PARTICIPATORY MODELLING PLATFORM FOR GROUNDWATER IRRIGATION MANAGEMENT WITH LOCAL FARMERS IN IRAN (KASHAN)

By

FOROUGH JAFARY

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School of Geography, Earth and
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University of Birmingham (UK)
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Abstract

This thesis develops a participatory modelling process to study improvement in the management of irrigation efficiency, including physical and social dimensions in the context of arid and semi-arid regions of Iran. This study develops an interdisciplinary and participatory method to understand and strengthen collective decision-making in local Iranian farming systems. Specific attention is given to groundwater irrigated agricultural practices under the Iranian governance system to provide wider context. Kashan City, in central Iran is selected as a case study area for specific reasons, such as historical water use, the farmers' rich indigenous knowledge, and successful agricultural practices under conditions of water scarcity. The accessibility and willingness of local farmers to engage in a participatory modelling process are considered. The thesis suggests the first use of role-play simulation for irrigation management practices in Iran, is an effective and insightful method of achieving adaptive management solutions. The application of an innovative participatory simulation modelling with farmers revealed their main incentives for collective irrigation practices, their capabilities to learn and evaluate the system. It is argued that management decisions have major impacts on farmers' livelihoods and therefore it is essential to integrate farmers' perspectives in local governance to sustain agricultural productivity.

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Table of Contents

CHAPTER 1 1

INTRODUCTION 1

1.1. Global Water Resources: Challenges and Management 1

1.2. The Role of Groundwater Resources in Irrigation Practices: Origins and Importance ... 6

1.3. Human-Related Water Scarcity: The Role of Local Indigenous Knowledge 16

1.4. Groundwater Governance and the Role of Local Farmers' Communities 17

1.5. Interdisciplinary Participatory Modelling Approach for Adaptive Groundwater Management 19

1.6. Thesis Aims, Objectives and Scope 24

1.6.1. Thesis Structure and Outlines 26

1.7. Conclusion 29

CHAPTER 2 30

Literature Review 30

Conceptualising Participatory Water Management; Reinforcing Collective Action Using Simulation Games 30

Introduction 30

PART I: Global Water Management 31

2.1. Water Crisis in Arid and Semi-arid Regions: 'A wicked' Problem 31

2.2. Integrated Water Resources Management (IWRM) Framework: Principles and Shortcomings 36

2.3. The Contemporary Challenges to Groundwater Irrigated Governance 43

PART II: Farmers' Decision Making 46

2.4. Characteristics of Groundwater Resources: Governance, Management Approaches and Farmers' Decision-making 46

2.5. The Factors Influencing Farmers' Participation in Groundwater Irrigation Management 52

2.5.1. Adaptive Rules (or rules-in-use) ... 53
2.5.2. Effective Local Institutions and Social Capital ... 55
2.5.3. Engineering Infrastructure and Size of Irrigation System ... 58
2.5.4. Property rights as an incentive ... 60
2.5.5. Economic Factors and livelihoods ... 61
PART III: Participatory Approaches to Water Management ... 62
2.6. Participatory Adaptive Management: Definition and Application Experiences ... 62
2.6.1. Decentralisation and Emergence of Participatory Irrigation Management ... 65
2.7. Socio-hydrological Modelling Platform: Human interactions with hydrological modelling within a participatory approach ... 70
2.7.1. Participatory Modelling Methods ... 71
2.7.2. Companion Modelling Approach for Irrigation Management ... 73
2.8. Simulation games and their role in fostering social learning ... 75
2.9. Conclusion ... 79
CHAPTER 3 ... 82
Introduction ... 82
PART I: Iran's Traditional Irrigation Management Practices ... 85
3.1. Geography, Hydrology and Climate Characteristics of Iran ... 85
3.2. Qanat Systems and their Role in Irrigation Practices in Central Iran ... 87
3.3. A Chronology of Water Management Developments in Iran ... 93
3.3.1. Traditional water management systems before land reform (in 1960s) ... 93
3.3.2. Nationalisation of Iranian Water Resources before the Revolution (1960-1979) ... 94
3.3.3. The Development of Wells after the Islamic Revolution until the Implementation of Fair Distribution Law of Water (1980-1998) ... 95
PART II: Iran's Contemporary Water Management Crisis ... 98
3.3.4. Contemporary Water Governance in Iran: The Impact of the National Water Management Policies on Local Irrigation Practices ... 98

3.3.4.1. Water Crisis in Iran 98
3.3.4.2. Agricultural Water Governance 100
3.3.4.3. Local Agricultural Institutions in Iran 102
3.3.5. Recent Consideration of Participatory Approaches in Water Policy of Iran 103
3.4. Existing Barriers to Participatory Water Management in Iran 104
3.4.1. Barriers 106
3.5. Conclusion 110
CHAPTER 4 113
METHODS 113
Introduction 113
4.1. Case Study Area Description 114
4.1.1. Case Study Selection 118
4.2. Part I: Justification of the Methodological Approaches 118
4.2.1. Research Tools and Methods: interviews 118
4.2.2. Participant Selection and Positionality 125
4.2.3. Ethical Concerns 129
4.3. Research Method: Role-Play Games 130
4.3.1. Investigating the Role of Games in Promoting Participatory and Collective Irrigation Management 133
4.4. Part II: Integrated Modelling Procedure and Different Phases 138
Phase 1- Formulation of Research Questions, Objectives and Identification of the Stakeholders (April-June 2011) 140
Phase 2- Hydrologic Model Structure Identification (April-June 2011) 141
Phase 3-Defining Indicators and Conceptualisation of the Modelling Process (2011) ... 141
Phase 4-Conducting a RPG Simulation (2013) 143
Phase 5-Validation of WEAP model Assumption, Testing Scenarios (2012-2013) 143

Phase 6- Farmers' Analysis of Hydrologic Model Results (July-Sep 2013) 146
Phase 7- Communicating the Participatory Model and Farmers' Feedback (2013) 148
4.5. Part III: The RPG Development 149
4.5.1. Self-designed irrigation management game (IMG) with farmers 150
4.5.2. Description of the Board Game and the Setting.. 152
4.5.3. Implementation of the Irrigation Management Game (IMG) 155
Stage 1: Selection of Participants and Design of the Board Game 156
Stage 2: Validation of the Board Game 157
Stage 3: Conducting the Game Rounds.. 159
4.5.4. Debriefing Session 163
4.6. Conclusion 164
CHAPTER 5.. 166
WEAP Modelling 166
Introduction 166
5.1. Hydrological WEAP Model: Description, Characteristics and Applications............. 167
5.2. WEAP: Modelling Steps and Data Requirement... 172
5.2.1. Problem Identification: Interviews and Group Discussions................................. 173
5.2.2. Database Structure.. 174
5.2.3. Scenario Development for WEAP Modelling within Participatory Processes 176
5.2.4. Calibration and Results 177
5.3. WEAP Modelling Steps for Kashan 177
5.3.1. Scenario Building.. 178
5.3.2. Testing Scenarios and Evaluation 180
5.4. Discussion and Conclusion.. 186
CHAPTER 6.. 188

Groundwater Irrigation Management and the Existing Challenges from the Iranian Farmers' Perspective 188

Introduction 188

6.2. Exploring the existing challenges for groundwater irrigation management in Kashan city by local stakeholders 191

6.2.1. Water Crisis and Efficiency Management: Reconciling Different Viewpoints 195

6.2.2. Small-scale Farmers' Main Adaptation Strategies 205

6.3. The Role of Governance and Trust for Collective Action Behaviour 210

6.3.1. Management Transfer and its Impact on Agricultural Water Management Performance 212

6.3.2. Modern Development and the Challenge to Traditional Values 213

6.3.3. The Impact of Modern Pump Technology on Groundwater Resources and its Failure to Bring Equity 217

6.3.4. Shifting agricultural costs and responsibilities to farmers under current governance 222

6.4. The factors influencing farmers' adoption of a Governmental Irrigation Schemes 225

6.4.1. Biophysical Adaptation 227

6.4.2. Economic Advantages/Returns 229

6.4.3. Social and Cultural Adaptability 233

6.5. Conclusion 236

CHAPTER 7 238

Towards Adaptive Agricultural Water Management in Iran 238

Introduction 238

7.1. Participatory RPG as a Democratic Approach 239

7.2. Participatory Simulation Exercise: Implementation and Outcomes 240

7.2.1. Farmers' knowledge and communication 242

7.2.2. Farmers' Incentives for collective action within behavioural analysis 246

7.2.3. Formulation of Scenarios ... 253
7.2.4. Reasons for Rejection of Drip Irrigation Method ... 257
7.3. WEAP Co-modelling to Foster Dialogues ... 261
7.3.1. Developing a Companion Modelling Process: The Insights ... 262
7.3.2. Farmers' Interactions and Evaluation of the Hydrologic Modelling Results ... 265
7.4. Building Adaptive, Flexible and Reflective Institutions for Irrigation Practices ... 276
7.5. Social Learning, Empowering local farmers and Capacity Building for Adaptive Management ... 278
7.5.1. Stakeholder Involvement ... 282
7.5.2. Objectives ... 283
7.5.3. Management actions ... 283
7.5.4. Models ... 283
7.5.5. Monitoring Plans ... 284
7.5.6. Feedback ... 285
7.6. Conclusion ... 285
CHAPTER 8 ... 289
Conclusion ... 289
Introduction and Contribution of Thesis ... 289
8.1. Summary of Findings ... 293
Appendix 1 ... 303
Appendix 2 ... 312
Appendix 3 ... 313
Appendix 4 ... 314
Appendix 5 ... 315
References ... 317

List of Figures

Figure 1 Groundwater Abstraction Proportions based on Water user Sectors……………………9

Figure 2 Groundwater Irrigated Areas by Countries………………………………………………9

Figure 3 Flowchart of Thesis Methodological Structure…………………………………………28

Figure 4 Integrated and Adaptive Water Management…………………………………………...37

Figure 5 IWRM: Vertical integration structure…………………………………………………...39

Figure 6 ComMod Perspective: Schematic representation of Socio-ecological relations………..74

Figure 7 The construction of Qanat (A)……………………………………………………… 89

Figure 8 Qanat system's deterioration when water table dropped below mother well level……..96

Figure 9 The Case Study Area of Kashan Catchment, in Isfahan Province (Iran)……………... 115

Figure 10 The case study villages are spread between Kashan city and Abu zeid Abad Village.117

Figure 11 The Companion modelling cycle, including RPG and WEAP tools…………………138

Figure 12 The Main Stages of a Participatory Modelling Process…………………………....140

Figure 13 ComMod: Social and biophysical relations within groundwater irrigated system…...142

Figure 14 Schematic view of the WEAP model and Scenario Management Screen…………....146

Figure 15 Presenting model outcomes to farmers on the laptop……………………………...…157

Figure 16 The sketch map of the irrigation system for designing board…………………..……157

Figure 17 Pre-designed game board, later completed by farmers during the game session…......158

Figure 18 The validation of pre-designed map and setting rules by farmers…………………....158

Figure 19 The completed designed map of the farmlands and water canals by farmers………...160

Figure 20 Light green square papers on left side, were used to represent neighbours' lands…....161

Figure 21 Map of the designed farmlands and canals in the board game……………………......163

Figure 22 Schematic View of the Catchment Area……………………………………………....174

Figure 23 Schematic View of Scenario Development in WEAP……………………………......180

Figure 24 Water demand under unimproved irrigation efficiency and population growth……....181

Figure 25 Water Demand under 'Tooba Scheme' with Improved Efficiency………………….....183

Figure 26 Water Demand with improved Irrigation efficiency……………………………….…184

Figure 27 Water Demand for Agriculture under different scenarios……………………………..185

Figure 28 Different irrigation systems in Kashan Villages………………………………………204

Figure 30 Unmet Water Demand, without improved efficiency and population growth ………..270

List of Tables

Table 1 Data Collection in Kashan Villages (2011-2013) 123
Table 2 Key governmental departments interviewed (2011 and 2013)................................. 124
Table 3 Data Used for Building the Model Baseline... 175
Table 4 Groundwater Data Used for Modelling (Units are based on Million Cubic Metres) 176
Table 5 The scenarios to be tested in the Model 179

CHAPTER 1

INTRODUCTION

This chapter provides an introduction to this research and gives an overview of current global challenges in the management and governance of water resources. It then reviews the important role of groundwater irrigated agriculture, different approaches to groundwater management and the need for interdisciplinary water management as a new tool for the allocation of common-pool resources. The main aims, objectives and research questions addressed by the work, as well as the outline of the thesis structure and chapter by chapter elaboration of the research are presented in the final section.

1.1. Global Water Resources: Challenges and Management

Water is life; it is both 'indispensable and incompatible in its form as drinking water' (UN, 2006), which reflects its vital role both for human society and for the environment.

Water covers approximately three quarters of the Earth's surface, and is almost ubiquitous beneath the surface. The total water resource on the planet is estimated at 1.38 billion cubic metres (10^9 m^3), of which only 2.5 percent or 35 million cubic metres (10^6 m^3), is freshwater and potable (Almasvandi, 2010). Over the past 100 years since 1900, while the global population has doubled, water consumption has increased by over six-fold (UNESCO, 2004).

Freshwater resources are essential components of nature, however, they are directly threatened by human interests and will be affected greatly by 'anthropogenic climate change' (Meybeck, 1998; UNESCO, 2006; Vörösmarty et al., 2000; Karl, et al., 2009). For example, half of the world's wetlands have been destroyed since 1900, and to prevent the remaining wetlands from degradation, there is a need to address the threats and improve management of freshwater resources (Zedler and Kercher, 2005).

Water systems and their management have been transformed globally through extensive land use change, the expansion of urban and industrial activities, massive engineering projects such as dams, reservoirs and irrigation infrastructure or water transfer schemes, which have sought to maximise human access to available water resources (Shiklomanov, 1999; Meybeck, 2003; Farming Committee of the Global Water System Project, 2004). Anticipated population growth, changing population distributions and uneven distribution of precipitation together lead to a reduction in per capita water availability. At the same time, increasing dependence on desalination, and increased water demand, will reduce the availability of potable water resources and, consequently new approaches for sustainable water management are essential.

In developed world, extensive investment has almost ensured security of water supply for an estimated 190 million people; however nearly 80% of the world population (1,800 million) in low-income countries currently experience high levels of water insecurity (Water for Growth and Development, 2006). One of the main principles of the Millennium Development Goals (MDGs) was to halve the population around the world who lack access to clean water by 2015, and provide safe drinking water; however this major challenge has yet to be resolved. Around 780 million people globally lack access to clean potable water, 2.5 billion do not have sanitation facilities, and 2-5 million people (over 5000 every day), mainly children, lose their life every year because of water-related diseases (Gleick, 2003; UN, 2003; WHO and UNICEF, 2012; Gleick, 2014. p.1). Around 13 percent (over 800 million) people are living under conditions of poverty and food insecurity (UNESCO, 2004). Thus one of the greatest challenges of this century is providing sufficient water to produce enough food and balance it with other water demands and interests (UN, 2006; MDGs-United Nations, 2011).

Within individual countries, the concentration of welfare and facilities in large cities in developing nations has attracted an increasing population and exerted more pressure on water supply resources and increasing competition between urban and rural areas. The ever increasing water conflicts in Middle Eastern countries on the competing use of water for energy development projects has become problematic (Siddiqi and Anadon, 2011). As agriculture and energy are the major users of water, these resources are closely interrelated and their sustainable consumption and management requires integrated approaches (Gleick, 2014, p.5). The concept of the 'water-energy-food nexus' has been considerably neglected by policy decision-makers (Gleick, 2014). This concept was developed in response to the need for integrated sectoral policies to reduce the cost of water management and to add benefits to both human and nature for the future sustainable development plans (Ringler et al., 2013).

Global assessment of water resources requires a systematic approach. Currently this assessment is based on fragmented data at a country level (Gleick, 2014) and when water demand reaches (or exceeds) water supply availability, water scarcity results. According to a standard hydrological index of water scarcity, (which defines it as "the number of hundreds of people who has to share one million cubic metres annually available renewable water") by 2025 around one third of the global population will live in water scarce countries, mainly in developing regions (Ohlsson, 1999). Scarcity of water essentially means that there is insufficient water to satisfy the requirements of agriculture, domestic and industrial water uses, this is traditionally known as ‘first order water scarcity’. The associated problems of water scarcity are more than just a lack of water; they also affect many other social aspects of life, or known as ‘second-order water scarcity’, which requires successful adaptation of people to the first-order water scarcity (Ohlsson, 1999). Successful water and groundwater management for irrigation under conditions of severe water scarcity and drought primarily depends on acquiring collective action and sharing knowledge by different resource users, which will be discussed in this study in Chapter 2.

To a certain extent, agricultural intensification and adoption of modern irrigation technologies such as drilled wells and micro-irrigation systems, has reduced water and labour use and provided sufficient food to satisfy global demand through a market oriented approach (see Chapter 2). While this provides short-term economic revenue, there are disadvantages including the spread of pollution and over-exploitation of natural resources. Moreover, limitations in access to food, water, land and technology in lower-income regions has led to an unequal distribution of food (UNESCO, 2004). Technological solutions might act as a short-term alternative to improve efficiency or economic development; however given the lack of consideration to the social-economic aspects of local users, the long-term consequences are usually not taken into account (Gleick, 2003; Turral et al., 2010; Gleick, 2014) (see Chapter 6). Within the past 60 years challenges in managing water resources have been addressed in many different ways. Early efforts mainly focused on the establishment of large-scale physical structures for water supply, e.g. dams to improve water availability. Later it was recognised that technology in itself is not sufficient to address water management issues. The concept of water governance emerged in the early 1990s, in recognition of the need for more integrated approaches to effective water management, and that the technology alone is inadequate to address the continual water management concerns (UN 2003) (see Chapter 2).

The United Nations consistently emphasised in the first World Water Development Report that: the "Water crisis is essentially a crisis of governance and societies are facing a number of social and political challenges on how to govern water more effectively" (UN, 2003, p. 370).

It is commonly stated that problems of water shortage mainly arise through mismanagement rather than for solely physical reasons (see Chapter 2). Water shortages may also reflect a lack of suitable institutions, corruption, bureaucratic phenomena and absence of sufficient investment in both human competency and physical infrastructure (UN, 2003).

One of the indications of water scarcity is a decline in groundwater levels. Although within the last 20 years well-drilling technologies have reduced the cost of groundwater exploitation, the withdrawal rate has tripled during the last 50 years, and rates of groundwater extraction exceed recharge in many countries (UN, 2011) (see Chapter 2). Agricultural technologies and modern irrigation infrastructures have constantly led to increased food production and rural welfare; however this has only benefited a limited portion of the farming community population around the world (UNESCO, 2004).

The water crisis and increased water demand represent social and political challenges for the future. According to UNESCO:

> *"This can be addressed by modifying water demand and usage through increased awareness, education and water policy reforms. The water crisis is thus increasingly about how we govern access to and control over water resources and benefits"* (UNESCO, 2006).

This suggests a need to develop more effective management practices for scarce groundwater resources, which particularly emphasise water demand management. Implementation of more efficient irrigation systems that are locally adapted by farmers is one of the main strategies in reducing agricultural water demand, improving efficiency and hence the sustainable management of groundwater resources that will be discussed further in this thesis. This statement also highlights the key role of education, raising awareness and stakeholders' interaction and collective action in managing scarce water resources.

In the next section the important role of groundwater resources particularly in irrigation management practices will be explored.

1.2. The Role of Groundwater Resources in Irrigation Practices: Origins and Importance

Irrigation represents an historical human adaptation to climate conditions and climate change specifically in the context of rainfall variability and resulting water shortages. Given the lack of adequate rainfall (which makes rain-fed agricultural practices difficult or unprofitable), irrigation has played a crucial role in providing an adequate and reliable source of water. Irrigation has formed and centralized social relations and human settlement; it has facilitated agricultural production and thus human wellbeing. Agriculture is currently the world's highest water consuming sector (Lopez-Gunn and Llamas, 2008). Agriculture constitutes the earliest economic sector to formalize cultural and ethical values of land and water through human settlements (UNESCO, 2004). Today around 17 percent of the world's cultivated land areas produce over one third or 40 percent of the world's food demand (Siebert et al., 2005; Fereres and Soriano, 2007; Hanjra and Qureshi, 2010). The future climate change will impact on water resources will be threatened by a reduction in available water resources (Falloon and Betts, 2010) which will increase demand for irrigated agriculture (Knox, 2012).

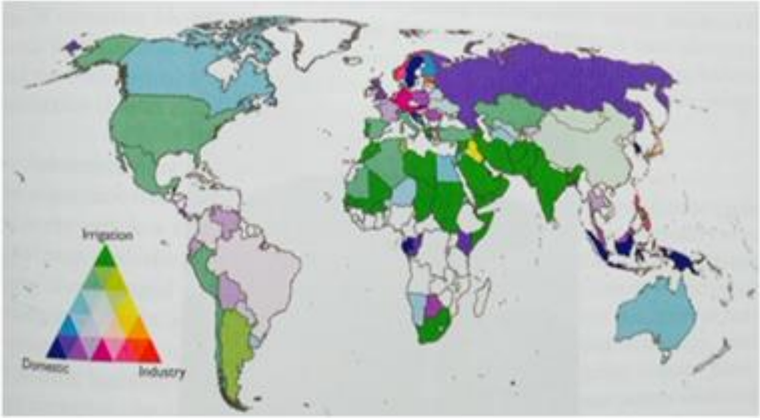
Degradation of available water quality because of salinization is another threat for the sustainability of water and land resources. Ghassemi et al. (1995) estimates that of 230 million hectares of irrigated land areas globally, nearly 45 million hectares are deteriorating due to 'irrigation-induced' salinization (Gowing et al., 2009). Sustainable agricultural practices are therefore required to meet the needs of both society and environment. Improving water management particularly irrigation efficiency is one of the main functions of agricultural practices which provides various benefits not only production of food (Knox et al., 2010) (see Chapter 6). The irrigation efficiency is an indicator to express the level of irrigation system performances, which for example in developing countries is around 38 percent (FAO, 2002). Improving irrigation efficiency is crucial in water scarce countries, to sustain food production, groundwater sustainability and local farmers' livelihood; which this study investigates further (see Chapter 6).

During the twentieth century, irrigated agriculture played a crucial role in food provision and in rural development in many arid and semi-arid countries around the world (Amichi et al., 2012). Globally, the estimated area of irrigated lands by 2030 will be 310 million ha, of which developed countries account for approximately a quarter of the total, while around 75 per cent is located in developing countries. China and India account for almost 56 per cent of the irrigated land (Bruinsma, 2009). Rain-fed areas covering an estimated 1,250 million hectares (5 times larger than cultivated lands), produce the remaining 2/3 of the world's food production (UNESCO, 2004). Irrigation has a significant role in improving agricultural production for a growing population under conditions of a changing climate (see Chapter 6). Irrigation is also acknowledged for its role in ensuring food security and enabling improvements in living standards, particularly for poor local farmers (Rijsberman, 2006; Turral et al., 2010). However agricultural development has various social and ecological consequences, including drainage problems and expansion of soil salinity (see Chapter 2).

Farmers have developed different ways of using and crafting rules and agreements to manage irrigation systems in different parts of the world (Molle, 2003; Ostrom, 1994) (see Chapter 2, 6). However, there is a need to emphasize the substantial role of groundwater resources in arid regions of the world, in irrigation. This is due to the adaptable abstraction of groundwater, which has enabled farmers to diversify and expand cultivation to secure food provision and overcome rural poverty (World Bank, 2006; Narayanamoorthy, 2007) (see Chapter 2).

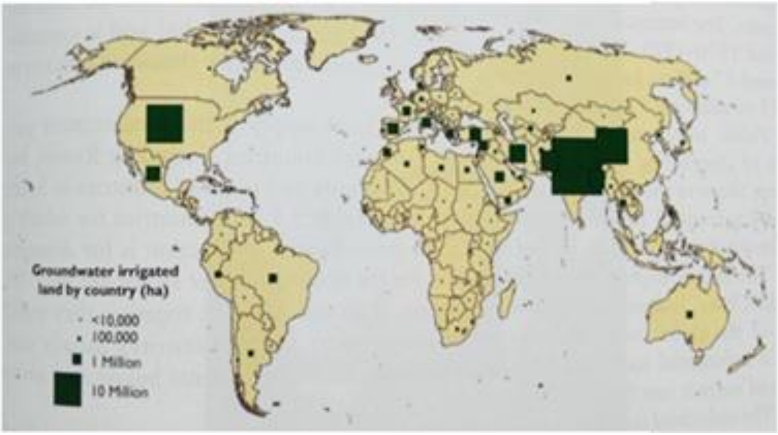
Currently annual groundwater abstraction rates are estimated at two hundred times more than oil in terms of volume. The concept of 'groundwater footprint' was introduced by Gleeson et al., (2012) to define the area needed to sustain groundwater use and groundwater-related ecosystem services. Their study of groundwater balances around the world showed that humans are overexploiting groundwater resources at unsustainable rates, and in aquifers which are essential for agriculture, particularly in Asia and North America (Gleeson et al., 2012). Groundwater is used in many countries often as the main source of drinking water, and supplies potable water for half the global population. It also plays a significant role in irrigation and agricultural economy in dry regions of the world (Figure 1 and 2) (Turral et al., 2010; Margat and van der Gun, 2013). For example data for India show that economic yield for land irrigated by groundwater is 5 to 10 times higher in comparison with surface irrigation. By increasing abstraction costs the crop value must increase, but in many cases poor farmers are unable to cultivate cash crops (Llamas and Martinez-Cortina, 2009).

Figure 1 Groundwater Abstraction Proportions based on Water user Sectors



Source: Margat and van der Gun, 2013, p. 145

Figure 2 Groundwater Irrigated Areas by Countries



Source: Margat and van der Gun, 2013, p. 141

Since the early 1980s, there has been increasing investment in groundwater exploitation. This trend has been classified by Shah (2007) as a 'groundwater economy' which is particularly important in south-east Asian where it provides annual water flow offering higher flexibility in using groundwater in conjunctive use with surface-water resources (Barker and Molle, 2004). Shah and Raju (1988) analysed the informal groundwater market in regional economic scale in India, and later focused on intensive agricultural groundwater use in South Asia. These studies revealed the critical role of groundwater resources in South Asian's rural areas and also the increasing water scarcity for economic development in that region (Shah et al., 2003) (see Chapter 2).

The increase in groundwater irrigation has largely arisen as a result of moderate levels of abstraction by millions of farmers in many arid countries in a quest for the major short-term benefits that groundwater development can generate. This occurred due to abundant, uncoordinated, and unplanned individual exploitation of groundwater resources, which is placing increasing stress on regional aquifers in many parts of the world (Llamas and Martinez-Santos, 2005; Margat and van der Gun, 2013). Many states have invested in building major dams, reservoirs and huge irrigation infrastructures (Gleick, 2003). In many developing countries, particularly in arid regions, numerous state-oriented large-scale irrigation schemes have been implemented, aiming for agricultural intensification to generate major economic benefit (Molle et al., 2008; Kuper, 2012).

The green revolution that occurred as a consequence of increased irrigation led to a global increase of food production lands, from 140 million to 240 million hectares from the 1960s to the 1980s (UNESCO, 2004). However, this trend has led to unsustainable increased rates of groundwater abstraction (Siebert et al., 2005) and the bilateral impacts of increased water demand, drought and mismanagement in irrigation development schemes, has put groundwater resources at the risk of overexploitation. This development has mainly occurred in arid developing countries, where pumped-well technology had played a major role in irrigation practices for example in Southern Asia in areas with little government control. This has subsequently resulted in significant groundwater depletion (Llamas and Martinez-Santos, 2005; 2008). Besides the green revolution that occurred around the world, another silent but major transformation occurred mainly in dry regions. The spread of fairly cheap pump technology made revolutionary changes in access to both groundwater and surface water resources for irrigation. This moderate but global movement of farmers around the world to exploit groundwater resources through private pumped-well technology is described by Llamas and Martinez-Santos (2005) as 'silent revolution'. A silent revolution has been reported by Wang et al. (2007) to extend over many arid regions in USA, South Asia, China and has been also observed in North Africa (Hammani et al., 2009). Llamas and Martinez-Santos (2005) suggest that an important advantage of the silent revolution was its positive impact on many farmers' socio-economic status, which enabled them to provide education for their children. In many developing countries the rural economy is largely dependent on groundwater irrigation to increase farmers' income and employment (Smith, 2004; Turral et al., 2010) (see Chapter 2). Groundwater development has also significantly changed the labour force in many countries as a consequence of development in technological infrastructures (Llamas and Martinez-Santos, 2005) (see Chapter 3).

During the silent revolution, many government agricultural agencies supported farmers by providing loans and energy subsidies, while the main focus of water management agencies was on planning, operation and maintenance of surface water irrigation systems. Thus groundwater development received much less attention from most policy makers (Llamas and Martinez-Santos, 2005; Margat and van der Gun, 2013). Some studies indicate that in regions where groundwater is a major source of water for irrigation, it is very challenging to control aquifer over-exploitation by water users, especially in areas where farmers' livelihood depends on agriculture (Llamas and Martinez-Santos, 2005). Thus, in this study groundwater irrigation practices at a local community level are used to explore and understand the management mechanism and governance structure through a participatory management study in case study area in Iran.

In many developing countries, the high number of farmers involved in irrigation practices and the lack of accurate recording devices to monitor their abstraction rates, make it more difficult to control over-exploitation of groundwater (Berahmani et al., 2012). This is coupled with a lack of suitable institutions and financial investments on controlling or monitoring systems for groundwater resources (Berahmani et al., 2012). Regulating adaptable and community-based rules (and infrastructures) for resource use is particularly needed in countries where the government has always played a main role within authoritative and top-down management decisions for natural resources (Ostrom, 1990; Agrawal, 2001; Mukherji and Shah, 2005). This top-down policy, for example in Iran, has usually neglected locally adaptable management strategies and in most cases has not introduced suitable infrastructures and technologies for resource management.

The amplified importance of groundwater resources for irrigation practices has increased the number of studies of groundwater governance using various analytical approaches within the last 50 years. In studies on groundwater governance three main schools of thought have been recognised (Faysse and Petit, 2013) including: Ostrom (1990) who consider groundwater governance as a collective action for common-pool resource management (Chapter 2). The common-pool resource approach is also adopted in this thesis as it addresses the local challenges in managing groundwater irrigation at local level and the role of collective action, which I will discuss further in this chapter and discussion chapters. The second main school of thought is Shah's (2007) evaluation of 'informal groundwater economies'. Shah concluded in his thesis that groundwater governance in South Asia is not appropriate for an Integrated Water Resources Management (IWRM) approach (see Chapter 2), and the water policy regulation and administration are not applicable and are not practical (Shah, 2009). He argued that, as the main principles of the global water management frameworks (such as IWRM) are not practicable at regional scale, policy-makers are required to consider more realistic and practical approaches and identify mechanisms that justify the informality of groundwater economies. Shah suggested that there is a need to develop management strategies based on the particular characteristic of an aquifer (Shah, 2012). For example while a groundwater recharge project is more practicable in hard rock aquifers, alluvial aquifers require more indirect demand management strategies because of their particular context. Shah and Raju (1988) analysed the informal groundwater market at a regional economic scale in India. A well-known example is a project in Gujarat, in which adoption of the scheme on installation of electric power water supply for controlling groundwater abstraction by farmers was successful, as it had no negative effect on the groundwater economy (Shah et al., 2008). Shah expanded his study to areas in Mexico (Scott and Shah, 2004), China and Spain (Mukherji and Shah, 2005). He developed a conceptual and methodological approach that resulted in a typology of the groundwater economy as the outcome of his worldwide evaluation of groundwater governance and use.

The 'political ecology' dimension of groundwater management forms the third school of thought (Faysse and Petit, 2013). Political ecology emerged in 1970s to address ecological concerns within the human organisation or global economic systems (Paulson et al., 2003). The main concept in this field is that politics are important to understand the interactions between human and environmental degradation. This also concerns the power relations, and specifically how environmental effects facilitate the control of powerful actors such as stat on people. This particularly concerns the challenges in access to natural resources, and the way is shaped by existing power relations among different stakeholders (Mukherji, 2006).

The studies by Prakash (2005), Mukherji (2006) and Birkenholtz (2009) focused on intensive groundwater use for agriculture in villages and the states of India, and the socio-political challenges regarding groundwater abstraction. The main issues regarding the political ecology of groundwater resources that have been undertaken emphasise that how different access to groundwater resources (caused by water availability, abstraction regulations or governance) lead to unequal distribution of water among farmers. In this study, based on social research understanding, I will reflect on the issues of inequity in water allocation in groundwater irrigation management in Kashan (Iran) in Chapter 6; however, the political ecology of groundwater resources is not the main subject of this thesis.

Prakash (2005) studied groundwater over-abstraction for irrigation in a village in Gujarat with the aim of assessing the impacts of declined water availability on increased differentiation between farmers. He suggested that because richer farmers who owned the wells refused to sell excess water to poorer farmers, agreements between rich and poor farmers to introduce a lower electricity tariff for water abstraction could reduce the risk on inequity in accessing to water for poorer farmers. Mukherji (2006) argued that confusion over groundwater governance structures in West Bengal and Gujarat, where there was no groundwater regulation, has led to overexploitation of aquifer. Birkenholtz (2009) analysed groundwater reform in Rajistan that was encouraged by the World Bank and which introduced more strict regulations on private property rights. Farmers agreed with the regulations of the reform as their assumption was that they can influence authorities. However in contrast their restrictions have increased and they could not influence authorities' decisions in governing groundwater resources (Faysse and Petit, 2012).

In this thesis, the concept of groundwater and irrigation system management as a common-pool resource is the main focus of analysis in the context of dry regions. Ostrom's (1990) analytical approach is particularly selected for this study, to explore the potential in local irrigators within the state-led governance system of Iran. Also this approach can shed light on the related concepts such as community-based irrigation management; collective action and the use of simulation games to improve social learning processes at local level, which will be investigated in this thesis (see Chapter 6 and 7). Different governance systems have made these three approaches distinctive to achieve sustainable management, particularly from the aspect of engaging water users in governance, implementation and users' benefits (Faysse and Petit, 2012). Although these approaches share many similarities in their methods, each approach seeks a different focus for academic analysis. While the grounded 'social dilemmas' (or tragedy of common-groundwater resource) (Ostrom, 2007) in using groundwater resources are similar in all three measures, the institutional context, governance and implementation, informal rules and social norms vary between different places in different countries and cultural contexts. Schlager (2007) stated that groundwater case studies demonstrate the capability of local users in crafting solutions to their own local common-pool dilemmas. This is consistent with Ostrom's (1990) viewpoint, which suggests that successful management of common-pool resources is more likely when users participate in the design, management and implementation of rules for water use, rather than when there is state management or privatization (see Chapter 6, 7).

In this section, I classify the main groundwater irrigation management concerns into broad themes, which help to analyse different aspects in a more structured way throughout the thesis. One general theme is **a.** local indigenous knowledge, which I will elaborate in the following section and will analyse further in Chapter 6, the other themes such as **b.** governance, **c.** adaptive management and participatory modelling will form the next broad themes to be discussed.

1.3. Human-Related Water Scarcity: The Role of Local Indigenous Knowledge

Groundwater scarcity is a social as well as a technological problem and as mentioned previously, solutions are difficult to find (Chapter 2) (Rosegrany et al., 2009; Cominelli and Tonelli, 2010). Regarding groundwater irrigation, generally farmers have been the stakeholders most affected in conditions of water crisis while "throughout the entire period… farmers have had very little say in the design and management of public irrigation systems" (Molle and Floch, 2008, p. 112). Due to the fact that farmers are the main stakeholders of water usage around the world, if socially crafted norms and beliefs deteriorate as a result of unsuitable management practices, there is the potential for negative human impacts on water resources and destruction of formal rules (Dietz et al., 2003).

Article 14 of the European Water Framework Directive (WFD), emphasises the need for stakeholder participation and the use of experts' knowledge in the water management decision-making process (European Union, 2000). This active involvement of different interested parties to generate mutual respect will promote transparency and trust among various stakeholders. Also provision of accessibility to information and representativeness are some of the factors required for effective decision-making processes. Equitable water allocation and distribution represents the main foundation for managing scarce water resources, while multiple organisational conflicts and disagreements in equitable distribution of water is the main cause of water scarcity (FAO, 2012) (see Chapter 2).

In this thesis I will argue that participation of farmers in groundwater irrigation management and sharing knowledge is essential. This is important because of the crucial impact that each individual action and decision has on the pattern of water use particularly in the common-pool irrigation system (Lankford and Watson, 2007). The fundamental role of participation in water management under harsh and water scarce conditions is evidence as the competition, and probable conflict, for water is very common for sustaining livelihood. Groundwater management for irrigation where there is a severe water scarcity and prolonged drought chiefly depends on acquiring collective action and sharing knowledge by irrigators. Thus, this thesis emphasises the importance of creating a dialogue and discussion amongst local stakeholders, aimed for improving social learning process and local capacity building for groundwater irrigation management (see Chapter 6, 7).

1.4. Groundwater Governance and the Role of Local Farmers' Communities

There has been little success in designing effective and successful groundwater management strategies. This is because of the complex nature of groundwater as an invisible resource and a common-pool resource property. Its governance also involves multiple users with different interests and stakes (Bouarfa and Kuper, 2012). Mukherji and Shah (2005) propose that successful groundwater management requires a shift from technical, legal or economic management towards a more integrated and holistic governance approach.

According to Mollinga (2008), water management is an inherently political process as it is based on water control in which ‘any human intervention in the hydrologic cycle that intentionally affects the temporal and/or spatial characteristics of water availability and/or its qualities, is a form of water control’ (Mollinga, 2008). Based on Mollinga’s viewpoint the technical/physical control, organisation/managerial controls and socio-economic and regulatory controls, must be carefully monitored to ensure effective water management. According to Mollinga (2008, P. 11-12) water allocation quotas and water rights comprise a crucial part of “everyday politics of water resources management”, and form part of the routine daily practices of water use and management among farmers. In this regard, and particularly in irrigation practices in which water rights and allocation rules are practiced daily by farmers, the social associations and power relations need to be clearly addressed (Semmahasak, 2013). According to Azkia and Hooglund (2011) many of the problems associated with water abstraction and use, are related to pressures imposed by managers and local political powers. The role of local institutions and non-governmental organisations in empowering individuals and local communities’ capabilities has been generally neglected (see Chapter 6 and 7).

Water management has been mainly controlled and regulated within the discipline of the natural sciences and engineering hydrology and through formal institutions for economic development purposes (Molle et al., 2008; Lankford and Hepworth, 2010; Pahl-Wostl and Kranz, 2010). Solutions that identify human need and address institutional arrangements are essential in confronting future irrigated agricultural practices in developing countries (Ostrom and Gardner, 1994; Lopez-Gunn and Llamas, 2008; Turral et al, 2010). This holistic approach is one of the main principles of the Integrated Water Resources Management (IWRM) framework which seeks efficient and impartial sustainable water resources development and management (Rahaman and Varis, 2005; Hooper 2006; UN-Water, 2007; Leidel et al., 2012; Semmahasak, 2013).

1.5. Interdisciplinary Participatory Modelling Approach for Adaptive Groundwater Management

Effective water resources management requires an integrative approach which includes both physical and social dimensions and their inter-linkages. Furthermore, interdisciplinary approaches to complex groundwater systems which address both socio-economic and environmental interests are critical. This thesis aims to develop an interdisciplinary and participatory modelling effort that engages participants in planning, designing and running a simulation exercise for their actual local irrigation practice. The study has partly contributed to the research effort by integrating a social simulation with a physical hydrologic model to achieve collective decision-making and foster dialogue (see Chapter 4, 7). Using an interdisciplinary method in a participatory and bottom-up approach can enable local farmers to contribute in government policy management and planning. This requires a participatory management approach using innovative methods for engaging various interests and viewpoints of stakeholders which this study has attempted (see Chapter 4, 6 and 7).

The concept of 'adaptive management' played a key role in governing groundwater resources which was in the centre of Shah's (2009) analyses. Shah (2009) considered users' participation in water demand management strategies as essential for good water governance. The adaptive management was identified by Blomquist (1992) as one of the indicators of performance and it is an essential element in analyses of institutions (Blomquist and Ostrom, 2008) (see Chapter 2). The adaptive management approach, by considering uncertainties and complexities of water resource systems, provides a systematic basis for improving management-decisions. The adaptive management approach implements different management strategies by actively involving stakeholders in the management process. The stakeholders learn from the consequences of applied strategies. Within an iterative and adaptive process of developing, implementing and monitoring of water resources management, the best management solutions can be formulated. This thesis aims to develop an innovative and participatory irrigation management process, which would lead to more effective adaptive management strategies (see Chapter 7).

Adaptive management is the most effective method in complex water resources management because this approach to water management allows stakeholders to learn from past experiences and adopt more appropriate solutions. Adaptive management is substantially different from traditional methods of resource management, which were based on command and control. The approach is based on discussion, mutual dialogues, scenario planning and quantification of risks to reach an acceptable solution. Within this approach, centralised governance is replaced by polycentric governance, following shared responsibilities and a participatory resource management approach. Adaptive water management also integrates technical, social and ecological problem solving approaches.

It is important to develop new approaches for water re-allocation which utilise natural and technological mechanisms, in combination with social and cultural considerations that are responsive to uncertainty and complexity of water management decision-making process (Poff et al., 2003; Qadir et al., 2003; Forouzani and Karami, 2010). Therefore, this study takes into consideration the local social and physical circumstances of farmers in an interdisciplinary effort, in order to provide a more integrated approach that also adds more complexity into a management process. As adaptive management approach is a learning-based process, participation of stakeholders is essential. Adaptive participatory process can empower local farmers in their decision-making and social learning process (see Chapter 7).

Some of the major water policy agendas, for example the European Water Framework Directive (EWFD, 2000) have emphasised the importance of stakeholder engagements through participation. In article 14 of the Water Framework Directive (WFD), a participatory approach to engage stakeholders' perspective is promoted. Implementation of the WFD presents water managers with considerable challenges. Water systems are complex and the majority of expert knowledge is represented in computer models with many and varied uncertainties (Walters, 1997). The Rio Conference and Agenda 21 (1992), and the World Summit on Sustainable Development (WSSD), the UN Economic Commission for Europe (UNECE) and Johannesburg Plan of Implementation in 2002, emphasized the importance of access to knowledge and public participation of stakeholders in decision-making to achieve justice in environmental management. Because water management is closely linked with many different human activities that potentially have conflicting interests over water, water policies must consider competing values, interests and the perspectives of various stakeholders during the decision-making process (Blomquist and Schlager, 2005; Blackmore et al. 2007). Socio-economic aspects of water related issues are embodied in different expert disciplines and different actors, who have specific interests in water resources. As a result, both physical and socioeconomic knowledge are frequently challenged by stakeholders (Fischer, 2003).

In this thesis a physical hydrological model is integrated with a social simulation exercise in an innovative and community-based manner. While there are different modelling approaches in the field of natural resources management to engage stakeholders in adaptive management process, here a participatory modelling process was developed with stakeholder participation.

The integration of stakeholder perspectives in the decision-making process is considered the most effective method for resource management and allocation (Mitchell et al., 2012). It is suggested that the combination of a participatory modelling process within adaptive management will lead to more deliberative and legitimate outcomes that take into account the different perspectives and viewpoints of users. Considering the crucial role of groundwater users' perspectives in management decisions, the participatory modelling approach was selected to deliver well-informed and adaptable management solutions in the specific context of Kashan, Iran.

The modelling process in this study develops a simulation role-play game which was designed by local farmers (see Chapter 4). An interdisciplinary modelling study was also undertaken by incorporating some of the local factors (e.g. scenarios) in a hydrological model and then discussing the outcomes with farmers to generate further dialogue. Using simulation models to manage complex natural resources such as groundwater or irrigation systems have been found to be effective social methods to elicit knowledge from stakeholders (e.g. Ostrom et al., 1994).

The modelling process, in contrast with common social research methods, are effective in visualizing the real system (i.e. invisible groundwater resources) for participants, which forms an ideal basis for investigating farmers' behavioural approaches, motives or conflicts for collective action regarding common-pool resources (Burton, 1989; Hagmann and Chuma, 2002) (see Chapter 4, 7). The participatory simulation model developed for groundwater irrigation management in this study also aimed to foster discussion and dialogue amongst participants so as to achieve collectively agreed management solutions which could be locally adaptable by farmers in Kashan.

The use of models in decision-making process is not a recent development as they have been applied in many studies from 1961 onwards (Rouwette et al., 2002). Different modelling approaches include group modelling or cooperative modelling (Tidwell et al. 2004), shared vision mapping (Palmer, 1999), and collaborative decision making (Kreamer and King, 1988). They all have a common aim which is to engage stakeholders in the process of conceptualizing and analysing knowledge and viewpoints into illustrative output (i.e. a model) to tackle a complex problem (Van den Belt, 2004). Participatory modelling creates group thinking and a dialogue exchange which can lead to group learning or social learning (Van den Belt, 2004).

Hydrological models can only represent specific and limited features of the physical environment. However, they create a 'black box' in which both stakeholders and policy decision makers may be unable to verify the legitimacy and validity of their outcomes and to what extent their predictions are realistic (as examined in Chapter 4). These models are heavily dependent on the modeller's expertise to produce a more reliable picture of the future which can be trusted to influence the policy-making process (Shackley 1997). The use of existing models might eventually be challenged by stakeholders, and when there is a lack of trust in the model results, it can ruin the process. In this study, the use of a hydrologic model is developed within a participatory modelling process (see Chapter 4). The main inputs and the final outcomes of the model are discussed and validated based on local farmers' knowledge. This has eventually increased the level of their trust to the model outcomes, thus the use of model was not entirely challenged or rejected by stakeholders (see Chapter 7).

1.6. Thesis Aims, Objectives and Scope

This thesis investigates the potential role of participatory role-play games for irrigation management, within an adaptive management approach in the Kashan area of central Iran.

The combination of disintegrated water management practices in Iran, inappropriate water allocation, low efficiency of irrigation distribution system and unsustainable water developments has failed to provide sufficient water for social, agricultural and environmental demand. Usually government policies depend upon technology or imported management strategies from abroad to address water management problems. Under this situation there is insufficient room to develop democratic approaches for participatory or community-based local resource management. This has led to a lack of capacity to improve the effectiveness of management decisions for the main stakeholders and to empower local institutions to adopt locally suitable technologies or management solutions. Understanding local stakeholders' behaviour can improve local water use efficiency. Thus this study contributes to the limited literature on social dimensions of farmers' 'deep' knowledge, their behaviour in decision-making and how they cope with water scarcity at a local level. Moreover, this research develops an innovative and participatory method to engage local farmers in in-depth discussions of the local management process. The study included the development of a simulation role play exercise within an interdisciplinary study effort for the first time, which engages local stakeholders from the beginning throughout the modelling process and also incorporates their viewpoints into a more technical hydrological model and its outcomes. The aim is to empower farmers' decision-making capacity within an adaptive water management process. The research examines the potential value of utilising innovative social simulation methods such as role-play game for achieving collective decision-making, to elicit more in-depth and valuable knowledge and improve communication among local farmers. In this study, a novel Irrigation Management Game (IMG) was used as a participatory modelling tool to provide detailed analysis on how to achieve agreement and collective decisions on irrigation systems in a way which is sensitive to the local situation (see Chapter 4, 7). This participatory management process should ultimately lead to a more transparent, self-organized and educational procedure for farmers to select better irrigation management options in the particular social-cultural and political system of Iran.

The Kashan case study area is located in central Iran: a region of arid climate with a low annual precipitation (140 mm/year) and high temperatures. The area is characterised by two separate mountain and plain regions. This study investigates groundwater irrigation practices in the arid plain region of this case study. Groundwater is the main source of water and farmlands are mainly cultivated with wheat, barley, maize, pistachio and pomegranate by small-scale farmers (see Chapter 4).

The aim of this study, to understand the effective role of role-play games in participatory adaptive irrigation management is addressed by the following objectives:

1. To evaluate the local capacities of farmers to participate in irrigation management game processes in the arid and semi-arid context of Iran;

2. To investigate farmers' perspectives and knowledge on different irrigation regimes, water use efficiency, contemporary water management challenges and the future difficulties for groundwater sustainability through social research method;

3. To examine the local motives and obstacles for shifting towards more self-managed and effective irrigation performance through participatory adaptive management and investigate how the occurrence of social learning could be facilitated and improved;

4. To develop an innovative participatory simulation modelling process with farmers to facilitate more collaboration and mediating between governmental authorities and farmers towards organization of a successful adaptive management approach.

1.6.1. Thesis Structure and Outlines

This chapter has reviewed the main challenges regarding global water management and governance and produced an overview of the main problems. It sets out the research questions and the main aims and objectives of the research.

Chapter 2 provides a literature review of this study. It is presented in two parts; the first giving an overview of the global water management problems particularly the current water crisis in arid regions of the world such as in the Middle East, the importance of groundwater resources for irrigation practices and existing governance problems in dry countries. The second part discusses the implementation of the participatory adaptive management approach in successful groundwater irrigation management around the world. This emphasises the crucial role of stakeholders' engagement in the development of participatory modelling for improving resource management decisions.

Chapter 3 consists of two main parts; Part I reviews the traditional water management and irrigation practices in Iran in three sections. First, it summarizes the geographical and climatic characteristics of Iran to provide background of the country; and second section describes the traditional irrigation water exploitation systems (i.e. Qanat). The third section provides a chronology of the water governance and management system of Iran including current challenges. Part II reviews the current water and irrigation management problems under the Iran's governance system, also the recent changes in management approaches towards participatory management. Finally the existing barriers for resource users to participate in the government management-decisions are reviewed.

Chapter 4 introduces the methods and describes the socio-economic as well as the biophysical characteristics of the Kashan case study area in arid central Iran. The methodology is divided into three parts: it first describes the social research methods that were used, including interviews and a role-play simulation. Second, it describes the development of the companion modelling process in a participatory simulation exercise and the use of a hydrological model of Water Evaluation and planning system (WEAP) for testing the scenarios obtained from the Role-play Game (RPG) simulation. Third, it describes the process of resource mapping, selection of participants and the development of the Role-play game for irrigation management study with Iranian farmers.

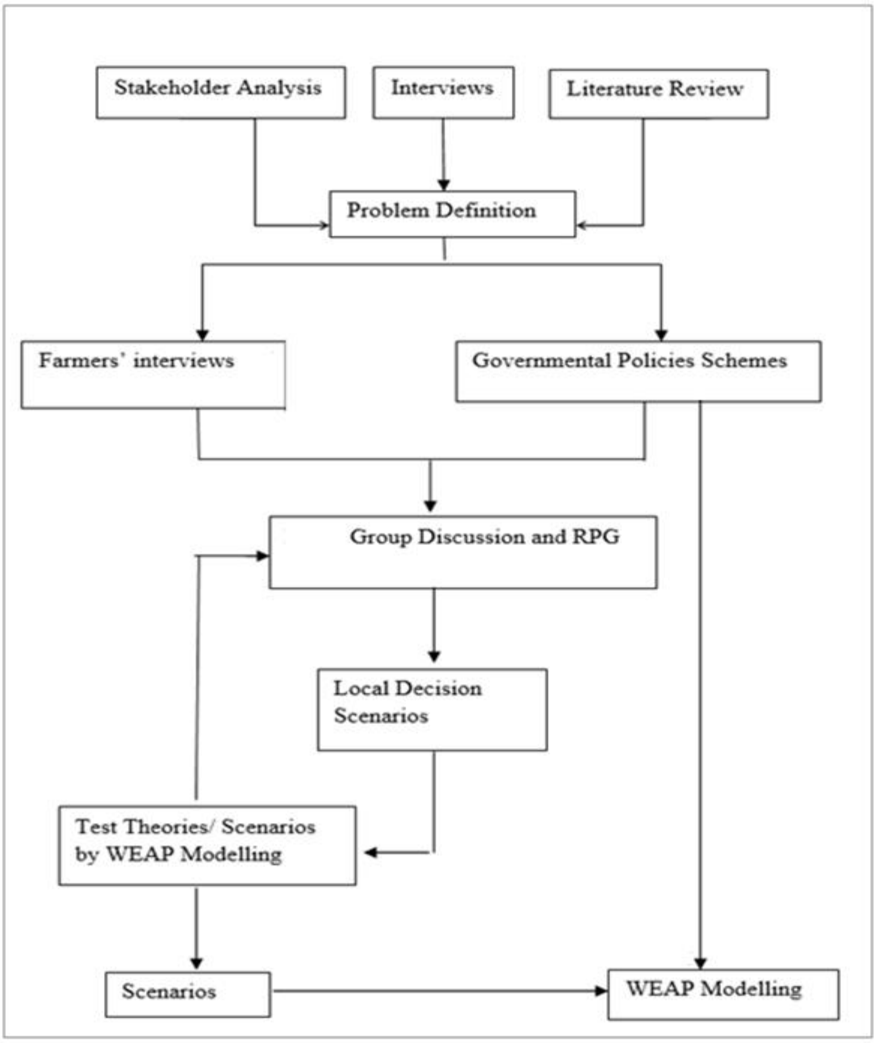
Chapter 5 describes the WEAP hydrological model and reviews its implementation in various case studies. A justification of choosing this model and its capability to incorporate socio-economic aspects of water management is provided. The results of the scenario evaluation are given in the final section.

Chapter 6 first reflects on the empirical findings of existing challenges regarding groundwater irrigation governance and management in Kashan, using interviews and group discussions with local farmers. The chapter then considers the empirical findings on the most influential factors affecting farmers' participation and behavioral approaches in joining governmental irrigation management schemes in the region.

Chapter 7 reflects on the outcomes of the participatory role-play game exercises as well as farmers' discussions and perspectives regarding the hydrologic modelling outcomes. The chapter then argues for the need to enhanced capacity building through local institutions for local farmers, and the need for a transition towards more adaptive and participatory irrigation management in Iran.

A review of the main research contributions and findings is provided in Chapter 8. Further recommendations, research gaps and potential for development of future participatory simulation exercises, particularly in a similar climate and management context are presented.

Figure 3 Flowchart of Thesis Methodological Structure



1.7. Conclusion

In summary this chapter has provided a general review of the existing global water-related challenges. It highlights the crucial role of groundwater resources as the main water supplier for social and economic development in arid regions of the world. Different concepts such as adaptive management, integrated and participatory modelling, local knowledge and farmers' engagement into management processes have been the main emphasis for developing the main objectives of this research study. The following chapter reviews the concepts regarding groundwater irrigation governance and the recent management approaches that provide further rationale for the methodological approach adopted for this study.

CHAPTER 2

Literature Review

Conceptualising Participatory Water Management; Reinforcing Collective Action Using Simulation Games

Introduction

This chapter develops the theoretical context of this study, expanding on the topics introduced in chapter 1, and elaborates on the research approach and the methods. The literature review provides broader perspectives on water and irrigation management, within certain biophysical and socio-cultural contexts. In particular, participatory adaptive groundwater/irrigation management is used as a foundation concept of this review to analyse and support research arguments and justify the research methods.

In this chapter, the context is divided into three parts: Part I. reviews global water management and governance systems. In this section, the analysis of the water crisis focuses on arid and semi-arid regions specifically in water scarce countries. The causes for conflicts, governance and the challenges for irrigation management are reviewed. Part II. reviews farmers' decision-making. The literature review focuses on areas where water users (irrigators) are effectively engaged in the management and decision-making process to create their own water governance system. Part III. reviews participatory adaptive water management at local/regional level, and particularly outlines empirical literature on the use of simulation games within participatory water/irrigation management to improve decision-making process and irrigation efficiency. This strand of the literature is utilised to shape the methodology design (Chapter 4), in which I test and examine an innovative methodological approach to engage stakeholders in the management-decision process to reinforce collective action by local irrigators, within social learning process.

PART I: Global Water Management

2.1. Water Crisis in Arid and Semi-arid Regions: 'A wicked' Problem

Water scarcity emerges from a lack of available freshwater resource. This is partly a drought-related phenomena but it also reflects policy failures leading to inefficient water delivery and distribution of water within the public or private sectors in addition to water overuse. These are mainly social and governance factors and result in water crisis over a long time (Loftus, 2009). The World Water Development Report (WWDR) (2006) and Human Development Report (HDR) (2006) have indicated that water scarcity is a consequence of inefficient governance and failed policies and management plans rather than the particular environmental characteristics of a region (Loftus, 2009).

A 'water crisis' is a familiar situation that has frequently occurred in arid and semi-arid parts of the world. This has caused ongoing historical water conflicts within and between nations in arid regions (Hatami and Gleick, 1993; Kamash, 2007). Water related disputes, particularly in the Middle East, go back to ancient eras (e.g. Tigris and Euphrates River basin is a symbolic example of water-related conflict~5000 years ago). Several recent reports (Ehrlich, 1972;

Gleick, 2000; Allan, 2002; Amery, 2002; Wessels, 2009) on water conflicts in this region, indicate that these problems continue today. The nature of existing arguments vary from conflicts over management of water supply, to issues of water accessibility and allocation at a national or international level (i.e. when water delivery systems are targeted to be attacked during modern wars) (Hatami and Gleick, 1993). Some statements emphasise the severity of water conflict, for example Hans van Ginkel (1999) indicated that 'Conflicts over water, both international and civil wars, threaten to become a key part of the 21st Century landscape' (Financial Times, 15 March 1999, p. 4). Also Butler (1995: 35) stated that 'nowhere is the potential for a water war greater than in the Middle East' (e.g. Starr, 1993; Lonergan, 1997).

Alongside these pessimistic perspectives on the potential for future water disputes in the Middle-East, there are some optimistic viewpoints that 'water wars' will not occur in this region. One of the earliest suggestions in this regard was made by Deudney (1991:26) who argued that the precious characteristics of water will make war less likely (Elhance, 1997; and Wolf, 1995, 1999). Alam (1998) argued that there is increasing evidence of collaboration around the world, to support international cooperation for freshwater management between nations. Alam's 'water rationality' concept is particularly expected from cooperation between India and Pakistan for good management of their shared water resource (Indus waters). It is proven that water war does not result in any long term security for the two nations (Alam, 2002). This concept suggests that countries will eventually act in ways to encourage security of their freshwater supplies through cooperation and negotiations.

Dolatyar and Gray (2007) have denied the potential for water war in the Middle East region, mainly due to the fact that water is very essential substance of human resources and it will cause greater damage to put water at the risk of war. Some scholars argue that water disputes can contribute to tensions around available water-supply resources; however the scarcity of water resources will generate greater collaboration between stakeholders for more equitable decision-making and innovative technologies for more negotiations among politicians to resolve water management problems (Dolatyar and Gray, 2007; Wolf, 1999; Hatami and Gleick, 1993).

