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Behavior Analysis and Modeling of Stakeholders in Integrated Water Resource Management with a Focus on Irrigated Agriculture:

A Case Study for an Agricultural Coastal Region in Oman

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A Case Study for an Agricultural Coastal Region in Oman

DISSERTATION

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Die Übereinstimmung dieses Exemplars mit dem Original der Dissertation zum Thema:

„Behavior Analysis and Modeling of Stakeholders in Integrated Water Resource Management with a Focus on Irrigated Agriculture:
A Case Study for an Agricultural Coastal Region in Oman“

wird hiermit bestätigt.

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Ort, Datum

....

Unterschrift

“All good decision processes are social processes.”

Prof. Dr. Thomas Dietz

A member of the Steering Committee of the Standing Group on International Relations (SGIR) of the European Consortium for Political Research (ECPR)

“The problem is reflected in how we manage water resources currently available, and whether we think of ourselves as a society globally have the political and the right to support the policies and invest in programs that protect the natural environment around us, and preserve water resources, and seek to use less of them to achieve the best results.”

Jacques Diouf

The Director-General of the Food and Agriculture Organization (FAO)

Acknowledgments

This thesis is reflecting efforts of five years of work and research. It intends to explain the dilemma of limitation in successes of the already applied solutions for the salt water intrusion occurring in the agricultural coastal region in northern Oman, with respect to the behavior of the stakeholders. It outlines how integrated water resource management can encompass social issues.

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Abstract

The scarcity of freshwater resources in the Sultanate of Oman, makes it essential that both surface and groundwater resources are carefully managed. Introducing new water demand management tools is important, especially for the coastal agricultural areas (e. g. Al Batinah coastal region) which are affected by sea water intrusion. Based on a social survey performed during this work, the existing situation generates conflicts between different stakeholders (SHs) which have different interests regarding water availability, sustainable aquifer management, and profitable agricultural production. The current aim is to evaluate the implementation potential of several management interventions and their combinations by analysing opinions and responses of the relevant stakeholders in the region. Influencing the behavior and drivers affecting farmers' decision-making manner, can be a valuable tool to improve water demand management. The work also introduces the use of a participatory process within the frame of an integrated water resources management (IWRM) to support decision makers in taking better informed decisions. Data were collected by questionnaires from different groups of stakeholders. These data were analysed statistically for each group separately as well as relations amongst groups by using the SPSS (Statistical Package for Social Science) software package. Differences were examined between opinions of farmers and decision makers (DM's) regarding potential interventions. Farmers' frequency curves showed differences in opinions in some interventions, while differences in opinions were not so high within the group of DM's. Therefore, Cross Tabulation and Discriminant Analysis (DA) were performed to identify the drivers influencing farmers' opinions regarding the intervention measures. As an advanced step, a Bayesian Networks (BNs) approach is used for mapping stakeholders' behaviors and to show the strength of a relationship between dependent and predictor variables. By using BNs it is possible to analyse future scenarios for implementation and acceptance of interventions.

Key words: Stakeholders, Participatory process, Bayesian Networks, IWRM, Oman

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Symbols

CCA	Canonical Correlation Analysis
cm	Centimeter
fd	Feddan (1 feddan = 0.405 Hectares)
ha	Hectares
H_0	Null hypothesis
H_1	Alternative hypothesis
Mm3/Yr	Million cubic meters per year
μ_0	Mean
µS	Microsiemens
n	Sample size
p	p- Value
$	US Dollars
TDS	Total Dissolved solids
$\bar{X}$	Sample mean
σ	Standard deviation
α	Level of significance
2Φ	2-tailed Hypothesis test

Abbreviations

APPM	Assessment, Prognosis, Planning and Management-Tool
BN	Bayesian Networks
CPT	Conditional Probability Table
DA	Discriminant Analysis
DG	Director General
DM's	Decision Makers
DPSIR	Drivers Pressures State Impacts Responses
DSR	Driving force–State–Response
DSS	Decision Support System
DV	Dependent Variables
EEA	European Environment Agency
EIA	Environment Impact Assessment study
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nation

GDP	Gross Domestic Product
GeNIe	Graphical Network Interface
GWP	Global Water Partnership
IV	Independent Variables
IWM	Integrated Water Management
IWRM	Integrated Water Resource Management
MAF	Ministry of Agriculture and Fisheries
MCDA	Multiple Criteria Decision Analysis
MECA	Ministry of Environment and Climatological Affairs
MOH	Ministry of Health
MRMEWR	Ministry of Regional Municipalities, Environment and Water Resources, (former Ministry)
MRMWR	Ministry of Regional Municipalities and Water Resources
MWR	Ministry of Water Resources (former Ministry)
NENA	Near East and North Africa
NCSI	National Center for Statistics & Information - Oman
NWIP	National Well Inventory Project (carried out in Oman, 1992-1995)
OECD	Organization for Economic Co-operation and Development
OOBN’s	Object-Oriented Bayesian Networks
OR	Omani Reals
PAEW	Public Authority of Electricity and Water
PSR	Pressure–State–Response
SD	Standard Deviation
SH’s	Stakeholders
SPSS	Statistical Package for Social Science
UAE	United Arab Emirates
UN	United Nation
UNEP	United Nation Environment Program
USAID	United States Agency for International Development
WQ	Water Quality
WRM	Water Resources Management

1 Introduction

1.1 Motivation

Water is the most valuable resource on the planet, and natural water systems are essential for life sustainability. They have a major role in shaping the life activities and determining locations of communities. However, the management of water systems is facing major challenges due to increasing uncertainties caused by climate and global change and by rapid changing socio-economic conditions (Pahl-Wostl, 2007). In history, water management worldwide has mainly focused on solutions of increasing water supply to solve the problems of water shortage. Currently, such type of solutions, alone, is not recommended anymore, especially that most of the accessible water resources have been already utilized. For this, a need of a shift in the management of water resources is essential.

Water scarcity also results from the uneven spatial and temporal distribution of water on earth (Oelkers et al, 2011). In arid and semi-arid regions, sustainability of water use is one of the most current and future challenging issue (GWP, 2000). The reason is that the rainfall amounts are very limited and the evapotranspiration (ET) is considered to be very high. On the other hand, water demand is increasing with the fast growing in population, urbanization and food production. In these regions, the agricultural sector uses more than 90% of the available water resources (UN Water, 2012). Furthermore, the comprehensive development in economic activities exerting pressure on available water resources which led to decreases in water availability. In addition to that, degradation of water quality and pollution problems in water resources in arid regions are more common compared to areas with higher rainfall amounts. In these regions, groundwater is the main source of fresh water, for meeting both; domestic and irrigation demands, and considered to be a common pool resource (Akkad, 1989).

Water use has been growing at more than twice the rate of population increase in the last century (FAO, 2016a). The following statement by FAO, act as a warning bell, about how future situation will be exacerbated.

"By 2025, 1 800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions" (FAO, 2016a).

According to United Nations Environment Program (UNEP, 2002) and the European Environment Agency (EEA, 2005) there is a continuing concern about shortages in freshwater availability. The imbalance between water availability and water demand causes water scarcity, which is one of the most pressing issues in the world now (Jeffrey et al., 2008).

As well, UNEP underlined that two out of every three people, in the world, would live in water-stressed areas by the year 2025 (UNEP/GRID-Arendal, 2008).

Most of the fresh water in the world occur as groundwater in aquifers (Oelkers et al., 2011), and society relies on it to meet their requirements. As common pool resources, a number of users are pumping from the same aquifer and the abstraction rates exceed the recharge rates. As a result, water conflicts might arise among users in the communities (FAO, 2016a). The reason is being the water management is associated with multiple component and conflicting needs. All this makes the need for sustainable and smart water management strategies becoming more and more important to meet future water demands (Montanari et al., 2013). The conservation of water resources in arid regions should therefore be based on the best management practices, including the optimal use of all the institutional, technical, economic, environmental and social opportunities available to water managers (Akkad, 1989).

The call for an appropriate water management is more critical for these regions, where water scarcity is acute. One of the effective solutions could be oriented toward reducing excessive demands. According to the African Development Bank (2000), the demand responsive approach is considered to be a key ingredient for the successful development of water resources. In spite of that all, for a sustainable water management, a shift to an integration of different sectors is needed and it should take into account the environmental, social and economic factors.

In the last few decades, the idea of Integrated Water Resource Management (IWRM) has gained a wide acceptance in many parts of the world. It is considered to be the best solution to achieve sustainable development, allocation and monitoring of water resources through the development of comprehensive strategies and plans especially in arid and semi-arid regions. However, the feasibility of implementing IWRM is still a great challenge worldwide. One issue among the challenges, is being what meant by integration is ambiguous. There is a need for a common understanding for those who are involved about what is meant by IWRM (GWP, 2000).

The IWRM is defined as:

"A process which promotes the co-ordinated 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" (GWP, 2000).

Based on “Dublin-Rio” principles and Ibisch (2016), the IWRM principles are summarized in three elements:

(i) The integration of different sectors and different uses and users of water,

(ii) The balancing of three pillars—economic, social and environmental sustainability and

(iii) The participation of stakeholders in decision-making and the strengthening of the role of women

Among all features of integration, stakeholders participation is a key issue of the integration processes, this was underlined by many researchers (e.g. Mostert, 2003; Pahl-Wostl, 2007; Özerol & Newig, 2008).

This is consistent with the importance of that; a successful water management process has to be participatory. Allowing the stakeholders working together to set criteria for sustainable management, to identify priorities and constraints, to evaluate possible solutions, to recommend technologies and policies, and, finally, to monitor and evaluate any possible impact (Giordano et al., 2004).

1.2 Regional Background

This thesis is focusing on a real management problem of a coastal agricultural area in a part of South Al Batinah region in the northern Oman. The Sultanate of Oman is an arid country and relies on groundwater as a source of fresh water, typically in shallow alluvial unconfined aquifers (Stoery, 1995). In the last three decades, there was a noticeable increase of water abstracted compared to the annual recharge of the coastal aquifer system in the Al Batinah region. Therefore, the region is facing a problem of water deficit which also impacts the sustainable development of the agriculture. Agriculture is the main consumer of groundwater, around 53%, of total cultivated areas in the country, is concentrated in Al Batinah (MAF, 2005). Mainly because this region is characterised of more fertile soils and easier access to water, in the form of groundwater, compared to other administrative areas in the country. The wells’ owners pump as much groundwater as they want, from the main aquifer along the coast, without any restriction (Al-Shaqsi, 2004). As a result, the groundwater abstraction exceeds the rate of recharge and leads to decrease in groundwater levels. This enforces the inflow of sea water into the coastal aquifer and causes salinization of the groundwater. The use of saline groundwater for irrigation yield to salinization of soils, which impacts the social and economic situation of farmers as well as the environment. The agriculture is continuously deteriorating and many farms are abandoned.

This is a typical example of a social dilemma (common-pool resources dilemma). The groundwater aquifer is a common source for the farmers to irrigate their farms but farmers are only focusing on their individual profit and immediate satisfaction rather than behave in larger societal best or long-term interests. Furthermore, the water resources management strategies are not considered. In such cases, of these shared resources, the existing situation may generate conflicts (Akkad, 1989) between different stakeholders regarding water availability and profitable agricultural production.

Several interventions (e.g. construction of groundwater recharge dams, a ban on construction of new wells without permission, etc.) are practiced by the government to maintain the groundwater aquifer. However, the situation is getting worse and may require more effective management interventions which may range between the extremes of stopping all agriculture activities to recover the local aquifer system, and producing as much as possible as long as water and soil are available (Subagadis el al., 2014).

According to Zekri (2008), controlling the groundwater pumping rates in the region is possible and profitable, by making more efforts on maximizing the likelihood of choosing and implementing successful management options. In fact, solutions should be through the ability to adopt a better management to achieve beneficial use for the available water.

For Al Batinah there are many studies and papers (e.g. Walther 2014 ; Gerner el al, 2012; Grundmann el al., 2012; Kacimov, 2006; Al- Shoukri, 2008; Schütze el al., 2012) investigating the physical and bio-physical processes and relationships of the system. On the other hand, the studies which investigated the situation (problem) taking into account the socio-economic consideration and the role of stakeholders' behaviors are very limited. One of them is the research done by Al Shaqsi (2004). The study indicated that there is a gap in controlling the rates of abstraction for irrigation purposes and there is no enforcement of schemes designed to encourage the use of water saver appliances or rules in houses or in agriculture.

Another study was an analytical study of the socio-economic factors, which was performed by Zekri (2008), he analysed the relative merits of strategies to control groundwater pumping based on water quotas, electricity quotas and electricity pricing.

Based on the above findings, the questions of interest, for this work, were formed as follow:

1. Why the previous interventions applied to control the salinity problem in Al Batinah, were not fully succeeded and the impact was very limited?

2. How do stakeholders think about agriculture and salinity problem in South Al Batinah, and how will they behave in the light of different management intervention?
3. Can we quantify human behaviors and thinking?
4. What can be done to improve the implementation potential of a specific intervention? Or what can be done to improve the probability of an intervention to be implemented?
5. What are the benefits gained from statistical models? Can we reproduce and forecast human behaviors by models?

1.3 Objectives and Structure of the Thesis

The study performed by Zekri (2008) was mostly from the economic point of view, while the study performed by Al Shaqsi (2004) was from the social point of view. However, these studies are considered to be old ones, since more than 10 years have passed. Therefore, new evaluation studies are needed to investigate if there are any improvements or changes in the system. The aim of the research is to evaluate the implementation potential of several management interventions and their combinations by analyzing behaviors and opinions together with the responses of relevant stakeholders in the study region. The work also aims to introduce the use of a participatory process within the frame of an integrated water resources management (IWRM) to support decision makers in taking more informed decisions.

In order to achieve these objectives, the scope of the research is summarized in six sub-objectives:

- Define the criteria and indicators, in order to evaluate the quality of the different management options, and identify potential conflicts which might occur among the different stakeholders.
- Identify if there is enough knowledge about the behavior of the relevant stakeholders. This part includes analysis of knowledge of both:

  If the decision makers have enough knowledge about farmers' ways of thinking, behaviors and requirements, and if the farmers have enough knowledge about how natural systems are working, the water problems in the region and suitable management interventions for the water resources.

- Explain the dilemma with respect to the behaviors of the stakeholders, and identify if the participatory approach is accepted or rejected by the involved stakeholders.

- Evaluate the implementation potential of several management interventions by analysing opinions and responses of the relevant stakeholders.
- Identify what could be done to improve the probability of a specific intervention to be implemented, and identify with what factor this intervention is more likely to be implemented.
- Identify if model approaches can be used to predict future scenarios in a changing environment.

To support the technical implementation of this analysis, this study proposes a methodology which combines models for social sources, statistics and soft computing within the application to a coastal agricultural-groundwater system. The thesis is intended to improve and raise the level of communications in both directions, among relevant decision makers and between decision makers and farmers. It focuses on analysing of stakeholders' (farmers and decision makers) behaviors and opinions regarding several management interventions aiming at water demand and water resources management as well as the understanding of decision makers on how farmers will behave.

The thesis is presented in seven chapters. The **first chapter** is focusing on the topic of the research and gives an overview of the study area and the problem definition.

Chapter two is about the state of the art in this particular field and the relevant literature published which are related to the topic. It starts with addressing the limitation of natural resources and the consequences of that on human and nature, the interaction between nature and society, the importance of IWRM and the decision support for stakeholders in water management. At the end it explains, in general, the connection of previous studies and the existing literature to this particular work.

Chapter three is focusing on water resources management in the Sultanate of Oman. It gives an overview of the water situation in Oman in general and the study area in particular. This chapter also addresses what has been achieved so far to conserve water in the region. It is also describing the importance of the agriculture for the country and the behaviors of farmers in Al Batinah region. Furthermore, it addresses the water issue organizations and government structure in Oman.

Chapter four deals with the methodology used for collecting and analysing data and information. It describes in details the research methods and how they are implemented. It starts with an explanation of the steps of the methodology framework, and why those steps are considered to be important. Then, it is focusing on the details of the data collection procedure and the different data analysis methods. The chapter ends with an explanation of the modeling approaches introduced in this particular work for the purpose of mapping the stakeholders' behaviours regarding implementing management intervention options.

Chapter five presents the results. It starts with an overview of the field survey performed for the study and the results obtained about the current situation of the agriculture and water management of the study area. The chapter also discusses the results obtained from the analysis of ideas and opinions of the different relevant stakeholders. It goes on to the evaluation of the implementation potential of the intervention measures. It also spots the light on the conflicts in opinions within the same group (farmers' group) and what might be the drivers behind farmers' opinions. The chapter also including an analysis of the visions of different groups regarding intervention methods, their visions about the participatory approach, and future management practices. It ends with a modeling analysis of the information gained from statistical approaches and validation of the methodological framework.

Chapter six assesses the relevance of the research work to foster a participatory process within the framework of an Integrated Resources Management for supporting decision makers.

Chapter seven succinctly summarizes the main findings and suggestions for future research in this field.

2 Literature Review

Development plans are important for every community in order to sustain life in the community, but with the passage of time it becomes clear that development influence the quality and quantity of environmental resources. Increasing population, agricultural development and industrial development have poses a great threat on natural resources. According to Vlek and Steg (2007), five general driving forces of global environmental change are distinguished: population, affluence, technology, institutions, and culture. They also argues that these are considered in view of critical transitions in the evolution of human society (Vlek & Steg, 2007). Human play an important role in interrupting natural systems in order to meet their requirements. Moreover, some organizations adopt environmental management practices that go beyond regulatory compliance (Delmas & Toffel, 2004). Many resources are subjected to depletion due misuse and wrong management decisions.

Making a decision is not an easy task; it is a difficult process which needs a lot of efforts, resulting in the selection of a course of action among several alternative scenarios. Jim (Nightingale, 2007), Author of *Think Smart-Act Smart*, states that:

"*We simply decide without thinking much about the decision process*".

Actually, this depends on how important is the decision to be taken. In the evaluation of a natural system, decision making process is a challenge and requires a combination of environmental, political, social and economic data.

In the field of water resources management, decision is surrounded by multiple actors (Simonovic & Fahmy, 1999), with contradicting interests and visions about the potential management options. In addition to that, the number of alternatives might be very high and the selection of a suitable one with the satisfaction of most of the stakeholders needs compromises. Therefore, a sustainable water resources management (WRM) is essential, to ensures the integration of social, economic, and environmental issues into all stages of water resources management (Sun et al., 2016). This should be done with the consideration of the associated uncertainties. Figure 1 describes an example of the complexity of a hydro-system and the challenge of water resources management.

