARAN AMOL-BABOL, IRAN**

Oleh

TAHOORA SHEIKHY NARANY

Mac 2015

Pengerusi : Mohammad Firuz Ramli, PhD

Fakulti : Pengajian Alam Sekitar

Air bawah tanah memainkan peranan penting kepada manusia, haiwan dan juga tumbuhan yang merupakan sumber utama kepada ekonomi, terutamanya di kawasan semiarid dan arid. Strategi pemantauan yang sesuai diperlukan untuk menilai keadaan kualiti air bawah tanah didalam sistem akuifer, menghalang potensi ancaman kepada kesihatan manusia, dan pengukuran kecekapan perlindungan air. Tujuan utama kajian ini untuk menilai dan mereka semula jaringan pemantauan air bawah tanah yang cekap dari segi maklumat dan kos menggunakan teknik-teknik geostatistik di Dataran Amoi-Babol, Iran. Integrasi analisis pelbagai varian (ANOVA) dua dengan teknik interpolasi geostatistik menunjukkan saliniti, dan jumlah koliform tinja merupakan pembolehubah bebas masa dan keliatan merupakan pembolehubah kadar masa mempengaruhi kualiti air bawah tanah di kawasan kajian. Analisis grafik geokimia menunjukkan variasi jenis air bawah tanah daripada jenis air tawar di bahagian barat dan selatan, kepada air payau di bahagian tengah dan timur kepada air masin di bahagian timurlaut. Penyiasatan hidrogeokimia menunjukkan peruwapan dan presipitasi, dan pelarutan mineral karbonat sebagai faktor dominan yang mengawal saliniti dan keliatan di kawasan kajian. Oleh kerana kawasan pertanian merangkumi lebih daripada 80% daripada dataran ini, pendekatan integrasi indek GIS yang baru dicadangkan untuk mengenalpasti kesesuaian air bawah tanah, dan untuk penentuan zon sesuai untuk aktiviti pengairan berdasarkan indek kualiti air pengairan (IWQ) dan faktor hidrogeologi. Pendekatan indek menunjukkan lebih daripada 90% kawasan kajian mempunyai keadaan kesesuaian yang cemerlang untuk kegunaan pengairan. Penilaian kualiti air bawah tanah berdasarkan telaga persampelan yang dipilih secara rawak, akan menyebabkan berlebihan atau kekurangan maklumat. Maka, rangkaian telaga pemantauan harus dioptimumkan supaya cekap maklumat dan kos berdasarkan data kualiti air bawah tanah sedia ada dan kerentanan akuifer. Model DRASTIC diaplikasikan sebagai model kerentanan berdasarkan kepada parameter fizikal alam sekitar untuk menilai zon potensi risiko pencemaran akuifer, menunjukkan lebih daripada 88% kawasan kajian diklasifikasikan sebagai berisiko rendah ke sederhana. Pendekatan baru dicadangkan untuk mereka

semula jaringan telaga pemantauan menggunakan algoritma optimisasi berdasarkan kerentanan akuifer kepada pencemaran, anggaran ralat telaga pemantauan, jarak terdekat diantara telaga, dan sumber pencemaran di kawasan kajian. aplikasi anggaran ralat menunjukkan 100 dan 74 telaga pemantauan adalah senario sesuai untuk memantau pencemaran semulajadi dan buatan manusia. Kombinasi daripada senario terpilih dalam GIS menunjukkan kapasiti mengenalpasti dalam sekitar 86% boleh didapati daripada 114 telaga pemantauan daripada 154 telaga asal.



ACKNOWLEDGEMENTS

I would never have been able to finish my thesis without the guidance of my research committee members, help from friends, and support from family.

I would like to express my deepest gratitude to my advisor Assoc Prof. Dr. Muhammad Firuz Ramli for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research. To my co-advisors, Assoc Prof. Dr. Ahmad Zaharin Aris and Prof. Dr. Wan Nor Azmin Sulaiman for they teaching, support and guidance.

Also, I would like to thank Assoc Prof. Dr. Kazem Fakharian, my co-advisor in Iran, for his valuable comments, consultation, and support throughout the thesis.

I would like to acknowledge the Soil and Water Pollution Bureau of the Department of Environment (DOE) in Iran for their financial support through a contract with Amirkabir University of Technology (AUT), Tehran, Iran. The financial support by DOE and the laboratory data and analyses provided by AUT are gratefully acknowledged.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as Follows:

Mohammad Firuz b. Ramli, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Ahmad Zaharin bin Aris, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Wan Nor Azmin b. Sulaiman, PhD

Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Kazem Fakharian, PhD

Associate Professor
Department of Civil and Environmental Engineering
Amirkabir University of Technology
(Member)

BUJANG KIM HUAT, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work
- quotations, illustrations and citations have been duly referenced
- the thesis has not been submitted previously or concurrently for any other degree at any institutions
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be owned from supervisor and deputy vice –chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No.: Tahoora Sheikhy Narany, GS28681

Declaration by Members Of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate studies) rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of
Chairman of
Supervisory
Committee: _____

Signature: _____
Name of
Member of
Supervisory
Committee: _____

Signature: _____
Name of
Member of
Supervisory
Committee: _____

Signature: _____
Name of
Member of
Supervisory
Committee: _____

TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	iii
ACKNOWLEDGEMENTS	v
APPROVAL	vi
DECLARATION	viii
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
LIST OF ABBREVIATIONS	xx
CHAPTER	
1 INTRODUCTION	1
1-1 Statement of Research Problem	5
1-2 Rational of the Study	6
1-3 Scope of the Study	7
1-4 Objectives of the Study	7
1-5 Outline of Thesis	10
2 LITERATURE REVIEW	12
2-1 Back Ground	12
2-2 Design Issue in a New Monitoring Network	12
2-3 Consideration for Assessment of an Existing Monitoring Network	13
2-3-1 Groundwater Quality	13
2-3-2 Multivariate Statistical Methods in Groundwater Quality Analysis	15
2-3-3 Geographic Information System (GIS)	21
2-3-4 Geostatistical Techniques	22
2-4 Groundwater Vulnerability and Risk Assessment	27
2-4-1 Definition of Vulnerability and Risk Term	27
2-4-2 Vulnerability and Risk Assessment Techniques	27
2-5 Groundwater Monitoring Network Design Method	29
2-5-1 Historical Perspective of Network Design	29
2-5-2 Network Optimization using Geostatistical Techniques	29
2-5-3 Groundwater Monitoring Network Design Criteria	33
2-5-4 Quality of Network Design	36
3 MATERIALS AND METHODS	38
3-1 Study Area	38
3-1-1 Geology	39
3-1-2 Hydrogeology	41
3-1-3 Land Use Activities	44
3-2 Sample Collection and Data Analysis	45
3-3 Multivariate Statistical Analysis	46

3-3-1	Data Pre-Processing	46
3-3-2	Principal Component Analysis/Factor Analysis	47
3-3-3	Discriminant Analysis	48
3-3-4	Hierarchical Agglomerated Cluster Analysis (HACA)	48
3-3-5	Analysis of Variance (ANOVA)	49
3-4	Geostatistical Interpolation Techniques	51
3-4-1	Variography	51
3-4-2	Semivariogram Fitting	51
3-4-3	Estimation Method	52
3-4-4	Redesign Groundwater Wells using Geostatistical Estimation Approach	53
3-5	Groundwater Suitability Zoning for Irrigation Approach	55
3-5-1	GIS-Index Integration Approach	55
3-5-2	Irrigation Groundwater Quality Index	56
3-6	DRASTIC Method	61
3-6-1	Vulnerability Assessment	61
3-6-2	Risk Assessment	63
4	SPATIOTEMPORAL VARIATION OF GROUNDWATER QUALITY	65
4-1	Introduction	65
4-2	Materials and Methods	66
4-3	Results and Discussion	67
4-3-1	Descriptive Statistics	67
4-3-2	Groundwater Pollution Sources Apportionment	70
4-3-3	Spatial and Temporal Variations of Groundwater Quality	80
4-4	Conclusions	83
5	IDENTIFICATION OF THE HYDROGEOCHEMICAL PROCESSES IN GROUNDWATER	85
5-1	Introduction	85
5-2	Material and Methodology	86
5-3	Results and Discussion	86
5-3-1	Hydrogeochemical Facies	89
5-3-2	Correlation of Major Ions	90
5-3-3	Ionic Ratio	93
5-3-4	Gibbs Plot	98
5-3-5	Saturation Index	100
5-4	Conclusions	101
6	EVALUATION OF GROUNDWATER QUALITY FOR IRRIGATION PURPOSES	102
6-1	Introduction	102
6-2	Materials and Methods	103
6-3	Results and Discussion	103

6-3-1	Statistical Summary	103
6-3-2	Mapping Groundwater Quality for Irrigation Purpose	107
6-3-3	Irrigation Groundwater Quality Map	116
6-4	Conclusion	117
7	GROUNDWATER SUITABILITY ZONING FOR IRRIGATION PURPOSES	118
7-1	Introduction	118
7-2	Materials and Methods	120
7-3	Results and Discussion	120
7-3-1	Assessment of Hazard Groups	120
7-3-2	Irrigation Water Quality Index	122
7-3-3	Hydrogeological Factors	123
7-3-4	Groundwater suitability zoning	123
7-4	Conclusions	127
8	A NEW APPROACH TO IDENTIFY HIGH POTENTIAL RISK ZONES IN AMOL-BABOL AQUIFER	129
8-1	Introduction	129
8-2	Materials and Method	130
8-3	Results and Discussion	130
8-3-1	Groundwater Vulnerability and Risk Map	130
8-3-2	Groundwater Probability Map	135
8-3-3	Monitoring Network Assessment	137
8-4	Conclusion	140
9	REDESIGN INFORMATION-COST-EFFECTIVE GROUNDWATER QUALITY MONITORING NETWORK	141
9-1	Introduction	141
9-2	Materials and Method	143
9-3	Results and Discussion	143
9-3-1	The Proposed Procedure for Designing Optimal Monitoring Network	143
9-3-2	Efficiency Evaluation of Designed Network	153
9-4	Conclusion	155
10	SUMMARY, GENERAL CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH	156
10-1	Summary and Links of Article	156
10-2	Conclusions	157
10-3	Recommendation	159

REFERENCES	161
APPENDICES	182
A: Cross Validation Results of Variograms in Kriging Methods	182
B; Irrigation Water Quality Map	186
C: DRASTIC Map	190
D: Minimization Command for NCF and ACF Cases and Coordinate Systems of Eliminated Sampling Wells	194
E: Publication Related to the Thesis Objectives	206
BIODATA OF STUDNET	210
LIST OF PUBLICATIONS	211



© COPYRIGHT UPM

LIST OF TABLES

Table		Page
2.1	Research on groundwater sources apportionment using multivariate analysis	16
2.2	Summary of the multivariate statistical techniques and their application	18
2.3	Advantages and disadvantages of kriging and IDW methods	23
2.4	Different type of kriging methods, their assumptions and definitions	24
2.5	Possible differentiation of the network density of observation in relation to depth and degree of confinement of the aquifers (Modified by (Jousma, et al., 2006)	36
3.1	Geological formation in Amol-Babol Plain	40
3.2	Total abstraction from groundwater from 2008 to 2009 (Fakharian, 2010)	41
3.3	Type and thickness of Amol-Babol aquifer	42
3.4	Land use activities in Amol-Babol Plain	44
3.5	Average of annual nitrate fertilizer usage in the study area (Ghods, 2004)	44
3.6	Classification of irrigation water suitability parameters	56
3.7	Modify classification for IWQ index parameters (Modified from Simsek and Gunduz (2007))	57
3.8	DRASTIC parameters (Aller, et al., 1987)	62
3.9	Land use classification (Adamat, et al., 2003)	63
3.10	Classification of vulnerability and risk index values	64
4.1	Descriptive statistics of dry season's variables	67
4.2	Descriptive statistics of wet season's variables	68
4.3	Varimax component matrix of dry season	71
4.4	Varimax component matrix of wet season	72
4.5	Results of the variogram analysis and Moran's Index for factor scores	73
4.6	Pearson correlation coefficient matrix of analyzed ions in the dry and wet seasons	74
4.7	Two-way ANOVA of groundwater quality parameters in the study area	81
4.8	The results of the LSD test following two-way ANOVA results	82
5.1	Descriptive statistical analysis for the 154 groundwater samples of Amol-Babol	88
5.2	Correlation coefficient matrix of groundwater samples of Amol-Babol	92

5.3	Statistical summary of saturation indexes of minerals in groundwater using PHREEQC	100
6.1	Groundwater quality and their comparison with irrigation water standard	105
6.2	Kolmogorov-Smirnov test for data distribution	106
6.3	Classification of waters based on EC (Handa, 1969)	108
6.4	Classification of waters based on SAR values (Todd, 1959)	109
6.5	Classification of waters based on sodium percent (Wilcox, 1955)	110
6.6	Groundwater quality based on RSC (after Richard (1954))	113
7.1	Statistical summary of hydrochemical parameters	121
7.2	Obtained area and percentage of the different IWQ index and hydrogeological factors	126
7.3	Classification and abundance of groundwater suitability index	127
8.1	Distribution of risk zones in the Amol-Babol Plain	133
8.2	Cross-validation and semivariogram model parameters for probability map of nitrate concentration	136
8.3	Probability ranges of area exceeding groundwater nitrate threshold by indicator kriging.	136
8.4	Classification of probability risk map of nitrate contamination	138
9.1	Principal component matrix for each parameter analyzed for groundwater	145
9.2	Results of the optimal network design for monitoring water quality at Amol-Babol Plain	147
A1	Results of the variogram cross validation for factor score 1 based on the ordinary kriging method	182
A2	Results of the variogram cross validation for factor score 2 based on the ordinary kriging method	182
A3	Results of the variogram cross validation for factor score 3 based on the ordinary kriging method	183
A4	Results of the variogram cross validation for the groundwater chemical composition based on the ordinary kriging method	184
A5	Results of the variogram cross validation Nitrate based on the indicator kriging method	185
D1	Samplings well were excluded to reach 130 wells in NCF case	195
D2	Samplings well were excluded to reach 100 wells in NCF case	197
D3	Samplings well were excluded to reach 74 wells in NCF case	199
D4	Samplings well were excluded to reach 130 wells in ACF case	201

D5	Samplings well were excluded to reach 100 wells in ACF case	203
D6	Samplings well were excluded to reach 74 wells in ACF case	205



© COPYRIGHT UPM

LIST OF FIGURES

Figure		Page
1.1	The water quality assessment and monitoring cycle (Source: (Jousma, et al., 2006))	2
1.2	Schematic map of Iran showing the study area, Amol-Babol Plain.	7
1.3	Conceptual framework of relationship between objectives and methodologies	9
2.1	A generalized variogram model (source: (Lakhankar, et al., 2010))	46
3.1	Location map of Amol-Babol Plain, Iran	39
3.2	Lithological map of Amol-Babol Plain	41
3.3	Aquifer thickness contour map of Amol-Babol Plain	43
3.4	Stratigraphic cross section of Amol-Babol extracted from the geological log data	43
3.5	(a) map of Iran, (b) Land use map of Amol-Babol Plain	45
3.6	Schematic flowchart of the proposed methodology	55
3.7	Schematic DRASTIC index computations	61
4.1	Spatial distribution of factor score 1 represents groundwater salinity in (a) dry season and (b) wet season	75
4.2	Spatial distribution of factor score 2 represents groundwater hardness in (a) dry season and (b) wet season	77
4.3	Spatial distribution of factor score 3 represents groundwater biological pollution in (a) dry season and (b) wet season	79
5.1	Dendogram of the cluster analysis	87
5.2	Schoeller diagram of the groundwater cluster	87
5.3	Piper diagram presentation for groundwater constituents	90
5.4	Spatial distribution of water type in the groundwater of the study area	90
5.5	Distribution of ionic ratios for major groundwater ions from the study area	94
5.6	Spatial distribution of Ca/Mg ratio of groundwater in Amol-Babol Plain	95
5.7	Spatial distribution of Cl/HCO ₃ ratio of groundwater in Amol-Babol Plain	96
5.8	Spatial distribution of Na/Cl ratio of groundwater in Amol-Babol Plain	97
5.9	Spatial distribution of electrical conductivity ratio of groundwater in Amol-Babol Plain	97
5.10	Gibbs plots explain groundwater chemistry and geochemical process	99

