

**Using spatial analyses tools to study the impact of changing demographics, agricultural extents and urban growth on water quality and availability in the Amman-Zarqa basin,
Jordan**

Khaled Abdallah Alqadi

A thesis submitted for the Degree

Of

DOCTOR OF PHILOSOPHY

At The

UNIVERSITY OF NEW ENGLAND

January 2014

Certification

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Khaled Abdallah Alqadi



Abstract

Jordan is one of the countries in the world facing a water crisis, as current water usage in the country is unsustainable in terms of both supply and quality. The water demands of Jordan have led to a decimation of underground water with a rise in salinity in the aquifers. The high population growth and pulse immigration stemming from worsening regional conflicts has led to serious water shortages in urban centres and villages. Jordan faces almost inevitable social conflict and the irrevocable loss of agricultural land due to the increase in refugee numbers from neighbouring countries and general population growth. With the consequences of climatic fluctuations, such as rainfall, there has been a significant shift in the agricultural sector towards intensification and a high reliance on irrigation.

The underground water sources are an important source of drinking water, agricultural production and industrial use. Underground water in Jordan is inherently susceptible to contamination from anthropogenic activities, which to remedy is difficult and costly. Identifying and preventing the sources of underground water pollution is critical for underground water management.

The aims of this project were primarily to address the water problem in Jordan through identifying the extent of the resource reduction, and establishing the reasons for its decline in quality. In this context we also set out to identify the changes in the demographics, urban areas and agricultural areas and the impact of these on water quality, in terms of increased demand for fresh water, and how these changes will affect water quantity and quality. Secondly we investigated monthly variation in water quality in the Amman-Zarqa basin to see the temporal changes of the underground water quality with respect to selected chemical variables such as

conductivity, nitrate, pH and ammonium, using different techniques such as Geographic Information Systems (GIS) to identify the fluctuations in the values of the selected chemical elements in the underground resources, as well as to localize the area of high risk of contamination. Thirdly we mapped long term changes in the underground water quality to see the changes in the selected elements between 2004 and 2010, and linked these changes with land use and land cover for the same period. This overlay helps explain how the changes in the land use and land cover have a significant impact on water quality in terms of urban, industrial and agricultural changes. Finally, having identified the problems of declining water quality and availability in Jordan, we suggest means of improving water management in the country, in the long term. This research will assist the country in rethinking long term planning to solve its water issues.

The results show that the spatial distribution of the elements in the underground water changed from time to time. The results indicate fluctuations in the values of the selected chemical elements in the underground water and a major localization of high values of hotspots in all parameters, during the study period. The areas of high values of hotspots were dominated by urban infrastructure, industries, and wastewater treatments and irrigated lands, while land use and land cover changes also had a significant impact on water quality. These findings have positive implications for understanding water quality across the region and for the management of water in the aquifers. The study concludes that the only means of improving the management of water in Jordan may be desalination from the Red Sea as a long-term viable option to meet the growing domestic water needs in Jordan.

Acknowledgements

I am grateful to my supervisor Associate Professor Lalit Kumar for his encouragement, support and generous contribution of time and knowledge. I would like to thank the Department of Statistics of Jordan and Water Authority of Jordan for their support in collecting the monthly and yearly data of my study. Thank you to Cate MacGregor for the technical support that you provided during my work on this thesis, and answering my GIS and remote sensing questions. Many thanks to Same and Ammer in Sydney for providing me a job during my study period, and to all postgrads and friends who provided help and encouragement during my time at UNE. Many thanks to all of my family in Jordan especially my parents (my father, Abdallah, my mother, Shaha) and to all of my brothers and sisters in Jordan for their unstinting support and prayers.

Publications from this thesis during Candidature

Published / in press

Alqadi, K.A., and Kumar, L. (2011). Review of water issues in the Kingdom of Jordan: A brief review with reasons for declining quality. *Journal of Food, Agriculture and Environment*, 9(3/4): 1019-1023.

Alqadi, K.A., Kumar, L., and Al-Zu'bi, J. (2013). Changing demographics, expanding urban areas and modified agricultural extents and their impacts on water availability and water quality in Jordan. *African Journal of Agricultural Research*, 8(25): DOI: 10.5897/AJAR12875.

Alqadi, K.A., and Kumar, L. (2013). Are there Monthly Variations in Water Quality in the Amman, Zarqa and Balqa Regions, Jordan? *Computational Water, Energy, and Environmental Engineering*, 2: 26-3: DOI:10.4236/cweee.2013.22B005.

Alqadi, K. A., Kumar, L., and Khormi, H.M. (2013). Mapping hotspots of underground water quality based on the variation of chemical concentration in Amman, Zarqa and Balqa regions, Jordan, *Environmental Earth Sciences*, DOI: 10.1007/s12665-013-2632-4.

Alqadi, K. A., and Kumar, L. (2014). Water policy in Jordan. *International Journal of Water Resources Development*, 30(2), 322-334.

Submitted

Alqadi, K. A., and Kumar, L. (**submitted**). Temporal changes in the underground water quality of the Amman-Zarqa basin, Jordan. *Journal of Hydrology*.