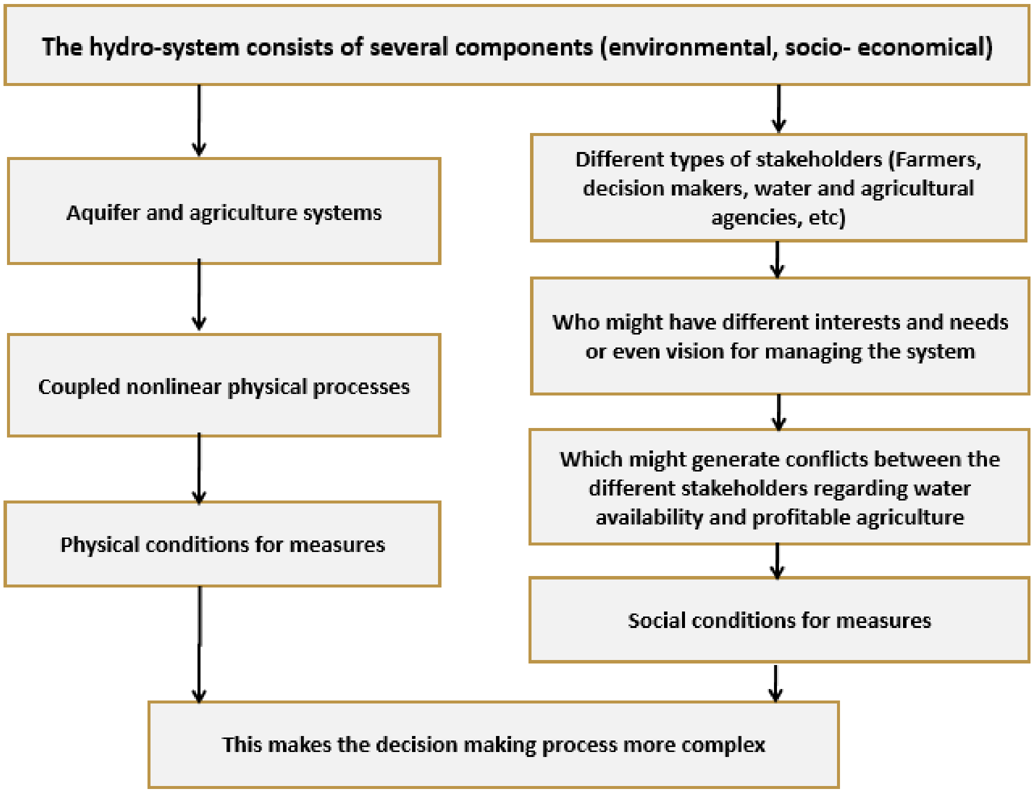


Figure 1: The complexity of a Hydro-system and the challenge of water resources management

In general, water resources managers face a challenge to find quantitative tools for evaluating the consequences of their management interventions (Subagadis et al., 2014). Challenges are getting more serious by both; inefficient governance and increased competition for the finite resource (GWP, 2000). The competition for water in areas with high demands causes conflicts of interests among various water actors with mostly contradicting objectives (Subagadis et al., 2014). The challenges are even unique with uncertainty about the consequences of potential management interventions (Pahl-Wostl, 2007). In this regard, Pahl-Wostl (2007) addressed that: "*It has become increasingly clear that the pressing problems in this field have to be tackled from an integrated perspective taking into account environmental, human and technological factors and in particular their interdependence".*

For a decision process (in areas with high demand) to succeed, an integrated water resources management (IWRM) approach is recommended. This should allow the assessing of different management policies and interventions. Moreover, it should include the application of a participatory approach which allows the participation of the relevant stakeholders in a system. The environmental decision makers need to be supported with a reliable decision support system (DSS) to help them take better informed decisions.

Subagadis (2015), argued that management interventions for a problem in only one part of a water system might lead to the emergence of another problem somewhere else in the system. This gives an indication that the feasibility of implementing IWRM is a great challenge. What would work to solve the complex problems is an improved management of these valuable natural resources (Oelkers et al., 2011).

Solutions should be studied very well, in order to avoid implementing an option which might start well but after some time a movement to another one is needed. In addition to that, natural conditions and the behavior of humans differ from one country to another and what suits a community may not suit another. Therefore, implementing approaches must take into account such variations. Such approaches should be able to structure multiple conflicting aspects and set individual’s views into context, and allow supporting decision makers to identify the best management strategy with a best chance to be implemented.

Talking about taking into account the complexity of water systems and the increase in their uncertainty, Pahl-Wostl (2007) called for a need of radical changes in water management:

– To *move from technical management to a true integration of the human dimension*, and

– To *make management more adaptive and flexible to make it operational under fast changing socio-economic boundary conditions and climate change.*

Which means there is a great need to move towards a real IWRM, taking into consideration the importance of involving stakeholders in the management processes.

In many countries Decision Makers (DMs) are responsible for the development process and the long-term planning to improve the quality of life and to maintain the resources for future generations. Moreover, responsible institutions, in many countries, act independently from one another (Vlek & Steg, 2007) and water resources management is usually left to top-down institutions (GWP, 2000). Governments and decision makers should believe that it is important to involve stakeholders in management processes. This should be done through approaches which are able to assist individuals and groups in representing and communicating their own perspectives (Giordano et al., 2004).

In history, there are so many projects in many countries have failed due to the neglect of stakeholders participation and involvement (World Bank, 1993). Regarding water resource management, Oelkers (2011) argued that past failures in the management of water supply and water resources have resulted in environmental damage, pollution of major surface water bodies, and human suffering. In one of the FAO reports (Hot issues: Water scarcity, 2016) it was stated clearly that:

"*As population increases and developmental calls for increased allocations of groundwater and surface water for the domestic, agriculture and industrial sectors, the pressure on water resources intensifies, leading to tensions, conflicts among users, and excessive pressure on the environment*" (FAO, 2016a).

Separating the society from environment aspects is no longer recommended as well as being only Decision Makers (DM's) are responsible for the development process.

Velk and Steg (2007) stated that many environmental problems basically are social and behavioral problems, especially in the form of failure of human decision making. In this regard, Matthies (2007) pointed out that environmental and natural resources managers and decision makers need models which help them to understand the effectiveness of alternative management decisions. Models are required together with decision support tools for a more efficient decision making processes in implementation of IWRM (Ticehurst et al., 2011). Decision Support models, which can facilitate the exchange of information concerning a particular problem in water management among different community members, are really important. They are employed to assist in evaluating alternatives in order to avoid future problems and consider likely learning opportunities from the decisions (Subagadis, 2015).

In this regard, many decision systems are built to help users to understand uncertainty issues in water resources. Decision support systems (DSS) are computer technology solutions that can be used to support complex decision making and problem solving (Shim et al., 2002). Such systems are designed to be used mainly by government agents (Silvert, 2010). They should be able to support decision makers in discussion, collaboration and help them to structure the problems and learn more about possible alternatives.

Silvert (2010) also argued, that the DSS for managing natural systems should be understood and accepted by all relevant stakeholders and not only limited to be used by managers and trained specialists. Moreover, it should contribute and lead to greater trust in the decision-making process. Therefore, the awareness of the stakeholders in sharing the decision process is important. This is even true with the primary stakeholders (e.g. water users). They should be ready and interested to be a part of the decision making process.

2.1 Participatory Approaches – Stakeholders into Support Tools for Decision Making in IWRM

Introducing new principles in the development of management plans for natural systems is a great challenge. In water resources management, increasing interest is posed to the stakeholder's participation (Giordano et al., 2004). The report of the conference of water and environment, held in Dublin (1992), stated clearly that "*Water development and management should be based on participatory approach, involving users, planners and policy makers at all levels*". This was one of the key guiding principles which have played a central role in IWRM (UN, 2005).

Regarding maintaining groundwater aquifers, Zekri (2008) argued that the establishment and implementation of law and regulations to improve groundwater management require the consensus of all the relevant stakeholders. Therefore participation of stakeholders is needed in many steps in water management.

In evaluating management options, it is useful to collect ideas and opinions of the relevant stakeholders in order to support the management process. For example; in evaluating the demand, users should be asked about their needs and amounts of water required to irrigate their farms and why do they need such amounts. This gives an indication of their opinions and their understanding of the water problems. On the other hand, the situation can be contradicting if stakeholders are not integrated into the management of evaluating the outcomes of the proposed options.

2.1.1 How Society can be involved

Participation of the relevant Stakeholders in a management plan is known as a participatory approach or a participatory process. A participatory process is a two-way communication process that explicitly seeks to identify and to clarify the interests at stake, with the ultimate aim of producing a well-informed water management strategy that has a good chance of being implemented (FAO, 2016b). A participatory process in water management was established by the European Community Water Framework, which strongly encourages the active involvement of all the affected parties in the resource management (Pahl-Wostl & Ebenhöh, 2004). This can be done by developing indicators and criteria to determine which option(s) is sufficient and/or efficient (to be implemented).

Society is described as a group of people who share similar values, laws and traditions living in organized communities for mutual benefits. Members of a society often share religions, politics or culture.

Stakeholders can be organizations or decision makers who deliver policies, projects and services to users. Stakeholders can also be individuals who have direct interest in the resource. According to Delmas and Toffel (2004) stakeholders can be including government agents, regulators, customers, competitors, community, environmental interest groups, and industry associations. In some literature the individuals are identified as primary stakeholders. Organizations and decision makers are identified as intermediaries or secondary stakeholders.

The participatory process can take place in many different forms, providing many options for users' participation in decision making process. For example, involvement can be through meetings and discussions, experiments or pilot projects, online questionnaires, etc. Rating is also a good tool, used with stakeholders, in evaluating if the intervention is accepted or not.

For the stakeholders to be integrated into the decision making process, at a step, there is a need to use models. The process can't just be carried out by thinking together during meetings and discussions. In addition, this can be done with the conjunction of using experiments or pilot projects from nature to support the evaluation process and examine how a particular option works.

Moreover, it has to be taken into account that the management option which suits many relevant stakeholders might not be the best in the scientific point of view. In this content Dietz (2003) argues that the decision which satisfies the majority of stakeholders and has functional outcomes, is regarded as a good decision, especially if it reached through a participatory process.

2.1.2 Advantages of the Participatory Approach

Although it is a very complex procedure to involve all related stakeholders in a decision making process, it is also essential. Based on many publications (see for example Pahl-Wostl, 2007; Ticehurst, et al., 2011; Ibnouf & Abdel-Magid, 1994; Ibisch et al., 2016), stakeholders involvement in decision making process, is considered very useful for the following reasons;

- It is a catalyst in the process of data collection and analysis. If stakeholders will be involved at an early stage, it will help in collecting useful information about the problem and even regarding the policy to be implemented.

- It helps spread the awareness about difficulties facing the decision making process during selecting the choices of policies. Also, makes the stakeholders aware that in some cases tradeoffs will have to be made for the best management to be implemented.
- It is considered to be a good tool in encouraging social behavior changes and help to build broad commitment to management plans and policies.
- It enhance the confidence of the users to the governmental institutions.

In this regard, Ticehurst (2011) addressed that "*Understanding landholder decision making is now acknowledged as fundamental to achieving better policy outcomes*". She also argued about the management of private landholders being the key element of improving the condition of natural resources in Australia (Ticehurst et al., 2011).

Delmas & Toffel (2004) also pointed out that decisions to adopt environmental management practices are influenced by the relations within the communities. Therefore, the stakeholder's involvement in any decision making process is a key point in the Integrated Water Management (IWM) (Giordano et al., 2004). This should be done with the consideration of the level and capacity of involvement. For this, a social research is highly recommended for a better understanding of who in the community is likely to respond to which type of policy instrument and why (Ticehurst et al., 2011). During such researches, a field survey should take place and data and information should be collected, then an appropriate knowledge can be built to facilitate the decision-making process.

Some authors argued about the participation methods. There are so many ways and methods to involve stakeholders in the decision making process. However, in many cases it is difficult to evaluate the quality of these methods because of the lack of appropriate benchmarks (Zorilla et al., 2010). In this regard, Zorilla (2010) mentioned that "*Identifying an adequate benchmark criteria is crucial in evaluating participatory approaches*".

2.2 Stakeholders Relationships and Biological, Physical, Socio-economic Interactions in Water Resources

Humans have continuously interacted with natural systems since the beginning of human history, and the scope and intensity of these interactions have increased dramatically since the industrial revolution (Liu et al., 2007; Savenije et al., 2014). In addition to this, there are different types of stakeholders (users, decision makers, environmental agencies, etc.) in such systems. The different relevant stakeholders have different interests and needs or even vision for managing the systems. Therefore, there is a need of a fundamental knowledge about linkages and feedbacks of the various system components to portray the complexity of systems and the outcome of future scenarios adequately (Montanari et al., 2013).

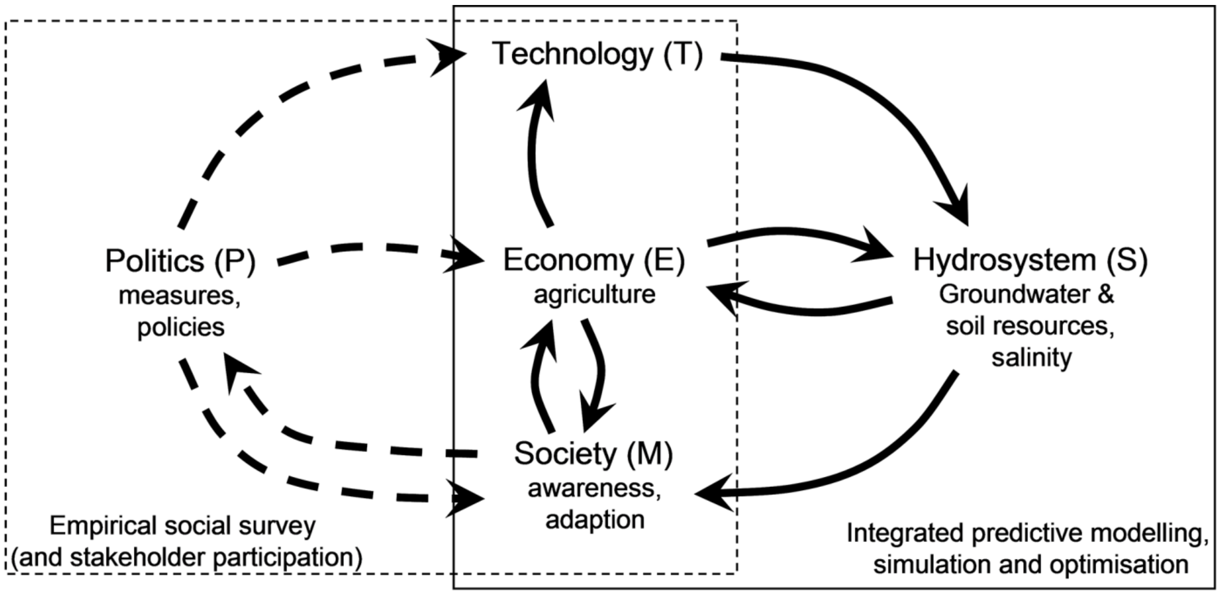


Figure 2: Schematic of system dynamics for managing saltwater intrusion in agricultural coastal plain (Grundmann et al., 2016)

Figure 2 illustrates the linkages between different components of a system affected by saltwater intrusion. The solid lines illustrate the feedback loops as a consequence of saltwater intrusion. The agricultural economy (E), hydrosystem (S), technology (T), society (M) and politics (P) are displayed by lines with arrows showing their direction. The increase in the application of technology (T) for groundwater pumping as well as inefficient agricultural practices (E) from a society (M), showing less awareness about resource limitation, the groundwater-soil-hydrosystem (S) is damaged by salinity. This has a feeds back to agriculture (E) by reduced crop yields and to the society (M) which loses its connection to water of quality. Therefore, for the Al Batinah regional development, societal, environmental, and economic aspects need to be considered for evaluating appropriate management options.

In Figure 2, Management feedbacks are illustrated by dashed lines. They are triggered by the request of the society (M) to politics (P), which may respond in different ways focusing or supporting on technology (T), agricultural practices (E), and society’s behavior (M), through e.g. technological countermeasures, agricultural incentives or training. The system components and their linkages are assessed and evaluated by different types of investigation and modelling. The responses of the system components on management interventions can be described by several criteria characterising the system states in the modeling system as well as the acceptance of interventions in the society represented by concerned stakeholders (e.g. decision maker (P), farmers (M)).

The need to couple human and natural systems when addressing social-economical and human-environment interactions has become essential (Liu et al., 2007). Those complex relationships have made researchers to develop tools to utilize environmental indicators. It has become necessary to seek the cause and effect relationships in order to make a better prediction and proper management. In recent years, most of the environmental assessment reports and publications are based on the causal chain frameworks (e.g., Pressure–State–Response (PSR), Driving force–State–Response (DSR), and Driving force–Pressure–State–Impact–Response (DPSIR)) (Niemeijer & de Groot, 2008). The DPSIR framework is a good technique to illustrate how socioe-conomic development impacts the environment (Kelble et al., 2013). The framework has also increasingly been applied in research projects with the aim of supporting decision making (Tscherning et al, 2012).

DPSIR was initially developed by the Organization for Economic Co-operation and Development (OECD, 1993). It has been used by the United Nations (UNEP 1994; UNEP 2007) to relate human activities to the state of the environment. It was also proposed by the European Environmental Agency (EEA) in 1999 to describe the component of a natural system under an anthropic pressure (EEA, 1999). The concept of it is: The *drivers* generate *pressures* that change the *state* of the system. This variation produces *impacts* on society, which reacts by devising and implementing *responses*. The responses can be directed at the drivers, as well as pressures, the state or the impacts themselves (see Figure 3) (Soncini-Sessa et al., 2007).

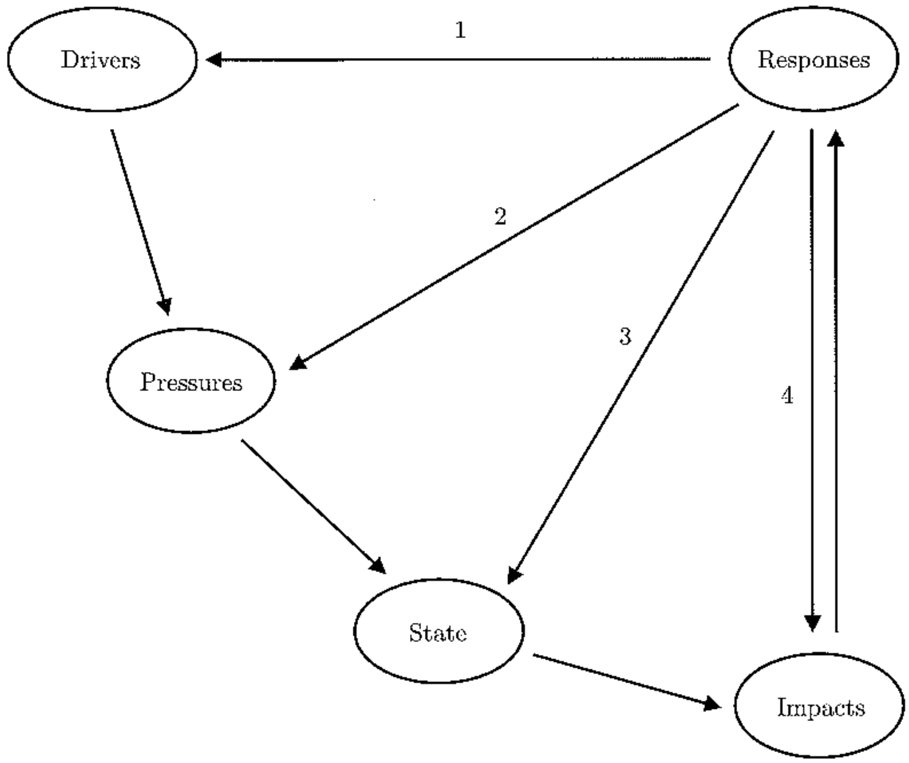


Figure 3: DPSIR framework (Soncini-Sessa, 2007)

In the matter of water resources systems, DPSIR can be used to establish the indicators to evaluate the sustainability of water utilization. One of the good examples, is a direct relationship between groundwater aquifers and agriculture especially in arid and semi-arid regions. The water management process, in such regions, might have conflicting goals to maintain and improve the water resources. Farmers are consuming fresh groundwater for irrigation (driver), which, together with the limitation of water resources, cause (pressure) on the groundwater aquifer and generate pollution problems (state) of depletion of the aquifer (state). This produces (impacts) on food production and lead to social consequences. (Responses) can be in a form of; designing and implementation of measures to maintain the groundwater aquifers, increase the water efficiency in irrigation and increase the agricultural productivity and income.

With the increase in complexity and uncertainty of natural resources, integrated approaches are required, which can facilitate communication and knowledge transmission between the relevant stakeholders of a system. In addition to that, it has to be in mind that natural resources need to be managed for a short term and a long term.