6.1	Salinity index for the groundwater sample of Amol-Babol Plain	107
6.2	US salinity hazard diagram (after Richards (1954))	109
6.3	Suitability of groundwater for irrigation in Wilcox diagram	111
6.4	Spatial distribution of sodium percent in the (a) dry season, (b) wet season	112
6.5	Spatial distribution of RSC (a) dry season, (b) wet season	114
6.6	Groundwater irrigation quality (a) dry season, (b) wet season	116
7.1	IWQ index map of Amol-Babol Plain	123
7.2	Slope angle map of Amol-Babol Plain	124
7.3	Hydraulic conductivity of Amol-Babol Plain	124
7.4	Aquifer thickness of Amol-Babol Plain	125
7.5	Groundwater suitable zones for irrigation purpose	127
8.1	Groundwater vulnerability map of Amol-Babol Plain	134
8.2	Groundwater risk map of Amol-Babol Plain	135
8.3	Experimental variogram of nitrate concentration and the fitting of theoretical model	136
8.4	Probability map of nitrate concentration in the Amol-Babol Plain	137
8.5	Combined probability map of nitrate concentrations and risk map of pollution	139
8.6	Suggested monitoring network for evaluating nitrate concentration	139
9.1	Schematic diagram of the optimization of groundwater monitoring network well's steps	143
9.2	Example of minimization command for NCF case in the GIS software	148
9.3	Optimal monitoring locations for case; NCF, based on the 154 wells	149
9.4	Optimal monitoring locations for case; NCF, based on the three proposed 130 wells	149
9.5	Optimal monitoring locations for case; NCF, based on the three proposed 110 wells	150
9.6	Optimal monitoring locations for case; NCF, based on the three proposed 74 wells	150
9.7	Optimal monitoring locations for case; ACF, based on the three proposed scenarios 154 wells	151
9.8	Optimal monitoring locations for case; ACF, based on the three proposed scenarios 130 wells	151
9.9	Optimal monitoring locations for case; ACF, based on the three proposed scenarios 110 wells	152

9.10	Optimal monitoring locations for case; ACF, based on the three proposed scenarios 74 wells	152
9.11	Comparison of mass estimation errors for cases NCF and ACF	153
9.12	Optimal monitoring locations based on 114 sampling wells	154
B1	Spatial distribution of salinity hazard in the (a) dry season, and (b) wet season	186
B2	Spatial distribution of SAR in the (a) dry season, and (b) wet season	187
B3	Spatial distribution of MH in the (a) dry season, and (b) wet season	188
B4	Spatial distribution of KR in the (a) dry season, and (b) wet season	189
C1	Depth to groundwater map in the Amol-Babol Plain	190
C2	The net recharge map in the Amol-Babol Plain	190
C3	The aquifer media map in the Amol-Babol Plain	191
C4	The soil media map in the Amol-Babol Plain	191
C5	The slope map in the Amol-Babol Plain	192
C6	The impact of vadose zone material in the Amol-Babol Plain	192
C7	The hydraulic conductivity map in the Amol-Babol Plain	193
D1	Minimization command for NCF case in the GIS software (n=130)	194
D2	Minimization command for NCF case in the GIS software (n=100)	196
D3	Minimization command for NCF case in the GIS software (n=74)	198
D4	Minimization command for ACF case in the GIS software (n=130)	200
D5	Minimization command for ACF case in the GIS software (n=100)	202
D6	Minimization command for ACF case in the GIS software (n=74)	204
E1	Article related to chapter four	206
E2	Article related to chapter five	207
E3	Article related to chapter six	208
E4	Article related to chapter eight	209

LIST OF ABBREVIATIONS

A	Aquifer
ACF	Anthropogenic Contaminant Factor
ANOVA	Analysis of Variance
As	Arsenic
B	Boron
Be	Beryllium
BLUE	Best Linear Unbiased Estimator
BOD	Biochemical Oxygen Demand
BOD5	5-days Biochemical Oxygen Demand
C	Hydraulic Conductivity
Ca	Calcium
CA	Cluster Analysis
Cd	Cadmium
Cl	Chloride
Co	Cobalt
CO ₃	Carbonate
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
D	Depth to Water
DEM	Digital Elevation Model
DO	Dissolved Solid
DWQI	Drinking Water Quality Index
EC	Electrical Conductivity
EPA	Environmental Protection Agency
F	Fluoride
FA	Factor Analysis
Fe	Iron
GIS	Geographic Information System
HACA	Hierarchical Agglomerated Cluster Analysis
HCO ₃	Bicarbonate
HSD	Honestly Significant Different
I	Impact of Vadose Zone
IDW	Inverse Distance Weighting
IK	Indicator Kriging
IWQ	Irrigation Water Quality
K	Potassium
KMO	Kaiser Meyer Olkin
KRMSE	Kriged Reduced Mean Squared Error
K-S	Kolmogorov-Smirnov
Li	Lithium
LSD	Least Significant Difference
ME	Mean Error
MCM	Million Cubic Meter
Meq/L	Milliequivalents per Liter

Mg	Magnesium
MH	Magnesium Hazard
Mn	Manganese
Mo	Molybdenum
MRWA	Mazandaran Regional Water Authority
MSE	Mean Squared Error
Na%	Sodium Percent
Na	Sodium
NCF	Natural Contaminant Factor
NAN	Natural neighbors
NN	Nearest Neighbors
NO ₂	Nitrite
NO ₃	Nitrate
NI	Nickel
Ok	Ordinary Kriging
Pb	Lead
PCA	Principal Component Analysis
PO ₄	Phosphate
QA	Quality Assurance
QC	Quality Control
R	Net Recharge
RMSE	Root Mean Square Error
RSC	Residual Sodium Carbonate
S	Soil Media
SAR	Sodium Adsorption Ratio
Se	Selenium
SD	Standard Deviation
SO ₄	Sulphate
SSP	Soluble Sodium Percentage
T	Topography
TDS	Total Dissolved Solid
TIN	Triangulation
Zn	Zinc

CHAPTER 1

INTRODUCTION

Groundwater has intrinsic valuable properties such as availability of reliable water resource compared with surface water, and compromising these properties has implication to human health (Aiuppa et al., 2003). Around 30% of the world's freshwater is stored as groundwater, which constitutes about 97% of all freshwater for human consumption (Delleur, 2010). Although, groundwater is mostly considered as an alternative source to surface water for drinking, domestic, irrigation, and industry usages, however it is relatively more reliable in terms of supply in arid and semi-arid areas because of its large storage, wide spread occurrence and protection from evapotranspiration and good quality of the water (Oladeji, 2012). It is also a vital element of groundwater dependent ecosystems such as wetlands.

Groundwater is the main source of water supply for potable and irrigation usages in the Amol-Babol Plain, Iran, where more than 70% of population utilize groundwater for drinking and agricultural activities (Fakharian, 2010). Fakharian (2010) reported that 68130 shallow and deep wells supply the water in the study area, where more than 80% of the plain's area constitute of agricultural lands such as irrigated lands, dry farming, and orchards. The large expanse of agricultural land is used to provide rice, crops, and citrus for growing population. Over exploitation of groundwater not only decreases the groundwater level, but also decrease the quality (Hoang, 2008). Extensive agricultural activities enable fertilizers and pesticides to leach into the groundwater, especially in shallow wells, which increase recognition of the impact of agricultural activities on groundwater quality. Moreover, surface runoff and soil erosion increase due to change land use patterns from forest and bush land to agricultural lands can impose negative stress to groundwater quality in the study area (MAHAB, 2004).

Poor drinking water quality, high cost of water purification, human health problems, and loss of water supply are attributable to groundwater contamination. The understanding of the chemical, physical, and biological conditions of groundwater and identification of the risks related to the groundwater quality are essential in devising planning strategies for groundwater resources protection. Effective management to support the water needs of the environment and its citizens depends on regular and systematic monitoring of groundwater resource. This kind of understanding can be obtained by groundwater monitoring which involves the water sampling to detect changes in the groundwater condition (Mogheir et al., 2006).

Groundwater monitoring can be defined as the scientifically-designed continuing measurement and observation of the groundwater situation, which also includes evaluation and reporting procedures (Jousma et al., 2006) (Figure 1.1). Data requirement for development, management, and control of groundwater sources may involve major

monitoring program. Monitoring program should be in balance with the budgets and capacity available. Groundwater monitoring is a complex, time consuming, costly process, and measurement of all parameters at every well is impossible. In Amol-Babol Plain, lack of primary water quality data, results in the selection of the initial groundwater quality monitoring network to be highly subjective. Groundwater monitoring network with many sampling wells is costly and provide redundant information. The uncertainty and error of estimation of groundwater quality may be increased by reducing the sampling points. Therefore, the application of advanced research techniques requires estimation errors and uncertainty minimization of the groundwater quality. Furthermore, existence of efficient groundwater quality monitoring network can reduce deficient or redundant information as well as be effective in terms of cost (Baalousha, 2010).

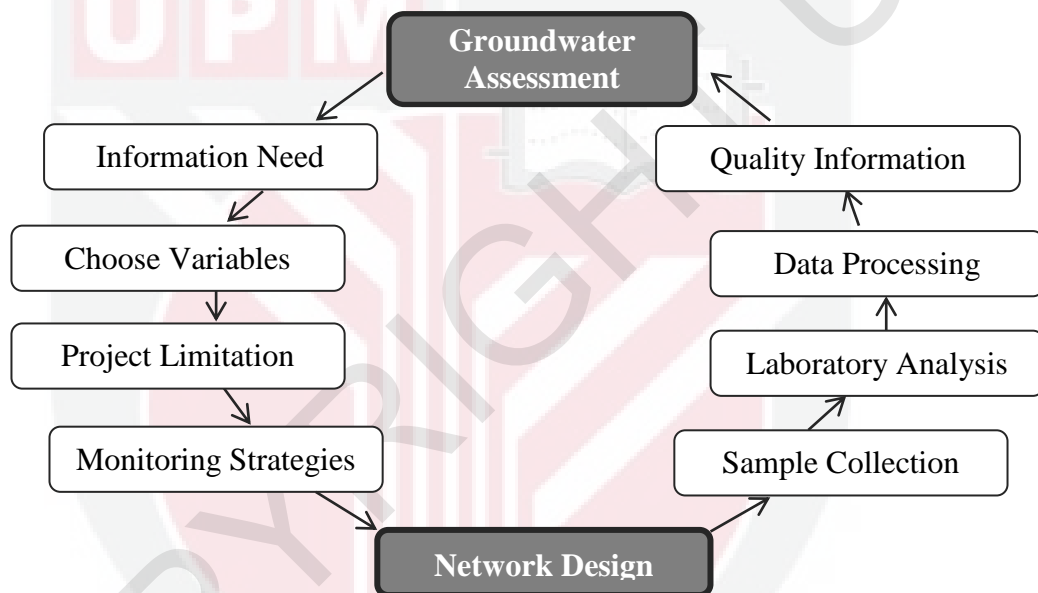


Figure 1.1 Water quality assessment and monitoring cycle
(Source: (Jousma et al., 2006))

Since the optimization of monitoring network is very complicated (Odom, 2003), the initial groundwater quality monitoring data, such as spatial distribution of quality parameters, aquifer hydrogeological information, and probable pollution sources play as a key role in assessing and redesigning status.

In Amol-Babol Plain previously studies restricted to drinking aspect of groundwater quality (MAHAB, 2004; Shahbazi & Esmaeili-Sari, 2009; Fakharian, 2010). Reliable picture of groundwater condition in different space and time can only be known by the integration of several techniques such as geostatistics, multivariate statistical analysis, classic geochemical methods, and vulnerability and risk assessment of aquifer to contamination (Wu et al., 2005; Baalousha, 2010; Chadalavada et al., 2011). Therefore,

accurate assessment of initial monitoring networks requires optimizing groundwater monitoring network design in the study area.

Temporal and spatial assessments of groundwater quality with multiple parameters, which were collected from several monitoring stations at different monitoring times is an important step in characterizing groundwater condition. Therefore, a complex data matrix is frequently applied to evaluate water quality (Chapman, 1996). In groundwater monitoring, it is usually complicated to determine whether a variation in the concentration of measured parameters could be related to anthropogenic activities (mostly spatial) such as fertilizers, over pumping, industrial and residential sewages, and landfills or to natural changes (mostly temporal) such as seasonal variation, rainfall average, or tidal influence. Thus, parameters that are the most significant to describe such spatial and temporal variation and pollution sources without losing useful information had to be identified (Alberto et al., 2001). The combination of multivariate statistics and geostatistical techniques have been applied as unbiased methods in analysis of water quality data (Singh et al., 2004).

The application of multivariate statistical analysis such as cluster analysis (CA), principal component analysis (PCA), factor analysis (FA), and analysis of variance (ANOVA) in complex water quality data matrix is useful to reveal significant relationship between water chemistry parameters, better characterization the water quality situation, identification of possible factors that influence water quality and also for verifying spatial and temporal variation caused by natural and anthropogenic factors linked to seasonality (Helena et al., 2000; Singh et al., 2004).

Hydrogeochemical studies can identify the natural processes, such as seawater intrusion to fresh water, cation exchange, dissociation and precipitation of minerals, evaporation, and oxidation and reduction that influence groundwater quality. Hydrogeochemical processes are generally intercorrelated over space and time. The intercorrelations of hydrochemical variables are difficult to interpret and understand, especially if it involves a large number of variables. Several studies applied geochemical modeling and graphical methods for interpretation of water quality indices to evaluate the groundwater chemistry (Mondal et al., 2010; Reddy & Kumar, 2010; Wanda et al., 2011). Multivariate statistical techniques coupled with classic geochemical methods and geostatistical techniques had been successfully utilized to detect significant information from hydrogeochemical data in a complex system (Hoang, 2008; Nas & Berktaş, 2010). This multidisciplinary approach could be useful in the identification of different physiochemical process in groundwater and to provide a unified method for spatial distribution of hydrochemistry parameters in thematic maps.

Natural and anthropogenic pollutants have threatened groundwater reliability and flexibility for irrigation purpose, where agriculture is a dominant economic activity. Quality of groundwater directly effects the soil's structure and crops production. Therefore, groundwater suitability for irrigation purpose needs to be assessed in order to improve water resource and land use planning. Although, traditional assessment of

irrigation water quality based on the chemical indices such as sodium percentage (Na%), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) is simple (Adhikary et al., 2012; Ramesh. & Elango, 2012; Al-Taani, 2013), but it is not sufficient to provide an accurate picture of suitability of groundwater for irrigation purpose.

Irrigation water quality index (IWQ) was developed to assess irrigation water quality regarding to salinity hazard, infiltration hazard, specific ions hazard, trace elements hazard and miscellaneous effect (Simsek & Gunduz, 2007). Application of IWQ index without consideration of hydrogeological factors which influence to the potential of the aquifer for irrigation water abstraction, may adversely affect groundwater quality. Therefore, integration of the IWQ index and hydrogeological factors provide a powerful method for delineating groundwater suitability for irrigation purpose.