Currently global water planning and management is challenged by diverse complexities, uncertainties and disagreements, and hence they are called 'messes' (Ackoff, 1979) or alternatively 'wicked problems' (Rittel and Webber, 1973). The 'ill-defined' (wicked) nature of water management problems reflects uncertainty, a limited understanding of water system, and the associated risks in decision-making and different viewpoints that describe the social value of water resources (Rittle and Webber, 1973; Reed and Kasprzyk, 2009).

Rittel and Webber (1973) described water management and planning as a class of wicked social value problem, as the problem was characterised by the following:

1. a lack conclusive formulations;
2. problems can be true or false;
3. they are unique;
4. they incorporate decisions that are usually irreversible, and
5. the consequences of planning and management decisions are uncertain or even unknown.

Only a fraction of the water resource management literature addresses the particular 'wicked' nature of water management problems through combining social, technical and scientific measures (Reed and Kasprzyk, 2009). Yet, finding management solutions for water resources requires further consideration of the variety of knowledge, perspectives and values in the decision-making process for sustainable water management. As a consequence, there is a need for different innovative methods of collaboration, to help improve water management and planning (e.g. HarmoniCOP, 2005; Mostert et al., 2007). This thesis addresses this gap by developing an interdisciplinary and innovative participatory method with stakeholders for local groundwater irrigation management (see Chapter 5).

Effective water resource management requires an integrated approach, which considers both physical and social aspects and their interactions for local or regional water management (See Part II). Under a condition of high uncertainty relating to the future sustainability of water systems, there is a need for more adaptive management solutions, which this study has investigated through its participatory modelling, using simulation role-play game (see Chapter 4). Water management has been perceived for a long-time as a political issue which must be controlled and managed under top-down governmental regimes, particularly in authoritative and arid countries of the world including Iran. However, modern management approaches seek more democratic and collaborative practices for the future sustainable management of available water resources (see Chapter 1). According to Ostroms' (1990; 1992) worldwide experiences, more effective and successful water management, particularly of smaller scales, is certainly possible through collaborative effort and a bottom-up approach, which involves water users in management decisions. Thus, in this study the development of a democratic and participatory approach for adaptive irrigation management with Iranian local farmers is designed and developed. This is undertaken within a particular farming community setting, in the arid Kashan region of the country. It is argued that in developing countries, specifically in the Middle-East, finding alternative solutions to the water crisis is even more problematic, because deterministic governmental policies are heavily dependent on technology to overcome water management conflicts (see Chapter 3).

Under this situation, there is usually a lack of capacity to improve water supply sources or the water transmission infrastructure as well as a lack of capacity and budget to empower institutions to make effective decisions. Consequently there has been little consideration and effort to develop democratic approaches to water management. There is a need for more investment in collaborative and integrated decision-making process in order to encourage participatory management at a lower level. This study addresses these shortcomings and management failures within Iran's authoritative governance system in terms of the problems this poses for water and irrigation management practices. To address this problem, I have reviewed existing approaches for successful irrigation management globally, presented in the third part of this chapter. I will emphasise the advantages of using participatory water management approaches, the characteristics of a successful participatory irrigation management and the way it should be applied in an interconnected social-ecological irrigation system. I will also address this question of whether this approach can lead to transition to a more transparent, democratic and sustainable water management within the particular socio-cultural and political system of Iran (see Part III of this Chapter and Chapter 7).

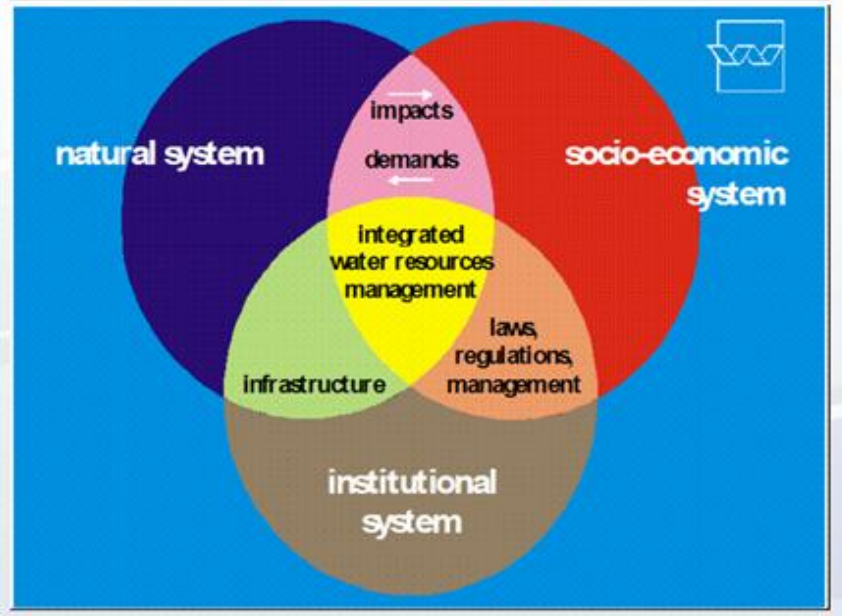
Before moving on to the participatory water management concept, this chapter reviews some of the most fundamental and recent management frameworks and perspectives. This will be the basis to develop my approach to more adaptable and sustainable water management for future groundwater resources management.

2.2. Integrated Water Resources Management (IWRM) Framework: Principles and Shortcomings

Traditional water resource management approaches have been mainly sectoral (domestic, agriculture, industry, environmental conservation, etc.) and lack effective coordination between different sectors. This has made this approach inadequate for addressing global/national water challenges. Due to the fact that water is flowing in nature and crisscrosses boundaries, particularly in river streams, the previous perspectives for development have resulted in various socio-economic and environmental disadvantages. Top-down centralized governance system in most Middle-East regions is mainly focused on supply-side management, and lacks a holistic vision for effective and integrated water management and development plans. This has led to insufficient and unsustainable water development plans in many developing countries (Xie, 2006). This trend has been observed in nations under fast development path, for example in Iran the supply-side water management efforts after the revolution (and during 1960s) have been concentrated on engineering and technical solutions such as establishments of hydro-power dams (see Chapter 3). The centralised governance and management approach has not led to integrated and successful water management strategies in Iran and over only a few decades has provoked a water crisis in the country.

Hence, as discussed the water crisis in both Iran and in other arid regions is currently regarded as a consequence of governance rather than physical scarcity. The inadequate water allocation, pollution, low efficiency of water supply or distribution services under disintegrated management approaches, fail to equally provide water for public and private, as well as social and environmental water demands (Xie, 2006). These limitations have led global regulatory bodies to create the Integrated Water Resources Management (IWRM) approach to address traditional water management practices. This has opened a new paradigm for future sustainable water management (Figure 4). In 1992, the Dublin Principles were merged into the Agenda 21 of the UN Conference on Environment and Development (UNCED). These have greatly influenced the expansion of the IWRM and its widespread application around the world. IWRM can potentially put the Dublin principles into practice.

Figure 4 Integrated and Adaptive Water Management



Source: www.newater.info, Accessed 2015

The Global Water Partnership (GWP, 2000) (an international organisation to promote sustainable water resources management), has defined IWRM as: (emphases are added in bold)

"*a process that promotes the* ***coordinated*** *development and management of water,* ***land*** *and related resources, in order to maximize the resultant* ***economic and social welfare*** *in an* ***equitable*** *manner without compromising the* ***sustainability*** *of vital ecosystems.*"

This definition emphasises the coordinated nature of the framework in terms of its holistic view which considers social and economic equality in management decisions as well as the sustainability of the water resources.

The United States Agency for International Development (USAID) definition of this framework is:

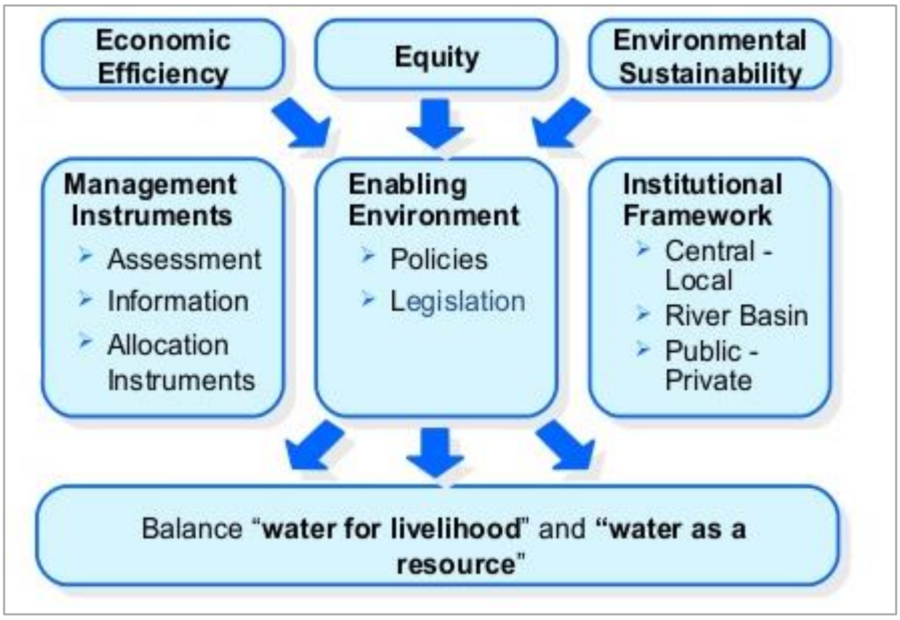
> *"IWRM is a* ***participatory*** *planning and implementation* ***process****, based on sound* ***science****, which brings together* ***stakeholders*** *to determine how to meet society's* ***long-term*** *needs for water and coastal resources while maintaining essential* ***ecological*** *services and* ***economic*** *benefits."*

From these two definitions it can be concluded that IWRM is a coordinated approach which considers water and land resources in conjunction, for sustainable management and equitable social and economic welfare. It utilises a participatory process that is based on scientific understanding and adopts a democratic approach for the long-term ecological and economic beneficiaries. The participatory aspect that is embedded in this framework definition is the key factor that links this framework to the adaptive management approach. The integrative aspect in terms of engaging various stakeholders, scientific vision and sustainability in ecological and economic features of water bodies in the future is another feature of this framework. This framework is a process and a tool in which different development projects can be evaluated. It does not provide direct prescriptions for water resources problems, but offers broad guidelines, principles and tools in an integrated mode which should be tailored to the particular context of any country or region (Xie, 2006).

In this framework the main conceptual approaches are: 'Integration, Decentralization, Participation, and Economic Sustainability' (Xie, 2006). This integrated approach aims to address the shortcomings of sectoral approaches in traditional water management by including economic, social and environmental development in all horizontal sectors influencing water management.

In addition to horizontal integration, vertical integration synchronises local, regional, national and international water users and organisations (Figure 5).

Figure 5 IWRM: Vertical integration structure



Source: Gurunathan, 2013, P. 4

Although IWRM provides some fundamental principles for a comprehensive and integrated framework for global water management, many criticisms and weaknesses have been suggested as the framework has been widely implemented in different countries. For example, the framework has not considered different socio-economic and physical variations in environmental conditions when rapid changes make the water management practices more complex and challenging (Biswas, 2008). According to Biswas (2008), this framework does not have any practical quality or value for recent and future water management, and has not improved water management at a macro or medium level (in South-east Asia and Latin America) (Biswas et al., 2004).

Three indications are believed to be the main downfalls of the IWRM framework (Biswas, 2008). First there is no clear definition of this concept or not any usable and implementable definition exists, which has reduced the application of this framework. Second, it is argued that many institutions around the world are still just continuing traditional management policies whilst attracting more funds and global acceptance without sufficient results. The third criticism outlined by Biswas (2008) is that a single paradigm of IWRM framework cannot simply be applied to diverse countries because the systems of governance, legislation, collaborative decision-making process and type of institutions are different from one country to another. More importantly, different social norms, cultures, physical and economic attributes, financial and institutional capacities and organisations (e.g. around groundwater abstraction) differ in different regions and countries. His conclusion is that fully integrated water management cannot be done and is not achievable in the real world. Although this framework provides comprehensive guidelines for policy makers the implementation of this approach is not applicable particularly in many developing countries.

The IWRM framework gives a holistic view to management approaches which are more legitimate in comparison with traditional top-down management system. However, inapplicability of the IWRM framework to the governance structure, legislation and collaborative decision-making process of Iran as well as the lack of institutional capacity to empower resource users' communities are the main reasons that this was not selected as a chief framework for this study. To implement this framework, it is important to translate the

IWRM guides into measurable criteria at a level that provides feasible integration of water resources in specific contexts. Furthermore, this framework does not adequately consider groundwater management decisions under conditions of high uncertainty. Moreover, this framework does not address the distinctive context of local irrigation management and does not provide practical solutions which can be achievable in short period of time. That is not to say that none of the principles of IWRM are applicable. Indeed in my study, I emphasise stakeholders' involvement in management processes and participatory actions. Water use efficiency is one of the main management instruments in IWRM that plays a crucial role in water demand management which is undertaken for this study. The main focus is to undertake a community-based management approach and to develop a participatory management process to achieve adaptive and locally relevant solutions, which are integral to some of the main principles of this worldwide framework.

My research focuses on groundwater resources. Here, the distinctive factor is that existing management approaches are very different from surface water resources. The conventional approach for groundwater resource management and governance is to balance water abstraction by the level that does not exceed recharge rate in a long-term within a particular aquifer; this is also known as the 'sustainable yield'. It has been argued that the IWRM framework would not be the best option for dealing with the groundwater over-abstraction phenomenon in developing countries (Moench, 2007). Moench (2007) argues that the lack progress in implementing conventional management framework (such as IWRM) to groundwater resources is a combination of social, technical, behavioural and organizational limitations that exist in different countries. This is why the adaptive solutions that can address the inherent limitations in different management context as well as the social aspects of groundwater resources are more effective than global water management frameworks. He argues that regarding groundwater resources, because the scale and boundaries of aquifers are unrecognisable and very difficult to identify, there is a mismatch between the scale and boundaries of human institutions and water management plans to develop any watershed institutions or management within the IWRM approach (Moench, 2007).

The adaptive management paradigm has emerged to address the impacts of climate change and high uncertainty and complexity that exist in managing groundwater resources. The adaptive management approach has been selected for this study over the IWRM framework because it can better account for the experimental participatory irrigation management practices in Kashan and their impacts on groundwater resource sustainability; flexibility in management approaches; self-organization by local users, high uncertainty of future groundwater resources under climate change. Adaptive management can also promote more deliberative methods of water management, and is more sensitive to the local conditions.

The adaptive management process provides useful community-based research and participatory tools (Mitchell et al., 2012). However, such approaches to groundwater resource management have not been widespread and the literature is not extensive. Ostrom's (1990) work on the role of social capital in managing common-pool resources by local communities has been a notable exception.

Recently the importance of farmers' decision-making behaviours for groundwater management has been noted (Mitchel et al., 2012). This is directly influenced by the level of farmers' engagement and collaborations for management (see Chapter 6 and Part II of this Chapter). There is still a lack of integrated management approaches which link physical and social aspects of groundwater management and which involve the participation of different stakeholders.

2.3. The Contemporary Challenges to Groundwater Irrigated Governance

The management of groundwater resources has faced different historical trends, and shows different features and problems in its development. Within the second half of the 20th Century, groundwater was considered as a threat to irrigation systems. This threat was due to the fact that irrigated systems were leading to a rise in the groundwater table leading to common problems of soil salinization and water logging or the so-called 'twin-menace' for many farming systems around the world (Bouarfa and Kuper, 2012). Large-scale irrigation and drainage schemes were applied around the world, for example in Pakistan 8000 public tube-wells were dug in following drainage programs and government provided subsidized diesel-powered pumps for numerous private tube-wells (Johnson, 1989). Drainage was increasingly considered as a supplementary water source given the lack of available surface-water supplies in large-scale agricultural schemes (Beltran, 1999).

Studies in Australia on the Murray Darling Basin emphasized improving drainage systems to remove excess salt from soil and lowering the groundwater table to avoid water logging problems (Beltran, 1999). Bouarfa and Kuper (2012) argued that the biggest challenge to the twin-menace problems occurred when the groundwater table dropped as a consequence of high number of private tube-wells. Water logging problems disappeared, but groundwater depletion has created a secondary reason for salinization due to poor groundwater quality (Kijne, 1995). Improving drainage systems in arid zones is necessary as without this, most systems are unsustainable (Bouarfa and Kuper, 2012), however, by using appropriate agricultural practices, soil salinity can be elevated as illustrated in North Africa by Bouarfa et al., (2009) and Ghazouani et al. (2009).

The main challenges regarding groundwater irrigation practices still remain problematic in arid and semi-arid regions. Shah et al. (2000) has identified a coherent framework of the three main problems that may occur for groundwater resources: 1. Depletion of aquifer due to over-exploitation; 2.Water logging and salinization due to inappropriate drainage and 3.Pollution of groundwater caused by agricultural, industrial and/or by domestic inputs. These three major problems are common in most arid regions that are dependent on groundwater resources for irrigation including the Kashan case study area in Iran. The main governance issues around groundwater resources are established based on controlling mechanisms, using economic tools and incentives such as increased water tariffs, removal of subsidies, penalties for over exploitation (see Chapter 6). However, this study looks at different innovative management approaches that encourage irrigators to collective decisions which are community-based and adaptive (see Chapter 4, 7).

By increasing demand for agricultural products, technological investments for exploiting more of groundwater resources have increased. According to literatures (e.g. Molle et al., 2003), changes in the governance structures from community-based to a state-led in developing countries have caused significant increases in levels of groundwater development and exploitation. Due to the increased number of individual investments in groundwater abstraction and numbers of technical and managerial problems, public tube-well schemes have declined. Many challenges have resulted when some countries have attempted to transfer public schemes to the individual farmers (Bouarfa and Kuper, 2012). Private tube wells have rapidly expanded in countries such as China, India and Pakistan since the 1990s (Chaudhry, 1990), which has affected the expansion of irrigated areas as well as agricultural productivity.

This trend has been observed in Iran as a result of introducing private pump technology to the traditional gravity irrigation systems and resulted in significant challenges for local farmers (see Chapter 4, 6). Currently, of an estimated 300 million ha of irrigated areas globally, 111 million are dependent on groundwater abstraction which represents 25% of the total irrigated water requirement (Siebert et al., 2005).

Over the last 50 years, the increased importance of groundwater resources for irrigation has increased the number of studies of groundwater governance in various analytical approaches. Numerous studies have been conducted with the aim of improving governance and institutional performance of groundwater resources around the world. The importance of localising irrigation studies and context-specific nature of groundwater irrigation systems for developing management options has been emphasised by Lankford (2006). The top-down governance tools have not been effective in arid developing countries. The bottom-up approach for designing or improving existing institutions requires reforms to not only make substantial changes in groundwater organization but also make reasonable and adaptable changes to adjust the system functions to local need (see Chapter 6). It is important to establish a powerful local institution, as many empirical studies illustrate, these local institutions are usually informal, fragmented and not efficient (Shah et al., 2004; Errahj et al., 2009) (see Chapter 7). This problem particularly exists in developing countries, because water resources are a substantial factor in their social and economic development, as the next section will explore.

PART II: Farmers' Decision Making

2.4. Characteristics of Groundwater Resources: Governance, Management Approaches and Farmers' Decision-making

Despite government responsibility for water scarcity in Iran at present, groundwater abstraction is unregulated and there has been considerable depletion of groundwater levels. This has caused land subsidence and increasing costs to farmers for abstracting further groundwater (Molle et al., 2003). In this context, government interventions have sought to ensure sustainable groundwater use, but have failed to consider either the socio-economic implications of the policy or the adaptability of local farmers (Molle and Mamanpoush, 2012) (see Chapter 4 and 6).

Local irrigation institutions play a major role in effective irrigation management practices, however in Iran key policies were designed by policy makers and engineers who, whilst they might have technical competence, generally lacked awareness of the local social, cultural and biophysical context (see Chapter 6). Many developing regions have seen a historical transition from community-based management to top-down governmental management, conflicts between these two management structures still exist, and their effectiveness is varied. In authoritative governance regimes it is important to understand the driving forces for improving management performances and empowering local capacity for better cooperation. Joshi et al. (2000) states that under farmer-managed system when institutional arrangements such as social sanctions, local monitoring, trust and farmers respect towards rules are stronger, the irrigation performance is higher.

Groundwater, as well as irrigation systems are regarded as common-pool resources and have been managed by a variety of governance structures which differ from each other (see next section). The main challenge in groundwater management is that it is seemingly an invisible source and its linkage to surface water resources (physically and ecologically) is so complex that it has not been well studied and understood. Thus the impact of human behaviour on groundwater resources is difficult to identify, observe and control (Mitchell et al., 2012).

Studies on common pool resources have identified two traditional approaches: a Pigovian approach (Pigou, 1932), and property rights. The first approach states that external governance, with centrally imposed regulations, can overcome over-exploitation of natural resources that might occur within the 'commons' (in this approach taxation is one of the most effective examples of an incentive for changing resource users' behaviour). Many policy analyses suggest that local communities are unable to establish their own norms, rules and property-rights to manage their common pool resources and to reduce the externalities (external costs) (Agrawal, 1998; Rasmussen and Meinzen-Dick, 1995). Based on this assumption, policy makers suggest external agents, such as central government agencies, should interfere in managing the resource to reduce the externalities for common users and to improve efficiency. The other most well-known suggestion was to establish property rights; specifically private property, as an effective way to manage common pool resources. In this regard, Coase (1960), Demsetz (1964-1967), Anderson and Hill (2002) focussed their studies on this approach which eliminates common access to limited public resources.

Although there were strong approaches towards governmental management and nationalization of resources, rich literatures emerged around common-pool resource management in the 1980s. This was followed by comprehensive field studies by Ostrom (1990, 1992), which emphasized the effectiveness and capabilities of local communities to self-organize their shared resources. Ostrom (1990, 2000) brought new insights on common-pool resources. She examined empirical case studies from communities around the world who successfully developed local-based institutions to collectively manage their shared resources, and had achieved higher management efficiency (Ostrom, 1990). It is evidenced by Ostrom that in the majority of examples, community-based management of natural resources were more successful and effective than conventional top-down governmental interventions. Her studies revealed that in most communities farmers were able to manage and organize themselves by overcoming collective action problems. Schlager (2007) suggested that the groundwater case studies demonstrate the capability of local users to craft a solution for their own local common-pool dilemmas. Weschler's (1968) study on groundwater management in California, at the same time as Ostrom, but in a different groundwater basin, indicates that the solutions that resource users craft are similar in comparable climatic and organizational settings.

Despite the limited number of recent studies in this field, the importance of social research on groundwater management has become increasingly recognized. Natural resource management is influenced by human activities, thus changing human practices and behaviour is important in improving the management of groundwater resources (Mitchell et al., 2012). There are some examples of how social researchers suggested different practical approaches to engage and improve human interactions with groundwater management. For instance as mentioned, the work by Ostrom (1965), on social norms in natural resources governance as her PhD thesis on groundwater management (Ostrom, 1965, 1990) or Syme et al. (1999)'s study of groundwater allocation reforms and justice in Australia. A comprehensive literature review on the social dimension on groundwater management has been conducted by Mitchell et al. (2012), who indicate that the importance and number of studies in this field is increasing. In their study, they emphasised the key role of trust and social norms in improving groundwater use behaviours (Mitchell et al., 2012). My study contributes to this existing research by investigating the role of social norms and equity in effective management of scarce groundwater resources by local farmers. I have also explored the role of participatory simulation exercises in achieving better management-decisions regarding irrigation practices by farmers (see Part III of this Chapter). In the Kashan case study the rules surrounding water use have been established through the historical evolution of traditional norms and fair water allocation (see Chapter 6, 7). Lam (1999) considered that there was "the need for efforts to help farmers enhance their capability to work together and to avoid a dependence mentality rather than imposing rules on farmers" (Lam, 1999, pp 192–193). Lam also emphasised that officials should not be involved in water allocation mechanisms as they lack the knowledge and understanding of 'socio-institutional aspects' of irrigation systems (Lam, 1999, P. 200).

Finally, Bouarfa and Kuper (2012) used case studies to analyse farmers' decision-making behaviours. They studied the impact of local institutions on groundwater sustainability and farming systems, fair access to groundwater and agricultural productivity. In their review they analysed the historical evolution of groundwater management to create a holistic analytical framework for the different case studies and to improve adaptive capacities of local groundwater users (Bouarfa and Kuper, 2012). Engaging farmers into the resource management process will reveal their main perspectives and attitudes as well as decision-making behaviours. Farmers as the main landholders play a crucial role in groundwater and irrigation management activities, they are entitled to resources, thus any changes to the resource is as a consequence of their practices and decisions (Mitchel et al., 2011). Mitchel's review of social groundwater management studies has revealed that there are very few papers done on farmers' decision-making in groundwater management, and among existing research the focus has been mainly on resources rather than actors (i.e. farmers and landholders). Some of the factors that affect landholders' behaviour have been explored by Bekkar et al. (2009)

and earlier work by Albrecht (1990; 1995) considers the connections between landholders' behaviour and their impacts on organisations. Bekkar et al. (2009) expanded their investigation to three different case study areas in Morocco, to understand the management, ownership, the attitudes toward aquifer recharge and the underlying reasons of groundwater overexploitation from the perspectives of local stakeholders. Farmers' behaviour towards groundwater use is classified as either offensive if they install private tube-wells, cultivate intensive water-use and high valued crops, adopt modern irrigation facilities such as drip irrigation or defensive strategies, when they decide to maintain their current water use that they are entitled by using the same tube-wells, cultivating less water consumptive crops, and reduce their land sizes (Mitchel et al., 2011; Kuper, et al. 2012). These two types of farmers' behavioural approaches exist in the Kashan case study area, as the offensive strategies are adopted by large-scale farmers and defensive strategies exist amongst small-scale farmer communities (see Chapter 6). These different strategies are believed to relate to the attributes of ownership status and accessibility to groundwater (e.g. individual/private vs. collective access), in which farmers with private tube-wells adopt offensive strategies while collective tube-well owners use defensive strategies (Mitchel et al., 2011; Bekkar, et al., 2009). Another pattern in the farmers' decision-making behaviour relates to the land size and farmers' access to water resources. In Albrecht's (1990) investigation on Ogallala aquifer in Texas, he revealed that farmers with large land holdings and better access to water resources were in a better financial status to invest in adopting more expensive irrigation equipment such as centre-pivots irrigation system. Also regarding groundwater governance and farmers' attitudes towards water scarcity condition, Albrecht (1995), compared the viewpoints of farmers and non-farmers on Edwards Aquifer in the Texas of United States (U.S.). In that study non-farmers had stronger beliefs that water issue in this particular aquifer was critically scarce. Farmers put more emphasis on the interfering role of government in worsening groundwater management practices and decisions.

However, as there is not any definite structured social theory on landholders' decision-making behaviours on groundwater resources, this is a significant gap in literatures (Mitchel et al., 2011). Relevant studies have been done on surface water resources, yet the nature of groundwater is different (as it is a hidden source, the boundaries are not clearly defined and it is recognised as a common-pool resource) and requires its own evaluation on decision-making indicators (Pannell et al., 2006). There are also very few research efforts pursuing an integrated approach, linking social and biophysical dynamics of groundwater resources management (Hammani et al., 2009). Some of the suggested trends for exploration are: the attributes of governmental interventions which affect farmers' decision-making behaviours; the attributes of global production prices; establishment of norms and social capital within local institutions (Mitchel et al., 2011; Ajzen, 1991). I will reflect on these factors in my analysis of local farmers' behaviour in my case study area in Chapter 6 and 7.

My research addresses the shortcomings of the existing Iranian literature on integrated participatory modelling approaches to link social and physical attributes (i.e. climate variables) for groundwater irrigation management. The research methodology introduces and develops an innovative participatory management approach to establish adaptive decision-making processes within an integrated approach, therefore addressing one of the main principles of IWRM framework. I have conducted a social simulation method in order to identify some of the main reasons behind local farmers' decision-making behaviours, regarding groundwater irrigation in arid context. Some of the social factors such as collective action and social capital revealed more insights on farmers' main incentives or obstacles for participation in local irrigation management practices as they directly engaged with this research study (see Chapter 3). In the next section, I discuss some of these influential factors on farmers' behavioural approaches in irrigation management. These factors improve the development of my participatory simulation game for this study (see Chapters 6, 7).

2.5. The Factors Influencing Farmers' Participation in Groundwater Irrigation Management

Considerable research has been completed by Ostrom and others (1990, 1992) on the effectiveness of community-based irrigation management, rather than governmental authorship. The most well-known comparison between different governance structure of Farmer-managed and Agency-managed irrigation systems was undertaken by Ostrom et al. (1994) in Nepal. This study explored how two different governance regimes can affect the incentives faced by governmental officials and farmers in one irrigation system. In this section, the incentives for farmer's participation in community based irrigation systems will be explored. It can be concluded from existing empirical studies that individual farmer communities can have different motives for cooperation in collective action. These motives may be generally classified into economic, social, institutional, technological and moral incentives as well as complex reasons. I will review the main incentives for collective action in community-based irrigation management system, in order to put my research findings into context.

According to Ostrom's (1994) research, that suggests several social factors as forming incentive structures in self-governance and farmer-managed irrigation system, the study by Wang (2009), uses this theoretical framework to analyse the governance of natural resources management in China and the factors which have crucial role in creating strong incentives for collective actions. Although the similar conceptual framework is not adopted for this thesis, however I review some of these features below, including: **a.** adaptive rules, **b.** effective institutions and social capital, **c.** structure of irrigators (irrigation land size; homogenous or heterogeneous farmer communities), **d.** property rights, and **e.** economic factors. Some of these factors proved to have crucial roles in creating behavioural decisions among farmers in my case study area. My empirical research revealed additional motivational factors which I discuss in Chapter 6.

2.5.1. Adaptive Rules (or rules-in-use)

Users of common-pool resources (or appropriators) are more likely to contribute to collective activity if they observe a set of trustworthy rules that help them to resolve the problems of collective action that may occur in their system. Any irrigation system requires valid and understandable rules to formulate relations between farmers and to assure them that their contribution will succeed and be of benefit to them. Farmers need to see the links between their self-interests and the results of collective action in irrigation system operation and maintenance (Williamson, 1985, 1990; North, 1990). The adaptive rules or 'rules-in-use' in each community are the product of years of social interaction and working together in resolving problems that farmers collectively face. These rules are unique and represent a set of shared social knowledge and experiences belonging to that community. Based on the empirical studies of Ostrom (1990), the written governmental rules, in the form of frameworks, have been proved to lack effectiveness and do not enforce resource management sufficiently. These rules can never "provide" common rules that have been established by years of experiences in each community (Ostrom, 1990). One of the most crucial features in self-governed irrigation systems is that farmers are able to make new rules to apply in their daily activities and re-structure the rules from time to time to match their everyday situations. There is a need to rationally establish and maintain rules that also provide positive incentives for farmers to cooperate. Since farmers are closely interconnected and deal with the existing problems, they will understand and perceive problems best (Freeman, 1989).

The similarity in understanding rules by farmers provides a higher level of effectiveness of rules and ultimately more effective irrigation (Pant and Lohani, 1983). These rules can be better understood by farmers which will reduce the cost of interpreting and monitoring the rules and deal with conflicts in local communities. Many researchers argue that farmer-organised irrigation systems in developing countries have proved to be effective, provoke fewer conflicts and contain a higher degree of collective action. These systems use a diversity of rules that are a result of long-term bargaining and power relations among farmers (e.g. Coward, 1980; Hunt, 1989; Ostrom, 1992; Ostrom and Gardner, 1994).

Within the community, collective problems could be resolved by the rules that distribute cost and benefits among farmers equally. Although not in every case the bargaining to set effective rules could enhance the efficiency of irrigation systems and reduce conflicts, the mutual reliance amongst farmers and the expected reciprocity created during long-term has helped to develop capacities among farmers to craft rules and overcome the majority of their collective problems. The rules are adopted and implemented within bargaining powers among farmers and changing any of these established rules would not be easy (Ostrom, 1990). These rules are more effective and collaborative, thus improving their independence from external agencies, rather than the enforcing rules imposed by governmental managed systems (Ostrom, 1990; Ostrom and Gardner, 1994).

The locally created rules are based on social capital and norms are representing the main values of that particular community, where they have agreed which decisions were correct and which were mistakes (Ostrom, 1992). Subsequently farmers are more likely to follow these types of rules and agreements. Within these agreements and collective activities farmers will be able to solve their collective action problems, and create norms and social capital which enable them to enhance their productivity and irrigation efficiency (Ostrom et al., 1994).

2.5.2. Effective Local Institutions and Social Capital

The capacity of communities' institutions to establish cooperation differs because of factors such as any history of cooperation, leadership, the level of social capital, and strong monitoring and sanctioning systems (Ostrom et al., 1994). Effective institutions are the foundation for establishing social capital and collective action. Through locally adopted institutions and rules, farmers will practice self-dependency, reciprocity and problem solving in their irrigation management. In the case studies reviewed by Ostrom (1994) it is observed that the chief (local leader) in irrigation systems is usually chosen and hired by farmers of the same community. In most cases the staffs are farmers themselves, who know the systems well and also have sufficient motivation to work and satisfy other farmers in keeping their job. The chief can work closely and in conjunction with other farmers to operate and maintain the system and reduce the cost of monitoring.

The importance of existing social capital for managing common-pool resources is due to recognition of the crucial role of human actions and behaviour in shaping and improving management of natural resources. The concept of social capital is chiefly about the effects of human interactions and individual relations within a social structure. Social capital in relation to natural resource management is defined by Coleman (1966, p.98) as a phenomena that is created by individuals who act collectively by spending time and energy with other individuals to seek better options to achieve particular ends.

The concept of social capital is an essential pre-condition for the participation of local people in decision making, and active adaptation. The notion of social capital is based on social relationships and the main factors included in this concept are norms of reciprocity, networks, social engagement and trust. Social capital can be defined as collective benefit in the form of shared values, beliefs, norms, trust and social networks and institutions that facilitate collective action for all individuals (Bhandari and Yasunobu, 2009). Participatory social research can build and strengthen human capital and social capital in terms of trust, social networks, norms and rules between users to engage stakeholders more effectively in collective actions and provide collaborative governance of water resources management (such as water governance or Co-management) (Lockwood et al., 2010; Mitchell et al., 2012). Social capital in relation to groundwater irrigation management emphasises the role of social norms, existing rules, water allocation mechanism, equity and other human dimensions such as trust and collaboration for improving the governance structure of groundwater resources (Ostrom, 1990) (see Chapter 6 and 7).

Social capital can improve environmental outcomes through decreasing transaction costs. It can also increase cooperation, information flows, monitoring and enforcement opportunities (Anderson et al., 2002). There has been much literature on the potential impact of social capital on collective action and the forging of sustainable institutions (Walters, 2002; Pretty and Ward, 2001) which has identified that where social capital is well-developed, local groups with locally developed rules and sanctions are able to make more of existing resources than individuals working alone or in competition. Adler and Kwon (2002) argued that social capital transforms individuals from self-centred agents and benefit-chasers to members of a community with shared interests, a common identity, and commitment to the common pool resources. Different ways of distinguishing between types of social capital include bonding, bridging and linking (Bhandari and Yasunobu, 2009; Pretty, 2003). It is stated that all three dimensions of social capital are associated and related to and can affect local natural resources governance (Pretty, 2003).

The definition of social capital for this thesis also includes the element of physical capital that Ostrom offered in her definition (1990, 1992), in which "social capital is the arrangement of human resources to improve flows of future income" (Ostrom, 1994, p.527). The physical capital includes a set of rules that are used to allocate the benefits from the physical source/facility and to sharing the costs of that facility by individual users, who invested in social capital (Ostrom, 1990, 1992). Other forms of social capital in terms of network, norms and social beliefs also exist (Putnam, 1993a). According to Ostrom the social capital is created when individuals have repeatedly operated the physical capital successfully over a long period of time (such as managing irrigation infrastructures by creating collective rules) (see Chapter 6).

It is stated that communities equipped with high levels of social capital are more likely to develop their own self-help organizations and establish and enforce locally-adopted institutions regarding collective goals (Putnam, 1993). It is stated that various types of collective action will be successful under balanced physical capital and social capital (Ostrom 1992; Uphoff, 1986) and these two should not be considered as isolated from each other. My research assesses the different social aspects of farmers in Kashan, in order to investigate the existing social interactions and farmers' behavioural approaches regarding groundwater and irrigation management choices.

There is a powerful social capital in terms of reciprocity in receiving water rights and fair allocation of scarce water among farmers in Kashan village community, which encourages them to mutually respect each other and respect the irrigation rules and norms (Chapter 6). My empirical findings show that farmers in Kashan, collectively cooperate in regulating water distribution in which each farmer receives his exact water right on time and in equitable manner. My study also shows that local farmers (including elder members) avoid isolation in society thus, farmers collectively respect irrigation rules and are interested to be involved in collective action projects (see Chapter 6, 7); this is also to obtain moral standing with other society members. Also the other influential factors on motives for collective actions are physical capital, which I have investigated in terms of farm land size, and adoption of modern irrigation infrastructures as follows.

2.5.3. Engineering Infrastructure and Size of Irrigation System

Apart from institutions and governance structures, different socio-economic elements affect individual motives for collective action. One of the main physical attributes that impacts the level of cooperation in communities is the size of irrigation system (Meinzen-Dick, et al., 2004). Barker (1984) argues that in large irrigation systems especially in developing countries only powerful governmental agencies will be able to successfully manage irrigation systems (Barker et al., 1984). This is particularly observed in the Kashan case study area, where large-scale farmers receive technical supports and financial aids from the government to produce for the national food market. As Olson (1965) stated in 'the logic of collective action', he believes that in larger groups the effort for collective action is less expected than in a small group. Based on Olson's argument, Hardin (1982) argued the main reasons why larger groups failed to achieve collective action, as by increasing the number of users the individual gain relative to the cost of a good reduces, thus free-riding behaviour increase in larger groups and inevitably individual's contribution and collective action diminish (Hardin, 1982). Although these findings conflict with Ostrom's (1990) empirical findings which indicate that large irrigation systems in Nepal were successfully managed by local farmers under the support of rich farmers who paid for the infrastructure. However, despite different studies, there is not any consensus among scholars to indicate the effect of size on the level of collective action (Poteet and Ostrom, 2004).

Numerous studies on the impacts of engineering infrastructures on the operation and maintenance of irrigation systems have concluded that 'technological fixes' are not solely suitable methods for improving irrigation performances (Ostrom and Gardner, 1994; Ostrom, 1994; Lee, 1994). Much of the literature emphasises the importance of technology in enhancing irrigation performance and productivity. Ostrom questioned whether appropriate modern technology can enhance irrigation efficiency of many farmer-led systems, however the technological interventions are mainly designed by outsiders, and neglect the existing reciprocities and mutual dependencies among farmers which may cause disruption and reduce performance. This forms the main argument by Ostrom and Gardner (1994) that self-organising common pool resources have proven local farmers' abilities to perform a very high efficiency and equity in managing their resources. As stated by Ostrom, to construct any engineering infrastructure there is a need to consider two factors to achieve successful management: 1) the engineering design of a new irrigation system infrastructure must be suited within a larger physical and socio-technical setting in irrigation system; 2) individual farmers play a major role in operation and maintenance of the system. In many irrigation systems such as in Nepal, construction of costly sophisticated irrigation infrastructure as a main policy to improve irrigation performance, has failed. The difficulties posed by modern irrigation technologies can discourage farmers to adopt new irrigation systems (see Chapter 7).

2.5.4. Property rights as an incentive

Because common-pool resources are large in size, it is very costly to identify particular users and exclude other beneficiaries from the resource. The concept and definition of common pool resource is similar to common-properties as well as open access resources. It is the opposite of private properties held by individuals. The property rights that are defined for common-pools and for common-property resources, are those rights which are held by communities of individuals, including official agencies as well as local users. Their use can be regulated by different institutions and in various ways (Common and Stagl, 2005). However, Ostrom (1990, 1992) argues that common-pool resources somehow differ from common-properties by having two main different features. In common-pool resources excluding beneficiaries from accessing the resource is difficult, and the resource is subtractable, which means that each individual usage of the resources, subtracts benefits of other users. Common-pool resources becoming open-access resources has been problematic in the past, because no one owned the resources or had control over them. Users did not therefore have any incentives to reduce their abstraction, and as a result, the resource was exploited, leading to the famous tragedy of commons (Ostrom, 1990). To avoid overexploitation of the resource, common-pool resources have been regulated in different ways. As stated, in common-pool resources such as fisheries, groundwater, forests, irrigation systems and pastures the privatized property rights are not possible, and different governance regimes should co-exist cover different property rights characteristics of the resource. For common pool resources the institutions might be the norms created by users, or religious, or formal written law that has been created by the main users during historical time, such as groundwater management and allocation mechanism for irrigation practices.

Therefore for successful management of common-pool resources and to avoid potential conflicts amongst different users, a strong governance regime is important. The establishment of an appropriate relationship between government and the main stakeholders is also necessary.

2.5.5. Economic Factors and livelihoods

Economic driving forces are the key determining motives for initiating locally-based collective action. Economic factors in terms of financial constraints can also act as a barrier for farmers' adoption of a particular irrigation system. Local farmers evaluate the cost and benefits of collective action based on economic, social or cultural issues. It is observed that farmers make rational decisions based on their economic estimates (Ostrom, 1990). Under water scarcity and reduced farmers' income (Forouzani and Karami, 2010), if a new irrigation system could improve farmers' production level by increasing their water availability, it is an advantage that enhances their agricultural revenue. Also farmers are more persuaded to participate in collective action when they economically benefit and when they can increase their irrigation efficiency through more appropriate water allocation systems. It is common for individuals to calculate the specific costs and benefits of participation related to their responsibilities, rights and commitments, and to compare these against the cost and benefits of all other members of union (Johnson and Libecap, 1982). Farmers gain more benefits when they collectively share the lands and tube-wells. This is to break the costs and responsibilities of repair and maintenance of the irrigation system infrastructures and bills (see Chapter 6).

Therefore this study investigates the important role of economic factors in farmers' behavioural approaches and decision-makings.

Farmers are faced with economic uncertainty in their agricultural production because the state does not provide sufficient support for capital investment, thus this motivates them for self-dependence strategies and collective management of their systems. The influence of the capitalist market economy is often indicated as one of the latest and strongest forces for changing usual collective action and local institutional arrangements (Barham and Chitemi, 2008).

PART III: Participatory Approaches to Water Management

2.6. Participatory Adaptive Management: Definition and Application Experiences

Adaptive management is a process of finding management problems, defining our knowledge of the system to define management alternatives or redesigning a particular policy. This process includes the development of dynamic models, created based on identified assumptions and future scenarios for the particular system, this process will continue while our learning of the system is improving (Hollings, 1986). Adaptive management is also defined as a "systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies" (Walters, 1986; Lee, 1993; 1999). The practical application of an adaptive irrigation management will improve the social learning and collective decision-making processes among farmers.

Adaptive management approaches have been applied for several decades, the first expression of adaptive management in the literature refers to Beverton and Holt (1957) in fisheries management (reviewed in Williams 2011). Later the conceptual framework of adaptive management was formally introduced by Holling (1978) and followed by the concept of resilience (Holling, 1986). Adaptive management incorporates uncertainty and complexity in order to face future challenges and changes in the system (Allen et al., 2010; Berkes and Folke, 1998). As Williams described: "adaptive decision making involving the articulation of objectives, identification of management alternatives, predictions of management consequences recognition of key uncertainties, and monitoring" (National Research Council, 2004). Therefore adaptive management is a structured decision-making process (Williams, 2011) rather than a simple trial and error.

Many studies have applied the adaptive management concept as their main strategy and analysis, for example the adaptive management framework was developed for the Great Ruaha Catchment in Tanzania by Lankford et al. (2007), aimed at implementing of effective and practical strategies for river basin management. Adaptive management has the flexibility to adjust to different changes that occur in system management (Gunderson and Holling, 2001). When uncertainty is high and controllability is low (e.g. under climate change impacts) the adaptive management approach can still be useful to eliminate some of the effects, and under high uncertainty and low controllability developing and analysing possible future scenarios are appropriate options.

Participation is the main concept that is considered in the adaptive management approach in natural resources management (Gunderson and Holling, 2001) as well as in adaptive water governance (Huitema et al., 2009). Several researchers have linked participatory resource management processes with a more sustainable resource management (e.g. Ostrom, 1990;

Enserink et al., 2007; Newig and Fritsch, 2009) and a transition to a more sustainable socio-ecological and political system. Once this transition is made, it plays a key role in improving the management process (Von Korff et al., 2010). Some have associated improved management process with development of adaptive capacity within system management (Pahl-Wostl, 2007). Users' participation in the management process has been also assumed as a precondition of good governance (Enserink et al., 2007). In the literature the concept of 'participatory environmental governance' has been suggested as an alternative option to the authoritative governance regimes around the world toward natural resources management (Huang et al., 2009).

Adaptive management does not only produce iterative learning outcomes from different applied management strategies for participants, but it also broadens the range of management options available to policy makers. These alternative management solutions are flexible, meaning they can capture and integrate various interests and perspectives from stakeholders (Stringer et al., 2006; Von Korff et al., 2010). The concept of adaptive management is related to the social learning process in which cooperation and sharing responsibilities to cope with uncertainties, and collaborative decision making is possible (Fiorino, 1990; Von Korff et al., 2010).

In the literatures, a more comprehensive explanation of adaptive management exists to account for wider socio-political dimensions (Walters, 1986; Lee 1993). However, in all cases, this process will eventually lead to **(1)** Better understanding of the system and **(2)** Enhanced management decisions according to improved understanding (Williams, 2011).

Particularly regarding water resources management, the increasing scarcity and vulnerability of water has resulted in more practical and integrated approaches around the world (e.g.

Walker and Salt 2006; Rijsberman, 2006; UNDP, 2006). According to Von Korff et al. (2012), the participation of different actors as well as expertise, and their integration into the discussion, can lead to a higher quality decisions. Engaging stakeholders, who are affected by decision-making, ensures wider agreement and greater support for successful implementations. Participation can also improve social capital, when intensive communication can potentially create new networks among participants. The development of social capital can assist in conflict resolution and create better problem solving alternatives (Von Korff et al., 2012).

2.6.1. Decentralisation and Emergence of Participatory Irrigation Management

In the international framework for Millennium Development goals, decentralization is one of the key aims. This involves transferring some governmental authority and administrative responsibility to the local communities. The local bodies then provide communities with the services and utilities (MDGs, p. 234). One of the main strategies to meet the water scarcity problem is to transfer management responsibility to water users. This provides a solution for optimizing the use of water resources and improving the productivity of land and water. Irrigation Management Transfer (IMT) is a scheme in which irrigation management responsibility and authority is transferred from government to local communities. In Iran as one of the most water scarce countries the changes in policies and devolution of responsibilities to water user associations has recently been piloted. The main goals of the IMT are that: operation and maintenance of irrigation systems will improve; the losses will reduce and the sustainability of irrigation infrastructures will be enhanced (Ul Hassan et al., 2007).

Within the past two decades there was a substantial trend towards transferring centralized governance to local users in Asia, Africa and America. This decentralization process has particularly occurred in water (irrigation management) but also in other common pool resources (Barker et al., 1984; Meinzen-Dick and Knox, 1999). The different titles associated with decentralisation or transfer schemes have different meanings such as community-based or participatory management and co-management. Community-based management is when the government has almost completely withdrawn from its role in managing natural resources and management is almost entirely transferred to local users. Co-management, or joint management, is when government continues with the majority of its roles in conjunction with local users and has transferred some management responsibilities. In participatory irrigation management local users are encouraged to increase their engagement in the management process and to complement the role of government (Meinzen-Dick and Knox, 1999).

Considerable attention was paid to the role of local institutions and the importance of collective action to take over resource management from the state. Irrigation Management Transfer (IMT) is one of the strategies to improve the operation and maintenance of irrigation systems and to enhance the sustainability of the irrigation infrastructure, however in many cases particularly in developing countries, due to high costs of sharing expenses and financial difficulties of local farmers' institutions, these programmes have not achieved the main goals of this scheme (Hamada and Samad, 2011). The IMT scheme has faced some financial difficulties in its implementation particularly in developing nations, and involves some organizational shortcomings to create sufficient collaborations between government and local users; if the implementation process was not conducted properly it cannot meet the main objectives of sustainable resource management. One key factor for successful IMT process is the importance of transfer early irrigation management to farmer communities (e.g. in Sri Lanka and Philippines). This assists local communities in forming organizations, selecting leaders, creating rules and responsibilities (Barker et al., 1984). A lack of success in each particular phase of this transformation, and in its implementation, will result in unsuccessful management experiences. In successful IMT process these organisations were not dictated to farmers but were used to supplement governmental intervention policies.

Although in theory, in most developed nations the advantages of devolution to local users have been proved (e.g. Turral, 1995); the outcomes of this policy in achieving equitable and sustainable resource management in developing countries have not been completely achieved. In some cases that lacked appropriate management transfer to local users and did not identify allocation rules, the resources were depleted, or could not be equally distributed, which has demonstrated the need for strong local management in the form of local institutions to act as an intermediates in transmitting the roles and responsibilities from states to the local institutions. This is another important factor for successful implementation of the IMT scheme to local communities. Apart from the role and capabilities of local institutions in successful decentralization process, other important factors such as collective action and clear property rights must be considered (Meinzen-Dick and Knox, 1999). Clear property rights provide further incentives for resource users to regulate sufficient rules and if necessary sanctions to manage resources equitably and to reduce conflicts.

In order to create a strong local institution, there is a need for innovative methods which emerge from local norms and rules and are developed by user communities within the bottom-up approach. There are numerous methods of such innovative and participatory approaches regarding natural resources management in the literature, which aim to step towards more decentralised and democratic management practices. One practical approach within participatory resource management is the adaptive management concept, in which stakeholder participation can increase understanding of the system and learning for both researchers and participants (Hirsch et al., 2010). In an authoritative governance regime particularly, the more innovative methodological approaches may be required, for example the study by Moellenkamp et al. (2010) in Spain focuses on formal and informal process within participatory management effort and includes: 1. integrating informal process of resource users' participation into highly structured governance systems 2. a 'co-design' participatory approach between researcher and participants for the study, and 3. outcomes in terms of social learning process, which may include educational outcomes for participants, governmental bodies and the researcher. It is crucial that each participation process be designed and adapted developed to individual circumstances in order to deliver successful outcomes (Stern and Fineberg, 1996; Carpini et al., 2004; Irvin and Stabsbury, 2004).

Although there have been numerous achievements in the field of participatory management, the main question to be addressed is 'which participatory approach to choose in which particular setting or context' (Rosenhead and Mingers, 2001; Rowe et al., 2004). In this regard, there are numerous guides for participatory practices and various case studies expand on this concept (e.g. Arnstein, 1969; Pateman, 1970; Webler and Renn, 1995; Mostert, 2003). A review of progress in the theory, exercise and evaluation of implemented participatory water management by Von Korff et al. (2012), utilising case studies from around the world, addresses these questions of what are the beneficiaries of participatory management and how should these approaches be implemented in different socio-ecologic and cultural complexities. Part of the literature also focuses on the criteria for effective or successful participatory process (e.g. Rowe and Frewer 2000, Beierle and Cayford 2002, Dietz and Stern 2008).

Successful participatory management is indicated when it results in improvements in the quality of participants' relationships, their social skills, their ability to reach common agreements through debates and negotiation (Von Korff et al., 2012). One of the challenges of this research study was how to ensure participants that the participatory irrigation management within adaptive management approach would be mostly beneficial for them and how it should be developed and implemented in complex natural systems (Von Korff et al., 2010). This challenge will be addressed within the development of methodology (see Chapter 4).

In light of the previously identified shortcomings of IWRM, my research investigates the possibility and usefulness of participatory process for farmers at local-level in Iran. It examines the capabilities of locals to bring their knowledge and experiences into the management process, as well as how to fit the process with this specific social context to improve its effectiveness.

Potential challenges to implementing a local participatory water management research approach are the conflicts that might be raised by different stakeholders' interests and perspectives that are involved in the discussions. However, not all their perspectives are involved in the policy making procedure, and thus there is a danger of increasing participant's expectations (Hirsch et al., 2010). This may increase demands for further and immediate improvement in participants' circumstances which the research cannot achieve. For example, in a participatory research study in Uzbekistan there were limitations in transferring local interests to a higher political level to improve system management (Hirsch et al., 2010).

The advantages of participation include improving legitimacy of decisions, increasing opportunities for more democratic management procedures (e.g. Fiorino, 1990; Larid, 1993; Sabatier et al., 2005) and developing social learning. Case studies around the world which have implemented participatory approaches have been successful in stakeholders' engagement and in achieving social learning (e.g. Bousquet et al., 1996; Barreteau, 2003; Hirsch et al., 2010; Van den Belt, 2004). When local stakeholders effectively participate in the system management there is better access to a more in depth and diverse source of knowledge which can be later incorporated into policies and regulations (Monroe et al., 2013).

Research on participatory methods of local irrigators or water resources users in hydrological modelling is not widespread. It is therefore necessary to provide a brief review of existing studies on the interactions between human and computerised models and to comment on the importance of engaging farmers' experiences and social variables into hydrological models.

2.7. Socio-hydrological Modelling Platform: Human interactions with hydrological modelling within a participatory approach

Some scholars believe that computer models could be ineffective tools, because they do not specifically involve stakeholders in the process of decision-making (e.g. Barreteau et al., 2001; D'Aquino et al., 2003). However, in capturing the complexity of natural resources, particularly water systems, there is a need for integrated models which are capable of incorporating different hydrological and socio-economic phenomena/variables. This physical and social integration enables a more effective decision-making process, as it provides multiple perspectives on particular water management problems that illustrate system complexity than is possible when physical models or social simulation are used alone (Robinson, 1991). These modelling attempts provide various opportunities to design participatory projects emphasising the social dimensions of users' participation and making linkages between practical experiences and scientific assumptions (Von Korff et al., 2010). In general participatory approaches can be used to explore the ways in which models can be used as a mediation tool to support dialogue and negotiation between stakeholders and formulate acceptable solutions (Von Korff et al., 2010). There are several different approaches to participatory modelling which I explain here.

2.7.1. Participatory Modelling Methods

The emergence of a wide range of participatory methods for water modelling, decision-making and planning aims to achieve more effective and integrated management of complex water systems (Bryson and Crosby, 2006).

Modelling water or other natural resources with stakeholders' participation has received increasing interest from researchers. The problem of how to include stakeholder perspectives in the modelling platform to increase system understanding and social ecological interactions has been one of the main concerns in this field (Daniell and Ferrand, 2006; Jakeman et al., 2006; Voinov and Bousquet, 2010). This interest has resulted in an expansion of various methodologies for stakeholders' engagement in participatory modelling processes for water management such as the companion modelling approach (Bousquet et al., 1996; Barreteau, 2003), which is mainly for social learning purposes.

Regarding participatory modelling, several studies have been conducted including models that are most adapted to specific contexts (Flood and Jackson, 1991; Mingers, 2010), participatory process assessments (Hare et al., 2003; Etienne, 2010) and identifying how to organise, select and impact the modelling design (Luna-Reyes et al., 2007). The participatory process has been designed under a number of different frameworks. Barrateau et al (2010) designed a framework which not only presents different steps of the process but also designed stakeholder's interactions that could lead to a successful participatory implementation.

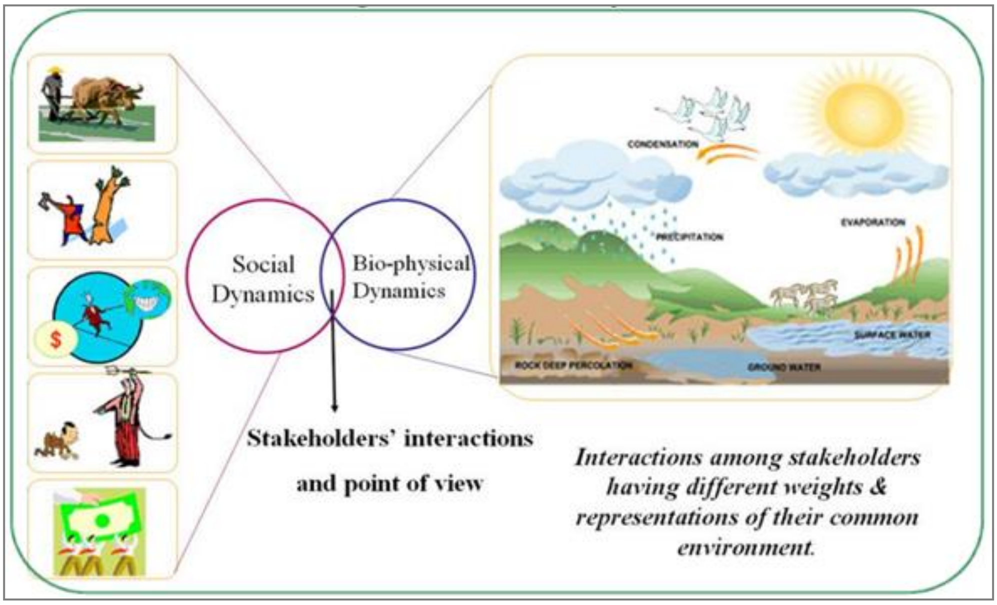
In participatory modelling, participants can be stakeholders, they may validate a model designed by a researcher prior to or within the simulation (Barreteau et al., 2010), or participants can be co-constructors of the modelling process. In this process, stakeholders are the main designer of the model and the researcher acts as an 'intervener' who engages in the process and learns lessons from it (Von Korff et al., 2010). Zorilla et al. (2010) studied the effectiveness of co-construction of different models to facilitate participatory process and social learning. Their case study in Upper Guadiana Basin in Spain focused on over-exploitation of groundwater resources which has led to the degradation of a wetland and conflict between farmers and officials as well as environmentalists. They concluded that co-constructing models could result in better understanding of the system, different factors and their interactions, as well as stakeholders' anxieties.

Other methods have been developed in order to tackle participant interaction in the hydrological modelling. In the study by Bots et al (2011) the researcher created a set of codes as informal 'rules of the game'. In this study it was mainly participants who influenced the organisation of the modelling process, and act as co-researchers or 'co-engineers' who make decisions. In this study, farmers particularly have identified the main influential factors in their groundwater irrigation management practice and dynamic. These factors were integrated into the hydrological modelling development (see Chapter 5) as specific input criteria and generated results for participant farmers (see Chapters 3, 7).

