

LIST OF FIGURES

Fig. 1.1 Distribution of Rainfall in India.....	37
Fig. 1.2 Annual Change in Water Level 2013.....	40
Fig. 1.3 Groundwater Category Map of Gujarat, 2011	42
Fig. 1.4 Map of Study Area.....	46
Fig. 1.5 Map of Study Area along with Sakar & Sang River basin.....	47
Fig. 1.6 Flow Chart of Methodology.....	50
Fig. 2.1 Administrative subdivisions of Kutch.....	56
Fig: 2.2 Map showing major geomorphic division of Kachchh.....	58
Fig. 2.3 First time ever produced active fault map of Kachchh region. Highlighted areas indicate locations of trench investigations carried out on three major faults of the area.	61
Fig. 2.4 Observed slip along the fault traces in Jhura Trench. Slip of 144 cm observed on fault F1-1 is cumulative slip for the two events.....	61
Fig. 2.5 Rainfall Analysis in Kutch	65
Fig. 2.6 Rivers of Kutch	66
Fig. 2.7 Connectivity and Communication of Kutch	71
Fig. 2.8 Population Growth in Study Area.....	74
Fig. 2.9 Socio Demographic Status of Study Area.....	75
Fig. 2.10 (a) Population Distribution of Study Area (1971).....	82

Fig. 2.10 (b) Population Distribution in Study Area (1981).....	82
Fig. 2.10 (c) Population Distribution in Study Area (1991).....	83
Fig. 2.10 (d) Population Distribution in Study Area (2001).....	83
Fig. 2.10 (e) Population Distribution in Study Area (2011).....	84
Fig. 2.11 Temporal Population Change in Study Area (2001 to 2011).....	84
Fig. 2.12 (a) Population Density of Study Area (1971)	85
Fig. 2.12 (b) Population Density of Study Area (1981)	86
Fig. 2.12 (c) Population Density of Study Area (1991)	86
Fig. 2.12 (d) Population Density of Study Area (2001)	87
Fig. 2.12 (e) Population Density of Study Area (2011)	87
Fig. 2.13 Total Population (SC)	89
Fig. 2.14 Total Population (ST).....	89
Fig. 2.15 Total Population (Literate)	90
Fig. 2.16 Main Agriculture Labour Worker Population (Female)	91
Fig. 2.17 Main Agriculture Labour Worker Population (Male).....	91
Fig. 2.18 Main Agriculture Labour Worker Population.....	92
Fig. 2.19 Main Cultivator Workers (Female).....	93
Fig. 2.20 Main Cultivator Workers (Male)	93

Fig. 2.21 Total Main Cultivator Workers Population.....	94
Fig. 2.22 Total Population of Main Workers	95
Fig. 2.23 Marginal Agriculture Labour workers (Female).....	95
Fig. 2.24 Marginal Agriculture labour Workers Population (Male)	96
Fig. 2.25 Marginal Agriculture Labour Workers (Total)	97
Fig. 2.26 Marginal Cultivator Population (Female)	97
Fig. 2.27 Marginal Cultivator Workers (Male)	98
Fig. 2.28 Marginal Cultivator Workers Population.....	99
Fig. 2.29 Population of Marginal Workers.....	99
Fig. 2.30 Total Population of Non-Workers.....	100
Fig. 2.31 Total Non-Worker Population (Female)	100
Fig. 2.32 Total Non-Worker Population (Male).....	101
Fig. 2.33 Total Population	101
Fig 2.34 Changes in different categories of population from 2001 to 2011 (Anjar (M)).....	104
Fig 2.35 Changes in different categories of population from 2001 to 2011 (Ningal)	105
Fig 2.36 Changes in different categories of population from 2001 to 2011 (Malingna).....	105
Fig 2.37 Changes in different categories of population from 2001 to 2011 (Bhadroi)	106
Fig 2.38 Changes in different categories of population from 2001 to 2011 (Sapeda)	107