Spatial groundwater quality assessment is usually undertaken using geostatistical techniques within Geographical Information Systems (GIS) (Elçi & Polat, 2011). GIS were mostly applied for the management, visualization, and analysis of the monitored data by environmental specialists (Goovaerts et al., 2005; Kumar et al., 2007; Assaf & Saadeh, 2009; Nas & Berktaş, 2010). In recent years, combination of GIS and geostatistical analysis are becoming an important tools to the optimal analysis of patterns in groundwater data (Adhikary, et al., 2010). Geostatistics is a spatial interpolation technique, which is used to estimate the concentration at un-sampled locations and predict spatial variation of groundwater properties (Johnston et al., 2001). Several scientists have applied kriging interpolation methods as the effective tools in consideration the spatial correlation between the measured points to estimate an unknown value (Dash et al., 2010). Kriging is distinguished from other interpolation methods such as Inverse Distance Weighting (IDW), due to application of the estimation of variance (Nas & Berktaş, 2010), which can be used to measure the reliability of prediction, especially in optimization studies (Hoang, 2008).

Data collection from a finite number of sampling wells are necessary for identifying, understanding and describing the groundwater quality situation, which is critical in planning strategy for the protection of groundwater quality. Besides the significant role of collected samples from existing monitoring network, which reveal the source of contaminations and characterize the groundwater quality conditions, the aquifer vulnerability and risk to pollution should also be studied. In this context, the combination of field observation, and the sensitivity of groundwater to contamination determined using geostatistical analysis provide reliable method to optimize monitoring network wells. The sensitivity of groundwater to contamination is introduced by vulnerability, which is characterized by the hydrogeological and geological attributes of the aquifer (Farjad et al., 2012). DRASTIC is a standardized method for evaluating groundwater vulnerability to pollution, which was developed by the Environmental Protection Agency (EPA) (Aller et al., 1987). DRASTIC can be integrated with other information such as land use to evaluate the potential risk of contamination and identify areas which need special attention or protection (Osborn et al., 1998). DRASTIC is applied as one of the criteria in siting decisions to conduct groundwater monitoring. For

example, denser sampling wells could be chosen in areas where aquifer vulnerability is higher and land use indicates a potential source of pollution. Generally, complex hydrogeological setting and limited information about contamination site are the primary sources of uncertainties in the site characterization (Chadalavada et al., 2011), which can be intensified by the uncertainties in number and location of network wells (Nabi et al., 2011). For this reason, the level of accuracy of the estimations should be considered in the monitoring wells using variance of error by geostatistics as another important criterion in network optimization (Ahmed, 2004; Chadalavada et al., 2011; Nabi et al., 2011). In view of this, adequate configuration of observation wells will accurately characterize the groundwater quality for a better management of the available sources under budgetary constraints.

1-1 Statement of Research Problem

Mazandaran is one of the wealthier provinces of Iran due to its high agricultural productivity and tourism activities, especially in the Amol and Babol Plain and in areas surrounding the Caspian Sea. Secondary data on population and climatic condition reveal that groundwater is the main sources of water supply for potable and irrigation purposes in Amol-Babol Plain. Since the last decades, about 10,000 wells have been constructed to supply water in the study area, where about 95% of the groundwater abstraction is attributed to agricultural activities (MAHAB, 2004; Fakharian, 2010). These abundant deep and shallow wells, which have been constructed by farmers for agriculture and domestic animal usages, exposed the groundwater under serious pressure. Based on the Mazandaran Regional Water Authority (MRWA) report, around 255.06 mcm of groundwater was drawn from 26,367 wells of the un-confined aquifer, out of which 139.81 MCM were used for domestic purpose, 111.24 MCM of groundwater were utilized for irrigation activities, and around 4 mcm were used for industrial purposes (Khairy & Janardhana, 2013).

The study area is located between recharge area (Alborz Mountain) in the southern side and discharge area (Caspian Sea) in the northern side thus groundwater quality could be influenced by several natural processes. Regional flow of groundwater is from the recharge zones in the southern side of the discharge area to the Caspian Sea in the northern area. The high flow rate had washed fossil saline water through sediment layers and prevented seawater intrusion into fresh aquifer water. In recent years, groundwater quality has been found to be degraded in the northern area, due to the influence of saline seawater and high evaporation of the fresh groundwater (Fakharian, 2010; Khairy & Janardhana, 2013). Over abstraction and utilization of freshwater in the plain will decrease the sea-ward flow and will lead to intrusion of seawater into coastal aquifer (MAHAB, 2004). Therefore, intrusion of saline water from Caspian Sea to freshwater could be reduced the groundwater quality for drinking and irrigation usages.

The population of Amol-Babal plain in 2007 was 1,080,840 inhabitants, where about 52.12% live in urban and around 47.82% rural areas. Urbanization changes the land use and transformation from rural to metropolitan pattern of organization, which has resulted

in gradual deterioration of water quality (Mustapha & Aris, 2012). The most important urban area are Amol (population 343,747), Babol (population 261,733), and Ghaemshar (population 107,470), which don't have waste water collection and treatment systems (MAHAB, 2004). Waste water is discharged in absorbing wells in most part of the study area. Central and northern areas are the most densely populated which used groundwater for drinking purpose, especially in the rural area. Contamination of groundwater can result in poor drinking water quality which increases potential health problem, clean up cost, and alternative water supplies (Nas & Berkday, 2010).

Groundwater quality assessment is a significant issue for planning strategy for protection and control of groundwater quality, which is started by establishing groundwater monitoring network wells. The data collected from sampling wells are valuable for understanding and identifying the characterization of groundwater quality. Often, monitoring locations are arbitrarily located in single well or groups of wells, where pollution in the aquifer is first detected. However, they may not be ideally located for accurately identifying the release history of the pollution sources. Since, number and location of sampling wells play vital role on data obtained from groundwater. Designing monitoring wells in an optimal manner helps to delineate water quality with a minimum number of sampling wells at optimal location at a contaminated site (Chadalavada et al., 2011).

1-2 Rational of the Study

Groundwater quality has become a global concern due to its effect on human life and natural ecosystem, especially in arid and semi-arid region such as Amol-Babol Plain (Figure 1.2), which is under pressure with intensive agricultural activity and population growth rate. Protecting groundwater quality for human health and ecosystem is one of the serious issue in water management, which is highly depend on accurate view about groundwater quality conditions (Schmoll, 2006). Structured approach is required to identify significant factors that influenced groundwater quality, groundwater pollution sources, and vulnerable zones in the study area. Although, some researches were undertaken in the Mazandaran's groundwater (MAHAB, 2004; Shahbazi & Esmaili-Sari, 2009; Fakharian, 2010), but, these studies mostly on the evaluation of the quality of groundwater as a drinking water based on WHO (2011a) and EPA (2011) standards.

Despite the several researches for groundwater monitoring network optimization, the majority of methods does not consider hydrology and hydrogeological characteristics of the aquifer, and mainly focus on only statistical aspects. Therefore, the integration of statistical, geostatistical, hydrogeological and hydrochemical methods are proposed as an adequate and reliable method for optimization groundwater quality monitoring network to improve groundwater monitoring strategies in the Amol-Babol Plain.

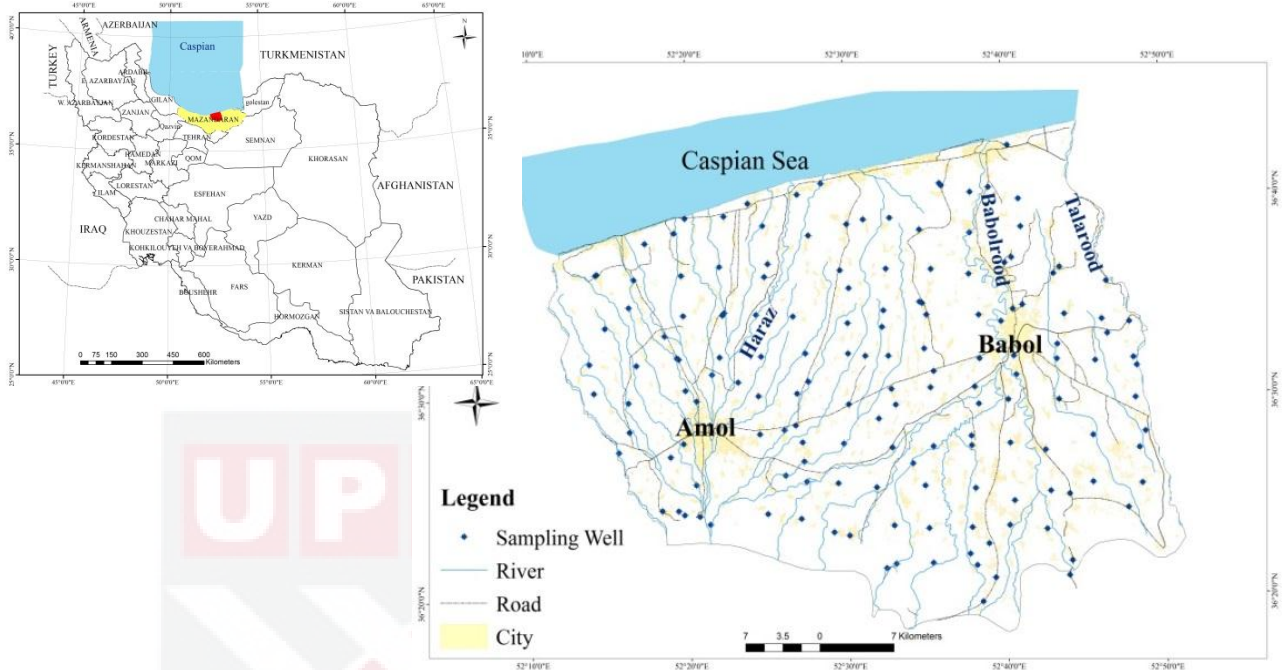


Figure 1.2 Schematic map of Iran showing the study area Amol-Babol Plain

1-3 Scope of the Study

Groundwater quality should be controlled on many sites to prevent migration of contaminants and keep groundwater safe for potable and agricultural usages. This study will be focused on assessment of groundwater quality for different usages, based on multivariate statistical analysis, geostatistical techniques, and hydrogeochemical investigation. Although, a typical monitoring program is needed to control groundwater quality, a typical monitoring program is very costly and time-consuming process. Therefore, a new approach will be suggested to optimize the groundwater monitoring network in Amol-Babol Plain, to provide the maximum information about the pollution sources in while employing the minimum number of sampling wells:

- i. This study focus on the hydrochemistry of groundwater in the Amol-Babol Plain using integration of hydrochemical methods and geostatistical technique.
- ii. Focuses on variation of groundwater quality, such as anions, cations, total and fecal coliforms, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solid (TDS), and water temperature, and compared with international water quality standards for drinking and agriculture water.
- iii. Applies the geostatistical interpolation techniques and multivariate statistical methods to identify significant parameters and possible pollution sources that influence groundwater quality in different time and space.

- iv. Studies irrigation water quality index to identify suitable zones for agricultural activities, based on the salinity hazard, infiltration hazard, specific ions hazard, trace elements hazard, and miscellaneous effects using GIS-based index technique.
- v. Concentrates to redesign information-cost effective groundwater quality monitoring wells, regarding to estimation of uncertainty in contamination concentration in the initial sampling wells and identification of risky zones based on the vulnerability and risk assessment and geostatistical estimation error approach in the study area.

1-4 Objectives of the Study

The main aim of this study is to assess and redesign the information-cost-effective groundwater monitoring network using geostatistical technique in Amol-Babol Plain, Iran. The specific objectives of this study are as follow:

- i. To determine spatial and temporal variations of the groundwater quality and pollution sources.
- ii. To characterize hydrogeochemical processes and spatial distribution on ionic ratios.
- iii. To identify suitability zones of groundwater for irrigation purposes.
- iv. To develop a new method to identify high potential risk zones based on anthropogenic contamination.
- v. To redesign cost-effective groundwater quality monitoring network for the study area using geostatistical estimation error approach.

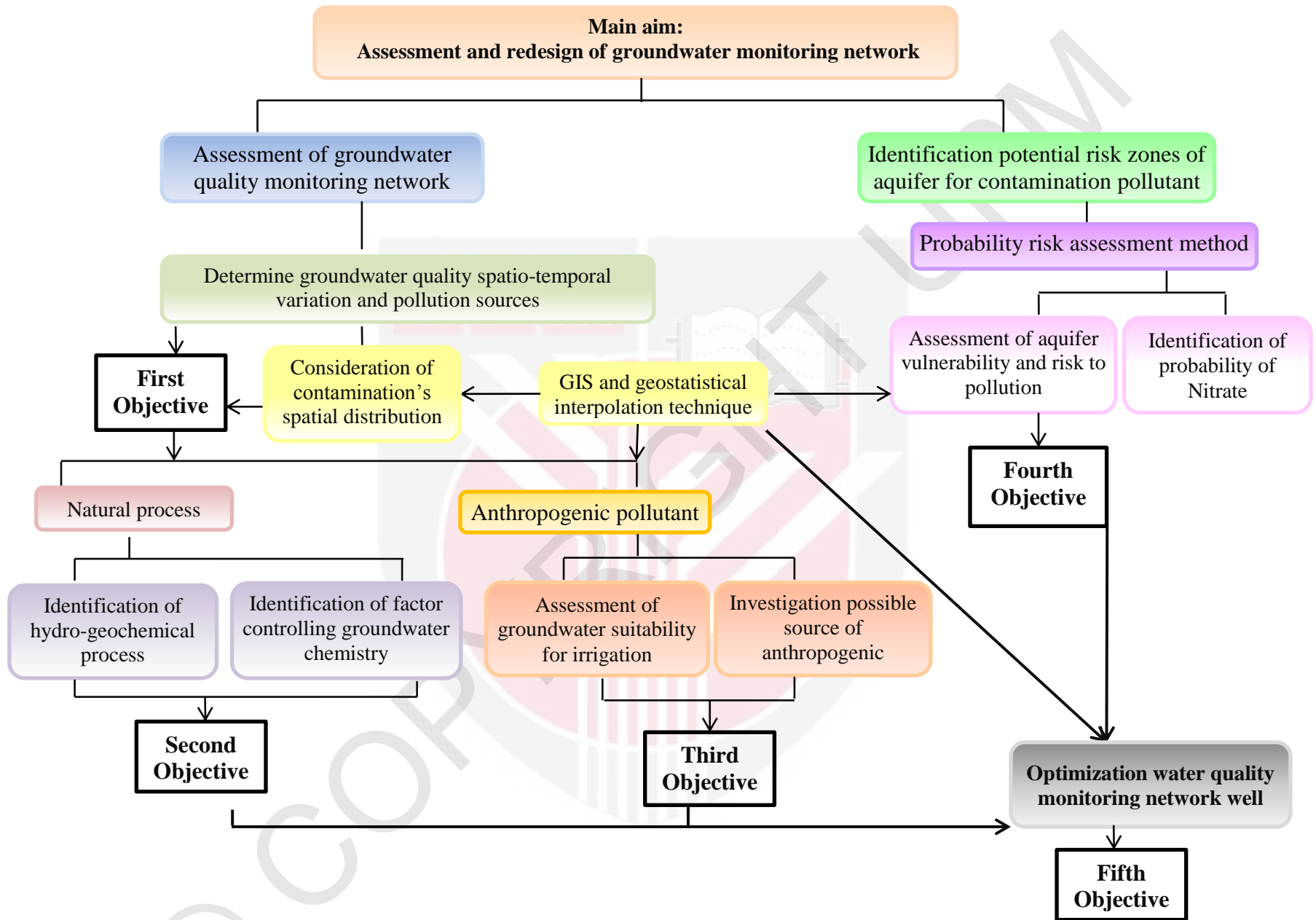


Figure 1.3 Conceptual framework of relationship between objectives and methodologies

1-5 Outline of Thesis

This thesis was organized into eight chapters. The results in chapters 3, 4, 5, and 7 had been published in ISI journals, and chapters 6 and 8 are still under review. These chapters have a specific introduction, methodology, result and discussion and conclusion.