2.7.2. Companion Modelling Approach for Irrigation Management

The Companion Modelling (ComMod) approach is an innovative methodology which uses multi-agent systems (MAS) in the form of computer models or human organizations to create simulation models as a collective learning platform (Bousquet et al., 2005). ComMod has been developed with the aim of including different stakeholders' perspectives within the continuously evolving adaptive management and social learning process (Bousquet et al., 1999; Barreteau, 2003). This approach suggests that participatory modelling is an effective method in which stakeholders can be directly involved into the modelling design, assumptions and selection of indicators, as well as in developing and evaluating relevant scenarios (Barreteau, 2003). The ComMod approach usually has two main objectives: 1) to capture and understand complex biophysical and social situations and 2) to support negotiation and collective decision-making processes in managing natural resources (ComMod Group, 2003; Bousquet et al., 2005) (Figure 6). In creating the ComMod platform, a combination of tools such as multi-agent system (MAS), role playing games or conceptual models can be used to involve participants in developing the methodology. Because this thesis develops a Role Playing simulation, ComMod is suitable to incorporate the outcomes of the simulation. ComMod usually uses different types of simulations to capture complexity in human-environmental systems. A multi-agent system is employed as a stakeholder-driven model integrating various viewpoints from different resource users (Etienne et al., 2003; Becu et al., 2005). In this study, the two main objectives of this process have informed the development of the companion modelling effort. The methodological framework has been modified to be tailored to the case study area, to specific research questions and to Iran's social-cultural circumstances.

Figure 6 ComMod Perspective: Schematic representation of Socio-ecological relations in natural systems



Source: Le Page and Abrami (2013)

The ComMod approach in participatory agent-based modelling utilises the 'Role Playing Game' to address the model's shortcomings (Barreteau, 2003). The 'Role Playing Games' provide basic settings to increase farmers' understanding of environment and assist them to decide in the real-life conditions. Games consist of rules which define every aspect of interaction between farmers and between farmers and the environment. They involve defined roles that will be played by farmers. RPG provides experimental experiences of decision making process and enable farmers to explore areas beyond their defined structured framework and modify or change some aspects of the game or the rules (Dionnet et al. 2008) (see Chapter 7). The literature on using RPG to develop collective decision-making or within the negotiation processes indicates the benefit of using RPG together with computerised models to support stakeholders' engagement in a process (Parent and Gallupe, 2001;

D'Aquino et al., 2003). One of the main advantages of RPG is that computer models lack the self-design process capability which might emerge from the personal opinions of participants (Gintis, 2000). Computer models are less flexible and may lack capacity to incorporate social assumptions that arise from participants' perspectives. RPGs usually involve some behavioural incentives in their construction, while computer models provide wider variability using assumptions and simulations, for example the climatic factors such as increased temperatures or population growth will affect groundwater resources condition and management in the future that computer models can simulate in the form of scenarios.

2.8. Simulation games and their role in fostering social learning

In the past, simulation games have proven to be an effective social method to investigate and elicit knowledge from local users on the management of common-pool resources (Ostrom, 1990; Ostrom et al., 1994). Simulation games have been widely used to create experiential learning for participants and to support negotiation and social learning processes (e.g. Burton, 1989) where specific agricultural policies and climate change scenarios can be explored, analysed and discussed. A critical aspect of participatory irrigation management and technological acceptance is the concept of 'social learning'. This refers to how the understanding of a particular natural and social system has changed among participants as a result of exchanging information (Von Korff et al., 2012) and this is closely related to the social capital concept. These changes also might have changed the quality of participants' relationships, their social skills such as their ability to reach a common agreements, their participation in a constrictive debates and negotiation process (Von Korff et al., 2012). This study is particularly aimed at providing the tools and conditions for social learning to take place, in order to change participants' understanding and perceptions of groundwater and irrigation management practices. The outcomes are discussed in detail in chapters 6 and 7. Social learning occurs during discussion and by interactions between participants. When various perspectives or viewpoints emerge, this can improve participants' understanding of each other's concerns or interests to explore preferences through dialogues (Von Korff et al., 2012; Muro and Jeffrey, 2012).

The study of Hoverman et al. (2011) in the developing small-scale state of Solomon Island indicated that in the participatory process can facilitate the creation of trust between traditional communities, water manager officials and water developers/experts. Under this situation participants agree to contribute their knowledge and to overcome cultural constraints through interacting in the process which will lead to social learning and collective action (Hoverman et al., 2011). Social learning is a concept which has yet to be integrated into the water management agenda of many countries. The study by Kuper et al. (2009) on participatory irrigation management in Morocco emphasises the development of a social learning process in improving local farmers' capacity to adopt modern irrigation systems. The question remains as to what extent this concept can be translated into a practice in natural resources management, as this can be culturally and physically difficult in some cases (Huitema et al., 2009; Von Korff et al., 2012).

There are other creative simulation methods to enhance social learning, for example Selman et al. (2010) focused on the less explored concept of 'imaginative engagement' in participatory approach which leads to social learning. This participatory method is 'art-based', so as to more practically engage participants in identifying and reflecting on their basin through conducting a series of creative writing workshops in a previous industrial area in Northern England, describing their recovering river basin. Participants found this method a positive experience. The research has explored the effectiveness of this method in raising awareness, changing values, knowledge, individual behaviours and actions in use and management of the river. Selman et al. (2010) reflected on the potential of this method for facilitating social and institutional capacity for sustainable river basin management and planning in coal mining area in South Yorkshire (UK). As stated by Von Korff et al (2010), participatory research can be flexible and creative in design either following a systematic approach or an artistic or imaginary dimension such as role playing game or imaginative modelling process. This study utilises a creative design in developing RPG which is simple and engaging for farmers in particular local irrigation context of Iran to improve their social learning.

This study further explores the role of participatory RPG in achieving successful adaptive management process for groundwater resources by engaging local farmers' knowledge and perspectives into management decisions (see Chapter 7).

The use of games to extract information and explore farmers' motives for collective action and behavioural approaches to water resource management issues has been widely applied in different contexts (Burton, 1989; Hagmann and Chuma, 2002). Collective action is defined as an "Action taken by a group (either directly or through an organization) in search of members' perceived shared interests" (Marshall, 1998). Empirical and theoretical research has focused on collective action in common pool resources established since 1965, by the studies of Olson and with growing interest in community-based management of resources, extended by Axelrod and Hamilton in 1981 and Uphoff in 1986. Olson (1965) believed that when the benefits of using a common pool resource is greater than the cost to produce it, or when collaboration in using a public good has higher benefit with the lower cost, individuals are keen to continue their collective action and cooperation in managing the common resource (Olson, 1965). Collective action requires investment in the system by members and to exclude outsiders from the benefits. Creating persistent collective action in managing natural resources depends on rules and decision making, the monitoring, and conflict resolution also play an important role (Ostrom, 1992).

Game theory is one of the most popular theories in explaining the mechanism of collective action problem. Games have been widely used to address the question of whether individuals are capable and inspired for cooperation and voluntarily organizing themselves to manage resources (Meinzen-Dick et al., 2004). The main perspective in Game theory is that one individual's benefit might be changed based on how many other participants contribute to a particular activity, in rational behaviour, individuals decide based on others' behaviours in contribution to common pool resources (Oakerson, 1992). To enhance the accuracy of game theories an artificial rules and setting of the games has been modified by facilitators in Role-play game simulations, by including norms, values and other social variables into the games. This has improved the transparency, understandings and perceptions of games and made them more applicable to the real world. However, there are some critical arguments indicating the limitations in game setting that fail their usage in reflecting complexity of the nature and the various alternative strategies faced by local resource users in the games (Rasmussen and Meinzen-Dick, 1995). In this study, this shortcoming of the RPG is addressed by incorporating a hydrological model and climate variables within Companion modeling process. This is to improve the accuracy of the assumptions and predictions for the local users in the case study.

2.9. Conclusion

This chapter first provided broader perspectives on water crisis, management and governance in arid developing countries. This has provided arguments on the water crisis conditions as mainly a social problem, which is a consequence of long-term governance and management failures. Water resource management plays a crucial role in ensuring social and economic development, political stability and international security. Thus governments are under increasing pressure to satisfy water demand, and develop the most suitable long-term strategy for future water development. As discussed in part I of this chapter, although there are pessimistic perspectives about the future water disputes particularly in the Middle-East, there are some optimistic viewpoints that water wars will not occur in this region. The increasing evidence of collaborations around the world is the evidence to support international cooperation for freshwater management between nations.

National governments are also responsible for controlling abstraction of strategic groundwater resources, water allocation and accessibility, providing high quality domestic water and resolving inter-basin conflicts (Rogers and Hall, 2003). Government responsibilities for these issues are of greatest concern in those developing countries where the agricultural sector has the main influence on social and economic development and food security (The World Bank, 2006; Namara et al., 2010). This study particularly focuses on the water management issues regarding groundwater sustainability and improving efficiency of irrigated water use at local level. There is still a need for innovative methods that encourage collaboration for future water and groundwater managements between nations and in the nations for future sustainable water developments. This thesis addresses this gap by developing an interdisciplinary and innovative participatory method with stakeholders for local groundwater irrigation management in the context of an adaptive management approach (see Chapter 4).

The effective water resource management requires an integrated management approach, which considers both physical and social aspects. Existing water management frameworks are not particularly adaptable and applicable in many countries worldwide and there is a need for more context specific and adaptive management options through participatory social methods.

The literature review provided the theoretical context to understand local farmers' decision-making and behavioural approaches for participatory irrigation management. This has identified some existing gaps in the literature on groundwater resources management as common pool resources in Iran, including a lack of empirical studies on the social dimensions of groundwater irrigation practices and farmers' decision-making behaviours. The present study addresses this by adopting a participatory simulation method which engages local farmers in the water management decision-making process. The study aims to obtain deeper understanding and knowledge from local irrigators in Iran and to evaluate different driving forces for their collective action behaviours. Different incentives such as adaptive rules, strong local institutions, social capital, engineering structure, property rights and economic motives provide a possible foundation to creating a successful farmer-managed irrigation system. Focusing on groundwater resources, different challenges in managing irrigation systems in arid and semi-arid regions in developing countries were explored; under authoritative governance regimes the main management strategies are based on controlling mechanisms, and there is lack of local-based and adaptable solutions based on resource users' perspectives and needs. The literature review elaborated on the driving forces for equitable resource allocation and management, particularly common-pool resources which require collective decision and collective action for its management. The study explores further motives for farmers' collective decision-making behaviours within empirical chapters (see Chapter 7).

The review then focused on the definition and selection of suitable management and methodological approaches to address one of the main objectives of this study which is to develop a participatory and adaptive management method for groundwater resources, the relevant literature is presented to support the arguments in discussion chapters. The importance of local knowledge in understanding the system dynamics and establishment of effective local institutions was highlighted. The existing literature provided background on implementation of successful adaptive management strategies in local resources users and incorporation of integrated and creative methods. I outlined the rationale for developing participatory approaches to adaptive groundwater management in semi-arid developing country in the third part of this chapter. This study has assessed the feasibilities and potential for implementation of community-based management approach in Iran (expanded in Chapter 6). The Companion modeling for participatory modelling effort was introduced here, to foreground the methodological approaches provided in the next chapter. The role of participatory simulation role-play game in fostering discussion and collective decision-making was analysed and its effective use in re-allocation of resources discussed. In the next chapter, I will show how these different participatory tools have shaped my methodological approach to better understand irrigation system dynamics, foster social learning and to improve the integration of local knowledge within integrative and transparent models of water management.

CHAPTER 3

Contemporary Water Governance in Iran: historical trends and current managerial approaches for groundwater irrigation practices

Introduction

In this chapter, I outline Iran's national water management context particularly on participatory irrigation management practices. This chapter emphasises the development of groundwater resources and irrigation practices as well as the historical development of irrigation rules and collective management of irrigation systems in local communities of Iran. This chapter also examines the impact of national regulations and administration on the management of collective farming systems at a national and regional scale, and the reasons for unsuccessful participatory management in irrigated agricultural. This chapter provides a background and review of the governance and management of groundwater irrigation systems in Iran (Kashan) prior to method development chapter.

Data for this chapter are collected from the academic literature, water related institutional reports, reviews of national water policies and regulations, and available published documents including local bulletins and national newspapers in Farsi and English.

The first part of this chapter reflects on the traditional water and irrigation management practices in Iran, and comprises three sections. The first section of this chapter reviews the geography, hydrology and climate of Iran to offer an overview of the particular climatic and biophysical characteristics of the region which have shaped past and current water management arrangements. The second section of chapter outlines the traditional water management system of Iran (the Qanats) which was developed prior to land reform in the 1960s, and reflects on the historical water trend, traditional irrigation management and institutional arrangements which are currently under practice. This review provides a context base for designing a participatory modelling platform as a research method. Therefore, understanding the nature of traditional arrangements around irrigation systems (i.e. Qanat) in Iran will assist to better reflect on the particular irrigation context and culture of Iran, which I will discuss further in later chapters (see Chapters 6 and 7). In the third section, the chapter provides a chronology of water management development and governance in Iran, comprising four different periods and traces Iran's history of water and irrigation management and the governance structure in each period since 1960.

The first period is that of traditional water and irrigation management, which was developed under the Qanat (is a system of underground canals that in hillsides taking water from the aquifers to farmlands) water supply and distribution mechanisms and the existence of the landlords. In the second period the chapter summarises nationalisation of water and irrigation management practices and organisations which commenced following implementation of land reform in the 1960s, particularly the regulations relating to water and land management after Iran's National Revolution in 1979. The third period of this chronology, describes the expansion of the pump-well technologies in Iran and the re-structuring the water governance and management in Iran will be explained. The fourth period examines current water management challenges, national water governance and the role of local institutions (read more in Chapter 7).

The second part of the chapter reflects on the contemporary water management and governance of Iran. The combination of a centralized water governance structure in Iran, together with the impacts of climate change, increased water demand as well as competition between different water use sectors (across the industrial, domestic and agricultural sectors) has created significant challenges for current decision-makers in water management. These factors are embedded in the scenarios that formulated by farmers, to reflect the future changes in the system (see Chapter 4, 5). Also in this chapter, I reflect on the recent changes/modifications in water policy of Iran in considering participatory approaches in management practices.

Iran as an Islamic country takes its constitution from the Islamic principles '*Shari'a'* or "Islamic framework which is unchangeable and unquestionable in terms of religious enquiries" (Hashemi, 2012, p. 259), and the government acts and makes management plans within this framework. Participation, which is one of the main principles of integrated water resources management approach, can be found in the Islamic principle of *'Shura'* (or consultation). This provides a powerful basis for public participation in manging natural resources built on ethical values (Hashemi, 2012), although the users participation is not sufficiently considered in current management agenda (read more in this Chapter). The review of historical water management and engineering in Iran, existence of traditional community-based management and the established water rights which are practiced until now and the strong ethical values for participation from religious perspectives all steer the current and future water governance towards more participatory management approach in Iran.

In the current national Iranian water development policy, the importance of improving water use efficiency and cooperation of stakeholders are highlighted, and this could influence the sustainable use of groundwater resources. In relation to the recent policy development in irrigation management and practices in Iran, I review the factors that influence farmers' participation in irrigation management practices, particularly the existing barriers identified in Iranian studies. There has not been any participatory modelling for groundwater irrigation management using simulation games in Iran, which I have undertaken in this study. However, I review the previous experiences of implementing different social methods on participatory management at national or regional scales to understand the driving forces and barriers for farmers' participation in government projects. In Chapter 6 and 7, I will reflect on these factors and expand more incentives of farmers' collective behaviours and decisions which have been achieved from conducting and developing a simulation game.

In Iran, irrigation rules are established around Qanat system and are still practiced by farmers, so there is a need to provide more detailed backgrounds on different physical, social and cultural aspects of Qanat prior to the main discussion chapters and methods. The irrigation rules for designing a participatory simulation exercise is extracted from the traditional Qanat system (see Chapter 4), and this chapter provides sufficient background for understanding. There was a significant change from Qanat system water delivery mechanism to the pumped-well technology. This has put major impacts on sustainability of groundwater resources and irrigation management and governance particularly in rural areas in Iran and on local farmers (see Chapter 6), which this chapter reviews this governance regime transformation.

PART I: Iran's Traditional Irrigation Management Practices

3.1. Geography, Hydrology and Climate Characteristics of Iran

The particular geography and climate of Iran has greatly affected the formation and establishment of water distribution and delivery systems as well as traditional rules and management practices. I will outline the main geo-hydrologic characteristics and general farming systems of Iran and then explain the development of a traditional irrigation system of Qanat and water right mechanism in the next section.

Iran is situated between 25^0 and 40^0N and 63^0E, and has a total area of 1,648,195 km^2 and population of 79 million (Hashemi, 2012). Iran is surrounded by three major water bodies: the Caspian Sea to the North, and the Persian Gulf and Sea of Oman to the South. The neighbouring countries to the East are Afghanistan and Pakistan; to the North, Turkmenistan, Armenia and Azerbaijan; to the West Turkey and Iraq and to the south the Arab States of the Persian Gulf. The topography is varied: the lowest altitude is found on the southern coast of the Caspian Sea (28 m below sea level) while the Mount Damavand is 5,671 m above sea level. Approximately 90% of the country comprises a Plateau (or tableland), one-fourth is desert and less than one-fourth is arable farmland while the remainder is highland and mountainous areas (Madani, 2014).

Climate variability is high and annual temperatures can vary from -20 to +50 C in different parts of the country. Mean annual precipitation is 250 mm equivalent to a total of 413×10^9 m^3 annually (Ardakanian, 2005). However, 75% of precipitation occurs during the winter, when there is no need for water to be used for agriculture (Madani, 2014). While 65% of the country is arid, 20% is semi-arid and the rest is humid or semi-humid, the annual renewable water per capita in Iran is 1,700 compared with the global level of 7000 m^3.

A total of 14×10^6 ha of land is cultivated of which 8×10^6 ha are irrigated while the remainder is supported solely by precipitation (Ehsani, 2005; Forouzani and Karimi, 2010). Rainfed farming in Iran is mainly practised in the North and West, where river and stream flow provides sufficient amount of water, and around 50% of population lives in this area which has ~70% of the country's total water resources (Motiee, 2001). There is, however, an unequal distribution of water resources across the country. Two mountain chains, the Alborz in the North and the Zagros to the West inhibit moisture transport and thus affect regional precipitation (Moradi-Jalal et al., 2010). However, surrounding local highlands receive more precipitation (rainfall, snow) which has supplied groundwater for Qanat systems for many centuries.

While 78% of farmers practise small-scale farming, farms totalling less than 10 ha extend across 37% of cultivation areas but only contribute 10% of total production. However, medium sized farmers (10 to 50 ha) cover 50% of cultivated lands and produce 75% of agricultural products (Madani, 2014). While cultivated land only covers 15% of Iran, agriculture consumes 92% of available water resources (7% is used in domestic and 1% is in industrial sector) (Ardakanian, 2005). Cultivation patterns and selection of crops follow traditional farming practices and crops which are guaranteed to be purchased by the government (such as wheat) are not adapted to the regional climate and water availability (Madani, 2014). Iran is prone to flood and drought risks and climate change impacts are expected to lead to increased regional temperatures and hence put higher pressure on available water resources (Abbaspour et al., 2009; Evans, 2009; Jamali et al., 2012). This will have considerable implications for the agricultural sector in Iran (Gohari et al., 2013).

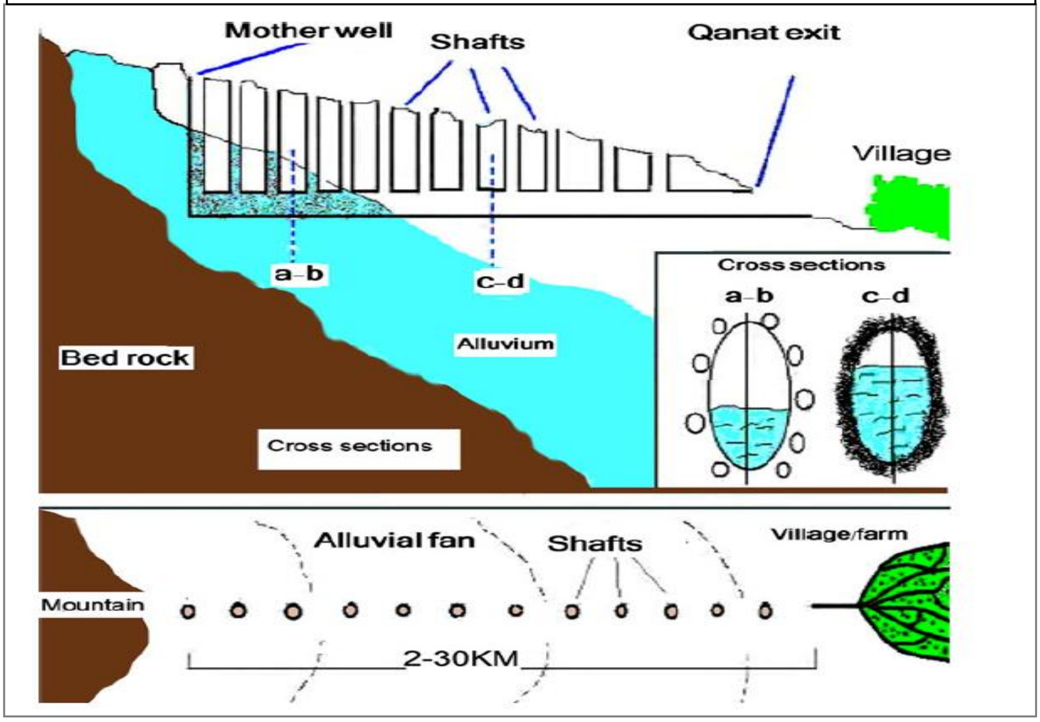
3.2. Qanat Systems and their Role in Irrigation Practices in Central Iran

The Qanat system has very deep roots in irrigation practices in rural communities. Thus, to understand the traditional as well as present irrigation rules and water allocation mechanism, it is essential to realise the socio-economic and cultural features of this system. The Qanat irrigation system consist of underground water transmission canals which provide an efficient way of moving groundwater from the uplands to the plains, where agricultural farmlands are concentrated (Figure 7). Qanat is a well-recognised and sophisticated system of traditional irrigation infrastructure which has been described as the world's oldest water supply system (Agarwal, 1999; Goldsmith and Hildyard, 1984; Wulff, 1968). Qanat is called by various names and pronunciations in different regions: Qanat (Iran), Karez (Afghanistan and Pakistan), Kanerjing (China), qanat romani (Jordan and Syria) Khettara (Morocco), galleria (Spain), falaj (UAE), Kahn (Baloch, Iranian ethnicity) and Foggara/fughara (the French translation of the Qanat, used in North Africa) (Sankaran Nair, 2004).

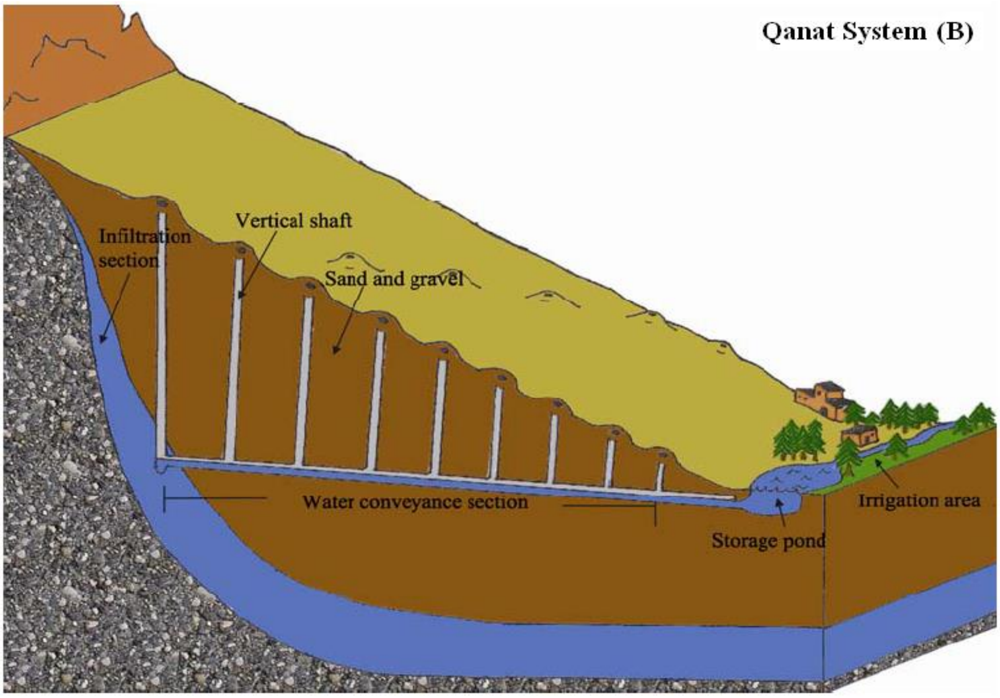
The Persian inspiration for Qanat goes back over 2000 years to when Persepolis was the capital of the Achaemenid Empire, when the city's water supply was provided through Qanats (Cressey, 1958). The system has spread around the world as a result of the Silk Road, Arab and Roman expansion and Spanish colonisation (Mostafaeipour, 2010). The Qanat system was developed in many countries including China, Pakistan, Afghanistan, Arabia, Morocco, Syria, Jordan and even in some American countries (Mostafaeipour, 2010) and the technique is used in South Asia and North Africa as a main supplier of freshwater.

The number of Qanat chains in Iran is estimated at ~22,000, with a total length of more than 272,000km. This system has been also the means for more innovative technological structures. Irrigated agriculture and expansion of Qanat systems extends throughout central and eastern arid regions of Iran. Many parts of Iran are reported to be highly dependent on Qanat for both domestic and agricultural purposes (Cressey, 1958). Although almost two-third of Iran's land is arid or semi-arid, this infrastructure has provided a suitable supply of water for agriculture for many centuries. This has enabled production of agricultural products as well as industrial crops for export such as pistachio, cotton, dried fruits, oilseeds, etc. (Mostafaeipour, 2010).

Figure 7 The construction of Qanat **(A)**



Source: Braemer, et al. 2009



Source: Hu et al., (2012)

McLachlan (1988:93) considers that the use of Qanat for irrigation had an important influence on the local Iranian villagers, in terms of the principles governing the rotation of water allocations (when water is in turn diverted to the land of different farmers according to their water right time-slot), seasonal flow and the use of water in drought or wet years and in agricultural activities, which in fact created the “irrigation culture”. Some of the water allocation rules of Qanat were used for designing a participatory simulation game exercise, which was explained by farmers (see Chapter 4).

The Qanat water distribution system is based on cycles of specific numbers of days and nights (24 hours) (Bonine, 1989: 148-52) this systems of water allocation and distribution is still largely practiced by local farmers (see Chapter 6, 7). Traditionally, the water share mechanism was based on a rotation of 6 to 22 days (each farmer could receive his water delivery turn, either in 6 days or in 22 days), which this is given to each individual farmer throughout a year. It has been suggested that the length of cycles might have roots in ‘cultural-historical development’ (Bonine, 1982). The water cycle is divided into different time-slots (water right delivery might receive during night or day), so each farmer can receive his own share based on that time.

McLanchlan (1988: 991) indicates that an understanding of the traditions of Iranian villages is impossible without an understanding of the role of Qanat systems. He states that this water supply system could provide powerful incentives for collective action, for supplying water, and both managing and maintaining the system by farmers (McLanchlan, 1988). Qanat could also sustain the ‘social cohesion’ in each village (Balali, 2009). It is noted that the communities which were using Qanats developed a complex system of management and distribution (e.g. in Oman Al-Isamily and Probert 1998; Dutton, 1995). These complex social and economic interactions developed around Qanat systems could be observed in Kashan case study area, and created a strong bond among farmers particularly for collective water allocation behaviours.

Qanat construction in dry regions has been a major economic investment to provide a water supply in water scarce areas. The introduction of new technology into Qanat-based systems required extensive amendment as English (1998) describes how this required changes in social patterns, law and customs that were developed around Qanat systems (see Chapter 7).

Over time, a set of rules and norms came into settlements which developed around Qanat systems, these Islamic rules (*Shari'a*) regulated water supply and distribution. The earliest book of this codification is the Ketabi Qani (book of Qanats) in the eleventh Century (English, 1998). The main purpose in regulating laws over this system was to support and protect the long-term investment of Qanat owners in agriculture. One of the most important laws was the *Harim* (border), which proscribes the distance between two Qanat tunnels. Each Qanat has an entrance where the surrounding land is reserved as *harim* and known as the territory around each Qanat and construction of any new mother well which can sink water within 1km of the existing mother well is forbidden (English, 1998). This regulation helped in areas with a high population density, and supported stable agricultural practices (English, 1998). Qanats are closely linked with community life in arid regions and the laws are regulated to ensure their constant function and fair water distribution. This indicates the precise mechanism for fair water delivery and distribution in historic irrigation systems and management agenda. These rules which have been passed through to the recent developments of tube-wells technologies made the modern development acceptable and successful among traditional farmers (see Chapter 6, 7).

Land ownership under the Qanat system is fragmented, and water flow is directed through each household before it is used for irrigation. Qanat construction is based on the social and organizational structure of settlements (Balali, 2009). Although Qanats were built by wealthy individuals, the continual necessity for maintenance led to rapid fragmentation in their ownership throughout the settlement population. In some cases the number of Qanat owners reach over two or three hundreds and some Qanat water is divided over 10,000 time-shares. These division rules extend back, in some cases, to only a hundred years ago. This fragmentation in land ownership of Qanat systems has currently caused difficulties for farmers, as scattered and small land pieces make ineffective use of agricultural machineries, also land integration and agreements has become problematic and very hard to achieve (see Chapter 7).

Beaumont (1989) states that although Qanat could provide irrigation water for arid and semi-arid regions, their future importance is uncertain. Within the past 50 years the number of Qanats has started to decline in Iran and elsewhere. This is mainly as a result of increased population and thus water demand, increased frequencies of drought and floods and the expansion of pumped-well development, that brought higher economic advantages, has all negatively affected the sustainability of Qanat systems (Haeri, 2003). Although it is indicated that Qanat cannot contribute to the development of modern capitalist agricultural practices, some still believe that Qanat can still play a major role in local economic development of agricultural settlements and that they should be maintained in future (English, 1998; Madani, 2014). This issue was discussed further with local farmers in Kashan, however they argued that scarcity of groundwater resources and increased demand does not allow for further development or maintenance of Qanat in drier regions.

The social regulations and norms of Qanat systems for farmers to access water and fair distribution of irrigation water are crucial. These rules are also linked with the local social capital arrangements among farmers. In my study, these water allocation rules among farmers were clearly observed during the social simulation exercise and were used to design the game board and the rules (see Chapter 4). Therefore, it is important for the researcher to know these social rules. The other key point regarding the Qanat system is that the operation and maintenance of the irrigation systems are established based on collective action and cooperation among farmers. This could encourage farmers to share the cost and responsibilities; this is still the main driving force for farmers to act collectively to maintain the operation of the current in-use pumped tube-wells (see Chapter 6). The other important point is that although the future sustainability of Qanat systems is unclear, it has nevertheless been crucial for local farmers to transfer the traditional norms, rules and social capital to the modern system of tube-wells for continuing their successful farming practices. This is particularly the case when poorer farmers need to collectively own the water and land in order to share the costs of water abstraction and repairs under the water scarcity conditions in the region (see Chapter 6).

3.3. A Chronology of Water Management Developments in Iran

3.3.1. Traditional water management systems before land reform (in 1960s)

During the 1960s, Iranian farmland was managed under a feudal system by landlords, however, the number of Qanat has since started to decline (Ehlers et al., 1989). At this time landlords reduced their financial support for annual repairing and cleaning of Qanat systems and expressed more interest in investing in motor-pumped devices, although the water law, established in 1943, required the protection of Qanats where necessary (Lambton, 1953). The *Buneh* system refers to the main social institution in the pre-modern era of water and land management in Iran during 1960s. The water allocation rules in Qanat, the land ownership status and Buneh system are the main components of traditional irrigation management in Iran, explained in the previous section.

3.3.2. Nationalisation of Iranian Water Resources before the Revolution (1960-1979)

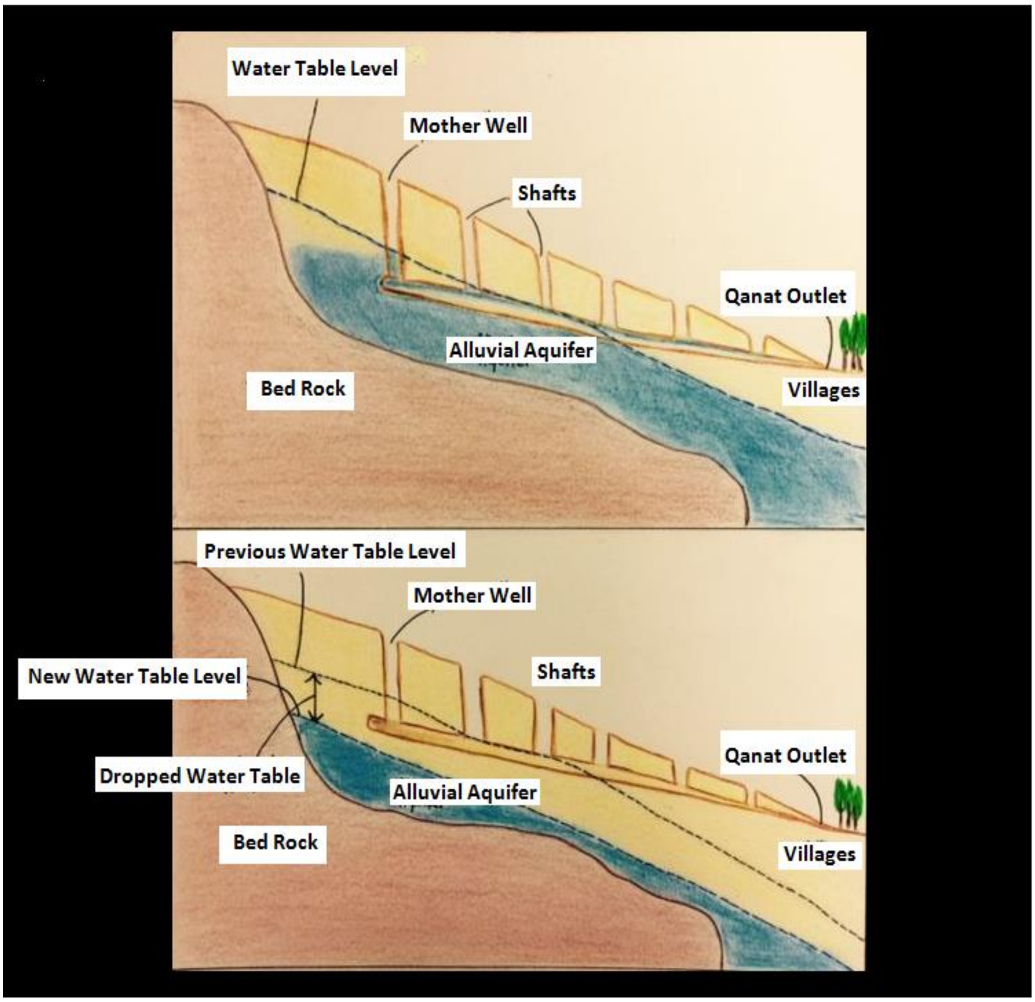
After water resources in Iran were nationalized in 1967, state interventions for centralisation of water governance began. The Shah's modernist ethos assumed that traditional irrigation in rural regions was primitive, regressive and inefficient. This came along with his nineteen point "White Revolution" scheme (reflecting the fact that the revolution was bloodless) which was to be applied across the whole country (McLachlan 1988; Ehlers et al., 1989). In general this scheme sought to give the state more control over water and land resources. After the Shah's White Revolution many traditional water rights and customary rules in local irrigation systems were destroyed, and major land owners were put under intense pressures to sell their lands at lower prices and to divide the land between other farmers, so that share-croppers would become landowners (Lambton, 1969; Ghazi, 2003). Regional water agencies started to evaluate and control water consumption and the state obtained power over taxation and charging private or common water source properties (Lambton, 1969). In the agricultural sector, due to a lack of understanding of traditional practices by both foreign and the new domestic organisations, as well as the rate of change, the pre-modern (traditional) irrigation and governance system considerably changed (Balali, 2009). Traditional irrigation institutions (*Buneh*) were replaced by a system of small holding farming and land-lords replaced by government agencies which led to many consequences in farming communities (Balali, 2009). These consequences were for example deterioration of the social capital and collective action among farmers to work together and maintain the irrigation system; also numerous farmers left their job (Azkia and Ghafari, 2005). Under the new structure, farmers were no longer able to collectively maintain the Qanat irrigation system and associated rural infrastructures and therefore they became dependent on the state for the necessary services (Balali, 2009). This is a problematic issue until present times, which due to high costs of repair farmers are not able to keep maintenance of irrigation systems and motor pumped-wells independently, and need financial support from the government (read more in Chapter 6). "The land reform plan seriously neglected the socio-economic aspects and the value systems of the rural areas" (Balali, 2009, p.167). The government could not include small land holder farmers in a modern system of agricultural transformation. After land reform in 1960s, Iran's water and land management systems was driven by technology. This encouraged mechanized agriculture and increased the production of large-scale commercial crops for export (Ardakanian, 2005, Karbasiuon, 2007, Balali, 2009).

3.3.3. The Development of Wells after the Islamic Revolution until the Implementation of Fair Distribution Law of Water (1980-1998)

As indicated above, between 1950 and 1960 and subsequently, the number of Qanats fell in Iran due to the introduction of diesel motor-pump wells (Balali, 2009). Numerous wells were drilled too close to Qanat mother wells and very close to each other and consequently there was a dramatic fall in the groundwater table in the central plateau of Iran. When groundwater tables fall below the depth of the mother well then the Qanat conduit will be completely dry

(Figure 8). Within a few years tube-well construction led to a drop in water table of 10-20m (Bonine, 1982). The new and more productive deep wells, which required considerable capital, were financed and owned by large landlords. They now had their own substantial supply of water in which the common villagers did not have a share (as they had under the qanat water arrangements). These landlords irrigated their own lands and changed to mechanized agriculture, the latter exempting their land for redistribution under the terms of the land reform programme of the early 1960s" (Ehlers et al., 1989).

Figure 8 Qanat system's deterioration when water table dropped below mother well level



Source: Author, 2015

After the Iranian revolution in 1979, the civil code was terminated by Islamic law, in which protection of Qanat systems was prioritized. However, McLahan (1988) reports that by the mid-1970s wells were supplying 8×10^9 m^3 of irrigated water in comparison with 9×10^9 m^3 provided by Qanats. Protection of Qanat systems ceased when government initiated support for pump technologies, as it sought to achieve food self-sufficiency for the country in the early 1980s. This was to be achieved by increasing production levels and expanding agriculture (McLachlan, 1988; Schirazi, 1993), in which it favoured the development of motor-pumped wells over existing Qanat systems, which could not supply sufficient water to satisfy growing demands (Molle et al., 2003).

Wells can provide water during drought thus securing water supply, and hence the expansion of pumped-wells was accelerated (Molle and Mamanpoush, 2012), although the government was unaware of the consequences of this development. Under Islamic law, the need to protect springs, wells and Qanats was addressed by defining a *harim* (borders) which prohibit digging a new mother-well within one kilometres of existing Qanat (this rule is currently applied for the pumped tube-wells), however this could not prevent the growth in the number of wells (Foltz, 2002). The pump technology gave richer farmers an advantage in selling their water to neighbouring farmers and increased the level of inequity (Ward, 1998; Milton, 2001) which is expressed by local farmers in Kashan (Chapter 6). The rationale for developing pump technology was twofold: First, to access deep or semi-deep aquifers to enable agricultural expansion and intensification, which is typical in much of the Middle East and North Africa. However, as a result of uncontrolled individual water abstraction this caused groundwater depletion, subsidence, and increased the cost of pumps (Molle et al., 2003). Second, to add reliability to irregular surface water supplies as is the case in Vietnam, Thailand, China and Iran (Molle et al., 2003). Uncontrolled and unregulated exploitation of groundwater resources has caused the 'Tragedy of the Commons' in many dry countries and in Iran, in which common-pool resources are being exploited at an unsustainable rate by a large number of shared owners (Ostrom, 1990) (see Chapter 2).

In 1983 the law of fair distribution of water resources was approved in Iran, under which construction or expansion of wells and Qanats systems required permission from the Ministry of Power (Hoogesteger, 2005). Although this restriction prevented expansion of drilling deep wells until now, there is a need for more restricted control. Molle and Mamanpoosh (2012) suggest that this law made control of groundwater centralised, without considering the local hydrology, transparency and interests of water users, which has led to corruption by rich and influential consumers who could obtain permission through their power.

PART II: Iran's Contemporary Water Management Crisis

3.3.4. Contemporary Water Governance in Iran: The Impact of the National Water Management Policies on Local Irrigation Practices

This section reviews current water governance structure in Iran through reflection on the existing water crisis in Iran, particular agricultural irrigation governance system of the country and the role of local agricultural institutions in promoting participatory resources management.

3.3.4.1. Water Crisis in Iran

As previously indicated, the government of Iran faces several long-term challenges in future water management (Madani Larijani, 2005). These include the consumption of 73.8% of the country's 'Total Renewable Fresh Water' resources annually, which places Iran amongst the most water stressed countries globally (IMPO, 2003). The annual renewable fresh water resource is currently declining, mainly due to population growth and a poor culture of water consumption. In large cities the amount of water that people consume is as much as that consumed by water-rich nations and as a result of increasing population, the water demand will increase significantly. The other major problem is deterioration of water quality due to a number of factors including sanitation problems, poor wastewater collection, inappropriate water distribution systems and expansion of urban areas, and increase of saline groundwater due to over-abstraction (Madani Larijani, 2005). Regarding groundwater resources, Iran is one of the top abstractors of groundwater globally (Gleeson et al., 2012). As the main water supply source in most of the arid regions of Iran is groundwater, the improvement in groundwater use efficiency is critical. Burke and Younger (2000), indicated three conditions that may occur regarding groundwater resources worldwide: 1. Access to groundwater and abstraction may continue, leading to an intensification of cultivation in response to changing demand patterns, 2. There will be limited groundwater demand management as poor farmers try to maintain their livelihood, 3. Groundwater will be over-abstracted and farmers will be compelled to accept social and economic transitions to leave their land or hand over their water rights to other competing sectors such as industry or urban centres (Burke and Younger, 2000).

In Iran, the circumstances mentioned above have been observed during different periods. At the beginning of the Islamic revolution (1979) the agricultural development brought economic growth in the region through expansion of drilled tube-wells, however later over-exploitation of groundwater resources and increased costs of pumping, made poor farmers even poorer. In the future, farmers predict that water resources will not be sufficient. The next generation may quit farming and migrate to other cities seeking more profitable jobs.

3.3.4.2. Agricultural Water Governance

Under the current regime, groundwater resources are considered a national property belonging to the government. The operation and maintenance of irrigation systems are public responsibilities; however pump ownership is private. Slight interventions have been made in recent Iranian civil law concerning water management that empower and strengthen the role of NGOs, reducing the role of government, and investing in community-based management systems (Azkia, 2005). The more development of participatory management approaches with local resource users can facilitate moving towards implementation of this policy which is discussed further in chapter 7.

In 1993 the formation of an independent council in Iran's agricultural and rural sectors was approved. However, its formation has not been fully established nor implemented by communities of local stakeholders. Therefore independent cooperative communities have not been created in the form of associations, unions or syndicates. Consequently a 'pseudo participatory' process has been followed which fails to understand and address the needs of farmers (Azkia, 2005). Most of the community or cooperative societies that were created are officially authorized by government and facilitate the implementation of government policies (Zand-razavi, 2004; Azkia, 2005). Therefore, this study suggests the creation of more community-based and local informal institutions that can empower farmers' capabilities in decision-making processes, which will be further discussed in this thesis (see Chapter 7).

While management schemes promise to increase the agricultural budget and farmers' welfare, in most cases by inappropriate budgetary allocation to different agencies, they seek to obtain public acceptance and farmers' participation in large-scale government schemes (Zand-razavi, 2004). Madani (2014) has highlighted Iranian policy makers have pursued populist policies, for example financing a new water infrastructure system which can enhance economic status of the region.

The Iranian water crisis has been analysed and described by various scholars over a long period of time (Foltz, 2002, Madani Larijani, 2005, 2014; Yazdanpanah et al. 2013) but it has not been taken seriously by Iranian water decision-makers. In this situation some scholars believe that agricultural water share must be reduced to protect the environment, while this may be problematic for poorer farmers with limited water rights (see chapter 6). The current Iranian government recognizes water security as a national priority and immediate actions have sought to address some of the major problems and ensure the sustainability of water use. The groundwater situation is a 'hidden tragedy' which needs to be addressed as a major environmental disaster.

The integrated water management approach in Iran, is mentioned in the 4^{th} 5-year socio-economic development plan of Iran (Hashemi, 2011). The laws of "comprehensive soil law" and the "fair water distribution act (1982)" contain some elements of concern for sustainability. The 'guidelines for implementing balanced use of water in agriculture' which was approved in 2008 represents a shift in management perspectives:

According to Article 6 of this guideline: "Before establishing any hydraulic structure such as irrigation and drainage networks the Ministry of Energy and Ministry of Jihad-e-Agriculture have to consider all requirements which are needed for the establishment and arrangement of farming systems in order to let producers/beneficiaries participate to foster their effective cooperation in all steps of study and implementation, and to accept responsibilities for exploitation, maintenance and irrigation management of those hydraulic structure".

There is also government regulation to protect farmers' right and empower them. The goal of a recent 'Farmers' House' social organisation is "to harmonize farmers' activities around the country in order to support and protect their political and socio-economic rights and their human rights in the Iranian context" (Farmers House constitution, Article 5). The government has facilitated creation of some participatory activities for farmers within the past 20 years, for example a village council whose members are directly selected by local farmers (Balali, 2009).

3.3.4.3. Local Agricultural Institutions in Iran

In the early 1970s the Iranian government established the Agricultural Production Cooperative in order to increase the production level of fragmented farm units. This was the main strategy of the Ministry of Agriculture aimed at achieving land consolidation. Although the number of these institutions increased, they were not successful in promoting land integration and collective agreement by farmers (Karami and Rezaei-Moghaddam, 2005). The creation of these cooperatives was mainly aimed at the integration of lands by participating voluntary farmers as members, improving soil and water productivity, improving irrigation infrastructures, land leveling, educating farmers in modern methods and technologies, developing agricultural industry and improving farmers' income and social welfare in each household village (Karami and Rezaei-Moghaddam, 2005).

According to Balali (2009) the two major rural organizations in Iran are generally known as 'Agricultural Production Cooperatives' (APC) whose main aim is to increase production level, the majority of farmers are members of this cooperation since their development in 1996; and the second group is the 'Village Council' which mainly deals with 'cultural and socio-economic issues' within a village. Different rural institutions that exist in Iran are for example Rural Production Cooperatives (tavoni tolid), Cooperative societies (sahami zeraie), Mosha Cooperatives, and Water associations (tavoni abbaran). The most important institution is the 'rural production cooperative' (tavoni tolid) which exists in every village in Iran. The main reason that farmers are not interested joining water associations is because they have their own private tube-well and thus they do not see any need for cooperation (Balali, 2009).

3.3.5. Recent Consideration of Participatory Approaches in Water Policy of Iran

The long term attempt to establish effective cooperatives in Iran has not been significantly successful. As stated before, in the traditional Qanat system, cooperation among peasants and landlords was based on hierarchical relationships and created through different generational experiences. The traditional system was shaped by unwritten rules and norms which could be understood and adopted by all resource users in the same society (Chapter 2). When the landlord was replaced by the government many of those rules and customs were destroyed, and the new cooperatives established based on a top-down mechanism. According to Balali (2009, p. 174) "this unilateral vision of organizing cooperatives which is still continuing is one of the main challenges of stakeholders' participation". It is indicated that new cooperation between farmers and governmental organization require new experiences to build trust which is currently insufficient, which the method development in this study tries to achieve (see

Chapter 6, 7). The culture of participation behavior needs to be more developed and promoted by engaging stakeholder from the beginning in the governmental projects, which this is one of the objectives follows by the participatory modelling development for this study (see Chapter 4).

Balali's study (2009) reveals that farmers are more willing and have more positive attitudes towards possibilities of increasing collective action in comparison with 20 years ago. They are also agreed that the government has improved farmers' participation in various rural issues. However the main remaining problem is the top-down governance approach and the necessity for early engagement of farmers into the introduction of a project and implementation through the process. Balali has found that projects are top-down and that the role of resource users are not included in the identification of the governmental projects from the outset. This has prevented resource users from participating in project implementation, reducing the efficiency of the project, due to a lack of trust towards the governmental project, and in the profitability and sustainability of the project for their particular social and economic context.

3.4. Existing Barriers to Participatory Water Management in Iran

This section outlines the incentives and barriers faced by farmers to take part in collective projects of water/irrigation management in Iran. This part is the critical review of the existing literatures on participation, incentives and barriers that were studied in Iran. From the reviews (e.g. Safinejad (1990), Sharma et al. (1996), Zand Razavi (2004)), it can be argued that there was a shift in the governance structure from traditional community-based Qanats to the modern regime. This is characterised by clear shifts in governance structure from community-based to state-led control, which does not leave room for stakeholders' engagement into the main management decision processes. This gap in management approach and planning in Iran is addressed in the thesis' method development (see Chapter 4).

In the traditional context, management decisions sought to address local needs and to benefit the majority of farmers. However, the traditional rules were not flexible and adaptive enough to system changes. Under the current regime, the hierarchical governance structure in the traditional system has been shifted from landlords to the government. Local participation is dismissed and traditional values in creating adaptive rules and local-based solutions are failing. Currently the conflicting issues are usually dismissed and the main aim is to conserve a part of natural resources which has been identified by government (Zand-razavi, 2004). Thus, this study tries to develop and implement a participatory research method in Kashan case study, in order to actively engage local farmers in management decisions of suitable irrigation management at local level. Also the social methods and simulation exercise that are developed for this study, reveals farmers' main perspectives and acknowledges existing social conflicts amongst farmers (see Chapter 4, 6, 7).

From the literature, in democratic governance systems, government is a facilitator for wider social participation in management decisions. This particularly highlights the significant role of local institutions in creating an effective collaboration with local users. The government organisations can provide opportunities for local stakeholders to voice their views and perspectives on management issues and participate in a policy decision-making process (see Chapter 7). Solutions are to meet local needs and conflicts are recognised from the beginning to be negotiated and resolved during the management process, under the support of powerful local institutions (Zand-razavi, 2004); these principles were considered when designing the research method.

A review of some relevant literature in Iran around different experiences on factors affecting farmer participation in irrigation practices in Iran (Zand-razavi, 2004; Azkia, 2005), identifies three main barriers to participatory management in agricultural water management namely: regulatory, economic and social barriers.

3.4.1. Barriers

A regulatory barrier within the governance system of Iran is one of the main downfalls for effective local participation in governmental management projects. This study has addressed the need for strong local institutions developed mainly by local stakeholders or independent associations that are not structured in a governmental top-down manner and are responsive to the local needs. Formation of an independent council was approved in Iran's regulations in agricultural and rural sectors. However the formation of these communities was prevented by different formal and informal interventions and it was not created in the form of associations, unions or syndicates.

This classification varies among different scholars. However most of the evidence indicates that on a large scale, these obstacles are in regulatory structures in Iran's civil law, as within the past 50 years, there was no rule to identify and recognize any independent agricultural community in this sector. Inadequate emphasises on public participation in civil law of Iran and a lack of recognition of any independent agricultural communities in this sector are some of the main problems. Lack of sufficient regulation and management on implementing participatory resource management, and also a lack of emphasis on the importance of public engagement in management decisions, makes little room for creation of innovative participatory methods. In addition, it does not receive enough funds or governmental supports for implementations in large scale.

Considering poverty in relation to environmental sustainability is a key issue. This aspect requires critical understanding of ecological and economic sustainability of agricultural activities; in many regions soil and water degradation is increasing which is threatening agricultural sustainability. Traditional inheritance rules have resulted in the fragmentation of agricultural land holdings. These small and scattered cultivation units have low productivity and consequently result in low investment by farmers in agriculture. This in turn has increased the exploitation rate of resources in the region particularly groundwater abstraction rate to increase productivity and sustain livelihoods. Although agriculture is assumed to be the most important source of income in most of the regions of Iran, poverty is a barrier to make any fundamental decisions which can lead to protection of environmental and water resources (see Chapter 6). Conducting a simulation role-play with farmers revealed the historical reasons for creation of this small and scattered landholding ownership, however the innovative method can also improve farmers' awareness of the ways to make collective agreements for their lands consolidation (see Chapter 7).

The most important social barrier for farmers' participation lies in previous negative experiences in participatory management of water resources in Iran (Zand-razavi, 2004 and Yaghobi, 2011), which have resulted in the reluctance of some farmers to accept membership of participatory communities. In this study, the attempt was to develop a participatory method that does not follow the previous management methods and is mainly designed and developed by local farmers within an innovative way which is not governmental, but completely voluntary and community-based. The findings (Chapter 6, 7) reflect on the successful outcomes as a result of building trust with farmers and engaging their cooperation in developing the methods from the beginning until the end that was significant in this study.

A study on 'Qazvin' province (in central Iran) indicates that one of the main problems of transferring water management to local communities was the government's underestimation of farmers' capability for solving their local water management (Kholdbarin et al., 2011). Local communities were not given equal opportunity to participate in water management as government organisations. Farmers' participation was neglected and at the end farmers could not observe any changes in their traditional management system. Baghaie, et al. (2011), indicates that during the formation of community-based WUA in 'Behbahan' (Khuzestan province in South-West Iran), there was no common agreement about the aims of participation; each stakeholder was following his own benefits from the committee. There was no clear plan for improving farmers' capability, nor any exchange of opinions, dialogues or discussion with farmers about their main water problems. This study put emphasis mainly on farmers' perspectives to define and understand the main problems in a particular farming context and in relation to groundwater exploitation and irrigating practices. The simulation exercise (see Chapter 4) has mainly designed to foster discussion, dialogues and debates among farmers which aimed in empowering their decision-making capabilities (see Chapter 7). Kholdbarin's et al. (2011) research on a water users association in Kerman Province (South of Iran) identified several problems that limited farmers' participation in collective projects. These issues included:

1.Lack of awareness in the water cooperative agency about farmers' main problems and lack of effectiveness of these governmental organisations for farmers (mainly due to these companies being authorized by governmental bodies); **2.**Constructing water canals without consulting with local communities, as there was no agreement on suitable location for constructing the canal by farmers; **3.**Local people believing that they were able to solve problems among themselves, but cooperative companies are governmental organizations who try to put higher costs and responsibilities on farmers which will enlarge their existing problems. Although there are not many well-known cooperative societies in large-scale farming in Iran, there are different kinds of collective activity among farmers and various sources of social norms (Baghaie et al., 2011).

The study on participatory irrigation management in 'Fars' Province by Khalkheili and Zamani (2008), reveals that farmers' perception of participation, has direct and positive impact on their participation in governmental organizations irrigation management. In summary, these experiences indicate that in most cases, participatory issues are national policies which are often in the form of governmental plans imposed on farmers and are not generally consistent with their interests. These organizations do not establish any collaborative process, regular meetings and discussion with farmers, and essentially negative experiences once again appear as an obstacle in implementing the next participatory program.

In this study I expand further on the factors that influence farmers' rejection of participation in governmental irrigation and groundwater management projects (see Chapter 7). I particularly argue that this lack of consideration of physical, social, cultural and economic factors has led to unsuccessful management outcomes in national agricultural water policy in Iran. In this study, I argue that if projects are aimed at engaging farmers in governmental schemes, there is a need for more adaptive and participatory management strategies which are local-based and adaptable, developed by the key stakeholders (see Chapter 6, 7).

A cultural pattern of behaviour is another important barrier for participation, which prevents cooperation in agricultural activities. One of the key factors for people to cooperate in a collective action management is the level of social capital. Social capital emphasises the idea that norms and social bonds are essential for sustainable management of common resources. This approach prevents resources being degraded as a consequence of being common properties (Pretty, 2003). Social capital in water resources management encourages people to invest in collective action decisions, it reduces costs of working together and eventually leads to protection of water resources. In Kashan case study area the emergence of private tube-wells especially the ones invested in by rich and individual farmers has reduced the level of social capital regarding cooperation, reciprocity and trust between rich and poorer farmers (see Chapter 6). There are four important features in social capital; trust, reciprocity, common rules and norms, and connectedness in networks and groups (including bonding, bridging and linking) (Woolcock, 2001) (see Chapter 2). These features can be used as key indicators for measuring the level of social capital in any community. In Kashan, the water right allocation mechanism and fair water abstraction has been disturbed by farmers who are investing in larger lands and buy water rights from poorer farmers (see Chapter 6). This has reduced the number of farmers in the region whose farming is the main source of livelihoods as well as causing degradation of lands and groundwater resources due to expansion of industrial crops by individuals.

3.5. Conclusion

This chapter has illustrated contemporary water management governance and historical trends in Iran. It has also provided an overview of the traditional and modern context of governance in Iran. The transformation in the governance regime of Iran particularly after land reform, was aimed at reducing inequalities among farmers (by giving small-scale farmers the land and water ownership). However, this policy framework was not successful and failed to achieve its goal. Analysis of water governance shifts in Iran shows that government could not completely convert the social structure (the roles and responsibilities) from traditional structure to the modern management system. As a result, inequality in the social and economic situation of farmers has further increased, this was particularly observed in the Kashan case study area. Within the traditional context, the power relations followed a top-down hierarchy structure. The emphasis on improving participatory management of water resources in the recent national plan of Iran is not significant, and this points towards the need for more research on how to achieve effective participation of farmers in water management decisions. Developing community-based management practices and building upon existing institutions to empower and support these local practices can lead to more locally adaptable management solutions (see Chapter 7). This does not require massive changes or expenses for large-scale project implementations, but at the local context, the participatory management can bring more advantages for farmers (see Chapter 4, 7).

In rural development planning in Iran, the use of local-based solutions within an integrated approach is very limited. In this regard, this chapter summarised some of the main driving forces as well as barriers for farmers; participation in irrigation management practices, within relevant literature in Iran. Although these factors are scattered within existing literature in Iran, this study will explore other influential elements in farmers' decision-making behaviours and their participation in irrigation management practices (see Chapter 6, 7). These motives which play a crucial role in farmers' behaviour and rational decisions are important to be understood and explored in a local context. This can assist policy-makers at regional scale to engage farmers in management decisions and to implement policies or schemes which are more adaptable to local management strategies.

