

LIST OF FIGURES

Figure	Page
1.1 Locations of the United Arab Emirates (UAE), and the study area (yellow rectangle) in the Eastern Coast Region (ALHOGARATY).....	1
1.2 Map showing the northern emirates in the UAE and the eastern coastal region (modified from the UAE Atlas, 1993 and the UAE Year Book 2005).....	3
1.3 Map showing the major drainage catchments in the Eastern Region of the United Arab Emirates traced from topography maps (modified from Rizk and Garamoon, 2006).....	6
1.4 Map showing the protected areas in the Eastern Region of the United Arab Emirates (Make different symbols of colors for terrestrial and marine reserves) (ALHOGARATY).....	7
1.5 Map showing Wadi Wurayah protected area between Fujairah and Khor Fakkan, northeastern coastal region of the UAE (modified from the topographic map of UAE).....	8
2.1 Classification of zones of a biosphere reserve (modified from www.unesco.org/mab).....	13
2.2 The World Network of Biosphere Reserves distributed by country (www.unesco.org/mab).....	14
3.1 Description of how the GIS Works (ALHOGARATY).....	22
3.2 The GIS layers created for the area of Wurayah and its hinterlands (ALHOGARATY).....	23
3.3 Flow chart shows the procedures of data automation and GIS process applied in this study (ALHOGARATY).....	28
4.1 Geomorphic map of the Eastern Coast Region in the United Arab Emirates, showing major landforms and regional faults (modified from IWACO 1986)	30
4.2 Drainage pattern (yellow lines) and catchment areas (red lines) in the northern part of the study area (modified after Almatari 2010).....	33

Figure		Page
4.3	Geologic map of the Eastern Coast Region in the UAE, illustrating the Wadi Wurayah drainage basin and its hinterlands (modified after the UAE atlas, 1993).....	34
4.4	Geologic cross-section across Wadi Wurayah, illustrating old terraces, recent gravel and contact springs (Tourenq, et al. 2006).....	35
4.5	Geological map of the Wadi Wurayah drainage basin (modified after Ebraheem et al., 2008).....	36
4.6	Schematic of surface and groundwater flow processes upstream of main waterfall (Joudah, 1994).....	37
4.7	Location maps of observation wells in wadis Zikt (Al Ruheib) and Wurayah respectively (modified from Almatari 2010).....	39
4.8	Subsurface geologic cross sections along different directions in Wadi Zikt (Al Ruheib). For wells locations see Figure 4.7 (above) (modified after Almatari 2010).....	40
4.9	Subsurface geological cross sections along different directions in Wadi Wurayah. For wells locations see Figure 4.7 (below) (modified after Almatari 2010).....	41
5.1	Location map of the meteorological stations used for investigation of climatic conditions in the Eastern Coast Region of the UAE.....	44
5.2	Mean maximum, mean and mean minimum monthly air temperatures (°C) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).....	45
5.3	Mean maximum, mean and mean minimum monthly relative humidity (%) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).....	46
5.4	The two major wind systems affecting the UAE (A), and the azimuth frequency diagram of wind speed and direction (B) form (Al Shamesi, 1993).....	47
5.5	Figure 5.5 The wind systems affecting the UAE (Al Shamesi, 1993).	48
5.6	Mean maximum, mean and mean minimum monthly wind speed (Knots) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).....	49

Figure		Page
5.7a	Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Dibba meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).....	50
5.7b	Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Masafi meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).....	50
5.7c	Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Masfut meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).....	51
5.7d	Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Kalba meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).....	51
5.8	Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).....	52
5.9	Map showing the mean annual rainfall in the UAE in mm/year (UAE National Atlas, 1993).....	53
5.10	Records of average annual rainfall (mm) in four meteorological stations along the eastern coast of the UAE for the period 1967-2000 (Rizk and Alsharhan, 2008).....	53
5.11	Isohytal map (mm/year) of the Eastern Coast Region of the UAE for the period 1976-2008 (ALHOGARATY).....	57
5.12	Positive and negative deviations from the average annual rainfall (mm) in three major meteorological in the Eastern Coast Region of the UAE for the period 1967-2003 (Rizk and Alsharhan, 2008).....	58
5.13	Records of maximum, mean and minimum annual rainfall (mm) in the Eastern Coast Region of the UAE for the period 1976-2006 (ALHOGARATY).....	59
5.14	Records of maximum, mean and minimum annual rainfall (mm) in the Eastern Coast Region of the UAE for the period 1976-2006 (ALHOGARATY).....	59
5.15	Predicted recurrence of rainfall maxima and minima of the study are for the period 1976-2006 (ALHOGARATY).....	61