Chapters 1, 2, and 3 introduce the motivation, back ground, and methodologies of the research in the study area.

Chapter 4 focuses on the first objective of the research, on spatial and temporal variations of groundwater quality parameters using multivariate statistical methods. Application of principal component analysis (PCA) and two-way ANOVA as a reliable approach revealed the significant factors influencing groundwater quality in the plain. Combination of multivariate analysis and geostatistical techniques demonstrate the possible source of contamination and the spatial structure of multivariate spatial data.

Chapter 5 focuses on the second objective of the research, which discuss the geochemical process, water chemistry type, and factors controlling the groundwater chemistry as natural factors influencing groundwater quality in the study area. Combinations of classic geochemical methods, statistical and geostatistical techniques, and PHREEQC software have been applied to characterize hydrogeochemical process of groundwater

Chapter 6 focuses on the first part of objective number three, which describes the suitability of groundwater for agricultural usage as a dominant economic activity in the Amol-Babol Plain. Application of irrigation water quality factors, geostatistical and statistical techniques, and geographic information system (GIS) revealed quality of groundwater for irrigation purpose.

Chapter 7 focuses on the second part of the third objective, which developed the irrigation water quality (IWQ) index in the Amol-Babol Plain and integrates with hydrogeological factors to assess suitable zones for agricultural activities in the study area.

Chapter 8 focuses on the fourth objective to evaluate the vulnerability and risk of aquifer to contamination using DRASTIC method and GIS. Application of indicator kriging provides powerful tool for identifying areas with probability of contaminants, specifically nitrate contamination in the study area. In this chapter, probability risk assessment had been proposed as new approach to identify areas with high potential to pollutant. DRASTIC method has been validated the efficiency of monitoring network.

Chapter 9 focuses on the fifth objective to develop new approach for designing an information-cost-effective groundwater monitoring network using geostatistics for extracting estimation error at all potential monitoring locations. To optimized monitoring network, extracted estimation error of significant parameters that influence the quality of groundwater, are combined with risk assessment map of aquifer. The efficiency of optimized monitoring network was examined using mass estimation error. The optimized monitoring network had been shown to provide accurate data for further water resource management under budgetary constraints.

Chapter 10 describes the conclusions of the finding of the studies and recommendations for future studies.



REFERENCES

- Abudaya, M., & Hararah, S. (2013). Spatial and Temporal Variations in Water Quality along the Coast of Gaza Strip. *Journal of Environment and Earth Science*, 3(2).
- Adamat, R., Foster I, & S, B. (2003). Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, remote sensing and DRASTIC. *J Applied Geography*, 23, 303-324.
- Adams, S., Titus, R., Pietersen, K., Tredoux, G., & Harris, C. (2001). Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. *Journal of Hydrology*, 241(1), 91-103.
- Adhikary, P., Dash, C., Chandrasekharan, H., Rajput, T., & Dubey, S. (2011). Evaluation of groundwater quality for irrigation and drinking using GIS and geostatistics in a peri-urban area of Delhi, India. *Arab J Geosci* 1-12. doi:10.1007/s12517-011-0330-7
- Adhikary, P. P., Chandrasekharan, H., Chakraborty, D., & Kamble, K. (2010). Assessment of groundwater pollution in West Delhi, India using geostatistical approach. *Environmental Monitoring and Assessment*, 167(1-4), 599-615.
- Adhikary, P. P., Dash, C. J., Chandrasekharan, H., Rajput, T., & Dubey, S. (2012). Evaluation of groundwater quality for irrigation and drinking using GIS and geostatistics in a peri-urban area of Delhi, India. *Arabian Journal of Geosciences*, 5(6), 1423-1434.
- Agha-Nabati, A. (2004). Geology of Iran.–586 pp. *Tehran (Geological Survey of Iran publications)(In Persian)*.
- Aghazadeh, N., & Asghari, M. A. (2010). Assessment of Groundwater Quality and its Suitability for Drinking and Agricultural Uses in the Oshnavieh Area, Northwest of Iran. *Journal of Environmental Protection*, 01(01), 30-40. doi:10.4236/jep.2010.11005
- Agoubi, B., Kharroubi, A., & Abida, H. (2013). Hydrochemistry of groundwater and its assessment for irrigation purpose in coastal Jeffara Aquifer, southeastern Tunisia. *Arabian Journal of Geosciences*, 1-10.
- Ahmadi, S. H., & Sedghamiz, A. (2007). Geostatistical analysis of spatial and temporal variations of groundwater level. *Environmental Monitoring and Assessment*, 129(1-3), 277-294.
- Ahmed, S. (2001). Rationalization of Aquifer Parameters for Aquifer Modelling Including Monitoring Network Design, Modelling in Hydrogeology (pp. 39-57): UNESCO International Hydrological Programme. Allied Publishers Limited.
- Ahmed, S. (2004). Geostatistical estimation variance approach to optimizing an air temperature monitoring network. *Water, Air, and Soil Pollution*, 158(1), 387-399.
- Ahmed., S. (2007). Application of Geostatistics in Hydrosociences. In M. Thangarajan (Ed.), *Groundwater* (pp. 78-111): Springer Netherlands.
- Aiuppa, A., Bellomo, S., Brusca, L., D'Alessandro, W., & Federico, C. (2003). Natural and anthropogenic factors affecting groundwater quality of an active volcano (Mt. Etna, Italy). *Applied Geochemistry*, 18(6), 863-882.
- Akouvi, A., Dray, M., Violette, S., de Marsily, G., & Zuppi, G. M. (2008). The sedimentary coastal basin of Togo: example of a multilayered aquifer still influenced by a palaeo-seawater intrusion. *Hydrogeology Journal*, 16(3), 419-436.

- Al-Adamat, R. A., Foster, I. D., & Baban, S. M. (2003). Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, Remote sensing and DRASTIC. *Applied Geography*, 23(4), 303-324.
- Al-Khashman, O. A., & Jaradat, A. Q. (2014). Assessment of groundwater quality and its suitability for drinking and agricultural uses in arid environment. *Stochastic Environmental Research and Risk Assessment*, 28(3), 743-753.
- Al-Sabhan, W., Mulligan, M., & Blackburn, G. A. (2003). A real-time hydrological model for flood prediction using GIS and the WSW. *Computers, Environment and Urban Systems*, 27(1), 9-32.
- Al-Taani, A. A. (2013). Seasonal variations in water quality of Al-Wehda Dam north of Jordan and water suitability for irrigation in summer. *Arabian Journal of Geosciences*, 1-10.
- Al Kuisi, M., Al-Qinna, M., Margane, A., & Aljazzar, T. (2009). Spatial assessment of salinity and nitrate pollution in Amman Zarqa Basin: a case study. *Environmental Earth Sciences*, 59(1), 117-129. doi:10.1007/s12665-009-0010-z
- Aladin, N., & Plotnikov, I. (2004). The Caspian Sea. *Lake Basin Management Initiative, Thematic Paper*.
- Alberto, W. D., María del Pilar, D. a., María Valeria, A., Fabiana, P. S., Cecilia, H. A., & María de los Ángeles, B. (2001). Pattern Recognition Techniques for the Evaluation of Spatial and Temporal Variations in Water Quality. A Case Study:: Suquia River Basin (Córdoba–Argentina). *Water Research*, 35(12), 2881-2894.
- Aller, L., Bennet T, Lehr JH, & RJ, P. (1987). *DRASTIC: A standardized system for evaluating groundwater pollution using hydrogeologic settings*: EPA.
- Aller, L., Lehr, J. H., Petty, R., & Bennett, T. (1987). Drastic—a standardized system to evaluate groundwater pollution potential using hydrogeologic setting. *Journal of the Geological Society of India*, 29(1), 23-37.
- Alsamamra, H., Ruiz-Arias, J. A., Pozo-Vázquez, D., & Tovar-Pescador, J. (2009). A comparative study of ordinary and residual kriging techniques for mapping global solar radiation over southern Spain. *Agricultural and Forest meteorology*, 149(8), 1343-1357.
- An, Y., Wang, Y., Zhang, H., & Wu, X. (2012). GIS-based Suitability Assessment for Shallow Groundwater Development in Zhangye Basin. *Procedia Environmental Sciences*, 12, Part B(0), 1397-1403. doi:http://dx.doi.org/10.1016/j.proenv.2012.01.442
- Antunes, I. M. H. R., & Albuquerque, M. T. D. (2013). Using indicator kriging for the evaluation of arsenic potential contamination in an abandoned mining area (Portugal). *Science of the Total Environment*(442), 545-552.
- APHA (2005). *standard methods for the examination of water and wastewater*. Washigton DC: American Public Health Association, American Water Workes Association, Water Environment federation. .
- Appelo, C., Postma, D., & Geochemistry, G. (1993). Pollution. *Balkema, Rotterdam*, 536.
- Aris, A., Abdullah, M. H., & M, B. (2008). Hydrochemical analysis on groundwater in shallow aquifer of Manukan and Mabul islands, Malaysia. *International Association of Hydrological Sciences Red Book* 387-394.
- Aris, A., Praveena, S. M., Abdullah, M. H., & Radojevic, M. (2012). Statistical approaches and hydrochemical modelling of groundwater system in a small tropical island. *Journal of Hydroinformatics*, 14(1).

- Aris, A. Z., Praveena, S. M., & Abdullah, M. H. (2010). The influence of seawater on the chemical composition of groundwater in a small island: the example of Manukan Island, East Malaysia. *Journal of Coastal Research*, 28(1), 64-75.
- Arslan, H., & Demir, Y. (2013). Impacts of seawater intrusion on soil salinity and alkalinity in Bafra Plain, Turkey. *Environmental Monitoring and Assessment*, 185(2), 1027-1040. doi:10.1007/s10661-012-2611-3
- Ashraf, S., Afshari, H., & Ebadi, A. G. (2011). Geographical information system techniques for evaluation of groundwater quality. *American Journal of Agricultural and Biological Science*.
- Assaf, H., & Saadeh, M. (2009). Geostatistical Assessment of Groundwater Nitrate Contamination with Reflection on DRASTIC Vulnerability Assessment: The Case of the Upper Litani Basin, Lebanon. *Water Resources Management*, 23(4), 775-796. doi:10.1007/s11269-008-9299-8
- Association, N. W. W. (1986). RCRA ground water monitoring technical enforcement guidance document. *National Water Well Association, Dublin, OH*.
- Astel, A., Biziuk, M., Przyjazny, A., & Namieśnik, J. (2006). Chemometrics in monitoring spatial and temporal variations in drinking water quality. *Water Research*, 40(8), 1706-1716. doi:http://dx.doi.org/10.1016/j.watres.2006.02.018
- ASTM (2001). *American Society for Testing and Material Standards*. New York: American Standard for Testing Materials.
- Avtar, R., Kumar, P., Singh, C., & Mukherjee, S. (2011). A comparative study on hydrogeochemistry of Ken and Betwa Rivers of Bundelkhand using statistical approach. *Water Quality, Exposure and Health*, 2(3-4), 169-179.
- Ayazi, M. H., Pirasteh, S., Arvin, A., Pradhan, B., Nikouravan, B., & Mansor, S. (2010). Disasters and risk reduction in groundwater: Zagros Mountain Southwest Iran using geoinformatics techniques. *Disaster Advances*, 3(1), 51-57.
- Ayers, R., & Westcot, D. (1985). Water quality for agriculture. FAO Irrigation and drainage paper 29 Rev. 1. *Food and Agricultural Organization, Rome*.
- Baalousha, H. (2010). Assessment of a groundwater quality monitoring network using vulnerability mapping and geostatistics: A case study from Heretaunga Plains, New Zealand. *Agricultural Water Management*, 97(2), 240-246.
- Babak, O., & Deutsch, C. (2009). Statistical approach to inverse distance interpolation. *Stochastic Environmental Research and Risk Assessment*, 23(5), 543-553. doi:10.1007/s00477-008-0226-6
- Babiker, I. S., Mohamed, M. A. A., Hiyama, T., & Kato, K. (2005). A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan. *Sci. Total Environ*, 345, 127-140.
- Babiker., I. S., Mohamed, M. A., Terao, H., Kato, K., & Ohta, K. (2004). Assessment of groundwater contamination by nitrate leaching from intensive vegetable cultivation using geographical information system. *Environment International*, 29(8), 1009-1017.
- Barlow, P. M., & Reichard, E. G. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology Journal*, 18(1), 247-260.
- Beamonte Córdoba, E., Casino Martínez, A., & Veres Ferrer, E. (2010). Water quality indicators: Comparison of a probabilistic index and a general quality index. The case of

- the Confederación Hidrográfica del Júcar (Spain). *Ecological Indicators*, 10(5), 1049-1054.
- Beamonte, E., Bermudez, J., Casino, A., & Veres, E. (2007). A statistical study of the quality of surface water intended for human consumption near Valencia (Spain). *Journal of Environmental Management*, 83(3), 307-314.
- Belkhir, L., Boudoukha, A., Mouni, L., & Baouz, T. (2010). Application of multivariate statistical methods and inverse geochemical modeling for characterization of groundwater—A case study: Ain Azel plain (Algeria). *Geoderma*, 159(3), 390-398.
- Belkhir, L., & Mouni, L. (2013). Geochemical modeling of groundwater in the El Eulma area, Algeria. *Desalination and Water Treatment*, 51(7-9), 1468-1476.
- Bierman, P., Lewis, M., Ostendorf, B., & Tanner, J. (2011). A review of methods for analysing spatial and temporal patterns in coastal water quality. *Ecological Indicators*, 11(1), 103-114.
- Bogárdi, I., Bárdossy, A., & Duckstein, L. (1985). Multicriterion network design using geostatistics. *Water Resources Research*, 21(2), 199-208.
- Bordalo, A., Nilsumranchit, W., & Chalermwat, K. (2001). Water quality and uses of the Bangpakong River (Eastern Thailand). *Water Research*, 35(15), 3635-3642.
- Boughriba, M., Barkaoui A, Zarhloule Y, L. Z., El Houadi B, & Verdoya M (2010). Groundwater vulnerability and risk mapping of the Angad transboundary aquifer using DRASTIC index method in GIS environment. *Arab J Geosci*, 3, 207-220.
- Boyacioglu, H., & Boyacioglu, H. (2008). Water pollution sources assessment by multivariate statistical methods in the Tahtali Basin, Turkey. *Environmental Geology*, 54(2), 275-282.
- Brimicombe, A. (2010). *GIS, Environmental Modeling and Engineering*: CRC Press.
- Bu, H., Tan, X., Li, S., & Zhang, Q. (2010). Temporal and spatial variations of water quality in the Jinshui River of the South Qinling Mts., China. *Ecotoxicology and Environmental Safety*, 73(5), 907-913.
- Buschmann, J., Berg, M., Stengel, C., Winkel, L., Sampson, M. L., Trang, P. T. K., et al. (2008). Contamination of drinking water resources in the Mekong delta floodplains: Arsenic and other trace metals pose serious health risks to population. *Environment International*, 34(6), 756-764.
- Cachada, A., Pereira, M. E., da Silva, E. F., & Duarte, A. C. (2012). Sources of potentially toxic elements and organic pollutants in an urban area subjected to an industrial impact. *Environmental Monitoring and Assessment*, 184(1), 15-32.
- Caridad-Cancela, R., Vázquez, E. V., Vieira, S. R., Abreu, C. A., & González, A. P. (2005). Assessing the spatial uncertainty of mapping trace elements in cultivated fields. *Communications in Soil Science and Plant Analysis*, 36(1), 253-274.
- Chadalavada, S., Datta, B., & Naidu, R. (2011). Uncertainty based optimal monitoring network design for a chlorinated hydrocarbon contaminated site. *Environmental Monitoring and Assessment*, 173(1-4), 929-940.
- Chadalavada, S., & Datta, B. (2008). Dynamic optimal monitoring network design for transient transport of pollutants in groundwater aquifers. *Water Resources Management*, 22(6), 651-670.
- Chang, H., Fu, A. Q., Le, N. D., & Zidek, J. V. (2007). Designing environmental monitoring networks to measure extremes. *Environmental and Ecological Statistics*, 14(3), 301-321.