Lack of a powerful organisation to take the main responsibilities, empower farmers' communities and facilitate their participation in management processes has not led to successful management outcomes. In this chapter, reviewing the water governance and management changes in Iran, highlights the necessity of developing more participatory, adaptive and local-based management options for farmers. When local communities are empowered through incorporation into management practices process they can influence policy-makers' decisions. As stated by Madani (2014, P. 10) "through bottom-up approaches, Iranian society can force the decision makers to change their behaviour, respond to the needs of the society, adopt more pro-environmental development actions, and give more power to regional water management authorities". In this study, I will argue that the potential exists in local communities of Iran (Kashan) for implementation of participatory studies (see Chapter 7). I will also argue that adaptive management approaches bring added value for farmer's community and enhance management approaches in the Kashan case study area (see Chapter 6 and 7).

CHAPTER 4

METHODS

Introduction

This chapter identifies the techniques and tools used during the research. It justifies the selection of the case study area, the logic in adopting the research methods for data collection and data analysis and summarises the positionality and ethical concerns of the researcher. This chapter is divided into three parts. The first part of this chapter reflects on the methodological approach of the study, the primary data collection, including: initial fieldwork, social research techniques such as semi-structured interviews, group discussions and the recording of participants' perspectives and concerns. The second part of the chapter explains the development of the participatory modelling process for local irrigation management practices in Kashan.

This stage proceeds through the intervention method into companion modelling (ComMod) approach (see Figure 11, p.138), and three main associated phases of: information gathering, modeling and Role-Play simulation. To conceptualise my method using ComMod approach, physical data attributes (e.g. precipitation, temperature as climate factors in a hydrologic model), were integrated with social aspects (Role-play game and associated scenarios) to create a platform for deeper understanding of the irrigation system, and to foster discussion and collective decision-making for improvement of irrigation efficiency and management.

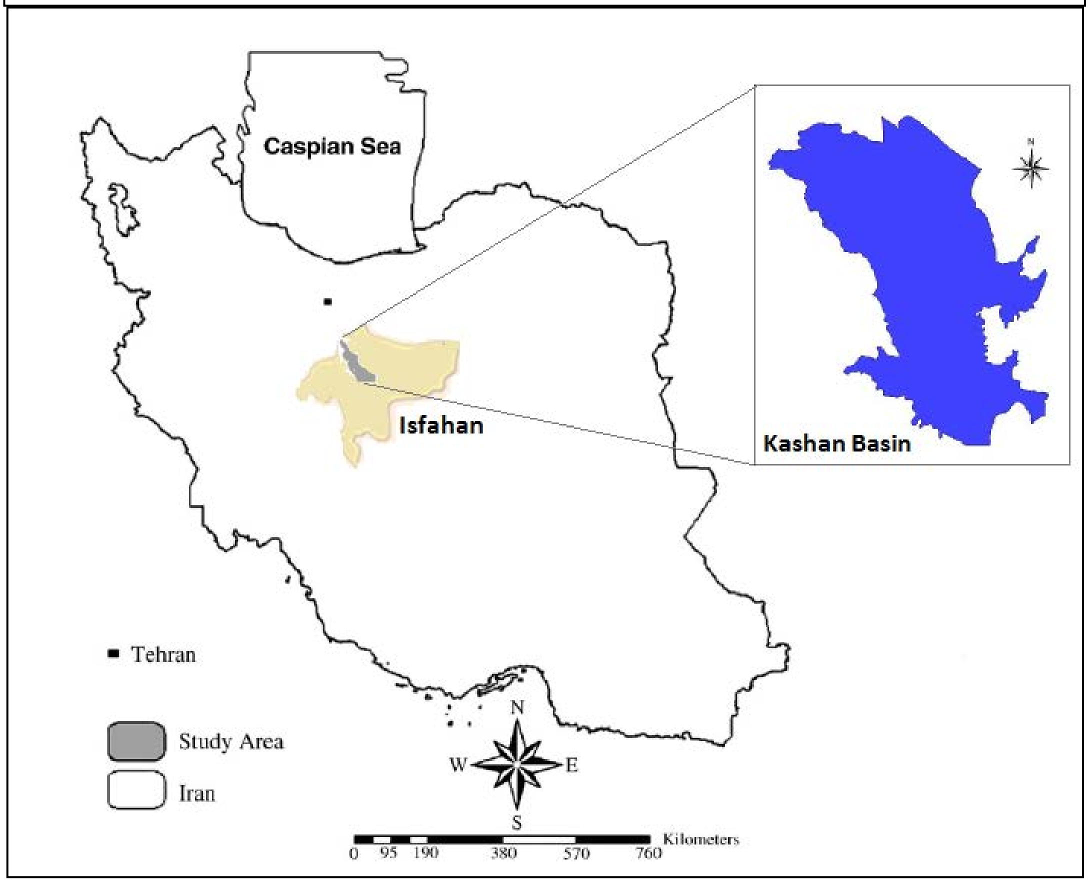
This methodological approach followed a bottom-up process, designed and led by local farmers within several phases in the Kashan case study area. The participatory modelling stage used the hydrologic model output to evaluate and discuss some of the scenarios derived from the Role-play simulation. The final part of this chapter describes the design and development of the 'Irrigation Management Role-Play Game' for sustainable management of groundwater resources, including the crucial role local farmers played in the different stages of sketching and designing the board game.

4.1. Case Study Area Description

Kashan: the Setting

The study area of Kashan city, with a population of 400,000 populations is the largest city in Northern Isfahan province in central Iran, located beside the Salt Lake (Figure 9). There are two different climates in the region: one is a mountain region with winter snow cover, where irrigation waters are supplied by springs, ephemeral rivers and Qanat systems (see Chapter 3). In this part of the region, due to greater availability of water, farmers practice different patterns of crop cultivations (e.g. fruit trees). The second climate is associated with a plain region located beside the great central Kavir desert of Iran, the soil is sandy and the only source of irrigated water is supplied by deep or semi-deep wells, and most of the Qanats are dry. However, water rights and water allocation mechanisms in both regions strictly follow the historic rules established for Qanat water allocation, and this was discussed further in chapter 3. In Kashan, agriculture could not remain highly productive given reduced water availability and according to the local farmers climate change impact (i.e. prolonged drought period since 2010) has limited diversity in crop cultivation patterns. Thus, farmers in this region are particularly affected by a significant fall in groundwater levels and long-term inefficient governance regime.

Figure 9 The Case Study Area of Kashan Catchment, in Isfahan Province (Iran)



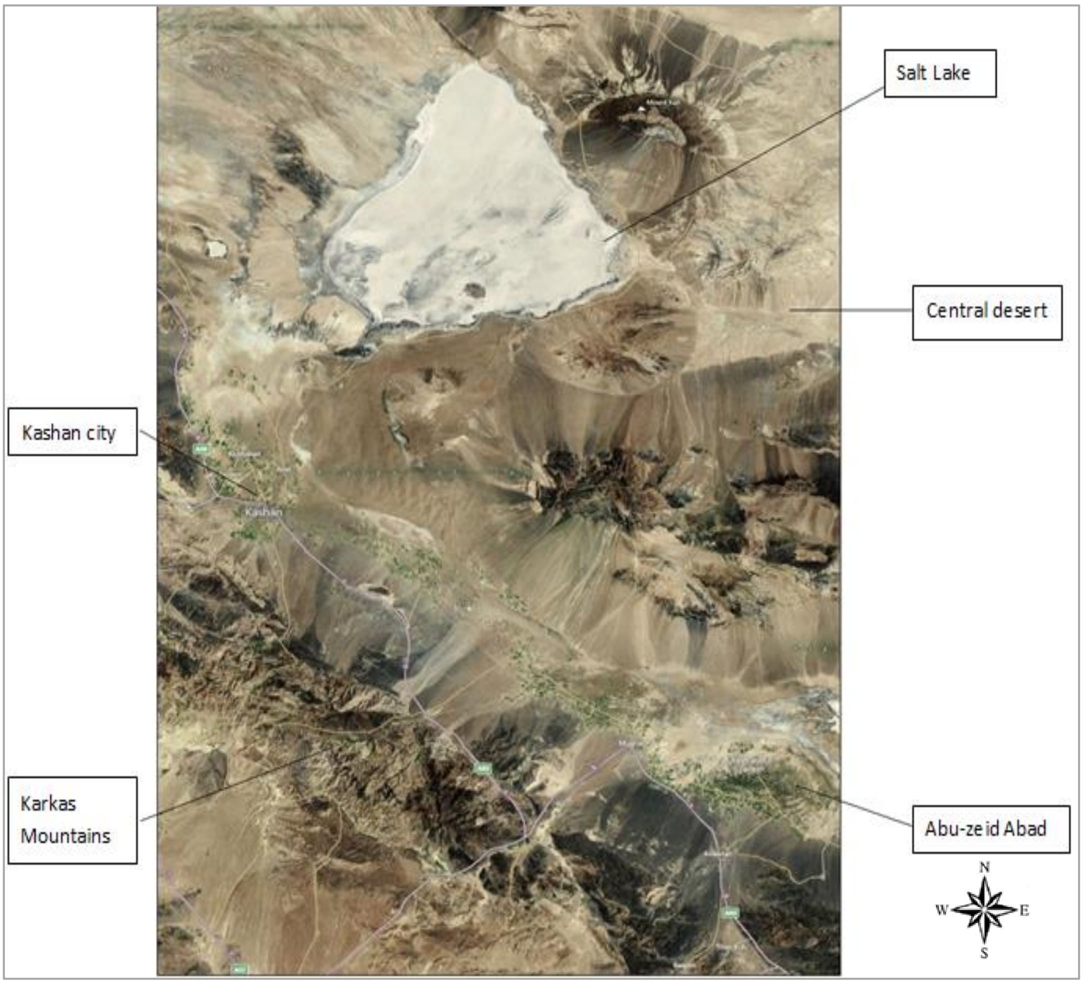
Source: Author, 2015

The Abu-Zeid Abad valley is located in the plain region of Kashan and contains several villages that were selected for this research. There are nine villages located within the valley, 30km from Kashan city: Fakhreh, Aliabad, Rijen, Mohammad Abad, Hossein Abad, Abu-Zeid Abad, Kaaghazi, Yazdelan, and Qasemabad (Figure 10). These villages are associated with the major areas of cultivation in the district and their area of agricultural land has expanded recently. Farmers in these villages were the main participants in the interviews and group discussions for this study. Most farmers have small or medium size farmlands (between 1 and 5 hectares); they produce mainly for their family and the regional market, while a few large-scale farmers produce industrial crops for the national market. Two major cultivation practices are orchards (fruit trees) and tillage. Local crops that are produced traditionally in Kashan include fruit trees (pomegranate, pistachio, and apricot); cereals (wheat, barley, maize, millet, and chickpea); vines, melons, cucumber and vegetables. Farmers in these regions have experienced substantial changes in their water supplier and delivery system developments, and water governance within the last 50 years. The majority of farmers have installed individual or collective tube-wells and they are currently confronted with significant reductions in their water availability. As stated in Chapter 3, around 30 years ago pump technology became dominant in the region, having been introduced by the government. Subsequent overexploitation of groundwater has forced farmers in some villages to change their practice, focusing on cultivation of crops that are more adapted to water shortage such as sugar beet, wheat, barley, alfalfa and pistachio.

Drought and climate variations (such as reduction in rainfall) have been clearly observed by local farmers over the past decades (Farmers' interviews in Abu-Zeid Abad village in Kashan, 2011) (see Chapter 6). Kashan city and the villages of Abu-Zeid Abad fall under two different water and irrigation authorities, the domestic and green-space water management of Kashan is under Kashan district's water authority, and the irrigation management of the Abu-Zeid Abad villages are under authority of Aran-Bidgol district (located on the east side of Kashan). Groundwater from the Kashan plain's aquifer (Salt-lake Basin), is recharged by rainfall and seepage from ephemeral rivers, and is abstracted by private tube-wells. In dry summer seasons there is no rainfall to recharge the aquifer but the main cultivation period is in summer and reports indicate that the aquifer does not replenish over the winter precipitation

(Research Committee of Water and Sewage Institute of Kashan, 2008). In many dry regions in Iran, and particularly in the Kashan Plain, soil and water degradation is increasing which is threatening groundwater quality, agricultural sustainability and expanding desertification (Jamshidzadeh and Mirbagheri, 2011). Traditional inheritance rules have resulted in the fragmentation of agricultural land holdings (see Chapter 6).

Figure 10 The case study villages are spread between Kashan city and Abu zeid Abad Village



Source: Google Earth, 2014

4.1.1. Case Study Selection

The empirical focus of this research is local adaptive management to improve irrigation efficiency in an arid region of Iran. Thus, the first criterion in selecting the study area was to identify a region located in an arid part of the country whose management draws on the rich indigenous knowledge of local irrigators. The second criterion was the accessibility to the researcher of the local communities, who have long-term experiences in groundwater irrigation practices and needed to be willing to cooperate in data collection and development of the methodology. The third criterion is that the study area should be at a regional level and include small-scale farming practices, however it should also fall under the remit of state-led irrigation development schemes (i.e. drip irrigation systems, land integration), which offer a wider context to analyse the irrigation efficiency performances and to evaluate the existing policies and the adaptive process of adopting these schemes by local communities. This condition offered an exploratory platform to better understand the particular local ecologic and socio-political characteristics of Kashan, which could deepen the analysis and provide a suitable context to explore new methods of stakeholder engagement.

In the following sections, I will elaborate on different stages of data collection and development of the methodology with farmers.

4.2. Part I: Justification of the Methodological Approaches

4.2.1. Research Tools and Methods: interviews

This section describes the social methodology used in this research, the methods of data collection and analysis. The concepts of positionality and ethical concerns will be discussed. The social research methods are mainly qualitative and a combination of different approaches including semi-structured interviews, group discussions, and social simulation methods such as participatory Role-play game.

The main objective of the method selection was to develop an appropriate research approach and research design to address the study objectives. The main objective for conducting interviews and group discussions was to obtain information and perspectives from local farmers, local institutions and academic experts. Four periods of field-work were undertaken over three years (2011-2013), each year for a period of 1 to 2 months and two periods of fieldwork in 2013. The first two fieldwork periods focussed on wider perspectives on irrigation management practices in Iran, and the particular irrigation context of the case study region.

Thus, the primary field-work was undertaken for observation and data collection in 2011 for the period of 3 months. This was of an exploratory nature to inform understanding of the existing problems. The main purpose of conducting primary interviews (2011) was to gain a better understanding of agricultural status in the region, the main problems in managing water resources and irrigation practices, also farmers' ethical perspectives regarding water values in this arid region. It was accompanied by several in depth interviews with local farmers and academics in the Kashan region of Iran. Later these interviews were translated and transcribed into English and analysed. The Nvivo software was used to code the transcripts, from these codes the information was classified and different themes were identified by the researcher. The elements of local knowledge, governance, groundwater challenges and management, and water crisis were considered to form some of the main research themes. The themes were interrelated to existing literatures and interpreted to generate the discussions. The analysis and interpretation of conducted interviews and group discussions are provided in detail in the discussion chapters (see Chapter 6 and 7). Secondary data collection from relevant agencies provided enough information to be considered for the selection of an appropriate hydrologic model, based on the availability and accuracy of the data. At the end of this stage, the selection of study sites, relevant stakeholders, appropriate research techniques and initial important parameters for modelling was completed.

Kashan city was selected as a case study area as described above, and three villages of Ali-Abad, Rijen, and Fakhreh were selected to undertake participatory social simulation modelling. This selection reflected the fact that farmers in these villages were relatively young and more active in farming, and showed more willingness to contribute to this research than farmers in other villages of Kashan.

In-depth Interviews: Nardi and Wittaker (2002) consider that for successful adaptive water management, direct communication between actors is necessary to maintain the social interaction. Therefore, in this study, I used in-depth interviews in an initial fieldwork period to first obtain general understanding of the system and farmers' practices, from this I could explore the main themes and perspectives exist in the irrigation system and management. Interviews provided rich and detailed responses with contextual explanation (Silverman, 2013). In exploring irrigation rules, culture and farmers' perspectives on water management and irrigation, interviews are important in creating a rich knowledge which can be matched to particular circumstances of farmers enabling the voice of participants to be heard. The primary interviews sought to understand the region's agricultural status, the main problems of water resource management and irrigation practices.

Semi-structured Interviews: Semi-structured interviews, in the second period of fieldwork stage (partly designed based on some of the key points and statements extracted from the initial deep interviews with farmers). These were mainly conducted in farmers' houses or on their farmland. Farmers were the main participants as they are the key stakeholders. Some interviews were also conducted with officials in the relevant local agencies, for example the Water and Sewage Agency of Kashan, and Agricultural Jihad Agencies in Kashan and Aran-Bidgol Districts. The questions were designed in Farsi, and a guide was provided, in an attempt to obtain more detailed information about individual farmers. Semi-structured interviews were conducted with a total of 25 persons, in some cases where older farmers were not able to contribute directly, the researcher read out questions to them and they responded in short or open ended manner (see Appendix 1).

Group Discussions: Most group discussions were conducted in a local mosque which offered a suitable arena for farmers to gather and meet. The mosque was suggested by farmers themselves as their informal meetings are usually held there. The large group of farmers included male and female farmers, and children participated in the more general meetings. In Kashan region male farmers are mainly involved with farming practices, some of them own the land or mostly are shared-owners, and in a few cases they rented land from another farmer. Females and children are not involved in the main farming practices (they might help in some labouring activities such as picking fruits, clearing lands, etc.) therefore, later they were excluded from the methodology development of the game design. This stage was prior to selecting suitable and interested farmers to participate in the design of the social role-playing simulation. Around 6 group discussions were conducted, to explore farmers' particular challenges in irrigation management and their perspectives towards government schemes, as well as discussions around the RPG simulation. As it was argued in Chapter 2, an integrated and more effective management approach is when the viewpoints and interests of all relevant stakeholders are included in the management process for better understanding of the system dynamic. Thus, within some of the conventional social research methods, an attempt was made to gather wide ranges of information from different resource users in Kashan region.

Role-Play Game/Simulation: This social simulation method was sketched and designed mainly by farmers (described in Part III). This method is widely acknowledged as the most effective method to foster discussion and achieve social learning (see Chapter 2). The selection of villages where the Role-play game would be conducted was based on the level of farmers' interest and cooperation and available time. Also as a critique of irrigation management schemes was the main objective, the three villages of Ali-Aabad, Fakhreh and Rijen were selected to develop and conduct the Role-play game, (one village had already adopted a sub-surface piped-line irrigation system and the other villages had registered for this scheme, all three villages had rejected adoption of drip irrigation method).

Interview with Official Water Regulatory Institutions: The Ministry of Energy is the main agency responsible for water development in Iran, including planning, management and protection for different sectors. Surface irrigation, drainage systems and large-scale groundwater irrigation projects are under the jurisdiction of this agency. In this study, because the scope of the research was regional and local management, and given difficulties in accessing the managerial board of this department an interview with this organization was not possible. However, a number of interviews were conducted with the Regional Water Authorities, whose main responsibilities are to manage and maintain the irrigation infrastructures (water canals, reservoirs and large-scale groundwater schemes) as well as water delivery to farmers. Maintenance of the irrigation infrastructure has been undertaken with both private companies and local irrigators, however in recent years part of the responsibilities have been transferred to farmers (see Chapter 6). The Ministry of Cooperation (MoC) is responsible for organizing and facilitating the activities of rural communities and monitoring their cooperation with the government organizations. One of the main responsibilities of this organization is implementation of groundwater schemes and cooperative farming, thus interviews with some of the employees of this department were completed in two districts of Kashan city and Aran-Bidgol. The other influential government organization is the Ministry of Jihad Agriculture (MoJA), which is responsible for the management of rainfed and irrigated agricultural practices, as well as drainage and tertiary water canals. The main role of this Agency is developing and managing on-farm irrigation schemes; therefore 5 in-depth and semi-structured interviews were conducted with different management bodies within relevant departments such as soil and water sector in two sub-district regions of Kashan and Aran-Bidgol. The two tables below summaries the interviews conducted with local farmers and relevant agencies (see Appendix 2).

Table 1 Data Collection in Kashan Villages (2011-2013)

Participants / **Methods**	Local Farmers Ali-Abad	Local farmers Fakhreh	Local farmers Rijen	Local farmers in Kashan
Deep Interviews	4	2	3	1
Semi-structured Interviews	3(total 12 farmers)	2(6 farmers)	1(4 farmers)	1(3 farmers)
Group Discussion	3 (total 38 farmers)	2 (25 farmers)	1(8 farmers)	
Role-play session	3 (total 40 farmers)		1 (6 farmers)	

Table 2 Key governmental departments interviewed (2011 and 2013)

Roles/Interviewees Official Agencies	**Official Role**	**Number of Interviewees and Types of Interviews**
Agricultural Jihad Agency	Chief of rural cooperative	1 Semi-structured Interviews
Water and sewage agency (in two sub-districts of Kashan and Aran-Bidgol)	The head of water agencies	1 In-depth Interviews and 1 Semi-structured Interviews
Academic Experts	University lecturer and PhD students	1 In-depth Interviews with academics 2 Group Discussions with PhD students

4.2.2. Participant Selection and Positionality

Any adaptive management process requires a participatory approach to engage people from all aspects. The sample interviewees in Kashan required participants from local level and state-level including farmers, water and irrigation agencies as well as academic perspectives (such as PhD students and local academics). The information provided by these groups, was essential to the research. The sample group was able to offer a 'representative characterization' of all participants in groundwater management (Rice, 2010).

It is important to recognize the differences and similarities between myself and my research participants (Hopkins, 2007, p.388). This refers to the positionality of the researcher during the study, which defines the situation of individuals in relation to others, and is a relatively complex issue (Merriam et al., 2001; Mellor et al, 2013). Here, I used my nationality and language to make a closer link to the participants. It is commonly believed that when researchers share the same language, culture and race, with participants then access and expression will be easier leading to more legitimate results (Merriam et al., 2001). Understanding these differences and similarities such as gender, race, class, and culture can be used to classify a researcher as an outsider or insider, this is particularly the case when researchers go from the 'West' to undertaken field-work in the 'East'.

Within the context of this research, I have experienced different positions in relation to different groups that I worked with. My main position is that I am a young female working on social issues in the Islamic society of Iran, interviewing farmers who are mainly men. My reflexivity is that as a western educated person I believe in the role of local farmers in my research (they are the most knowledgeable interviewees regarding irrigation practices), although in Iranian culture, farmers have been usually perceived as not being sufficiently knowledgeable to be engaged in the policy-decision making process by the majority of politicians and Iranian academics.

In conducting the research in Iran which is my home country, there were some cultural comforts. I am from the capital city Tehran and grew up in a modern environment and have travelled less to other historic cities of Iran (while I was living there), which made my first impression on visiting Kashan very impressive. Kashan is one of the most historic and cultural religious cities of Iran, and understanding different aspects of people's life and particularly water provision systems was a motivational factor in conducting this study. Although of the same nationality and religion, when visiting rural villages of Kashan, I was an outsider. Also, as a female researcher from Tehran, a city with diverse ethnicities which does not have good reputation in traditional Iranian cities, made me feel a bit uncomfortable. Thus, my gender, urban status and social class made my 'lived experiences' different from my research participants (Mellor et al., 2013).

During several visits, and assuring locals that I had no affiliation with government bodies or foreign countries, I created a sense of trust and bonding with several farmers in different villages. I had the privilege to receive a higher level of trust and interest from male farmers who were always willing to participate in my research, without any financial demand and in a very polite and hospitable manner. This made the process easier and more collaborative, as hospitality, curiosity and intellect are some of the well-known characteristic of Kashani people.

In the first year of field-work, I stayed in accommodation provided by Tehran University (the Desert Institute). I was introduced to some local farmers for interview through a local person, who worked in the same institute in Kashan and was familiar with farmers. However, in the following years, I stayed in a hotel and travelled by car to the rural villages (spread on both sides of the road, 30km away from the town centre) (Figure 10). To organise a meeting, especially at a local mosque to conduct the RPG, I first contacted (called) a village leader whom I had met before. In other cases, I approached farmers directly in their villages and interviewed them near their houses or on their fields. In some cases when I arrived in their villages, farmers gathered around my car to greet and accompany me to the local mosque to conduct participatory group discussions, although this would rarely, or never, happen when officials conduct such meetings with farmers. As a result, they willingly participated in different stages of my methodology development and provided honest and deep responses to my questions and doubts. Also, the innovative methodological approach, which depends on local users' participation, added more trust and openness to enrich my study. During the Role-play games, farmers' engagement in evaluating irrigation schemes provided rich and insightful results that could solve the 'wicked' aspect of the water management problem for me. When we were gathering in local mosques usually a few women were accompanied or sitting there, which in my opinion was to make me feel more comfortable talking with males, also they were willing to add to their personal knowledge. I spoke in Farsi with people. However, they have their own local language, and sometimes the leader or dominant person in the meetings, used that language to translate what I meant to other farmers. The power relationship, which is observant of any social form, was also evidenced in the interviews (Bondi, 2003) as well as through group discussion. However, I tried to involve other farmers who were quiet into the discussion. According to Sultana's (2007) observation in her fieldwork in Bangladesh, people in rural area show respect to urban educated people, which was evident in this study as well. Although I received some complimentary comments from farmers such as ‘we feel proud of you’ or ‘student such as you will be the future leaders’ etc. in communicating with government agencies this level of respect and modesty towards students does not usually exist or is not expressed. When interviewing officials, and particularly when interviewing local farmers, I did not want to come across as pretentious in any way (coming from a University in the West), and so I adopted a more considerate approach. This was also to develop trust with farmers, so I mentioned that I studied in Tehran. In some cases with some more open-minded officials, I mentioned that I was studying at a western university, which in one case made an official criticise government schemes in the region.

In many situations, I put myself in an inferior position (Rose, 1997) to avoid participants hindering my access to them. Common identities can bring negative or positive influences on the interview process (Bondi, 2003). By having a different identity as a female, and through soft and bottom-up social methods, my impression is that male farmers were more considerate and generous to share their knowledge and to trust me. Farmers later told me that at first they assumed that I was a government investigator, but that later they could trust me. They also mentioned that an official has never visited them several times and paid such attention to the knowledge they provide, without criticising or inferring superior behaviour. Although many government agencies or experts visit farmers in the field to educate or criticise their practices, I have made it clear that I had no intention of doing so, and was willing to learn from them and their experiences in managing irrigation water. As a result, the farmers greatly assisted me in designing and running the simulation board game and even interpreting the outcomes to other farmers in the region.

Although in interviewing with representatives from official agencies and even male academics, I experienced condescension in my position as a young female, I did not have such an impression with young or elder farmers. Farmers encouraged my methodology and asked me to develop and repeat similar Role-play game process with them for this region. Also conducting my group discussions and interviews in the local mosque, which was suggested by farmers themselves, provided added advantages in creating a comfortable, familiar and interesting environment for participants, there were no obligatory rules among men and women for gathering together in the same place and role-playing in a mosque (which as a religious arena might be assumed prohibited). In public places in Iran women have to wear scarf, so did I. I preferably dressed in lighter and brighter colours, which could suggest to farmers that I did not work for government body, as they usually arrive in villages with labelled (branded) cars and dressed formally. However as a religious city, the people of Kashan expect religious considerations from each other and whoever visits them.

4.2.3. Ethical Concerns

To interview official agencies, I needed an official header letter with university stamped, which I presented. Prior to recording my interviews, I requested verbal permission. I recorded most of my interviews and video recorded some parts of my Role-play game for better observation. However, it was appropriate to ask farmers for permission. Some did not want me to include their names in my thesis, so I reassured them that it will be anonymous. Women did not allow me to record their voice or take pictures of them for cultural and religious reasons and so I did not. In some cases I had to explain that my research would not bring immediate benefits or changes to farmers. In some cases farmers expected me to communicate their requests or problems to the agencies, which I did, and later informed them of the result of my meeting with officials.

After reflecting on my data collection in the first part of this chapter, the next section describes the development of my interventional participatory methodology.

4.3. Research Method: Role-Play Games

In this study, several tools, methods and modelling processes were used to provide a better understanding of a complex and dynamic Iranian irrigation system. Following the literature reviewed in the previous chapter, in order to move towards adaptive management process, it is essential to first understand the irrigation system's dynamic and its interaction with groundwater resource thus in the first stage of the methodology, qualitative social research method of data collection was undertaken to provide the basis for subsequently conducting the companion modelling process. In the literature review chapter, it was argued that future groundwater resource management and irrigation projects need more holistic and integrated approaches, which include the perspectives of various stakeholders. This provides more legitimate and collaborative management options which is also applicable for the local resource users. Interview with knowledgeable local farmers provides better understanding of the irrigation system dynamics and farmers' perspectives on different management issues. Particularly the use of game is helpful to create a shared platform of understanding and to achieve collective-agreed solutions for local groundwater irrigation management (see Chapter 7). Conducting irrigation management game put groundwater resource users in their actual roles within the irrigation system and this can reveal their real behaviors, motives, driving forces for collective action and also conflicts at local level.

Groundwater irrigation is a common-pool resource (Ostrom, 1990) therefore adaptive management approach is chosen which can address the complexity and uncertainties in management decisions for groundwater resource in Kashan (see Chapter 2). This approach uses participatory modelling process, which includes different perspectives and users' interest in decision-making process. The adaptive management approach provides more deliberative management strategies that are more sensitive to local conditions. The community-based participatory approach is also chosen as a principle method to explore the potentials in local farmers to join and develop participatory groundwater resource management at local level in Kashan within an authoritative governance regime of Iran. In capturing the complexity of natural resources, particularly groundwater, there is a need for integrated models that include hydrological as well as socio-economic variables. The physical and social integration provides more effective management-decisions considering the complexity and uncertainty of the future management options. The use of the WEAP model (see Chapter 5) in this study integrates uncertainties of climate change and water demand and also tests different scenarios of the future water management at local level. This physical model can also be used as a mediation tool to support dialogues and exchange of viewpoints on wider subject around groundwater sustainability, which I will discuss in more detail in Chapter 5 and 7.

In developing the methodology, emphasis was given to the engagement of stakeholders, the community-based groundwater and irrigation management, collective resource allocation and agreements. Simulation games are proposed as the most effective methods for users' participation in adaptive management process at local level (see Chapter 2).

The main stakeholders involved in the modelling process included farmers, government agencies, regional water and irrigation institutions and academics (in agricultural water and land management disciplines), who all have an important role in groundwater and irrigation management.

The growing importance of public engagement within sustainability sciences, has transformed traditional tools and methodologies in natural resource management (Kasemir, 2003; Bousquet et al., 2005). In participatory approaches to natural resource management, models have been used as tools for engaging both researchers and local participants in the management process (Kasemir, 2003; Voinov and Bousquet, 2010). Participatory modelling is regarded by Voinov and Bousquet, (2010) as a powerful tool that can improve participants' knowledge of the system dynamic within a collaborative learning process. The models are also used to define and clarify the possible solutions and their impacts to support decision-making, policy regulations or management issues.

In managing groundwater resources particularly, the identification of social and ecological boundaries is harder. The resource is invisible, and thus the water allocation and distribution mechanism is more complicated. Moreover, managing groundwater irrigated systems as a common-pool resource is challenging because of the various conflicts of stakeholders and different management interests at local, private or public organisation (Voinov and Bousquet, 2010).

Through the next section the role of the games as a driving force in managing common-pool resources and collective action will be reviewed. This is to support the arguments provided in Chapter 7 on the role of games in understanding the system dynamics and in promoting collective action behaviour and collective decisions in common-pool resource management.

4.3.1. Investigating the Role of Games in Promoting Participatory and Collective Irrigation Management

In the past, simulation games have proven an effective social method to investigate and elicit knowledge from local users on the management of common-pool resources (Ostrom, 1990; Ostrom et al., 1994). Games have been used to extract knowledge and explore farmers' motives for collective action and elucidate behavioural approaches to water resource management issues in different contexts (Burton, 1989; Hagmann and Chuma, 2002). In this study, an innovative Role-play game was used to provide deeper understanding of irrigation systems and farmers' perceptions in Kashan for groundwater irrigation management practices. 'Role Playing Games' provide basic situations to increase farmers' understanding of the environment and assist them in deciding in real situations (Greenblat, 1975).

Games should simplify a complex system to help participants understand the system and express deeper perspectives within a participatory management process. The successful participatory modelling process is when a simulation game creates a simple but realistic representation of irrigation systems and social relations. This provides a platform that engages farmers in a conversation and elicits their knowledge and behaviour towards collective action. There are various existing participatory simulation games in the field of irrigation management (Burton, 1989; Daré and Barreteau, 2003; Steenhuis, et al., 1989). The use of games specifically for irrigation management extend back to the early 1980s (Smith, 1986; Chapmen, 1981) with the development of various participatory simulation and gaming tools (Burton, 1989; Daré and Barreteau, 2003; Steenhuis, et al., 1989; Lankford and Watson, 2007). Simulation games typically use existing values, norms and social capital to assist farmers in formulating their own water management and distribution strategies (Lankford et al., 2004; Hagmann and Chuma, 2002). In this study a simulation game was chosen for participatory irrigation management. Irrigation system is a suitable context for developing a participatory game because irrigation system exemplifies farmers' knowledge, their motives for participation and collective action, and behavioural approaches in decision-making. The innovative and context specific Irrigation Management Game (IMG) was particularly developed for this study by local farmers in Kashan.

Irrigation is an inter-linked and complex issue, which usually involves conflicting water and land ownership claims. The biophysical structure, the institutions and the established rules of the system influence the incentives and behaviour of resource users in managing water resources, and inevitably this varies according to cultural and economic context (Ostrom, 1990). As reviewed in the previous chapter, different incentives influence farmers' particular behaviours and decision-making, which I will later reflect on further through conducting the IMG exercise (see Chapter 7).

Irrigation games are effective because they reveal farmers' preferences and the potential barriers to change, and encourage co-operation within existing social networks. Game simulations can also be used as a decision support tool to facilitate negotiation and foster discussion that provides insight to the facilitator, as well as to the farmer (Ubbels and Verhallen, 2000; Burton, 1989). Simulation games put participants in a simplified version of the real system. This is illustrated by Lankford and Watson, (2007) with a metaphor in which water flow is represented by glass marbles in their river basin game study providing a link between model and reality which improves the quality of the simulation.

Simulation games have been widely used to create experiential learning for participants and to support negotiation and social learning processes (e.g. Burton, 1989) where specific agricultural policies and climate change scenarios can be explored, analysed and discussed.

This provides deliberative information and wider perspectives from farmers within the process of adaptive management, which can motivate farmers to join participatory actions and find solutions for their environmental problems (Bluemling et al., 2006). As discussed previously, a critical aspect of participatory groundwater irrigation management and selection of a suitable irrigation technology to improve irrigation efficiency is the concept of social learning. This helps to investigate how the understanding of a specific natural and social system of irrigation management and groundwater resource has been changed among local farmers as a result of exchanging knowledge and perspectives. Another objective is to examine how the simulation game influences can encourage them to participate in the implementation of a collective irrigation system. Social learning occurs during the iterative adaptive management process, when constructive debate and discussion between participants enhances their understanding of each other's interests and viewpoints through dialogues and collective agreements (Muro and Jeffrey, 2012).

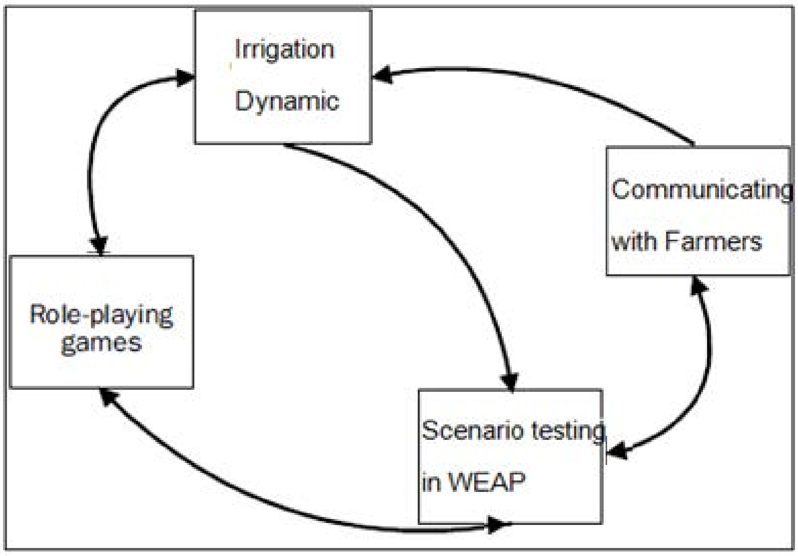
This study used the Companion Modelling (ComMod) approach as the concept/framework of the methodology. ComMod is a participatory modelling process, which utilizes Role-play games and simulation models as well as physical models to address complexity of the system and has been applied for different renewable resource management. The first recognition of the role of stakeholders' involvement in the physical model results and implementation was during the 1970s (Greenberger et al., 1976), when the models entered into the field of policy-making. For many decades physical models were developed by experts, who knew how the system worked. However within recent years, stakeholders' involvement has been seen as essential to diversify viewpoints to achieve more legitimate management decision, as which has been a positive development, although in many cases these engagements might be only nominal (Voinov and Bousquet, 2010). Whilst without resource users' engagement in the management decision, the proposed solutions may not be adaptable to the specific physical, social and cultural conditions at local level and be rejected by resource users (see Chapter 6).

As indicated previously, this approach includes different perspectives from participants in an iterative process of adaptive management strategies and social learning (Bousquet et al., 1999). Stakeholder engagement throughout the modelling process can make the model truly adaptive. New information or perspectives about system dynamics can be incorporated and adjusted to the goals of physical modelling, policy decisions or management requirements (Lynam et al., 2010). In this process dialogue, social learning and collective decision-making are fostered in an iterative process by engaging participants in different stages of the modelling (Bousquet et al., 2005; Barreteau and Bousquet, 2001). Traditionally groundwater models are developed based on the dialogues between experts and water managers (Refsgaard and Henriksen, 2004), but these models were not including wider social, economic and cultural aspects of water management. Public participatory modelling with stakeholders that involves managers and experts creates a shared language for dialogue to reach more legitimate decisions (Henriksen, et al., 2007).

The Role-play game is used to solve the 'black box' effect when using physical models with stakeholders for resource management (Etienne et al., 2003). Computer models, such as MAS, are not essential when developing a companion modelling process, and in this study none of the conventional Agent-based Models were utilised. However, the process is developed by integrating a hydrologic model of WEAP (this is the first time this model has been used within the companion modelling process), and the process is progressed by following the two main criteria which must be considered in adopting the ComMod approach. This approach usually contains two main objectives: **a.** to capture and understand a complex biophysical and social situation and **b.** to support negotiation and collective decision-making processes for managing natural resources (ComMod Group, 2003; Bousquet et al., 2005).

As stated previously, a wide-ranging qualitative research method has been carried out within two years of field-work study, which will be explained in the first part of this chapter. The second objective of this approach is achieved by developing a participatory Role-play exercise which is developed in the later stage to incorporate the main assumptions and perspectives into a single platform and create a successful tool for decision-making and negotiation process for local irrigators. The formulation of the methodological framework and different phases of an intervention process into a companion modelling approach will be explained in the second part of this chapter. This study uses a hydrologic model (WEAP) and social simulation to integrate stakeholders' perceptions, institutional management policies and hydrological variables (in the form of different scenarios), through which different management options can be explored and discussed with farmers. This phase of the methodology will be discussed in the second part of this chapter and further details on this hydrologic model will be provided in Chapter 5.

Figure 11 The Companion modelling cycle, including RPG and WEAP tools



Adapted from: Barreteau and Bousquet, 2001

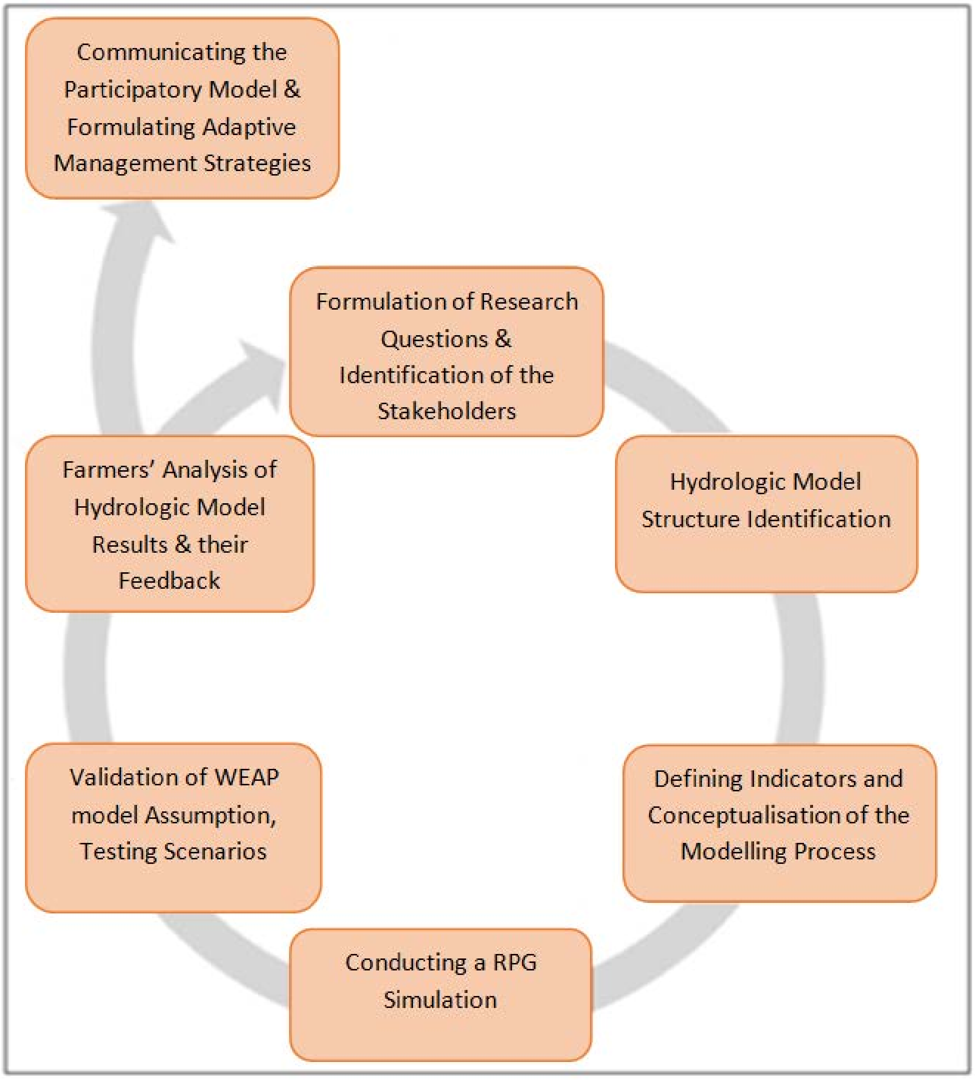
4.4. Part II: Integrated Modelling Procedure and Different Phases

As described in chapter 2, the companion modelling approach and its main objectives were applied when developing my methodology. This approach was introduced in the mid-1990s by a French research group (CIRAD). The main principles of this approach, which are considered in my methodological intervention include: constructing the model with stakeholders, transparency of the procedure, and the outcomes should be adaptive (Voinov and Bousquet, 2010). This approach is widely used for natural resources management and usually seeks to raise the awareness of participants, incorporating different perspectives in the process and testing the outcomes. This approach has led to successful social learning outcomes in many case studies and can be used for educational purposes, or to achieve technological or institutional improvements within a collaborative management-decision process.

In this section, different steps of my methodology are described, including: 1. Contextualisation of the framework and development of the ComMod process, 2. Development of a Role-play game simulation, 3. Integrating scenarios into a hydrological model and evaluation of the outcomes by farmers.

In this approach, participants are directly involved in model design, indicator selection and evaluation of modelled scenarios (Barrereau, 2003). Different phases of this methodology were developed at different periods during my field-work study. The structured framework of this methodology follows the general steps in constructing participatory modelling (Voinov and Bousquet, 2010). In order to make my methodology effort scientifically repeatable, I have structured the different stages of my methodology into the participatory adaptive modelling framework (Figure 12). The following steps were taken in developing my participatory modelling approach through a co-construction process with local stakeholders.

Figure 12 The Main Stages of a Participatory Modelling Process



Source: Author, 2014

Phase 1- Formulation of Research Questions, Objectives and Identification of the Stakeholders (April-June 2011)

The first stage of the participatory process was to understand and identify the main problems which need to be tackled, and the main goals of developing the model (completed in the first part of the methodology). As mentioned in the previous section, in this step primary field-work study was conducted to define the project aim and objectives, to identify system boundaries, data availability, location of the case study area (spatial and temporal), map and access routes to the rural communities and the relevant agencies and main stakeholders. Using semi-structured interviews and observations, farmers' perspectives towards water values, water management, traditional methods of harvesting water, irrigation mechanism and farmers' main problems/interests were collected and analysed during two years field-work studies (see Part I). In the first stage, agriculture had been identified as the main water consumer sector, the main stakeholders (local farmers) and their interests also existing problems/conflicts were gathered and later incorporated to construct an overview of the catchment area.

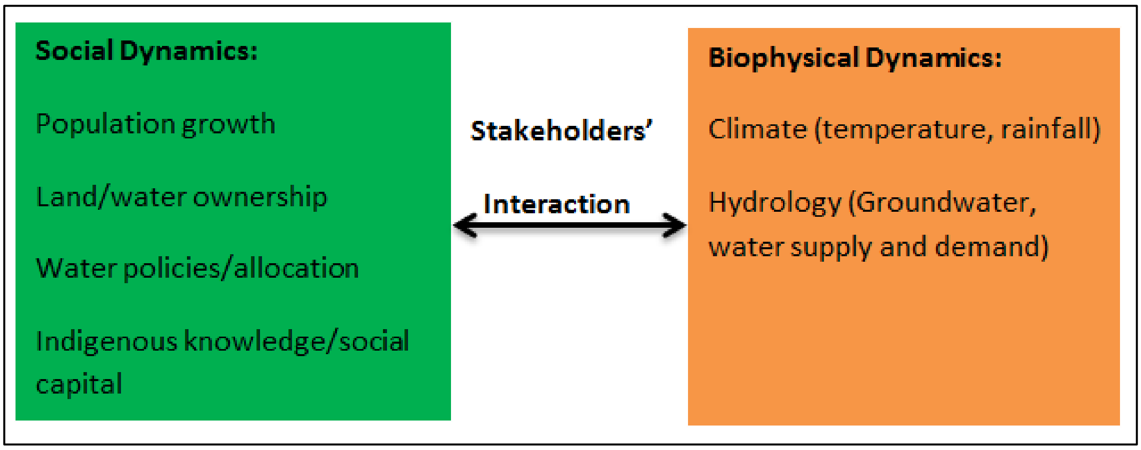
Phase 2- Hydrologic Model Structure Identification (April-June 2011)

In this stage, different methods regarding stakeholders' engagement in the development of participatory process were considered. The suggested hydrologic model (WEAP) and its capability of representing results were discussed in a seminar with PhD students and academics (total numbers of 10 PhD researchers in the relevant fields of desertification, agricultural water and land management) in Iran. In this process, the aims in using the model, the suitability of the model for the case study area, data availability, and relevant indicators were discussed.

Phase 3-Defining Indicators and Conceptualisation of the Modelling Process (2011)

In this study, different stages of the methodology follow the ComMod approach with the aim of including different stakeholder's perspectives into a participatory physical modelling development. This approach suggests the direct use of participants in the design, identification of indicators as well as evolving scenarios into the participatory hydrologic modelling. In this study, to capture and understand the complex biophysical and social situation of the irrigation system of Kashan and to create a shared platform for further negotiations and dialogues among stakeholders, different parameters are formulated based on farmers' perspectives. In this step, different views and perceptions regarding the most influential factors in irrigated water use were gathered from relevant stakeholders. As a result of different parameters elicited from farmers' perspectives and from expert knowledge, the most relevant parameters were identified, such as biophysical and climate variables, population, land and water ownership. To create a primary modelling platform and to facilitate analysis, relevant parameters were grouped into two different clusters of social and biophysical elements and their relations within irrigation system of Kashan. Some of the physical factors such as climate and hydrological variables were used as input data into the hydrological model of WEAP to obtain graphical results (Figure 13).

Figure 13 ComMod approach: Social and biophysical relations within groundwater irrigated system, and farmers' interactions and perspectives



Source: Author, 2011-12

To validate/upgrade the hydrological model and incorporate more accurate assumptions, and trustworthy scenarios in the modelling process, a participatory RPG by local farmers was conducted at a later stage. Different climatic, social and technical factors in the form of scenarios, were elicited from Iranian farmers' perspectives within the simulation, and were utilised in the design and simulation process. The hydrological model ran under new scenarios in WEAP model that will be present in Phase 5 of this chapter.

Phase 4-Conducting a RPG Simulation (2013)

In this stage, the use of the RPG included different objectives. The main aim of the study was to encourage communication and facilitate a negotiation process among farmers and eventually obtain the collective-agreed management scenarios; the other purpose was to use the simulation as a mediation tool to validate the method approach. In my study, conducting RPG has added considerable value to the research findings; it has also facilitated the formulation of more accurate scenarios and provided a holistic view of the problem from farmers' perspectives, for testing in the hydrological model. Within the simulation process, group discussion was fostered leading to commonly-agreed decisions for improving irrigation management strategies. In the third part of this chapter, the designing and conducting an Irrigation Management Game (IMG) with farmers will be explained. The outcomes of integrating scenarios into a hydrologic model will be discussed later in this chapter and further in discussion Chapter 7.

Phase 5-Validation of WEAP model Assumption, Testing Scenarios (2012-2013)

The WEAP model produces predicted future water demands for agricultural water use under different scenarios such as improved irrigation efficiency and climate change (see Chapter 5). As mentioned, for executing the first version of the WEAP model historic hydrological data as an input including climate variables (i.e. temperature, rainfall pattern, water supply and water demand), collected from the local water and irrigation institutes, were utilised. The model was initially run with fewer scenarios (i.e. future decrease in rainfall and increased temperature), obtained from national/regional climatic and population status for the future.

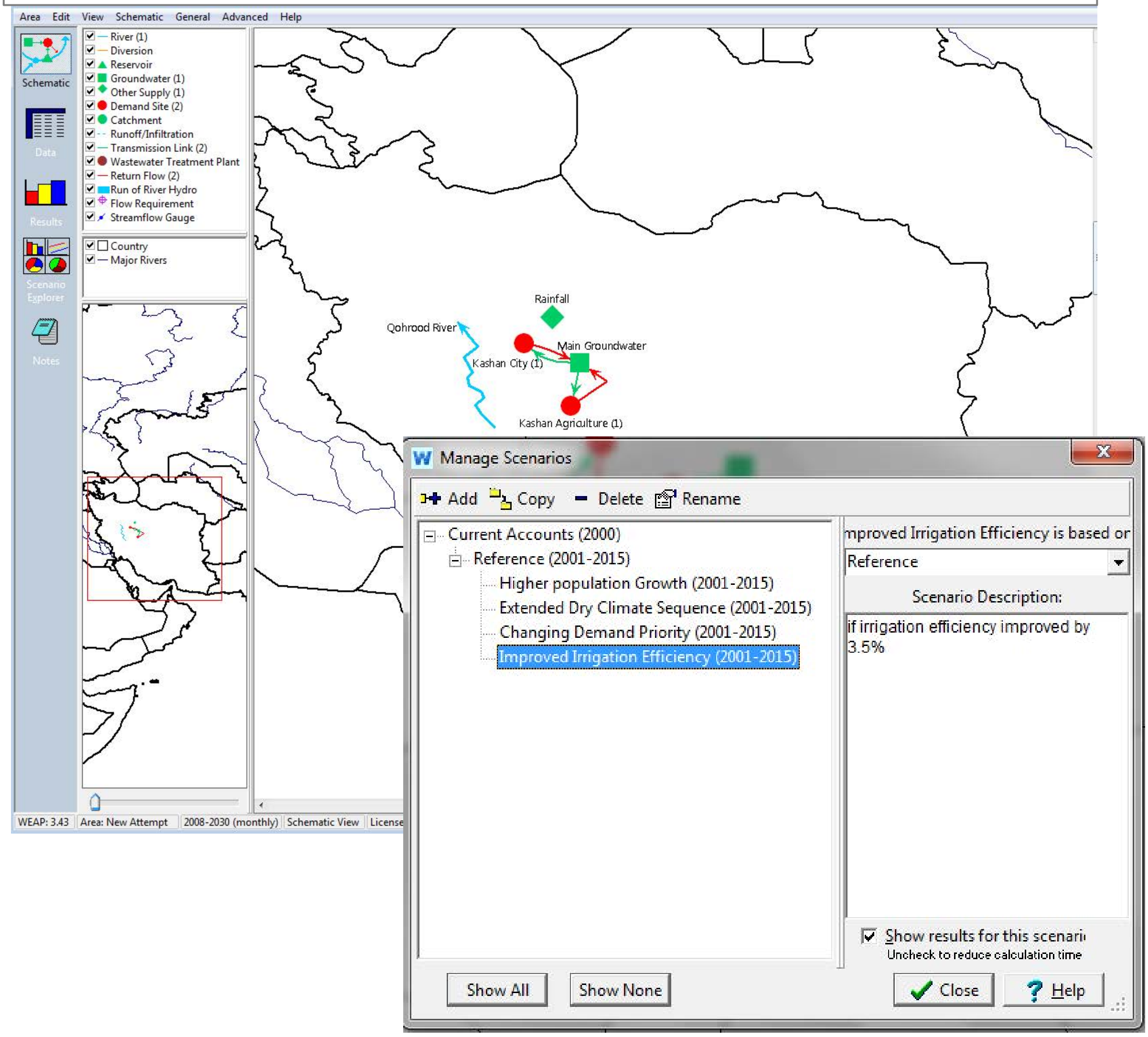
Because the conceptual hydrological model cannot exactly predict the future groundwater status of the region, it was essential to consider and compare more pertinent future scenarios that reflect farmers' predictions. To obtain more local-based scenarios, an RPG simulation was used in the next stage (described in detail in the following section), in order to elicit more knowledge from farmers which could be used in defining modelling assumptions. Following validating the model assumption based on the outcomes of the RPG simulation, the model was run for the second time and the final results were discussed with farmers. The modeling process was undertaken in an innovative and experimental way by introducing WEAP into the simulation process. This model could be effective as it can be run with limited data (See Chapter 5). In creating the ComMod platform, a combination of tools such as agent-based systems (ABM), Role-playing games (RPG) or conceptual models can be used to involve participants in developing the methodology (see Chapter 2). In this study to develop a companion modelling process, conventional agent-based models (ABM) (such as Netlogo/ Cormas) which are usually used for this approach, were not used. In this methodological intervention, however, the modelling process and evaluation of the relevant scenarios (elicited from local farmers) were undertaken using the Water Evaluation And Planning system (WEAP) model (see Chapter 5 for details). The model selection reflected the different objectives of this research study, the lack of required data, limited expertise for model implementation and validation.

The main advantage of using this model is its ability to compare different scenarios graphically; it also has the capacity to be used as an educational tool to effectively describe complex water systems in a simplified and visual manner (Cockerill et. al., 2004). This capability can facilitate dialogue and broadens discussion on model structure and results (Harris, 2007). This hydrologic model is used as a mediation tool to give an integrated view (including physical parameters) to our thoughts and approach. The main purpose of incorporating a particular hydrologic model is to create a suitable decision support tool in order to assist farmers to decide and evaluate which irrigation management options are more appropriate, and to observe the future trends in their agricultural water demand under particular conditions that scenarios are simulating. This process can bring more in-depth discussion and dialogue amongst participants in an iteratively simulating manner.

After implementation of the RPG and formulation of the relevant scenarios, testing of the scenarios and evaluation of the outcomes with farmers was conducted, I will reflect on in this section. Some of the scenarios that were obtained from farmers' perspectives such as improved irrigation efficiency, future climate and population changes in the region and land integration were tested in a hydrological model to observe how agricultural water demand will change under each specific scenario (Figure 14). These scenarios are tested so that the outcomes could be discussed with farmers and to expand discussions. This is also to add complexities and including future uncertainties to the farmers' existing assumptions by incorporate hydrologic and climate variables.

Construction of the hydrological model and each individual procedure could not be discussed in details with farmers, due to lack of expertise and availability of time and funding. However, some of the models' outcomes could be discussed and evaluated by farmers (see Chapter 7). In many cases participants are new to models and when learning about a model for the first time, it can be difficult to engage and interact (Voinov and Bousquet, 2010). When developing the hydrological model, the researcher attempted to engage participants from the beginning in developing a conceptual model and later by running the Role-play simulations, which helped farmers engage in co-construction of the modelling process.

Figure 14 Schematic view of the WEAP model and Scenario Management Screen



Phase 6- Farmers' Analysis of Hydrologic Model Results (July-Sep 2013)

The method contributes to the ComMod approach as it links some aspects of the conducted IMG to the physical hydrologic model of WEAP. As part of this approach the outcomes of the modeled scenarios need to be discussed with local farmers who participated in the IMG development. In this stage some of the results that were recognised to be more relevant to farmers' interests were presented to them to obtain their reflections on the outcomes. In the group discussion with farmers, they were first reminded of the previous RPG session held with them during the previous field-work visit, brief steps and outcomes of the RPG were summarised for them, and some of the farmers who had previously attended the RPG session, assisted in explaining the procedures to the other farmers.

To analyse the hydrologic model results, first the outcomes of simpler modelled scenarios were shown to farmers. These graphs were first shown to a smaller group of farmers on paper and after it was observed that farmers could interact and give meaningful feedback on their results, within the next group discussion, the results were shown to a larger group of farmers on a lap-top computer, and the user-friendly result interface of the WEAP model software was used to discuss the outcomes with farmers and generate more dialogues (Figure14). A group discussion was subsequently conducted to explore their thoughts and opinions regarding the accuracy of the modelling results, as well as their confidence and trust in the final outcomes. My role as a facilitator was to make the graphs easier and more understandable for farmers, thus, after presenting each graph the facilitator explained each graph, the meaning of the different colours and the changes in bar charts and the trends to clarify the outcomes. It was explained to farmers that, these graphs were produced based on available regional data, gathered from different local water and irrigation agencies; also it was explained that the main scenarios were formulated from the previous RPG (in which they played a major role in designing and simulation of the game).