2.3 Behavior Modeling of Stakeholders

2.3.1 The Use of Statistical Analysis of Questionnaires in IWRM

One of the most appropriate tools to explore the opinions of stakeholders in a domain is a social survey by distributing questionnaires and face to face interviews. A questionnaire is considered to be a good tool for collecting data and information about a particular subject of interest. Many researchers rely on it, the reason is that they allow contacting a large number of people and many information can be gathered and statistically analysed. It can be designed according to the research topic and distributed either by written papers questionnaires or sent by mail, email, or conducted electronically on the internet. A questionnaire can be also carried out via telephone calls or face to face interviews (Robson, 2002).

Questionnaires are mainly used to collect information related to people's circumstances. They are helpful in classifying people into groups based on their behavior or opinions, social situations, education levels, needs or interest, etc. They can also be used to measure the satisfaction of a society with a product, service or management options for a particular subject of interest. Data collected through questionnaires, can be useful as well, in creating a baseline of information for a changing system or environment, and could be updated periodically, to explore the changes with time. However, there are some disadvantages of using questionnaires. For example, they do not allow to develop a conversation between researchers and the respondents. Moreover, response rates can be low, respondents might refuse to answer some questions especially the open-ended questions. Furthermore, some respondents might not bring back the questionnaire or fill it in a hurried way. In this case, a questionnaire which is filled through interviews is considered to be more reliable.

Many researchers in the field of IWRM used questionnaires as a tool for data collection. For example Zorilla (2010) used stakeholder evaluation questionnaires for evaluating a participatory process of water resources management at upper Guadiana basin in Spain (see Zorilla et al., 2010). Martin (2005) used questionnaires to meet the data required for an evaluation of the participation of stakeholders who are somehow involved in water resource use or management of a hydrogeological unit in Eastern Mancha (see Martín et al., 2005). Al Shaqsi (2004), performed a field survey and used questionnaires for data collection in order to explore the potential for introducing a water demand management in Oman.

2.3.2 Common Approaches in Supporting the Decision-Making Process in IWRM

In the field of social science in water resources, it is very hard to combine decision elements, for example the available decision options, dependent key factors, independent key factors, etc. To explore the relationships between the relevant elements and evaluate the available or proposed options, good management tools are needed. This section is spotting the light on some of the common known integrated approaches in supporting decision making processes in water resource management.

According to Subagadis (2015), a suitable model depends on two questions; what should be integrated and what is the intended purpose of modeling. After answering the two questions, a variety of approaches to develop models of complex systems are available. Subagadis (2015) summarized the most common ones as follow:

- Coupled component models: employed when integrating different components of hydrological, economic, social and/or environmental processes (see Grundmann et al., 2013).
- Bayesian Networks (BNs): employed for management and decision-making applications in which stakeholder participation and uncertainty is a key consideration (see Ticehurst et al., 2011).
- Multiple Criteria Decision Analysis (MCDA): This is a type of an integrated modeling approach for prioritizing or scoring the overall performance of decision options against multiple criteria or objectives (see Afshar et al., 2011). It is commonly used in water resources management and other natural resources.
- System Dynamics: these are system dynamic models which are used to study the dynamics, feedbacks and evolving interaction in a system over time (see for instance Akbar et al., 2013).
- Agent-Based Models and Knowledge-Based Models: These are simulation models partly driven by increasing demand from decision makers to provide support for understanding the potential implications of decisions in complex management systems (see Rounsevell et al., 2014).

The following paragraphs summarizes some remarkable studies, in natural resources associated with social research, which mostly were performed using Bayesian Networks (BNs).

Giordano (2004) used cognitive maps and he considered them to be the core of methods used to structure multiple conflicting aspects, in the field of water resources, and set individual’s views into context. He also used clustering procedure to gather the stakeholders who have similar needs and identify conflicts among them. In addition to this, he used fuzzy similarity measures for conflict identification among stakeholders. In his opinion, identification of conflicts plays an important role in understanding stakeholders' interests.

Castelletti and Soncini-Sessa (2007) developed an integrated model of a water reservoir network by using a BN structure coupling to a hydrological model. BNs were used to describe, in a probabilistic way, the behavior of farmers within an irrigation district in response to some planning actions.

Molina (2010) applied an Object-Oriented Bayesian Networks (OOBNs) to the domain of integrated water management of overexploited hydrogeological systems and used it as a Decision Support System (DSS). The purpose was to show how this type of DSS can be used to evaluate the impacts of a range of management strategies that are available to local planners. He identified all the relevant factors related to water management in a region near Murcia in Southern Spain. Then he converted these factors to variables within a Bayesian Network (BN) and investigated the relationships between them. Many BNs were constructed, a network for each aquifer. After that an entire water system was constructed using a group of conventional BNs within a DSS simulation. In addition to this, he involved the stakeholders of the region in the processes of designing and constructing the network. In this regard, he stated that *"By working closely with stakeholders it proved possible to construct a model that was a representation of reality acceptable to all groups"*. At the end he proved that the production of an OOBN helps to represent the complex real-world situation. After running the OOBN simulation, he concluded that the impact of interventions on socio-economic variables in the system, are not strong.

Ticehurst (2011) presented findings from a study done to explore the benefits of combining BNs with conventional statistical analysis. BNs were used with conventional statistical analysis to examine landholders' adoption of conservation practices for Wimmera region in Australia. After discussing the findings, she argued that BNs provide enhanced understanding of the presence and strength of causal relationships. However, she also mentioned that the interpretation of the results of the BNs was complemented by the conventional data analysis and expert review. Which means, that the conventional data analysis is important in supporting BNs construction and performance. The statistical analysis contributes in identifying the strength of relationships between the variables within a BN.

2.3.3 The Use of Bayesian Networks in IWRM

In the field of water resource management, there is a lack of a tool which can facilitate understanding system processes (hydrological, environmental and socio-economic). Subagadis (2015), argued that BNs are the most appropriate for modeling complex systems under uncertainty.

BNs can integrate data and knowledge of different types and from different sources (Ticehurst et al., 2011) in which, the variables are joined by causal links. In fact, a BN is a type of DSS based on a probability theory which implement Bayes' rule (Larrafiaga et al., 1996; Molina et al., 2010).

According to different literatures (Subagadis, 2015; Ticehurst et al., 2011; Jones et al., 2010), the advantages and disadvantages of modeling with BNs can be summarised as follow:

Advantages:

1. They represent the relationship between cause and effect and quantify the strengths of those relationships.
2. Being able to deal with complex issues of a system, and incorporate quantitative and qualitative data.
3. Uncertainty among variables can be represented simply and the model can be easily updated if new information is available.
4. They provide a means of documenting a current understanding of a system, and to produce assumptions of how the system works.
5. Facilitates participation between scientists and stakeholders when applied to management issues.

However, the BNs found to have some disadvantages and limitations as well, which are summarised below:

1. They poorly represent spatial and temporal dynamics.
2. Poor decision about the states of the variables, can lead to hiding the impact of a particular scenario or input condition.
3. Poor structure of a BN might fail to provide insight into the issue of concern. The quality of the BN depends on the quality of the data used for training (i.e. the quality of the questionnaires/interviews and statistical analysis).
4. Jongsawat (2008), argued that constructing BN models is a complex task and consuming a lot of time.

2.4 Recent Examples for the Implementation of Socio-economic Issues in IWRM in Oman

Several studies have been performed in water resources management and decision support of stakeholders using the mentioned approaches or other approaches.

For Al Batinah Al Shaqsi (2004) explored the potential for introducing a water demand management in Oman. He used questionnaires and interviews to collect data then he analysed them statistically.

The study indicated that there is a gap in controlling the rates of abstraction for irrigation purposes and there is no enforcement of schemes designed to encourage the use of water saving technology or rules in houses and in agriculture. At the end he concluded that competition for water between agricultural, and other sectors will continue unless a proper water allocation system is introduced. It was mentioned as well that, without an effective water demand management, the water deficit together with salinity intrusion will increase. However, the study tried to explore Omani society's reactions to the application of a number of water management options, but did not spot the light on the implementation potential from the social point of view.

Al Shaqsi (2004), focused on incorporating quantitative data to study the reactions of society. However, incorporating quantitative as well as qualitative data or information for management and decision-making applications in which relevant stakeholders are involved, are important for modeling such complex systems.

Another study, in Al Batinah, was an analytical study of the socio-economic factors, which was performed by Zekri (2008). He analysed the relative merits of some strategies to control groundwater pumping based on water quotas, electricity quotas and electricity pricing. Zekri argued that the net present loss to the community when no active policy is implemented can reach up to $288 million.

The aim was to evaluate the feasibility of controlling pumping and to ensure that the benefits of controls outweigh the costs. A cost benefit approach is used to evaluate the feasibility of three strategies over a period of 25 years and to compare them to the ‘‘business as usual’’ option. The first was to control the groundwater pumping through the installation of flow meters on tube wells. This was coupled with the removal of the subsidy on electricity. The second was taxing the use of electricity (based on using an economic incentive). The third was to control water pumping through the implementation of an electricity quota for both tube wells and dug wells in the region.

At the end, he concluded that imposing water quotas on tube wells would give a net present benefit of $153 million. He also pointed out that such quotas would give the lowest present benefit and create inequity among farmers. He argued that the electricity quota, coupled with removal of the subsidy on the electricity price, is the easiest and most equitable solution to be implement.

Zekri (2008), insisted that controlling groundwater pumping is possible and profitable. However, the likelihood of choosing and implementing successful policy options should be maximized by involving relative stakeholders in the community. In this regard, Zekri (2008) argued that the participatory approaches are recommended in such cases by saying: "*farmers should be provided with detailed information regarding alternative strategies and they should be consulted frequently when evaluating policy choices*".

Subagadis (2014) proposed a framework which conceptualises hydrological and socio-economic interactions by constructing a Bayesian Network (BN) as a decision support tool for management problems of agricultural coastal regions. He argued that the framework should be able to support decision making under uncertainties for the management of complex hydrosystems. The aim was to demonstrate the value of combining two different, commonly used, integrated modeling approaches:

1. Initially, Coupled domain models are applied to simulate the nonlinearities and feedbacks of a groundwater–agriculture hydrosystem.
2. Afterwards, a BN model is used to integrate the obtained results together with stakeholders' opinions regarding potential management interventions.

The framework was explained through a prototype application of the Al-Batinah coastal region in Oman. Where over abstraction from a coastal aquifer for irrigated agriculture has resulted in an intrusion of sea saltwater. The BN model was intended to assess the impact of different management interventions on sustainable aquifer management. Several interventions (either refer to water resources side or water demand side) were investigated.

Subagadis (2014) argued that the BN based model forms the basis to analyse linkages within hydrology and socio-economic processes in a single framework. However, he added that such types of models might have some limitations. Therefore, more studies are recommended for improvement.

Models are highly used in the field of water resources. However, BN model applications have not been widely used in studies related to agriculture irrigated by groundwater in coastal areas, which are affected by saline water intrusion. Although such types of models are helpful in extending knowledge, they require additional efforts. Moreover, they have not been used, so often, in exploring the influence of social factors on adoption of management options related to water resources in those particular regions.

In Oman, no social research studies have been done associated with behavior analysis of both DM's and farmers in the field of IWRM with a focus on irrigated agriculture. Moreover, modeling approaches, applied as decision support tools, have not been introduced yet in such fields.

3 The Specific Case of Water Resource Management in an Agriculture-Groundwater System at a Coastal Region in Oman

3.1 Introduction

Sultanate of Oman is situated in the southeastern part of the Arabian Peninsula between latitudes 16° 40' and 26° 27' north and longitudes 52° 00' and 59° 52' east. It is bordered by United Arab Emirates (UAE) from the northwest, Saudi Arabia from the west, Oman sea and Arabian sea from the east and southeast and the Republic of Yemen from the south. The land area of the Sultanate is 309,814 km^2. The desert represents 75% of the total area, 15% mountainous area and 5% are coastal areas and the rest is alluvial plains (MWR, 1999). Figure 4 shows a map of the location of the Sultanate of Oman with a focus on the study area in South Al Batinah region.

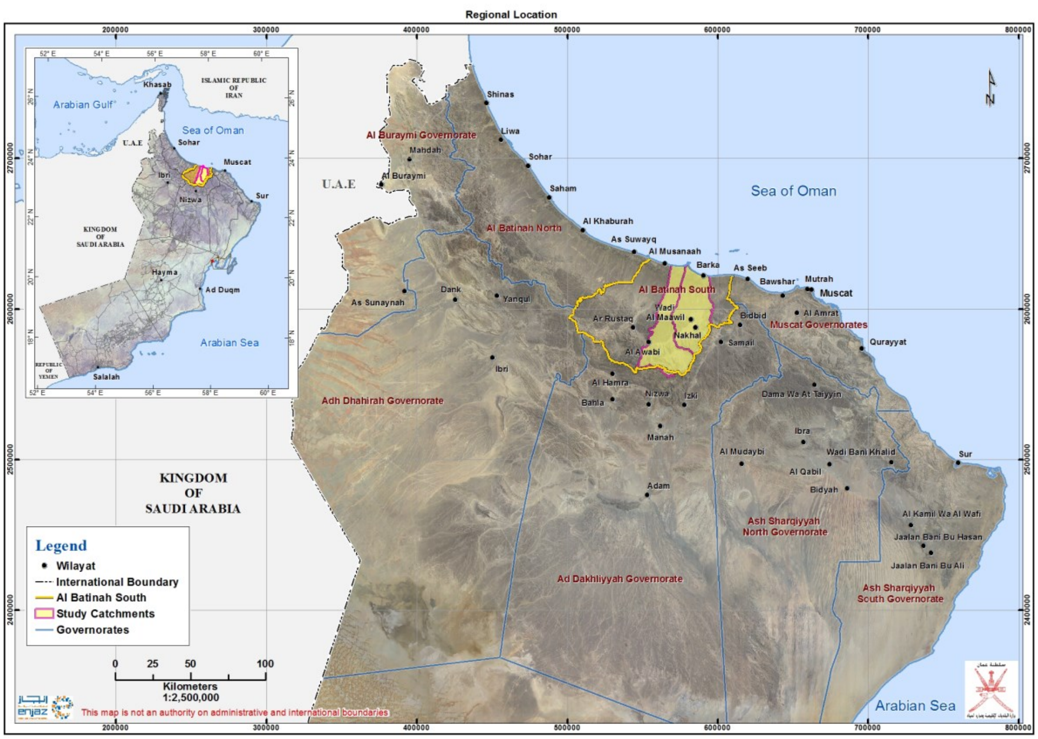


Figure 4: Location of the Sultanate of Oman, & the Study Area – Map provided by MRMWR (2017)

3.1.1 General Information

Oman's total population is 4.4 million (NCSI, 2017) growing at a rate of 3 percent per annum. The population is unevenly distributed; the coastal regions, Al Batinah plain (25%), and Muscat (the capital of Oman) contains the largest concentration (30%). As present, the Sultanate has 11 main administrative governorates which are, North Al Batinah, South Al Batinah, Ad Dhahirah, Ad Dakhiliyah, North As Sharqiyah, South As Sharqiyah, Al Wusta, Al Buraimi, Musandam, Muscat, and Dhofar.

Oman's economy is based largely on income from oil production representing 75% of the total GDP and exports (NCSI, 2017), beside industry (13%) and commercial (wholesale and retail) (10%). The other incomes for the country are agriculture and fisheries which are representing 2% (NCSI, 2017).

3.1.2 Climate

Oman is considered to be a hyper-arid country; the average annual rainfall is 51 mm (MRMWR, 2013), varying from less than 20mm in the internal desert regions to over 350mm in the mountain areas. The overall total annual average rainfall on Oman is estimated to be 15,842Mm^3. Of this amount, 79% evaporates, 5% drained to the sea and only 16% is the amount considered to be the effective rainfall which generates runoff and direct infiltration to the groundwater aquifers (MRMWR, 2013).

In the north of Oman, rainfall occurs mostly during the winter (November-April), whilst in the south it occurs as results of the monsoon which is a seasonal summer storm (June-September) and named locally as *Khareef*. The analysis of the departure from mean for Muscat rain gauge (Figure 5) shows many extreme events and in particularly, more persistent dry periods with no statistically significant trends (Helmi & Al Khatri, 2012).

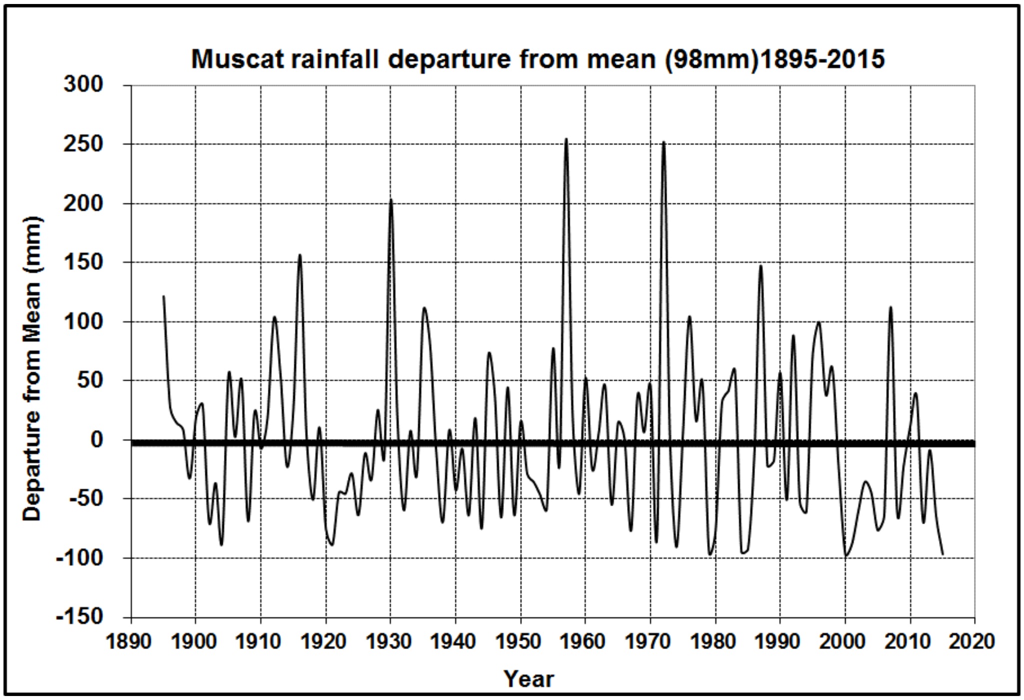


Figure 5: Muscat rainfall departure from mean (1895-2015)

The potential evaporation is ranging from 2000 to 3000mm/yr in the northern part of the country. It is around 1800mm in Salalah, which is the southern part of the country (MRMWR, 2013). The temperature varies between 3° C in winter (in the mountains) to 48° C in summer. It is hot and humid during summer in the coastal areas and hot and dry in the interior regions. While in the southern part of the country (Dhofar region), the climate remains moderate throughout the year.

3.1.3 Water Resources Overview

The water resources in Oman are either conventional or non-conventional (Table 1). The conventional water resources are considered to be the surface water and the groundwater. The non-conventional water is obtained from two sources. The first one is from desalination processes, and the second one is the water produced through wastewater treatment plants.

Table 1: Water resources in Oman (After MRMWR, 2013)

Water Resources in Oman			
Conventional Water ($1318Mm^3$)		Non-conventional Water ($238Mm^3$)	
Surface Water	Groundwater	Desalination	Treated Waste Water
102 Mm^3/yr	1216 Mm^3/yr	196 Mm^3/yr	42 Mm^3/yr

Surface water consists of *wadi* (temporary rivers) flows. As a result of an arid climate, *Wadi* flows occur during rainy seasons as flash floods, lasting for several hours and even few days in the year. These flows are very important to recharge the shallow aquifers (Al Khatri, 2006).

Groundwater representing 94% of the total resources, it is either renewable which is abstracted from the aquifers via traditional *Aflaj* systems, or rarely-renewable which is abstracted via wells. The renewable resources are described as aquifers that receive recharge from rainfall or infiltration of surface water flows.