Alqadi, K. A., and Kumar, L. (**submitted**). The impact of land use and land cover changes on the underground water quality of the Amman, Zarqa and Balqa regions in Jordan. *Journal of Water Quality, Exposure and Health*.

Table of Contents

CHAPTER	TITLE	PAGE NO
	Abstract	ii
	Acknowledgment	iv
	Publications During Candidature	V
1.	Introduction and background	1
	1.1. Introduction	2
	1.2. Aims and Objectives of the Study	9
	1.3. Significance of this Study	10
	1.4. Content and Structure of the Thesis	11
2.	Water Issues in the Kingdom of Jordan: A Brief Review with Reasons for Declining Quality	13
	Abstract	14
	2.1. Introduction	15
	2.2. Water in the Middle East	16
	2.3. Water Use in Jordan	20
	2.4. Pollution and Water Supply	22
	2.5. Salinity in Water Source in Jordan	25
	2.5.1. Surface Water	25
	2.5.2. Groundwater	25
	2.5.3. Dead Sea Watersheds	27
	2.6. Conclusion	27
3.	Changing Demographics, Expanding Urban Areas and Modified Agricultural Extent and their Impact on Water Availability and Water Quality in Jordan	31
	Abstract	32
	3.1. Introduction	33
	3.2. Water Resources	34
	3.3. Population Trends	37
	3.4. Agricultural Land Use	44
	3.5. Climate	48
	3.6. Water Contamination	49
	3.7. Conclusion	50
4.	Are There Monthly Variations in Water Quality in the Amman, Zarqa and Balqa Regions, Jordan?	53
	Abstract	54
	4.1. Introduction	55

4.2. Hydrology of the Amman-Zarqa Basin	56
4.3. Description of the Study Area	59
4.4. Methods	60
4.5. Results	62
4.5.1. pH	64
4.5.2. Nitrate	67
4.5.3. Ammonium	70
4.5.4. Conductivity	72
4.6. Discussion	74
4.7. Conclusion	75
5. Using GIS Hotspot Techniques to Map the Temporal Variation in the Underground Water Quality	78
Abstract	79
5.1. Introduction	80
5.2. Study Area	83
5.3. Methods	84
5.3.1. Data Collection and Analyses	84
5.3.2. GIS Analyses	85
5.4. Results	87
5.4.1. Result Summary	87
5.4.2. Monthly Spatial and Temporal Changes of Conductivity Hotspots	91
5.4.3. Monthly Spatial and Temporal Changes of Nitrate Hotspots	93
5.4.4. Monthly Spatial and Temporal Changes of pH Hotspots	94
5.4.5. Monthly Spatial and Temporal Changes of Ammonia Hotspots	96
5.5. Discussion	98
5.6. Conclusion	102
6. Mapping Hotspots of Underground Water Quality Based on the Variation of Chemical Concentration between 2004 and 2010	106
Abstract	107
6.1. Introduction	108
6.2. Data and Methods	109
6.2.1. Study Area, Data Source and Organising	109
6.2.2. Data Analysis	111
6.3. Results	113
6.3.1. Spatial and Temporal Changes of pH Hotspots	113
6.3.2. Spatial and Temporal Changes of Nitrate Hotspots	114
6.3.3. Spatial and Temporal Changes of Conductivity Hotspots	115
6.4. Discussion	116
6.5. Conclusion	121

7. The Impact of Land Use and Land Cover Changes on the Underground Water Quality of the Amman, Zarqa and Balqa Regions in Jordan	125
Abstract	126
7.1. Introduction	127
7.2. Methods	129
7.2.1. Study Area	129
7.2.2. Data	131
7.2.3 Data Analysis	132
7.3. Results	134
7.3.1. Spatial and temporal changes of land use land cover from 2004 to 2010	134
7.3.2. Spatial and temporal changes of conductivity, nitrate and pH from 2004 to 2010	135
7.4. Discussion	138
7.5. Conclusion	141
8. Water Policy in Jordan	145
Abstract	146
8.1. Introduction	146
8.2. Policy	151
8.3. Micro-reform Policy	153
8.3.1. Regulatory Control of Water	154
8.3.2. Education	156
8.3.3. Infrastructural Improvement	156
8.3.4. Augmentation	157
8.3.5. International Co-operation	158
8.4. Policy and Mega-Projects	159
8.5. Desalination, Replenishment or New Sources of Potable Water	161
8.5.1. Cost of Desalinisation	163
8.6. Conclusion	164
9. Synthesis and Conclusion	168
Bibliography	175