- Chapagain, S., Pandey, V., Shrestha, S., Nakamura, T., & Kazama, F. (2010). Assessment of Deep Groundwater Quality in Kathmandu Valley Using Multivariate Statistical Techniques. *Water, Air, & Soil Pollution*, 210(1-4), 277-288. doi:10.1007/s11270-009-0249-8
- Chapman, D. V. (1996). *Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring*: E & Fn Spon London.
- Chau, K.w., & Muttil, N. (2007). Data mining and multivariate statistical analysis for ecological system in coastal waters. *Journal of Hydroinformatics*, 9(4), 305-317.
- Chen, K., & Jiao, J. (2007). Seawater intrusion and aquifer freshening near reclaimed coastal area of Shenzhen. *Water Science & Technology: Water Supply*, 7(2).
- Childs, C. (2004). Interpolating surfaces in ArcGIS spatial analyst. *ArcUser*, July-September, 32-35.
- Chowdhury, A., Jlia, M. K., & Machinal, D. (2003). Application of remote sensing and GIS in groundwater studies: an overview, *Ground Water Pollution: Proceedings of the International Conference on Water and Environment (WE-2003), December 15-18, 2003, Bhopal, India* (p. 39).
- Cloutier, V., Lefebvre, R., Therrien, R., & Savard, M. M. (2008). Multivariate statistical analysis of geochemical data as indicative of the hydrogeochemical evolution of groundwater in a sedimentary rock aquifer system. *Journal of Hydrology*, 353(3), 294-313.
- Collins, F. C. (1995). *A comparison of spatial interpolation techniques in temperature estimation*.
- Conover, W. I. (1980). *Practical nonparametric statistics*: New York: Wiley.
- Cynthia, S. A. W., Joseph, M. W., & Stephen, R. Y. (2000). Characterizing the spatial structure of vegetation communities in the Mojave Desert using geostatistical techniques. *Comput Geosci*, 26, 397-410.
- Dar, I., Sankar, K., & Dar, M. (2011). Spatial assessment of groundwater quality in Mamundiya basin, Tamil Nadu, India. *Environmental Monitoring and Assessment*, 178(1-4), 437-447. doi:10.1007/s10661-010-1702-2
- Dash, J., Sarangi, A., & Singh, D. (2010). Spatial variability of groundwater depth and quality parameters in the national capital territory of Delhi. *Environmental Management*, 45(3), 640-650.
- Daughney, C., Raiber, M., Moreau-Fournier, M., Morgenstern, U., & Raaij, R. (2012). Use of hierarchical cluster analysis to assess the representativeness of a baseline groundwater quality monitoring network: comparison of New Zealand's national and regional groundwater monitoring programs. *Hydrogeology Journal*, 20(1), 185-200. doi:10.1007/s10040-011-0786-2
- Davis, J. C., & Sampson, R. J. (2002). *Statistics and data analysis in geology*.
- Dawoud, M. A. (2004). Design of national groundwater quality monitoring network in Egypt. *Environmental Monitoring and Assessment*, 96, 99-118.
- Debels, P., Figueroa, R., Urrutia, R., Barra, R., & Niell, X. (2005). Evaluation of water quality in the Chillán River (Central Chile) using physicochemical parameters and a modified water quality index. *Environmental Monitoring and Assessment*, 110(1-3), 301-322.
- Delgado, C., Pacheco, J., Cabrera, A., Batllori, E., Orellana, R., & Bautista, F. (2010). Quality of groundwater for irrigation in tropical karst environment: The case of Yucatán, Mexico. *AGR Water Manage*, 97(10), 1423-1433. doi:10.1016/j.agwat.2010.04.006

- Delhomme, J. P. (1974). *La cartographie d'une grandeur physique a partir des donnees de differentes qualities*. Paper presented at the IAH.
- Delleur, J. W. (2010). *The handbook of groundwater engineering*: CRC press.
- Demirel, Z. (2004). The history and evaluation of saltwater intrusion into a coastal aquifer in Mersin, Turkey. *Journal of Environmental Management*, 70(3), 275-282.
- Desbarats, A., & Srivastava, R. (1991). Geostatistical characterization of groundwater flow parameters in a simulated aquifer. *Water Resources Research*, 27(5), 687-698.
- Deutsch, C. V., & Journel, A. G. (1998). *GSLIB, Geostatistical software library and user's guide*: New York' Oxford University Press.
- Dimitriou, E., & Zacharias, I. (2006). Groundwater vulnerability and risk mapping in a geologically complex area by using stable isotopes, remote sensing and GIS techniques. *Environmental Geology*, 51(2), 309-323. doi:10.1007/s00254-006-0328-8
- Dobesch, H., Dumolard, P., & Dyras, I. (2010). *Spatial interpolation for climate data: the use of GIS in climatology and meteorology* (Vol. 663): John Wiley & Sons.
- Domenico, P. A., & Schwartz, F. W. (1990). *Physical and Chemical Hydrogeology* New York: John Wiley and Sons.
- Doneen, L. D. (1964). *Notes on water quality in agriculture*. Davis: Water Science and Engineering, University of California.
- Drever, J. I. (1997). *The geochemistry of natural waters: surface and groundwater environments*.
- Eaton, E. M. (1950). *Significance of carbonate in irrigation water*: Soil Science.
- El Moujabbber, M., Samra, B. B., Darwish, T., & Atallah, T. (2006). Comparison of different indicators for groundwater contamination by seawater intrusion on the Lebanese coast. *Water resources management*, 20(2), 161-180.
- Elango, L., & Kannan, R. (2011). Rock–water interaction and its control on chemical composition of groundwater. *Concepts and Applications in Environmental Geochemistry*, 5, 229.
- Elçi, A., & Polat, R. (2011). Assessment of the statistical significance of seasonal groundwater quality change in a karstic aquifer system near Izmir-Turkey. *Environmental Monitoring and Assessment*, 172(1-4), 445-462.
- EPA (2011). *Drinking Water Standards and Health Advisories*. Washington, DC: Environmental Protection Agency Office of Water U.S.
- ESRI (2003). *Environmental Systems Research Institute, Using ArcGIS geostatistical analyst USA*.
- EU, D. (1998). 98/83/EEC. *Official Journal of the European Communities*. No. L, 31(1).
- Everett, L., Wilson, L., & McMillion, L. (1982). Vadose zone monitoring concepts for hazardous waste sites. *Groundwater*, 20(3), 312-324.
- Fakharian, K. (2010). *Hydrogeology report of Amol-Babol plain , Study of prevention, control and reduce pollution of Amol- Babol aquifer. (Persian ed.)*. Amirkabir University of Technology: Department of Environment of Iran.
- FAO (1994). *Water quality for agriculture*. Rome: Food and Agriculture Organization of the United Nations

- Farjad, B., bin Mohd Shafri, H. Z., Mohamed, T. A., Pirasteh, S., & Wijesekara, N. (2012). Groundwater intrinsic vulnerability and risk mapping. *Proceedings of the ICE-Water Management*, 165(8), 441-450.
- Farnham, I., Johannesson, K., Singh, A., Hodge, V., & Stetzenbach, K. (2003). Factor analytical approaches for evaluating groundwater trace element chemistry data. *Analytica Chimica Acta*, 490(1), 123-138.
- Fisher, J. C. (2013). *Optimization of Water-Level Monitoring Networks in the Eastern Snake River Plain Aquifer Using a Kriging-Based Genetic Algorithm Method*: United States Geological Survey.
- Forno, D. A., Yoshida, S., & Asher, C. J. (1975). Zinc deficiency in rice. *Plant and Soil*, 42(3), 537-550. doi:10.1007/bf00009941
- Foster, S. (1987). Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy, *Vulnerability of Soil and Groundwater to Pollutants, TNO Committee on Hydrogeological Research, Proceedings and Information* (pp. 69-86).
- Freeze, R. A. (1975). A stochastic-conceptual analysis of one-dimensional groundwater flow in nonuniform homogeneous media. *Water Resources Research*, 11(5), 725-741.
- Fritch, T. G., McKnight, C. L., Yelderman Jr, J. C., & Arnold, J. G. (2000). An aquifer vulnerability assessment of the Paluxy aquifer, central Texas, USA, using GIS and a modified DRASTIC approach. *Environmental Management*, 25(3), 337-345.
- Gaur, A. S., & Gaur, S. S. (2006). *Statistical methods for practice and research: A guide to data analysis using SPSS*: Sage.
- Gaus, I., Kinniburgh, D., Talbot, J., & Webster, R. (2003). Geostatistical analysis of arsenic concentration in groundwater in Bangladesh using disjunctive kriging. *Environmental Geology*, 44(8), 939-948.
- Gazzaz, N. M., Yusoff, M. K., Aris, A. Z., Juahir, H., & Ramli, M. F. (2012). Artificial neural network modeling of the water quality index for Kinta River (Malaysia) using water quality variables as predictors. *Marine Pollution Bulletin*, 64(11), 2409-2420.
- Gerber, S. B., & Voelkl, K. E. F. (2005). *Using SPSS for Windows*: Springer.
- Ghods, M. (2004). *Supplementary environmental and social assessment of Alborz intergrated land and water Iran*: Mahab Ghods Consulting Engineers. .
- Gibbons, J. D. (1993). *Nonparametric statistics: An introduction*. CA: Sage: Newbury Park.
- Goldberg, V. M. (1989). Groundwater pollution by nitrates from livestock wastes. *Environ Health Perspect*(83), 25-19.
- Gomezdelcampo, E., & Dickerson, J. R. (2008). A modified DRASTIC model for Siting Confined Animal Feeding Operations in Williams County, Ohio, USA. *Environmental Geology*, 55(8), 1821-1832. doi:10.1007/s00254-007-1133-8
- Gong, F., & Li, X. (2007). Application of Distance Discriminant Analysis Method to Classification of Engineering Quality of Rock Masses [J]. *Chinese Journal of Rock Mechanics and Engineering*, 1, 027.
- Goovaerts, P. (2000). Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. *Journal of Hydrology*, 228(1), 113-129.
- Goovaerts, P., Avruskin, G., Meliker, J., Slotnick, M., Jacquez, G., & Nriagu, J. (2005). Geostatistical modeling of the spatial variability of arsenic in groundwater of southeast Michigan. *Water Resources Research*, 41(7).

- Grunsky, E. C. (2010). The interpretation of geochemical survey data. *Geochemistry: Exploration, Environment, Analysis*, 10(1), 27-74.
- Guler, C., & Thyne, G. D. (2004). Hydrologic and geologic factors controlling surface and groundwater chemistry in Indian Wells-Owens Valley area, southeastern California, USA. *Journal of Hydrology*, 285(1-4), 177-198.
- Gustafson, D. I. (1989). Groundwater ubiquity score: a simple method for assessing pesticide leachability. *Environmental toxicology and chemistry*, 8(4), 339-357.
- Guttman, J. (2000). *Hydrogeology of the eastern aquifer in the Judea hills and Jordan valley*.
- Haimes, Y. Y. (2006). On the definition of vulnerabilities in measuring risks to infrastructures. *Risk analysis*, 26(2), 293-296.
- Hajiboland, R., & Salehi, S. Y. (2006). Zinc Efficiency is Not Related to Bicarbonate Tolerance in Iranian Rice Cultivars. *Journal of Agronomy*, 5(3), 497-504.
- Handa, B. K. (1969). *Description and classification of media for hydro-geochemical investigations*. Paper presented at the In Symposium on ground water studies in arid and semiarid regions.
- Hanshaw, B. B., & Back, W. (1979). Major geochemical processes in the evolution of carbonate—Aquifer systems. *Journal of Hydrology*, 43(1), 287-312.
- Haritash, A. K., Kaushik, C. P., Kaushik, A., Kansal, A., & Yadav, A. (2008). Suitability assessment of groundwater for drinking, irrigation and industrial use in some North Indian villages. *Environmental Monitoring and Assessment*, 145(1-3), 397-406. doi:10.1007/s10661-007-0048-x
- Harman, H. H. (1960). *Modern factor analysis*. Chicago: University of Chicago press.
- Harmancıoğlu, N. (1999). *Water quality monitoring network design* (Vol. 33): Springer.
- Harmancıoğlu, N. B., & Alpaslan, N. (1992). Water quality monitoring network design: a problem of multi-objective decision making. *JAWRA Journal of the American Water Resources Association*, 28(1), 179-192.
- Harper, D. A. (1999). *Numerical palaeobiology*: John Wiley and Sons.
- Hartkamp, A. D., De Beurs, K., Stein, A., & White, J. W. (1999). *Interpolation techniques for climate variables*: CIMMYT Mexico, DF.
- Healy, R. E. (2013). *Integration of Factor Analysis and GIS in Spatial Modelling of the Dublin Surge Geochemical Data Set*. Dublin, Ireland.
- Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J. M., & Fernandez, L. (2000). Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis. *Water Research*, 34(3), 807-816.
- Helsel, D., & Hirsch, R. (2002). Statistical methods in water resources: US Geological Survey Techniques of Water Resources Investigations, book 4, chap: A3.
- Hem., J. D. (1985). *Study and interpretation of the chemical characteristics of natural water* (Vol. 2254): Department of the Interior, US Geological Survey.
- Hinton, P., Brownlow, C., & McMurray, I. (2004). *SPSS explained*: Routledge.
- Ho, C. J. (2001). Effect of land use and urbanization on hydrochemistry and contamination of groundwater from Taejon area, Korea. *Journal of Hydrology*, 253(1-4), 194-210.