In general, freshwater resources are extremely limited. Most of the population and water consumption sectors rely on groundwater supplies. The rarely renewable sources receive little recharge or, sometimes, no recharge at all. Most of the water was accumulated thousands of years ago during historic times when the climate was much wetter than it is now. Moreover, rarely renewable resources are located within the interior basins where thick tertiary carbonate occurs and have a total thickness of several hundred meters.

Oman is also characterized by *Aflaj*[1] (plural of *falaj*) conduits which are dug in the ground to convey water by gravity from one place to another. The discharge of the *falaj* is related to rainfall intensity and frequency, topography and geology, infiltration into alluvium and lateral formations, hydrogeological properties of the formations wherein the ground water is stored, hydraulic properties of a *falaj* and human activities (wells, diversions).

According to the source of water, the *Aflaj* in Oman are classified into three categories:

Daudi Aflaj: these are carrying water from shallow aquifers through dug wells, then conveyed to the village by an underground tunnel that may reach up to 17km (Zekri & Al-Marshudi, 2008). They are constructed by locating the suitable places to reach the groundwater manually through hand–dug wells to collect the water, which is then transported horizontally through the hand–dug wells to the open section of the *falaj* channel.

Ghaily Aflaj: the water for this type of *Aflaj* is obtained from the upstream reaches of major wadis where base flow can be found, mainly during or after the rainy seasons. Water is diverted into a man-made channel to a collecting (known locally as *Al Share'ah*) point and distributed among the irrigated plots. Wells are constructed to support add more water for longer periods to this type of *Aflaj* systems.

[1] *Traditional water supply systems*

Ainy Aflaj: these *Aflaj* obtain the water from one or more of the natural springs emanating from bedrock fractures particularly in the mountainous parts of northern Oman where all springs are developed and used in *aflaj* water systems.

Aflaj water systems play a very important and essential role in Oman's history as well as water regulation system within a community. They represent 31% of the water consumed (MRMWR, 2013). It is believed that *aflaj* in Oman have existed for over than 1500-2500 years. They are owned by farming communities and have a well-entrenched system of rules governing water use.

The Sultanate witnessed a great transformation in water uses during the last four decades. Consumption of water has extremely increased. Table 2 illustrates the current water use in Oman.

Table 2: Current water consumption in Oman (After MRMWR, 2013)

Water Use in Oman (1872 Mm^3/yr)			
Agriculture (1546 Mm^3)		Drinking water	Industrial &commercial
Via Wells	Via Aflaj		
1060 Mm^3	486 Mm^3	196 Mm^3	130 Mm^3

It is worth to mention here that the person share (per capita) is about 500 m^3/ yr (MUSCATDAILY.COM, 2017).

The expansion of the irrigated areas in Oman, in the last 40 years, led to increasing in water consumption compare to the annual available recharge water. Recent studies show that there is an average water deficit equivalent to 316 Mm^3/yr (MRMWR, 2013). The demand of water in many regions in the Sultanate exceeds the renewable amount by 25%. However, over pumping in wells and strong variability of rainfall led to the lowering of groundwater levels and the dryness of the systems.

3.2 Al Batinah and the Selected Study Area

3.2.1 Location

Al Batinah coastal area is located at the Sea of Oman. It is representing about 3% of the area of the country and was formed by valleys descending from the Oman Mountains (Al Hajar Mountains). It is between 15 and 80 km wide and 300 km long. The total population is 1,105,000 people (NCSI, 2017). Most of the population are concentrated along the coast and mostly depend on irrigated agricultural production.

Al Batinah region is providing a variety of different crops by small-scaled farms owned by local farmers. However, according to the latest information from MRMWR, about 539Mm^3 annually (which represent 86% of the water use in Al Batinah) is consumed by agricultural sector (MRMEW, 2011)

The administrative area of Al Batinah is divided into two main parts, **North Al Batinah** and **South Al Batinah**. This Thesis focuses on the status of water resource management in a part of the agricultural area at the coastal line of South Al Batinah (Lower catchments). South Al Batinah lies on the northern side of the Hajar Mountains (Al Gharbi Mountain) and extends across the coastal plain to the Sea of Oman. It is bounded by North Al Batinah from the northwest, Ad Dhahirah Region from the west, Oman Sea and the Arabian Sea from the east and Ad Dakhliyah Region from the south. Principal *wilayat* of the area are Barka, Al Ma'awil, Nakhal, Ar Rustaq, Al Musa'ana, and Al Awabi. The total population of South Al Batinah is 387,000 people (NCSI, 2017)

The elevations of the area range from greater than 2,000 m in mountain areas to near sea level on the plain and coast. The most important *wadi* catchments are Manumah, Taww, Ma'awil, Bani Kharus, Al Fara' and wadi Bani Ghafir, which drain from the mountains at the south toward the sea in the north.

The region is characterized by two terrains, the **Mountain/piedmont** and the **Alluvial fan/plain**. Following is a brief description of the two terrains.

1. **Mountain/piedmont:** Elevations along the northern and eastern boundary of Barka rise to 2,500 meters and are mostly above 2,000 meters. Between the high limestone Jabal Akhdar Mountains and the coast, a much lower range of ophiolite hills (up to about 900 meters) intervenes and is cut through by Wadi Bani Kharus and skirted to the east by Wadi Ma'awil (MWR, 1999).

2. **Alluvial fan/plain:** The alluvial plain occupies the eastern part of the Batinah coastal plain. In Barka, the Batinah plain narrows from 30 km to 15 km towards Muscat. In upper alluvial fan systems, older gravel and sand ridges are interspersed with and incised by more recent wadi channels. Towards the coast, the terrain becomes flatter and wider. Much of the wadi flow infiltrates into the plain. Wadi channels tend to narrow towards the sea sometimes forming multiple small outlets. Adjacent to the coast, aeolian and beach sand deposits occur with sabkha, clay and silt deposits (MWR, 1999).

3.2.2 Climate and Water Resources

Like the other parts of the Sultanate, the weather in South Al Batinah is hot during summer season but lower temperatures occur at higher altitudes. Following are the hydrological features in the area:

- *Climate*: In South Al Batinah, the average winter temperatures at the coast range between 20-28 °C, at As Seeb, and 17-23°C at Saiq on Al Jabal Al Akhdar Mountains. While the summer temperatures tend to lie between 27 and 37°C. Evaporation depends mainly on temperature. Potential evaporation in Al Batinah coast is estimated to be 2,100mm.
- *Rainfall*: Although the weather is dry during the winter, rainfall sometimes occurs in association with low pressure systems. The rainfall amounts are estimated to be 350mm/yr in the Al Hajar Mountain to 50mm/yr along the coast with wide variations. The annual average rainfall is around 105mm.
- *Wadi flows:* Annual average wadi flow in South al Batinah is estimated to be 3.1Mm^3/yr, which is ranging from 1.8Mm^3/yr in Wadi Bani Kharus, 2.2Mm^3/yr in Ma’awil and 4.5Mm^3/yr in wadi Bani Ghafir (MWR, 2000).
- *Dams*: There are 10 recharge dams constructed in South Al Batinah since 1985. The largest 2 are located in Wadi Bani Kharus (with a storage capacity of 5Mm^3) and Wadi Ma’awil (with a storage capacity of 10Mm^3).

In general, the total water use in all South Al Batinah is estimated to be 143 Mm^3/yr (MRMWR, 2013). Of this 138 Mm^3/yr is the agricultural water use (MRMWR, 2013). On the other hand, the average water deficit in South Al Batinah is around 91 Mm^3/yr (MRMWR, 2013).

The main part of interest for this thesis, consists of two *wadi* catchments; wadi Bani Kharus and wadi Ma'awil (Figure 6). The study area comprises two *Wilayat* (villages) Al Musana’a and ‘Barka’ where the farms are located near the coast line and the aquifer is affected by the salinity intrusion. The aquifer consists mainly of coarse, gravels and boulders with occasional cemented beds.

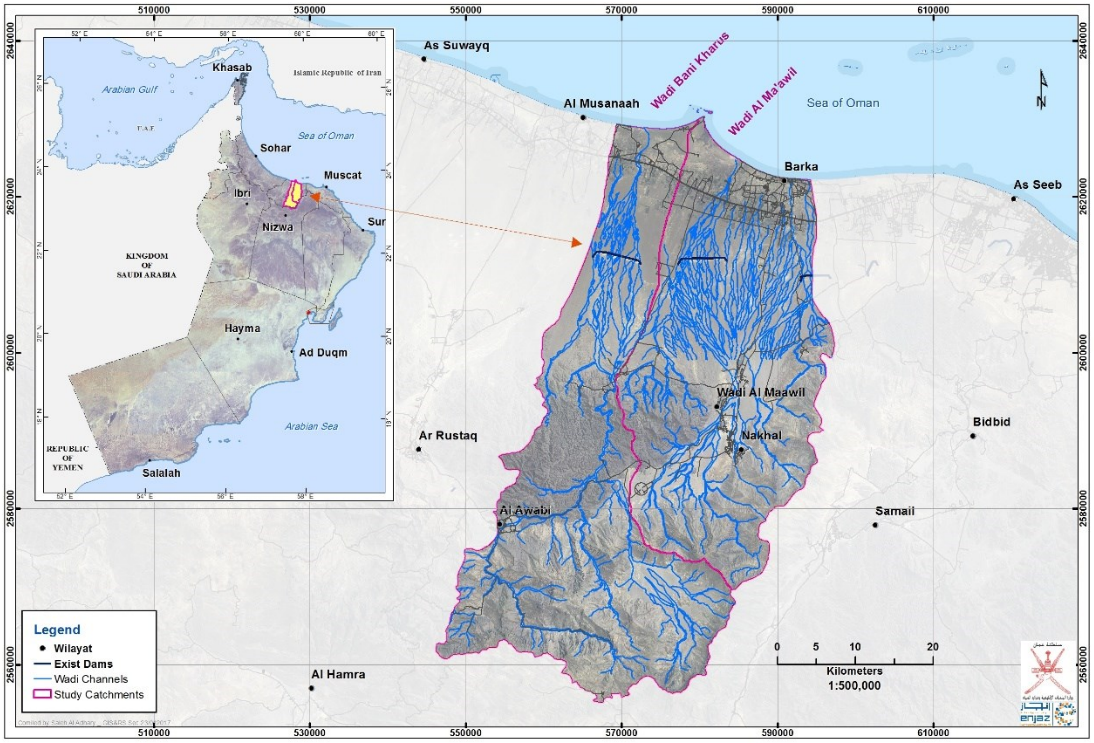


Figure 6: Location of wadi Bani Kharus and wadi Ma'awil – Map provided by MRMWR (2017)

The coastal part of the aquifer system is characterized by **alluvial deposits** which are collectively form the main aquifer and supply the majority of the groundwater in the study area. Well yields vary considerably depending on the nature of the *wadi* deposits, their saturated thickness and degree of sorting and cementation. Its storage and transmissivity are generally good with average transmissivity value of 550 m^2/day at Barka – As Suwaiq area. Underlying the upper gravels are the clayey gravels marked by the appearance of brown and red marly gravels and clayey sands associated with decreased well yields. At the bottom of the clayey gravel sequence are the cemented gravels with the smallest specific capacities and biggest drawdown, thus making them marked as poorer aquifers (MWR, 1995).

The aquifer is connected to the sea and the farmers use the pumped freshwater from the aquifer to irrigate their lands. The agricultural and domestic water demand of most of the rural population is met by *Aflaj* in the mountainous part (the sustainable part) and by private wells in the coastal part (non-sustainable part). Table 3 is showing the water use in Wadi Bani Kharus and Wadi Ma'awil.

Table 3: Catchment characteristics and water use in Wadi Bani Kharus and Wadi Ma'awil

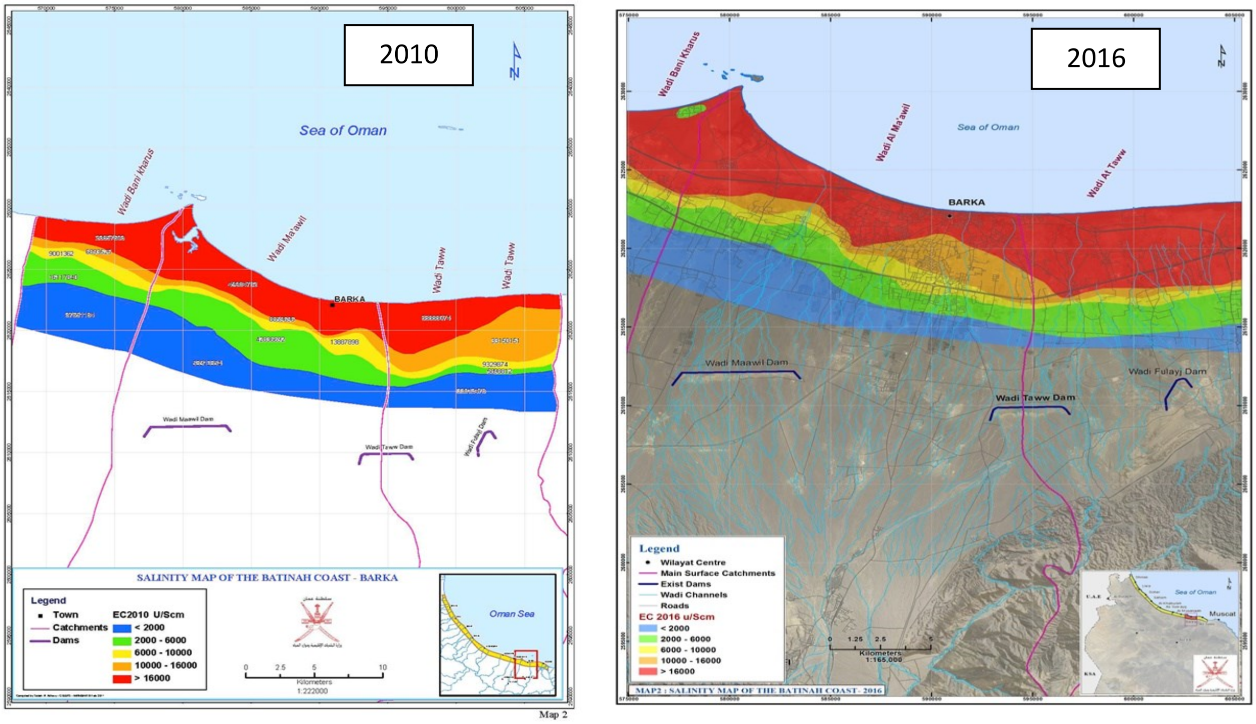
Catchment	Area(Km^2)	Alluvium Area (Km^2)	Water Use in Mm^3/Yr	
			Agriculture	Domestic
Bani Kharus	1183.37	393.22	29.7	1.23
Ma'awil	835.06	546.94	48.79	2.09

The annual amount of precipitation in Wadi Bani Kharus and Wadi Ma'awil is 176 Mm^3/yr. Of this 122Mm^3/yr evaporate and 50.25Mm^3/yr is the estimated recharge to the groundwater aquifer (MRMWR, 2013). The water deficit is 54.3Mm^3/yr. Of this, more than 90% (51.54Mm^3/yr) is estimated to be in Wadi Ma'awil. In such cases the demand is covered by over abstraction from the groundwater which results in lowering water levels and allow for salt water to intrude into the aquifer. This has a great impact on soil fertility, water quality, and agricultural production and sustainability.

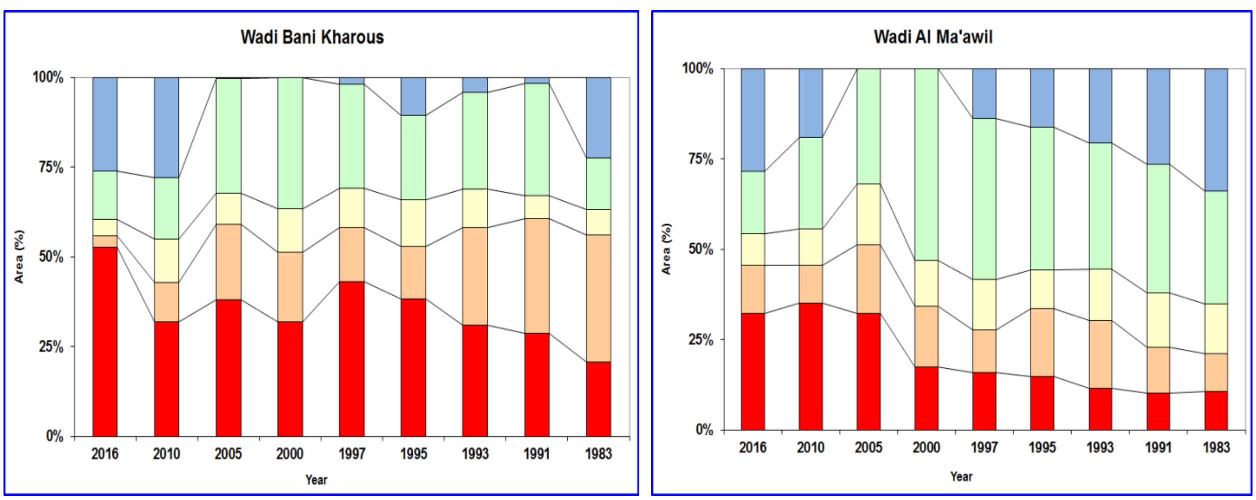
The water table depth in the coastal zone is 1-10m, in the central plain and mountains it reaches 40m to 80m, respectively (Kacimov, 2006). According to the recent information obtained from MRMWR in Oman, the water situation in South Al Batinah is still at risk. The hydrological data showed an additional decline in the water table near the coast to about 6 to 9 m below sea level in Barka (MRMWR, 2016).

In general, studies in the area illustrate and emphasize an extensive and serious increasing in saline water intrusion beneath the Batinah coast. Salinity survey programs were carried out by Ministry of Regional Municipality and Water Resources along the Batinah coastal area since the year 1983. The programs focus on the productivity wells which are tapping the alluvium aquifer. The well depths range between 20-70m. The results showed progressive salinity increase during the last 2 decades in spite of an exceptional rainfall period during 1995-1997 and the year 2007. In the salinity report of the 2010 survey, it was mentioned that the intrusion is affecting new areas in the region. The water quality, in these areas, were still in a good condition in the year 2005. The reason might be attributed to the low rainfall availability between the year 2005 and 2010. The salinity increases during the 5 years, between 2005 and 2010, in spite of some low refinement in the parts which were affected by an extremely cyclone (Gonu) in 2007.

The maps and graphs in Figure 7 show the increasing trend in salinity during the period (1983-2016) at the two selected catchments.



(a) Map of Salinity Intrusion in Wadi Bani Kharus and Wadi Al Ma'awil (2010 and 2016)



(b) Salinity variation (1983-2016) in Wadi Bani Kharus and Wadi Al Ma'awil

Figure 7: Salinity Intrusion in Wadi Bani Kharus and Wadi Al Ma'awil (MRMWR, 2010, 2016)

Figure 7 (b), shows the percentage of the area covered by the survey program in Wadi Bani Kharus and Wadi Al Ma'awil respectively. The colours (Red is saline water and blue is fresh water) representing the expansion of salinity intrusion during the period 1983-2016 (MRMWR, 2016).

From Figure 7 (b), it can be noticed that the area which is represented by 10,000µS/cm (the red colour) in Wadi Bani Kharus is over 32% in 2010, which has increased by about 11% compared to 1983. This figure shows an increase again by 20% in the last six years (2010-2016), and the red area is 52%.

In general the area effected by high salinity ranges (orange and red colours), increased by 31% in Wadi Bani Kharus in the last 33 years (1983-2016). These areas are considered to be not suitable for cultivation any more.