In this study, the aim was not to make stakeholders to accept the WEAP model as an accurate or analytical tool, (there was not any organised workshop to explain the model functions and outcome for farmers). The attempt was not to make farmers to choose any outputs of the model or RPG in their daily practices, but it was used to influence their perspectives and elicit knowledge. In this case, the effort was to direct the process towards development of self-management irrigation practices and empower local decision making ability to apply more efficient water use strategies. The hydrologic model was used as an appropriate tool that can represent integrity of different factors and compare different assumptions in a very simple outlook. However developing RPG with farmers was intended to obtain relevant scenarios and therefore give farmers a sense of trust and ownership of the participatory model results. Although not every element of the game could be simulated into the hydrologic model or vice versa, the development of the game and hydrologic model with farmers has broadened discussions and engaged their participation in the model development.

Phase 7- Communicating the Participatory Model and Farmers' Feedback (2013)

Farmers' analyses of the results and suggestions were taken into account for future improvement of the modelling effort. Presenting the model result to a larger audience is a useful step in disseminating the main messages and including wider perceptions for results. This session was similar to the debriefing session that was conducted after the Role-play simulation in the previous part. The details of this stage will be discussed in Chapter 7.

Figure 15 Presenting model outcomes to farmers on the laptop

Sources: Author, 2013 (Ali-Abad Village)

4.5. Part III: The RPG Development

A game for natural resource management is a serious learning method in terms of both communication between participants and collective decision-making. Game allows stimulation of participants' behaviors and actions in a near reality modelled system. Role-play is used in this study as a legitimate tool (Bloor, 2001; Lankford, 2006) for conducting a qualitative social research method. Regarding using Role-play game for common-pool resources management Barreteau et al. (2003, section 1.1) believes that games are "a means to reveal some aspects of social relationships by allowing the direct observation of interactions among the players". The main aim of using game for this study is to elicit farmers' knowledge to evaluate different irrigation policy schemes in the case study area. Role-play game facilitate eliciting farmers' knowledge and perspectives on various management options and finally come to a common-agreed solution for a more sustainable groundwater irrigation management in the future.

In the final part of the methodology chapter, the development of a Role-play game with local farmers in Kashan is explained throughout different phases. The discussion of the simulation outcomes will be expanded in Chapter 7.

4.5.1. Self-designed irrigation management game (IMG) with farmers

In summary the RPG began with a farmer-led exercise of collaborative resource mapping to produce a board game reflecting the specific local context (field location, crop type, existing irrigation canals) in which the rules and specific context of this game were created. Farmers were allocated a farm on the board while they defined the existing rules of their farming systems and were invited to respond to a number of irrigation scenarios during a RPG.

A participatory and self-designed groundwater irrigation board game was developed with local farmers. The aim of utilising a Role-play game (RPG) was to elicit knowledge of local farming systems and irrigation practices in Iran, and evaluate government policy prescriptions from the perspective of participating farmers. The other objective was to explore further scenarios to improve irrigation efficiency by farmers. The main question to be addressed during the game is why the drip irrigation method (proposed by one government policy scheme) has not been adopted by the farmers in this region. This section describes the game design.

The biophysical structure and the established rules of the irrigation system influence the incentives and behaviour of resource users in managing water resources, and inevitably this varies according to cultural and economic context (Ostrom, 1990). In this study, water allocation rules play vital role in defining farmers' relations to each other, so it was included in the design of the game. A wide range of local rules give clear guidelines for water allocation based on location, time, type of water user and other factors, which are effective in resolving potential conflicts in water allocation. The irrigation and water allocation rules used in this game design were established for Qanat systems in the past and also apply to motor-pump groundwater abstraction wells (see Chapter 3). These allocation rules, the location of the tube-wells and irrigation pipes were carefully located on the board by farmers.

Incorporating farmers' real roles and community-based rules can help replicate their behaviour successfully during the simulation, thus removing possible constraints on participant's behaviour and their attitude to the game (Toth, 1988). In developing and playing the irrigation management game (IMG), the main participants were local farmers who designed the board game and were situated within the simulation exercise by their actual roles and responsibilities as in the real system.

Different initial game designs were tested in a pilot study with PhD students in the UK and Iran. This improved the game design, in terms of better understanding of the cultivation pattern, land use and irrigation techniques in arid regions of Iran, and also provided different perspectives on implementing modern drip irrigation methods in agricultural fields. During pilot study with PhD student in Iran and in UK, different rules and roles were written on a card and given to participants; however in the field given literacy problems and farmers' limited time, this was not possible. Also farmers were not given different or controversial roles: they acted in their actual role in real farming activities which could address the aim of this game (to elicit relevant knowledge and generate dialogue through farmers' perspectives on different irrigation issues).

4.5.2. Description of the Board Game and the Setting

Materials- The basic materials for the game were provided in the case study at negligible expense. A wooden panel (1m x 1.5m) was prepared for the game using iron rings to represent boreholes, green or yellow sticky paper to represent farmlands with different crops. Blue paper lines were used to symbolize the water canals extending from boreholes and to farmland.

Rules- In this study, the government 'Tooba' scheme (installation of drip irrigation system), and associated policy of reducing water abstraction to one-third, and land consolidation, was used to design the initial rules of the RPG. Subsequently other rules, relating to water rights, were derived by the farmers themselves during the simulation. Water allocation rules were explained by farmers during the group discussion, and these were incorporated into the game design by the facilitator.

The water allocation rules, which were applicable to the underground piped-water system, were explained and discussed by the farmers. During the simulation, thick blue lines were used by the facilitator to represent underground piped-water (or cement-lined canals) on the pre-designed board game, whilst narrow lines represented a less efficient water transmission network. Each water outlet from the transmission canals was linked to one of the nodes (representing allocated water).

Roles:

- Irrigator farmers (2 players- see next section): In each round of the simulation process after proposing an irrigation scheme as a scenario, irrigators should assign a suitable size of blue papers to represent the efficiency of the proposed scheme. They should locate these symbolic pipes or canals from their shared tube-wells to their farmlands. Also, they were asked to respond and engage in the discussions and share their knowledge during the simulation exercise.
- The Tractor driver: He was selected based on his knowledge and experiences regarding scattered land ownership status in the region. He has important responsibilities that could significantly affect farmers' production levels and income, as he does the ploughing, land surfacing, harvesting, and land clearing after harvest for farmers. This farmer was invited to the game session to share his knowledge in different rounds of the game.
- Well-chief: In each round of the simulation, when the scenarios of different irrigation schemes were proposed, the well chief was asked to explain different rules in water allocation, distribution and maintenance, and to summarise specific difficulties or advantages that could be brought by a particular scheme for shared-well owners regarding their system' irrigation efficiency.

Each farmer played his actual role in the irrigation field, and when asking different questions by proposing a scenario, he was expressing his knowledge and perspectives regarding the question and shared dialogues with other farmers. For farmers acting in their actual role could bring their relevant experiences and perspectives into the simulation and this was insightful for other farmers to understand the difficulties associated with that farmers' particular role/responsibility.

Participants- Four participants were selected for the RPG; one of the irrigator farmers was a member of the rural council so he could also provide insights into a discussion on the governance and management problems in organisational level. The other irrigator farmer was an older and experienced farmer, who owned several small and scattered pieces of land. The tractor driver was also a local farmer who owned a tractor and the manager of the local abstraction well (well-chief) who was also a farmer. The well manager was trusted by the local community and was responsible for repairing the motor-pump and collecting fees for using the motor-pump (to pay for electricity, etc.), as well as providing pesticides and fertilizers from the agricultural agency for farmers.

Those four farmers, who were selected, were able collectively to represent the main institutions responsible for irrigation practices in the case study. Women and children were not involved in the main irrigation or farming activities because they are not actively involved with the irrigation or farming practices in Kashan.

Organization- In the particular village of Ali-Abad, the village leader had an assigned role in bringing farmers together for local meetings and mediating between farmers and official organizations. The researcher based on the established trust with local farmers' communities, communicated with the rural leader and he was willing to organise the group meeting for conducting the Role-play game (in total 12 farmers were in the meeting, however four of them showed interest and were selected to participate in the Role-play game). The farmers proposed the local mosque in Ali-Abad village as the most convenient place to meet and conduct group discussions for the RPG. Also, the debriefing sessions (discussion after conducting Role play game) were held in the local mosque. This provided suitable and comfortable environment for farmers and the researcher, particularly during summer and in Ramadan, gathering farmers at prayer times mid-day or in the evening, could provide useful information and productive collaborations (see Chapter 4).

Group discussions were conducted before the game session and after the game session for debriefing. Each group discussion before the game took 1 hour and a half. The RPG session took 2 ½ hours. The game was played with four farmers and within three rounds (according to the three proposed scenarios). The outcomes of the game were later reported by participants to others and also debated among farmers who could not attend the game session, due to their busy time schedule. Participants played their role in their own place and there was no changing role amongst farmers because of the time constraint. All the group discussions and game sessions were recorded, and the transcript was translated and coded in English afterwards. Some parts of the RPG were video recorded for further analysis and to understand farmers' interactions and behaviour. After the RPG session, farmers were given a reasonably priced gift. The transcripts of the RPG discussion sessions were coded in Nvivo, the highlighted codes were used to extract different themes to analysis the responses, which are discussed in Chapter 7.

This particular Role-play game designed for this study will be termed Irrigation Management Game (IMG), throughout the rest of the thesis.

4.5.3. Implementation of the Irrigation Management Game (IMG)

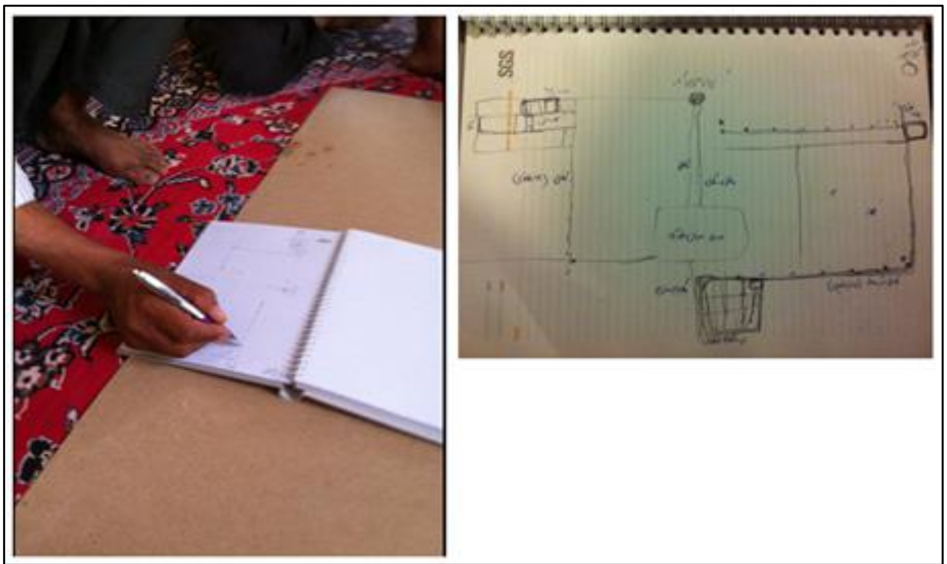
Generally, natural resource games tend to represent a particular conceptual model with specific socio-ecological features, which prompts the imagination of game participants thereby facilitating discussion (Meadows, 2001). Games should generate communications and exchange between participants so they must replicate the reality of the system (Schelling, 1961) also simulates actual institutional characteristics or policies. In this study, the game provided a simplified representation of a groundwater irrigation system for farmers. The use of 'real life' rules, recognized by participants, provides a number of opportunities for participant learning (see Chapter 7). The simulation required participants to consider a wider perspective, and focused on historical rules which are closely related to current practices.

In this part, in order to make the presentation of the Role-play game simpler, I will explain the process within different phases which ran by farmers' participation.

Stage 1: Selection of Participants and Design of the Board Game

In the first phase of the simulation, group discussions were conducted in a local mosque to introduce farmers to the scope and the overall structure of the session. Vital information about the current rules and management strategies was obtained. The provision of deliberative information and wider perspectives from farmers can be elicited through group discussions which also make the game setting more realistic (Daré and Barreteau, 2003) (see Part I expanded in Chapter 6). 10-12 farmers were invited to a local mosque by the facilitator and the village leader (often the oldest and most respected person in a village). The farmers all belonged to the same tube-well, but also had a share in other wells. The group discussion assisted the facilitator in recognizing key individual roles and assigning responsibilities regarding the irrigation system. Participants were asked to provide information on the structural characteristics of their farmland, the transmission canals to access irrigation water, cultivation patterns of their farmland and the rules governing water allocation and distribution. At the conclusion of the session, one of the farmers drew a sketch map of the area which was used as a model to design the RPG for the next meeting. The sketch map of the village started by locating the mosque as farmers stated this is the main area in each village of Kashan, then the access roads, the tube-wells and the canals distributing water to the farmland were located on the map (Figure 16).

Figure 16 The sketch map of the irrigation system for designing board



The group discussion provided an opportunity to improve communication between the farmers, and provided details of the farmers' irrigation rules and understanding (for the facilitator) of the interaction between farmers. At the end of the session, some of the farmers, who were interested in cooperating, and who could also represent different institutional roles were selected as participants in the game session.

Stage 2: Validation of the Board Game

In the second phase of the RPG, the researcher's pre-designed board game was used to present a controlled environment, whilst also enabling realistic simulations (Figure 16). The game was conducted over two days. In the second group discussion on day two, the pre-designed wooden map was completed and validated by the farmers (Figure 17). The geography and settings of the game design were solely based on maps provided by the participating farmers, which replicated the characteristics of their farmlands and water canal systems. The aim was to provide a better understanding of the location of farmers' land and their interactions.

Figure 17 Pre-designed game board, later completed by farmers during the game session

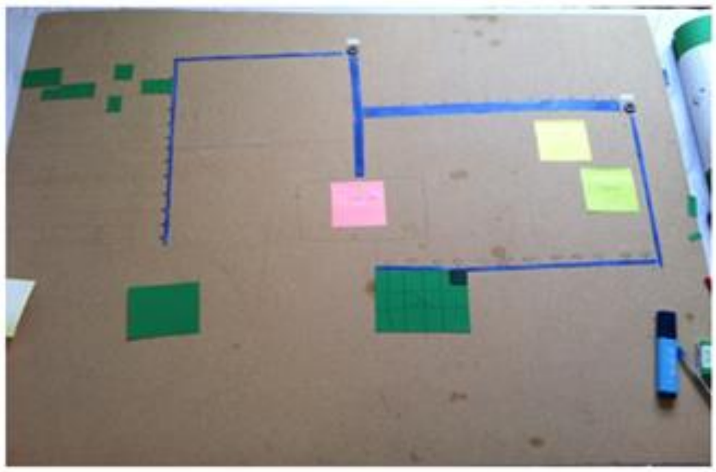
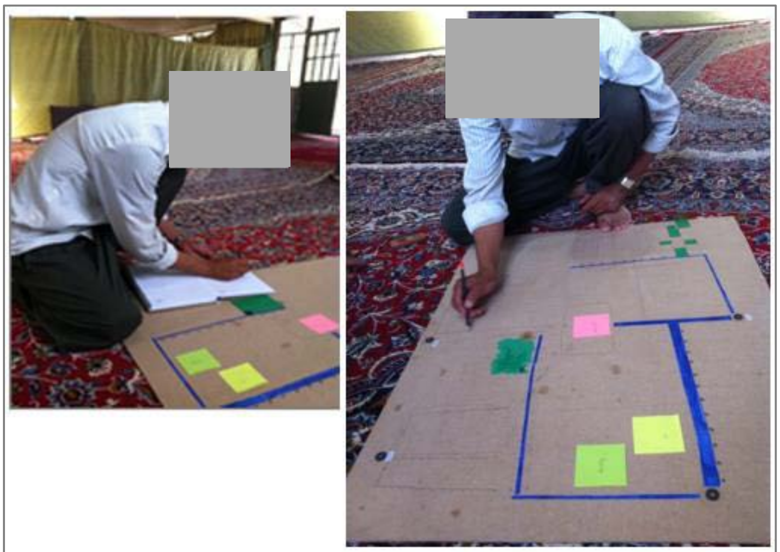


Figure 18 The validation of pre-designed map and setting rules by farmers



Participant farmers indicated which tube-wells they had a share in, so it was decided to locate two common tube-wells on the map; from these two wells the main water canals were drawn. Farmers emphasised that the distances between tube-wells in reality should not be less than 100 metres, so when preparing the board game this scale criteria was considered as a rule.

The farmers indicated that their summer crops were barley and wheat and that some land was not cultivated (for example some of the alfalfa plots in summer are lie fallow (or uncultivated to restore soil fertility). So these plots were located on the board game in places where farmers decide to put their actual farms. The farmers then identified their farm location on the map. At the same time, different crop patterns were illustrated by different green and yellow papers. The other rule was that farmers had to reduce their water abstraction rate to one-third of the current rate. This was initially stated by farmers and was considered during the discussion of the game sessions.

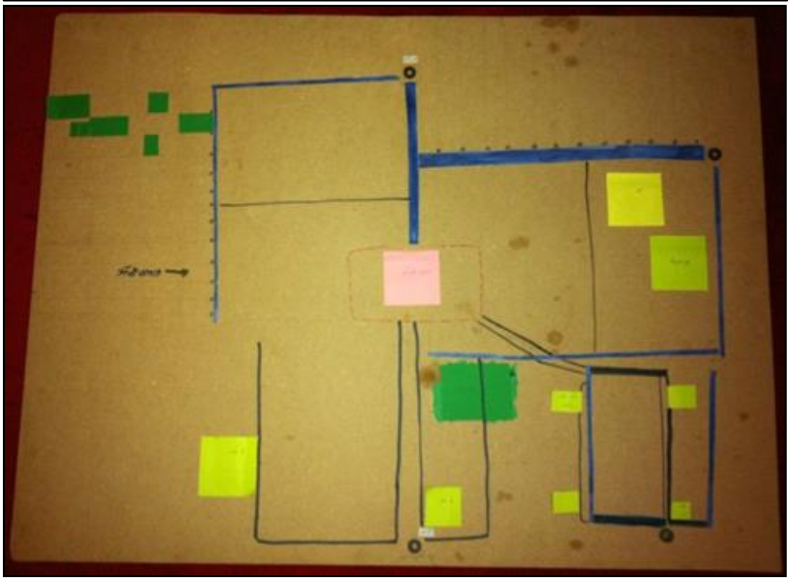
Stage 3: Conducting the Game Rounds

After validating the pre-designed board game, the farmers were then encouraged to participate in the RPG. Different crop patterns were illustrated by green and yellow papers that farmers positioned on the board. The restriction rule of reducing water abstraction rate to one-third of the current rate was part of the drip irrigation scheme, so this was embedded in a proposed scenario of 'Tooba' scheme and was discussed under policy evaluation during the simulation.

The main scenario of the simulation was to change the muddy, or canal irrigation system, to cement-lined, to underground pipes, or into a drip irrigation method. This was proposed in the form of different scenarios and farmers who had drawn their farms, reservoirs and tube-wells on the board game were asked to discuss different schemes and play the game using symbolic water canals of different sizes. This selection was based on their understanding of the increased efficiencies and other advantages that each proposed scheme could bring for them. The farmers linked the irrigation canals to their lands by using different symbols. As noted above, blue paper lines of differing thickness were used to represent high and low-efficiency irrigation canals as this was found to be practical for farmers to use while they were explaining their irrigation management strategies. Each round of discussion commenced with questioning farmers about current irrigation policy schemes.

The new scheme of piped-line irrigation system was discussed with farmers. Irrigator farmers mainly participated in the discussion and explained to the researcher and other participants how this intervention technology could match their traditional water allocation mechanism (see Chapter 7).

Figure 19 The completed designed map of the farmlands and water canals by farmers

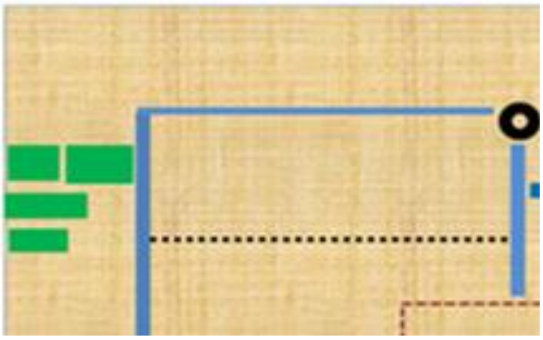


The facilitator (researcher) asked farmers to discuss different scenarios attached to the Tooba policy scheme which might affect their agricultural practices. For the initial design of the

Role-play game, some scenarios were drawn from the existing policy scheme and the attached rules to them (i.e. Tooba scheme), throughout the game.

The researcher began the game by questioning farmers about pre-defined scenarios (e.g. implementing a drip irrigation system; reducing water abstraction rates). This stage clarified farmers' perspectives on irrigation schemes and yielded new scenario of land integration for future development, which is discussed in more details in chapter 7. During the game, a particular scenario of land integration emerged and this was discussed by farmers, as it was found very critical factor for farmers to reject drip irrigation installation because of their fragmented lands and high costs of the new system for poorer farmers. The farmers drew different pieces of land on the other corner of the board game (symbolized by small green pieces of paper by the facilitator) to illustrate possible ways in which farmers might exchange their closest pieces of land to create larger plots (see Chapter 7).

Figure 20 Light green square papers on left side, were used to represent neighbours' lands and how farmers can reach an agreements to join their land pieces or swap them with each other



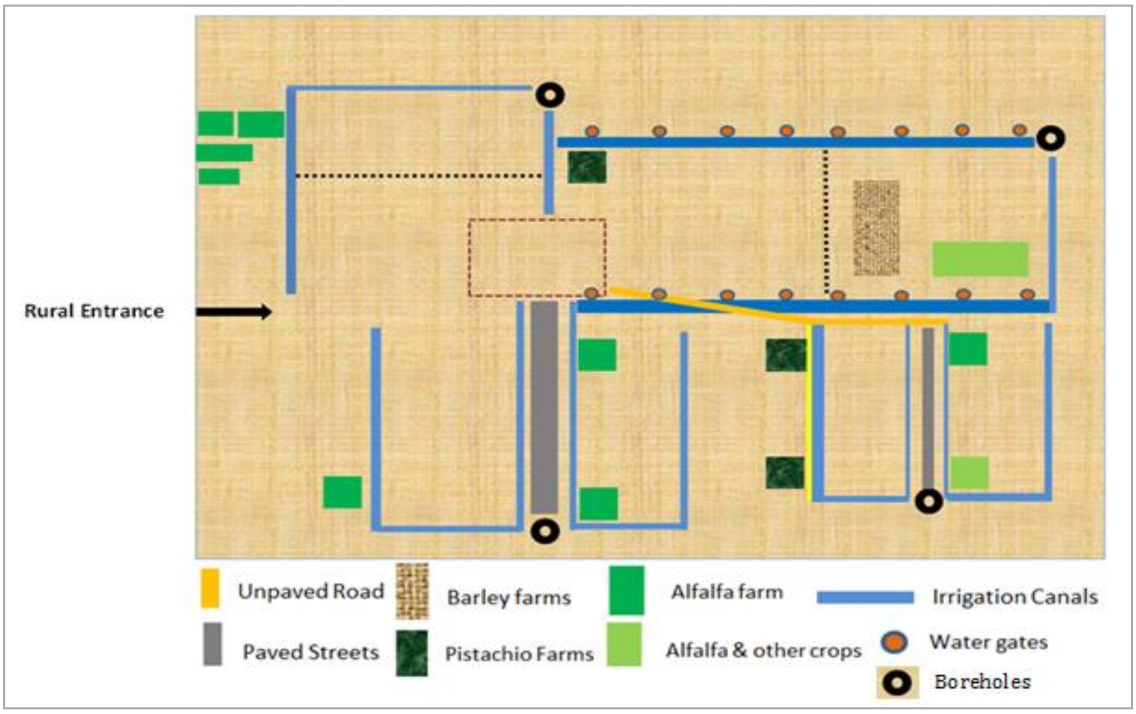
At the conclusion of this element of the RPG, farmers were asked to evaluate the RPG session by reflecting on the game that they had designed.

Throughout phase 2 of the RPG and during the subsequent debriefing, farmers were asked to list their main water-related management problems. They were encouraged to discuss and agree on new ways of improving the management of their groundwater resources and were asked to decide whether they should accept or reject government policies. Some of their concerns included:

- How might the policy of modernizing the irrigation system affect future agricultural water status for farmers in Kashan?
- What kind of support would farmers need from government to improve water management and agricultural practices?
- How might the RPG provide useful material for the farmers and would they be willing to participate in a similar simulation study in the future?

During this stage, farmers were asked to express their ideas, consider the negotiation phases and evaluate how they reached the final decision regarding the most appropriate irrigation management strategies and suitable irrigation technology. Finally, they were encouraged to list some of the locally based solutions in terms of the most suitable technology and also land management practices to improve irrigation efficiency in the village, which will be discussed in more detail in Chapter 7.

Figure 21 Map of the designed farmlands and canals in the board game (refers to the sketch map Figure 19)



Source: Author, 2013

4.5.4. Debriefing Session

Debriefing was conducted after the game session finished for an hour within group discussion. Debriefing is described as the processing of the experiences and reflection on the observations, which will lead to learning outcomes. For this stage, after the game session ended, I questioned farmers about their feelings during the simulation process and afterwards. I also asked farmers about their first reaction and attitudes towards the game design and procedure. They reflected on the usefulness of the game, the similarities and differences between the designed board game and the reality and the lessons they learned from the session about their system and regarding other farmers in their village. Discussing scenarios of actual irrigation policies and their implementation (such as adoption of 'Tooba Scheme'), provided opportunity for farmers to reflect on real-life problems, which they could later extrapolate back to their experience. Primarily scenarios and rules were designed to create a productive and familiar environment for farmers. The objectives were to simulate the realistic procedure of policy decisions and enable farmers to evaluate specific policies. The scenarios provided the initial basis for individual simulations. Thus, the well-known scenario describing the drip irrigation policy scheme was initially used as it is currently the farmers' main challenge.

I will discuss the outcomes of this simulation exercise (such as generating social learning and collective motives), as well as the debriefing session in more depth in Chapter 7.

4.6. Conclusion

This chapter has described the main methodological approach and the different stages taken to develop a participatory research process for adaptive irrigation management. Different data collection methods and tools were used to facilitate the flow of information and foster discussion. The qualitative research methods of interview and group discussion were used to collect social data. The interviews were conducted to provide general understanding of the irrigation system in Kashan, the main problems regarding irrigation efficiency and sustainability of groundwater resources, irrigation rules and management practices as well as existing cultures and farmers' perspectives. Group discussions proved useful for engaging farmers in debates, particularly prior to and within the Role-play game exercise and this created a basis for conducting a simulation game for irrigation management (see Chapter 7). Farmers were given equal opportunity to express their views and engage into the conversation with other participants to provide a rich knowledge.

In this study, particularly the incorporation of physical and social dimensions of irrigation system could provide richer knowledge. The spatial characteristics of the irrigation system dynamics were transferred to the board game and social interactions and policy regulation comprised the rules of the game. The simple and familiar outlook of the board game and the scenarios of the actual irrigation policy scheme combined a simple as well as complex dynamic of the irrigation management. The game can also be designed to simulate land integration with farmers to improve further future development of the irrigation management system.

Participatory modelling using the Companion Modelling approach was adopted for this study as a methodology approach to integrate social and biophysical dimensions of groundwater and irrigation system dynamics and to create a shared platform to enhance communication and collective agreed solutions. The participatory process facilitated the flow of information and fostered discussion on the wider socio-hydrological aspects of irrigation management practices in the arid region of Kashan, Iran (see Chapter 7).

CHAPTER 5

WEAP Modelling

Introduction

Effective water resources management requires an integrated approach that considers both physical and social aspects and their interactions for local or regional water management (e.g. Gurunathan, 2013). Hence interdisciplinary approaches to complex water systems which address both socio-economic and environmental interests are crucial. This can be partly achieved through the implementation of integrated models such as Water Evaluation and Planning System (WEAP) model. In situations where water resource availability is limited, for example by various ecological and socio-economic factors, managing water resources is a challenging issue, which must consider both ecological and sustainable use of water resources (see Chapter 2). The concept of integrated water resources management (IWRM) has developed over recent decades, and integrates technical and social aspects, in order to improve management approaches. The main concerns emerging from this approach are water demand management, improvement of water quality and ecosystem conservation (Chapter 2). In this study, the WEAP hydrological model is used to test different scenarios of climate change variables and changing agricultural water demand.

As part of the Companion Modelling process described in the methodology chapter, the Water Evaluation and Planning System model (WEAP) was integrated into the participatory adaptive modelling process. In the process of model development, stakeholders' perspectives were obtained through a number of different social methods, to formulate appropriate parameters for input to the model and subsequently, to discuss the modelling results with participant farmers. In this study, the scenarios of irrigation management, population growth, climate change, 'Tooba' irrigation scheme (including land integration and technical changes) were evaluated using the hydrologic model (described subsequently in this Chapter). This chapter is a standalone methodology chapter that seeks to justify the adoption of the WEAP model within the participatory modelling process. The chapter outlines the model structure and provides background for its wider implementation and suitability for this study. The application of the model to the case study area and the steps taken in constructing the model are described. The chapter concludes by summarising the outcomes of modelled scenarios for future water demand in Kashan.

5.1. Hydrological WEAP Model: Description, Characteristics and Applications

The WEAP (Water Evaluation and Planning) model was developed by the Stockholm Environmental Institute (SEI) (Jack Sieber in 1988). WEAP is an integrated water resource planning tool that provides a flexible, user-friendly and integrated framework for policy analysis. WEAP attempts to include different values of concern and given its focus on policy orientation, it provides a mechanism for testing alternative scenarios and management strategies. WEAP provides a forecasting capability by simulating water demand, water supply, flows and storage, treatment and discharge and generation of pollutions (SEI, 2009). It also facilitates the evaluation of various management alternatives and water developments in multi-stakeholder situations. WEAP is a hydrological and scenario-driven platform that is based on evaluation of a series of selected scenarios under defined biophysical and socio-economic conditions (Raskin et al., 1992). It integrates demand and supply-based data together with hydrological simulations to facilitate the analysis of wider policy options and uncertainties, thereby contributing to adaptive water management. In this process, the responses of the social and environmental systems that face future uncertainties with respect to water development and climate changes are simulated (Varela-Ortega et al., 2011). WEAP is specifically designed to aid scenario development; thus, scenarios reflect optional choices and allocation priorities. The scenarios can enable simulation of different water rights regimes, water supply facilities, water and land use management, water equity and other water related subjects (Rodrigues et al., 2006). In addition, WEAP allows the simulation and analysis of scenarios of water demand management and more important, scenarios describing users' behaviour (Levite et al., 2003). Levite et al. (2003) argue that different scenarios, established within a WEAP model, can answer a wide range of 'what if questions' such as: What if population and economic growth rate changed? What if irrigation technology or crop patterns change? What if a new water demand management scheme is implemented? The features of WEAP and its associated hydrological model can be linked to external models, including the MODFLOW groundwater model, water quality QUAL2K, as well as socio-economic models (e.g. GAM). Some of these integrated models can facilitate a path for greater changes in communities' livelihood and improve water allocation (Rodriges, et al., 2006).

It has been suggested that the main advantage in using WEAP is that it combines demand and supply sides in one equation while the main disadvantage is its reliance on scenarios, whose validity or accuracy might be doubtful or uncertain (Haddad et al., 2007). To address the latter shortcoming in this thesis, scenario building is developed within a participatory process to validate the reliability of the scenarios, and contribute to the local policies and irrigation schemes in Kashan. Conducting IMG (see Chapter 4) has provided legitimate and validated scenarios of future development of groundwater development and irrigation practices to be tested and discussed with local farmers in Kashan and to achieve adaptive management options.

The integration of a WEAP model into a participatory social simulation modelling approach has yet to be widely attempted, especially in semi-arid regions, such as Iran. Hence in reviewing research on the development of WEAP, this chapter focuses on the use of the model within participatory management studies. There are few examples of WEAP model applications in a participatory modelling approach. For example, Varela-Ortega et al., (2007) used WEAP in a participatory approach to determine the vulnerability of stakeholders to the future water availability in the arid region of Upper Guadiana in Spain. In their study a participatory and innovative agro-economic modelling approach was developed at farm level. The different economic, social and environmental factors were incorporated to provide an analytical framework and finally to improve policy decision-making. The use of an agent-based model, and Role-play game was suggested by Varela-Ortega et al. (2007), however there was no structured methodology nor were there clearly defined steps to explain the use of these methods.

WEAP enables forward-looking studies which change physical and social variables to assess their impact on water availability, water flow, and predict unmet demand for different scenarios. This can enhance understanding of future water conditions and management strategies for model users. While this aspect of the model was not the main objective of this study, the possibility of integrating climate variables and social-technical aspects into the participatory modelling approach has added more complexity and enhanced the discussions amongst farmers.

Specifically in water management case studies, WEAP can be used to investigate scenarios for future water development in catchments, including water utilization for domestic, agricultural water and industry (Rodriges, et al. 2006). WEAP can represent different adaptive water policy options and the responses of the social and environmental systems; and hence the model can be used to address future uncertainties in developing water resources and responding to climate change (Varela-Ortega et al., 2011). To provide an overview of the use of WEAP, different examples of the application of WEAP within the academic literature are presented in the next section.

The functionality of WEAP makes it useful as a multi-scale water management tool whose strength has been demonstrated in studies worldwide (Varela-Ortega et al, 2009; Purkey et al., 1998; Levite et al., 2003; Purkey et al., 2007). The experience of the Hydrologic Engineering Center of the US Army Corps (2000) indicates that WEAP can enhance the quality of decision-making with improved levels of analysis and quicker decisions. There is an advantage in developing a model in cooperation with policy-makers in order to enhance institutional capacity to improve policy-making, thereby reducing effort and decreasing regional vulnerability to establish an adaptive management process (US Army Corps of Engineers, 2000).

WEAP can be used for education as a tool to describe complex water systems in simplified and visual outcomes (Cockerill et. al. 2004). Moreover, Sorisi (2006) suggests that presenting the outcomes of WEAP at community level can result in better understanding of water management problems and their consequences. His survey of the Spanish Guadiana River basin suggests that using the WEAP can be useful in raising public awareness for educational purposes (Sorisi, 2006). The use of this model for this study, has also offered educational advantages for local farmers in Kashan regarding their improved understanding of the function and shape of the available groundwater resource and also future water demand changes under climate change variables and population growth (see Chapter 7). WEAP can have different audiences and users, and there are different ways which stakeholders can interact with this model: for example, water planners and local stakeholders might find it easier to describe the study area using the schematic overview that WEAP provides (Rodrigues et al., 2006).

WEAP has been used in several case studies to predict trends in water availability (and in water quality) under scenarios including population growth, adoption of a new technology or construction of a new infrastructure, the implementation of a new policy or economic changes (Rezaian and Jozi, 2011). In this study these factors were used to stimulate future groundwater demand trend in Kashan, as described subsequently in this chapter. The predictions of WEAP (depending upon quality of the data) provide evidence of future water and agricultural water changes. It can make politicians more willing to make difficult decisions regarding resource allocation and authorise investment (Harris, 2007). For example, Harris (2007) used WEAP in a catchment in Guatemala, applying the model to evaluate the impact of future climate change. The aim of her work was vulnerability assessment and developing adaptation strategies. Model outcomes were shared through participatory workshops to inform the stakeholders and improve decision-making ability and finally recommend collaborative cross-sectoral management policies. However, Harris did not work with stakeholders from the beginning in identifying the main parameters and assumptions when building the model and this resulted in a lack of trust in the model's results by local stakeholders. In this study, this lack of integration of stakeholders in the design and development of the model assumptions and scenarios has been addressed. By constructing the initial conceptual model (Chapter 4), stakeholders are involved in identifying the main parameters and criteria for model development from the outset, rather than only being considered in the implementation of the policy or model outcomes and recommendations.

The application of WEAP model in Iran is limited to only a few studies. For example in a study of Golestan province in north Iran, different solutions were defined and tested in the form of scenarios within a WEAP model to provide the best water management solutions for this region, alongside other alternative management options (Rezaian and Jozi, 2011). Another study by Gohari et al. (2013) in the Zayandeh-Rud River Basin in central Iran used the two climate variables of temperature and precipitation to develop different adaptive management scenarios. They concluded that due to future increases in temperature and reduction in rainfall, crop productivity and crop yield will decline; and hence they suggested changing from highly water consumptive crops such as rice and corn to more adaptable crops for the arid region of Isfahan (Gohari et al., 2013).

In the following section, different stages of developing the model, data requirements and the results of modeled scenarios are presented.

5.2. WEAP: Modelling Steps and Data Requirement

Applications of WEAP involve the following steps (SEI, 2001):

i. Identifying the problem;

ii. Identifying the current status of all water supplies and demands;

iii. Establishing scenarios based on existing water policies, technology, population growth and any other factors that might affect demand and supply or hydrological status;

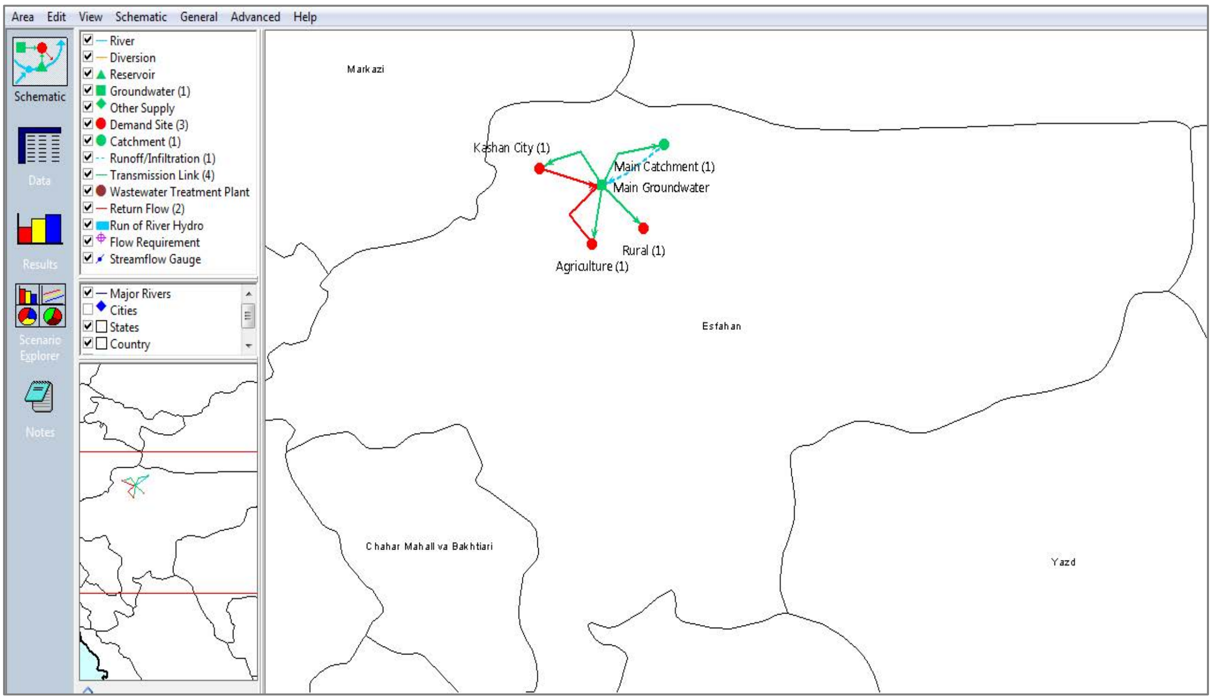
iv. Evaluating scenarios that concern different water management criteria such as water resource sufficiency, water cost (Levite et al., 2003);

In this study, these steps were used to develop a WEAP model. However, the model assumptions are limited and only the main supply and demand sites are represented for this catchment. The different steps are explained below.

5.2.1. Problem Identification: Interviews and Group Discussions

The first step involved identifying the main water consumption sources, agricultural water demand and water supply (groundwater resources) at a local level in Kashan catchment. The purpose was to derive a schematic view of the case study area. The information on both demand and supply sites are represented schematically by two green and red nodes and are linked together to create a network system (Figure 22). The model uses very few nodes to keep the model in the simplest format, to avoid complexity of the results. The assumptions are created around a few nodes representing the aggregated demand and supply sites. Usually, to provide and establish different scenarios in WEAP, comprehensive information is required to represent the future trend of water resources. However, as the comprehensive modelling effort does not address the main objective of this study, which is to engage stakeholders in evaluation of the model outcomes, the simplicity of the model development and results are prioritised so that they can be later related to local farmers. For groundwater resources, the required data include: maximum abstraction, natural recharge, primary storage and storage capacity, moreover, population growth, annual per capita water usage, water consumption, water demand during different month, demand priority are necessary to construct the model.

Figure 22 Schematic View of the Catchment Area



5.2.2. Database Structure

Water supply and demand sources

The main water source in the region is groundwater abstraction, which is widely used for irrigated agriculture. Domestic water for Kashan city and abstraction for agricultural land in Kashan, constitute the main water demand in the region (see Chapter 4).

Climate and Hydrology:

Catchment Hydrology

The catchment hydrology is defined by local precipitation and evapotranspiration. Average precipitation and temperature were calculated according to the estimations by 5 different meteorological stations within Kashan catchment area (Regional Water Agency of Kashan, 2008-2011).

Different hydrological data are required to establish the model water balance as tabulated below:

Table 3 Data Used for Building the Model Baseline

	Area	**Population**	**Annual activity level**	**Annual water use rate**	**Climate Variable data Used**
Kashan Catchment	7076km^2	390,000	1470km^2		Precipitation Actual ETs Runoff
Agriculture	20,000ha			350 MCM	
Kashan City	270,000			47 MCM (1500m^3/person)	

Source: Regional Water Resources Management of Kashan (2008-2011)

Secondary data provided by the Kashan's regional water resources agency were obtained from the annual report for the water resources management authority in the Isfahan Province. Although the data may not have high quality and accuracy to provide high standard modeling results, these regional data (average quality) were used in developing the WEAP modelling assumptions. It was explained to farmers that these data are local-based in order to improve their trust into the model's outcomes.

Table 4 Groundwater Data Used for Modelling (Units are based on Million Cubic Metres)

Storage capacity	-
Initial storage	500 Mm^3
Maximum withdrawal	~350 Mm^3- 216 Mm^3
Natural Recharge	~226 Mm^3- 219 Mm^3
Reservoirs	12 Mm^3
Total Abstraction from Aquifer (Current Account Year)	358.4 Mm^3

Source: Regional Water Resources Management of Kashan (2008-2011)

5.2.3. Scenario Development for WEAP Modelling within Participatory Processes

One of the most important steps in building a WEAP model is scenario development. The literature suggests that one of the main shortcomings in previous studies using WEAP has been invalid scenarios. This shortcoming is addressed in this study, by establishing relevant scenarios that were derived from local farmers' concerns and policy context through a community-based participatory simulation exercise. In this study, to include local farmers' perspectives in the WEAP modelling assumptions and improve the accuracy of the model outcomes, scenarios were developed and formulated based on the views and perspectives of farmers for the future irrigation management in the region, within the social simulation exercise (see Chapter 4).

Scenarios are developed based on stakeholders' viewpoints and interests, which can enhance the quality of the decision-making process for irrigation management in Kashan.

Scenario development largely depends on the views and perspectives of various stakeholders that have potential interest and historical water rights, which makes it essential to incorporate local water users when planning different management development stages. This involvement is required prior to undertaking WEAP simulations; stakeholders' perspectives and decisions should be identified and incorporated into WEAP model assumption, prior to the simulation.

5.2.4. Calibration and Results

For this modelling project, and based on the outcomes of the participatory simulation exercise, different scenarios were identified for testing in WEAP. The following section explains the modelling steps and evaluates the scenarios through the methodology.

5.3. WEAP Modelling Steps for Kashan

The basic structure to build scenarios in WEAP comprises three steps. First: creating a current account year, this is the base year of the model for a particular time horizon (in this study from 2000-2010). The current account represents the basic information of the existing water system. The second step is to create a reference scenario which is established from the current account year (in this study reference scenario is set from 2011-2020). The reference scenario is the 'business as usual' scenario from which more scenarios can be generated. The reference scenario excludes any interventions or future changes into the model assumptions; this is to understand the best predicted situation within the studied time-horizon. The final step is to establish scenarios and run the model to evaluate the future impacts of implemented policies and technologies.

The model was developed for a small-scale area of Kashan catchment with an area of 7076km^2 and a population of 390,000. After defining the area and setting the boundaries in WEAP, the time horizon was selected from 2000-2010 (this is the baseline data until the last year of scenario in 2020, based on calendar month). The major demand sites are agricultural fields and domestic water use in Kashan city, and so the aggregated agricultural water demand in the catchment and the domestic water consumption are represented by two separate demand nodes.

To set up the model, the current account year was created using the data presented in Tables 3 and 4. The monthly variation in groundwater level has been entered into the current account assumption. Under the climate indicator for the Kashan Catchment area, for the two variables of precipitation and ET, the monthly values were used.

In the data view, the key assumption of 'unit irrigation water use' was changed to reflect a new annual pattern for the period 2011-2020. This scenario illustrates the water demand trend under the current water consumption rate until 2020, without improving the irrigation efficiency.

5.3.1. Scenario Building

Preparing the Ground for Scenarios

Scenarios in WEAP represent self-consistent story-lines outlining the evolution of the water system under given socio-economic conditions and a particular set of water or agricultural policy and technological innovations. In this study, the scenarios are intended to evaluate changes in water demand in the region. Scenarios inherit data from baseline data time series (2000-2010) and are used to address a wide range of 'what if' questions such as population growth, or 'What if irrigation efficiency improved?' or 'What if summer precipitation decreased?' The scenarios are based on the yearly time-series Wizard, including the decline in water demand after improving efficiency until 2020. The amount of water that can be saved through applying the 'Tooba Scheme' was estimated using secondary data collected from the water agency in Kashan. The WEAP model can represent the results of annual as well as the monthly water demand changes for agriculture under the different scenarios. The agricultural practice in the case study area, assumes a seasonal pattern of cultivation. Thus, the results of the monthly water demand changes could represent clear water use trends in different months for the participants and this effectively fostered discussion among local farmers (see Chapter 7).

The Table below illustrates some of the scenarios to be tested in the model. The scenario of the 'Tooba scheme' aims to increase irrigation efficiency by introducing a drip irrigation system and a land integration programme. It is formulated from the existing policy and the main concerns of farmers in the region. These scenarios were built to analyze the agricultural water demand for the period of 2010-2015 as illustrated in Table 5.

Table 5 The scenarios to be tested in the Model

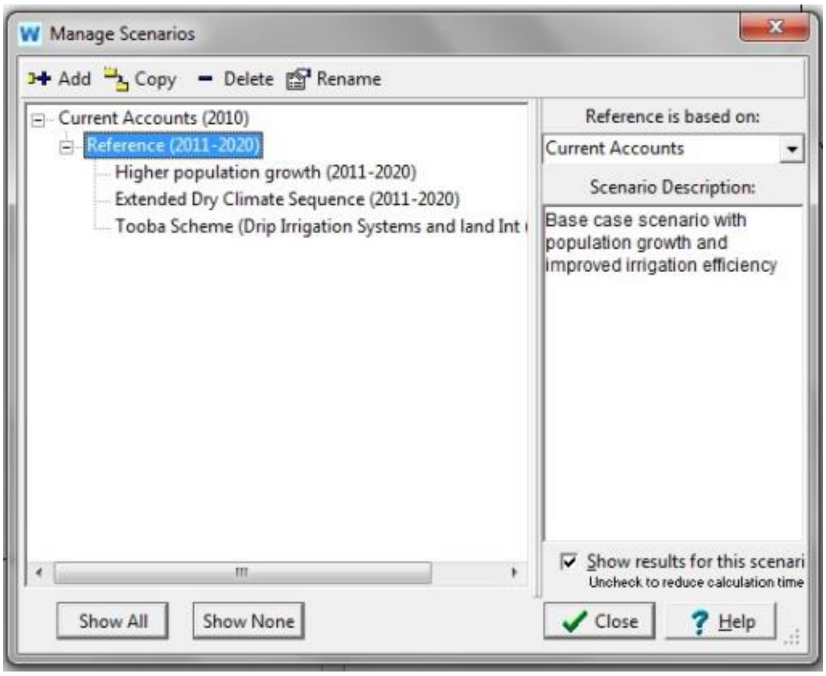
Level of Scenario	Scenarios	Remarks
0	Reference	Models of catchment based on baseline data and no changes to a system
1	Unimproved irrigation efficiency	The continues trend under the current consumption rate, Increased population to 0.2% in the region within future ten years
2	'Tooba' scheme	Improving irrigation efficiency by applying drip

		irrigation system and land integration, to medium and large-scale farms (based on available data in regional water agency~15Mm^3 water saving in future 15 years)
3	Climate variability	Reduced rainfall and increased Evapotranspiration in most arid regions worldwide (IPCC report, 2008)

Source: Author, 2014

5.3.2. Testing Scenarios and Evaluation

Figure 23 Schematic View of Scenario Development in WEAP

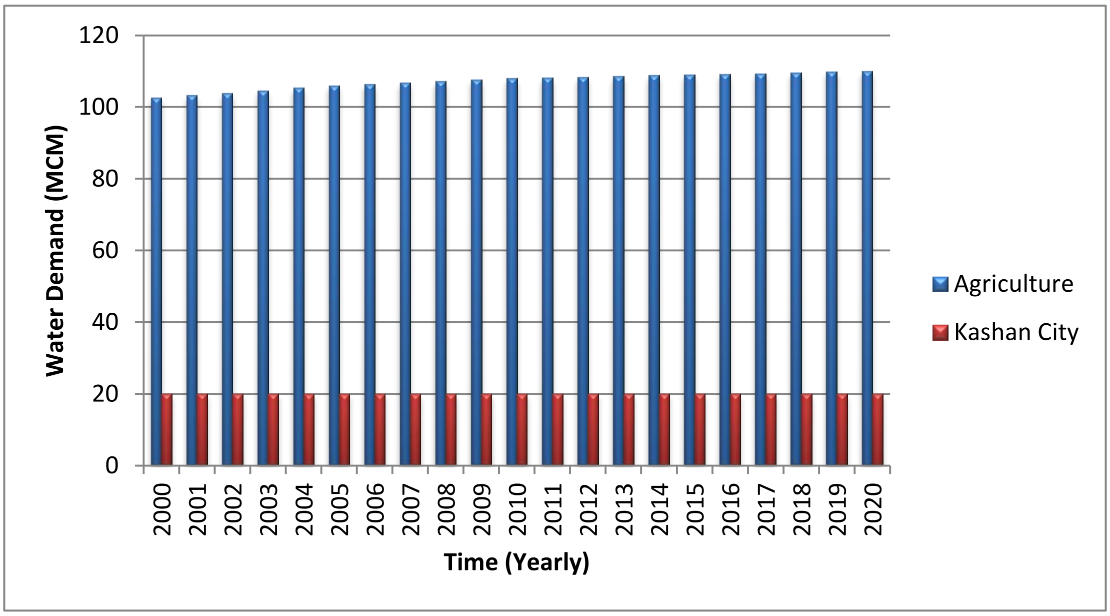


Scenario1:

Unimproved Irrigation Efficiency

In modelling the scenarios, the time horizon was first changed to 2000-2020, (the current account year remains 2010, and the last year scenario was changed to 2020). The first scenario assumed a population growth rate of 0.2% for the first ten years (based on the regional figures provided by the water agency in Kashan), with no change in irrigation efficiency to observe the impact on groundwater demand.

Figure 24 Water demand under unimproved irrigation efficiency and population growth, based on million cubic metres (MCM)



The result of the first scenario indicate that under population growth and the impact of climate variables in the region (temperature and precipitation) the water demand for agriculture increased slightly over 20 years (Figure 24). The agricultural sector consumes > 90 per cent of groundwater resources while domestic water use accounts for around 6 per cent (Regional Water Agency of Kashan, 2011). The graph shows low water demand for Kashan city with no significant increase in water demand in the next 10 years. However, agricultural water demand shows a steady increase in future in this region.

Sceanario2:

Demand Management, 'Tooba Scheme' Project

In developing scenarios to represent the main irrigation policies in the region, a new node (representing aggregated water demand under improved efficiency), was allocated as rural demand site. The new scenario utilised the same climate and population growth rate as the reference scenario (2020). The new scenario evaluates the impact of reducing water demand by reducing the water consumption rate (in this case by adopting new drip irrigation technology). In the participatory model with farmers, it was suggested that it would be appropriate to develop a model scenario that assumed that half of the farmers (50%) accepted the new irrigation technology to reduce water consumption to one-third (66.6%) of the current rate (i.e. the scenario was: what if half of the farmers in the region (50%) implement this irrigation system?). In this model scenario, under the above mentioned assumptions for aggregated agricultural demand, the annual rate of water use was 3.5%. This is the percentage of saving, or increasing, the share of efficient water use, that the model anticipates (the demand management formula is adopted from the modelling tutorial).

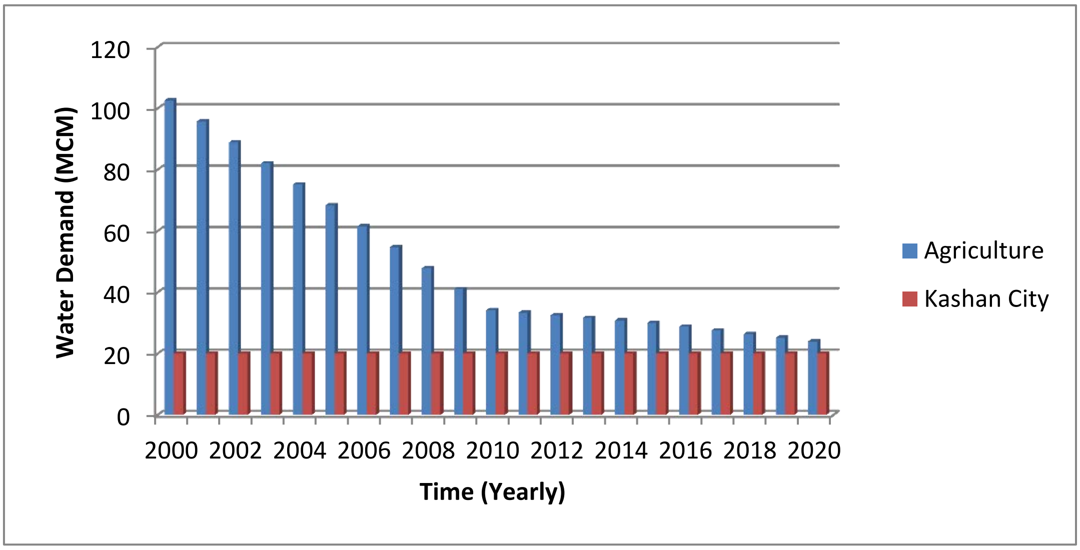
Demand Management: Aggregated: % of saving or increase the share of efficient water use

66/100* 5= 3.5%

Another method of updating the water consumption rate under 'Tooba Scheme' would be to enter the saved amount of water as the table below illustrates.

Water saving by applying drip irrigation method	15 Mm^3 (million cubic metres)
Water saving by land integration	92 ha (10,000 m^3 per ha)

Figure 25 Water Demand under 'Tooba Scheme' with Improved Efficiency



As Figure 25 illustrates until 2010, under unimproved irrigation efficiency agricultural water demand was very high. As discussed previously, the high water demand rate is due to climate, and specifically the aridity of the region and inefficient irrigation systems. Particularly, after 2000 a sudden reduction in groundwater demand rate can be observed when the model illustrates the change in groundwater demand when irrigation systems start to fall under the irrigation policies of the 'Tooba Scheme' (this scenario starts from 2000), in which agricultural water consumption falls considerably. Data for Kashan city remained the same as the reference scenario and there is no change in future water demand for Kashan city. The WEAP model can represent the water demand trend under monthly or yearly periods (the current account year for the model is from 2000-2010, and the model assumption for developing scenarios is the yearly time series for the period of 2011-2020).

Figure 26 Water Demand with improved Irrigation efficiency

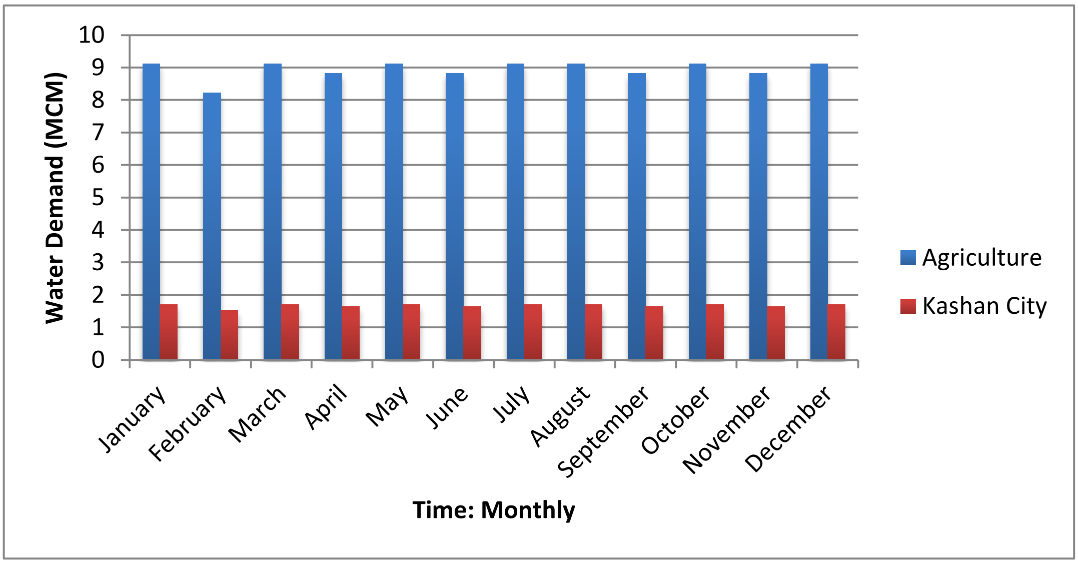


Figure 26 illustrates monthly water demand for agriculture, based on averaged monthly data over 2010-2020. As figure shows, water demand for agriculture varies in different months due to reduced abstraction rates by farmers in certain months. The lowest water demand is in February when precipitation provides supplementary water for agriculture. Kashan City is included as its input data for the modelling assumption and process is required.

Sceanrio3:

Extended Drought

To calculate the drought index in Kashan region, the dryness was calculated using the Domarten method* (UNEP, 1991). As Kashan has 4.8 dryness coefficients it is classified as an arid region with high drought intensity, which is considered in the WEAP modelling assumptions.