Figure		Page
5.16	Rainfall - runoff relationship for Wadi Wurayah basin in the Eastern Coast Region of the UAE (ALHOGARATY).....	62
6.1	Map showing the distribution of the Aquatic Habitat in the area of the study (ALHOGARATY).....	70
6.2	Map showing the type of vegetation in the area of the study (ALHOGARATY).....	74
6.3	Map showing the Mammal distribution in the study area (modified from Tourenq et al., 2006).....	75
6.4	The Wadi Wurayah protected area after the Amiri Decree (modified from Tourenq et al., 2006).....	83
6.5	Sighting of wildlife in Wadi Wurayah during the last 15 years period since 2006 (Tourenq, et al. 2006).....	84
7.1	Location map of the roads, tracks and the settlement villages in the area of study (ALHOGARATY).....	86
7.2	The Wadi Catchment areas in the northern part of the Fujairah Emirate (ALHOGARATY).....	87
7.3	The land use map shows the distribution of the human activities in the area of the study (ALHOGARATY).....	96
7.4	The map shows the recorded activities at the protected area and its surrounding (ALHOGARATY).....	102
7.5	The boundaries of core, buffer and transition zones for the proposed Wurayah Biosphere Reserve (ALHOGARATY).....	111
8.1	Forty-eight DEM-derived drainage basins of the northern UAE and their associated channel networks, superimposed on the hill-shade (after Ghoneim 2008).....	114
8.2	Drainage basins analysis for the area of study using Strhaler Method (modified from the topographic map of UAE).....	115
8.3	Flash flood and infiltration potential of major drainage basins in the Eastern Coast Region of the UAE The (Rizk and Alsharhan, 2003)....	116
8.4	The Locations of permanent springs and the closest observation wells in the UAE (Rizk and Alsharhan, 2003).	117
8.5	The Location and drainage areas of the UAE falajs (Rizk and Alsharhan, 2003).....	121

Figure		Page
8.6	Total annual discharges (MCM/yr) of UAE falajs versus the mean annual rainfall (mm) on the eastern mountain ranges and gravel plains (Rizk and Alsharhan, 2003).....	122
8.7	Hydrographs of Al Ain falajs for the period 1964-1996 (compiled data based on studies of Gibb and Partners, 1970; Ministry of Agriculture and Fisheries, 1993; and Rizk and Alsharhan, 2003).....	122
8.8	Discharge of the remaining falajs in the northern UAE during 2006 and 2007 (Rizk and Alsharhan, 2008).	123
8.9	Iso-electrical conductivity ($\mu\text{S}/\text{cm}$) contour map of groundwater and falaj water during early 1996 in northeastern region of the United Arab Emirates (Rizk and Alsharhan, 2003).	125
8.10	The trilinear plot of chemical analyses of water samples collected from UAE falajs during early 1996 (Rizk and Alsharhan, 2003).....	126
8.11	Evaluation of falaj water suitability for irrigation, based on EC ($\mu\text{S}/\text{cm}$) and SAR (Rizk and Alsharhan, 2003).	127
8.12	Map showing the major aquifer in the UAE. The Eastern Coast Region is dominated by Ophiolite and gravel aquifers (Rizk and Alsharhan, 2008).....	128
8.13	Hydrogeologic map of the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.....	130
8.14	Hydrogeologic map of Wadis Basserah, Al Ruheib (Zikt), Al Ghmour and Hamad in the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.....	131
8.15	Hydrogeologic map of Wadis Ham, Wurayah and Ain Madab in the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.....	131
8.16	Hydrogeologic map of Ain Madab and surrounding area in the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.....	132
8.17	Frequency diagram of tritium (^3H) in the alluvial gravel aquifer in the Eastern Coast Region of the UAE (Rizk and Alsharhan, 2008).....	132