Fig 2.39 Changes in different categories of population from 2001 to 2011 (Ratatalav).....	107
Fig 2.40 Changes in different categories of population from 2001 to 2011(Varsamedi).....	108
Fig 2.41 Changes in different categories of population from 2001 to 2011 (Nagalpar Nani)	108
Fig 2.42 Changes in different categories of population from 2001 to 2011 (Nagalpar Moti)	109
Fig 2.43 Changes in different categories of population from 2001 to 2011 (Khambhra).....	109
Fig 2.44 Changes in different categories of population from 2001 to 2011 (Sinugra)	110
Fig 2.45 Changes in different categories of population from 2001 to 2011 (Vidi).....	111
Fig 2.46 Changes in different categories of population from 2001 to 2011 (Meghpar Borichi)	
.....	111
Fig 2.47 Changes in different categories of population from 2001 to 2011 (Meghpar	
Khumbhardi).....	112
Fig 2.48 Changes in different categories of population from 2001 to 2011 (Chubdak)	112
Fig 2.49 Changes in different categories of population from 2001 to 2011 (Gandher)	113
Fig 2.50 Changes in different categories of population from 2001 to 2011 (Gandhidham	
(Urban))	113
Fig 2.51 Changes in different categories of population from 2001 to 2011 (Mithi Rohar) ...	114
Fig 2.52 Changes in different categories of population from 2001 to 2011 (Shinay).....	114
Fig 2.53 Changes in different categories of population from 2001 to 2011 (Kidana)	115
Fig 2.54 Changes in different categories of population from 2001 to 2011 (Galpadar)	116

Fig 2.55 Changes in different categories of population from 2001 to 2011 (Antarjal).....	116
Fig 2.56 Total Persons of SC Group holding the Agriculture Land.....	122
Fig. 2.57 Total Holding Areas of SC Group (in Hectare)	123
Fig. 2.58 Total Persons of ST Group Holding the Agriculture Land.	124
Fig 2.59 Total Holding Areas of ST Group (in Hectare).....	125
Fig. 2.60 Institutional Holdings of Agriculture Area (in Hectare)	126
Fig. 2.61 Total Persons of Others Group Holding the Agriculture Land	127
Fig. 2.62 Total Holding Areas of Other Group (in Hectare)	128
Fig. 2.63 Total Holding Persons of All social Groups (Institutional+SC+ST+Others)	130
Fig. 2.64 Total Holding of Areas of all Social Groups (Institutional+SC+ST+Others)	131
Fig. 2.65 Chart of Implemented RWH structures in Coastal Watershed	135
Fig. 2.66 Chart of Implemented RWH structures in Urban Watershed	135
Fig. 2.67 Chart of Implemented RWH structures in Rural Watershed.....	136
Fig 2.68 Questionnaire Survey at Anjar	136
Fig. 2.69 Land use Map of Study Area (1990).....	144
Fig. 2.70 Land use Map of Study Area (2000).....	144
Fig. 2.71 Land use Map of Study Area (2015).....	145
Fig. 2.72 Exposed Rocky Terrain.....	147

Fig. 2.73 Agriculture Field	148
Fig 2.74 Fallow Land	148
Fig 2.75 Flood Plains.....	149
Fig 2.76 Industries	149
Fig 2.77 Settlements / Village Area	150
Fig 2.78 Village Lake / Water bodies.....	150
Fig 2.79 River	151
Fig. 2.80 Saline Lands	151
Fig. 2.81 Salt works / Saline area	152
Fig. 2.82 Tree Clad Area	152
Fig. 2.83 Wastelands	153
Fig. 2.84 Road Network	153
Fig. 2.85 Quarries	154
Fig 3.1 Geological map of Kutch showing major stratigraphic units (After Biswas and Deshpande, 1970) (Source: K. Swarna et. al).....	159
Fig. 3.2 Geological Map of Study Area	183
Fig. 3.3 Lineament Density Map of Study Area.....	183
Fig. 3.4 Rose Diagram of Lineaments in Study Area.....	184