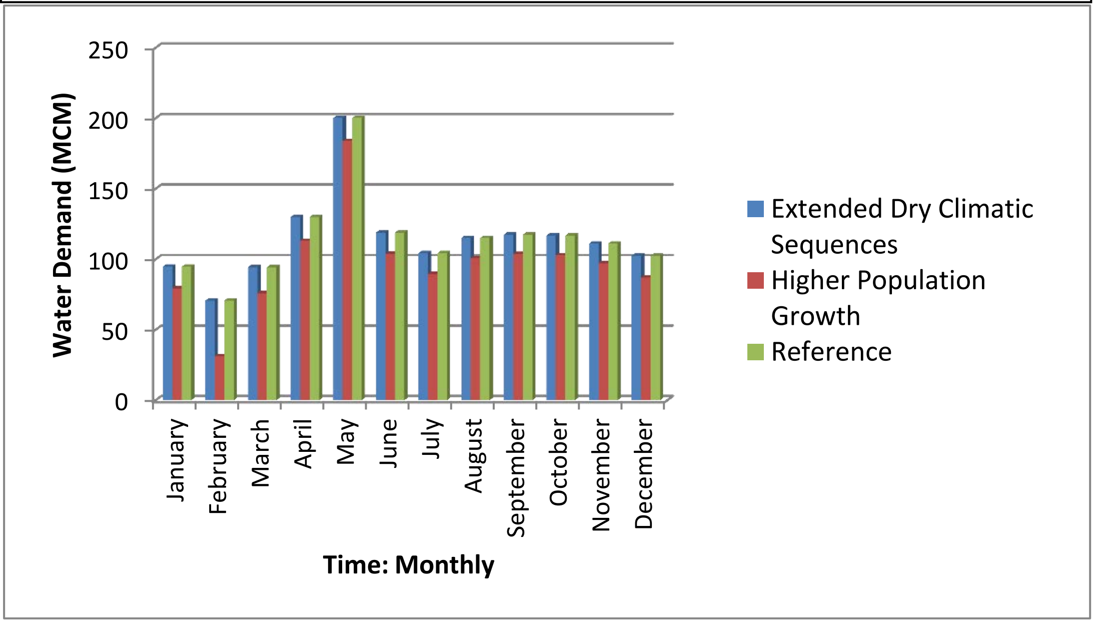
$$I = \frac{P}{T + 10}$$

*I= Domarten Climate index

P=Average annual precipitation (mm)

T=Temperature (^{0}C)

Figure 27 Water Demand for Agriculture under different scenarios



Figures 27 illustrates monthly changes in agricultural water demand, under two scenarios of extended dry climate (extended drought) and higher population growth. Water demand during spring and summer seasons is higher and the graph illustrates that under extended drought in the region, summer water demand shows a slight increase and during May reaches its highest level (when it is in a middle of the cultivation season). However, during February, water demand does not show a significant increase, due to increased water availability as a result of precipitation in this month (see Appendix 6).

5.4. Discussion and Conclusion

The conflict on scarce common groundwater resources requires a holistic approach to manage different components of the hydrological cycle. The transparent technical tool of WEAP makes it suitable for reflections of various groups of water stakeholders. In this study, WEAP is developed utilising different socio-economic and management factors to investigate different policy-based strategies to advance the sustainable management of groundwater resources. This includes climate change uncertainties in developing model assumptions, which has assisted in developing adaptive water management options for the case study area. The user-friendly model interfaces make it easy to use in discussions facilitating collaboration on water resource management between water stakeholders. This can also provide wider awareness and understanding of the main issues in water management among public users.

The integrated hydrologic model of WEAP was used in this study to test the scenarios of water demand management in the Kashan case study. Different climate change variables and irrigation efficiency management were formulated under specific scenarios and were tested and evaluated in this model. Considering the importance of validity of scenarios in this model and to increase the accuracy of the model assumptions and the results, the scenarios were formulated within the participatory social simulation with local farmers in Kashan (see Chapter 4). At the end of the participatory modelling process, the outcomes of the model were discussed with farmers and who evaluated the results (see Chapter 7). The scenarios of ‘Tooba Irrigation Scheme’ (including changing the irrigation system to drip method and the land integration scheme) as well as population growth and the impacts of future climate change in the region are embedded in the formulated scenarios. In this study, using WEAP model has several advantages such as its user-friendly feature that allowed the researcher to present and discuss the results with farmers. The model was also educational as it could foster more discussion and dialogues amongst participants during the participatory modelling process (see Chapter 7). Due to limited data availability, this model was useful as it required few data for running the model at a local scale. The model illustrates that, under unimproved irrigation efficiency, the groundwater demand will increase until 2020 in the region. Improved irrigation efficiency as a result of demand management projects in the case study area, will reduce the demand for groundwater, specifically for the agricultural sector (agriculture sector consumes ~90 per cent of available groundwater resources). The climate change scenario illustrates different water demands under the extended drought conditions. However, the result of this scenario could not be discussed with local farmers given the complexities discussed in Chapter 7.

CHAPTER 6

Groundwater Irrigation Management and the Existing Challenges from the Iranian Farmers' Perspective

Introduction

This chapter investigates existing challenges in groundwater irrigation management in my case study area in Kashan, and the need to develop participatory and adaptive management approaches in this specific region. This chapter particularly reflects on the findings obtained from interviews with local farmers and water agencies on their role within this irrigation system and the existing management plans for the future sustainable use of groundwater resources. As discussed previously, groundwater is the chief source of water for domestic and agricultural practices in Iran (see Chapter 2) and in the arid Kashan area. In the Kashan case study, current groundwater abstraction is not at sustainable rate, thus its future maintenance is under threat. Local farmers are seen to play a vital role in the irrigation management process and sustainable groundwater abstraction. However, as the previous chapter noted, they have been largely neglected within the management-decision process in Iran. The sustainability of groundwater in Kashan is under serious threat due to harsh climatic conditions, long-term overexploitation of aquifer, declined water quality and lack of effective controlling and monitoring mechanisms for abstraction. Under these conditions farmers in Kashan play a critical role in maintaining their irrigation practices by adoption of locally based adaptive solutions and collective management strategies such as appropriate crop pattern selection under water scarcity conditions so sustain their livelihood. This chapter explores the main irrigation challenges from the local farmers' perspectives and provides more in-depth discussion on the reasons why farmers in this particular case are not willing to join or collectively participate in the government imposed schemes for irrigation efficiency management and contribution in a more sustainable use of scarce groundwater resources. The literature on farmers' behavioural approaches (including farmers' main incentives and obstacles for joining governmental projects and adoption of particular irrigation system/method) in the field of groundwater irrigation management in arid regions of Iran is very limited (see Chapter 2). Thus, this study identifies for the first time, some of the influential factors that affect farmers' decision-making for participation in local irrigation management practices in Iran. As reviewed in Chapter 2, global or national water problems require locally based solutions. Local knowledge could lead to improving and empowering local capacity by utilising their knowledge in embracing alternative solutions (Von Korff et al., 2010). In this study specifically, the crucial role of local knowledge and community-managed systems has been considered and this has greatly influenced and shaped the understanding of the traditional and current management practices in this case study.

The chapter reflects on different factors causing challenges for the farmers in my case study area from their perspectives, to better understand the local irrigation system and the dynamics as well as farmers' particular behavioural approaches. In general, irrigation practices in Iran including surface/ groundwater irrigation face many challenges. The common-pool groundwater resource is invisible; as the major source of water supply in arid regions, its abstraction measurement and control is problematic. Some of the groundwater irrigation management problems are created at national policy and managerial level, and some are developed as a consequence of water scarcity, ineffectiveness of the local institutions or farmers' decision-making behaviours at local level. Different challenges in Kashan's irrigation system could be analysed under some general themes, including water crisis, governance, local indigenous knowledge, and socio-economic issues.

Empirical findings suggest that farmers in this region face particular challenges which prevent them from collaborating in collective actions and management decisions. These include: their differing perceptions of the causes of water crisis, different definitions of irrigation efficiency, the difficulties created by management transfer for small-scale farmers (such as shifting costs on farmers), and an unhelpful focus on governmental schemes which promote technological solutions without considering the socio-ecological conditions of the systems (i.e. importing technologies that are not adaptable to the local need).

The empirical findings contribute to a deeper understanding of the existing challenges when scarce groundwater resources are the only source of water supply for domestic and irrigation practices for local farming and livelihoods. This emphasises the need for local solutions to improve resource management, engaging local knowledge and farmers' main concerns into the management-decisions. This could be effective approach for water management in similar climatic regions globally, and also in similar circumstances in arid or semi-arid areas at national level.

This chapter particularly reflects on the perspectives of different groups of farmers who participated in this study during group discussion and semi-structured interviews. The data for the current chapter is gathered from the qualitative interview method which was conducted with some experienced farmers and local water manager authorities in the region (see Chapter

4). However, the main findings of conducting innovative participatory irrigation management game are reflected and discussed in detail in Chapter 7. There are different classifications of farmers based on various criteria in Iran. The classification that is offered by the Statistic Centre of Iran (1993) is still the most valid in the country. To introduce the main groups of farmers in the Kashan region, Appendix 4 characterises different farming types.

6.2. Exploring the existing challenges for groundwater irrigation management in Kashan city by local stakeholders

The analysis of the outcomes from the interviews and group discussions with local farmers show that the perspectives on water values, the main purposes for groundwater protection and sustainability of water resources, differs between local communities and official authorities. Thus there is a need to tackle different viewpoints to identify commonly-agreed understandings.

The contemporary water status and governance of Iran has been described in detail in Chapter 3. Currently one of the major failures in government management of groundwater resources is a significant inefficiency in agricultural water use, as well as unfinished water projects and an inadequate budget for future water development schemes (Panahi, 2000). Particularly in groundwater irrigation, the main existing challenges are the over-use of water, inappropriate water delivery systems and extensive water seepage from the main canals to the farmlands, muddy canals, poor leveling of lands, and drainage problems causing low efficiencies and dropped level of groundwater table (efficiencies is between 33 to 37 percent) in the country (UI Hassan, et al., 2007). Environmental degradation such as desertification, salinization, land subsidence and desiccation of wetlands are some of the major consequences of inappropriate agricultural water management, which has occurred in Iran and globally (see Chapter 2). Several researchers have therefore concluded that groundwater conditions in Iran are in a critical state (Hojjati and Boustani, 2010; Izady et al., 2012; Soltani and Saboohi, 2009). However similar to many countries around the world, most of the controlling mechanisms over groundwater resources which aimed to increase irrigation efficiency have not been successfully implemented in Iran.

The case study area of Kashan is one of 277 regions, of a total of 609, which are experiencing a critical decline in groundwater levels and a water scarcity problem (Forootan et al., 2014; Joodaki et al., 2014; Madani, 2014). The current declining trend in groundwater level in Iran, increased demand for food and potable water, while intensive abstraction rate for agricultural practices is taking place are some of the major challenges for managing groundwater sustainability. The over-exploitation of the aquifer is also because of the existing crop pattern, inefficient irrigation system and huge water wastage occurs under the traditional irrigation practices (Madani, 2014). This suggests the need for adopting modern irrigation technologies which are adaptable to specific local/regional conditions and are more efficient for farmers. Increased water demand and insufficient recharge rate and reduced water availability (Forouzani and Karimi, 2010) have aggravated the 'tragedy of the commons' problem (see Chapter 2). Regarding groundwater use, this is more catastrophic as there is not sufficient controlling and monitoring mechanism for maintaining sustainability of the groundwater resources, particularly in developing countries.

As indicated before, in the Kashan district of Iran, the government is encouraging smallholder farmers to participate in large-scale (>10 ha) irrigation schemes (termed 'Tooba') in which irrigation systems are being converted to drip irrigation systems to improve water use efficiency. Currently, national agricultural development policies specifically seek to widen the adoption of drip irrigation methods. The particular reasons for farmers to reject this scheme are analysed further through conducting a RPG simulation which will be discussed in Chapter 7.

The governmental suggested micro drip irrigation system (under the 'Tooba' scheme) provides water (and fertilizers) through a network of narrow plastic tubes and water is delivered directly to the root zone, or soil surface, to supply plant water requirements. This method can prevent groundwater over-exploitation and reduces water wastage (Lamaddalena and Sagardoy, 2000) especially in semi-arid or humid regions. However as my study argues, its implementation in arid regions face many difficulties and challenges which require careful measurements and precise studies on different aspects of irrigation system and dynamics (see more in this Chapter). The more recent irrigation development scheme of sub-surface piped water technology has included the use of 30cm diameter polyethylene irrigation pipes installed at depths of ~1m. These were introduced by the government in 2012, to improve irrigation efficiency by reducing water transmission losses. However, different water distribution systems (such as canals or pipes) are usually tested and evaluated by farmers, and their reflections on these systems help local agencies in improving or introducing different methods or devices.

There is a lack of critical evaluation of the local farmers' perceptions of these governmental schemes within the literature on Iran. Particularly there is no local-based evaluation of the 'Tooba' irrigation scheme. Furthermore, there are no studies of management plans within participatory and adaptive modeling process with farmers (see Chapter 7).

However, here the main problematic issue is the purpose of these schemes, which is to improve irrigation efficiency while a different definition of efficiency is perceived by local farmers that discourages adoption of such governmental schemes. In Kashan, introducing a drip irrigation system is not the sole project to improve efficiency of water use in agriculture; some other schemes identified by the manager of the water and soil department (in the Agricultural Agency in Kashan) included projects on: land integration, installation of piped water and paved access roads, land preparation, introducing cement lining on muddy canals to reduce water seepage (which also keeps the waterway clear of vegetation). Other major schemes include the rehabilitation and cleaning of Qanat systems, and installation of devices to control abstraction rate (smart water meters-functioning based on the initial abstraction permissions in hours, issued when the wells were drilled).

As one of the Iranian government's long-term mechanisms to control over-abstraction of groundwater, electricity subsidies have been reduced by the government. Although energy prices for using electric or diesel pumps have increased significantly, water and energy prices are insufficient tools to prevent groundwater over-abstraction (the harsh climatic conditions of the region does not allow reduction of the abstraction rate), and thus farmers continue to abstract considerable volumes of groundwater. Rather, groundwater is controlled and restricted by the state; farmers also initially agreed that their water use should be controlled to ensure future water availability. For instance one of the farmers' motives in reducing water abstraction is to avoid higher electricity bills which shows governmental strategy worked for him.

Although smart water meters on deep wells allow monitoring of abstraction rates, in reality in most cases the only limiting factor for groundwater abstraction is a fall in water level, which is evidenced by local farmers and increases in the cost of pumps. Morris (2006) suggested that increasing water charges can be an effective mechanism to increase water use efficiency. However, increasing water prices at times when water is limited and when the economic return per unit of applied water is high, can present major difficulties for farmers. In most arid and semi-arid parts of the country when tube-wells dry up, richer farmers who can afford to dig deeper wells gets permission and install more powerful motor pumps.

Different schemes to improve irrigation management efficiency have been introduced by the government over a long period of time to evaluate the adaptability and their acceptance by the local farmers. However, there is a need for studies to critically and more in-depth analyse Iranian farmers' reason for not adopting these schemes.

To briefly outline the challenges in participatory irrigation management in a context-specific region of Kashan, I will expand on the following factors including:

1. Conflicting viewpoints on the causes of water crisis, and thus the proposed solutions such as irrigation efficiency for future sustainable groundwater usage in Iran;
2. Irrigation Management transfer (i.e. in Iran, from community-based to authoritative management, and then later under the contemporary governance regime to transfer some responsibilities from the government to the farmers' communities- See Chapter 3), the consequences of this policy is expressed from the farmers' points of view ;
3. Pump-technology and increasing inequity to access water supplies among large-scale and small-scale farmers;
4. Governmental enforced schemes and interventions in irrigation technologies which are not adapted to the local conditions (I will expand further in Chapter 7).

6.2.1. Water Crisis and Efficiency Management: Reconciling Different Viewpoints

One of the main problems in Iran's national water management policy is that the majority of governors or agencies believe that the main reason for the water crisis in the country is long-term drought, and they put far less emphasis on inappropriate management or water governance (Foltz, 2002). Usually the water crisis has been blamed by Iranian policy makers (i.e. the Ministry of Energy and Agricultural Jihad Agencies) on climate change and increased drought frequencies. The government press in Iran, blame drought events which are natural disasters and out of their control hence consider it as a temporary and a periodic crisis (Madani Larijani, 2005).

To investigate the perspectives on the main causes of water crisis in my particular case study region, I interviewed some of the main managers of the water and sewage agency and the agricultural Jihad agency in Kashan and Bidgol districts of Kashan city. These organisations are particularly responsible for irrigation practices and management and providing farmers with agricultural facilities and educational workshops. Regarding my question about the main reasons for water crisis in the region the manager in Kashan's agricultural water agency responded:

"The main reason (for water crisis) is drought which has occurred within the last 5-6 years in the region. In the past it was said that drought is an event but recently it has become a natural phenomenon, unfortunately".

Many academics and water experts in Iran believe that the water crisis is partly related to drought events, and they believe that 50% is due to mismanagement (Foltz, 2002). As stated by Madani (2014) the main water resources management strategy was to restore the previous condition rather than a comprehensive study of the main causes of the water crisis. Water management of Iran requires serious and immediate actions to prevent more tragic consequences as a result of deterioration in the quality and quantity of the available water resource.

Most groundwater quantity or quality degradation is due to inappropriate groundwater governance, disintegrated management plans, or poor land use management, and not only extensive groundwater abstraction or drought. Although it is expected that water planners in Iran, will sensibly plan to meet current and future water challenges, unfortunately there has been a lack of planning for decades (Madani Larijani, 2005). Lack of agreement amongst water experts and policy makers about the main causes of the water crisis has not led to the formulation of any comprehensive plan for future water management. Consequently different solutions to the problem have been suggested such as improving water use efficiency, the definition of which differs particularly between local communities and the main governmental decision-makers.

Recent literature challenges the concept of efficiency in irrigation practices (Lankford, 2014). There is a belief that what is usually known as irrigation efficiency is a misleading concept of efficiency. In some cases, the governmental proposed schemes to improve water use efficiency are in contrast with what local users perceived as efficiency in irrigation. Therefore, understanding the definition and accurate meaning of efficiency (particularly at local scale) is essential in planning for a particular water system. As Lankford (2014) stated the condition under which the efficiency can be concluded to have improved, is that the usage of resource has reduced and the lesser water consumed has freed up more of the resources to be saved to be later allocated to other purposes such as environmental or industrial activities.

Farmers in Ali-Abad (2013) defined the improved irrigation efficiency as:

"Based on each farmers' water right (refer to the Qanat allocation system), a farmer needs to receive his water at time and if the total water reaches his plot increased by saving (water) from seepage through the transmission canals, then it means efficiency has improved so he can cultivate more lands… and his final revenue is higher"

Another farmer in Ali-Abad village (2013) stated:

"For farmers, improved irrigation efficiency is evidenced when their production level increases, so it shows that their water availability has improved by reducing the water wastage through canals"

Socio-economic conditions, livelihood arrangements, technological, institutions and ecological dimensions exist at each local level and must be understood separately, as they can greatly affect water management and efficiency (Lankford, 2006). The statement indicates the crucial importance of water right and allocation mechanism among farmers, as this provide fair access and distribution of irrigated water among them (see Chapter 7). This also indicates the realisation of farmers regarding the huge water wastage occur during water transmission when using poorly efficient water canals. The main measurement for improved efficiency for local farmers seems to be the improvement in the accessibility to their allocated water right, in order to maintain or increase their production level. This is particularly recognisable from some of the farmers' statement regarding improved irrigation efficiency, as indicated below:

"When efficiency improves it means more water available to reach our plots, less seepage and evaporation which occurs through delivery canals; therefore our productivity and agricultural revenue will increase…"

Lankford (2006) describes that at local level, irrigation efficiencies are wrongly assumed by experts and managers not to contribute significantly to basin-level water management. This means that improving local efficiency is incorrectly assumed by them to be unnecessary. He argues that local irrigation efficiency is important to water management and productivity, as it can replicate the opinions of experts and farmers on irrigation practices in a basin level. He believes that “efficiency at the local level is bound up with equity, timing and scheduling, affecting the performance and costs of irrigation and drainage, and with perception of water misuse, affecting policy choices and conflicts” (Lankford, 2006. p.346).

In this study, local irrigation efficiency is considered important by the researcher for Kashan case study area, as irrigation contains its own particular timing and equity measures, established historically in Iran and the water allocation rules are adjusted and protected by local irrigators (see Chapter 3). The concept of “local irrigation efficiency” or “classical” approach was introduced by the International Commission on Irrigation and Drainage (ICID) (1978), in contrast with the “neoclassical” or “effective irrigation efficiency”.

The classical definition of irrigation efficiency is summarised by Bos and Nugteren (1990) and Wolters (1992), and indicates that within the irrigation system, the aim is to allocate the limited amount of supplied water with the right amount to every part, or plots, of the irrigation system, which does not include recapturing (re-use) or water recycling. This emphasises appropriate control over quantity and timing in delivery and distribution of irrigated water in canals or pipes (Lankford, 2006). Lankford argues that irrigation efficiency management employs knowledge to control irrigation mechanisms to schedule water rights and to divert irrigation water to the correct plot of land and at the right time to improve irrigation performance (Lankford, 2006). Worldwide there is “no guidance on what should be measured and how data might be interpreted to demonstrate ‘efficient use’” (Knox et al., 2012, p.5). Thus, it mainly depends on local measures how to define efficient use of resources and sustainability of the groundwater resources during their daily practices. In the case study, while improved efficiency for farmers means increase accessibility to their specific water right, the government enforcing mechanism to reduce water right and to install drip irrigation systems for improving efficiency and secure sustainability of aquifer, has resulted in contradiction and farmers rejecting the scheme (see Chapter 7).

In the local irrigation system in Kashan, the rules-in-use for irrigation management follow traditional and precise mechanisms of water allocation and distribution, in which the equity and timing play a major role in water delivery and division. Farmers stick to these rules and water right allocation because of the legacy of the Qanat systems (see Chapter 3), and they believe that their irrigation is in parallel with the definition of efficiency that they perceive. This factor points towards the need to understand local culture in planning water management. In farmers' point of view the sustainability of future groundwater resources is under threat, however they believe that their historical water allocation and irrigation rules provide each farmer with his own water right, therefore sustain farming practices, whilst governmental approaches do not consider these mechanism will not be successful to manage groundwater resources.

In Kashan, while farmers' main objective by improving efficiency is to have more available water reaching their plot (to increase or maintain their production level, depending on farmer's type) the water authority's main objective is to reduce farmers' access to restricted groundwater. This is to protect the aquifer from over-abstraction, and to maintain water availability over a longer period of time in terms of sustainability and to be used for agricultural or industrial activities. Thus, the main difficulty is how the efficiency should be measured by the water regulator and how the abstraction permission should be issued to not deplete the aquifer and to meet the both farmers and governmental agencies' objectives.

One statement indicated by local farmers in Kashan (Ali-Abad village, 2013) is that:

"They (government) say because groundwater is reducing, therefore within the next 10 years our water ends, so let's reduce the water usage to some extent, so that water exist for 15-20 more years to be used by farmers"

It was observed that farmers' definition of efficiency is different from the officials, as their main concern is not about maintenance of groundwater resources for the future (young generation have already migrated to larger cities), but to improve or maintain their crop yield and livelihood every year.

One water agent has also criticised the policy-makers' attitudes regarding improving efficiency through restricting farmers' access to water resources as he stated that:

"The challenge felt by authorities is to put more pressure by different means or bodies to make farmers accept drip [irrigation] systems, but they mainly observe the problem from their own perspective and thinking of groundwater protection by using as less as possible water to be used or abstracted by farmers".

Moreover, the concept of sustainability of groundwater use is different for farmers and in some cases it seems not to be a very critical issue. In response to the question of: *"whether farmers chose to reduce their water abstraction and continue farming for longer periods or continue this trend of abstraction without considering its sustainability for the future?"*

As one farmer in Fakhreh village of Kashan (2013) stated:

"If we try to keep groundwater table in its sustainability status, we would not get anything (it won't be profitable) and it's like wasting time and energy, so when our wells get dry then we will leave farming and will find a new job".

The controversy or conflict between environmental issues and farming practices can be observed here, which usually results in conflict between agencies and farmers. As the current situation in the region illustrates, the government tries to protect the sustainability of groundwater resources, while farmers' reliance on groundwater and economic constraints does not allow any significant improvement in groundwater protection. Rogers (2002) states that generally tube-well owners pay the construction, maintenance and operation of their wells but they usually don't pay those external costs resulting from extensive groundwater abstraction on environment or aquatic ecosystems. The water regulatory body (the Environment Agency) aims to balance the abstraction amount with the water demand of aquatic environment thus conserving water to ensure environmental sustainability (Knox et al., 2010b). In this regard, Knox et al., (2012) has suggested formulating a framework through an adaptive approach which can reflect the need of farmers as well as regulators whose aim is to protect the environment. Similarly, within the context of developing nations, Lankford (2006) argues that notions such as sustainability are not necessarily transferable in developing nations, where poor local farmers depend on natural resources for their livelihood. The economic conditions act as barriers for improving or concerning environmental protection, therefore in most cases the natural resources get depleted and environmental consequences will be inevitable. In this study, my effort is to engage the main stakeholders to discuss and formulate common-agreed solutions to improve irrigation practices and increased productivity by more efficient use of available water, therefore prevent further damage of groundwater resources.

It is also indicated that the sustainability of the ecosystem is not carefully valued by policy-makers' decisions. In this regard, some official agents criticise national water policies that have affected regional and local water management, by not carefully considering the long-term consequences of their policies on the sustainability of the resources.

One example of inappropriate agricultural management policy by the government in the past was given by a farmer in Ali-Abad village (2013):

"We have problem from policy maker level, because they believe in expansion of agriculture and export products which are related to virtual water trade, but policy makers have not realised the actual value of water. They used to put very high subsidies on water and electricity for agriculture and cheapest water tariff on irrigated water, farmers were not bothered to even switch off their pumps when they did not use water".

Groundwater resources are strategic as the main water supply sources for agriculture. However, the critical status of unsustainable use of groundwater resources in the country requires that the Iran's national policy re-consider the urges in their long-term policy plan for food self-sufficiency. Iran's water management sector prioritises improving agricultural productivity by adopting modern irrigation technologies while aiming to increase water use efficiency for protecting groundwater resources. However, there is a need for more effective management plans and government support to introduce funded irrigation technologies that are adaptable both to the local circumstances and to future water availability for agricultural expansion.

Regarding farmers' decision on adopting particular irrigation management strategies, their main concern is how the particular irrigation scheme can improve farmers' access to the available water resources thus, improve their water use efficiency. For example, cement or sub-surface tube water canals can provide higher access to water for farmers. Therefore, farmers consider these irrigation systems more advantageous over using muddy irrigation canals (Figure 28). This could significantly affect their decision-making behaviour on selecting suitable technology (Further discussed in Chapter 7).

Figure 28 Different irrigation systems in Kashan Villages, **a.** muddy flood irrigation canals, **b.** lined cement canals, **c.** Sub-surface tube canals

Source: Author, (2011-2013)

Regarding improved irrigation efficiency, over-abstraction of aquifers and occurrence of externalities is as a result of the disfunction of the whole basin management and not only farmers must be blamed. Farmers are the main stakeholders who suffer from the impacts of water scarcity, thus there are the main group who will be affected by water reallocations. In this basin, better efficiency in irrigation systems does not necessarily advance farmers significantly. This point is addressed by Lankford (2014), who raises the critical question that if we save the resource who will get the 'saved' materials? And who will obtain the benefit of the so called 'efficiency gain'?

As stated by Seckler (1996), with high competition over water, efficiency gain for farmers is limited. The efficiency which may be gained through demand management or economic incentive tools is not considerable. In Kashan the efficiency gain through adoption of a drip irrigation system in such a highly competitive environment to access more water is not considerable in comparison with the economic return by abstracting more available water. Furthermore, the concept of efficiency gain comes with a paradox as what it is saved from resource use does not return to nature and thus does not reduce the resource consumption (Lankford, 2014). For example in my case study, the impression is that by adopting drip irrigation systems the discharge rate to groundwater resources will be reduced. Other influential factors in this region such as: high aridity and evaporation rate; highly water consumption due to intensive cultivation patterns; the deep level of the groundwater table; and reduced recharge rate to the aquifer, all prevent the irrigated water from returning to the common pool source. Therefore the sustainability of aquifer is still under risk.

By protecting groundwater from over-exploitation, the gain for farmers is through maintaining their water source for more years, on the other hand, huge volumes of water are planned to be used in industrial developments or for energy generation by the government, which overshadows the gain for farmers. In the case study, when there is not sufficient control over aquifer water level, where some stakeholders have better access to scarce groundwater resource and under water scarcity, the re-allocation may aggravate competition over water sources and lead to environmental degradation.

6.2.2. Small-scale Farmers' Main Adaptation Strategies

When groundwater is the only source of available water for agricultural-dependence livelihoods, control of groundwater over-exploitation is a difficult and challenging task.

The empirical findings in the case study area show farmers' adaptation strategies to cope with prolonged droughts in Kashan, mainly include deepening tube-wells or changing cultivation patterns.

Literature on the use of groundwater resources in similar climatic geographical areas in the world indicate that farmers usually use two main strategies to cope with groundwater resources 1.Chasing groundwater resources by deepening existing tube-wells or increasing water availability through governmental surface-water transferring schemes, 2. Resilience strategies to continue intensive cultivation and face prolong droughts, which are based on farmers' long-term experience and knowledge. Other adaptation strategies by farmers in India and Nepal are indicated by Moench, (2007) including: 1. Diversifying income sources from other non-agricultural livelihood strategies. 2. Water-harvesting methods to increase access to water sources and secure water for domestic and livestock need. For example, drilling deeper wells, purchasing water from informal markets 3. Reducing the water consumption rate (Moench, 2007). Although not all these strategies are economically or environmentally sustainable, different possible strategies are tested and analysed by farmers. Large-scale farmers in Kashan have got permission from the government to deepen their tube-wells, and because of having larger integrated pieces of lands they can have more water rights over small-scale farmers. Moreover due to financial affordability, large-scale farmers can install modern irrigation systems and expand their agricultural lands. Under drought condition rich farmers' main strategy is to deepen their tube-wells and to continue abstracting more water while farming is their second job.

This condition is different for small-scale farmers, as they cannot afford to deepen their tube-wells or to engage in large-scale governmental schemes for installing modern irrigation technologies. When small-scale farmers find the governmental schemes not feasible to be adopted by them they create their own adaptation strategy, or different coping mechanism to face water shortages and to improve their irrigation water use efficiency (e.g. cultivating less water demanding crops). Small-scale farmers cultivate seasonal crops that use less water but are less valued in market, however due to short-term growth period they can obtain short-term revenue by selling their products to local market. Water shortage provides a strong incentive to adopt different coping mechanisms and adaptation strategies amongst farmers (Williams, 2011). In my study it appeared that with reducing groundwater resources and extended water scarcity in the region, local farmers tried to adjust to this situation by taking on different adaptive management strategies. Particularly small-scale farmers have coped with the reduced water level by crafting some adaptive solutions such as making more investments in deepening shared tube-wells to cut the expenses, or establishing of ponds in farmlands to increase their access to water. In some cases small-scale farmers collectively act to purchase and install small-scale micro-irrigation systems.

Regarding some of the main local adaptation strategies when there is a drought, one farmer in Ali-Abad (2013) stated:

"When its drought and water availability is reduced we have to cope with the situation by applying various traditional solutions … first of all we change our crop patterns to less water consumer crops such as barely instead of wheat, also we reduce our land size to use less water, … beside farming we keep small husbandry and our wives are financially assisting us by weaving rugs."

Consequently some of these management strategies (such as changing cultivation pattern) have reduced their overall income because their pumping costs increased, while they chose to cultivate less valuable crops and to reduce their land sizes. However, farmers found historical management strategies which are created based on their indigenous knowledge as an appropriate alternative responses to water crisis under lack of governmental support.

Some of the ways in which the local farmers in this study adapted to sustain their livelihoods have been discussed with them and were listed as:

- Extending their sources of income (e.g. husbandry, weaving carpets, working in factories)
- Keeping small livestock to be sold during the period of financial crisis
- Collective action to reduce the cost of labour
- Sharing the cost of land and drilling tube-wells and their maintenance
- Renting harvested lands to other farmers for grazing their domestic animals in exchange for reducing the cost of labour for clearing the land
- Relying on their social network to provide food or cash during a time of financial crisis
- Engaging in an informal market for water and land renting, and dairy products

The various coping strategies adopted by local farmers in Kashan, revealed that they can create the most appropriate management alternatives to sustain their daily activities and livelihood. A farmer in Fakhreh Village in Kashan (2013) indicated:

"Our lives and livelihoods depend on farming and these clever but simple management decisions that we debate through our local meetings before implementation, have always made us get through difficult times… without deep thinking and consulting in our community we could not sustain our farming practices under this harsh climatic situation."

It was stated by farmers that these management plans and coping strategies that are discussed amongst farmers in their local meetings and get approval to be adopted have been more successful and advantageous in addressing their needs under water crisis conditions. These various management strategies created by local farmers over a long period of time, are perfectly adaptable to the particular irrigation system context.

Discussing these adaptive management strategies crafted by small-scale farmers in the region, has raised their awareness towards the crucial importance and effectiveness of community-based and adaptive management solutions which this study is pursuing.

One farmer in Ali-Abad (2013) indicated that:

"From discussing our adaptive strategies, it is obvious that we can still learn from each other's experiences; so the government should also consider farmers' knowledge and experiences by discussion and to develop management plans based on our final collective decisions".

The local adaptive management strategies are alternative solutions implied by farmers under critical situations, which are not governed, controlled or imposed by the government. If farmers realise that government management plans are not well-developed or will not be profitable or advantageous for them in the future, they will stick to their own management strategies and reject the proposed governmental policies which is to avoid possible consequences of the government under-developed and possibly inapplicable management proposals.

6.3. The Role of Governance and Trust for Collective Action Behaviour

The role of trust in improving governance structure and management of groundwater resources particularly has been emphasized in literature (Ostrom, 1990; Mitchel et al., 2012). Establishment of social capital in terms of trust can greatly affect farmers' collective action and improve participatory behaviors for collaborative water governance for irrigation management (Lockwood et al., 2010).

As water master (*Miraab*) in Kashan stated:

"We trust government (with hesitation), but if they implement schemes correctly, our situation becomes better, sometime these schemes (or technologies) are brought from abroad, that we cannot trust and even adopt them, otherwise for farmers it would be good to try different management options"

This indicates the crucial role of trust for farmers to collectively respond and act towards a particular management strategy. This is evidence that in the absence of trustworthy rules or management techniques, farmers lose their willingness to participate in collective action and improvement of their resource management (North, 1990; Ostrom, 1992). The sense that the scheme is not localised and is imported from abroad, as well as difficulties regarding technical issues for elder farmers in the operation and maintenance of a particular irrigation technology can significantly affect farmers' acceptance and trust in the scheme (see Chapter 7).

Farmers want every village to be dealt with based on their particular problems by authorities and not general solutions, in this way they can build more trust with the governmental management options. As one farmer in Ali-Abad village of Kashan (Group discussion, 2013) stated:

"The best way is that officials in agricultural jihad sit and find the root of the problems, in its own region (district). Each district must have meeting with above hand officials to find out how they can increase production level and then discuss it with farmers"

Farmers believe that there is not enough communication and mutual agreement between farmers and officials, which has destroyed the trust between them. On the other hand, when I interviewed an official in the agricultural agency in *Aran Bidgol* district, he indicated that:

"We agree to consider farmers requests, and if we only consider it scientifically and do not listen to farmers we will be loser. We believe that farmers are one step ahead of us. We personally believe in this, and every month we have meeting for integration scheme and farmers chief participate and we listen to farmers viewpoints. In several occasions because of their opinion, our plan has been changed and we improved it by integration of their ideas"

Whilst this was expressed by the official, farmers disagree that officials consider their concerns and believe that their meetings with officials lack effectiveness.

Another farmer indicated the statement below and other farmers concurred.

"I believe that government should listen to farmers and then adopt a new policy, and should be matched with farmers' need the policy should be supported by the government and farmers to be satisfied".

One consequence is the differing perception of the problem and solution at local level as discussed earlier in this chapter. The different consequences of an appropriate governance approach (i.e. introducing unsuitable technologies and lack effective local institutions) will be discussed under different headings in the following section.

6.3.1. Management Transfer and its Impact on Agricultural Water Management Performance

Iran is one of a few historic societies in which the water allocation and distribution system in the past has been created based on scientific and participatory management and sustained for many decades. However, a major change of shifting responsibilities of control and maintenance of water supply and distribution system from communities to the governmental authorities has occurred after irrigation management transferred from feudalism to the state governance regime in Iran (as a consequence of land reform in Iran, see Chapter 3).

As a result of this change in governance regime, several consequences have occurred for local farmers. Farmers in Kashan expressed their perspectives on these issues, which I reflect on here. The changes in water valuing system amongst local farmers when the water supply and delivery system transformed from Qanat to tube-wells is discussed here. Farmers could manage to adapt to this modern development, as they have adjusted their historical water allocation rules to the new pump technology. The introduction of pump-technology in Iran is assumed to be successful as it was largely adopted by farmers, although it has threatened the sustainability of groundwater resources. The other important factor governing the acceptance of technology is its fluidity and the different advantages it can provide over previous systems. For example, pump technology is described as 'the source of health, irrigation, power and control' (Kamash, 2012). Farmers in Kashan indicated that when the government introduced pumped-well technology they were encouraged to drill tube-wells and were provided by different types of incentives such as a cheap tariff on groundwater and subsidized electricity, long-term loans, free manure and aerial spray of pesticides on their farms in order to support development of agricultural practices at local level. In the next section I reflect on some of the main challenges that this modern development has brought for local farmers in Kashan.

According to the experience gained from this analysis I evaluate the adoption of introducing a new irrigation technology, and the factors required to be considered by the government.

6.3.2. Modern Development and the Challenge to Traditional Values

Farmers stated that in traditional systems the collective action could be observed in different participatory activities such as irrigation, harvesting, land preparation and cultivation and in cleaning and maintaining Qanat and canal.

The other crucial factor is that in contrast with the past, when the main landlord was responsible for the maintenance of the water supply resources, after shifting management this responsibility has been transferred to the government, which gives them the power to control and monitor abstraction rates by farmers. Farmers believe that protecting and controlling groundwater abstraction rates is not their responsibility, although when they were using Qanat systems they had more responsibility for the maintenance of the water supply system. In recent decades the majority of farmers (medium and small-scale farmers) are tending to reject modern irrigation systems (e.g. drip irrigation method) (see Chapter 7).

Today, the controversial viewpoint which affects groundwater management is recognition of the body responsible for common-pool groundwater resources monitoring. Farmers strongly assume this is the government. Thus, they do not feel pressured to consider the sustainability of the aquifer, but only the operation and maintenance of their irrigation system and water delivery and distribution facilities.

A farmers' representative in Kashan stated (Group discussion- Ali Abad, 2013):

"Groundwater is called national property it belongs to the entire nation. The government is responsible for it on behalf of the nation to overtake its ownership. It belongs to nation but government has its authority".

Under the traditional Qanat system and when the population was low, water resources were abundant and could readily supply a village's agricultural and domestic water need.

The main ethical vision of older farmers towards water is that water is perceived as a free source which is provided as a gift by God. One farmer in Abu Zeid-Abad village of Kashan (2012), regarding the value of water stated that:

"Water is a gift by God and must be free… When it rains it is a blessing by God, rainfall is a freshwater and it is like manure for the crops…"

Another old farmer in Rijen village (2012) stated that:

"Water is a foundation of life, we have been created from water, and Quran told us if God does not give water, what could happen to us. Water is truly created for cultivation, without water we don't have life…"

The main reason and motivation factor for farmers in Kashan to stay and continue farming is because of water availability. Recently farmers are more prepared to acknowledge the value of water as a scarce resource. They all admit that the water of the Qanat was of much higher quality and it was more sustainable in terms of cost and constant providing freshwater.

After introducing tube-well technology the availability of water which provides profit has become the main criteria of valuing water and land.

One farmer in Abu-zeid Abad village in Kashan (2012) stated that:

"Today it's the water that gives value to the land. The value of water is increased because its price has increased…We stayed here because of available water".

Water authorities believe that over the past 30 years farmers continued in their traditional culture of 'wasting water'. However, farmers state that due to increased aridity of the region and decreased water level the crops require more water and without sufficient irrigation they cannot have any harvest.

The social relations around using irrigation systems (particularly Qanat) in different parts of Iran have been created over centuries and within scientific and participatory management. Woolgar (1998) argues that social relations are one of the outcomes of technological choice, and it is the particular type of technology which creates particular sets of rules for using it, and formulates interactions between users and their relations. Thus these rules have been integrated in each community cemented through social capital and adaptive rules, which are very difficult to be changed by governmental interventions. Because individual technologies can greatly affect social relations among farmers, this element of human relations makes them resistant to accepting technological innovations (see Chapter 7). This is because society is scared of changing traditional and recognized relationships, as new technologies may potentially bring different social interactions into a society (Kamash, 2012). Introducing pump-well technology brought many challenges and difficulties for farmers who decided to adopt it. However, this technology could increase their access to more water resources, and the traditional rules of Qanat have been transferred to tube-wells by farmers. Here, I argue that any new technology that does not bring value for farmers or improve their access to water (improve efficiency), and does not match with their water allocation mechanism is very unlikely to be adopted (see more in Chapter 7). The successful introduction of a new scheme or technology could be more effective if appropriate participatory methods including social learning process and engagement of the main stakeholders with various interest and views be developed and conducted (see Chapter 7).

Any restrictions on water rights are set in the national parliament and must be adopted by provinces through a new regulatory framework and in every district it is implemented by the Agricultural water agency (see Chapter 3). In Kashan, tube-wells have initial permission which clearly states the amount of water that can be abstracted (e.g. 20, 15 or 25 lit/s). The agency has installed smart water meters on most tube-wells, which will automatically switch off the motor pump when the abstraction rate exceeds the permitted amount. In this case farmers have to re-charge their smart cards when their 3000 hour allocation of abstraction is reached. This scheme has yet to be approved and adopted at a local scale, but the smart cards are in use and farmers have to pay to re-charge their cards as they always exceed this amount and need more water for irrigation.

In response to this question of whether the new water allocation rule has been re-assessed recently and is appropriate for the current crop water need in the region the agricultural water agent responded:

> *"This is not a new regulation, in their initial permission it is stated to abstract no more than 3000 hours in year, but it was not implemented because water was available and no one was preventing farmers, but now the government wants them to stick to this rule".*

The agency agrees that there is an implementation problem for this scheme to be accepted by farmers, but on the other hand the agency has to deal with groundwater over-abstraction.

In response to the following statement by the researcher that: *"Farmers understand that groundwater level is decreasing but their concern is that by having 8 hours water instead of 24 hours the formula cannot be adopted by them.*"

The agent responded:

"Yes, it's because they have been used to traditional water right system, any time they wanted can switch on the wells and now reducing to 8 hours will definitely make some problems for them".

The initial estimation of groundwater abstraction rate needs to be re-evaluated because it's not compatible with current need. As one farmer in Fakhreh village (2013) stated:

"Farmers cannot cope, government has to evaluate any new policy first with farmers and then set the rules, we cultivate based on our water right and if the policy interferes with this we cannot accept it..."

Many farmers stated that this state-oriented policy of water right allocation can affect their historical water rights, and that the new irrigation systems are neither suitable nor effective for a particular region. State control of groundwater resources and implementation of restriction rules on water rights could potentially disturb the water allocation mechanism in every farming system in Iran, and add extra uncertainty and increase the inequity among farmers to access water (see Chapter 7).

6.3.3. The Impact of Modern Pump Technology on Groundwater Resources and its Failure to Bring Equity

Infrastructural changes in irrigation systems and methods in Iran, and particularly the transition from Qanat systems to pump-well technology, represents a significant transformation of irrigation arrangements and water distribution mechanisms.

As was discussed in Chapter 3, introducing pump well technology has led to significant agricultural expansion and rural developments in most villages of Iran. The expansion of agriculture after the introduction of tube-wells and population growth has changed the regional groundwater economy.

The pump also brought flexibility in accessing groundwater resources and was adaptable to uncertain precipitation patterns (see more in Chapter 3). Communal construction of tube-wells also made it relatively easy to fix and share the costs and all these factors together initially made the pump technology successful in Iran.

It has required the modification by farmers of the social relation and water allocation rules at a local level to enable them to adapt to new abstraction method and water delivery systems. Kamash (2012) argues that the technology is interconnected with the history, culture and norms in each society. Thus technology cannot be separated from history and society, and it is the main factor shaping people's identities, to the extent that modifying technology means changing peoples' behaviour and characteristics (Kamash, 2012).

As defined by Morgan (1990, p. 160), the fluidity is recognized by the adaptability, flexibility and receptivity of a technology. In Iran the expansion of tube-well technology was due to a significant rise in irrigation practices and the need for agricultural expansion. Hence their construction was related to the apparent need to increase water supply for agriculture. Therefore pumps could be seen to hold some features of fluidity and 'social appropriateness'. Farmers all had to survive and compete for a greater share of groundwater resources. If circumstances and water availability allowed, farmers would not have changed the traditional Qanat system. As farmers in Kashan expressed their vision on introducing pumps to the agricultural system they emphasise that:

"Agriculture has expanded not under Qanat but through construction of deep wells"

The introduction of wells to expand agriculture, created short-term economic benefits for most farmers but has also led to a number of problems (see Chapter 3). By introducing the motor pump technology, groundwater has become the main source of water. It is a more resilient supply source in the drought prone region of Kashan, and sustains the livelihood and income of the poor. Researchers have described how “Groundwater development usually helps to improve the socio-economic status of the poor to a greater extent than traditional surface water”, because it needs much less initial investment to dig a new well, and it can be drilled inside the farmland (Dep Roy and Shah, 2003). However, as it was not adapted to the irrigation culture of Iran and was not managed in a sustainable manner, the benefits are very short-term. The fact that the cost of pumping has increased and the abstraction rate has been controlled by the state has left poor farmers more vulnerable. As pumping costs have increased the costs of irrigation have likewise increased and government subsidies have been removed.

Some of complaints refer to the governance system towards which the farmers were critical:

“In each period the national policy has some faults, around 15 years ago they wanted to expand agriculture so during Rafsanjani presidential period they invested a lot on pistachio cultivation under modern irrigation systems and supported these rich farmers and the capitalism! We are confused about their policies. They make rich people richer and poor poorer.”

Farmers indicate that the main reason for the collapse of Qanat was the construction of numerous wells which were very close to each other. The farmers’ assumption is that wells lower the water table and thus groundwater does not flow in the Qanat. An inappropriate governance system over irrigated agricultural system in the country, which coincides with the Islamic revolution and the war with Iraq, has reduced controlling mechanisms on natural resources management in general (Azkia and Hooglund, 2011). This is also due to the focus of water policy worldwide that has prioritized development of water supply sources rather than establishing water demand management over past decades (see Chapter 2). Managing water demand has not been the central objective, thus provoking water wastage (Rogers, 2002). Within 15 years of the construction of numerous tube-wells and reflectance of the sustainability of the scheme, today water quantity and quality is not enough to maintain existing agricultural activities.

At a local scale this increased uneven water distribution and accessibility has greater social and economic disadvantages for farmers. Inequity in access to water resources is the main social disadvantage that has been initially brought by pump technology. While richer farmers have sufficient capital to purchase more land and water rights, their production levels and revenues are much higher than poor farmers who have limited access to water. Higher revenues mean that rich farmers can easily pay the ever increasing expenses for labour, electricity bills and obtaining loans to adopt modern irrigation facilities. Richer farmers purchased water for a cheaper price in the past. They bought even more water right from poorer farmers to improve their land and grow crops such as pistachio. Moreover, although rich farmers work individually, farming is not their main job in comparison with poor farmers. Thus the high number of shared owners of wells has reduced the benefits each can gain and reduced their income/ ultimate profits.

Differing access to groundwater resources, has divided farmers in the region into small-scale and large-scale farmers. Large-scale farmers with higher water rights and lands are eligible for receiving governmental loans and can cultivate industrial crops such as pistachio, under modern irrigation facilities.

A large-scale farmer in Rijen village (2013) who produces pistachio to industrial level stated that:

"A large-scale farmer cultivating only pistachio, mono cropping is due to that they have another job. Although their water right will be reduced but because they are financially able to purchase more lands thus their water right will be increased. Reduced groundwater level and water quality are the main limiting factor for land expansion and continuing agricultural activities for large-scale farmers in Kashan and will not be profitable enough".

Small-scale farmers, who cannot afford to purchase more water rights rather than keeping their historic allocated water, believe that richer farmers who have better access to water sources have created a level of corruption within recent years. Groundwater is less susceptible to corruption in comparison to large-scale surface schemes; however groundwater when it is the only source of water can be corrupted for use in other sectors such as energy or industry.

Regarding inequity in access to groundwater resources, farmers urge that the government should interfere and control corruption, that primarily committed by richer farmers.

One small-scale farmer in Ali-Abad (2013) stated that:

"Government should stick to rules for such investors, they must not let rich farmers to buy more than 24 hours water right in one well. If he wants more water he must invest in a new well, so other farmers will be able to work with more freedom, he must not ride on poorer farmers".

When one rich farmer purchases water rights from poor farmers the number of water right sharers is reduced and he captures their jobs and removes them from farming. Under this situation other share farmers have to accept anything he suggests or decides as he has the most water right.

6.3.4. Shifting agricultural costs and responsibilities to farmers under current governance

As part of the contemporary water governance regime in Iran, the government tries to promote a decentralized management approach and to improve engagement of stakeholders in the irrigation management practices.

Regarding this, one of the main strategies is to transfer management responsibility to water users by adopting an Irrigation Management Transfer (IMT) framework (see Chapter 2). The effort has been started and has largely applied to most agricultural regions in Iran. However this framework will only be successful with increased participation of resource users into management-decision processes, but it will be impossible unless the government establishes a new relationship with the resource owners.

Under the new governance structure, the government has attempted to reduce support for farmers to reduce expenditure, and gradually transfer irrigation management to farmers. However, I argue here that the adoption of this policy requires capacity building among small-scale farmers who are still dependent on governmental financial support for implementation and maintenance of their irrigation technologies. The policy of decentralization seems to just shift the agricultural costs to poorer farmers, as well as the cost of installation and maintenance of the recently introduced technologies, without sufficient financial support, education and establishment of capacity building among local farmers through the local institutions. From this argument, it can be concluded that the government is not the final arbitrator for groundwater irrigation management and sustainability. Managing groundwater resources requires collaborative efforts between local farmer communities and responsive governmental organizations. While the role of government's financial supports in developing countries is crucial, farmers also need to have their own self-regulated strategies and alternative management solutions. The role of government should be eliminated and most responsibilities be transferred to the local institutions and farmers' communities. However, it is essential that the government still provide financial supports and infrastructures for poor systems, as well as trying to establish effective institutions to engage farmers in management decisions and empower local capacity to undertake parts of governmental roles and responsibilities.

Within the past few decades, numerous cooperative organisations have been created to improve the role of local users in decision-making (Azkia and Hooglund, 2011). However, these cooperatives are governmental organisations. The effectiveness of these cooperatives is very low and as local farmers in Kashan stated (2012), they are officially not interacting with local farmers' need. Based on Balali's study (2009) 22% of farmers indicated that traditional cooperative systems exist in their villages. However one of the main reasons why farmers quit these cooperative organizations was because of land reform, scattering lands resulted from the land inheritance mechanism that divide land pieces among inheritors, declining of Qanats and other local issues (Balali, 2009).

Farmers in Iran have positive attitudes towards the possibilities of increasing collective action in comparison with 20 years ago (Balali, 2009). They are also agreed that government has improved farmers' participation in various rural issues. However the main remaining problem is the lack of trust and a top-down governance approach. This highlights the necessity for early engagement of farmers in the introduction of a project and during its implementation. Balali (2009) found that because resource users are not included in the design of the irrigation management projects, they have not adequately participated in the management process and could not build trust in the governmental schemes. This lack of trust will consequently reduce the success and effectiveness of the project.

One of the main shortcomings in the water governance system of Iran is that in the absence of strong local institutions and the mechanisms to enhance farmers' capacity (through actively engaging them in the local management decisions) achieving any adaptable and effective management solution will not be possible. The governmental enforcing mechanism to put pressure on farmers for accepting their schemes (such as threat to reduce farmers' water right to one-third of the current amount), has only raised dissatisfaction and destroyed trust and any sense of cooperation with local governmental agencies.

For most projects, because government support is insufficient, farmers have to provide funding to install new irrigation systems. A member of the water agency stated that:

"In some of the irrigation efficiency projects, farmers are responsible for the costs but if we be financially able we will try to assist them".

Some natural phenomena such as hail, droughts and floods can significantly affect farmers and reduce crop production by up to 3 to 4 ton per year. However, the mechanism of insurance has changed. The government entitles loans only to the farmers who can certainly return it. Therefore, the government requires two guarantors with official jobs to guarantee farmers who want to be entitled to receive loans. One small-sale framer believes that:

"Large-scale farmers have influence in Jihad agricultural agency, the loans mainly go to large-scale farmers who produce and contribute to the national economy".

Removal of subsidies from chemical fertilizers, due to environmental protection, as well as a reduction in some government expenditure has led to a considerable increase in fertiliser prices. In the past cheap and available chemical fertilizers were widely used by farmers which in the long-term can accumulate in plants, affecting crops and soil as well as human health. Chemical fertilizers are now offered by the 'free market' and farmers can only receive subsidized fertilizers in specific amounts set by the government for every individual.

"Recently government has stopped supporting agriculture, I do not know maybe it wants to remove agriculture from here, they left us all on our own and we have to manage all by ourselves".

The management transfer, instead of sharing responsibilities and transferring part of the power from the governmental bodies to the local farmers, has mainly shifted the costs to farmers who lack strong local institutions. Shifting the costs to farmers and privatization of services are aimed to reduce governmental expenses. For the last 15 years, particularly after the government of Iran decided to cut part of its major financial support to local farmers as a national policy, for many year farmers in Kashan were not supported by subsidised water and energy (Nattagh, 1986). In a situation when government does not support or cut its financially supported technologies, farmers would not afford to collectively purchase and install modern equipment (e.g. to install sub-surface piped water) (see more in Chapter 7).

6.4. The factors influencing farmers' adoption of a Governmental Irrigation Schemes

Apart from water scarcity problems and the governance issues, which make difficulties for farmers in Kashan and act as barriers for their participation in governmental irrigation policy schemes, there are other factors that affect farmers' participatory behaviours. From analyzing interviews some of the main influential factors for farmers' acceptance of new technologies or governmental schemes are explored and discussed in this section. The main schemes discussed here are the 'Tooba' scheme and associated policies (e.g. installation of drip irrigation system, reduced water right and land integration), changing cultivation pattern to pistachio, installation of piper-water irrigation systems.

To make the read easier, the outcomes of interviews and the analysis of the main findings from conducting a RPG simulation are synthesized in this chapter, and all the influential factors in accepting governmental schemes by farmers in Kashan are classified and discussed under different headings in the next section.

In addition to this, some of the underlying reasons for farmers to reject particular governmental scheme of drip irrigation system which is elaborated from conducting a RPG exercise, will be discussed further in Chapter 7. These factors could not be simply elicited by conducting interviews with farmers. Although interviews can provide trustworthy outcomes, the role-play simulation processes can stimulate farmers' imagination by associating particular role for a farmer and therefore elicit their deeper knowledge more effectively. The interviews can address the concerns of farmers for the current situations or the histories of traditional practices in the past. However, the scenarios of the future irrigation management within social simulation exercises can reveal farmers' thoughts and future perspectives towards different irrigation management alternatives. Instead the participatory simulations exercise revealed more insightful outcomes and generated wider perspectives from the local farmers (see Chapter 7).

The factors which discourage farmers to participate in irrigation schemes are also mainly due to poverty, the lack of financial affordability to invest in a project, the lack of agreements and existing cultural differences, the lack of efficiency and coordination by rural institutions and unsuitability of the project for farmers in term of its profitability. On the other hand, poverty is the main factor underpinning capacity for farmers' adaptation to water shortage conditions. Balali (2009) stated that poverty and land ownership status are the main driving forces that shape farmers behavior and actions.

In the following section, different influential factors in accepting or rejecting governmental schemes/technologies by farmers are summarised and classified under different headings. These factors include: biophysical adaptability, economic return, cultural and social adaptability, which are analysed from the empirical findings and appropriate literatures.

6.4.1. Biophysical Adaptation

As stated earlier, the shift in water supply systems and the transformation of water abstraction mechanisms has led to significant changes in the irrigation and distribution infrastructure in Iran. However, government policy particularly over the last 30 years has mainly focused on improving irrigation efficiency by introducing different irrigation technologies and by encouraging farmers to adopt devices to control abstraction. Empirical evidence (e.g. Morris, 2006) suggests that farmers do not accept many of these policies, controlling mechanisms, or technologies, as in most cases these are not adaptable to the local circumstances. Introducing any new technology (e.g. drip irrigation method) requires social and material adaptability and the most successful technologies are those that are flexible to the existing social, biophysical and cultural circumstances (Kamash, 2012). Bijker et al. (1989, p.13), argue that technological choices often require an iterative process of negotiation between members of each group to eventually shape and confirm the best technological options. Implementation of each technological solution may bring different advantages or problems for local users; therefore it is important that the technology be evaluated and adaptable to different aspects such as ecological, social and cultural conditions (see Kamash 2012, page 28).

The climatic and biophysical characteristics of a region are also influential factors in adoption of a particular irrigation technology. For example, in my case study area, reducing water abstraction rates to one-third of their current amount, farmers outlined their main reasons for rejecting this scheme. According to the farmers' viewpoints given the harsh regional climate, it is very difficult to use less irrigation water. At present, they are irrigating continually (for almost 24 hours a day) and yet they still cannot achieve a good yield, and so question how they might produce more with much less water.

Therefore, regarding the adaptability of drip irrigation systems to the regional climate, one farmer in Ali-Abad village (2013) said:

> *"This region is a desert land and it must be irrigated with flood method and consumes lots of water because the region is hot, and the soil is clay, so within 10 days we should irrigate again"*

The other main limitation to adopting the drip system is that it is only suitable for wells where the electrical conductivity is less than 3000 μScm^{-1}. Where water has a higher EC, the drip system becomes blocked by sediment, and the EC of groundwater in most villages in the Kashan plain is above this threshold.