Figure		Page
8.18	Graph showing observation wells (colored circles) surveyed during the period 2005-2009 (ALHOGARATY).....	135
8.19	Graph showing groundwater levels in observation wells in 2005 (ALHOGARATY).....	136
8.20	Graph showing groundwater levels in observation wells in 2009 (ALHOGARATY).....	137
8.21	Photograph showing location of observation wells in Wadi Ham area. Wadi Ham Dam is illustrated by red lines in the northwest (Almatari, 2010).....	138
8.22	Graph showing groundwater levels in observation wells (colored curves) and rainfall events during the period 1987-2004 (colored squares) (Almatari, 2010).....	138
9.1	Schoeller-Berkalof diagram of the mean chemical composition of surface water and groundwater samples collected from Wadi Wurayah Basin (Almatari, 2010).....	143
9.2	Piper diagram of the mean chemical composition of surface water and groundwater samples collected from Wadi Wurayah Basin (Almatari, 2010).....	143
9.3	Graph illustrating the relationship between mean Cl^- and Na^+ concentrations of surface water and groundwater samples collected from Wadi Wurayah Basin (Almatari, 2010).....	144
9.4	The ^2H - ^{18}O relationships of rainfall and shallow groundwater samples collected from wadi Wurayah Basin (Almatari, 2010).....	145
9.5	Locations of water wells sampled for chemical analysis of groundwater in the eastern gravel aquifer within the study area (ALHOGARATY).....	149
9.6	Contour map of groundwater salinity in the northern part of the Eastern Coast Region in the UAE. Regional faults (yellow lines) and location of the 2D earth resistivity imaging profiles (green lines) are also shown (Almatari, 2010).....	151
9.7	Contour map of groundwater salinity in Wadi Ham. Regional faults (yellow lines) and location of the 2D earth resistivity imaging profiles (thick green lines) are also shown (Almatari, 2010).....	152

Figure		Page
9.8	Contour map of groundwater salinity in the core area (Wadi Wurayah in Green), buffer zone (Blue) and transition area (Orange), in 2005 (ALHOGARATY).....	154
9.9	Contour map of groundwater salinity in the core area (Wadi Wurayah in Green), buffer zone (Blue) and transition area (Orange), in 2009 (ALHOGARATY).....	152
9.10	Contour map of hydrogen ion concentration for groundwater samples in the core area (Wadi Wurayah in Green), buffer zone (Blue) and transition area (Orange) in 2005 (ALHOGARATY).....	155
9.11	Contour map of hydrogen ion concentration for groundwater samples in the core area (Wadi Wurayah in Green), buffer zone (Blue) and transition area (Orange) in 2009 (ALHOGARATY).....	156
9.12	Isoconcentration contour map of calcium ion (Ca^{2+}), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	158
9.13	Isoconcentration contour map of calcium ion (Ca^{2+}), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	159
9.14	Isoconcentration contour map of magnesium ion (Mg^{2+}), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	161
9.15	Figure 9.15 Isoconcentration contour map of magnesium ion (Mg^{2+}), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	162
9.16	Isoconcentration contour map of sodium ion (Na^+), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	163
9.17	Isoconcentration contour map of sodium ion (Na^+), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	164
9.18	Isoconcentration contour map of potassium ion (K^+), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	165

Figure		Page
9.19	Isoconcentration contour map of potassium ion (K^+), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	166
9.20	Isoconcentration contour map of bicarbonate ion (HCO_3^-), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	168
9.21	Isoconcentration contour map of bicarbonate ion (HCO_3^-), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	169
9.22	Isoconcentration contour map of sulphate ion (SO_4^{2-}), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	170
9.23	Isoconcentration contour map of sulphate ion (SO_4^{2-}), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	171
9.24	Isoconcentration contour map of chloride ion (Cl^-), in mg/l, in groundwater samples collected from the study area in 2005 (ALHOGARATY).....	172
9.25	Isoconcentration contour map of chloride ion (Cl^-), in mg/l, in groundwater samples collected from the study area in 2009 (ALHOGARATY).....	173
9.26	Dominance of the $Ca(HCO_3)_2$ groundwater dissolved salt (%) in the eastern gravel aquifer (ALHOGARATY).....	176
9.27	Dominance of the $Mg(HCO_3)_2$ groundwater dissolved salt (%) in the eastern gravel aquifer (ALHOGARATY).....	177
9.28	Dominance of the $MgSO_4$ groundwater dissolved salt (%) in the eastern gravel aquifer (ALHOGARATY).....	178
9.29	Dominance of the $MgCl_2$ groundwater dissolved salt (%) in the eastern gravel aquifer (ALHOGARATY).....	179
9.30	Dominance of the NaCl groundwater dissolved salt (%) in the eastern gravel aquifer (ALHOGARATY).....	180
9.31	Dominance of the KCl groundwater dissolved salt (%) in the eastern gravel aquifer (ALHOGARATY).....	181