In Wadi Al Ma'awil catchment, it can be noticed in Figure 7 (b) that the area effected by salinity ranges above 10,000µS/cm (orange and red), increased by 13% in the last 33 years (1983-2016). On the other hand, there is a slight increase (9%) in the blue area, which is considered to be a fresh water. The reason might be because there is a reduction in the agricultural area due to land use change or because the area is supported by a recharge dam (Al Ma’awil dam). This dam stored around 51Mm^3 in the last 6 years.

Based on the salinity survey programs undertaken by MRMWR, there has been substantial deterioration in the water quality. This was indicated by a 7% reduction in areas with suitable water for agriculture use (2,000–6,000µS/cm) which reflects the loss of 2.714ha of irrigated land within the Wadi Bani Kharus and Wadi Ma’awil.

3.2.3 Agriculture and the Behaviors of Farmers in South Al Batinah

Water scarcity is threatening world’s population lives. Agriculture uses 70% of global freshwater withdrawals and is probably the sector where water scarcity is most critical (FAO, 2012). In arid regions, this fact is in conjunction with the severe depletion of groundwater aquifers (Shahin et al., 2015). The problem becomes more serious with the limitation of water resources especially for the coastal agricultural areas. One of the well-known problems, which has become a source of concern in many coastal areas in arid and semi-arid regions, is the problem of seawater intrusion into the coastal aquifer systems. The growing pressure on fresh groundwater resources, as a result of high demand and wasteful use, leading to contamination and depletion of the aquifers. This situation leads to destruction of the agricultural resources and the economic basis of farmers in such regions (Grundmann et al., 2016)

Many of the population in Al Batinah rely on agriculture as over half of the agricultural area in Oman is located in this region (Zekri, 2008). Subagadis (2015) reported that one-third of the economically active population in Al Batinah is working in the agriculture sector. He intended that, this underline the importance of agriculture for the region. The irrigated agricultural area is estimated to be 65,400 ha and the main products are date, lime, banana, wheat and sorghum. Farm sizes vary from less than 0.4ha to more than 84 ha (MAF, 2011). The farms less than 1.26ha are about 11% of total farm holdings; and those range between 1.26 to 2.60ha are 65%, while those greater than 12.6ha are about 23.8% (MAF, 2011).

In the selected study area (Wadi Bani kharus and Wadi Ma'awil – coastal zones), the source of irrigation water for almost all of the farms is the groundwater abstracted from the aquifer by private wells (Figure 8). The introduction of high capacity water pumps and new machinery, after the renaissance of Oman in 1970, has encouraged people to develop new farms in the region. Consequently, new wells were constructed to irrigate the new farms. According to the data provided by MRMWR, the number of private wells in South Al Batinah increased from about 3000 in 1970 to 8000 in 1975. This reflects how rapid the expansion of well drilling took place. In the FAO (2013) report of Regional Initiative on Water Scarcity in NENA region- Oman Initiative report, it was mentioned that ,the rapid drilling of the new wells during 1975 to 1989 led to dryness of hundreds of *Aflaj* (FAO, 2013) in the interior region. The growing in the number of wells continued until the early 1990s when a ban on construction of new wells for agricultural expansion was strictly enforced. However, the water abstraction in South Al Batinah increased, mostly in the area of "Wadi Bani Kharus", "Wadi Ma'awil" and "Wadi Al Taww" from 30Mm^3 annually in 1970 to 120Mm^3/yr in 2008 (Al- Shoukri, 2008). In "Wadi Bani Kharus" and "Wadi Ma'awil" the recharge amounts received from the mountains into the aquifer system is estimated to be only 50Mm^3/yr (Gerner et al., 2012). The imbalance between the abstraction rates (ca. 120Mm^3/yr), and recharge rates (ca. 50Mm^3/yr) led to a dramatic decline in groundwater levels accompanied with saltwater intrusion into the coastal aquifer of the region.

Agriculture is also facing challenges in Al Batinah. The study done by MRMWR in 2011 (MRMEW, 2011), reported that the land area effected by salinity above 10,000µS/cm, in Al Batinah, has increased with time since the year 1995 by 14,500fd. As a result of seawater intrusion, many trees, mainly date trees, in the traditional farms have died. With time, several agricultural lands of the coastal areas have become unsuitable for cultivation (MAF, 2011) and some farms have become abandoned (Zekri, et al., 2010).

Moreover, the uncontrolled use of the resource, in the case of a common property resource, leads to a social problem since each user maximize his own use without recognizing society's needs as a whole (Ibnouf & Abdel-Magid, 1994). Additionally, farmers started to change the land use from agriculture to commercial and constructing buildings instead of crop production.

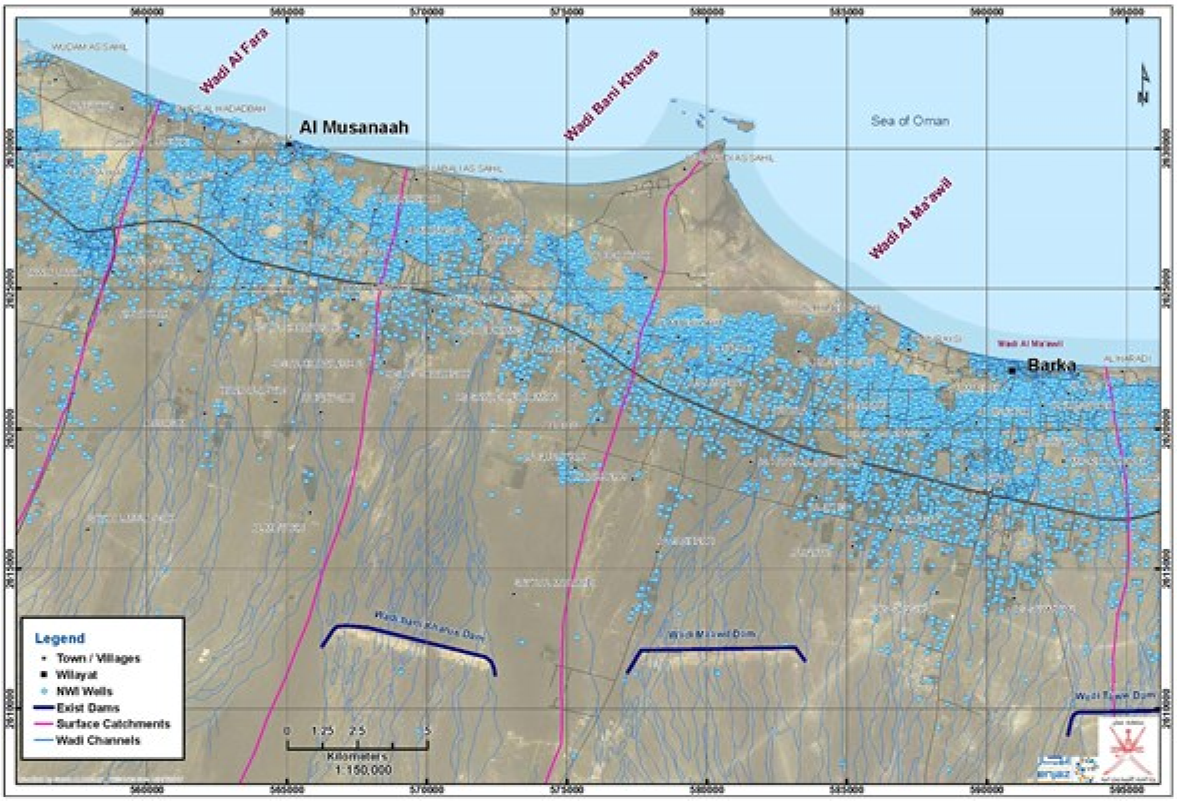


Figure 8: The private wells & artificial recharge dams in Wadi Bani Kharus and Wadi Ma'awil – Map provided by MRMWR (2017)

The practices followed by farmers are generally affecting the water situation in the region, and particularly have an effect on food production and agriculture sustainability.

The behaviors of farmers in the area can be summarized as follow:

- Over pumping of the groundwater for irrigation, the abstraction rates exceeded the recharge rates.
- Consume a lot of water for crop irrigation without taking into account crop water requirements.
- Not all of the farmers are taking into account the suitable irrigation hours.
- The cultivated crop types are not selected to be salt tolerant or of a good economic return.

- Most of the farmers are farming partially because either they are retired from jobs or still in government or private job employments (Zekri et al., 2010).
- Some of the farm owners are renting their farms to foreigners for a low amount of money which is less than the value of the groundwater used. Water conservation is not on the renters' priority agenda. Their concern is oriented more towards getting a high yield rather than conserving water (Al-Shaqsi, 2004).
- Many of the farm owners employ foreign labourers to take care of the farm irrigation and productivity. Those labourers come from countries which are not suffering from water shortages. Therefore, they are not aware of water problems and water deficit in the region.
- In many cases, farmers refuse to implement water meters to the wells of their farms even with the support of the government concerning purchase and implementation. The private wells are registered with the government, but not the amount of abstraction (abstraction rates are not limited) for each well. Therefore, it is very difficult to control or observe the exact amount of water abstracted from the aquifer.
- Recently, farmers have been interested to change their land use from agriculture to urban uses instead for crop production.

The main conclusion from the above information is that farmers are playing a major role in the over abstraction of the groundwater aquifer in South Al Batinah region and threatening its sustainability.

3.3 Water Resources Management in Oman

A lot of efforts have been done in the Sultanate concerning the conservation of the environment and natural resources. In regard to the water sector, Oman has focused on the development and implementation of plans relating to the assessment, management and development of water resources. The integrated water resource management is considered an essential component of a strategy to diversify the Omani economy and the preservation of natural environments and other environmental components of the Sultanate.

3.3.1 Oman's Water Institutions and Legislation

The administration and institution system of water activities is different from one country to another (Al-Shaqsi, 2004) , hence not all water sector activities within a country are unified under one umbrella. In general, the existing institutions in a country determine how far the objectives and strategies can be achieved in practice. There is no common prescription for the best formula for institutional and organizational arrangements. The ultimate institutional form adopted by a country should also suit its own political, cultural and socio-economic conditions (UN, 2005).

In Oman, Water and other environmental institutions have undergone significant development over the last four decades. This reflects an understanding of the importance of conserving the environment and using it in a sustainable manner as it acts as a main element of the national economy. It should be highlighted here that, the institutional development has three major stages. The first one concerns with building up the general strategy and evaluation of the socio-economic development and its effects on the environment. The second stage deals with implementing the rules and regulations governing the different environmental issues which include the necessity for any project to supply an Environment Impact Assessment study (EIA study) for permitting the project. The third stage includes studying the environmental problems and preventing and overcome those problems.

The water sector is a part of the environmental institutions and has received high attention from the government. Several organizations with different responsibilities were established to deal with water activities. Each organization (Table 4) is playing very specific roles in functions related to the water sector in Oman. The irrigation responsibility falls under Ministry of Agriculture and fisheries (MAF). Water supply is under Public Authority for Electricity and Water (PAEW). Well permits are under Ministry of Regional Municipality and Water Resource (MRMWR), and so forth.

The most important organization dealing with water activities and integrated water resource management in Oman is the Ministry of Regional Municipality and Water Resource (MRMWR). It consists of two sectors; the municipal sector and the water sector. The water resource sector consists of the directorate general of water resource management and the directorate general of water resource assessment. The ministry involvements related to water are:

- Development of policies plans and programs necessary for the sectors of water resources and municipalities.
- Monitoring, evaluation and development of water resources in order to achieve a balance between water uses and renewable resources.
- Conservation of water resources from depletion and the rationalization of water consumption in all areas and in coordination with the concerned authorities.

- Development and activation of the prospects for cooperation, coordination and consolidation of the partnership with countries, organizations and regional and international bodies in the areas of municipal and water.

In each region in the country there is a Director General (DG) for municipalities and water resources. Moreover, in each *wilaya,* belonging to a particular region, there is an office for water resource affairs, dealing with well permits, monitoring, studies and *Aflaj* maintenance.

Another important organization is the Ministry of Agriculture and Fisheries (MAF), the agricultural sector. The agricultural sector now plays a leading role in food self-sufficiency and contributes considerably towards non-oil export. In this regard, His Majesty Sultan Qaboos bin Said, the Sultan of Oman, expressed on the 22nd National Day in 1992 through his guidance the following phrases:

"*We stress the continual importance of agriculture, fisheries and animal husbandry. Our efforts to secure our food requirements cannot succeed if they are dependent on the outside world. The development of productive projects in these vital areas and the encouragement of our people to utilize agricultural land effectively without exhausting our water resources is the only answer (way). Carefully studied and organized agriculture work can increase this sector of our economy and thus contribute to the provision of food we need*" (MAF, 2011).

Due to continuous and growing inter - relationship with other economic sectors, the agricultural activities developed great impact on social development as well as on employment and rural communities (MAF, 2011). Agriculture is a very important sector in the country. It represents the major consumer of water in the country.

Table 4: Oman's water related Institutions and their responsibilities

Organization	Sector	Responsibilities
Governmental		
Ministry of Regional Municipalities and Water Resource (MRMWR)	Water Resources	• Water resources management • Water resources Assessment • Water resources development
Ministry of Agriculture and Fisheries (MAF)	Irrigation	• Irrigation water management
Public Authority of Electricity and Water (PAEW)	Water supply	• Potable Water Supply (domestic, commercial, Industrial)
Ministry of Environment and Climatological Affairs (MECA)	Environment	• Safeguarding the Environment
Ministry of Health (MOH)	Community health	• Health aspects of water quality
Ministry of Communications (Directorate General of Meteorology)	Data collection	• Meteorological data collection
Non- Governmental		
Falaj Associations (Water users Associations)	Community	• Falaj protection • Falaj maintenance • Falaj water distribution • Falaj water allocation
Oman Water Society	Community water use	• Water conservation
Oman Waste Water Company	Waste water	• Collection and treatment and reuse of treated water (Muscat Governorate)
Salalah Waste Water Company	Waste water	• Collection and treatment and reuse of treated water (Salalah Governorate)
Oman agricultural Association (recently) Al Batinah Governorate Farmers Association (former)	Irrigation	• Improve productivity

Several Royal Decrees have been issued to control demands, abstractions and protection of water resources in the Sultanate. Following are the most remarkable Royal Decrees related to the historical development of the Institutions of the water sector in Oman:

1979 Royal Decree No. 36/79 Initiation of Public Authority for Water Resources.

1985 Royal Decree No. 104/85 amending the title of the Ministry of Environment to be the “Ministry of Environment and Water Resources”. Including the responsibilities of the Directorate of Water Resources (this was separated later on to establish the Ministry of Water Resources in 1989).

1986 Specifying the responsibilities of the Ministry of Environment and Water Resources and the Council for the Conservation of Environment and Water Resources by Royal Decree No. 91 and 92/86.

1989 Establishment of the Ministry of Water Resources and specifying its responsibilities under Royal Decree 100/89.

1990 Amending the organizational chart of the Ministry of Environment and specifying its responsibilities after the establishment of Public Authority of Water Resources by Royal Decree No. 11/90.

1994 Royal Decree No. 3/94 states the transfer of *Aflaj* and Dams to Ministry of Water Resources.

2001 The Ministry of Water Resources was merged, by Royal Decree No. 47/2001, with the Ministry of Regional Municipalities and Environment to become one Ministry titled the Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR).

2007 The Ministry of Environment and Climatological Affair (MECA), was separated by Royal Decree No. 93/2007, and then the title became the Ministry of Regional Municipalities and Water Resources (MRMWR).

3.3.2 **Management Strategies**

More than 10 years ago, the United Nations Environmental Program (UNEP) cited Oman as a country with one of the best records in environmental conservation (MRMEW, 2005). Laws and regulations have an important role in protecting Oman's natural resources either from degradation, pollution or extinction. In regard to the regulation of water, specific laws and regulations for protecting groundwater resources from depletion and pollution have been developed over a considerable period of time. Royal Decree 82/88 refers to "the water of the Sultanate of Oman as a national resource to be used according to the restrictions made by the government for organizing its optimum utilization in the interest to the state of the comprehensive development plans". This is considered to be the most far-reaching and important piece of legislation on water resources. Followings are the major important regulations in water resources sector:

- Royal Decree 29/2000 refers to a new water law "Water Protection Law" emphasizes the regulations of wells and *Aflaj*, permits, maintenance and regulates desalination units on wells.

- Royal Decree 114/2001 organizes the disposal of solid & dangerous wastes, environmental pollutant & wastes without a permit.
- Royal Decree 115/2001 refers to organizing the disposal of liquid and solid waste products.
- In 2001 a series of Ministerial Decrees, refer to the implementation of water supply well field protection zones at several regions of the Sultanate

In this regard, several action plans were carried out by the government in the field of water, and a lot of studies and projects related to water resources and water quality have been carried out by (MRMWR). The most remarkable actions could be summarized as follows:

- In the period between 1992 and 1995, a national well inventory project (NWIP) was carried out in order to register all the wells in the country.
- In the year 1997, another project was carried out which is the national project for registering *aflaj*.
- The Sultanate has prepared a national water resources master plan (2000-2020) to conserve and protect water wealth and a national master plan for drinking water.
- Several recharge dams were constructed in the wadi channels in order to recharge the groundwater aquifers and minimize the freshwater losses during flash floods.
- Desalination plants were constructed to supplement domestic water supply in the capital area (Muscat) and some other administrative areas.
- The government has initiated programs to relocate some of the large-scale farms in Al Batinah and Salalah plains, where the water resources are over-utilized.

The Omani governmental structure is strongly a top-down structure, which leads to a high degree of centralization of power in a few governmental organizations, leaving little space for the legislative or private sectors (for example farmers' organizations) influences (USAID, 2010). In this regard, the obstacles facing the Sultanate to overcome the environmental problems could be identified on the shortage of capacity building in the field of environmental economics, the existence of institutional research centers, and the participation of the private sector to help in solving such problems and the shortage of awareness towards environmental pollution.

As a conclusion, the challenges for integrated approaches can be confined to the scattered responsibilities of the institutions, scattered sectoral structure and scattered decisions.

In response to the problems posed by groundwater over abstraction in Al Batinah region and parts of other regions, the government started after mid-1970's extensive groundwater studies (Ibnouf & Abdel-Magid, 1994). This included adopting policy actions to increase supply, rationalize water consumption and to call for water conservation programs. For example, after the completion of the (NWIP), several water management and conservation measures were undertaken by the government. The most important ones are listed below.

- The expansion of agriculture was stopped.
- A ban on construction of new wells was strictly enforced. Nowadays no wells are allowed to be constructed within 3.5km of a mother well of a *falaj*. Ministerial Decision No. 2/1990 established an important set of measures requiring the registration of all existing wells and the issue of permits for any new or modified ones.
- Permits are required for the construction of new wells, also for deepening existing wells and for changes in use or installing a pump inside any well (Ministerial Decision No. 13/1995). The digging of new wells is permitted only for municipal, industrial and commercial purposes.
- All drilling and well digging contractors are required to be registered with MRMWR.

In addition to this, the Ministry of Agriculture and Fisheries started new plans in researching new crop varieties and cultivation methods to make most efficient use of water resources (USAID, 2010). This includes helping farmers to adopt modern irrigation technologies and determine the crops that they should plant.

In this regard, Ibnouf and Abdel-Magid (1994) summarized three major facts which could be taken into consideration for any management option to be implemented in the country:

1. The first fact is that agriculture is the major consumer of the groundwater.
2. The second fact, is that abstraction of the groundwater is mainly of two types; *Aflaj* systems and pumping through wells.
3. The third fact is that over abstraction is getting worse in some major areas, for example Al Batinah region.

Based on these facts, the current governmental applied solutions are encouraged to be continued as long as they prove to be economically reliable. However, the solutions which have been already tried showed only a limited success (Zekri, 2008). The current water demand especially for agriculture consumption is still much higher than the groundwater recharge. Well owners pump as much as they want of water from the ground without any restriction (Al-Shaqsi, 2004). At the same time the process of changing from traditional flood irrigation to modern irrigation systems is going on, but it is very slow. According to the agricultural annual report (2014), in Oman 80% of the farms are irrigated by flood irrigation method, while only 20% of the farms are irrigated by modern irrigation systems (15% subsidies by the government and 5% by farmers' own efforts) (MAF, 2014).