Fig. 3.5 Exposed Basalt Formation at Anjar	185
Fig. 3.6 Cross Bedding at Anjar	185
Fig. 3.7 Geomorphology of Study area	191
Fig. 3.8 Structural Hills seen at Anjar Taluka	191
Fig 3.9 Soil Map of Study Area.....	193
Fig. 3.10 Fine grained Yellow Soil at Anjar	193
Fig. 3.11 Maps of SWL for the year 1978.....	196
Fig. 3.12 Maps of SWL for the year 2000.....	196
Fig. 3.13 Maps of SWL for the year 2005.....	197
Fig. 3.14 Maps of SWL for the year 2010.....	197
Fig. 3.15 Maps of SWL for the year 2015.....	198
Fig. 3.16 Maps of SWL for the year 2015 Post Monsoon.....	198
Fig. 3.17 Depth of Borewells Map for the year 2015.....	199
Fig. 3.18 Discharge Map of Study Area.....	199
Fig. 3.19 Specific Capacity Map of Study Area.....	200
Fig. 3.20 SWL wrt MSL Map of Study Area	201
Fig. 3.21 White patch seen on an exposed rock formation due to salinity	201
Fig. 3.22 Bore cum recharge well at anjar	202

Fig. 3.23 Field visit to various Borewells site with Sr. Geologist Kuldipsingh Bist, Bhuj	
Division	202
Fig. 3.24 (a) Geophysical Logging Report Fig. 3.24 (b) Geophysical Logging Graph	205
Fig. 3.25 Location of the Borewell Lithologs	206
Fig. 3.26 Borewell Lithologs of the study area	207
Fig. 3.27 Cross Sections from the Solid 3D model of the Study Area.....	208
Fig. 3.28 3D solid Model of the study area	208
Fig. 3.29 Water table wrt Ground Level of Study Area	208
Fig. 3.30 Cross Section of Seven Villages of Anjar Taluka.....	209
Fig 4.1 (a) On Site Groundwater testing with Sr. Geologist, Kuldeep Singh Bist, Bhuj	
Division.	225
Fig 4.1 (b) Groundwater testing on site through HANNA DISK 2 kit.	225
Fig. 4.2 Location of Borewells considered for water sample.....	227
Fig. 4.3 pH Map of Study Area Pre Monsoon 2009.....	231
Fig. 4.4 Nitrate Map of Study Area Pre Monsoon 2009.....	232
Fig. 4.5 Fluoride Map of Study Area Pre Monsoon 2009	234
Fig. 4.6 Iron Map of Study Area Pre Monsoon 2009	236
Fig. 4.7 Carbonate Map of Study Area Pre Monsoon 2009	238
Fig. 4.8 Turbidity Map of Study Area Pre Monsoon 2009	240

Fig. 4.9 TDS Map of Study Area Pre Monsoon 2009	242
Fig. 4.10 (a) Hardness Map of Study Area Pre Monsoon (Pre Earthquake)	244
Fig. 4.10 (b) Hardness Map of Study Area Pre Monsoon 2009	244
Fig. 4.11 Calcium Map of Study Area Pre Monsoon 2009	246
Fig. 4.12 Magnesium Map of Study Area Pre Monsoon 2009.....	247
Fig. 4.13 (a) Chloride Map of Study Area Pre Monsoon (Pre Earthquake).....	250
Fig. 4.13 (b) Chloride Map of Study Area Pre Monsoon 2009.....	250
Fig 4.14 (a) Sulphate Map of study area (Pre-Earthquake).....	252
Fig. 4.14 (b) Sulphate Map of Study Area Pre Monsoon 2009	252
Fig. 4.15 Alkalinity map of study area Pre Monsoon 2009.....	255
Fig. 4.16 Sodium Map of Study Area Pre Monsoon 2009	256
Fig. 4.17 Phosphate Map of Study Area Pre Monsoon 2009	258
Fig. 4.18 Potash Map of Study Area Pre Monsoon 2009	259
Fig. 4.19 Bicarbonate Map of Study Area Pre Monsoon 2009	261
Fig. 4.20 Piper Diagram of Study Area Pre Monsoon 2009	264
Fig. 4.21 Durov Diagram of Study Area Pre Monsoon 2009.....	264
Fig. 4.22 Gibbs Plot of Study Area Pre Monsoon 2009	265
Fig. 4.23 pH Map of Study Area Post Monsoon 2009	267