Figure		Page
9.32	Contour map of iso $\text{Cl}^-/(\text{HCO}_3^- + \text{CO}_3^{2-})$ ratio in groundwater within the study area (ALHOGARATY).....	183
9.33	Contour map of iso $(\text{Na}^+/\text{Cl}^-)$ ratio in groundwater within the study area (ALHOGARATY).....	184
9.34	Contour map of iso $\text{Na}^+/(\text{Na}^+ + \text{Cl}^-)$ ratio in groundwater within the study area (ALHOGARATY).....	185
9.35	Contour map of iso $(\text{Ca}^{2+}/\text{Mg}^{2+})$ ratio in groundwater within the study area (ALHOGARATY).....	186
9.36	Presentation of groundwater chemistry in the study area on the trilinear diagram (ALHOGARATY).....	188
9.37	Groundwater types in the study area based on the concentration of total dissolved solids (TDS) (modified after Almatari, 2010).....	189
9.38	Total hardness (TH in mg/l) of groundwater samples collected from the study area in 2005 (ALHOGARATY).....	191
9.39	Total hardness (TH in mg/l) of groundwater samples collected from the study area in 2009 (ALHOGARATY).....	192
9.40	Sodium adsorption ratios (SAR) of groundwater samples collected from the study area in 2005 (ALHOGARATY).....	193
9.41	Sodium adsorption ratios (SAR) of groundwater samples collected from the study area in 2009 (ALHOGARATY).....	194
9.42	Evaluation of the suitability of groundwater in the eastern gravel aquifer in the UAE for irrigation (Rizk and Alsharhan, 2008).	195
10.1	Theoretical surface runoff hydrograph according bifurcation ratio (Rb), modified after Patton (1988) (Rizk and Alsharhan, 2003).....	197
10.2	Graph illustration the correlation between stream order and stream number in Wadi Zikt, the main drainage basin within the study area (ALHOGARATY).....	199
10.3	Graph illustration the correlation between stream order and stream number in Wadi Zikt, the main drainage basin within the study area (ALHOGARATY).....	201
10.4	Major drainage basins in the Eastern Coast Region of the UAE and locations of main groundwater recharge dams (Rizk and Alsharhan, 2008).....	203

Figure		Page
10.5	Difference in heads within the Quaternary gravel aquifer within the study area, in meters above mean sea level, between 2005 and 2009 (ALHOGARATY).....	205
10.6	Difference in salinity within the Quaternary gravel aquifer within the study area -between 2005 and 2009 (ALHOGARATY).....	207
11.1	Location map of Sharm village (ALHOGARATY).....	212
11.2	Structural arrangement of the Wurayah Biosphere Reserve (ALHOGARATY).....	233
11.3	The Management Plan for the Wurayah Biosphere Reserve (ALHOGARATY).....	235
12.1	The map of conflicts of the core zone. Red circles used to identify the areas needing environmental protection measures (ALHOGARATY).....	261
12.2	The map of conflicts of the buffer zone. Red circles used to identify the areas needing environmental protection measures (ALHOGARATY).....	264
12.3	The land use developments of the transition zone. Red circles used to identify the areas needing environmental protection measures (ALHOGARATY).....	265
12.4	Villages included in the transition zone (ALHOGARATY).....	270
12.5	Geologic map of the study area, illustrating the core, buffer and transition zones of the proposed WBR (modified after Ebraheem et al., 2008).....	274
12.6	Hydrogeological map of the study area, illustrating the core, buffer and transition zones of the proposed Wurayah Biosphere Reserve (modified after Ebraheem et al., 2008).....	279
12.7	The theoretical suggestion to enlarge the boundaries of the core, buffer and transition zones (ALHOGARATY).....	295