Another farmer in Ali-Abad village (2013) stated that the permitted water abstraction amount and the rate by which farmers' must reduce their abstraction hours copies the practice in other countries in the region, and it has not carefully assessed based on the basis of local water needs and climate. Finally, farmers suggest that water rights should be gradually reduced by the government, as a sudden reduction will present many financial problems.

It is evidenced that although farmers have struggled to maintain traditional water right systems, which could potentially ensure equity in access to groundwater resources, some government policies, such as encouraging drip irrigation systems, affect existing water right regimes in ways that present particular difficulties for poorer farmers as discussed earlier in this chapter. Farmers were able to explain how drip irrigation systems were inappropriate for this landscape, particularly as given their scattered land holdings, it is not feasible to use drip systems to irrigate pistachio trees. However, in the role playing game (will be discussed in Chapter 7) farmers explained that the structure of the recent sub-surface piped water scheme, particularly the water outlets matches the time slots of their traditional water allocation mechanism, which could make this irrigation technology more acceptable for local farmers in Kashan. On the other hand, farmers who were interviewed mentioned that the other advantages of using pipe-lined water (apart from increasing water availability) are that pipes do not allow grass and other plants to grow inside the tubes and block the waterway. The pipes are therefore not damaged under exposed sunlight and evaporation losses are much less in comparison with cement canals.

6.4.2. Economic Advantages/Returns

Economic factors act as both incentives (in terms of providing higher agricultural revenue) as well as barriers (financial constrains) for farmers' acceptance and adoption of a particular irrigation scheme or technology. Under water scarcity and reduced farmers' income (Forouzani and Karami, 2010), any new system that could improve the production level by increasing water availability for farmers is an advantage and this would help the technology to be accepted by farmers (i.e. acceptances of sub-surface piped irrigation systems, see more in Chapter 7). On the other hand, farmers' financial constraints can affect their choices of particular scheme or irrigation technology. Here, I argue that financial status of farmers should be considered when introducing a governmental scheme. The government is required to provide sufficient financial supports or loans for farmers, based on the correct estimation of the project's cost. In the region, due to the water scarcity problem, the area of cultivated land has fallen, and farming costs have increased (because of electric pump, using machinery, removed subsidies, etc.). This has caused more financial difficulties for Iranian farmers to invest in suggested irrigation infrastructure to improve their efficiency and income.

The empirical findings of conducting interviews showed that farmers are aware of the importance of sustainable abstraction and irrigation practices. However, their poverty status (mainly as a consequence of their small and fragmented land ownership) is the main obstacle for them to consider the sustainability of their actions. As mentioned before in this chapter, amongst local communities increasing agricultural productivity varies according to the type of farmer (their land-sizes), farm location and access to water supplies and farmers' financial status to install modern agricultural technologies. Wealthier farmers who can afford to purchase more water rights are usually interested to consolidate the fragmented lands to expand their land size and adopt modernized irrigation facilities to enhance their valued crops and economic revenues. Regarding poorer farmers who own small or medium-scale land sizes, the acceptance and adoption of new technologies are problematic (see Chapter 7).

Farmers are faced with economic uncertainty in their agricultural production because the state does not provide sufficient support for capital investment and due to water scarcity in the region, there is a significant barrier for farmers to adopt new technologies which might have economic risk for them.

The other influential economic factor in accepting a particular scheme is the crop values, which are the most important aspect related to farmers' agricultural revenue. As farmers became more educated and wealthier they move from low value to higher value or cash crops (as water availability increased through expansion of private tube-wells led to silent revolution- see Chapter 2). This has compelled them to use more efficient technologies and have national or regional market for their production (Rogers, 2002). However, this has only occurred for wealthier farmers: medium or small-scale farmers in Iran have had to retain their traditional crop pattern to sustain their livelihood and they could not join the industrial agriculture. Recently government has sought to persuade poorer farmers to partly change their cultivation patterns to crops using less water; aiming to conserve groundwater resources in the region (this scheme also requires land integration by farmers).

Regarding the government plan to encourage a change in cultivation patterns to pistachio trees, one major consequence would be the associated changes that would occur in the life of local farmers whose livelihood depends on short-term crops such as wheat and barley. It seems that small-scale farmers adopt an economic strategy based on the profitability of individual cultivated crops. One farmers' strategic behaviour in choosing appropriate crop pattern, stated by a farmer in Rijen village (2013) that:

"Our strategy is to see which crop is profitable for us in a short term, if it has economic return then we plant it otherwise we don't follow governmental crop pattern. Because we have to pay for everything so it must be profitable for ourselves. Officials just express their request blindly but they do not stick to their promises to support us".

To implement new irrigation systems provided by government, farmers, particularly the poorer farmers, expect and need more financial aid or support. However, as their production does not contribute to the national economy, the government has cut the major financial supports and allocates the budget to large-scale industrial cultivation.

"If they want to remove agriculture we are not disagree, but they should give us another job, we are ready for work. If our small-scale farming does not profit the country they must provide industrial job for us we need to earn money, but we need financial support. Our kids

left farming because in industry every month they are paid much higher, but in farming no one will pay them".

However, some farmers' concern is that by removing agriculture from this area in the future and introducing industrial activities, for majority of them particularly older ones sustaining livelihood will be problematic and leaves them with a catastrophic situation, as they do not have any experience in working at industry.

The other main governmental policy, as stated previously is to reduce water rights to one-third of their current volume, thus the economic disadvantage that can bring for farmers is the main barriers for accepting this policy. One farmer indicated that the government would not give farmers any choice and the scheme would have significant economic disadvantage for small-scale farmers. One farmer complained that:

"When one litre fuel for the motor bike costs 400 Tomans, every day we travel between our lands 2 or 3 times, if we pay let's say 2000 Tomans per day for the fuel (and all other expenses) and if the government wants to reduce our water right, our harvest and revenue will diminish and we have to quit farming and leave the region (70% of the rural livelihood is from the agriculture). For example if a farmer has to irrigate with 2 hours water per 5 days, it would not be profitable for him to travel between his lands…"

The adoption of this policy by small-scale farmers is not adaptable to their economic situation, and the reduce in water right means significant reduction in their agricultural revenue, which leave them with no choice but abandoning farming practices and migrating to other cities searching for new jobs.

6.4.3. Social and Cultural Adaptability

Flexibility of technologies to local irrigation traditions and allocation rules is a crucial factor. Many cases exemplify that technological solutions when they were not socially acceptable could not be widely adopted (Pannell et al., 2006). The importance of social norms (in my study, such as water rights and allocation rules) is a key factor in influencing communities in acceptance of new technology or practices (Minato et al., 2010). However, there is a gap in understanding different social aspects related to groundwater irrigation management and governance (Mitchell et al., 2011).

As stated earlier, it is essential to consider social and cultural factors when adopting a new scheme or technology. Issues such as water right and allocation mechanism, as well as cultivation pattern and landholding systems are historical circumstances which are rooted in farmers' local culture and social norms which creates sense of social capital among them to cooperate and trust each other and the local agencies (see Chapter 7). Changes in any of these conditions will be consequential.

When I asked an agent the reason why farmers do not accept a drip system, given that government loans are provided to encourage their implementation, the agent replied that "farmers are afraid of committing any risks and also cultural aspects are very important and influential in this case". For example, one controversial element of the drip method is that farmers assume that they must irrigate crops with less water than their water rights, and this as a cultural factor affects their selection of drip irrigation method. In response to this question that despite Qanat systems that could provide free and abundant water for irrigation, drip system may create confusions about water allocation measures among farmers (as a cultural factor), a manager in agricultural jihad agency responded:

He added his opinion about the main reason that farmers reject drip system:

"In flood system (under Qanat), because farmers used to see 5-10 cm water on top of soil now they don't accept drip method, they say that, tree fails. Maybe under drip system, long rooted trees fail (because of insufficient water seepage through soil layers), it is based on farmers' experience but scientifically drip system is approved, and for their new crops they can adopt this system".

The other crucial factor that has been evidenced in the case study area is that the technologies or policy schemes are not localised (refer to Lankford, 2006) and therefore the rules are not adaptable to a particular climate or to the socio-economic conditions of the region. For example regarding changing cultivation pattern one farmer in Ali-Abad (2013) anxiously emphasised that farmers would regret changing the cultivation pattern to mono-cropping within a few years. He stated that:

"I am not against pistachio cultivation but I'm saying that farmers get regret in 10 years. Now farmers say that cultivating tree is easier but if all cultivate pistachio, farmers would not bother to plant any wheat. Because the main livelihood is bread, if we do not have anything we can just eat bread but pistachio is an economic crop and cannot feed us. Under that situation, government may import more wheat.... I think government is trying to make this region economic or industrial…"

To emphasise the important role of their historical cultivation pattern, which has particularly sustained their income, one farmer in Ali-Abad (2013) indicated that:

"The land value is not that much, if the land be under barley, wheat, alfalfa or even empty land, farmer can rent the water right and obtain some revenue, with pistachio tree farmer would not be able to rent the land, this scheme is particularly not suitable to be adopted by older/poorer farmers".

The change in cultivation pattern scheme neglects/threatens the traditional sustainable livelihood, which emphasises the integration of agriculture and husbandry activities. Farmers historically used groundwater resources as resilient options to reduce the risk-levels of water shortage. Traditionally agriculture and animal husbandry are interlinked, creating a resilient system for vulnerable farmers, and any minor impacts has a significant impact on other activity. One farmer explained that: "for example, if someone wants to have husbandry he must have alfalfa or barley production beside it". Farmers indicated that husbandry has reduced because the price of fodder has increased (unstable market for barley) and it is not profitable to continue husbandry. The majority of farmers find it unprofitable if they do not keep farming and husbandry along with each other. It seems that having husbandry can significantly help traditional farmers to pay for agricultural costs. Thus retaining the existing diverse cultivation pattern represents a more strategic and resilient option for farmers rather than changing to an industrial crop such as pistachio. Crop selection, when performed by farmers, is undertaken on the basis of water availability and climate, also cultural tradition and economic need. Changing cultivation patterns are one of the strategies that farmers use when one crop has low yields; however the crop they choose must be adapted to saline and water deficit conditions. Government attempts to introduce new crops into the region are based on observations of a few large-scale farmers' experience in pilot studies, but these crop patterns usually differ from the majority of farmers' circumstances, who are practicing small-scale farming, and have financial limitations.

6.5. Conclusion

This chapter reviewed the main challenges in groundwater irrigation management and practices in the arid region of Kashan from local farmers' perspectives. The main challenges that farmers in Kashan are facing include: differing perspectives on the causes of water crisis, lack of agreement on appropriate solutions, and differing definitions of irrigation efficiency.

In this chapter, it was also emphasised the necessity for articulating local knowledge and local solutions in management-decisions in the region. The chapter argues that by considering the role of local irrigation culture and social economic factors in shaping current water management regimes and existing obstacles for farmers' participation in governmental schemes, there is a possibility to develop a more integrated approach to irrigation management in the region. There is a need for more local adaptive management solutions to respond to shortages in governmental financial support. These kinds of solutions will only become more necessary in the light of an uncertain climatic (e.g. increased temperature and reduced precipitation) and socio-political future. The climate variability, population growth and changes in irrigation management system are reflected in the scenarios that formulated by local farmers in Kashan; the scenarios are tested and evaluated within WEAP model (see Chapter 5).

My interviews with farmers for this study, suggested that the irrigation technologies used to improve efficiency need to match the definitions which exist amongst farmers. They want to increase the accessibility of available water to their lands and to maintain their production level and this is the case for particularly small-scale farmers. There are also challenges related to governance issues in the region, which have consequently resulted in shifting agricultural costs and responsibilities on farmers. Because of a lack of capacity building programmes to empower farmers' decision-making abilities, this has increased the social and financial constraints facing poorer farmers.

This chapter also reflected on some of the main influential factors on farmers' decision to select particular irrigation scheme or technology. These included the adaptability of the irrigation management solution in terms of its biophysical, economic, social and cultural adaptabilities within the local irrigation context. To introduce new irrigation schemes or new technologies there is a need for the system to be tested and evaluated through pilot studies and after observation of the suitability of the project, it could be implemented at wider scale. The adaptability of the irrigation technology to the dry climatic conditions, the traditional culture and social norms of water allocation mechanisms must be carefully considered, in order to work with, rather than against farmers' prevailing values and behaviours. An in depth understanding of these challenges, and the main factors in implementation of successful irrigation management scheme in the region, points towards the need for more adaptive and participatory management process for irrigation management practices in Iran. According to the study's findings (further discussed in Chapter 7), there is good potential for farmers at local level in Kashan village, to adopt participatory irrigation management. Farmers are willing to improve collective action and they accept strategies which are adaptable to their irrigation practices to improve water use efficiency. The following chapter proposes a transition in the Iranian governance structure towards more community-based and adaptive approaches for future sustainable water and irrigation management.

CHAPTER 7

Towards Adaptive Agricultural Water Management in Iran

Introduction

In this chapter, I discuss the outcomes of designing and testing Role-play simulation I refer as the 'Irrigation Management Game' (IMG) with Iranian farmers. Based on the outcomes of the IMG, I will argue that there is feasibility and potential among local Iranian farmers for conducting a successful participatory management approach. Designing and testing an irrigation management simulation exercise (Chapter 4) has revealed that local farmers in Kashan villages have the capacity and interest for participation in a more participatory and collaborative management processes. Farmers proved to have an influential role in management decision-making and policy evaluation. My findings support my recommendation for enhancing participatory and adaptive management practices, particularly in an authoritative system of Iran for the future sustainable groundwater management. In this chapter, I will also point out that existence of local management institutions can greatly facilitate communication and collective action among local farmers.

After expanding my discussion on the outcomes of the Role Play irrigation management game (IMG), in the next section, I will highlight that the combination of some of the factors of role play simulation exercise (e.g. scenarios) with the physical hydrological model (as part of the method development process), could widen perspectives and foster more dialogue amongst farmers. This collaborative effort has revealed that this intervention can open a new way of engaging policy considerations and managerial perspectives into the creation of more flexible management approaches and alternative options. Overall, farmers suggested that this can pave the way for future collaboration between locals and agencies in the region.

In this chapter, I will demonstrate how participatory management processes as mediation provide better opportunities and more reflective results for management practices, under which the management can move towards establishment of more participatory and adaptive approaches. In conclusion, this chapter deliberates the conditions under which building successful participatory and adaptive management for groundwater resources at local villages of Iran could be promoted.

7.1. Participatory RPG as a Democratic Approach

As discussed in chapter 2, groundwater management in developing countries is faced with several managerial and administrative challenges. There is a gap in literatures on using different participatory research tools/methods, for promoting adaptive water management in countries under state-led governance regimes. Particularly the Iranian literature on using participatory management approaches for water and irrigation management practices at local level is very limited, and studies are usually undertaken by researchers or governmental agencies. The implementation of adaptive participatory research methods employing simulation games in developing countries therefore appears to confront some obvious challenges (Mitchel, 2009). In these countries the governance regime is usually state-based, structured in a top-down manner, and management approaches are in general resistant to change.

Participatory approaches to rural development have played an influential role since the 1970s, (Belshaw and Chambers 1973; Uphoff et al., 1979; Von Korff et al., 2010). As mentioned previously, it is important to bear in mind that when designing a participatory management tool, this process may not always lead to successful outcomes. Therefore in conducting a participatory method each process must be designed and adapted within a particular condition. The importance of context-specific circumstances is emphasised by several scholars (e.g. Stern and Fineberg 1996; Webler, 1999; Delli Carpini et al. 2004). It is through local-managed systems run by local users that data can be manipulated to be used in a beneficial way. In this study, the attempt was to design such a process which is developed based on local knowledge and the particular socio-cultural circumstances of Iran.

The particular value and effectiveness of participatory tools within authoritative governance regimes remains underexplained. My study therefore uses the case of natural resource management in Iran to examine the capability, usefulness and limitations of conducting local-based participatory research methods for groundwater management. By consulting with local farmers in the villages of Kashan city, I designed a suitable participatory tool that was mainly sketched and run by the local farmers.

7.2. Participatory Simulation Exercise: Implementation and Outcomes

The development of an innovative participatory IMG (Chapter 4) was aimed at eliciting knowledge from local farmers and farmers' evaluation of different irrigation policy schemes at local scale. The findings indicate that there are feasibilities for some community-based rules and the underlying reasons why farmers reject particular drip irrigation system. I reflect on the use of RPG as a communication tool to share the differing perspectives of resource managers and users, and as a mediation tool to facilitate collective resource allocation agreements, and ultimately create locally acceptable and feasible scenarios to improve irrigation efficiency which are also acceptable by the policy decision-makers in the region.

My IMG included farmers, water agents, and academic experts, who offer various viewpoints, management goals, problems and incentives for collaboration for more deliberative discussions.

In this self-designed IMG, the primary rules and understanding of the local system were drawn from information collected and the knowledge built from the conducted semi-structured interviews and other complementary communication methods, including group discussions and in-depth interviews, to elicit farmers' knowledge and a review of current irrigation schemes (see Chapter 4 and 6).

Farmers cooperated as a team to map different resources in their irrigation system and to locate them as accurately as possible to their actual location on the field. In this regard, crop patterns, water canals, access road and tube-wells as well as the sketch map of the village was drawn by farmers themselves. It was observed that during this stage, farmers were excited, sometimes argumentative and they spent a relatively long time discussing in their local language to agree on how to locate different resources on the board. At the start of the game session, as this was the first time such a participatory process has been conducted for them, they were unfamiliar with the roles and the process of the simulation. In their experience a similar attempt had been previously undertaken by officials to map their land holdings for a land integration scheme. Farmers indicated that officials took many hours to acquire information about their land and tube-wells locations and in the end there was no discussion or educational achievement for them. This experience led farmers initially to doubt the value of the IMG and contributing to the process, but during observation of the development of the simple map of their field, they gained more interest in participating. In this IMG, farmers were actively engaged and cooperated within the communication and playing their assigned roles. They observed other farmers' reactions and behavior through the session and listened to others' viewpoints.

At the end of the game, farmers indicated that this mapping and evaluation of different policy schemes was very useful and brought all their thoughts and opinions together. Farmers were interested in seeing more of the similar game design for the future and suggested that this could represent their actual water practices and irrigation problems, particularly regarding the difficulties that they faced in accepting new irrigation technologies.

The findings from conducting the IMG (Chapter 4) are summarised under the following four headings, which I will explore in turn:

I. Farmers' knowledge and communication

II. Incentives for collective action within behavioural analysis

III. Formulation of scenarios

IV. Reasons for rejecting drip irrigation system

7.2.1. Farmers' knowledge and communication

Generally, natural resource games tend to represent a particular conceptual model with specific socio-ecological features, which triggers the imagination of game participants thereby facilitating discussion (Meadows, 2001). Farmers participated from the planning stage throughout the design and evaluation of the policies, within Role-play IMG exercise. The game design was realistic and thus could elicit different knowledge and a new behavioural approach from farmers. As farmers had initially designed the game, they were aware of their irrigation functions and management, particularly as in the game they were assigned with their actual role. This greatly supported their involvement in different aspects of the simulation. They eventually reached common agreements and collectively decided which management approach is more sophisticated. The Irrigation Management Game (IMG) has greatly assisted me as researcher in collecting information to improve my understanding of the role of farmers in relation to other stakeholders. Here it was important to refer to the knowledge and understanding of the irrigation context which was provided through social research methods discussed in Chapter 6. This could also assist the researcher prior to the implementation of the IMG to identify the farmers' main vulnerabilities in terms of existing challenges and difficulties. These are such as i. a significant reduction in groundwater levels which would increase the cost of pumping; ii. persistent drought; iii. increased cost of fertilizers and pesticides following removal of governmental subsidies, as well as the possible adaptation strategies available to farmers in response to a water crisis, and evaluating how farmers perceive sustainable agricultural practices in the future (see Chapter 6).

As noted previously, in Iranian irrigation systems, water allocation is based on fixed time slots, which in most cases have been inherited by farmers (Chapter 3). In this system, local farmers manage water allocation and distribution rules through a process of negotiation and agreement, and in most cases it is not necessary to monitor farmers' behaviour (Ostrom et al., 1994). The irrigation and water allocation rules that were established for Qanat systems in the past also apply to motor-pump groundwater abstraction wells (see Chapter 3). Within the simulation which facilitated better visualisation to explain the irrigation rules, farmers further explained to the facilitator (researcher) that, based on the amount of water that can be abstracted from each tube-well, specific pieces of shared agricultural land are associated with that well. During the role-play simulation exercise, farmers in Ali-Abad village (2013) explained some of their rules as follows:

"Based on each person's water hour right, lands are divided between farmers. Water right for each person was the main basis of assigning the lands to him ...Larger farms have more water rights allocated to them. A farmer, who in the past has paid more money to construct the Qanat, can get more water now".

Farmers indicated that after they changed their system from Qanat to motor-pump technology, the problems that arose in allocating water were eventually resolved through negotiation and by mutual agreement.

As stated by one local farmer in Ali-Abad village in Kashan (2013):

"The water right system in our tube-wells is the same as Qanat, each person receives his water turn based on 24 hours water allocation (we have sometimes slightly modified rules), but in Qanat the cost was lower...

However, they emphasised that there was less conflict when they were largely using the Qanat system. It seemed that motor pump technology contributed to many difficulties in water allocation specifically relating to sharing the cost of repairing wells.

They added that managing tube-wells created several difficulties for their daily management and practices:

"Motor pumped tube-wells break frequently (it is collectively owned so we have to set some rules for its operation and maintenance), well chief should go after to fix the pump and after meeting with managerial panel and approval of the repairing cost (plus electricity bill) the cost is collected from all share owners (mainly in instalments)...".

The farmers' engagement in a social learning process has been improved throughout the simulation processes and the discussions. This is mainly occurred when farmers exchanged their knowledge and experiences and also listened to others. This provided higher quality discussion and understanding while Role-play simulation provided better opportunity to explain and reflect on different biophysical and social aspects of irrigation system context and farmers' behaviour. This is consistent with the findings of (Von Korff et al., 2012; Muro and Jeffrey, 2012; Kuper et al., 2009), who indicated the generation of social learning through discussion process and during participant's interactions by dialogues (see Chapter 2). In my case study, the social learning eventually developed when simulation was proceeding with more accurate and relevant information which was gathered from farmers' perspectives. The visualization of farmers' irrigation system and incorporating actual rules and responsibilities for the participants has assisted them in better explaining the rules and water allocation mechanism to the researcher, which was also educational and insightful for them (see more in section 7.2.2.). Also later social learning was generated among farmers when the outcomes of the modelled scenarios were discussed with them during the Companion modelling process (see section 7, 4).

One farmer in Ali-Abad (2013) stated:

"Describing these water and land management rules and farmers' interactions in this system is a good reminder for us to realize that we have a strong bond and cooperation amongst ourselves; these small reciprocal acts and respecting rules by farmers have increased trust between us and have brought us closer for more collective action."

Some of the incentives that revealed the reasons for farmers' collective action behaviours were further explored by conducting the role-play simulation, which I will reflect on in the following section.

7.2.2. Farmers' Incentives for collective action within behavioural analysis

Some of the main incentives for farmers' collective actions in irrigation system management have been reviewed within the worldwide literatures (see Chapter 2). Also some of the main influential factors for Iranian farmers' participation in national or regional irrigation schemes and the existing obstacles (e.g. governance, economic, social and cultural issues) have been reviewed within the Iranian relevant literatures (see Chapter 3).

One important outcome of the IMG was to reveal some of the main incentives in local communities for engaging in collective action. This outcome is consistent with the findings of several studies (Burton, 1989; Hagmann and Chuma, 2002; Bluemling et al., 2006), which have proven the role of simulation games as a powerful motive for farmers to join collective and participatory actions for their water resource management, and to elucidate their behavioural approaches. Some authors have developed particular tools and methods to design and implement simulation games to create close connection with participants and encourage them to collectively participate in the game. For example Lankford and Watson (2007) have used glass marbles in their River Basin Game, symbolising water to stimulate participants' mind and make easier connection with them for better engagement. Incorporating farmers' real roles and community-based rules can help replicate their behaviour successfully during the simulation, thus removing possible constraints on participant's behaviour and their attitude to the game (Toth, 1988). This was also the case when conducting IMG with farmers in Kashan, as they could express their actual behaviours and interactions with other farmers and also their conflicting attitudes regarding water allocation mechanism and fair distribution.

During the game farmers showed awareness of the advantages of collective action as there is a long history of collective action in Iranian rural community management. Some of the existing incentives that have fostered collective action are outlined below. These include: **1.**

fairness; the ability to create justice and adaptive rules; and the emergence of **2.** social capital within traditional community rules and ethics. Farmers described and reflected on their traditional irrigation rules during the simulation, and used piped-water irrigation to explain how their water right system operates (indicating that the installation of the piped water system was exactly based on their water allocation time-slots- see more in this chapter). **3.** economic motives also encourage farmers to make rational decisions and develop more efficient management strategies, in order to achieve higher profit for example by adopting pipe-line irrigation systems the water availability and thus production level will increase.

In the following section, I elaborate further on the main incentives among Iranian farmers to participate in the collective irrigation management practices. This is one of the main outcomes of conducting an IMG with local farmers in Kashan villages.

7.2.2.1. Fairness

Inequalities in water allocation between large-scale and small-scale farmers in the region, have led to the inefficient use of groundwater as a common pool resource (see Chapter 6). This has led to conflicts between richer and poorer farmers that have reduced individual farmer's incentives for collective action, which this is consistent with the findings of Ostrom et al. (1994). A wide range of local rules give clear guidelines for water allocation based on location, time, type of water user, and other factors, which are effective in resolving potential conflicts in water allocation in the case study area. In this study, the game simulation board provided an appropriate environment for farmers to describe and consider past conflicts, for example between head-end and tail-end farmers, who sought to cultivate land near tube-wells.

“A new scheme needs to include farmers’ agreement, because maybe one piece of their land is far away from wells or near wells, so their land should be divided into two pieces one close and one further from the wells. This is the main problem that farmers do not get to agreement for land integration and sub-surface pipelines, because they want lands near wells”.

During the problem-solving process, farmers mutually negotiated the division and re-distribution of land near the tube-well, such that they kept that part of their land close to the well and exchanged some of their land for farming further from the well. This ensured that other farmers also had land near the well and ensured fairness.

A water rights system provides equity in accessing groundwater resources among farmers. Efficiency in water distribution systems is evaluated by comparing the water that has reached the final farmer with the water that is lost by seepage through the irrigation system (Roa-Garcia, 2014). A farmer in Ali-Abad (2013) reflected on the new sub-surface piped irrigation scheme, while using the board game for explanation that:

‘When a tail-end farmer had muddy canal, his water was wasting all the way, but when they installed sub-surface pipes, it is like the well is brought just nearby his land (it means no water wastage through the delivery canal), so it is much fairer and profitable”.

This was noted by farmers as an educational point and has raised their knowledge about the advantages of this new irrigation scheme which can enhance their water availability that reaches their plots of lands. The simulation revealed that adoption of the sub-surface piped irrigation system can increase water use efficiency by providing farmers’ share of water right in a more equitable water distribution system. Kuper et al. (2012) suggests that this allows small-scale farmers to improve their agricultural income and livelihood which is consistent with our findings.

7.2.2.2. Social capital

There has been much research on the potential impacts of social capital on collective action and the forging of sustainable institutions (Walters, 2002; Pretty and Ward, 2001). This suggests that where social networks are well-developed and an existing sense of community is strong, local groups with locally developed rules and sanctions are able to make better use of existing resources than individuals working alone or in competition. The simulations revealed some of the behavioural approaches and incentives for farmers to participate in collective action, consistent with existing theories on driving forces for collective action (Ostrom, 1990). Farmers described how they will reach agreements within community-based rule setting. From this, it can be argued that informal local meetings could be more effective and productive in outcomes, rather than official institutions which enforce such meetings for farmers.

For example, a farmer in Ali-Abad (2013) stated:

"If farmers need to meet to discuss any issue, the Wells Manager organizes a meeting (e.g. to discuss installing pipelines). If we all do not reach an agreement we will not request pipes from the official agency".

This indicates the importance of collective decision for farmers which can be achieved in their local meetings and through negotiation and agreement to satisfy every farmer expectation.

The researcher established a close relationship with local farmers in this case study area (see Chapter 4), as a result they were more comfortable in expressing their perspectives and feelings which they usually do not share with official bodies. When asked how they usually convince other farmers to engage in collective decision-making, one farmer in Ali-Abad village responded:

"We have almost become a big family after many years; most people in rural regions marry within the same village, so they must follow the community and the majority vote. They do not have any other options".

The farmers' viewpoints on collective action and the powerful social capital that we observed between farmers in each community encourage mutual respect and respect for social norms, which are crucial factors in creating a successful institution.

7.2.2.3. Economic motives

Economic driving forces provide a key motivation in initiating locally-based collective action. Local farmers evaluate the cost and benefits of collective action based on economic, social or cultural issues. It has been observed that farmers make rational decisions based on their own economic position and thus farmers are persuaded to participate in collective action when they derive economic benefit (Olson, 1965), such as increasing their irrigation efficiency through a more appropriate water allocation systems. It is almost impossible for small scale farmers to achieve higher economic benefits from agricultural practices individually; hence collective action brings economic advantage. As a result of discussing the advantages that underground piped irrigation system can bring for farmers during IMG, some indicated that mainly due to the economic advantages that this system provides by increasing water availability and higher productivity, they will be willing to participate in installation of the pipes.

As one farmer in Ali-Abad (2013) stated:

"I had different (negative) views on this governmental new irrigation scheme, but today discussion on its economic benefits persuaded me to replace my cement tube canals with

more water efficient underground pipelines…it will save my time and effort to catch water and reduce the time taken for a farmer to receive water on his land."

The underlying factors that led farmers to reject modern irrigation scheme which is proposed under the top-down governance regime of Iran, were also explored during the game:

One farmer stated that:

"*This is why we cannot accept drip irrigation system, because then we have to establish a shared water reservoir but each farmer wants to have his own authority on his 4-5 hours of water. The official Jahad Agriculture agency wants a farmer to manage his water in reservoir*".

As part of the 'Tooba' scheme on installation of the drip irrigation system, farmers have to build small reservoirs on their lands. The establishment of a reservoir is followed by acceptance of a drip irrigation system, which requires farmers' agreement to integrate their land and hence become eligible for a government loan. For small-scale farmers, construction of the reservoir also installation of drip systems and its maintenance is expensive, requiring collective ownership of the infrastructure to share their cost. And if farmers are to benefit from the application of a drip system, they need to consolidate their land holdings to obtain larger plots. The agreements for land integration to become eligible to receive loan from the government for installation of drip system requires extensive effort between farmers, which is not possible within a short period of time.

Regarding the more affordable sub-surface pipe irrigation scheme and its economic advantages, one farmer in Ali-Abad village (2013) stated that:

"With pipelines the volume of water that reaches crops has increased and I can cultivate more. If government continues to give pipes for free we have enough lands to install them, it makes huge difference, I can irrigate with more available water and less costs".

Farmers indicated a preference for using piped irrigation systems over drip system, and in this case economic motives (for collective action) also encouraged farmers to make rational decisions and develop efficient irrigation management strategies. Otherwise if the scheme has higher economic return in the short-term and does not require massive financial investment, (e.g. piped-water technology) this could be feasible for small-scale and poorer farmers to accept the scheme.

The land integration scheme which was pointed out particularly during the Role-play game, and the reasons for rejecting the scheme by farmers were explored, is one of the main barriers to improving economic returns for small-scale farmers. The main reason for rejecting, or reluctantly accepting, schemes such as land integration and changing crop pattern might be rooted in social and cultural aspects of a particular region (see next section). For example, historical water rights were adjusted to provide a fair distribution of water to small and scattered pieces of lands. Currently these small and scattered lands are economically disadvantageous for farmers, although farmers believe that this is a good scheme and are aware that integrated land can significantly reduce water wastage and facilitate the use of machinery, but land integration is hard for farmers to implement.

In the IMG, farmers revealed that they find it hard to adopt land integration and thus are reluctant to adopt drip irrigation system for the following reasons:

1. Their cultivation patterns are different and are not matched in one plot, hence when they plant pistachio they cannot exchange it,
2. The quality and size of their land are different,
3. Each well-sharer must exchange land with each other and two farmers who have shares in two different wells cannot exchange their land because of the long distance to reach their tube-well,
4. It is hard to reach agreement because land holdings are small and scattered,
5. When water right owners are limited, land integration is more likely to be implemented (but in villages with more water right owners and with scattered land it is more difficult),
6. Accessibility to water is the main issue to be agreed and resolved between farmers for land integration.

If farmers are to benefit from the application of drip systems, they need to consolidate their land holdings to obtain larger plots. This requires considerable effort and agreement between them, which is not possible within a short period of time. The main motive for farmers to accept and implement the scheme is that by having larger plots of land, their income will increase and the scheme will provide more facilities for them.

7.2.3. Formulation of Scenarios

Farmers raised the issue of land integration and described how this scheme would increase their water use efficiency. This scenario was used for another round of the IMG by asking farmers to demonstrate how they thought land integration could reduce water wastage. The land integration project which is associated with the 'Tooba irrigation scheme' is considered as a scenario in WEAP model to be tested. Farmers indicated that this scheme would only be possible if they agreed amongst themselves to consolidate their land holdings into one location, preferably closer to the well. This would entail farmers with scattered land holdings, exchanging land with other farmers to retain a larger, single, plot of land (ghafis).

As one local farmer in Ali-Abad village (2013) indicated:

"Land integration has many advantages, when we did it the government supported us, my lands which is around 1 hectare were scattered in 5 to 7 different locations, but now they are all gathered into one piece. Pavement was also important, it's now very comfortable to travel by cars between plots, we did not have it in the past and now it's very good".

The farmers represented the process of land integration by attaching small pieces of green paper to their land to illustrate how it could function with water distribution canals.

By proposing the land integration scheme as a new scenario, farmers expressed their perspectives. The tractor driver in particular, explained the difficulties and the advantages of land integration schemes. He demonstrated on the board game that scattered and small-size lands create difficulties for him to move between lands. Also, irrigators explained that farmers with scattered lands have difficulties to receive their water rights in time and need to travel between their scattered lands several times.

A tractor driver in Ali-Abad (2013) reflected on a conflicting issue that occurs in their system, while using the board game to explain as below:

"If two farmers have different time schedule for planting their crops, one might has already cultivated and the other just wants to start ploughing to prepare his land; under this condition, my work with the tractor damages the neighbor's crops and this lead to conflicts.

The land integration which farmers need to cultivate the same crops in same plots can greatly resolve these conflicts."

The IMG has assisted tractor drivers to discuss and explain the main source and the reason for a conflict that occur between neighbor farmers. The debate around this issue was educational for participants as they discussed the advantage of land integration as the best resolution to reduce this conflict.

An important result obtained from the game was the formulation of relevant scenarios (some of which were tested subsequently by a hydrologic model representing future trends in water availability) (Chapter 5).

Specific scenarios that were obtained from farmers include:

- Land integration to reduce water wastage through transmission canals;
- Changing cultivation practices to increase the use of Pistachio (a drought resistant crop);
- Using sub-surface piped-water to reduce water wastage and increase water availability for irrigation; and
- Changing from agriculture to industrial development to increase farmers' income.

Based on the above mentioned scenarios that farmers agreed upon to be important, the WEAP model (Chapter 5) was used to model these scenarios. Some of the most relevant scenarios to farmers' need (such as change in irrigation technology, under which specific amount of water usage is saved, land integration and estimated water saving provided by the governmental reports), was used in a form of storyline scenarios to be modelled and evaluated in WEAP (see Chapter 5) and further discussion will be presented in this chapter.

Ultimately, farmers produced their own evaluations of the various official irrigation schemes, and decisions on the best possible technical design and organization regarding their irrigation management. The game procedure is closely defined by the different steps of scenario-analysis. Primarily scenarios and rules were designed to create a productive and familiar environment for farmers. The objectives were to simulate the realistic procedure of policy decisions and enable farmers to evaluate specific policies. The scenarios provided the initial basis for individual simulations. Thus, the well-known scenario describing the drip irrigation policy scheme was initially used as it is currently the farmers' main challenge. According to Toth (1988), scenario development is an essential (and central) factor in policy evaluation exercises. Scenarios create a framework in which a variety of issues, including existing problems and particular policy alternatives, are tested during the interactive simulation process. Regarding simulation of new developed scenarios, some farmers argued that it was inefficient to install modern drip irrigation systems or piped water on scattered small fields. Farmers also concluded that without integrating their land, it would be difficult to cultivate pistachio as a large space between trees is required to establish water canals for irrigation.

One educational aspect of discussing the scenario of land integration scheme that has led to social learning for farmers, was pointed out by a farmer in Ali-Abad (2013):

"The debate on this board could better visualize for us some aspects that we need to carefully consider. For example we could imagine that if we want to plant pistachio with 7 metres distances between each, this requires land to be integrated to larger plots, otherwise changing crop patterns even under piped irrigation system, would not be profitable for us."

Farmers indicated that there were several conflicting issues when seeking to agree on land integration, and in some cases they could not reach an agreement as they had insufficient evidence to accept the benefits of the exchange. However, farmers observed the feasibility of this method and the way in which it might benefit them. Finally all farmers agreed that land integration and also installation of sub-surface piped irrigation system were the most appropriate strategies to increase their irrigation efficiency.

7.2.4. Reasons for Rejection of Drip Irrigation Method

From analysis of the conducted interviews with local farmers in Kashan, some of the underlying reasons why farmers might initially reject government irrigation management policy included: a) land use structure, b) unsuitability of introduced irrigation devices (which does not match their historical water allocation mechanism), c) economic problems and d) crop patterns. Particularly regarding drip irrigation method, other influential factors include: labour-intensive nature of maintenance, leakage, cost of repair, and concern about theft. During the IMG simulation exercise, farmers gave an insightful evaluation of the drip irrigation systems. Although farmers have struggled to maintain traditional water right systems, which could secure equity in access to groundwater resources, some government policies, such as drip irrigation systems, can disturb existing water right regimes that present particular difficulties for poorer farmers. Many farmers stated that this state-oriented policy disturbs their historical water allocation. They considered it to be neither suitable nor effective to apply drip irrigation system for their excising crop pattern and farmers could not be persuaded to accept this method.

During the game, farmers, who had installed gravity-fed subsurface pipelines to transfer irrigation waters, represented their tubes with wider blue lines linked to their farmland to demonstrate the higher water use efficiency of their irrigation network compared with the other methods. Farmers used thin blue lines to indicate muddy canals with high seepage losses. Scattered farms, receiving less water, were represented by thinner blue lines. This issue stimulated further discussion, and was educational for other participants as it was argued that based on farmers' experiences of using these tubes, it could significantly reduce water wastage from transmission canals. Farmers mentioned that due to the scattered distribution of their lands (*Kardu*), and the time taken for water to flow through the canal network, considerable time would elapse before water reached every piece of land.

They also indicated preferences of using piped-line irrigation system over costly drip system, and in this case economic motives also encourage farmers to make rational decisions and develop efficient irrigation management strategies. Thus, attention to socio-political dynamics is essential to improve irrigation and land management, rather than enforced or compulsory imposition of technical options by government.

The IMG enabled farmers to appreciate the complexity of their irrigation system. As discussed previously, farmers could explain how drip irrigation system for this particular landscape is inappropriate, particularly when due to their scattered lands it is not feasible to apply drip system for the pistachio trees.

More importantly this system could not be adapted to their historical water allocation system. To install the pipe, which is the farmers' responsibility, they put one gate as a water outlet in any one or two 24 hour periods of water right. Farmers explained that the water outlet from the sub-surface lined-pipes matches the time slots of their water allocation mechanism which could make this irrigation technology more acceptable. They also indicated that the recent pipe scheme does not make significant changes into their current system, but considerably improves water transition efficiency. This potential adaptability to the water right system can facilitate acceptance of the use of pipes in the irrigation system. This finding is consistent with Kamash (2012) who considers that: “The factors that governed the acceptance of water technology include how people viewed water and how those technological choices were wrapped up in historical and social, as well as pragmatic, negotiations”. Also de Laet and Molle (2000) state that it is important: “to do technological things in the socially right way”, in the context of their study in a Zimbabwe bush pump. The installation of the modern technology of sub-surface piped system is adaptable for the specific characteristics of the arid Kashan region, and it is a preferred option by farmers regarding biophysical, social, economic and cultural suitability (see more in Chapter 6) within their traditional irrigation system.

From analysing the debates occurred amongst farmers during IMG process, the game as a mediation tool could provide more insightful thoughts and deeper understanding for farmers regarding some of the advantage that governmental irrigation scheme can provide. The game board actively involved farmers in the management evaluation process by assigning real roles and rules, so that farmers could explain and understand different aspects of the proposed irrigation policies. Also understanding the conflicts and farmers’ expression of dissatisfaction with some of the governmental policies was provided through participatory modelling development. This is while conducting conventional social research methods or even governmental educational workshops does not produce as much effective outcomes as the participatory role-play simulation processes.

One major source of conflict in farming communities arose from the government policy of compelling farmers to join official cooperatives and pay for government services. A well manager participating in the simulation game revealed that this has reduced farmers’ trust of officials. This field observation is consistent with Ostrom's (1990) experience that in many cases the use of government power has reduced the legitimacy of subsequent decisions, thus creating more problems in managing common resources. One example, raised by farmers in the discussion, indicates that weakness in defining government responsibilities could destroy farmers' agreements and their ability to make collective decisions giving rise to conflicts among them. For example, in our study, it is the local farmer's responsibility to install pipes. In the village, the well manager is a farmer himself but has the skill to undertake the installation, and other farmers pay him for his services. In this case, even when farmers reach agreement and try to form a local cooperative, the government provide insufficient pipes for the well manager who consequently fails to fulfil his responsibilities, thereby also disrupting the farmers' agreements.

As government has the primary responsibility to restrict groundwater abstraction and charges farmers to monitor abstraction rates, it has reduced the farmers feeling of ownership, and responsibility to manage the resource thus ultimately jeopardising protection and maintenance of groundwater resources (see Chapter 6). This significantly highlights the crucial role of the government in supporting collective action behaviour among farmers. In the Kashan case study, it was revealed that in successful managing of groundwater resources not only community-based rules and collective participation in management is crucial but also the government can play an important role to encourage creation of cooperation among farmers. The government by providing sufficient funds for new irrigation schemes need to take more responsibility in making thoughtful decisions that could ensure farmers their collective actions will be completely supported and succeed to improve their income.

Considering the important role of interaction between local farmers and officials to manage groundwater irrigation practices, this study attempts by including a simulation game exercise and integrate it with the physical hydrologic model, foster more dialogues and improves communication between farmers and also farmers and policy makers. The following section reflects on the outcomes of this effort, which is experimented for the first time with local Iranian farmers in Kashan case study area.

7.3. WEAP Co-modelling to Foster Dialogues

As this study is an interdisciplinary effort, the use of IMG simulation was used to provide wider social dimensions to analyse farmers' behavioural approaches within groundwater irrigation management. On the other hand, this research study steps further to integrate local knowledge with some physical factors using a hydrological model, to illustrate the future water trend and changes in the irrigation system. Using a hydrological model was to assist farmers to obtain better understanding of their invisible aquifer and to raise their awareness about the main parameters that can affect groundwater balance level, through discharge and recharge mechanism. The WEAP model has broadened farmers' understanding about climate factors such as changes in precipitation and its impact on groundwater level in a simple representation of graphical results. This has produced more dialogue and tested farmers' capability to engage into more complicated decision-making arrangements. Farmers also indicated on several occasions that integrating their local knowledge into the physical model can be influential as a tool engage them with policy makers, to enhance communication with them at regional level. This can be more educational and insightful for farmers as well as for authorities on how to improve water use efficiency using more adaptive management options.

7.3.1. Developing a Companion Modelling Process: The Insights

In this study it was proved that physical and social integration enables a more effective decision-making process. It is stated that this provides a wider dimension and perspectives associated with particular water management problems that illustrate system complexity, in comparison to when models or social simulation are used alone (Robinson, 1991).

For this purpose, the aim of this study was to select an appropriate modelling process approach which enables incorporating physical and social aspects of irrigation management. I will signify the outcomes of this intervention and the challenges as well as the opportunities that these participatory and integrative methods have created in order to move towards more successful participatory adaptive management for irrigation practices in the region. The discussion previously emphasised the need for more adaptive irrigation management strategies (see Chapter 6). This requires an adaptive modelling process by engaging and incorporating the local knowledge and their perspectives into policy development assumptions; which facilitates moving towards implementation of more adaptive solutions.

According to the literature, the Companion Modelling (ComMod) approach has been developed with the aim of including different stakeholders' perspectives within the continuously evolving adaptive management and social learning process (Bousquet et al., 1999; Barreteau, 2003). Not all features of this approach could be integrated into the methodological process. For example instead of using multi-agent system models, it was decided to use a user-friendly hydrological model which enables to incorporate climate variables and add more complexity to the final outcomes (see Chapter 4). This hydrologic model is used as a mediation tool to give an integrated view to our thoughts and approach, as it links between physical and social dimensions to water management in an integrated manner. The other objective of incorporating a particular hydrologic model is to create a suitable decision support tool, which can bring in-depth discussion and dialogue between participants and provide iterative simulations of key processes. In this study, the importance of incorporating officials' concerns, whose management plans focus on protecting groundwater resources, has been actively considered in the modelling process (the secondary data used in the model was gathered from the local agencies and the main simulated scenario was based on the governmental irrigation scheme).

The combination of IMG simulation with a hydrological model of WEAP was an experimental effort to integrate stakeholders' perceptions, institutional management policies and hydrological variables to create a conceptual framework (Chapter 4, 5), through which different management options can be explored and discussed with the relevant agents. However, the modification and the use of a different physical model was done to adapt to a particular physical and socio-cultural circumstances in the case study area. The adoption of this model could broaden discussion and added enough complexity to the simulation modelling assumptions for deeper evaluation and to enhance local decision-making ability for irrigation management, while creating common-agreed sustainable agricultural water management strategies for future water management in the region. Within different stages of the methodology, the specific climatic, social and technical factors affecting water use were elicited as scenarios from the perspectives of Iranian farmers within the simulation. The hydrological model was run using some of these scenarios, some of the outcomes were presented and discussed with farmers to validate the model and to generate wider discussion.

The participatory modelling process in general, resulted in educational achievements for farmers (as well as for the researcher) and has empowered social learning and collective decision-making in irrigation management practices in the case study area. Another achievement was the investigation of the social concerns regarding groundwater use and irrigation practices and associated hydrological processes, to evaluate the impact of climate change on groundwater resources and eventually share the knowledge with local farmers. The outcomes of this modelling process may be interesting for authorities and can create a suitable linkage to improve the collaborations between local farmers and the local authorities.

The main stakeholders involved in the modelling process included farmers, government agencies, local institutions and academics. The viewpoints of all these stakeholders have an important role in groundwater and irrigation management. The main findings from this study are:

- Farmers denied parts of the modelling results which conflicted with their actual observations and belief.
- Showing graphs can foster more in-depth dialogue and wider discussions among farmers, e.g. about different irrigation time schedule during seasons and duration of irrigation practices.
- Showing statistical graphs was a new experience for the farmers. They expressed their knowledge more confidently about groundwater and its interaction with surface water and climate change parameters. Interestingly they could comment on and even criticized some aspects of the results and the input data.
- It has improved their trust towards the researcher regarding existing concerns about their groundwater level status by officials. And observing the decline trend in groundwater level and storage capacity (which was agreed by farmers) could raise their awareness about the irreversible degradation of the groundwater resources.

- Farmers suggested that this modelling effort can also be useful in representing their actual water need to the officials, if their knowledge of real water use and crop water need is integrated into the model assumption.

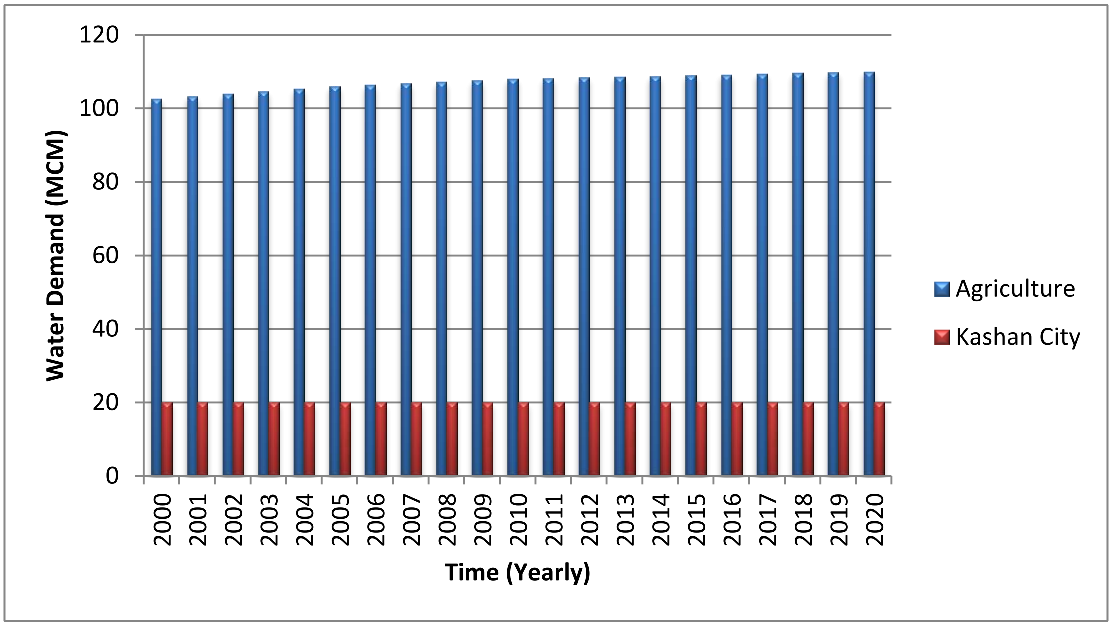
In the next section, different outcomes of this combination effort will be discussed in more depth. Afterwards the challenges of adopting interdisciplinary methods and the difficulties of direct use of a hydrologic model with farmers as main stakeholders will be discussed.

7.3.2. Farmers' Interactions and Evaluation of the Hydrologic Modelling Results

When discussing the WEAP model outcomes with farmers, they showed interest and understanding of the simpler modeling results which fostered more discussion among them, but when the facilitator tried to present more complex graphs, some farmers tried to change the topics to other issues. Discussion was still carried out among farmers on relevant subjects, but dialogues on the model results could not be continued. Also in the co-construction process, time is another major issue which has been considered, because the process is iterative and this depends on farmers' ability to interact with the results or other participants (Voinov and Bousquet, 2010).

One simple graph (Figure 29), regarding the trend in water demand in agriculture and domestic use, within the next 10 years also during different months, was discussed with farmers.

Figure 29 Water Demand for Agricultural and Domestic Sectors (agricultural water demand is under improved Irrigation efficiency)



In contrast with what the graph illustrates, that water demand in the future is likely to increase, farmers disagreed. They indicated that water demand has not increased over the last 30 years because there were restrictions on digging new deep tube-wells in the region, thus they believe the abstraction/discharge rate from groundwater has not significantly changed. They also stated that water discharge or delivery rates were the same as previously, and according to their historical water right. Because once farmers realised that their abstraction rate had fallen, they will try to get permission to deepen their existing wells and compensate the reduction. Farmers stated that this indicates the flexibility of groundwater resources, but surface-waters such as rivers are less resilient. In response to the significant reduction in groundwater levels, farmers agreed that there has been a significant drop in water table in the case study region.

One old farmer in Ali-Abad (2013) mentioned that:

"In our village in 50 years ago we could reach water in 2 meters depth, in 35 years ago was is 20 meters and now its 80 meters in depth".

They also reflected on the rainfall rate in the region, and showed awareness that the mean rate of rainfall in this region is less than in many other parts of the country:

"If rainfall pattern changes the situation will be different, if God send us 250mm we will have less difficulties, but rainfall rate is currently 90mm or below 100mm, therefore the water level does not come up. Even during winter the rainfall is not significant".

In criticizing the graph when it is indicating that water demand will increase by 2020, however, groundwater levels will decrease. Some farmers explained this to others, they accepted that groundwater level will drop further in the future but they eventually disagreed that water demand in the region will increase, they emphasized that water demand will decrease because the number of farmers is reducing and when there is lack of water then demand cannot grow.

As indicated by Olsson and Andersson (2007), stakeholders might reject scientific model results not only because of the model accuracy level, but due to different economic, political or social factors that influence public's acceptance of the model's outcomes. When farmers observe contradictory results from their personal interest or belief about system function, they criticise the model outcomes and doubt its validity (Cockerill et al., 2004). In our case a similar situation emerged when farmers did not want to accept the fact that their abstraction rate is increasing, which might be due to various social and political reasons. The facilitator explained to farmers that these graphs were produced from available regional data, gathered from different local water and irrigation agencies, which could increase farmers' level of trust in the results.

When discussions continued it was realized that farmers know that water demand is currently high but they believe that it would not increase further, they think groundwater levels will decrease but their water consumption will remain steady or maybe even reduce. One farmer (Ali-Abad, 2013) stated:

> *"Water demand might increase because of climate change (higher temperature) but they do not let us to dig more wells and increase current abstraction rate".*

Discussing another graph with farmers, regarding the trend in groundwater levels after improving irrigation efficiency fostered discussion among farmers. On seeing a graph illustrating that groundwater decline might change after improving efficiency (by a certain percentage), they commented on the accuracy of the modelling results (Figure 30). The graph illustrates the monthly changes in groundwater level, therefore one farmer (Ali-Abad, 2013) stated that: "In our real system, during January and February water level is higher and in April it is reduced". In this case, the model showed a contradictory result which farmers noticed. Farmers indicated that during January and February because it rains, the motor-pumps are off and water demand decreases, therefore water level should increase. In other months for example during March, April and May crops consume more water, so water demand should increase and groundwater levels will fall. It is stated that local stakeholders, particularly farmers who have deep knowledge and awareness about their environmental or resource changes, are more likely to criticise the model outcomes, when it does not properly represent the system (Olsson and Andersson, 2007). In our study, this situation has occurred, however the facilitator was prepared to give adequate information to increase transparency of the model outcome to farmers.

Showing graphs to farmers encouraged them to expand more details about irrigation schedule and justify their reasons for rejecting the model outcomes. They refer to the type of crops and crop water need during different seasons and different months. Also they emphasised that their cropping pattern changes has made different water abstraction rate during different seasons.

This has also brought another perspective into the discussion as one farmer stated that:

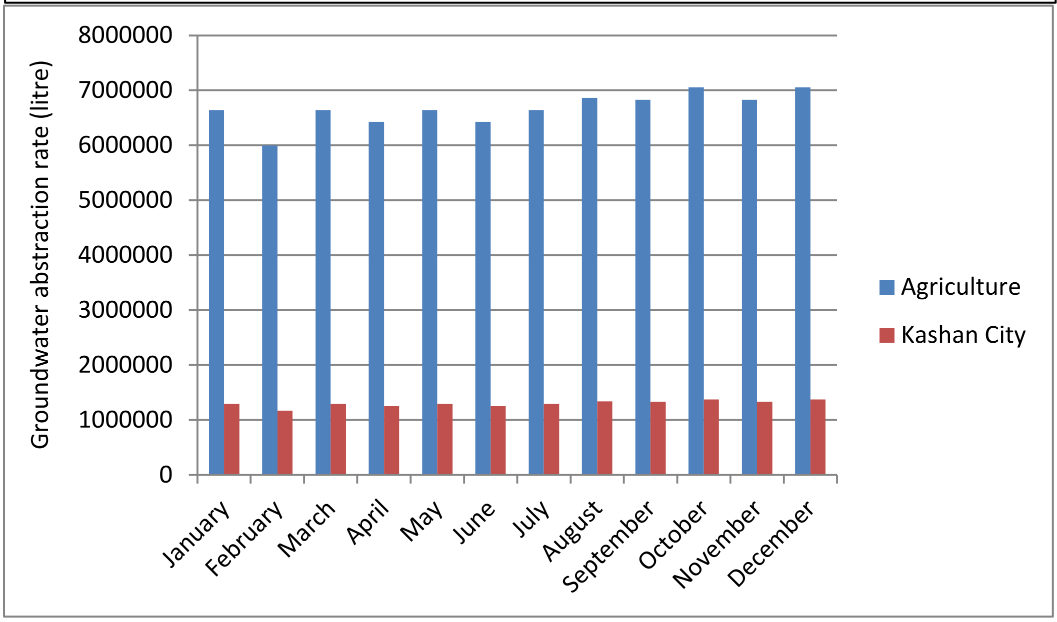
"Currently with pistachio cultivation, we need water in all months, because pistachio uses even more water during winter for the first two years, so we need to do flood irrigation (20 cm of irrigated water on top-soil) which this increase water consumption".

Discussing the graphs of results encouraged farmers to reflect deeper on their seasonal and duration of irrigation, as well as their irrigation schedules and crop water requirements during different seasons and for different crops.

The other farmer in Ali-Abad (2013) added that:

"Only during winter, when other crops do not need water, pistachio requires 2, 3 times irrigation. However, it is a very resilient tree and after these two years, even if farmers don't irrigate it for 50 days it does not get dry, that is why it needs more water at the beginning to resist longer".

Figure 30 Unmet Water Demand, without improved efficiency and population growth by 2.1%



Discussing the fall in groundwater levels revealed farmers' perceptions and understanding of groundwater and the impacts of its reduction, also on recharge mechanism. As one farmer in Ali-Abad village (2013) stated:

"The problem is that groundwater level has decreased and as a result land surface has lost its moisture and gets dry more severely. In the past the moisture was in 3 to 10 meters depth and it was penetrated to the top soil but now underneath the soil is dry and that is the reason we must use more water for irrigation".

Discussion around seasonal irrigation pattern, the crop types and the groundwater table decline, led the researcher to question whether farmers believe that by continuing flood irrigation method, the water recharge to groundwater will maintain or increase, they expressed different perspectives.

Some of the farmers believed that flood irrigation method could increase groundwater recharge rates particularly in the past, before groundwater levels fell this deep, but today the recharge is not significant, because currently the water table is very deep and temperature is very high (see Chapter 6). Some others assume that because the abstraction rate is high and different layers of soil is dry and absorb moisture immediately, thus the aquifer does not replenish at all. This is consistent with the reports published by the local water and irrigation institutions in the region. They think when they were using Qanat system and rainfall was relatively higher, groundwater could recharge during winter but today this does not happen.

One farmer (Ali-Abad, 2013) said:

"Of course irrigated water penetrates into earth (when we use flood-irrigation) however, during summer days there is high evaporation, but during night, irrigation could recharge the groundwater".