From the above information, it can be concluded that law is not fully implemented in practice. Farmers are still pumping as much as they want from the groundwater aquifer, in spite that article No. 24-a in the (Official Gazette, 1995), states:

"The ministry shall specify the water quantity discharged from any well and may oblige the well owner to install a flow meter according to its specifications or may itself install the flow meter".

Meanwhile modern irrigation systems have not significantly contributed to water saving. Probably the irrigation efficiency has been improved, but most of the farmers might not be able to use the technology in the right way.

All this gives an indication that the integrated water resource management is not fully implemented in Oman. A major concern is how to raise particular society's involvement (Ibnouf & Abdel-Magid, 1994). Civil society organizations in Oman have a limited involvement in the designing of environmental policies and strategies. They have a minor role in environmental action and could be only reported in the field of awareness programs directed to students. Al Shaqsi (2004) reported that 62% of the water specialists, participated in the study he performed, admitted that there is a deficiency in water users' involvement in the management of water in Oman. This refers to socio-economic characteristics of the country and lack of the issue of capacity building. According to Subagadis (2015), the management has to consider different socio-economic and environmental issues as well as viewpoints of involved stakeholders. As well, Integration tools are needed to integrate diverse knowledge obtained from different relevant stakeholders, to support the decision making process in finding the most suitable management option(s).

The current situation might create problems and conflicts which can be summarized as follows:

- National (general) conflicts regarding balancing the food and water requirements.
- Conflicts between different stakeholders regarding water availability and profitable agricultural production in Al Batinah region.

To solve such complex problems an Integrated Water Resources Management (IWRM) approach is recommended, which allows for assessing different management options and interventions. This should include plans for water conservation and consumption in a suitable way to ensure its sustainability for the future generation.

3.3.3 Challenges Facing the Water Sector in Oman

The Sultanate has made great efforts in the field of water resources management to find a balance between supply and demand of water. However, its geographic location within the arid regions and its reliance on annual rains to recharge the limited water resources and the growing demand for water, is creating challenges for the water sector. Under water limited conditions, the issue of high profit and water conservation is contradicting (Grundmann et al., 2012; Subagadis et al., 2014).

Oman's water sector, in general, is facing six main challenges:

1. Challenges due to climatic conditions. This can be observed in the limitation of water resources. Rainfall events are very rare and the drought seasons are so long (Al-Ismaily & Probert, 1998).
2. Increasing in population and urban demand, which will generate pressure on the limited available water resources. This insists the need for further development of non-conventional water resources to cover the water deficit (e.g. desalination plant and waste water reuse management).
3. Water demand is increasing in all sectors, this led to *falaj* and well depletion because of excessive abstraction for domestic water and for agriculture. Many wells and springs were reported to be dry in the last 20 years and 42 monitoring *falaj* out of 525 monitored by (MRMWR) were reported dry-up since the year 2000.
4. Challenges in the problem of inefficient water use in agriculture, as many farmers still use the traditional system of surface irrigation that allows a considerable waste of water via evaporation and deep percolation.
5. The challenge, which is mainly the major challenge especially in Al Batinah coastal area, is the degradation of groundwater quality and saline water intrusion in the coastal aquifers.
6. The uncertainty in future climate development (Karajeh, 2014; Barfus & Bernhofer, 2014).

It worth mentioning here that, an expert-based assessment of water governance was undertaken by the United states Agency for International Development (USAID) in a rating session in Oman in December 2009. It was attended by 24 Omani experts belonging to different water-related organizations. From that it was concluded that potential challenges for Omani water sector are: the level of training and staff available to perform the assigned tasks in the water sector, the central government's coordination with regional authorities, and the forecasting and matching of supply and demand (USAID, 2010).

Regarding Al Batinah, water problems can be summarized as; water scarcity, sea water intrusion in the coastal area, lowering of groundwater levels and deterioration of *aflaj* systems and groundwater pollution as a fact of growing development activities. The main challenge now is how to control the problem of water shortage in South Al Batinah and at the same time increase agricultural production. The challenge is even more because the coastal aquifer agricultural hydro-system has an interaction with several relevant stakeholders (e.g. decision makers, farmers, etc.) which have different opinions and views about managing the system. Zekri (2010), stated that "*The phenomenon of groundwater salinization is most likely irreversible in the Batinah region due to the existence of depressions in the aquifers*". In order to assess the remediation potential of the groundwater aquifer in Al Batinah, Walther (2014) performed a stop pumping scenario by using a density driven groundwater flow model. He assumed that all pumping activities stopped by the year 2005, and run a simulation of the future scenario for 500 years period of time. The results showed that, after the first 100 years, the fresh water recharge from the mountainous plumes only partly reach the sea again and there was a slight refill in the aquifer storage. He concluded that the recovery time of the water levels is supposedly more than 100 years and even longer for the salinity (See Walther et al., 2014).

In general, approaches dealing with natural resource management mainly focus on drivers such as climate as the main cause of changes in a system rather than seek the cause and effect relationships. In Oman, decision makers in each organization are focusing on drive forward the 5 years development plans of the country, with preservation of available resources and creating mechanisms for optimal use. In this issue, the role of the private companies is contracted to build desalination plants and other water infrastructure. The government policy is oriented towards privatization of the water supply, mostly obtained from desalinated seawater (USAID, 2010).

The situation is very complex and it needs more knowledge and concerted efforts of the different stakeholders to be improved. It also needs a combination of different measures or management interventions (Subagadis et al. 2014). Moreover, to perform a successful water management, it is very important to evaluate the consequences of the management interventions from the social point of view, taking into account the reaction of the relevant stakeholders. Therefore, influencing the behavior and drivers affecting farmers' decision-making manner, could be a good tool to improve water demand management in the South Al Batinah region.

The work presented here is part of a cooperation project between MRMWR, in Oman, and TU Dresden, in Germany, for implementing an IWRM process in South Al-Batinah region. To consider the interactions and nonlinearities between the hydrologic, meteorological, agricultural and socio-economics systems in the region an integrated Assessment, Prognosis, Planning and Management-Tool (APPM) was developed and customized on the specific characteristics of the region (Schmitz et al., 2010; Grundmann et al., 2012).

This work intends to explain the dilemma of limitation in successes of the already applied solutions with respect to the behavior of the stakeholders. It outlines how integrated water resource management can encompass social issues. It elaborates ways for prediction and estimation of the implementation potential of selected interventions by analyzing opinions and responses of the relevant stakeholders. It is an attempt to bring closer the views of the stakeholders to achieve the goal of accepting the proposed interventions gradually. This should support water conservation strategies and help decision makers to make rational decisions, especially those made under conditions of uncertainty.

4 Methodology

4.1 A New Methodology Framework for the Assessment and Modeling of Stakeholder Participation

Seawater intrusion into the coastal aquifer systems is one of the major sources of concern in many coastal areas in arid and semi-arid countries. The problem has impacts on agricultural and the economic basis of farmers in such regions.

Managing and maintaining such systems is very complex and surrounded by uncertainties. The reason is that they consist of many components (social, economic, environmental, etc.) and multitude of stakeholders who might have conflicting interests and needs or even vision for managing the system. In the field of water resources management, there is a lack of tools to quantify the impacts and consequences of management interventions. Therefore, integrated approaches are required, which can facilitate communication and knowledge transmission between the relevant stakeholders of a system.

In Oman, the problem of sea water intrusion into the coastal aquifer system of the Al Batinah coastal area, as a result of over abstraction, has been addressed by the Government since the beginning of the 1990s. However, the water situation in the region is still at risk and the sea water intrusion inland is expanding over time. Therefore, the region is facing a problem of water deficit which also impacts the sustainability of the agricultural production.

Several possible solutions were tried by the government. For example, the expansion of agriculture is stopped and a ban on construction of new wells is strictly enforced. On the other hand, a construction of several recharge dams has taken place in the *Wadi* channels in order to minimize the freshwater losses during flash floods. Such solutions are essential, but have shown only a limited success (Zekri, 2008). Such solutions alone are not enough and might take a long time to show a clear success. In addition to that, water resources management is under responsibility of two ministries (MAF, 2012). The MRMWR which is responsible for controlling actual access and abstraction of natural water use, and MAF which is responsible for water use in agriculture including irrigation management (see Section 3.3.1). Moreover, human behavior is not taken into consideration in water management (see Section 3.3.2).

There is thus a need for new tools to integrate knowledge of diverse stakeholders and multiple issues in such type of a common resource system. These tools are necessary to help decision makers to assess the potential impact of implementing different management alternatives.

This chapter describes, in details, the methodology framework (see Figure 9) used for mapping human behavior and opinions in regard to agriculture and water management for the case of South Al Batinah region in Oman.

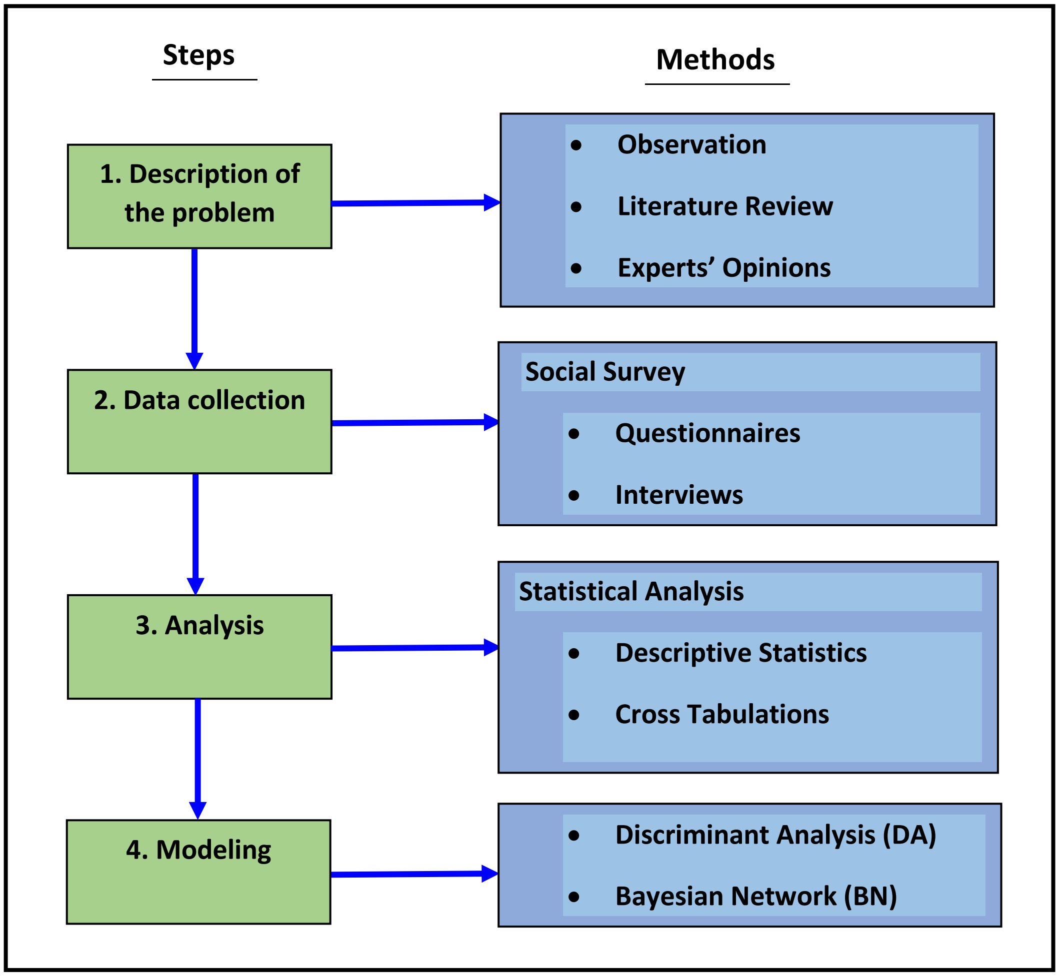


Figure 9: Methodology framework for human behavior and opinions in agriculture and water management for the Omani case, South Al Batinah

Based on the information obtained in Chapters 2 and 3, and to try to answer the research questions (see Chapter 1), a methodology framework for the Omani case was proposed. The new methodology proposed here, allows to combine both social analysis and technical analysis. From the description and evaluation of the problem, it is concluded why the previous interventions applied to control the salinity problem in Al Batinah, have not fully succeeded and the impact was very limited. Data collection and analysis are necessary to facilitate understanding of stakeholders' opinions and ideas about agriculture and the salinity problem in South Al Batinah and how will they behave in the light of different management interventions. The analysis and modeling parts spot the light on how behavior change can contribute in improving the probability of an intervention to be implemented.

As it is seen in Figure 9, the framework includes four major steps:

Step 1: Description of the problem

The work starts with a description of the problem using the available data and information from observations, literatures, and experts' opinions. This part reflects how human behavior can have impacts on natural resources.

Step 2: Data, information and knowledge collection

This task is done by performing a social survey. Questionnaires are designed for the purpose of collecting data from different groups of stakeholders e.g. water professionals, farmers from the study area and decision makers of different organizations.

Two different procedures are followed. The first one is distributing the questionnaires either hand to hand or by mails to the group of water professionals in different relevant organizations and research centers. The second one is interviews, which are used to collect data and information from farmers within the selected study area. Those data and information are important to quantify the impacts.

Step 3: Data analysis

The following step is data analysis, where data are analysed statistically by applying descriptive statistics, cross tabulation and independent samples T-test. Descriptive statistics such as frequencies, means, medians, standard deviation (SD), correlation and percentages are used to analyse the answers of particular questions. Cross tabulation tables, which are known as well as contingency tables, are used to display the relationships between two or more variables. They are helpful in understanding whether or not some variables have an effect on others. Both; step 2 and 3, are performed in order to explore if the impacts, which are the consequences of potential management interventions, can be quantified.

Step 4: Modeling

This is an advanced step, to explore if models can be used to reproduce the relations in the data, and for allowing future forecast. In other words, to forecast how the different groups of stakeholders will behave with changing conditions.

The modeling part includes two different analysis:

1. **Discriminant Analysis (DA)**, which is performed to identify the drivers influencing farmers' opinions regarding different intervention measures.
2. **Bayesian Network (BN)**, which is an approach used for mapping stakeholders' behaviors and to analyse the strength of a relationship between dependent and predictor variables. BNs are presented in an easily understandable graphical structure which can also incorporate uncertainties.

The new framework is validated using an application in the Batinah region in Oman. The problem under consideration is that the groundwater system is damaged by salinity which feeds back to agriculture by reduced crop yields and to the society which loses its connection to water of good quality (see Chapter3). Therefore, for the Al Batinah regional development, societal, environmental, and economic aspects need to be considered for evaluating appropriate management options.

4.2 Data Collection

4.2.1 Stakeholders Identification

For this particular work, the stakeholders are identified to be the irrigation water users from the selected study area in South Al Batinah, water experts from the water and agricultural organizations, and water professionals from different research organizations.

4.2.2 Development of the Questionnaires

Questionnaires are fundamental in collecting data (quantitative and qualitative) and explore opinions of different stakeholders in a domain of interest. Two different types of questionnaires were developed for this work; one for farmers and the other for decision makers (DM's) and water professionals.

A Long list of questions (around 50 questions) was created for the purpose of designing the questionnaires. The questions were evaluated and reviewed by experts through meetings and mails. After that, the data and information which are needed, for the research purpose, were decided and the questionnaires were developed. The total number of questions in the questionnaire for farmers is 36 [Appendix A.1] while the number of questions in the decision makers' questionnaire is 20 [Appendix A.2].

4.2.2.1 Structure of the Questionnaires

The information collected for this work is a combination of environmental, social and economic data. Following are the type of information which was decided to be collected for the study purposes:

- Information related to water availability and water quality
- Farm size, irrigation sources, and irrigation methods
- Information related to opinions of farmers and DM's
- Information related to knowledge about water and agricultural management
- Information related to training and subsidies
- Information related to suitable interventions and stakeholders participation in water management

After deciding where and who can provide these information, the groups of involved participants were identified. For this Thesis, two groups were defined; farmers from the study area and decision makers from different related organizations.

The type of questions included in the questionnaires were; selective questions, rating questions, filling gaps and open questions. For each questionnaire four sections were determined according to the information needed. Each section is grouping (categorising) a certain type of information. In the questionnaire for farmers, there was a section for the farm survey. This was not included in the DM's questionnaire. There was no need for this section in DM's questionnaires since they are not the farm owners. Also, there was a section in DM's questionnaires which is dealing with water resource and agricultural management which is not included in farmers' questionnaires. The purpose was to explore the orientation of DM's regarding ways to encourage farmers to change the agricultural management behaviors.

The sections in the questionnaire for farmers include:

1. General information; these are the demographic data in relation to age, educational levels, knowledge and experience in water and agricultural management.
2. Farm survey; these are information regarding water resources and agricultural management in the farms.
3. Ideas and opinions; believes and faith of farmers regarding the water problems in general, and the suitable management options in particular.

4. The vision for future; farmers’ expectation for future and their tendencies for the farm management.

The sections included in the questionnaires for decision makers were:

1. General information, these are the demographic data in relation to age, educational levels, and period of experience in the field of interest.
2. Ideas and opinions; believes of DM’s regarding the solution of water problems, obstacles facing implementation of management options, and the needs of farmers to improve agricultural sustainability.
3. Water resources and agricultural management; their orientation regarding ways to encourage farmers to change the agricultural management behaviors.
4. Vision for future; their expectation for the future of agriculture and irrigation water management in South Al Batinah.

The preliminary questionnaires were tested with 15 selected stakeholders. After performing the pre-test survey, the questionnaires were reviewed and improved based on the feedbacks. Finally a social field survey performed was accomplished by the support of MRMWR and MAF.

4.2.2.2 List of Interventions for Agriculture and Water Management

The main goal, for the management interventions, is that groundwater levels are to be stabilized in conjunction with maintaining social and economic interests of the relevant stakeholders. Based on this idea, a list of interventions was constructed.

The list of the intervention was constructed based on different sources;

- Some are from the literature review and were used in similar studies, not only in Oman, but also in different other regions.
- Some of them are already applied in Oman.
- Some of them are suggestions from expert consultation through the project meetings and discussions (expert knowledge).
- Some of them are results of an analysis of a pre-test survey

The general specifications of the management options and interventions either focus on water demand side measures (e.g. an implementation of water quotas, and subsidies) to reduce water consumption and use the resources more efficiently, or on water resources side measures (e.g. climate conditions and artificial recharge) to increase the availability of water.

At the end there was a group discussion during the research meetings with experts and professionals about which interventions might be suitable for the region. Furthermore, the justification for each of the intervention option, included in the study, was discussed with some relevant experts and decision makers in Oman.

Some of the interventions were combined with subsidies in the form of training or modern irrigation equipment. The reason was to explore if subsidies have an impact on the behavior of farmers and their opinions or responses to the water conservation strategies.

The list of interventions was provided to the farmers and the DM's, and they were asked to give their opinions. Furthermore, the list was provided again to the DM's, in order to ask them, based on their opinions, how farmers would answer. The repetition aims to find out if DM's are aware and familiar with farmers' thinking, ideas, and opinions.

4.2.3 Pre-Test Survey

Questionnaires were used in the field during a pre-test survey to make sure that the questions included are clear to the participants, and to collect any additional information required for the work. This step was important for the improvement of the questionnaires in general, and improving the list of possible management interventions in particular. Additionally, the validity of each question was established by asking experts opinions with experience in water and agricultural management.

After that a conclusion was drawn with some suggestions for improvement.