- Hoang, D. N. (2008). *Geostatistical tools for better characterization of the groundwater quality- case studies for the coastal quaternary aquifers in the Nam Dinh Area/Vietnam*. Universitätsbibliothek.
- Hofierka, J., Parajka, J., Mitasova, H., & Mitas, L. (2002). Multivariate interpolation of precipitation using regularized spline with tension. *Transactions in GIS*, 6(2), 135-150.
- Horton, R. K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Federation*, 37(3), 300-306.
- Huang, C., & Mayer, A. S. (1997). Pump-and-treat optimization using well locations and pumping rates as decision variables. *Water Resources Research*, 33(5), 1001-1012.
- Huang, T., & Pang, Z. (2011). Estimating groundwater recharge following land-use change using chloride mass balance of soil profiles: a case study at Guyuan and Xifeng in the Loess Plateau of China. *Hydrogeology Journal*, 19(1), 177-186.
- Hudak, P. F., & Loaiciga, H. A. (1993). An optimization method for monitoring network design in multilayered groundwater flow systems. *Water Resources Research*, 29(8), 2835-2845. doi:10.1029/93wr01042
- Husain, T. (1989). Hydrologic uncertainty measure and network design1. *JAWRA Journal of the American Water Resources Association*, 25(3), 527-534.
- Isa, N. M., Aris, A. Z., & Sulaiman, W. N. A. W. (2012). Extent and severity of groundwater contamination based on hydrochemistry mechanism of sandy tropical coastal aquifer. *Science of the Total Environment*, 438, 414-425.
- Isaaks, E., & Srivastava., R. (1989). *Applied geostatistics* (Vol. 2). New York: Oxford University Press.
- Jafar Ahamed, A., Loganathan, K., & Ananthkrishnan, S. (2013). A comparative evaluation of groundwater suitability for drinking and irrigation purposes in Pugalur area, Karur district, Tamilnadu, India. *Archives of Applied Science Research*, 5(1), 213-223.
- Jagadeesan, L., M. M., Perumal, P., & Anantharaman, P. (2011). Temporal Variations of Water Quality Characteristics and Their Principal Sources in Tropical Vellar Estuary, South East Coast of India. *Research Journal of Environmental Sciences*, 5(8), 703-713.
- Jain, C. K., Bandyopadhyay, A., & Bhadra, A. (2010). Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India. *Environmental Monitoring and Assessment*. 663-676. doi:10.1007/s10661-009-1031-5
- Jalali, M. (2007). Salinization of groundwater in arid and semi-arid zones: an example from Tajarak, western Iran. *Environmental Geology*, 52(6), 1133-1149.
- Jamab (1995a). *Geological report of the comprehensive water plan of Mazandaran (Persian version)*. Iran: Jamab Consulting Co.
- Jamab (1995b). *Soil and land classification and land resource evaluation (Persian version)*. Iran: Jamab Consluting Co. Ministry of Energy.
- Jang, C. S., & Liu, C. W. (2004). Geostatistical analysis and conditional simulation for estimating the spatial variability of hydraulic conductivity in the Choushui River alluvial fan, Taiwan. *Hydrological Processes*, 18(7), 1333-1350.
- Jang, C., Chen, S. K., & Kuo, Y. M. (2013). Applying indicator-based geostatistical approaches to determine potential zones of groundwater recharge based on borehole data. *CATENA*, 101(0), 178-187. doi:http://dx.doi.org/10.1016/j.catena.2012.09.003
- Jeong, C. H. (2001). Effect of landuse and urbanization on hydrochemistry contamination of groundwater from Taejon area, Korea. *J Hydrol*, 253, 194-210.

- Jha, M. K., Chowdhury, A., Chowdary, V., & Peiffer, S. (2007). Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. *Water resources management*, 21(2), 427-467.
- Johnson, R. A., & Wichern, D. W. (2002). *Applied multivariate statistical analysis* (Vol. 5): Prentice hall Upper Saddle River, NJ.
- Johnson., T. (2007). Battling seawater intrusion in the central & west coast basins. *WRD Technical Bulletin. Volextraction seams to be feasible to all site conditions.*
- Johnston, K., Ver Hoef, J. M., Krivoruchko, K., & Lucas, N. (2001). *Using ArcGIS geostatistical analyst* (Vol. 380): Esri Redlands.
- Journel, A. (1983). Non-parametric estimation of spatial distribution. *Mathematical Geology*, 15(445-68).
- Journel, A., & Huijbregts, C. J. (1978). *Mining Geostatistics*. New York: Academic Press.
- Journel, A., & Keith, L. H. (1988). *Non-parametric geostatistics for risk and additional sampling assessment (Ed.), Principles of environmental sampling*. Washington, DC: American Chemical Society.
- Jousma, G., Attanayake, P., Chilton, J., Margane, A., Navarrete, C., Polemio, M., et al. (2006). Guideline on: groundwater monitoring for general reference purposes. *International Groundwater Resources Assessment Centre (IGRAC), Utrecht.*
- Juahir, H., Zain, S. M., Aris, A. Z., Yusoff, M. K., & Mokhtar, M. B. (2010). Spatial assessment of Langat river water quality using chemometrics. *Journal of Environmental Monitoring*, 12(1), 287-295.
- Júnez-Ferreira, H., & Herrera, G. (2013). A geostatistical methodology for the optimal design of space–time hydraulic head monitoring networks and its application to the Valle de Querétaro aquifer. *Environmental Monitoring and Assessment*, 185(4), 3527-3549.
- Kaiser, H. (1958). The varimax criterion for analytic rotation in factor analysis. *Psychometrika*, 23(3), 187-200. doi:10.1007/bf02289233
- Kallioras, A., Pliakas, F., Diamantis, I., & Emmanouil, M. (2006). Application of Geographical Information Systems (GIS) for the management of coastal aquifers subjected to seawater intrusion. *Journal of Environmental Science and Health Part A*, 41(9), 2027-2044.
- Kannel, P. R., Lee, S., & Lee, Y.-S. (2008). Assessment of spatial–temporal patterns of surface and ground water qualities and factors influencing management strategy of groundwater system in an urban river corridor of Nepal. *J Environmental Managemnet*, 86(4), 595-604.
- Kaown, D., Hyun, Y., Bae, G.-O., & Lee, K. K. (2007). Factors affecting the spatial pattern of nitrate contamination in shallow groundwater. *Journal of Environmental Quality*, 36(5), 1479-1487.
- Katz, B. G., Coplen, T. B., Bullen, T. D., & Davis, J. H. (1997). Use of chemical and isotopic tracers to characterize the interactions between ground water and surface water in mantled karst. *Groundwater*, 35(6), 1014-1028.
- Kelly, W. P. (1940). *Permissible composition and concentration of irrigation waters*: Proceedings of ASCE.
- Kelly, W. P. (1951). *Alkali soils—their formation, properties and reclamation*. New York: Reinhold.

- Khairy, H. (2009). *Groundwater monitoring network optimization using geostatistical methods (case study Qaemshahr-Joybar plain) (Persian ed.)*. Mazandaran, Iran: Mazandaran Regional Water Company.
- Khairy, H., & Janardhana, M. (2013). Hydrogeochemical features of groundwater of semi-confined coastal aquifer in Amol–Ghaemshahr plain, Mazandaran Province, Northern Iran. *Environmental Monitoring and Assessment*, 185(11), 9237-9264.
- Khashoggi, M. S., & El Maghraby, M. M. (2013). Evaluation of groundwater resources for drinking and agricultural purposes, Abar Al Mashi area, south Al Madinah Al Munawarah City, Saudi Arabia. *Arabian Journal of Geosciences*, 6(10), 3929-3942.
- Khodapanah, L., Sulaiman, W., & Khodapanah, N. (2009). Groundwater quality assessment for different purposes in Eshtehard District, Tehran, Iran. *European Journal of Scientific Research*, 36(4), 543-553.
- Kim, J. H., Kim, R. H., Lee, J., Cheong, T. J., Yum, B. W., & Chang, H. W. (2005). Multivariate statistical analysis to identify the major factors governing groundwater quality in the coastal area of Kimje, South Korea. *Hydrological Processes*, 19(6), 1261-1276.
- Kitsiou, D., & Karydis, M. (2011). Coastal marine eutrophication assessment: a review on data analysis. *Environment International*, 37(4), 778-801.
- Kooveei, H., Ghayomian, J., & Gieske, A. (2005). Geostatistical assessment of groundwater quality in Sarchahan. 02/05/2011
- Kovács, J., Tanos, P., Korponai, J., Kovácsné, S. I., Gondár, K., Gondár-Soregi, K., et al. (2012). Analysis of Water Quality Data for Scientists. *Water Quality and Water Pollution: Evaluation of Water Quality Data*. In Tech Open Access Publisher, Rijeka, 65-94.
- Krige, D. (1951). *A Statistical Approach to Some Mine Valuation and Allied Problems on the Witwatersrand: By DG Krige*. University of the Witwatersrand.
- Kumar, A., Maraju, S., & Bhat, A. (2007). Application of ArcGIS geostatistical analyst for interpolating environmental data from observations. *Environmental Progress*, 26(3), 220-225.
- Kumar, M., Ramanathan, A., Rao, M., & Kumar, B. (2006). Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India. *Environmental Geology*, 50(7), 1025-1039.
- Kumar, P. J., Jegathambal, P., & James, E. (2011). Multivariate and geostatistical analysis of groundwater quality in Palar river basin. *Int. J. Geol*, 4, 108-119.
- Kura, N. U., Ramli, M. F., Sulaiman, W. N. A., Ibrahim, S., Aris, A. Z., & Mustapha, A. (2013). Evaluation of factors influencing the groundwater chemistry in a small tropical Island of Malaysia. *International journal of environmental research and public health*, 10(5), 1861-1881.
- Lakhankar, T., Jones, A. S., Combs, C. L., Sengupta, M., Vonder Haar, T. H., & Khanbilvardi, R. (2010). Analysis of large scale spatial variability of soil moisture using a geostatistical method. *Sensors*, 10(1), 913-932.
- Lakshmanan, E., Kannan, R., & Kumar, M. S. (2003). Major ion chemistry and identification of hydrogeochemical processes of ground water in a part of Kancheepuram district, Tamil Nadu, India. *Environmental Geosciences*, 10(4), 157-166.
- Lark, R. M. (2000). Estimating variograms of soil properties by the method-of-moments and maximum likelihood. *Eur. J. Soil Sci*, 51, 717-728.

- Lettenmaier, D. P. (1979). Dimensionality problems in water quality network design. *Water Resources Research*, 15(6), 1692-1700.
- Leuangthong, O., McLennan, J. A., & Deutsch, C. V. (2004). Minimum acceptance criteria for geostatistical realizations. *Natural Resources Research*, 13, 131-141.
- Li, J., & Australia, G. (2008). *A review of spatial interpolation methods for environmental scientists* (Vol. 137): Geoscience Australia Canberra.
- Liou, S. M., Lo, S. L., & Wang, S. H. (2004). A generalized water quality index for Taiwan. *Environmental Monitoring and Assessment*, 96(1-3), 35-52.
- Liu, C. W., Jang, C. S., Chen, C. P., Lin, C. N., & Lou, K. L. (2008). Characterization of groundwater quality in Kinmen Island using multivariate analysis and geochemical modelling. *Hydrological Processes*, 22(3), 376-383. doi:10.1002/hyp.6606
- Liu, C.-W., Lin, K.-H., & Kuo, Y.-M. (2003). Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Science of the Total Environment*, 313(1), 77-89.
- Liu., W. C., Yu, H. L., & Chung, C. E. (2011). Assessment of Water Quality in a Subtropical Alpine Lake Using Multivariate Statistical Techniques and Geostatistical Mapping: A Case Study. *International Journal of Environmental Research and Public Health*, 8(4), 1126-1140.
- Llamas, M. R., & Martínez-Santos, P. (2005). Intensive groundwater use: silent revolution and potential source of social conflicts. *Journal of Water Resources Planning and Management*, 131(5), 337-341.
- Lo, C., & Yeung, A. (2003). *Concepts and techniques of geographic information system*. New Delhi: Prentice-Hall of India Pvt. Ltd.
- Loaiciga, H. A., Charbeneau, R., Everett, L., Fogg, G., Hobbs, B., & Rouhani, S. (1992). Review of Ground-Water Quality Monitoring Network Design. *Journal of Hydraulic Engineering*, 118(1), 11-37. doi:doi:10.1061/(ASCE)0733-9429(1992)118:1(11)
- Loaiciga, H. A. (1989). An optimization approach for groundwater quality monitoring network design. *Water Resources Research*, 25(8), 1771-1782. doi:10.1029/WR025i008p01771
- Love, D., Hallbauer, D., Amos, A., & Hranova, R. (2004). Factor analysis as a tool in groundwater quality management: two southern African case studies. *Physics and Chemistry of the Earth, Parts A/B/C*, 29(15), 1135-1143.
- Lowrance, W. W. (1976). *Of acceptable risk*: William Kaufmann.
- Lu, K. L., Liu, C. W., & Jang, C. S. (2012). Using multivariate statistical methods to assess the groundwater quality in an arsenic-contaminated area of Southwestern Taiwan. *Environmental Monitoring and Assessment*, 184(10), 6071-6085. doi:10.1007/s10661-011-2406-y
- MAHAB (2004). *Supplementary Environmental and Social Assessment of Alborz, Integrated Land and Water Management Project, (Persian)*. Tehran, Iran: Mahab Ghodss Consulting Engineers.
- Manap, M. A., Nampak, H., Pradhan, B., Lee, S., Sulaiman, W. N. A., & Ramli, M. F. (2012). Application of probabilistic-based frequency ratio model in groundwater potential mapping using remote sensing data and GIS. *Arab Journal of Geosceinces*, 1-14.
- Maqsood, I., Huang, G., & Huang, Y. (2004). A Groundwater Monitoring Design through Site Characterization, Numerical Simulation and Statistical Analysis- A North American Case Study. *Journal of Environmental Informatics*, 3(1), 1-23.

- Margat, J. (1968). Groundwater vulnerability to contamination. *Bases de la Cartographie, Doc*, 68.
- Martínez, D., & Bocanegra, E. (2002). Hydrogeochemistry and cation-exchange processes in the coastal aquifer of Mar Del Plata, Argentina. *Hydrogeology Journal*, 10(3), 393-408.
- Masoumi, F., & Kerachian, R. (2010). Optimal redesign of groundwater quality monitoring networks: a case study. *Environmental Monitoring and Assessment*, 161(1-4), 247-257.
- Matheron, G. (1970). *Les variables régionalisées et leur estimation*. Masson, Paris.
- Matheron, G. (1971). *The theory of regionalized variables and its applications* (Vol. 5): Ecole nationale supérieure des mines de Paris.
- Mayo, A. L., & Loucks, M. D. (1995). Solute and isotopic geochemistry and ground water flow in the central Wasatch Range, Utah. *Journal of Hydrology*, 172(1), 31-59.
- McCoy, J. (2004). *ArcGIS 9: Using ArcGIS Spatial Analyst*: Esri Press.
- McMahon, G., & Lloyd, O. B., Jr. (1995). *Water-quality assessment of the Albemarle-Pamlico Drainage Basin, North Carolina and Virginia-Environmental setting and water-quality issues*. USGS: U.S. Geological Survey Open-File Report.
- Mehrdadi, N., Daryabeigi Zand A, Matloubi AA, & A, B. (2007). *An investigation of sources of environmental pollution and its impact on groundwater quality in Mazandaran province, north of Iran*. Paper presented at the 10th international conference on environmental science and technology.
- Mehrjardi, M. Z., Mehrjardi, R., & Akbarzadeh, A. (2010). Evaluation of Geostatistical Techniques for Mapping Spatial Distribution of Soil PH, Salinity and Plant Cover Affected by Environmental Factors in Southern Iran. *Notulae Scientia Biologicae*, 92-103.
- Melles, S., Heuvelink, G. B., Twenhöfel, C. J., Van Dijk, A., Hiemstra, P. H., Baume, O., et al. (2011). Optimizing the spatial pattern of networks for monitoring radioactive releases. *Computers & Geosciences*, 37(3), 280-288.
- Mendiguchía, C., Moreno, C., & García-Vargas, M. (2007). Evaluation of natural and anthropogenic influences on the Guadalquivir River (Spain) by dissolved heavy metals and nutrients. *Chemosphere*, 69(10), 1509-1517.
- Metcalf, & Eddy (2000). *Integrated Aquifer Management Plan: Final Report. Gaza Coastal Aquifer Management Program*.
- Miguel, L. H., & Rosario, J. n.-E. (2008). Impact of agricultural activity and geologic controls on groundwater quality of the alluvial aquifer of the Guadalquivir River (province of Jaen, Spain): a case study. *Environmental Geology*, 54(7), 1391-1402. doi:10.1007/s00254-007-0920-6
- Mitra, B., Sasaki, C., Enari, K., Matsuyama, N., & Fujita, M. (2007). Suitability assessment of shallow groundwater for agriculture in sand dune area of Northwest Honshu Island, Japan. *Applied Ecology and Environmental Research*, 5(1), 177-188.
- Mogheir, Y. K. Y. (2004). *Assessment and redesign of groundwater quality monitoring networks using entropy theory: the Gaza Strip case study*. University of Coimbra, Coimbra.
- Mogheir, Y. K. Y., De Lima, J., & Singh, V. (2005). Assessment of informativeness of groundwater monitoring in developing regions (Gaza Strip Case Study). *Water Resources Management*, 19(6), 737-757.