The other farmer had an important perception as he believed that by night time irrigation in summer, they can irrigate larger pieces of lands and the runoff discharge to groundwater, however, drip irrigation systems do not function like this, because the irrigated water does not reach the deeper soil level. This is in accord with the scientific assumptions, and the new concept of efficiency gain introduced by Lankford (see Chapter 6). When discussing future water demand graphs, under extended climatic condition and unimproved irrigation efficiency, it was stated by the researcher that groundwater recharge rates were very slow and under these climatic conditions, might not occur, so there is a need for more control and monitoring of farmers' abstraction rates.

When discussing groundwater storage capacity, and future declines in level, farmers responded to the question as to whether they believed there is still abundant water stored underneath their farmlands. They responded positively and explained that:

"If we face severe water shortage we will have to reduce our abstraction, but we have not got there yet, because when you do not have water then all people should cooperate and reduce their consumption".

This indicates that farmers have their own measurements of water availability and assume that there is a considerable volume of water stored as groundwater in the region. Farmers' perceptions about how their aquifer looks, is in similar to the shape of a bowl in which its boundaries are higher and storage is lower. They showed awareness about the recharge mechanism of their aquifer as stated that the melted snow from mountain regions recharge the aquifer in winter. One farmer stated what he learnt is that groundwater is a shared resource in which each farmer by having his deep tube-well is like putting a straw into the storage and abstracting from the same bowl. One farmer indicated that they learnt from one government engineer that within 100-150 years the aquifer gets dry. My impression is that this might have influenced farmers' estimation of groundwater sustainability.

Discussing different graphs with farmers has resulted in educational achievements for farmers and has empowered social learning process as farmers debated several irrigation-related experiences within irrigation management practices. When a graph was discussed with farmers, they mentioned that this was the first time that they had looked at graphs of their groundwater resources, because the official agencies never discuss any graphs with them. In any participatory modelling, stakeholders can be engaged in various ways, such as extracting knowledge, selection of the suitable model and development, collecting data and integration, development of relevant scenarios, analysis and discussion around results, developing new policy or management strategies (Voinov and Bousquet, 2010). In this modelling effort local participants were engaged in knowledge provision, developing model and scenario building as well as interpreting the results and suggesting collective-agreed management decisions. The final step in ComMod process is that different developed scenarios should be used to discuss and to define alternative resource management strategies with resource users. The results could be used to inform water users about the future predictions of water availability or evaluation of the scenarios.

In this study, local farmers participated in evaluation of the results of a scientific model which illustrated the groundwater declining trends, and its control is under governmental responsibilities. For eliciting farmers' feedback on the participatory modelling process, the facilitator explained that the main scenarios were formulated from the previous IMG (in which they played a major role in designing and simulation of the game and articulation of scenarios). Enough time was given to the group discussions for the emergence of more dialogues among farmers. Finally, to obtain more accurate results within iterative process, this methodology can be improved by connecting with more usual technical simulations (indicators, biophysical dynamics, GIS, vulnerability assessment, databases, etc.). These technical supports are useful to assist the operational management of the simulation exercise. Farmers were more enthusiastic to see more related result towards their crop pattern and groundwater level condition in the future.

Here, I reflect on the main challenges of conducting this methodology. Within ComMod process it is essential to identify two different contexts: the generation of knowledge emerged from complex system within systematic research approach and the use of this to support collective decision making process for resource management.

In this study, the attempt was to use the same conceptual model for the IMG design and for the indicators used in the hydrologic model. However, the nature and outcomes of using these two different tools was varied. In our study, IMG and computerized model were used in turn and one after the other.

The IMG was used to create an interdisciplinary area to build a multi-perspective system platform, which included farmers' perception of their actual irrigation system, their rules and factors affecting their water situation, and some elements of climate variables. In this stage the information and assumption were incorporated from different interviews and group discussions. However the main focus was to give farmers the priority to have a main role in designing the simulation process.

In ComMod (companion modelling) process, validation is an essential step, which in fact it is different from the conventional model validation and does not exist in the same way as physical and mathematical models (Barreteau et al., 2001). This stage was completed during the Role-play simulation and revision of the main scenarios and the model assumptions.

In the first phase in generating knowledge the challenge is to deliver and understand the interaction among resource users and managers and their evaluation of the existing problem. The challenge of this study was how to integrate different hydrologic variables with different stakeholders' perceptions toward groundwater use and irrigation management, to create a shared-agreed conceptual model for all. In the second phase, the concrete knowledge and any technical decisions to support the deliberation of the participants' concerns was employed to formulate a shared understanding of the problems and to identify shared solutions for collective action and management.

The modelling approach is not to produce a practical application for improving irrigation efficiency but it is step forward to facilitate collective decision making process and eliciting knowledge from wider range of stakeholders. The modelling and IMG are tools to capture part of the complex system, which relates to climate variables and water use strategies in irrigation. This study provides an innovative method to identify the effectiveness of this approach in decision-making processes and facilitating negotiation. The effectiveness of a participatory approach has been proven, as it produced a shared perspective, more critical analysis of the system and more in depth discussions. The model could provide relatively easy outlook of results, raise farmers' awareness about their groundwater level trend, and foster more dialogues regarding climate variables and how these factors affect the aquifer in general. Although farmers' interaction with the model result for the first time attempt was successful, there is still a need to find methods and interactive ways to represent more transparent outcomes to farmers. It can be suggested that training farmers in a workshop to enable them to directly use the model and observe their own inputs in construction of the modelling assumption, can build more trust in the model's outcome.

According to my findings, local farmers in Kashan have the capacity and interest to participate in a more cooperative management process. This requires the existence of effective local institutions to promote collective action and strengthen social capital among farmers' communities (see Chapter 2). The powerful local institution also develops a higher level of trust for farmers and affects their behaviours in adopting governmental schemes and being actively involved in more collaborative resource management with the governmental agencies. In the next section, I briefly reflect on the role of this important factor. Then I will argue that according to my empirical findings and the potential for promoting participatory management for irrigation practices in the region, moving towards adaptive management purposes is necessary. I will discuss the possibilities and the values of developing adaptive management process, and suggest the use of innovative methodologies under informal and reflective local institutions to improve irrigation management for Kashan.

7.4. Building Adaptive, Flexible and Reflective Institutions for Irrigation Practices

From this study it could be concluded that solely community-based management over groundwater irrigation in Iran cannot be possible, although community-based management gives stronger legitimacy to the users' rights in comparison with other governance regimes such as co-management. Co-management or joint management is when government continues with the majority of its roles in conjunction with local users and has transferred some management responsibilities. In participatory (community-based) irrigation management local users are encouraged to increase their engagement in the management process and to complement the role of government (Meinzen-Dick and Knox, 1999). In my case study, poorer farmers still require governmental support for managing their irrigation infrastructures and to provide a suitable market for their products (see Chapter 6). Indeed, a lack of governmental support in most cases has discouraged many farmers from continuing their practices and they migrated to urban areas (Katouzian, 1978). Thus, there is a need for capacity building to empower local farmers and local institutions to improve management decisions, before transferring the responsibilities to farmer communities.

In promoting an adaptive management process, the existence of strong local institutions is important. The knowledge linkage with institutions represents long-term adaptation of socio-ecological system to dynamic changes (Berkes and Folke, 2002). To bring local users into effective management of resources and not just as a topic, governments need to transfer power to local institutions or local communities for more engaging decision-making processes (Ribot, 2002).

As noted by Neef (2009) many participatory approaches in developing countries are still restricted to pilot studies, e.g. study on polycentric river basin management or transferring irrigation management to local water users (see Ostrom, 1990). It is observed by Neef (2009) that in the participatory management of water resources, officials lack trust in local communities' capability, and do not believe that farmers can have such significant influence and input into governance and management of resources, which is particularly widespread in managing scarce water resources in developing countries (Neef, 2009). It is usually argued that unsustainable use of water resources by local communities is evidence of their inability to regulate and establish rules to increase efficiency use of water resources, and this argument has been used to increase the state control over water usage in local communities (see Chapter 2). This is in contrast with the findings which indicate the capability of local users in developing common rules and valuing system for water rights and distribution which provides equal access to water for all members and follows the established rules of water management (Neef, 2009; Ostrom, 1992). This is an actual issue as some scholars challenged the fact that governance of common resources will be successful only if the rules are established based on interests of users (Dietz et al., 2003; Allen et al., 2010). Generally adaptive management approach requires flexibility and openness which the state-led governance usually lacks. This approach normally faces many limitations because of the certainty of regulations and strictness of the organisations (Garmestani et al., 2009). My study confirms that participatory research must be flexible in order to be adaptive and lead to democratic management decisions. It is an argument that informal participatory efforts are more likely to develop towards adaptive management compared with formal processes which are organised by official regulatory mechanisms (Gunderson et al. 2006, Olsson et al. 2004). Sustaining flexibility of stakeholders' views is the condition that needs to be met.

One of the main problems in the agricultural water management sector in Iran is that there has been much less attention to the sustainability of governmental development projects and lack of effective educational system in this regard (Balali, 2009). In the study by Karbasioun (2007) in Esfahan, he argued that the "uncontrolled influence of political visions on decision making in the agricultural sector is one of the crucial problems of agricultural development in Iran". An individual's behavior is influenced by the institutions and environmental context which has surrounded him (Rier and Foster, 2003). Thus although farmers are concerned about water resources' declining level, the social, ecological and economic circumstances counterbalance their behavior in over-using resources (Folke et al., 2002). Reshaping water/irrigation management institutions or policy frameworks to adjust to changing social-environmental interactions which promote more sustainable water management has still not been completely achieved (Dietz et al., 2003; Folke et al., 2002). Any changes in local level require administrative and legislative changes at a higher political level, and within organisational boundaries. Under an appropriate framework approved and encouraged by political will and communities' capabilities for engaging in management decisions, the implementation of wider participatory research would be possible.

7.5. Social Learning, Empowering local farmers and Capacity Building for Adaptive Management

The need for a more integrated water management approach is the recent focus in many water policies and plans in developing countries (see Chapter 2). The gap still exists for developing more democratic and participatory research to address the limitations and advantages of this process for natural resources governance (Stringer et al., 2006) but also "to critically reflect on the links between communities, science, institutions, knowledge, and power" (Stringer et al., 2006).

It was discussed that to avoid failure in management of complex system as a result of incomplete understanding (Gunderson, 2003), there is a need for improving social capacity by learning about the systems dynamics to protect the system management (Olsson et al., 2004). Learning through management is the main emphasis of adaptive management which follows the philosophy that our knowledge is incomplete or even wrong, the uncertainty in natural resources management is high, however policy makers must act and make decisions (Walters, 1986). As indicated earlier, adoption of optimal models which rely on predicted future outcomes cannot be the most suitable outlook for environmental management (Holman and Trawick, 2011). The use of models to generate social learning requires understanding the ways in which knowledge is gathered, integrated and validated (Berkes 1999, Berkes and Folke 2002). In this case study different methods of participation including interviews, discussion, and farmers' engagement into mutual dialogues have been adopted in order to obtain deeper understanding and collective information of the local system. This process has transferred the role of farmers from participant to active players in decision-making, in which they selected particular irrigation technology and suitable management approach, when evaluating policies.

This study allowed farmers to incorporate themselves into the simulation process in different stages, and eventually within the process they could change the way of their participation in the process to playing a more dominant role by teaching others about the model and by initiating some new scenarios. Thus within IMG, as knowledge was formed during different stages, the role of farmers has evolved from 'target population' to 'active participant' and 'decision-makers'. In this study, farmers gradually offered their own criteria and priorities for selecting particular irrigation systems and more adaptable options for the future.

In this study, it was also found that the integrated methodological effort has greatly resulted in better understanding of the context and irrigation practices of this particular case study area. This is consistent with the findings by Revene (2011), who also found that integrated methodological effort enhanced their understanding of semiarid region livelihood and the factors affecting their vulnerabilities (Knutsson and Ostwald 2006). My study showed that combining qualitative knowledge from stakeholders with a quantitative model has created more discussion and improved participatory outcomes by providing higher valued information for local usage. Enhancing participatory research approaches in different or similar contexts will empower local capacity and bring insights for researchers, policy makers and local users to improve management approaches.

The methodology used in this study facilitated social learning, which also assists in maximizing democratic approach and in flow of information. Social learning plays a crucial role in smoothing stakeholders' participation in the adaptive management approach and assisting in building trust and increasing local capacity (Pahl-Wostl 2006; Muro and Jeffrey, 2008; Collins and Ison, 2009). As stated by Stringer et al. (2006) the key factor is flexibility in participation under which adaptive management can be achieved, because this can provide means to facilitate more dialogue and social learning. Within group discussions farmers showed care and awareness about climate change and expressed their evaluation in terms of observation of increased temperature and changes in rainfall pattern that affected every individual's livelihood. The model proved that it can function as a suitable tool for educational purposes.

From this study, it can be argued that the role-play simulation can generate more discussions and dialogues among farmers that can enhance the social learning process. The frequent occurrence of social learning increases social capital among farmers and thus improves farmers' capacity to respond to harsh and unexpected natural phenomena. This is expressed as one key factor to transition towards adaptive management procedure (Pahl-Wostl, 2007). In local farming regions of Iran, implementation of such participatory management exercises can lead to facilitation of formulating more adaptive management solutions. Local solutions empowered and supported by strong local institutions will lead to more effective management procedures. The effective collaborations and social learning between farmers and local agencies can help broaden perspectives and management options and has provided some kinds of horizontal learning (between farmers) and vertical learning (feedback to officials) as indicated in the studies of Olsson et al. (2004).

As Berkes and Folke (1998) stated, for successful adaptive management it is necessary to 1. Understand the system, resources and dynamics; 2. Initiate practices that respond to system mechanism; 3. Encourage reflective and flexible institutions to promote adaptive management. When these conditions are provided, the system can move towards a more collaborative form of adaptive management or cooperative management. There is an emphasis in conducting a participatory process that it should be related to policy issues in which the findings can be employed in policy decision-making and thus be practical (Rowe and Fewer 2004; Creighton 2005). It is indicated that the communication between local stakeholders and policy-makers needs to continue to lead to more informed decisions for groundwater management in the future and under this condition adaptive management could be promoted.

In this study, I argue that complex and adaptive systems such as irrigation require flexible and adaptable management system. Groundwater resources face significant uncertainty in future climate change impacts, thus there is a need for a more bottom-up and community-based approach in developing adaptive management and improving local capacity to deal with changes. My study has implications for designing successful adaptive and participatory management protocols. These include: structure, careful formulation of objectives and setting up alternative management scenarios, collection of data and assessment and monitoring the outcome within an iterative process with participants. Different constituents of adaptive management processes are defined by Williams (2011) including “stakeholder involvement, objectives, management alternatives, models and monitoring protocols”. These factors are the main elements in the iterative process of learning about complexity of the system and improved management decisions based on the learning. In my case study these different phases were achieved through conducting social research methods and IMG simulation which will be examined as follows.

7.5.1. Stakeholder Involvement

Participatory approaches require continuous collaboration between stakeholders, scientists and policy makers. In this participatory modeling study, I have engaged stakeholders and the perspectives of policy makers into a conceptual framework to support the decision-making process in a complex irrigation system (Chapter 4). The modeling attempt has assisted participants to better understand the system interactions and farmers’ behavioral approaches towards particular schemes or technologies. This was an attempt towards more open and integrated modeling effort, which has revealed the main causes of conflicts or misbehavior as well as underlying factors for mutual cooperation, collective action, local knowledge and values in local farmers’ communities. The selection of a participatory approach is well suited with the concept of integrated water resources management which tries to improve management by considering social and economic aspects at local level (Voinov and Gaddis, 2008).

7.5.2. Objectives

It is important to have agreed upon the main objectives as they will play an important role in assessing performance, reducing uncertainties and enhancing management decisions. In this study, I could eventually articulate clearer, common agreed and measurable objectives to evaluate the improved management decisions (see Chapter 4). The validation of objectives had been undertaken several times prior to design the simulation modelling process through redefining study objectives based on updated modelling assumptions during the field-work.

7.5.3. Management actions

Different management strategies which were introduced by the government and were completely or partly adopted by local farmers have formed the iterative decision-making process for farmers. Different scenarios that were formulated by farmers have been discussed and some were tested to illustrate the future changes in their irrigation system. The most appropriate set of management actions and alternatives should be identified by resource managers in order to constitute adaptive management (Williams, 2011). It is indicated that if potential management activities fail to be identified, it will be unlikely to produce effective and useful strategies (Williams, 2011).

7.5.4. Models

The use of a hydrological model in this study, helped to compare different management alternatives and evaluate their cost and benefits from the local farmers' perspectives in the case study area. Various scenarios in terms of management options have been used in the WEAP model in order to predict their possible future impacts and changes. The use of a hydrological model could represent the dynamics of the resource and its complexity and provide the opportunity to compare the different outcomes under different scenarios. The role-play simulation has also captured the social dynamics in this specific irrigation context of

Kashan. As the adaptive management approach is a learning-based process, using different participatory tools can lead to educational achievements in different ways. In this study, the main method is the development of scenarios of future changes, for each scenario a management option is identified and being tested through adaptive decision-making process and these scenarios were evaluated by resource users, regarding the most suitable one (Williams, 2011).

One of the main challenges of using models is that if models fail to integrate meaningful assumptions or scenarios, the adaptive approach may not produce or suggest effective management strategies. This study stimulated a social learning by linking local knowledge within different farmers' perspectives of different villages and integrated the knowledge with researcher and policy schemes to create varied and sometimes innovative management options. The participatory research was designed locally but the process was inspired by scientific literature, which provides more insightful results rather than scientific and local knowledge alone.

7.5.5. Monitoring Plans

The learning outcome of adaptive management emerges from the comparison of the model outcomes and the observations. In this way having learned about the irrigation system and its dynamic, the most appropriate management or strategy can be articulated and this can be the best response to the management alternatives. The monitoring phases mainly conducted through role-play simulation to validate the WEAP model assumptions, can facilitate evaluation of the process and learning about the system dynamics. Monitoring system and management options are to produce information and assess different strategies, update measures and prioritise alternative options. In this study, these management priorities were formulated by local farmers and incorporated as different scenarios into the WEAP model for evaluation. The outcomes of such an adaptive management process can be integrated into the decision making procedure, assessment performance and learning, moving towards more local adaptive solutions.

7.5.6. Feedback

The evaluation and feedback by adopting particular management strategies and assessment of the project is one essential element in an adaptive management process (Williams, 2011). In this study engaging the main stakeholders in the management processes improved the understanding of the irrigation system. Through discussing and farmers' evaluation of the main irrigation management policies in the region, the farmers' decision making influenced and improved. This is a continuous process, thus within an iterative adaptive management process, both management and system understanding will be improved further.

This study showed the successful application of participatory modelling for adaptive management solutions at local scale of Kashan. The application of adaptive management has been successful in various localised scales (Williams et al., 2007). The potential of an adaptive management approach at local scales has been recognized not only because of the majority of problems that exist at local scale but also because structuring of the problems is easier, also the identification of uncertainties as well as stakeholders involvement in management process can be facilitated with less effort (McConnaha and Paquet, 1996).

7.6. Conclusion

In this study, the simulation game is used to present farmers' interests and knowledge by generating discussion on different technical, socio-economic and managerial issues and the decision-making process. The debates enabled farmers to evaluate different government irrigation policies in Kashan, Iran. In this chapter, the important role of local communities' knowledge is emphasised, the main attempt is to establish a participatory tool for local irrigation management, which is built upon existing knowledge provided by local farmers, which could empower local capabilities and foster collective action. In this case because the novel participatory process was developed, conducted and improved by local water users, it can be applied in similar contexts and in similar climatic and socio-economic circumstances. The participants in this process were also the users of the results that were generated. Based on their inputs, their evaluation of the policies were practical and empowering and knowledge flow between technical aspects of the irrigation systems and local knowledge of farmers could further support farmers' participation and result in social learning. Regarding policy evaluation outcomes, the game process provided opportunity for local stakeholders to evaluate the current policies regarding groundwater and irrigation management and their viewpoints and suggestions were taken into account.

During the debriefing session, farmers suggested how the design and the game process should be improved in the future, for example they emphasized that a larger board game, which represents locations more accurately with more land holdings or irrigation canals would offer better visualization. Farmers thought that this kind of participatory action could be undertaken in future for new subjects such as land integration, in which a comprehensive redesign of their farmlands, could encourage collective agreement and action between farmers, particularly those ones who were unwilling to adopt the scheme. To improve the governance system one farmer suggested that a local-based solution which is adaptable for farmers (in terms of costs and efficiency) and is deeply analyzed can be the most appropriate.

The main effort to be made in a participatory process is to direct management towards development of shared understanding of the existing problem by exploring shared perspectives which link different knowledge together, (e.g. improving efficiency is a goal for both farmers and agencies). This requires conceptualisation of the process and not simply enforcing particular methods assuming that they will be accepted by stakeholders. Externally imposed rules or technologies have consequent social, institutional and political outcomes which can have a significant impact on every farmer's life and on agriculture generally. Thus, management decisions have a major impact on the agricultural system and production in general and on farmers' livelihood. Introducing technologies or the governmental intervention schemes, does not address farmers' needs and they are not adaptable to the local social-cultural circumstances to be implemented by traditional farmers. They expressed dissatisfaction and anxiety with the Iranian Government's adoption of this rule. These factors have been better understood through conducting an IMG. As my findings indicate the evaluation of technology by farmers has crucial role in its adoption and improving performance of irrigation practices. For instance, piped-water systems were better accepted in Kashan villages by farmers over a drip irrigation method. Another important outcome was that the boundaries of knowledge between experts and locals reduced as the knowledges were integrated. The new knowledge and collective understanding of the underlying reasons for farmers' rejection of particular system resulted from capturing different interests, values and criteria which leads to more comprehensive decision making. An Irrigation Management Game (IMG) helps farmers appreciate the value of cooperation with each other which enables efficient operation and maintenance of their irrigation facilities. However, further improvement of the game is possible, for example, organized workshops could be introduced to design the game; evaluate the success of the game design; and determine the added value to farmers (and researchers) in understanding complex groundwater-irrigated systems in arid regions.

Regarding the companion modeling effort, the whole participatory modeling process has led to social learning for farmers and insights for the researcher; also it provided a platform to test scenarios and understand farmers' behaviors in more depth. It is important that participants do not assume any of the outputs from the hydrologic model or simulation as a final solution, but they are just for representing part of the complex system. The incorporation of farmers into designing, planning and acting within the simulation created a sense of ownership and trust in the outcomes, however there is a need for more interactive methods to familiarise farmers with the final results and the future consequences of their decisions. For future development of this process, I would also suggest to engage a greater diversity of stakeholders, and some official bodies into the entire modelling process. Conducting educational workshops to introduce the model and different processes would be useful and more engaging for farmers. In that case, the IMG should also be designed for surface water resources, and transferred into the WEAP model background screen. The modeling process is a time and budget consuming task, so it is more advantageous if the researcher lives nearby or does not have to travel to conduct the workshops. In that case, the repetition of the entire process would be more affordable and efficient. However, this could not be possible in this study due to distance and cost of travel to the case study region.

CHAPTER 8

Conclusion

Introduction and Contribution of Thesis

This interdisciplinary study set out to develop participatory irrigation management processes with local farmers in Iran. The study investigated the role of participatory modeling for adaptive irrigation management in an arid case study region (Kashan) in central Iran. It has also drawn attention to the crucial importance of groundwater resources as the major water supplier for agriculture, economy and social welfare, and their sustainable use in arid parts of the world. The research has highlighted the need for the development of more adaptive and innovative strategies to improve the management and efficiency of irrigation systems as a common-pool resource. One of the main contributions of the thesis is in establishing the principals and techniques for involving farmers in the development of the research methods. The research was therefore able to elicit farmers' deep knowledge and perspectives on water management and their responses to certain irrigation policies. The study involved stakeholders' engagement at the early stages of the research design and throughout the research process. This addresses a lack of such studies within Iranian literatures on participatory groundwater management at a local level. The second important contribution of this thesis is that it is the first study to develop and use a role-play Irrigation Management Game (IMG), which is designed and developed mainly by the local irrigators in the Kashan case study area. The thesis demonstrates how the innovative use of this participatory game has facilitated social learning (see Chapter 4, 7). The development of an interdisciplinary platform including physical and social dimensions was undertaken to understand and strengthen the collective decision-making process for irrigation management within the local farming system of Iran. The study particularly sought to answer two main questions:

1. What is the potential role of participatory modeling in adaptive groundwater irrigation management in Iran?
2. Can the use of a participatory simulation exercise with local farmers be successful in achieving collective decision-making and improved irrigation efficiency in Iran?

As discussed in the introduction and literature review, irrigated agriculture is the predominant abstractor of groundwater resources worldwide. It is the largest water consumer sector globally, which plays a major role in water and food security around the world (see Chapter 1). Groundwater resources are the most important water sources in Iran. However due to over-exploitation and prolonged droughts, their sustainability and maintenance has become under threat within recent decades. The thesis has outlined how in most arid and semi-arid regions of the world, the management of groundwater resources and their sustainability is a major challenge for the maintenance of agricultural production and aquifers. The uncontrolled abstraction of groundwater resources and a lack of effective governance systems has caused major damage to the environment and has resulted in significant depletion of groundwater resources in arid regions worldwide (Molle et al., 2003) including in Iran (see Chapter 2). The sustainable use of groundwater resources, irrigation practices and efficiency are interlinked and require better collective management by farmers. Therefore policies and management approaches need to be integrated and collaborative in order to create cross-sector dialogues for improving management decisions (Mitchel et al., 2012). The participatory methods developed in this thesis set out to meet this urgent demand.

In consideration of a lack of analytical studies on the role of farmers' behaviour in managing groundwater resources in Iran, and the specific characteristics of groundwater resources as an invisible common-pool resource, this study has paid particular attention to groundwater irrigation management, farmers' behaviour and decision-making processes in irrigation management for local farming.

Within the Iranian governance system, farmers have been largely neglected and their perspectives undervalued within irrigation management decision-making processes. Considering these shortcomings in both water governance itself and within the Iranian academic literature, this study has highlighted the need to recognize the role of social research studies of groundwater irrigation management within a participatory modelling approach. A social research approach has enabled the thesis to investigate and identify the role of farmers in successful management of common-pool resources, the main problems, challenges and appropriate management strategies at a local level. This has been achieved by conducting a community-based study. The participatory management approach produced shared perspectives, more critical analysis of the irrigation system and more in depth discussions by farmers. The application of a participatory modelling approach in this study is recognized to be an effective community-based research method, as it combines physical and social factors. Different viewpoints from farmers and the local agencies were integrated and discussed within a participatory research method development, which created a more legitimate management options for participants (see Chapter 7). As the evidence from the empirical findings present, the application of a participatory modelling approach facilitated better understanding of the main drivers for farmers' collective action, and also improved collective decision-making for more efficient groundwater irrigation practices in Kashan (see Chapters 6, 7). This study recommends an adaptive management approach to the governance of natural resources that is driven from a community level which incorporates resource users' perspectives into the development of more informed and higher quality management decisions (see Chapter 2, 7). A participatory approach to groundwater resource management has proven to be a more effective strategy than top-down governance imposed from beyond the local area. Participatory approaches can engage different viewpoints and interests in the management procedure to create a deliberative platform for more legitimate and informed decision-making at a local scale. Within this approach, a specific simulation and role playing gaming method were used to facilitate the flow of information and to foster discussion. This study has particularly provided a critical evaluation of government irrigation efficiency and management schemes (e.g. Tooba) regarding the adaptability of technologies in the region. For example, policy evaluation by farmers regarding the reduction of water rights to one-third of current amount under this scheme, revealed that the initial estimation of groundwater abstraction rate needs to be re-evaluated because it's not compatible with current need (see Chapter 6).

The study has engaged local farmers in the discussions around sustainability of groundwater resources through a participatory method which specifically incorporates a hydrological model in the process to foster dialogue, improve social learning and predict future trends in the state of the aquifer in the local farming system of Kashan (see Chapters 4, 7). The participatory physical model could provide a relatively easy outlook of results, raised farmers' awareness of groundwater drop level, and fostered more dialogue regarding climatic variables and how these affect aquifer in general (Chapter 7).

8.1. Summary of Findings

In this section, the findings are synthesized to answer the two above research questions. To understand the potential role of participatory modeling in achieving adaptive management, a methodology was designed to develop a participatory and innovative irrigation efficiency management exercise. The first stage of building a successful model is to understand the dynamics and context of the particular irrigation system. Different social research methods were undertaken to obtain sufficient and rich knowledge from the local irrigator farmers as the main stakeholders. In my study, interviewing different stakeholders such as agencies and local farmers revealed that working and understanding different groups is a challenging task. However, being an Iranian researcher and sharing a similar language and culture was helpful in engaging with farmers effectively (see Chapter 4). My study on local groundwater irrigated agriculture in Kashan has demonstrated that water and particularly groundwater resources are under ever-increasing demands from various stakeholders and interests. The high uncertainty and low controllability of groundwater as a 'common-pool resource' requires more adaptive strategies which incorporate local resource users' knowledge and future predictions into management decisions (see Chapter 2).

I developed an innovative IMG as a participatory modelling tool to provide detailed analysis of how to achieve agreement and reach collective decisions for groundwater irrigation systems management in a way that is sensitive to the local biophysical and social geography. The methodology was carefully developed through step by step incorporation of local knowledge and farmers' feedback into the process. Therefore, the process has led to the establishment of a novel and context-specific participatory modelling technique for groundwater irrigation practices in Kashan, Iran. It has also provided opportunities to broaden perspectives and elicit local knowledge to improve the decision-making process, which mainly benefited farmers.

Integrating different forms of knowledge including farmers' perspectives and interest, expert knowledge, values and physical criteria provided collective understanding that reduced the boundaries of knowledge among stakeholders and improved the decision-making process. For example, IMG revealed that one of the reasons for rejecting or reluctantly accepting schemes such as land integration and changing crop pattern might be rooted in social and cultural aspects of a particular region. For example, historical water rights were adjusted to provide a fair distribution of water to small and scattered pieces of lands and now this has become problematic and land consolidation is a difficult task.

Farmers collectively decided and agreed that sub-surface piped irrigation system and also land integration scheme are some of the most appropriate irrigation management solutions to increase their water use efficiency and to ensure future sustainability of groundwater resources in the region (see Chapter 7). The game facilitated the explanation of the real rules underlying farmers' attitudes and behaviours regarding preferences for adopting new irrigation technologies and barriers to change. The IMG was particularly designed as a shared platform to evaluate different irrigation policy schemes (such as drip irrigation and sub-surface piped irrigation system) by local users. It was also to uncover the main reasons why farmers in Kashan are reluctant to accept a drip irrigation system for improving their irrigation efficiency.

From the IMG it was concluded that a particular irrigation technology such as a drip irrigation system must be matched to the existing water allocation system and traditional water rights and distribution mechanism. Farmers found the government proposed sub-surface piped irrigation system more adaptable to their water allocation mechanisms and more affordable, thus increasing the efficiency of water use. My research interviews showed that the efficiency measure by local users is defined as an increase in the volume of water that reaches each plot of their lands. This is particularly achievable for farmers through the adoption of sub-surface piped irrigation system that is funded by the government rather than installation of an expensive drip irrigation method (see Chapter 6, 7).

The IMG process has expanded discussions among farmers and has revealed the main causes for conflicts, further reasons for rejecting governmental irrigation schemes, and the incentives for farmers' collective action and decision-making behaviors in irrigation practices. The main motives for farmers to participate in collective action for irrigation efficiency and performance were found to be: fairness in access to water, social capital and ethics within farming society as well as economic incentives for poorer farmers to make rational decisions for their irrigation management. The challenges that were identified through the research interviews included the differences in definition of irrigation efficiency between officials and the local farmers, the difficulties that followed changes in governance regime, such as shifting costs on farmers, promotion of technological solutions without considering the local biophysical and socio-cultural conditions of the irrigation systems. The lack of trust and mutual understanding between farmers and officials seems to be one of the main barriers to improving cooperation (see Chapter 6).

A participatory approach is well suited to the concept of integrated water resource management (IWRM) (see Chapter 2). It is aimed at improving management through effectively engaging stakeholders with different interests into a management process and considering social, economic and technical aspects of management particularly at local level (Voinov and Gaddis, 2008). The interdisciplinary and participatory modeling carried out in this research was able to engage participants in planning, designing and running a simulation exercise for their actual local irrigation practice, providing a rich and valid platform for farmers to join the process. This study has also contributed to my innovative research method of integrating social simulation with a physical model to achieve collective decision-making. The participatory modelling procedure including hydrological modelling gave more complexity to the process and fostered wider discussion around the future sustainability of Kashan's aquifer. The integrated methodology empowered local farmers to reflect on the advantages and disadvantages of their suggested solutions as different scenarios (see Chapters 4, 7). However, it was argued that one of the main challenges of using physical models is that if a model fails to integrate meaningful assumptions or scenarios, the participatory management process may not produce effective management strategies. Thus, my research involved knowledgeable farmers as the main resource users, managers and academic viewpoints to collaborate in the deliberative creation of the model assumptions and also to formulate the most relevant scenarios by local farmers for evaluation and test by the hydrological model at local level. It is important that participants do not assume any of the outputs from the hydrological model or simulation game as a final solution. Instead this process provides collective agreed management options that consider social aspects of governmental policy recommendations. Although there is still a need for more interactive methods to familiarise farmers with the final results of the hydrological model and the future consequences of their short-term decisions, the incorporation of a physical model within social studies was recognized by farmers as a potential and effective method to facilitate the interactions between authorities' and farmers' perspectives and enhance the flow of information from local scale to the managerial level (see Chapter 7).

The second research question is whether the interdisciplinary and participatory methodology approach could lead to improved collective decision-making ability and improved groundwater management and sustainability at a local level. To address this question, I reviewed the major obstacles as well as driving forces for engaging stakeholders in the management process (Chapters 3, 7). Water management in Iran is chiefly under government control and management, thus not much space is left for a more democratic approach and collaborative management. However, the improvement of management decisions at a local level is still possible. My research recommends the introduction of a participatory approach as the main principle of 'good governance' in order to achieve sustainable water management in the future. Building upon theories of common-pool resource management, the use of games in collective resources management and the empirical findings in chapter 4, 6 and 7, I have evaluated how implementing a more participatory and adaptive management procedure in Iran (e.g. developing role-play irrigation game) could be promoted and be effective. Shifting towards adaptive and integrative water management has been encouraged widely as a means for achieving efficient water use (Stakhiv, 2003). This study has the following implications for designing successful adaptive and participatory management protocols. These include: structure, careful formulation of objectives and setting up alternative management scenarios, collection of data and assessment and monitoring the outcome within an iterative process with participants. This study showed that implementation of participatory irrigation management for groundwater resources at a local scale in Iran is possible and introducing an innovative participatory tool revealed the potential in local water users to evaluate the irrigation management policies (see Chapter 7). The challenge of this study was how to integrate different hydrological variables with different stakeholders' perceptions toward groundwater use and irrigation management, to create a shared-agreed conceptual model for all. In this modelling effort local participants were engaged in knowledge provision, developing model and scenario building as well as interpreting the results and suggesting collective-agreed management decisions. The study provided evidence of how participatory research effort could lead to more adaptive and acceptable choices, for example selection of sub-surface piped irrigation method over drip irrigation system in the Kashan region (see Chapters 6, 7), thereby improving water use efficiency, future sustainability of groundwater resources and agricultural productivity for local farmers.

The following improvements in water governance were identified by this research. Firstly, from a managerial perspective, the adoption of a new scheme or project requires that farmers and governmental bodies reach common agreements around alternative solutions that include benefits and profitability for farmers as well as groundwater sustainability. More effective management decisions can be achieved when projects are first designed and introduced at a local level and within a participatory process that includes different farmers' viewpoints, conflicts and motives for collective action. The introduction, implementation and the government financial support mechanism of a new irrigation scheme or system is key and has a crucial impact on farmers' decision-making behaviours regarding whether to adopt or reject the project, as the findings discussed in Chapter 6 of this thesis.

Secondly, a lack of critical evaluation of management projects and governance systems in Iran has resulted in ineffective management strategies and outcomes which are designed in a top-down manner. For example the authoritative approach towards reducing water rights to one-third, without enough investigation and comprehensive evaluation of the local conditions has caused anxiety and dissatisfaction among farmers' communities in Iran specifically in drier parts such as in Kashan. This study tried to address the farmers' problem by empowering their decision-making ability and by ensuring them that their collective action and agreement, when choosing a suitable irrigation scheme, can influence policy decision-makers to impose the most appropriate management option (see Chapter 6).

Thirdly, a lack of integrated approaches in irrigation management decisions and no discernable improvement in agricultural productivity in Iran has led to further disappointments and distrust among farmers towards the effectiveness of governmental projects and even higher economic burden for poorer farmers as a result of reducing their agricultural revenue (see Chapter 6). The lack of trust and mutual understanding between farmers and officials seems to be one of the main barriers for improving cooperation, for example as farmers assume the proposed solutions are brought from abroad. However this study suggested that the inclusion of farmers in the design, planning and action within the participatory modelling process created a sense of ownership and trust in the outcomes and in the final management solutions. Observing the declining trend in groundwater level and storage capacity (which was agreed by farmers) could raise their awareness about the irreversible degradation of the groundwater resources (see Chapter 7). For example discussing the hydrological modeling results with farmers, evaluated their own scenarios, fostered more in-depth discussion and gave educational advantages for farmers. Viewing statistical graphs was a new experience for the farmers. They expressed their knowledge more confidently about declining groundwater and its interaction with surface water and climate change parameters.

This study in brief, aimed to improve local capacity and collective decision-making amongst farmers to move towards adaptive management solutions in the future. Through the interviews, IMG and associated discussions, participants began to see the 'whole picture' emerging from interactions between technical, socio-economic and political issues affecting irrigation management (Dionnet et al., 2008). It can therefore be concluded that introducing new irrigation technologies to improve efficiency needs to match with farmers' own needs, definitions and expectations of efficiency. These needs include; to increase the accessibility of available water to their lands, and to maintain their production level, particularly for small-scale farmers. As part of an analysis of farmers' behavior and the factors affecting their decision-making process, this study has further explored some of the specific factors and reasons for such behaviors. The main reason for farmers' lack of interest to join government projects and thus improve adaptive management in the region is a lack of adaptability of the irrigation management solution offered. These governmental solutions do not take sufficient account of the biophysical, economic, social and cultural aspects of the local irrigation context. Externally imposed rules have consequent social, institutional and political outcomes which can have a significant impact on every farmer's life and on the agricultural industry. Thus the irrigation management game demonstrated the major impact that management decisions relating to the agricultural system can have on farmers' livelihood and agricultural production in general. On the other hand, engaging groundwater users' perspectives and considering their main challenges and difficulties in irrigation management can facilitate introducing a more suitable irrigation technology and improve collective agreement for adoption of governmental policy schemes.

There is also a lack of capacity building programmes to improve farmers' decision-making abilities. In the long-term, this has led to social and financial constraints in terms of economic difficulties for poor farmers to sustain their livelihood. The study emphasised the crucial role of local informal meetings as the main support for integrating locals' knowledge and perspectives into management decisions. Such local institutions which can be established through farmers' meetings at local level (e.g. at a local mosque, where interviews were conducted) promote social capital and empower farmers' decision-making abilities within participatory irrigation management. The research recommends that the participatory modelling process could have further value if farmers' viewpoints or experience can influence the management decisions of local agencies. It could assist officials to introduce technologies or a particular management scheme more adaptable to the local need. The use of game in this study proved to have some insightful outcomes in comparison with conventional participatory methods, as it triggers imagination of game participants thereby, facilitating discussion and revealing farmers' underlying behaviours and attitudes. The study argues that participatory management methods which produce more adaptive management options under uncertainties of complex groundwater resources and irrigation system have the potential to improve governance and management approaches of groundwater irrigation systems. A game can create an experiential learning platform for farmers on their irrigation system and imposing future management scenarios to be evaluated. The IMG visualised irrigation system dynamics and social interactions by giving farmers their actual roles in a game and real rules which added complexity to a simplified board game model, this facilitated farmers interactions, revealed their underlying behaviors and flow of information, which is not achievable in usual interviewing methods. Using an interdisciplinary method and a participatory and bottom-up approach could bring local farmers and their rich knowledge into governmental policy management and plans. This will assist policy makers as well as researchers to better understand farmers' perspectives, their driving forces, obstacles to change, the main motives for policy scheme adoption and also their main challenges at local farming system (discussed in Chapters 6 and 7). This study also recommends that while participatory modeling in natural resource management is widespread globally, there has been limited effort to pursue interdisciplinary methods which combine physical and social science data in order to engage local users into the plan, design and implementation of the project.

To cope with future droughts under increased water demand, there is a need for more innovative and participatory management methods including models of future water use and decline trends. The use of IMG as a novel methodological process under the authoritative governance regime of Iran was a valuable experience that also proved the existence of potential, deep knowledge of farmers and their capacities and motives for evaluating management decisions and to reach well-informed management strategies. It is important that locally-based solutions are integrated and valued in decision-making and irrigation management policies and those are tailored to the local hydro-ecological irrigation context in order that they can eventually improve agricultural water use efficiency and productivity. The common-agreed policies and management options should be developed under suitable institutional settings which empower farmers by engaging them in management processes as key stakeholders.

Appendix 1

Interview Guide: Local Farmers in Kashan and associated Villages

Personal Information:

Serial no:

Sector:

Rural:

Date of Interview:

Interviewee: Gender: Age: Mobile Number:

Name of Farm:

Location of Farm:

Farm establishment date:

General Questions on Occupations, Ownership Status, Cultivation Pattern, Irrigation Methods:

Is agriculture your main job? How many years you are doing agriculture? Do you have any other occupation?

What are your responsibilities/roles in agricultural activities?

Are you satisfied with your income from agriculture?

Are you the main land owner? How large is your farmland area?

If you are sharing your land how many farmers you are working with?

What is your cultivation pattern in different seasons?

What is your irrigation method?

Questions from local Farmers on Water Value and Traditional Irrigation Practices:

How local people value their natural systems? (Their worldview or understanding)

How they value water resources?

How much people believe in ethics and Islamic ethics?

How much they are relied or motivated about considering Islamic ethics in their water consumption behaviour?

How modern allocation schemes affected farmers’ traditional perspectives and behaviours towards agricultural water consumption?

How inappropriate governance in the past affected farmers attitudes towards new governmental water scheme projects?

What are farmer’s perspectives towards reducing agricultural water consumption?

Which factors affected farmers’ behaviours and attitudes towards reducing agricultural water consumption?

What are the most important physical and social factors which will lead drip irrigation method to reduce water abstraction rate?

To what extent increased water use efficiency will improve trust between farmers towards sustainable water management schemes?

How to build trust and effective collaboration between farmers and water stakeholder agencies?

How different governance structures affect individuals' incentives and capabilities to cope with collective-action problems involved in system operation and maintenance?

How diverse combinations of institutions and engineering infrastructures affect irrigation governance, management, and performance?

Compare Agency-managed Irrigation system with Farmers-managed irrigation system with reference to how they affect the intensive structures faced by irrigation officials and farmers on the system?

How incentives affect actions and interactions of officials and farmers that in turn affect irrigation performance.

Social and Cultural Questions: Kashan

What is your current agricultural water condition? Do you see any reasons to reduce/increase your water abstraction?

Do you cooperate/negotiate with any water institutions or water experts? What are their responsibilities? Do you trust them?

What are the most common problems/concerns for farmers in this region?

If in the worst situation your well dry up, which organization you ask for support?

What is your prediction for future agricultural water status for you area?

Will you cooperate in participatory irrigation management for your farmland in the future? When is the best time for you to take part in the meeting? Where?

Have you ever participated in any cooperative or participatory activities for agriculture or irrigation management? If yes, what is your experience?

Would you accept new ideas or methods in agricultural or irrigation practices? Do you use any innovative method for irrigation?

How traditional ethics influenced farmers' preferences about modern system of water allocation?

How modern system of water allocation has affected your agricultural activities and your income?

Are you interested to increase your knowledge about new irrigation systems? Why this is important for you?

What is your preferred ways/organization to receive new information about irrigation management?

Governmental or public sector

Private sector/water experts

Water association

Farmers

What is the main factor for rejecting new irrigation scheme?

Lack of the participatory rules and legislations

Negative previous experiences

Lack of knowledge and awareness

Technical and planning weaknesses

All cases

Which factors would increase/affect your trust in agricultural water schemes?

Irrigation and agricultural Issues:

Would you emphasize on using traditional irrigation systems? To what extend those systems are in use?

What are the advantages or disadvantages of using your irrigation method?

Do you know about using intelligent water meter scheme to control water abstraction rate? What do you think about this scheme?

Would you apply Tooba scheme for your farmland? Which factors affect your decision to accept or reject it?

Do you know farmers who have applied Tooba schemes for their garden? How would they evaluate it?

Have you ever had a successful cultivation? What were the main factors/reasons of this success?

Do you think of changing your cultivation pattern to halophyte crops? (Less water consumption plants?) What do you think about this method?

The most important factor on farmers' participation:

These factors are essential in communities and farmers' cooperation in participatory management, and can assist to motivate farmers' Participation:

Individual/personal factors

The level of knowledge, and accepting risk by farmers (What is the level of your literature? To what extent you would accept risks?

Responsibilities and farmers' capability (What are your responsibilities and your roles in agriculture?)

Individual benefits (How do you benefit from agriculture?)

Ages (What is your age?)

Farmers' land owner status (Do you have your own property right? What is your land ownership status?)

Income (Are you satisfied with your income from agricultural products?)

Work Experience (How many years you are doing agriculture? Do you have any other occupations?

Economic factors

The economic status of farmers and their incomes (What is your economic status/ What is your average income?)

The cost of irrigation and drainage canals (How much irrigation canals or water schemes costs?)

The occupation status and job security in area (What is your job status and security?)

Land Use and Ownership status

1-What is the history of farming in this region and what's the history of this particular farm? What is the farmland size and water provision? Did the farm exist before the modern era of deeper wells and motor pumps?

2-Was the land sub-divided as inheritance? Were the water rights also subdivided in exactly the same way, or were they reallocated or sold in a different way?

3-What's the future of farming in this area? What do you see as the biggest problems or opportunities in the future?

4-How many years have you been living and working in this region?

5-How did you gain your land ownership? Devoted□ Heritage□ Buying□ Rented□ Devoted-heritage□ Heritage-buying □ Rented-devoted□ Heritage-rented□ Devoted-buying□ other ways of obtaining land/water ownership? ....

6-What is your current land ownership status?........ What is the size of your farmland and how many pieces you have?

5-What is your cultivation pattern this year? and what is the size of under cultivation for each crop?

6-How much water do you use? How many hours is your water right?

7-In how many motor pumps (well) you have a share?

8-If you are a Qanat shared user, what is your water right status?

9-Do you have any other occupation apart from agriculture? Is agriculture your main source of income?

To measure the level of farmers' willingness for investment in Agriculture in the future:

10-Have you ever invested in agricultural field? Yes□ No□ Gardening□ type of garden........ Size of garden......... Water store (pool)□ House inside the farm□ Land surfacing□ pipeline□ Machinery□ which types..... Pressure Irrigation□ Canalization□ other investments.......

10-1-How did you fund these investments?

Farm income□ Bank loans□ Both□ other sources............

10-2-Have you invested by yourself or in share? Alone□ Shared□ how many people....

11-Have you ever invested in Husbandry? No□ Yes□ Number of domestics........... Establishing stable□

11-1-How did you fund it? Was it shared or an individual investment?

Farm income□ Bank loan□ Both□ other............

12-If one day you pass away how would you predict the future of your land in heritage process? (For example all your kids will sell the land, or one of them buys it from the rest or rent it, etc....)

13-Do you want your children to continue your job? If your answer is no, why?

Very much□ Very□ to some extend□ not very□ too little□

13-1-How much your children would like to continue your job?

Very much□ very□ to some extend□ not very□ too little□

14-If you gain any fund, what would be your first option to invest or spend the money for yourself or your children for a better future?

15-What are the agricultural activities that require investments?

15-1-What are the investment can be done by the government to solve your water problems?

16-Do you think for solving agricultural water problem such as reduction in water well, manure provision or marketing for a specific crop, what are the best strategies to be used?

17-Is any of the following problem has occurred for your pump or your well?

Decrease water level Yes□ No□ Make the well deeper Yes□ No□ Transferring wells' location yes□ No□ Changing pipes and motor pumps Yes□ No□

17-1-How did you cope with your particular water related problem?

Hydro-ecological characteristics of the region

18-How rainfall pattern has been changed within recent decades in your region?

19-Do you have a soil salinity problem? Yes□ No□

19-1-If yes, to what extend it has affected your cultivation?

Very much□ very□ to some extend□ not very□ too little□

19-2-How would you combat soil salinity? Which methods are you using to remove salinity from your lands? Or which kind of crops are you cultivating that are tolerance to salinity?

Questions relate to access to groundwater and social inequity

1. Are there any informal arrangements organised by small-scale farmers for accessing to groundwater? Why do they need this, and what is their approach?

2. Do you think access to groundwater is equal between small-scale and large-scale farmers? How land integration can improve farmers' access to water and improve irrigation efficiency?

2.1. If there is an unequal access to groundwater, how has this affected small-scale farmer? How farmers overcame this differentiation?

2.2. Which factors do you believe influenced farmers' access to groundwater? Do farmers think that access to groundwater is related to financial capabilities?

2.3. How much land ownership status (small or large scale, assignees or tenant) has affected social inequity in terms of accessing groundwater and irrigation distribution systems?

2.4. How farmers have secured their access to water resources? Which obstacles exist against their water security?

3. How forestation (plantation) scheme by natural resources department, has affected groundwater level and soil condition in your region?

4.1. Are there any ethical (religion) or traditional norms that affected farmers' preferences in adapting or rejecting the new water restrictions? (and changes in water right system?)

5. Do farmers have a sense of ownership over aquifers? To whom they believe groundwater belongs?

5.1. What are farmers' main reasons for rejecting groundwater restrictions, if they believe that groundwater control is the government responsibility?

6. Is there any (higher) fee charge for large-scale farmers for over-abstraction?

7. What is the mechanism of the (public) lands property rights, operated by assignees or tenants? Who are assignees and tenants and why they rent their lands?

7.1. Are the lands public? Does any new arrival (non-farmers) can buy or rent a land here and obtain water right?

8. Howdid you obtain your land ownership?

(Devoted□ Heritage□ Buy□ Rent□ Devoted-heritage□ Heritage-buying□ Rented-devoted□ Heritage-rented□ Devoted-buying□)

Questions related to incentives for collective action

9. What is the subsidization mechanism in the region?

10. Why do you think the government has removed electricity subsidize from pumps? Did it make conflict between farmers and officials?

11. How much external event such as drought has incentivized collective action among farmers and on their cooperation?

Understanding farmers strategies toward groundwater use

12. How much farmers believe that surface irrigation (flood irrigation) systems will lead to increase groundwater recharge rate?

12.1. How do you think water inflows and outflows into the groundwater in this basin?

13. Are farmers willing to increase their production level or they want to maintain the same production level? How it differs about large-scale farmers?

13.1. How groundwater development resulted in your socioeconomic transition? How much pump technology brought economic and social welfare for you?

14. What are the short-term strategies to cope with scarcity and salinity? What are the long-term policies to cope with this problem? What are the conflicting issues?

15. Do you concern about the volume of water you use for farming? How much protection of groundwater is important for you? Which organisation or body should be responsible or make decisions about this?

(Islamic Form□ Each farmer□A society of all motor pump owners□ Old and reliableleader□A governmental organisation such as Irrigation management agency□)

16. Which activities are overtaken by the government to cope or assist farmers with water crisis situation? What is their support for farmers in uneven climatic situation?(e.g. hailstone)

17. Have you ever requested to obtain insurance through your cooperatives?

Appendix 2

Interview Guide: Governmental Organizations in Kashan

Personal Information Name, Age, Occupation, Size of land, Land and water ownership status, Type of irrigation infrastructures,

General Questions: Water and Climate Changes in the Region

Which organizations are involved in addressing key issues and problems related to impacts of Climate change/ water resources problems?

What are the policy or strategy documents to guide their work?

What are the activities related to adaptation?

What are the strengths and weaknesses of the institutions?

How people have access to information on current and future water problems?

What livelihood or economic sectors are the most vulnerable to climate change impacts (water shortage problems?)

Local water organizations:

How water is used? In which economic sectors?

Who is entitled to it?

How it is managed?

The size and technology of new projects?

The role of the public in water management? The role of the equity in water treatments and distribution?

Questions related to incentives for collective action

9. What is the subsidization mechanism in the region?

9.1. Does government pay compensation for reducing water entitlements? Is an entitlement reduction has be adjusted in favour of irrigators who are active users and non-active users?

10. Why do you think the government has removed electricity subsidize from pumps? Did it make conflict between farmers and officials?

11. How much external event such as drought has incentivized collective action among farmers and on their cooperation?

Appendix 3

Two General Types of Farmers in Local Farming Villages of Kashan District (Iran)

Large-scale Farmers	**Small-scale Farmers**
-Private pumps owners -Integrated lands/Individual land properties -Drip Irrigation -Capital (to bring more water into their farms) -High valued crops (for national market) -Interested in more investment for the higher productivity / expanding cultivation areas -Higher income **Offensive/Chasing Strategies:** -Individual Access to groundwater -Water-intensive farming -Less responsible towards sustainable management (do not adapt their water use to groundwater stress level) -Less cooperative in collective actions -Applying Less adaptive strategies (drilling deeper wells, renting land with more available water, organizing partnership with farmers who own wells) -Well-connected to Gov. officials -Access to loans and Gov. equipment -Better accessed to water resources, through purchasing more lands and their entitled water rights	-Collective pumps owners -Collective/Shared lands Canal or flood irrigation methods -Limited capital -Less valued crops and seasonal (short-duration) crops (to maintain livelihood) -Interested in water-saving mechanisms and maintaining current production level -Low income **Defensive/Adaptive Strategies:** -Collective access to groundwater -More responsible towards sustainable management (adapt their water use to groundwater status) -Highly co-operative in collective activities -More adaptive strategies (adapting farming to available water, cultivating less water demand crops, change sowing dates, land preparation, improving irrigation distribution systems) -Weak connections to Gov. agencies -Very difficult access to Governmental loans -More restricted access to groundwater, as it takes long time to negotiate on costs and drill deeper well due to financial difficulties

Source: Author, 2014 (Adapted idea from Bekkar et al., 2009)

Appendix 4

Farmers' Classification Based on Statistic Centre of Iran (1993)

Capitalist Farmers: individuals or institutions who own the farm. They produce crops for national and international markets. To reduce labour and other farming costs they produce high valued crops and use intensive cultivation (e.g. pistachio, cotton, sugar beet) and they usually pay wages to the work-force labours. This group of farmers are previous landlords during feudalism and before land reform in Iran.

Independent farmers (peasant): this group owns the land, water and farming tools. They rely on family members as labour, but production is not merely for their own consumption (livelihoods), they offer part of their cultivation to the local market (bazaar). Due to land heritage and consequently fragmentation of their lands they are under economic pressures. These groups of farmers are classified under three levels: low class, intermediate and upper classes. The medium and low classes are faced with scattered and small-scale lands problems. (This group were workers during feudalism system, and they were working for the rural landlords on the large pieces of lands)

Landowners: Generally are residents in cities, based on the size of their lands are divided into three groups of small-scale, medium-scale and large-scale. Farming is their second job and their aim of farming is to improve their economic status.

Appendix 5

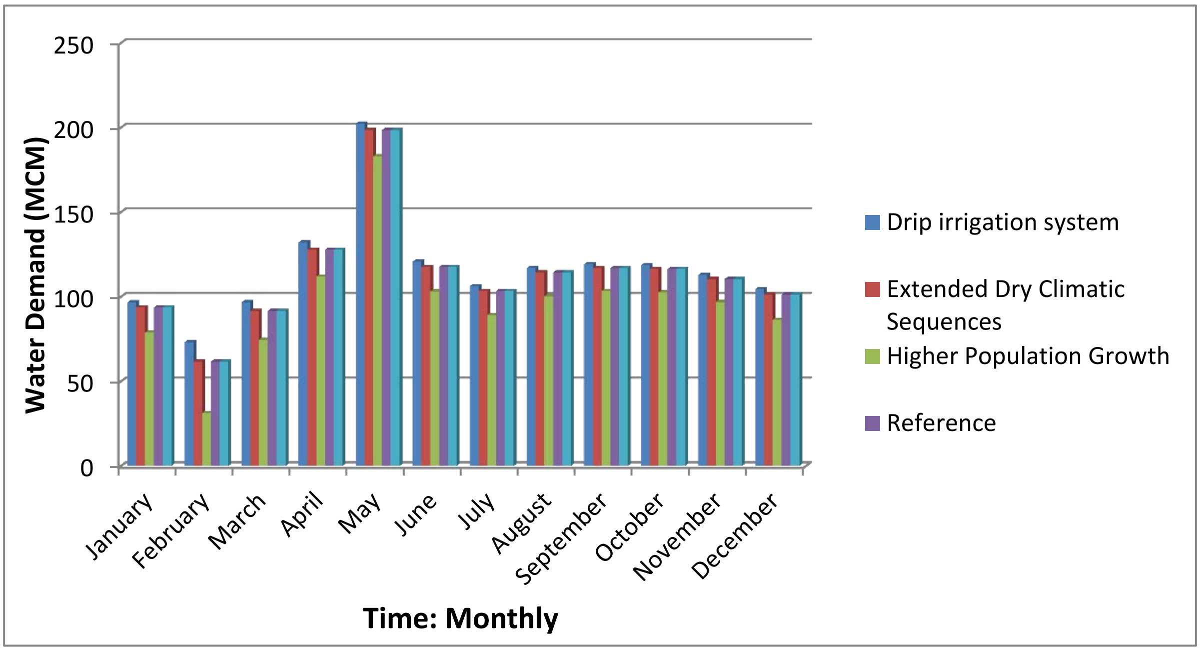
Kashan Aquifer Water Balance

Recharge Factors	Million Cubic Metres	Discharge Factors	Million Cubic Metre
Infiltration of Rainfall in Plain	22	Groundwater Abstraction	283
Infiltration of streams, and runoffs	35	Qanat and Spring Extraction	9
Infiltration from Irrigation	73		
Infiltration from swage	27		
Groundwater Inflow rate?	139		
Total	157	Total	292
Changes in groundwater storage	-135		

Source: Regional Water Resources Management of Kashan (2011)

Appendix 6

Water Demand for Agriculture under different Scenarios



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