List of Tables

Table 2.1	Strategic approach to WDM and the areas of water management that fall within that strategic sphere (Qdais, 2003).	19
Table 2.2	Water use in Jordan by sector and source (million m ³ per year) (Hussein <i>et al.</i> , 2010).	20
Table 2.3	Household water consumption and associated costs (Potter <i>et al.</i> , 2010).	22
Table 3.1	Current water consumption in Jordan by source (million m ³ per year) (after Hussein <i>et al.</i> , 2010, p.185).	36
Table 3.2	Changes in the population of Jordan through time represented by the 12 governorates) (in '000).	40
Table 3.3	Land use in the greater Amman Region 1918-2002 (area in km ²). (Source: Al Rawashdeh and Saleh, 2006, p. 214).	41
Table 3.4	Climate and regional classification in Jordan.	48
Table 4.1	The geology and hydrogeology classification of the Amman-Zarqa Basin (Rimimawi, 1985).	56
Table 4.2	The average hydrological and hydrochemical data for the three major aquifers in the Amman-Zarqa Basin for the period 1995-2003 (Al-Mahamid, 2005).	58
Table 4.3	Identification, location and land use of the wells and surrounding area used in this study.	61
Table 4.4	The pH for the maximal and minimal months and the percentage change over the period for each of the 11 wells investigated.	65
Table 4.5	The Nitrate concentration (mgL ⁻¹) for the maximal and minimal months and the percentage change over the period for each of the 11 wells investigated.	68
Table 4.6	The Ammonium (NH ₄ mgL ⁻¹) for the maximal and minimal months and the percentage change over the period for each of the 11 wells investigated.	70
Table 4.7	The conductivity for the maximal and minimal months and the percentage change over the period for each of the 11 wells investigated.	72
Table 5.1	Changes in Conductivity (μS/cm ⁻¹) from July 2012 to June 2013 in the selected wells in the Amman-Zarqa Basin.	88
Table 5.2	Changes in Nitrate (mg/L ⁻¹) from July 2012 to June 2013 in the selected wells in the Amman-Zarqa Basin.	89
Table 5.3	Changes in pH (mg/L ⁻¹) from July 2012 to June 2013 the selected wells in the Amman-Zarqa Basin.	90
Table 5.4	Changes in Ammonia (mg/L ⁻¹) from July 2012 to June 2013 in the selected wells in the Amman-Zarqa Basin.	91
Table 6.1	Changes in conductivity μS/cm ⁻¹ , nitrate mg/L ⁻¹ and pH mg/L ⁻¹ quantity for 2004 and 2010 in the selected wells.	119
Table 7.1	Details of the Landsat and ASTER data of 2004 and 2010 for the study area.	132
Table 7.2	The change in the land use and land cover classes from 2004 to 2010.	136
Table 8.1	The main sector of water consumers in Jordan.	148
Table 8.2	Jordan water use (MCM) according to the Ministry of water and Irrigation in Jordan.	149

List of Figures

Figure 3. 1	Population trends in Jordan since independence (Source: Department of Statistics, 2011).	39
Figure 3. 2	Growth of urban and rural population in Jordan from 1994 to 2008.	39
Figure 3. 3	Changes in the spatial extent of Amman between 1918 to 2010 with the consequence of loss of agricultural land as the urban footprint rose from 0.3 km ² in 1918, to 4.5 km ² in 1953, and over 170 km ² in 2010. All maps are to the same scale. Black dots show locations of bore holes and wells.	43
Figure 3. 4	Agricultural land use in Jordan showing trends in irrigated and non irrigated sectors from 1994-2009 (Source Department of Statistics, 2011).	45
Figure 3. 5	Agricultural fertiliser use in Jordan 1961-2009 (Adapted from Assi and Ajjour, 2009).	47
Figure 4.1	The monthly long term rainfall average rainfall of the Amman-Zarqa Basin, for the period 1970-2002 (data Al-Mahamid, 2005).	59
Figure 4.2	The location of the Amman, Zarqa, and Balqa regions and the location of the wells investigated in this study.	60
Figure 4.3	Land use images shows surrounding each well (from Google Earth, 2004).	63
Figure 4.4	The pH records for in each well in 2004.	66
Figure 4.5	The Nitrate (mgL ⁻¹) records for in each well in 2004.	69
Figure 4.6	The ammonium (NH ₄ mgL ⁻¹) records for in each well in 2004 with inferred data shown as a dotted line.	71
Figure 4.7	The Conductivity (µScm ⁻¹) records for in each well in 2004.	73
Figure 5.1	The Amman-Zarqa basin and the 20 wells used for hotspot analysis in this study.	84
Figure 5.2	The changes in the conductivity level hotspots from July 2012 to June 2013.	92
Figure 5.3	The changes in the nitrate level hotspots from July 2012 to June 2013.	94
Figure 5.4	The changes in the pH level indicating hotspots from July 2012 to June 2013.	96
Figure 5.5	The changes in the ammonia level hotspots from July 2012 to June 2013.	98
Figure 6.1	The study area with 57 wells and the three primary administrative regions.	110
Figure 6.2	The changes in the pH level indicating hotspots between 2004 and 2010.	114
Figure 6.3	The changes in the nitrate level indicating hotspots between 2004 and 2010.	115
Figure 6.4	The changes in the conductivity indicating hotspots between 2004 and 2010.	116
Figure 7.1	Location of the study area showing the 57 wells used in this study in the Amman, Zarqa and Balqa administrative regions of the Amman-Zarqa basin in Jordan.	130
Figure 7.2	Changes in conductivity, nitrate and pH hotspot levels and the land use land and cover changes between 2004 and 2010.	137