- Mogheir, Y. K. Y., & Singh, V. (2003). Specification of information needs for groundwater management planning in developing country. *Groundwater Hydrology, Balema Publisher, Tokyo*, 2, 3-20.
- Mogheir, Y. K. Y., Singh, V., & de Lima, J. (2006). Spatial assessment and redesign of a groundwater quality monitoring network using entropy theory, Gaza Strip, Palestine. *Hydrogeology Journal*, 14(5), 700-712.
- Mohapatra, S. S., Ravikumar, S. V., Andhare, S., Chakraborty, S., & Pal, S. K. (2012). Experimental study and optimization of air atomized spray with surfactant added water to produce high cooling rate. *Journal of Enhanced Heat Transfer*, 19(5).
- Mohebbi, M. R., Saeedi, R., Montazeri, A., Azam Vaghefi, K., Labbafi, S., Oktaie, S., et al. (2013). Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). *Ecological Indicators*, 30, 28-34.
- Mondal, N., Singh, V., Singh, V., & Saxena, V. (2010). Determining the interaction between groundwater and saline water through groundwater major ions chemistry. *Journal of Hydrology*, 388(1), 100-111.
- Moran, P. A. (1950). Notes on continuous stochastic phenomena. *Biometrika*, 17-23.
- Morgan, T., & Polcari, D. (1991). Get set! Go for mapping, modeling, and facility management, *Proceeding of Computers in the Water Industry Conference* (
- Munch, Z. (2004). *Assessment of GIS-interpolation techniques for groundwater evaluation: A case study of the Sandveld, Western Cape, South Africa*. Stellenbosch: University of Stellenbosch.
- Mustapha, A., & Aris, A. Z. (2012). Spatial aspects of surface water quality in the Jakara Basin, Nigeria using chemometric analysis. *Journal of Environmental Science and Health, Part A*, 47(10), 1455-1465. doi:10.1080/10934529.2012.673305
- Mustapha, A., & Aris, A. Z. (2012). Multivariate statistical analysis and environmental modeling of heavy metals pollution by industries. *Pol J Environ Stud*, 21, 1359-1367.
- Mustapha, A., Aris, A. Z., Juahir, H., Ramli, M. F., & Kura, N. U. (2013). River water quality assessment using environmetric techniques: case study of Jakara River Basin. *Environ Sci Pollut Res Int*. doi:10.1007/s11356-013-1542-z
- Nabi, A., Gallardo, A. H., & Ahmed, S. (2011). Optimization of a groundwater monitoring network for a sustainable development of the Maheshwaram Catchment, India. *Sustainability*, 3(2), 396-409.
- Nalder, I. A., & Wein, R. W. (1998). Spatial interpolation of climatic normals: test of a new method in the Canadian boreal forest. *Agricultural and Forest Meteorology*, 92(4), 211-225.
- Nas, B., & Berktaş, A. (2010). Groundwater quality mapping in urban groundwater using GIS. *Environmental Monitoring and Assessment*, 160(1-4), 215-227.
- Neshat, A., Pradhan, B., Pirasteh, S., & Shafri, H. (2013). Estimating groundwater vulnerability to pollution using a modified DRASTIC model in the Kerman agricultural area, Iran. *Environmental Earth Sciences*, 1-13. doi:10.1007/s12665-013-2690-7
- Nishanthiny, S., Thushyanthy, M., Barathithasan, T., & Saravanan, S. (2010). Irrigation water quality based on hydro chemical analysis, Jaffna, Sri Lanka. *American-Eurasian J. Agric. & Environ. Sci*, 7, 100-102.

- Nosrati, K., & Eeckhaut, M. (2012). Assessment of groundwater quality using multivariate statistical techniques in Hashtgerd Plain, Iran. *Environmental Earth Sciences*, 65(1), 331-344. doi:10.1007/s12665-011-1092-y
- Nunes, L. M., Cunha, M. C., & Ribeiro, L. (2002). Monitoring network optimisation using both spatial and temporal information, *3rd International Conference on Decision Making in Urban & Civil Engineering, London, November*
- Odom, K. R. (2003). *Assessment and redesign of the synoptic water quality monitoring network in the Great Smoky Mountains National Park*. The University of Tennessee, Knoxville.
- Oh, H.J., Kim, Y. S., Choi, J.-K., Park, E., & Lee, S. (2011). GIS mapping of regional probabilistic groundwater potential in the area of Pohang City, Korea. *Journal of Hydrology*, 399(3), 158-172.
- Oladeji, O. (2012). *Quantitative risk assessment of groundwater quality utilizing GIS technology and coupled groundwater models*. Aston University.
- Olmer, M., & Rezac, B. (1974). Methodical principles of maps for protection of groundwater in Bohemia and Moravia, scale 1: 200,000, *Intl. Assoc. Hydrogeologists, Memoris, Tomex, Congress de Montpellier* (pp. 105-107).
- Olmez, I., Beal, J. W., & Villaume, J. (1994). A new approach to understanding multiple-source groundwater contamination: factor analysis and chemical mass balances. *Water Research*, 28(5), 1095-1101.
- Omo-Irabor, O. O., Olobaniyi, S. B., Oduyemi, K., & Akunna, J. (2008). Surface and groundwater water quality assessment using multivariate analytical methods: A case study of the Western Niger Delta, Nigeria. *Physics and Chemistry of the Earth, Parts A/B/C*, 33(8), 666-673.
- Osborn, N. I., Eckenstein, E., & Koon, K. Q. (1998). *Vulnerability assessment of twelve major aquifers in Oklahoma*: Oklahoma Water Resources Board.
- Ott, W. R. (1978). *Water Quality Indices: A Survey of Indices Used in the United States* Wshington, DC: US Environmental Protection Agency.
- Ouyang, Y. (2005). Evaluation of river water quality monitoring stations by principal component analysis. *Water research*, 39(12), 2621-2635.
- Owlia, R., Abrishamchi, A., & Tajrishy, M. (2011). Spatial-temporal assessment and redesign of groundwater quality monitoring network: a case study. *Environmental Monitoring and Assessment*, 172(1-4), 263-273. doi:10.1007/s10661-010-1332-8
- Ozkul, S., Harmancioglu, N. B., & Singh, V. P. (2000). Entropy-based assessment of water quality monitoring networks. *Journal of hydrologic engineering*, 5(1), 90-100.
- Paliwal, K. V. (1967). Effect of gypsum application on the quality of irrigation waters. *The Madras Agricultural Journal*, 59, 646-647.
- Papaioannou, A., Mavridou, A., Hadjichristodoulou, C., Papastergiou, P., Pappa, O., Dovriki, E., et al. (2010). Application of multivariate statistical methods for groundwater physicochemical and biological quality assessment in the context of public health. *Environmental Monitoring and Assessment*, 170(1-4), 87-97.
- Parkhurst, D. L., & Appelo, C. (1999). User's guide to PHREEQC (Version 2): A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations.

- Pazand, K., Hezarkhani, A., Ghanbari, Y., & Aghavali, N. (2012). Groundwater geochemistry in the Meshkinshahr basin of Ardabil province in Iran. *Environmental Earth Sciences*, 65(3), 871-879.
- Piccini, C., A., M., R., F., & R., F. (2012). Application of Indicator kriging to Evaluate the Probability of Exceeding Nitrate Contamination Thresholds. *Int. J. Environ. Res.*, 6(4), 853-862.
- Piscopo, G. (2001). Groundwater vulnerability map, explanatory notes, Castlereagh Catchment. *Parramatta NSW: Australia NSW Department of Land and Water Conservation*.
- Polat, R. (2009). *Spatial and temporal assessment of groundwater quality for the Nif mountain karstic aquifer*. Dokuz Eylul University, Izmir, Turkey.
- Post, V. (2005). Fresh and saline groundwater interaction in coastal aquifers: Is our technology ready for the problems ahead? *Hydrogeology Journal*, 13(1), 120-123.
- Pramanik, A., Singh, V., Vig, R., Srivastava, A., & Tiwary, D. (2004). Estimation of effective porosity using geostatistics and multiattribute transforms: A case study. *Geophysics*, 69(2), 352-372.
- Preziosi, E., Petrangeli, A., & Giuliano, G. (2013). Tailoring groundwater quality monitoring to vulnerability: a GIS procedure for network design. *Environmental monitoring and assessment*, 185(5), 3759-3781.
- Puckett, L. J. (1995). Identifying the major sources of nutrient water pollution. *Environmental Science & Technology*, 29(9), 408A-414A.
- Pulido-Leboeuf, P., Pulido-Boscha, A., Calvacheb, M. L., Vallejosa, Á., & Andreuc, J. M. (2003). Strontium, $\text{SO}_4^{2-}/\text{Cl}^-$ and $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratios as tracers for the evolution of seawater into coastal aquifers: the example of Castell de Ferro aquifer (SE Spain).
- Purdy, G. (2010). ISO 31000: 2009-setting a new standard for risk management. *Risk analysis*, 30(6), 881-886.
- Rahman, A. (2008). A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India. *Applied Geography*, 28, 32-53.
- Rajaram, T., & Das, A. (2008). Water pollution by industrial effluents in India: discharge scenarios and case for participatory ecosystem specific local regulation. *Futures*, 40(1), 56-69.
- Ramesh, K., & Elango, L. (2012). Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. *Environmental Monitoring and Assessment*, 184(6), 3887-3899.
- Ravi Shankar, M., & Mohan, G. (2006). Assessment of the groundwater potential and quality in Bhatsa and Kalu river basins of Thane district, western Deccan volcanic province of India. *Environmental Geology* 49, 990-998.
- Ravikumar, P., Somashekar, R., & Angami, M. (2011). Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya River basin, Belgaum District, Karnataka State, India. *Environmental Monitoring and Assessment*, 173(1), 459-487. doi:10.1007/s10661-010-1399-2
- Reddy, A., & Kumar, K. N. (2010). Identification of the hydrogeochemical processes in groundwater using major ion chemistry: a case study of Penna–Chitravathi river basins in Southern India. *Environmental Monitoring and Assessment*, 170(1-4), 365-382.

- Reghunath, R., Murthy, T. R. S., & Raghavan, B. R. (2002). The utility of multivariate statistical techniques in hydrogeochemical studies: an example from Karnataka, India. *Water Research*, 36(10), 2437-2442.
- Rehman, S., & Ghorri, S. G. (2000). Spatial estimation of global solar radiation using geostatistics. *Renewable Energy*, 21(3), 583-605.
- Rentier, C., Delloye, F., Brouyère, S., & Dassargues, A. (2006). A framework for an optimised groundwater monitoring network and aggregated indicators. *Environmental Geology*, 50(2), 194-201.
- Reyment, R. A., & Joreskog, K. G. (1993). *Applied factor analysis in the natural sciences* (Vol. 2nd edition): Cambridge University Press (Cambridge England and New York, NY, USA)
- Rezaei, F., Safavi, H., & Ahmadi, A. (2013). Groundwater Vulnerability Assessment Using Fuzzy Logic: A Case Study in the Zayandehrood Aquifers, Iran. *Environmental Management*, 51(1), 267-277. doi:10.1007/s00267-012-9960-0
- Richards, L. A. (1954). *Diagnosis and improvement of saline and alkaline soils*. US Salinity Laboratory: US Department of Agriculture hand book.
- Romanelli, A., Lima, M. L., Londono, O. M. Q., Martínez, D. E., & Massone, H. E. (2012). A Gis-Based Assessment of Groundwater Suitability for Irrigation Purposes in Flat Areas of the Wet Pampa Plain, Argentina. *Environmental Management*, 50(3), 490-503.
- Rouhani, S. (1985). Variance reduction analysis. *Water Resources Research*, 21(6), 837-846.
- Rouhani, S., & Hall, T. J. (1988). Geostatistical schemes for groundwater sampling. *Journal of Hydrology*, 103(1), 85-102.
- Ruhakana, A. (2013). *Spatio-Temporal Variability of Water Quality and its Response on Growth of Irrigated Rice in Rusurirwamujiyanga Sub-catchment, Rwanda*.
- Sadat-Noori, S. M., Ebrahimi, K., & Liaghat, A. M. (2013). Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer, Iran. *Environmental Earth Sciences*, 1-17. doi:10.1007/s12665-013-2770-8
- Saidi, S., Bouri, S., & Ben Dhia, H. (2010). Groundwater vulnerability and risk mapping of the Hajeb-jelma aquifer (central Tunisia) using a GIS-based DRASTIC model. *Environ Earth Sci*, 59, 1579–1588.
- Saidi, S., Bouri, S., Ben Dhia, H., & Anselme, B. (2011). Assessment of groundwater risk using intrinsic vulnerability and hazard mapping: application to Souassi aquifer, Tunisian Sahel. *Agricultural Water Management*, 98(10), 1671-1682.
- Sajil Kumar, P. J., Jegathambal, P., & James, E. J. (2011). Multivariate and geostatistical analysis of groundwater quality in Palar river basin. *International Journal of Geology*, 5(4), 108-119.
- Salama, R. B., Otto, C. J., & Fitzpatrick, R. W. (1999). Contributions of groundwater conditions to soil and water salinization. *Hydrogeology Journal*, 7(1), 46-64.
- Schaefer, K., & Einax, J. (2010). Analytical and chemometric characterization of the Cruces River in South Chile. *Environmental Science and Pollution Research*, 17(1), 115-123. doi:10.1007/s11356-009-0116-6
- Schmoll, O. (2006). *Protecting Ground Water for Health: Managing the Quality of Drinking-water Sources*: World Health Organization.

- Sevilla, J. B., Lee, C. H., & Lee, B. Y. (2010). Assessment of spatial variations in surface water quality of Kyeongan Stream, South Korea using multi-variate statistical techniques *Sustainability in Food and Water* (pp. 39-48): Springer.
- Shaban, M., Urban, B., El Saadi, A., & Faisal, M. (2010). Detection and mapping of water pollution variation in the Nile Delta using multivariate clustering and GIS techniques. *Journal of environmental management*, 91(8), 1785-1793.
- Shahbazi, A., & Esmaeili-Sari, A. (2009). Groundwater quality assessment in north of Iran, a case study of the Mazandaron province. *World Appl Sci J*, 5, 92-97.
- Shannon, C. E. (1948). A note on the concept of entropy. *Bell System Tech. J*, 27, 379-423.
- Sharma, S. (1995). *Applied multivariate techniques*: John Wiley & Sons, Inc.
- Shrestha, S., & Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environmental Modelling & Software*, 22(4), 464-475. doi:http://dx.doi.org/10.1016/j.envsoft.2006.02.001
- Shyu, G. S., Cheng, B. Y., Chiang, C. T., Yao, P. H., & Chang, T.-K. (2011). Applying factor analysis combined with kriging and information entropy theory for mapping and evaluating the stability of groundwater quality variation in Taiwan. *International Journal of Environmental Research and Public Health*, 8(4), 1084-1109.
- Simsek, C., & Gunduz, O. (2007). IWQ index: A GIS-integrated technique to assess irrigation water quality. *Environmental Monitoring and Assessment*, 128(1-3), 277-300.
- Singh, C. K., Shashtri, S., & Mukherjee, S. (2011). Integrating multivariate statistical analysis with GIS for geochemical assessment of groundwater quality in Shiwaliks of Punjab, India. *Environmental Earth Sciences*, 62(7), 1387-1405.
- Singh, K. P., Malik, A., Mohan, D., & Sinha, S. (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study. *Water Research*, 38(18), 3980-3992.
- Singh, K. P., Malik, A., Singh, V. K., Mohan, D., & Sinha, S. (2005). Chemometric analysis of groundwater quality data of alluvial aquifer of Gangetic plain, North India. *Analytica Chimica Acta*, 550(1-2), 82-91. doi:http://dx.doi.org/10.1016/j.aca.2005.06.056
- Siska, P. P., & Hung, I.-K. (2001). Assessment of kriging accuracy in the GIS environment, *21st Annual ESRI International Conference, San Diego, CA* (
- Smalley, J. B., Minsker, B. S., & Goldberg, D. E. (2000). Risk-based in situ bioremediation design using a noisy genetic algorithm. *Water Resources Research*, 36(10), 3043-3052.
- Smith, D., & McBride, G. (1990). new zealand's national water quality monitoring network design and first year's operation1. *JAWRA Journal of the American Water Resources Association*, 26(5), 767-775.
- Somay, A. M., & Gemici, Ü. (2009). Assessment of the salinization process at the coastal area with hydrogeochemical tools and geographical information systems (GIS): Selçuk plain, Izmir, Turkey. *Water, Air, and Soil Pollution*, 201(1-4), 55-74.
- Somay, A. M., Gemici, Ü., & Filiz, S. (2008). Hydrogeochemical investigation of Küçük Menderes River coastal wetland, Selçuk–Izmir, Turkey. *Environmental Geology*, 55(1), 149-164.
- Sparks, T. (2000). *Statistics in Ecotoxicology*. Chichester: Wiley.
- Srinivasa, R., N., & Rajendra, P., P. (1997). Phosphate pollution in the groundwater of lower Vamsadhara river basin, India. *Environmental Geology*, 31.