Fig. 4.24 Nitrate Map of Study Area Post Monsoon 2009	268
Fig. 4.25 Fluoride Map of Study Area Post Monsoon 2009	269
Fig. 4.26 Iron Map of Study Area Post Monsoon 2009	270
Fig. 4.27 Carbonate Map of Study Area Post Monsoon 2009.....	271
Fig. 4.28 Turbidity Map of Study Area Post Monsoon 2009	272
Fig. 4.29 TDS Map of Study Area Post Monsoon 2009	273
Fig. 4.30 Hardness Map of Study Area Post Monsoon 2009	274
Fig. 4.31 Calcium Map of Study Area Post Monsoon 2009	275
Fig. 4.32 Magnesium Map of Study Area Post Monsoon 2009	276
Fig. 4.33 Chlorides Map of Study Area Post Monsoon 2009	277
Fig. 4.34 Sulphate Map of Study Area Post Monsoon 2009	278
Fig. 4.35 Alkalinity Map of Study Area Post Monsoon 2009.....	279
Fig. 4.36 Sodium Map of Study Area Post Monsoon 2009.....	280
Fig. 4.37 Phosphate Map of Study Area Post Monsoon 2009.....	281
Fig. 4.38 Potash Map of Study Area Post Monsoon 2009	282
Fig. 4.39 Bicarbonate Map of Study Area Post Monsoon 2009.....	283
Fig. 4.40 Piper Diagram of Study Area Post Monsoon 2009.....	286
Fig. 4.41 Durov Diagram of Study Area Post Monsoon 2009	286

Fig. 4.42 Gibbs Plot of Study Area Post Monsoon 2009	287
Fig. 4.43 pH Map of Study Area Pre Monsoon 2015	289
Fig. 4.44 Nitrate Map of Study Area Pre Monsoon 2015	290
Fig. 4.45 Fluoride Map of Study Area Pre Monsoon 2015	291
Fig. 4.46 TDS Map of Study Area Pre Monsoon 2015	292
Fig. 4.47 Hardness Map of Study Area Pre Monsoon 2015	293
Fig. 4.48 Calcium Map of Study Area Pre Monsoon 2015	294
Fig. 4.49 Magnesium Map of Study Area Pre Monsoon 2015	295
Fig. 4.50 Chloride Map of Study Area Pre Monsoon 2015	296
Fig. 4.51 Sulphate Map of Study Area Pre Monsoon 2015	297
Fig. 4.52 Alkalinity Map of Study Area Pre Monsoon 2015	298
Fig. 4.53 Piper Diagram of Study Area Pre Monsoon 2015	300
Fig. 4.54 Durov Diagram of Study Area Pre Monsoon 2015	300
Fig. 4.55 Gibbs Plot of Study Area Pre Monsoon 2015	301
Fig. 4.56 pH Map of Study Area Post Monsoon 2015	303
Fig. 4.57 Nitrate Map of Study Area Post Monsoon 2015	304
Fig. 4.58 Fluoride Map of Study Area Post Monsoon 2015	305
Fig. 4.59 TDS Map of Study Area Post Monsoon 2015	306