During the pre-test the questionnaires were distributed to 15 participants:

- 10 to decision makers and water professionals (From MRMWR, MAF and Public Authority for Electricity and Water (PAER).
- 5 to farmers (2 from Barka and 3 from Musa'ana').

Here it is worth mentioning that the questionnaires are prepared in English and some farmers are not familiar with the language. A translation to Arabic was also not appropriate since some farmers are not educated. Moreover, it was important to make sure that every question is clear to the farmers.

Therefore, structured interviews were used, based on the questionnaires, to collect the data from the group of farmers.

It was noticed that interviews were taking longer time than what was suggested, as well as participants were not available in one place, and sometimes arrangements were needed to meet them. Therefore, a need of support was required from the MRMWR in Oman, at least 2 staff were needed to be involved in the interviews performance.

At this stage, the sample of participants, representing DM's, were obtained only from three organizations which are not giving enough picture of DM's opinions. For the survey (survey of this work) more participants are needed to represent, at least most of, the related organizations. Therefore, a list of employers in water and agricultural management was requested from the personal department in each involved organization.

4.2.4 Procedure of the Survey

The data collection period was decided to be two months. To ensure the success of the data collection process contacts were made with Ministry of Regional Municipality and Water Resources (MRMWR), and Ministry of Agriculture and Fisheries (MAF) in Oman.

To collect data and information from the field, the following steps were followed:

Step 1: Distributing the questionnaires to the decision makers and water professionals in different water and agricultural organizations. Sometimes a permission was needed in order to arrange meetings with some senior staff in each involved organization. Therefore, an official letter from the Ministry of Regional Municipalities and Water Resources (MRMWR) including an explanation and purpose of the research was provided to facilitate the meetings. The distribution and meetings were completed in two weeks. This process was done without the support of the two staff from MRMWR.

Step 2: Collecting the questionnaires from the participants. This work was completed in two weeks, at the end of the survey period.

Step 3: Two staff were provided by the Ministry of Regional Municipalities and Water Resources to be involved and to support the data collection via interviews with farmers. The two staff were trained, by the researcher, on how to carry out the survey. The training process was performed in one week.

Step 4: Visiting and interviewing farmers in both *Wilayat*, Al Musa'ana' and Barka (Wadi Al Maawil and Wadi Bani Kharus). This was done through special arrangements with the Ministry of Agriculture and Fisheries (MAF) to facilitate meetings with the farmers. Face to face interviews were used with farmers and they were semi-structured in-depth interviews. Interviewees were contacted by phone to arrange visiting periods in their farms. Some meetings were arranged to be in the agricultural centers of the *Wilaya.* The average time of each interview ranged from 30 to 40 minutes. Arrangements, visiting and interviews were completed in four weeks.

4.2.5 Sampling Size Requirements

The sample size requirements were decided with taking into account the following points:

- What are the categories of participants needed to represent the study area (Farmers) and to represent the related organizations (Decision makers or water experts)
- How many samples are required in each category?

The sampling size is considered to be important in many studies, especially social ones. For this Thesis, a list of farmers was provided by the Ministry of Agriculture and Fisheries for each *Wilaya*. The sampling size was discussed through meetings with a social scientist.

In Oman, farmers who are looking for support or subsidies have to register themselves (MAF, 2012) in the agricultural centers belonging to their villages (see Sections 3.2.3 and 3.3.2). In this regard, lists of farmers, for the selected Wilayat of the study, were provided by the Ministry of Agriculture and Fisheries (MAF). Since the registered number of farmers was only 33 in Barka and 45 in Musa'ana', the best way was to randomly cover as much as possible farmers from the given lists[2]. Decision makers and water professionals, were also selected randomly and meetings were held and mails were sent to as many as possible. One of the important issues was to cover as many organizations (see Table 4, Section 3.3.1) as possible in the county.

At the end, the decided sample sizes were to be:

- 60 Farmers, from Barka and Musa'ana' (wadi Bani Kharus and Wadi Al Ma'awil)
- 30 water professionals and
- 30 decision makers (DM's) from relevant organizations

[2] In fact these numbers does not reflect the real number of farmers in the region. The analysis consists of the registered farmers only.

The total number of respondents should be at least 120 participants, taking into account that participants are representative of all existing viewpoints.

4.3 Data Analysis

4.3.1 Descriptive statistical analysis

Data were analysed statistically for each group separately as well as regarding relations amongst groups by using the SPSS (Statistical Package for Social Science) software package (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.).

The collected data were used to create a large spreadsheet in SPSS. The qualitative data were identified by special cods in order to be used in the analysis.

In SPSS there is a step prior to the entering of data from the questionnaire to the computer for the purpose of analysis which is a coding. Each participant was given a code in the table, and each group was identified by a special code. The answers for each questions were also given a code. For example if the answer of a particular question is “Male” or “Female”, the code could be 1 for the answers including “Male” and 2 for the answers including “Female”. Always the coding process starting with 1.

After that, Descriptive statistics such as frequencies, means, medians and percentages (Abebe et al., 2001) were used to analyse the answers to particular questions.

4.3.2 Hypothesis Test

Independent Sample T-test is used, which allows comparing the means for two different groups to find out whether the difference between group means is statistically significant. Differences were examined between opinions of the farmers and decision makers (DM’s) regarding the potential interventions. The null hypothesis (H_0) was that; there is no differences between the mean score of opinions of the group of farmers and the group of DM’s. The alternative hypothesis (H_1) was that; there is differences between the mean score of opinions of the group of farmers and the group of DM’s. A significance or alpha (α) level is specified to be at 0.05 (5%). To perform the test, P-values was calculated to decide if the hypothesis is accepted or rejected. For this work, level of significance was considered high if the P-value ≤ 0.01, medium if the P-value is between 0.01 and 0.05 and not significant (ns) if P-value ≥ 0.05.

P values were calculated using (Eq. 2).

$$p = 2\Phi(\bar{X} - \mu_0)/\frac{\sigma}{\sqrt{n}} \quad (1)$$

Where μ_0 is the hypothesized mean, σ is the population standard deviation, $\bar{X}$ is the sample mean and n is the sample size. The test was performed as a 2-tailed test (2Φ).

The results from this test should be able to answer the following questions:

1. Are there any differences between the opinions of farmers and decision makers regarding the interventions measures?
2. Are there any differences between farmers' actual opinions and what decision makers believe about farmers' behaviors and opinions?

Therefore the test was repeated once again to explore the thinking of decision makers and what do they believe about farmers' behaviors and opinions. The null hypothesis (H_0) was that; there is no differences between the mean score of farmers' actual opinions and what decision makers believe about farmers. The alternative hypothesis (H_1) was that; there is differences between the mean score of farmers' actual opinions and what decision makers believe about farmers.

4.3.3 Cross Tabulation

Cross tabulation tables, which are known as well as contingency tables, are used to display the relationships between two or more variables. They are helpful in understanding whether or not some variables have an effect on others.

In this work the cross tabulations were used to explore the relationships between a particular parameter (e.g. Age, level of salinity in the farm, farm size), and the implementation of three deferent (two of them are combined with subsidies) options of water quota for the groundwater used for irrigation purposes.

4.4 Modeling

4.4.1 Discriminant Analysis (DA)

Discriminant function Analysis (DA) is a statistical technique used for classifying observations (Klecka, 1980). It is similar to multiple linear regression in predicting outcomes. The difference is, multiple linear regression is limited. It is only used in cases where the dependent variable is continuous, while in many research works the interesting variables are categorical. It is a parametric technique to determine which weightings of quantitative variables (or predictors) best discriminate between two or more than two groups of cases (Cramer, 2005).

There are several purposes of DA, it is a statistical way of deriving a mathematical model for prediction. It can also be used to investigate differences between categories within the same group and explore the parameter playing a role in the process of separation. In this regard, Ramayah (2010) stated that *"Caution must be taken to be clear that sometimes the focus of the analysis is not to predict but to explain the relationship"*.

The analysis is performed in three steps:

Step 1: Data preparation

The observations of the group of farmers were classified according to their opinions. For each intervention, the group was classified to farmers who agreed with that particular intervention or disagree.

For this type of test, they must be at least two groups or categories for each grouping variable. The one performed, in this Thesis, is a simple test with only two groups at a time (Agree and Disagree).

Step 2: Selection of indicators

A list of indicators which thought to be good discriminators between those agree or disagree groups, is generated. It is important to mention here that during this stage, only items that describe the farm, water situation and the farmer himself are included. The items refer to farmers' opinions are not included. That is because the analysis focuses more on the items shaping the farmers' behavior and might play a role in driving their opinions. The indicators should be independent, and not strongly correlated.

At the beginning the list included many variables, but some were correlated to each others and play the same role during the analysis e.g. salinity range and distance from the sea. Therefore, some of them are excluded and the list ended up with only the independent ones.

The analysis was applied to one intervention at a time. This intervention is considered to be the grouping variable or dependent variable (DV) and the indicators are the Independent variable (IV's).

Step 3: Application of the method

DA is used to address the question of what was the variable which attributes or contributes most to group separation.

To apply the method, there are two options: ‘Enter Independents Together’ and ‘Use Stepwise Method‘. For this work, both of them were selected each at a time. For evaluating the results, a Canonical Correlation Analysis (CCA) was used (see Christensen, 1983). A canonical correlation analysis is describing the relationship between the discriminator selected from the set of independent variables (IV’s) and the dependent variables (DV).

4.4.2 Bayesian Network Modeling

Bayesian Networks (BNs) are one of the techniques used to represent a probabilistic dependency model. They are graphical models for reasoning under uncertainty in a domain (Ticehurst et al., 2011). The graph consists of nodes and arcs as a part, but there is another hidden part which is a set of local conditional probability distributions (see Figure 10). The two parts together are able to represent the joint probability distribution of a domain and explain or show the cause and effect between the variables and outcomes throughout the network. Therefore, the basic idea of BNs is Probabilistic reasoning. It is a graphical way of representing a probabilistic dependency model. The main elements of a BN, which can be seen in Figure 10, are described below:

- **Variables (Nodes):** Each network consists of various types of nodes (parents, intermediate, and children). Any node without a parent is a root node (input), while any node without children is a leaf node (output). Any other node (non-leaf and non-root) is called an intermediate node (Korb & Nicholson, 2010). A parent node is the node that has causal influence or effect over the node in question. For this reason, ordering the variables is very important during constructing the network. Both root and leaf nodes are terminal nodes. This means that root nodes represent original causes (departure terminal), while leaf nodes represent final effects (destination terminal).
- **Causal relationships between the variables (Links)**: In general, causality is not a well understood concept and it is not easy to establish causal relationships. The main reason why it is difficult to establish causal relationships is that it cannot actually be observed when one phenomenon producing change in another. Even though one event might always follow another, we do not know that this is because one event causes the other (de Vaues, 2001). Therefore most of the time causal relationships are formed by inferences rather than observations. In causal relationships, two criteria must be met. First, there must be co-variation of causal and outcome variables and the second, the assertion that variable affects the other must make sense (de

Vaues, 2001). It is very important in forming causal relationships that the cause come before the effect. So during building a causal network, the causal variable should occur before the presumed effect in the chain of variables. In some relationships, it is even difficult to work out which variable comes first in the system.

- **Conditional Probability Tables (CPTs):** For each variable which is connected (by a link) to a parent, a conditional probability table (CPT) has to be attached to it. This table is representing the relationship between the node (variable) and its parents based on a prior information or knowledge and experience. The table should include all the possible combinations between the values of the node of interest and values of its parents' nodes. The states of a node can be binary values e.g. true (T) and false (F) which represents propositions and the node known as Boolean nodes. The values can also be ordinal values e.g. (low, medium, high). Finally, states might represent measurable values of ranges e.g. (Age from 1 to 20), these are integral values (Korb & Nicholson, 2010). The variables can be discrete or continuous and the connections can be; serial, diverging or converging. Each variable has to have a finite set of states and the total of probability values of the states in each classification should be 1.

The structure of the network can be either based on experts' knowledge (manual construction) or on a source of data and information, which can be used automatically to develop the network (automatic construction). The construction process is also known as 'learning' (Horný, 2014). Automatically learning, is to learn the network from databases using experience-based algorithms, which are often built-in appropriate software (Lucas et al., 2004).

BNs are one type of techniques of using computer technology for dealing with probabilities to integrate data, experience, knowledge and information along with their uncertainties from different sources. They provide a useful tool for inferring hypotheses from the available information by transmitting probabilistic information from the data to various hypotheses (Suermondt, 1992). This is referred to as probabilistic reasoning, i.e.:

Assume the events are A and B respectively, than "the probability of A given B"

$p(A|B)$

Rule for Conditional Probability:

$p(A|B)=p(B)p(A\cap B)$

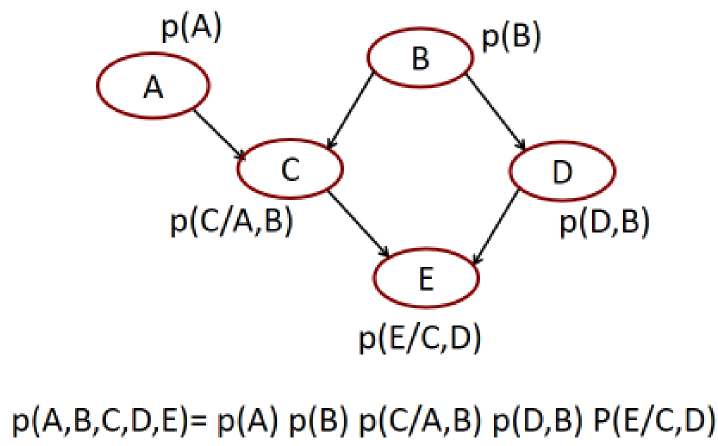


Figure 10: An example of a simple Bayesian network formed by five variables with the corresponding factorisation of the joint probability distribution of the nodes

Figure 10 shows an example of a simple probability Bayesian network formed by five variables and corresponding factorisation of the joint probability distribution of all nodes.

For this particular work, a BN is introduced as an explanation and modeling method, to evaluate and explore the degree of implementation potential of certain types of management options in Al Batinah. This is done through simulation of scenarios for implementation and acceptance of management interventions. In other words, it is a tool for evaluating the uncertainty about the acceptance of the management strategies by the society. Furthermore, the output can be analysed to identify how the acceptance can be influenced.

The output quantifies the degree of acceptance of a certain management intervention. The intervention can then be used as an indicator in a wider decision support matrix on how farmers, in the study area, will behave if some adjustments are made to some variable in the network.

Ticehurst (2009), argued that if sufficient data are available, there are software packages that can be used to learn the structure of the BN from the data alone. Fortunately the data obtained during the survey were considered to be sufficient for developing the network. The network was developed by using GeNIe (Graphical Network Interface) software[3], which is a development environment for building decision networks.

[3] (http://genie.sis.pitt.edu/)

The network is constructed manually, based on experts' opinions on factors that are believed to be affecting farmers' decision regarding implementation of certain interventions. Variables included represent the economic situation, water resource situation, knowledge situation and trust or confidence situation of the community.

The technique used is based on a probabilistic method. Conditional probability approaches are useful to be used as criteria for inferring cause. Probabilistic approaches to causation are those that argue that a given factor increases (or decreases) the probability of a particular outcome (de Vaues, 2001).

The BN was developed by following six major steps. These are almost similar steps used by Ticehurst (2011) (see Figure 11).

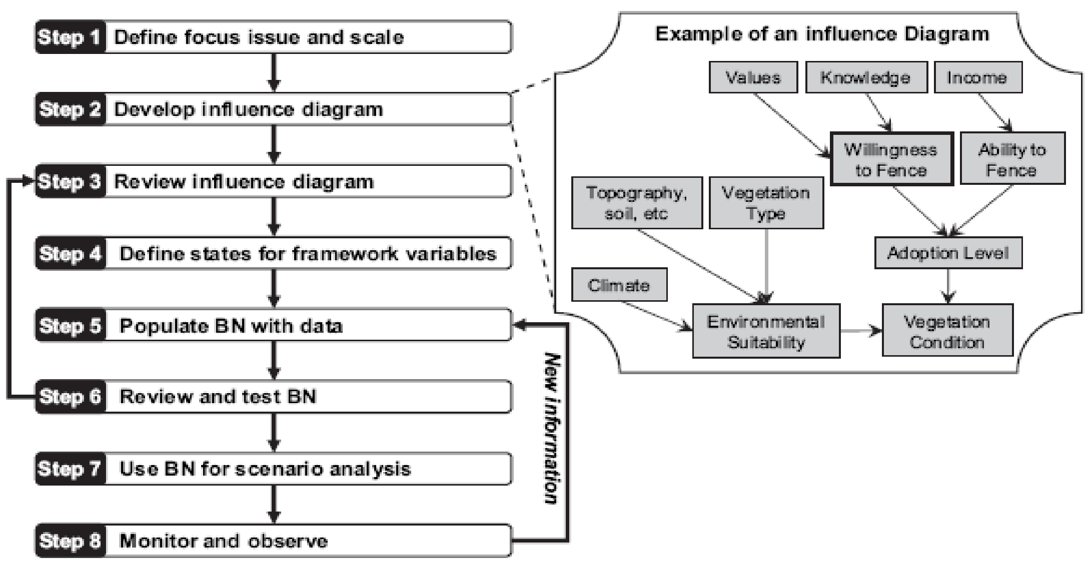


Figure 11: An example of typical steps for designing a BN (After Ticehurst (2011))

Step 1: Define focus issue

The list of collected interventions is reviewed and narrowed down, to determine which of the interventions can be considered during developing the BN. This ended up with the selection of implementation of water quota (WQ) to be the intervention analysed through the network.

Step 2: Develop influence diagram (Manual step of determination of the variables and conditions)

This step started with a map which is also known as an influence diagram. Variables and links among them were assigned and a proposed BN map was developed. After that, the map is used in the step of validation of the BN structure. The BN should not miss the important variables and their dependence.

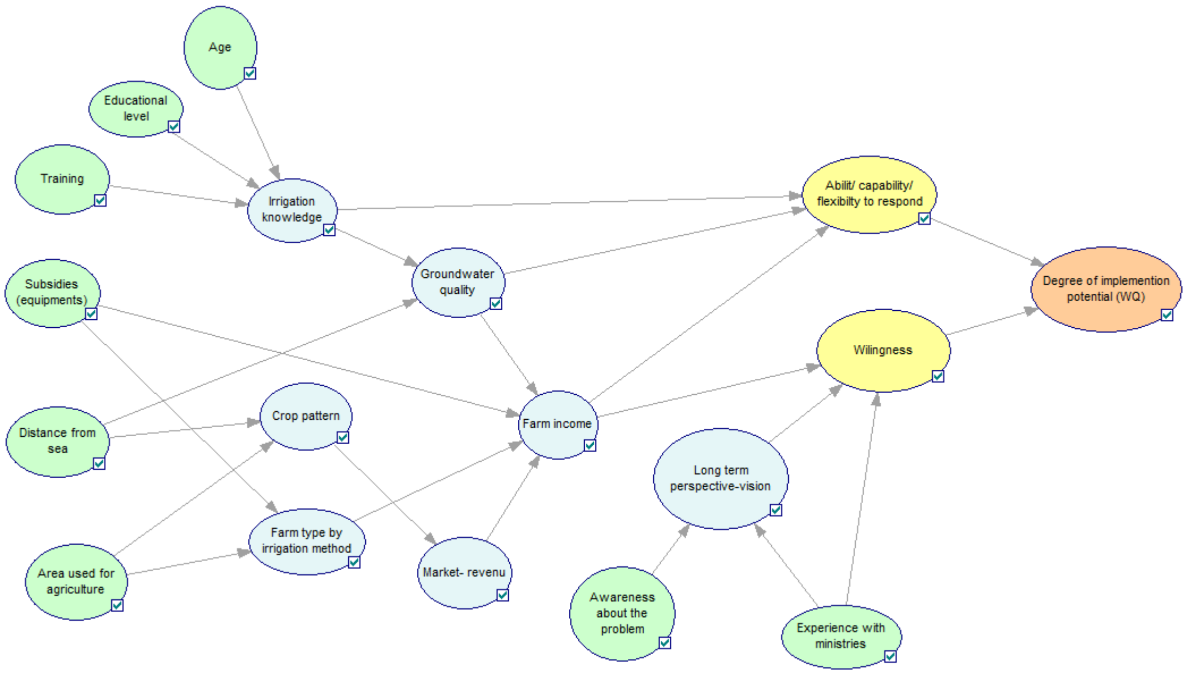


Figure 12: The suggested influence diagram for the Batinah case

An influence diagram illustrating the variables, which may contribute in shaping farmers' willingness and ability or capability to change and respond is illustrated in Figure 12. The input variables are green in colour, the intermediate variables are in blue, the sub-output variables are in yellow and the output variable is in orange.