- Srivastava, S., & Ramanathan, A. (2008). Geochemical assessment of groundwater quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. *Environmental Geology*, 53(7), 1509-1528.
- Stansfield, B. (2001). *Aquatic Ecology and Water Quality Sampling Procedures Manual*: Hawke's Bay Regional Council Report EMI 0110.
- Stempvoort, D. V., Ewert, L., & Wassenaar, L. (1993). Aquifer vulnerability index: a GIS-compatible method for groundwater vulnerability mapping. *Canadian Water Resources Journal*, 18(1), 25-37.
- Subbarao, C., Subbarao, N. V., & Chandu, S. N. (1996). Characterization of groundwater contamination using factor analysis. *Environmental Geology*, 28(4), 175-180. doi:10.1007/s002540050091
- Subramani, T., Rajmohan, N., & Elango, L. (2010). Groundwater geochemistry and identification of hydrogeochemical processes in a hard rock region, Southern India. *Environmental Monitoring and Assessment*, 162(1-4), 123-137.
- Subyani, A. M., & Al Ahmadi, M. E. (2010). Multivariate statistical analysis of groundwater quality in Wadi Ranyah, Saudi Arabia. *JAKU Earth Sci*, 21(2), 29-46.
- Tatalovich, Z., Wilson, J. P., & Cockburn, M. (2006). A comparison of Thiessen polygon, kriging, and spline models of potential UV exposure. *Cartography and Geographic Information Science*, 33(3), 217-231.
- Thakur, J. K., Srivastava, P., Singh, S., & Vekerdy, Z. (2012). Ecological monitoring of wetlands in semi-arid region of Konya closed Basin, Turkey. *Regional Environmental Change*, 12(1), 133-144.
- Theodossiou, N., & Latinopoulos, P. (2006). Evaluation and optimisation of groundwater observation networks using the Kriging methodology. *Environmental Modelling & Software*, 21(7), 991-1000.
- Todd, D. K. (1959). *Groundwater hydrology*. New York: Wiley.
- Townsend, M. A., & Marks, E. T. (1990). *Occurrence of nitrate in soil and ground water in south-central Kansas; in, Proceedings Ground Water Management*. Paper presented at the Cluster of Conferences.
- Uyan, M., & Cay, T. (2010). *Geostatistical Methods for Mapping Groundwater Nitrate Concentration*. Paper presented at the Paper presented at the 3rd INTERNATIONAL CONFERENCE ON CARTOGRAPHY AND GIS.
- Vasanthavigar, M., Srinivasamoorthy, K., Ganthi, R. R., Vijayaraghavan, K., & Sarma, V. (2012). Characterisation and quality assessment of groundwater with a special emphasis on irrigation utility: Thirumanimuttar sub-basin, Tamil Nadu, India. *Arabian Journal of Geosciences*, 5(2), 245-258.
- Vengosh, A., & Ben-Zvi, A. (1994). Formation of a salt plume in the Coastal Plain aquifer of Israel: the Be'er Toviyya region. *Journal of Hydrology*, 160(1), 21-52.
- Ver Hoef, J. M., Krivoruchko, K., & Lucas, N. (2001). *Using ArcGIS geostatistical analyst*: Redlands: Esri.
- Vias, J., Andreo B, Ravbar N, & H, H. t. (2010). Mapping the vulnerability of groundwater to the contamination of four carbonate aquifers in Europe. *Journal of Environmental Management*, 91(7), 1500-1510.

- Vicente Serrano, S. M., Sánchez, S., & Cuadrat, J. M. (2003). Comparative analysis of interpolation methods in the middle Ebro Valley (Spain): application to annual precipitation and temperature. *Climate Research*, 24(2), 161-180.
- Villeneuve, J. P., Banton, O., & Lafrance, P. (1990). A probabilistic approach for the groundwater vulnerability to contamination by pesticides: the VULPEST model. *Ecological Modelling*, 51(1), 47-58.
- Vrba, J., & Zaporozec, A. (1994). *Guidebook on mapping groundwater vulnerability*: Hannover : H. Heise.
- Wakida, F. T., & Lerner, D. N. (2005). Non-agricultural sources of groundwater nitrate: a review and case study. *Water Research*, 39(1), 3-16.
- Walton, W. C. (1970). *Groundwater resource evaluation* (Vol. 664): McGraw-Hill New York.
- Wanda, E., Monjerezi, M., Mwatseteza, J. F., & Kazembe, L. N. (2011). Hydro-geochemical appraisal of groundwater quality from weathered basement aquifers in Northern Malawi. *Physics and Chemistry of the Earth, Parts A/B/C*, 36(14), 1197-1207.
- Wang, H., Liu, G., & Gong, P. (2005). Use of cokriging to improve estimates of soil salt solute spatial distribution in the Yellow River delta. *Acta Geographica Sinica*, 60(3), 511-518.
- Wang, Y. B., Liu, C.-W., Liao, P.-Y., & Lee, J. J. (2014). Spatial pattern assessment of river water quality: implications of reducing the number of monitoring stations and chemical parameters. *Environmental monitoring and assessment*, 186(3), 1781-1792.
- Ward, R. C., Loftis, J. C., & McBride, G. B. (1990). *Design of water quality monitoring systems*: John Wiley & Sons.
- Wayland, K. G., Long, D. T., Hyndman, D. W., Pijanowski, B. C., Woodhams, S. M., & Haack, S. K. (2003). Identifying relationships between baseflow geochemistry and land use with synoptic sampling and R-mode factor analysis. *Journal of Environmental Quality*, 32(1), 180-190.
- Webster, R., & Oliver, M. A. (2007). *Geostatistics for Environmental Scientists*: John Wiley & Sons.
- Whitlock, J. E., Jones, D. T., & Harwood, V. J. (2002). Identification of the sources of fecal coliforms in an urban watershed using antibiotic resistance analysis. *Water Research*, 36(17), 4273-4282. doi:http://dx.doi.org/10.1016/S0043-1354(02)00139-2
- WHO (2011a). *Guidelines for drinking-water quality, fourth edition*. Geneva: World Health Organization.
- WHO (2011b). *Nitrate and nitrite in drinking-water*. Geneva.
- Wiktor, T., & Kucharek, M. (2010). *Optimization of groundwater quality monitoring network using information theory and simulated annealing algorithm*. Paper presented at the IAH
- Wilcox, L. V. (1955). *Classification and use of irrigation waters* USDA Circular No. 969.
- Wingle, W. L., Poeter, E. P., & McKenna, S. A. (1999). UNCERT: geostatistics, uncertainty analysis and visualization software applied to groundwater flow and contaminant transport modeling. *Computers & Geosciences*, 25(4), 365-376.
- Wissuwa, M., Ismail, M. A., & Yanagihara, S. (2006). Effects of Zinc Deficiency on Rice Growth and Genetic Factors Contributing to Tolerance. *American Society of Plant Biologists*, 142(2), 731-741.

- Witczak, S., Bronders, J., Kania, J., Kmiecik, E., Rózański, K., & Szczepańska, J. (2006). *Deliverable 16: Summary guidance and recommendations on sampling, measuring and quality assurance*. POLAND: AGH–University of Science and Technology.
- Wu, B., Zhao, D., Zhang, Y., Zhang, X., & Cheng, S. (2009). Multivariate statistical study of organic pollutants in Nanjing reach of Yangtze River. *Journal of Hazardous Materials*, 169(1), 1093-1098.
- Wu, J., Zheng, C., & Chien, C. C. (2005). Cost-effective sampling network design for contaminant plume monitoring under general hydrogeological conditions. *Journal of Contaminant Hydrology*, 77(1), 41-65.
- Yammani, S. R., Reddy, T., & Reddy, M. (2008). Identification of influencing factors for groundwater quality variation using multivariate analysis. *Environmental Geology*, 55(1), 9-16.
- Yeh, M., Lin, Y. P., & Chang, L.-C. (2006). Designing an optimal multivariate geostatistical groundwater quality monitoring network using factorial kriging and genetic algorithms. *Environmental Geology*, 50(1), 101-121.
- Yidana, S. M. (2010). Groundwater classification using multivariate statistical methods: Southern Ghana. *Journal of African Earth Sciences*, 57(5), 455-469.
- Yidana, S. M., Banoeng-Yakubo, B., & Akabzaa, T. M. (2010). Analysis of groundwater quality using multivariate and spatial analyses in the Keta basin, Ghana. *Journal of African Earth Sciences*, 58(2), 220-234. doi:<http://dx.doi.org/10.1016/j.jafrearsci.2010.03.003>
- Yidana, S. M., Ophori, D., & Banoeng-Yakubo, B. (2008). Hydrogeological and hydrochemical characterization of the Voltaian Basin: the Afram Plains area, Ghana. *Environmental Geology*, 53(6), 1213-1223.
- Zahn, M. T., & Seiler, K.-P. (1992). Field studies on the migration of arsenic and cadmium in a carbonate gravel aquifer near Munich (Germany). *Journal of Hydrology*, 133(3), 201-214.
- Zaidi, F. K., Ahmed, S., Dewandel, B., & Maréchal, J.-C. (2007). Optimizing a piezometric network in the estimation of the groundwater budget: a case study from a crystalline-rock watershed in southern India. *Hydrogeology Journal*, 15(6), 1131-1145.
- Zhang, X., Wang, Q., Liu, Y., Wu, J., & Yu, M. (2011). Application of multivariate statistical techniques in the assessment of water quality in the Southwest New Territories and Kowloon, Hong Kong. *Environmental Monitoring and Assessment*, 173(1-4), 17-27. doi:10.1007/s10661-010-1366-y
- Zhou, M., Fu, W., Gu, H., & Lei, L. (2007). Nitrate removal from groundwater by a novel three-dimensional electrode biofilm reactor. *Electrochimica Acta*, 52(19), 6052-6059.
- Zirschky, J. (1985). Geostatistics for environmental monitoring and survey design. *Environment International*, 11(6), 515-524.

LIST OF PUBLICATIONS

- **Sheikhy Narany, T.**, Ramli, M. F., Aris, A. Z., Sulaiman, W. N. A., & Fakharian, K. (2014). Assessment of the Potential Contamination Risk of Nitrate in Groundwater Using Indicator Kriging (in Amol–Babol Plain, Iran). In *From Sources to Solution* (pp. 273-277). Springer Singapore.
- **Sheikhy Narany, T.**, Ramli, M. F., Aris, A. Z., Sulaiman, W. N. A., & Fakharian, K. (2013). Spatial Assessment of Groundwater Quality Monitoring Wells Using Indicator Kriging and Risk Mapping, Amol-Babol Plain, Iran. *Water*, 6(1), 68-85. Impact factor: 1.291
- **Sheikhy Narany, T.**, Ramli, M. F., Aris, A. Z., Sulaiman, W. N. A., Juahir, H., & Fakharian, K. (2014). Identification of the Hydrogeochemical Processes in Groundwater Using Classic Integrated Geochemical Methods and Geostatistical Techniques, in Amol-Babol Plain, Iran. *The Scientific World Journal*, 2014. Impact factor:1.219
- **Sheikhy Narany, T.**, Ramli, M. F., Aris, A. Z., Sulaiman, W. N. A., & Fakharian, K. (2014). Groundwater irrigation quality mapping using geostatistical techniques in Amol–Babol Plain, Iran. *Arabian Journal of Geosciences*, 1-16. Impact factor:1.152
- **Sheikhy Narany, T.**, Ramli, M. F., Aris, A. Z., Sulaiman, W. N. A., & Fakharian, K. (2014). Spatiotemporal variation of groundwater quality using integrated multivariate statistical and geostatistical approaches in Amol–Babol Plain, Iran. *Environmental Monitoring and Assessment*, 1-19. Impact factor:1.679
- **Sheikhy Narany, T.**, Ramli, M. F., Aris, A. Z., Sulaiman, W. N. A., & Fakharian, K. A New GIS-Index integration approach to suitability assessment of groundwater for irrigation purposes. *Environmental Science and Pollution Research* (under review). Impact factor: 2.757
- **Sheikhy Narany, T.**, Ramli, M. F., Fakharian, K. Aris, A. Z., & Sulaiman, W. N. A., Information-cost-effective groundwater monitoring network design using geostatistical estimation approach. *Stochastic Environmental Research and Risk Assessment*. (under review). Impact factor: 2.673
- **Sheikhy Narany, T.**, Ramli M.F., Aris A.Z., Esmail, W.N., Fakharian, K (2012). “Assessment of groundwater quality for irrigation purpose in Amol Plain, Iran” 6th international symposium on advance in science and technology. 24 March 2012. Kuala Lumpur, Malaysia.
- **Sheikhy Narany, T.**, Ramli M.F., Aris A.Z., Esmail, W.N., Fakharian, K (2012). “Multivariate and Geostatistical Approaches in Assessment of Groundwater Quality for Drinking Purpose in Shallow Wells (Amol-Babol Plain, Iran)”. *The International Conference on Water Resources (ICWR 2012)*, 6 November 2012, Langkawi, Malaysia.
- **Sheikhy Narany, T.**, Ramli M.F., Aris A.Z., Esmail, W.N., Fakharian, K (2012). “Evaluation of arsenic contamination potential in groundwater using indicator kriging in Amol-Babol Plain, Iran”. *40th International Association of Hydrogeologists Congress (IAH 2013)*.15– 20 September 2013 Perth, Australia.

- **Sheikhy Narany, T.,** Ramli M.F., Aris A.Z., Esmail, W.N., Fakharian, K (2012).
“Assessment of the Potential Contamination Risk of Nitrate in Groundwater Using Indicator Kriging (in Amol–Babol Plain, Iran)” *International Conference of Environmental Forensics. 12-13November. Putrajaya. Malaysia.*





UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : _____

TITLE OF THESIS / PROJECT REPORT :

NAME OF STUDENT : _____

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (✓)

CONFIDENTIAL

(Contain confidential information under Official Secret Act 1972).

RESTRICTED

(Contains restricted information as specified by the organization/institution where research was done).

OPEN ACCESS

I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

PATENT

Embargo from _____ until _____
(date) (date)

Approved by:

(Signature of Student)
New IC No/ Passport No.:

(Signature of Chairman of Supervisory Committee)
Name:

Date :

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentiality or restricted.]