Fig. 4.60 Hardness Map of Study Area Post Monsoon 2015	307
Fig. 4.61 Calcium Map of Study Area Post Monsoon 2015	308
Fig. 4.62 Magnesium Map of Study Area Post Monsoon 2015	309
Fig. 4.63 Chloride Map of Study Area Post Monsoon 2015	310
Fig. 4.64 Sulphate Map of Study Area Post Monsoon 2015	311
Fig. 4.65 Alkalinity Map of Study Area Post Monsoon 2015.....	312
Fig. 4.66 Piper Diagram of Study Area Post Monsoon 2015.....	314
Fig. 4.67 Durov Diagram of Study Area Post Monsoon 2015	314
Fig. 4.68 Gibbs Plot of Study Area Post Monsoon 2015	315
Fig. 4.69 pH Map of Study Area Pre Monsoon 2016.....	317
Fig. 4.70 Nitrate Map of Study Area Pre Monsoon 2016.....	318
Fig. 4.71 Fluoride Map of Study Area Pre Monsoon 2016	319
Fig. 4.72 TDS Map of Study Area Pre Monsoon 2016	320
Fig. 4.73 Hardness Map of Study Area Pre Monsoon 2016.....	321
Fig. 4.74 Chloride Map of Study Area Pre Monsoon 2016.....	322
Fig. 4.75 Magnesium Map of Study Area Pre Monsoon 2016.....	323
Fig. 4.76 Chloride Map of Study Area Pre Monsoon 2016.....	324
Fig. 4.77 Sulphate Map of Study Area Pre Monsoon 2016.....	325

Fig. 4.78 Alkalinity Map of Study Area Pre Monsoon 2016	326
Fig. 4.79 Piper Diagram of Study Area Pre Monsoon 2016	328
Fig. 4.80 Durov Diagram of Study Area Pre Monsoon 2016.....	328
Fig. 4.81 Gibbs Plot of Study Area Pre Monsoon 2016.....	329
Fig. 5.1 Average annual rainfall of the kutch district.....	345
Fig. 5.2 Graph of Rainfall Analysis for Kutch District with 5 years moving average	346
Fig. 5.3 Graph of Probability Analysis for Kutch District	346
Fig. 5.4 annual rainfall pattern for Anjar taluka and its 5 years moving average	349
Fig. 5.5 Graph of Probability of Occurrence (Anjar)	349
Fig. 5.6 Comparison of Distribution of Rainfall for Anjar Taluka with Kutch District.....	351
Fig. 5.7 Rainfall Vs SWL Graph for Nagalpar Nani Village	354
Fig. 5.8 Rainfall Vs SWL Graph for Ningal Village.....	354
Fig. 5.9 Rainfall Vs SWL Graph for Khambra Village.....	355
Fig. 5.10 Rainfall Vs SWL Graph for Vidi Village.....	355
Fig. 5.11 Rainfall Vs SWL Graph for Varsamedi Village	356
Fig. 5.12 Rainfall Vs SWL Graph for Sapeda Village	356
Fig. 5.13 Rainfall Vs SWL Graph for Sinugra Village	357
Fig. 5.14 Rainfall Vs SWL Graph for Anjar town	357

Fig. 5.15 Annual Rainfall Pattern for Bhuj Taluka and 5 Years Moving Average	358
Fig. 5.16 Graph of Probability of Occurrence (Bhuj).....	359
Fig. 5.17 Comparison of Distribution of Rainfall for Bhuj Taluka with Kutch District	361
Fig. 5.18 Rainfall Vs SWL Graph Gandher Village, Bhuj.....	363
Fig. 5.19 Rainfall Vs SWL Graph for Chubdak Village, Bhuj	364
Fig. 5.20 Annual Rainfall Pattern for Gandhidham Taluka and 5 Years Moving Average ...	364
Fig. 5.21 Graph of Probability of Occurrence (Gandhidham).....	365
Fig. 5.22 Comparison of Distribution of Rainfall for Gandhidham Taluka with Kutch District for last 18 years	366
Fig. 5.23 Double-Ring Infiltrometer (Field Test).....	376
Fig. 5.24 Reclassified Soil Map of Study Area	382
Fig. 5.25 Reclassified Land use Map of Study Area (1990)	387
Fig. 5.26 Reclassified Land use Map of Study Area (2000)	388
Fig. 5.27 Reclassified Land use Map of Study Area (2015)	388
Fig. 5.28 Rainfall Runoff Map of Study Area (1990)	390
Fig. 5.29 Rainfall Runoff Map of Study Area (2000)	391
Fig. 5.30 Rainfall Runoff Map of Study Area (2015)	391
Fig. 6.1 Importing the Map of Study Area along with Recharge sites	406

Fig. 6.2 Map showing the Boundary of Study Area.....	407
Fig. 6.3 Map of Active and Inactive Cells.....	407
Fig. 6.4 Coverage Setup for Source and Sinks	408
Fig. 6.5 Attribute Table for assigning Specified Head	409
Fig. 6.6 Creation of Rivers and Assigning the Conductance Value	409
Fig. 6.7 Creation of Recharge Structures	410
Fig. 6.8 Creation of Coverage boundary for Assigning the Recharge Rates.....	411
Fig. 6.9 Creation of Layer for Hydraulic Conductivity	411
Fig. 6.10 Creation of Elevation layer	412
Fig. 6.11 Creation of Grid Frame for Model Simulation.....	412
Fig. 6.12 Map showing the Active Grid Cells within the study area	413
Fig 6.13 Assigning of Evaporation Values.....	414
Fig. 6.14 Assigning of Starting head and Model Calibration.....	415
Fig. 6.15 Modflow Outputfor Present Scenario	415
Fig. 6.16 Modflow Output for Future Secnario (2035)	416
Fig. 6.17 Depth to water table Map of the study area recoded for Drastic Model	426
Fig. 6.18 Recoded Net Recharge Map.....	428
Fig. 6.19 Recoded Aquifer Media Map	430

Fig. 6.20 Recoded Soil Media Map.....	432
Fig. 6.21 Recoded Topographic Map.....	433
Fig. 6.22 Recoded Map of Vadose Zone.....	435
Fig. 6.23 Recoded Hydraulic Conductivity Map.....	436
Fig. 6.24 Drastic Index (Source: Yahia Alwathaf et al (2011))......	437
Fig. 6.25 Output Map of Drastic Model.....	437
Fig. 6.26 Recoded Geomorphology Map.....	457
Fig. 6.27 Recoded Geology Map.....	458
Fig. 6.28 Recoded SWL Map.....	460
Fig. 6.29 Recoded Slope Map.....	462
Fig. 6.30 Recoded Land Use Map.....	464
Fig. 6.31 Recoded Drainage Buffer Map.....	465
Fig. 6.32 Recoded SCS Rainfall Runoff Map.....	467
Fig. 6.33 Recoded Soil Map.....	468
Fig. 6.34 Recoded Average Rainfall Map.....	469
Fig. 6.35 Groundwater Prospect Zone Map.....	474
Fig. 6.36 Sink Area and Flow Accumulation Map.....	478
Fig. 6.37 Existing Recharge Structure overlaid on Recharge Zone Map.....	479

Fig. 6.38 Proposed Recharge Structure Map overlaid on Recharge Zone Map	479
Fig. 6.39 Proposed Check Dam type overlaid on Drainage Map	480
Fig. 6.40 Proposed & Existing Recharge structures overlaid on Recharge Zone Map	480
Fig. 6.41 Village Map overlaid on Recharge Zone Map	481
Fig. 6.42 Hydro Geomorphic Map with Prospective Recharge Zones.....	489
Fig. 6.43 Bore Cum Recharge Well at Anjar	490
Fig. 6.44 Recharge Tank with Check Dam	490
Fig. 6.45 GWSSB Groundwater Recharge Site.....	491
Fig. 6.46 Recharge Bore inside the GWSSB recharge site	491
Fig 6.47 Newly constructed Check Dam Site	492
Fig 6.48 Check Dam (Requiring Maintenance).....	492