Step 3: Review influence diagram (Validation of the structure of the BN)

During performing the pre-test survey (see Section 4.2.3), an example of the proposed BN was distributed to the water experts and decision makers from different water related ministries (e.g. MRMWR, MAF, MECA, PAEW) in Oman. This is done for the purpose of discussion and obtaining experts' opinions. The feedbacks should enable the validation of both; the variables included in the network and the links between the variables.

Step 4: Define states for the framework variables (Assignment of conditional probabilities to input/output variables and learning of CPT for the manual variables)

Data collected through the survey, were used to develop a spreadsheet (generate data file in GeNIe) containing data and information for each variable in the network. The spreadsheet was directly constructed from the responses to the survey questions that were relevant to the management options. Then the relationships between variables are quantified by conditional probability distributions.

After the assignment of the probability values, the data in the spreadsheet were merged with the network. The full network then consists of the three main elements mentioned above:

- The variables that represent the factors relevant to the implementation of a particular intervention measure.
- The relationships between the variables that quantify the links between them.
- The Conditional Probability Tables (CPTs), which are used to calculate the states of the variables.

The first two elements can be seen from the BN diagram, while the third element is hidden behind.

Step 5 and 6: Validation of the variables and links between variables (Performance of the BN)

Running of the method should allow investigating the linkage and feedbacks between hydrological and socio-economic interactions for the management problem of Al Batinah. After the developing and constructing the BN and justification of all variables and links are done, the first simulation was run. This was done to evaluate if the network represents the current situation and the outputs (re-production) are similar to the ones obtained by statistical analysis. The results obtained from the first simulation are compared to the statistical results obtained from analysing the intervention table. This is how the performance of the network was validated.

Step 7 and 8: Sensitivity analysis -Monitor and observe

Afterwards, the model is used for further simulation to investigate the effects of the selected variables on implementation and acceptance of interventions, which is the final goal in the network.

Hypothesis: Identify how the network should behave if some adjustments are made to some variable.

A sensitivity analysis was performed for some variables in the network. This helps to rank the influence of those variables, in the network, on the variable of interest.

5 Results

5.1 Overview of the Survey

5.1.1 Population Characteristics

The study population consisted of 131 respondent, combining 64 farmers from the study area, 12 water professionals from different research centers, and 55 water experts from different relevant organizations. Figure 13 represents the percentage of each group.

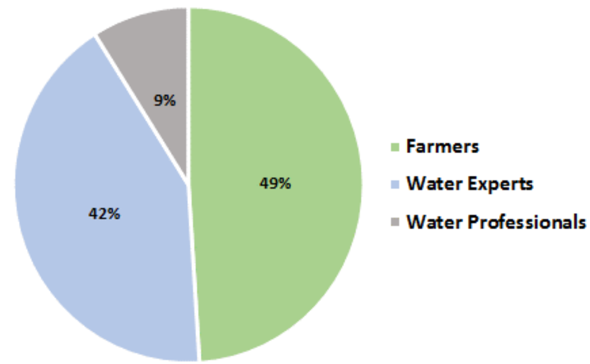


Figure 13: The study population in percentage

Since the group of water professionals was too small and for the analysis purposes, water professionals were combined together with the group of water experts to be treated as one group.

The group of farmers (n=64), 37 from *Wilaya*[4] 'Al Musa'ana' and 27 from *Wilaya* 'Barka'. The survey covered at least 80% of the total number of farmers in each list, of the two selected *Wilayat,* provided earlier (see Section 4.2.5) by Ministry of Agriculture and Fisheries. Those are considered to be the irrigation water users. Around one third (30%) of them are old age farmers, whom their ages are above 65 (Figure 14). While, both of the percentages of farmers in the category of 'below 30 yrs.' and the category of '(30-44 yrs.)' are very low, 12% and 6% respectively. The low proportion of young farmers indicates that agriculture is no longer attracting young people in the region. This fact was also mentioned by Zekri (2010).

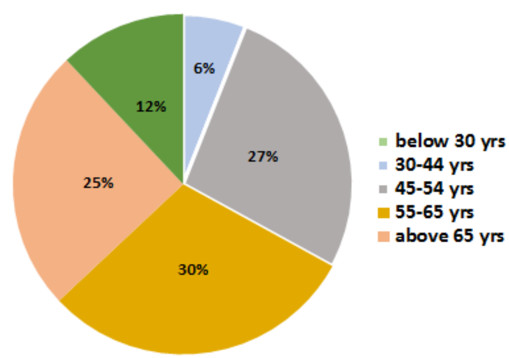


Figure 14: Age of farmers

Nearly one third of the farmers are either uneducated at all, or only read and write. Furthermore, 24% of the farmers received only primary school education (Figure 15).

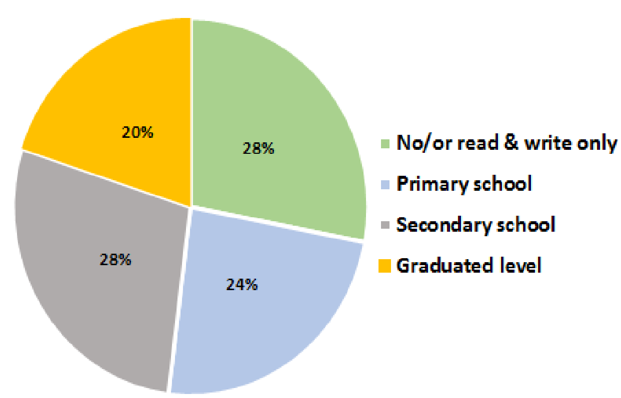


Figure 15: Farmers' educational levels

[4] Wilaya (Arabic) – administrative region (Plural: Wilayat)

Additionally, it is worth here mentioning that the sample includes only male farmers or farm owners, females did not contribute in this survey.

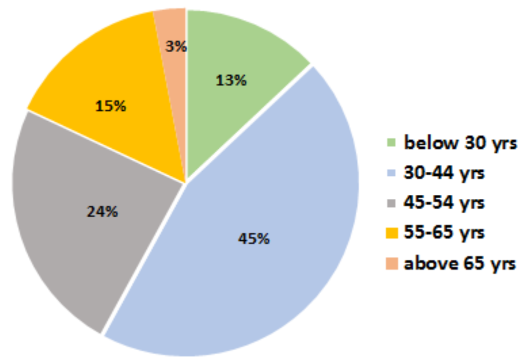


Figure 16: Age of DM's

Questionnaires were handled and sent by mails to 84 decision makers, with 79% response rate. The group of decision makers includes 67 respondent from different fields of interest (e. g. groundwater, agricultural water use, water resources management and planning, surface and sub-surface hydrology, climate change, environment protection, and others). Most of them are post graduated (around 61%) and are senior employers in the involved ministries and research centers. Around 69% of them are between 30 and 55 years old (Figure 16). The majority (23) were from MRMWR, 19 from PAEW, 8 from MAF, 5 from MECA and 12 from different research organizations. As mentioned earlier, for the purpose of presenting the results, water professionals are combined together with the water experts, and this group is called as decision makers (DM's).

5.1.2 Lessons Learned from the Survey

In general most of the participants were good in responding and were given the choice to write their own opinions and suggestions. The questions were clear, understandable and straightforward with a minor exception of few questions. The following points are raised as lessons learned from the test:

1. It was found out that the introduction [see Appendix A.1] on top of every questionnaire was useful, that gave the respondent a chance to understand the questions and the purpose of the research.
2. Few questions were not very clear to the participants. Especially those who were just filling the forms alone.
3. Some of the participants took so long time to fill the questionnaires and some of them (only 2) lost the forms.
4. Few of the participants were not serious in answering the questions especially the open-ended questions. It is obvious that questionnaires were filled in a hurried way.

5. Participants should be from all, or at least most of the related organizations. For the pre-test the samples of participants were only from 3 organizations which is not giving the full picture of decision maker's opinions.
6. In this survey, the interview was used as a supplementary tool to the questionnaire survey for two reasons; the first one is to make sure that every question is clear to the farmer and the second reason is that it was prepared in English and some farmers are not familiar with the language.
7. The self – completed questionnaires by the researcher were better, it was easy to clarify the answer immediately from the participant and it was a quick way of receiving the information. It was even an opportunity to ask the farmers more questions rather than the one in the questionnaire. On the other hand, filling the questionnaires by a respondent gives him a feeling of anonymity compared to interviews.
8. It is important for the researcher, during the interview, to avoid the problem of giving an impression to the respondent that there is a particular he should give rather than the one he believes.
9. Two of the farmers did not come in the right time. Those farmers had hesitation in cooperation.
10. 52% of the farms were in the same range of size. It is important to follow a good strategy in collecting the information, e.g. what are the appropriate sizes of farms needed for the research.
11. The time was limited as the participants were not available in one place, and for some of them appointments were arranged to have a chance to meet them. Another thing is that they needed some time to fill the questionnaires. Some of them asked for one to two weeks.
12. It is important to choose the right season during the year to carry out the questionnaire survey. In Oman, during the hot seasons, it is very difficult to conduct a field survey for both the researcher and the respondents.

5.2 Situation of the Agriculture in the Study Area

5.2.1 Farm Size, Location and Purpose

Most of the registered farms in the study area are small scaled farms and the sizes range between less than 10 fd to 30 fd. Figure 17 illustrates the different classes of farm sizes in the study area and the percentage of the number of farms in each class. Majority of the farms (52%) are less than 10 fd in size[5].

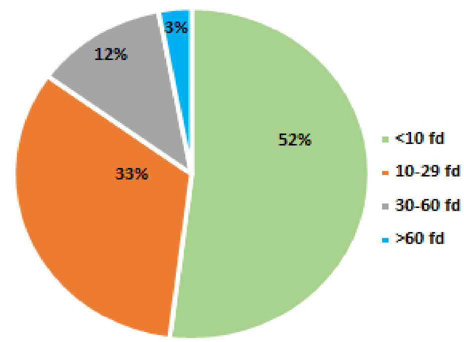


Figure 17: Classes of farm sizes in the study area

84% of the farmers reported that they are the owners of the farms and are taking care of them by themselves. 10% mentioned that the farm which they are taking care of, belongs to one of the relatives, and 6% said that they are renting their farms to others for agricultural use. The farms of the survey (Figure18), are mainly used for food production (71%). Only 2% are used for family gatherings during vacation seasons. Some farmers (around 27%) reported that their farms are used for both agriculture and family gathering.

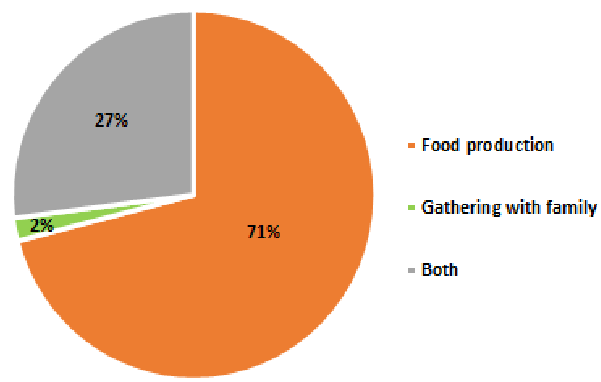


Figure 18: Farm purpose

Farmers were asked to determine the approximate distance form their farms to the sea. The results showed that 96% of the farmers are fully aware about the distance of their farms from the sea and if the saline water affects the agriculture management

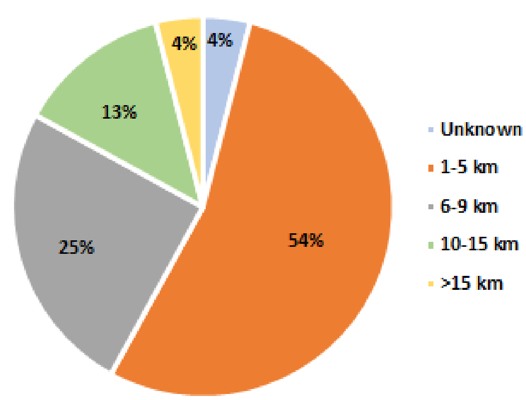


Figure 19: Distance from Sea

[5] According to MAF (2012), 85% of the farm sizes in Al Batina are less than 5 feddans. Compared to the sample, the registered farms are larger in size.

or not. It is noticed from Figure 19 that most of these farms (54%) are located between 1 and 5 km only from the sea. Only 4% of them are 15 km or above far from the sea. This means that the farms are highly subjected to be affected by salinity problems. This is consistent with information gathered in chapter three in which; there has been substantial deterioration in the water quality and reduction in areas of suitable water for agriculture use within the Wadi Bani Kharus and Ma'awil (see Chapter 3).

5.2.2 Cultivation and Irrigation

Farmers were asked to identify the percentage of the cultivated area in their farms. The results are represented in Figure 20, where it is noticed that more than one third of the farms (39%) are laying in the category of 90 to 100%, which means almost all of the farm area is cultivated. It is also noticed that 32% of the farms are laying in the category of 70 to 89%, this is also representing another third of the farms. Only a few (around 9%) number of farms which are not mainly used for agriculture. Therefore, it is obvious that most of the farm area is actually used for cultivation.

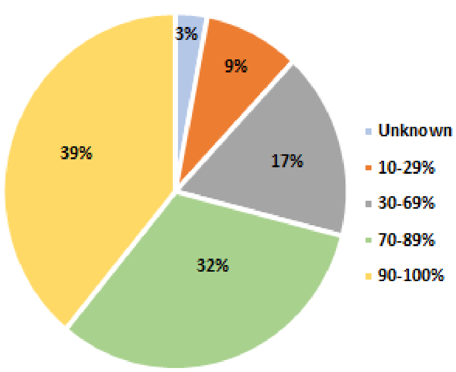


Figure 21: Distribution of the cultivated area

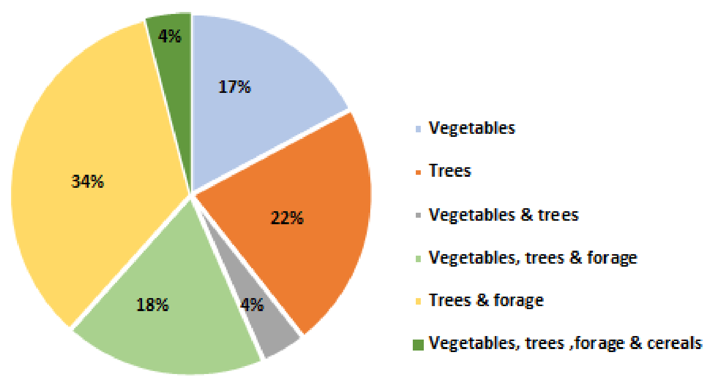


Figure 20: Crop patterns

Figure 21 is representing the information collected about the crop patterns in the farms. Crop patterns vary from trees (which are mainly date palms), forage, vegetables and cereals. The crop types are classified into categories and the percentages (in Figure 21) are representing how they are distributed within the farms. It is noticed that trees and forage (about more than 50%) are the main types of crop in most of the farms. Beside this, some farms (22%) are used only for cultivating trees. By combining each category including vegetables, it is found that around 43% of the farms are cultivated by vegetables. Moreover, it can be noticed that more than 20% of the farms are growing vegetables, tree and forage. Finally, around 4% of the farms are cultivated by vegetables, tree, forage and cereals.

It can be concluded that vegetables are the common type in many farms. The reason might be because it is easy to grow and take care of them. Moreover, high quantity can be produced with simple irrigation methods compared to trees and forage which require a lot of water which contribute in wasting water through flood irrigation systems. This is clearly showing that there is a relationship between crop pattern and irrigation methods used. It is therefore, a good indicator of finding the potential for improvement.

Table 5: Irrigation methods in the study area

Irrigation method	Number of farms in Percentage (%)
Flood	66 %
Bubbler	0 %
Sprinkler	31 %
Drip	56%
Others	3%

Farmers are following different methods in irrigating their farms (Table 5) and, in some farms, more than one type of irrigation method can be found. The flood irrigation is the main method for irrigation in 66% of the selected farms included in the survey. Beside this, 56% of the farms are irrigated by drip irrigation method and 31% by the sprinkler. Moreover, farmers were asked to identify if they use greenhouses or not. Around 70% of them answered 'No' while 20% said 'Yes' and some (10%) did not answer this question.

These are similar results obtained by Al-Shaqsi (2004), where he mentioned that around 73% of the farmers, from his study area, are still irrigated by flood irrigation system. It worth mentioning here that Al Shaqsi selected a representative sample of the population (farmers[6], domestic water users, and decision makers) from four different *Wilayat* (Rustaq, Suwaiq, Awabi, and Musa'ana) of Al Batinah region. Additionally, Zekri reported that 50% of the total cropped lands, in his sample, are irrigated by flood irrigation method (Zekri et al., 2010).

Farms were classified, according to the percentage of area irrigated by flood irrigation. These are modern irrigated farms, mixed irrigated farms (irrigated by flood and other types of irrigation methods) and traditional irrigated farms (use only flood irrigation method). The less percentage of area irrigated by flood the more modern the farm is and so on. The total number of farms is 69. Few (around 4) farmers reported that they own more than one farm. The following table (Table 6) shows the categories of each classification and the number of farms in each category.

[6] The sample size of farmers in Al Shaqsi's survey was 75, and 48 decision makers.

Table 6: Farm classification according to the area irrigated by flood method, N=69

Percentage of area irrigated by flood	No. of Farms	Farm classification	Percentage (%)
< 10 %	27	Modern	39 %
11-70 %	21	Mixed	31 %
71-100 %	21	Traditional	30 %

Based on irrigation methods and crop patterns, it can be concluded that “modern farms” are mainly used for cultivating vegetables. While “traditional farms” are used to cultivate trees and forage. The ‘mixed farms’ are mostly for cultivating other types of crops.

5.2.3 Water Situation

In Oman, as mentioned earlier (see Section 3.1.3), the surface water is very rare and groundwater is the main source of water. Thus the farmers in the study area use groundwater for irrigation. All of the farmers (100%), participated in the survey, abstract water from the aquifer to irrigate their farms by private wells (Table 7). Beside this, one farmer said that he is also using tankers for providing irrigation water.

Table 7: Irrigation sources in the study area, (n=64)

Irrigation source	Number of farms (%)
Wells	64 (100 %)
Falaj	0 (0 %)
tanker	1 (1.5 %)
Others	0 (0 %)

Regarding the situation of water resources in the farms, some farmers (29%) described it as bad or very bad (Table 8), but the majority (71%) mentioned that the water situation is good or very good.

Table 8: Overall situation of water resources in the selected farmers, (n=64)

Overall situation of water resources	Number of farms (%)
Excellent, I'm happy with my farm	5 (7 %)
Very good, it is ok but improvement needed	8 (12 %)
Good	36 (52 %)
Bad	13 (19 %)
Very bad, I'm not happy with my farm	7 (10 %)

The groundwater in the coastal area is affected by salinity. Figure 22 is representing the number of farms (in percentage) in each category of salinity level. The level of salinity is familiar to the farmers because they are updated about the records during the salinity survey programs carried by MRMWR.

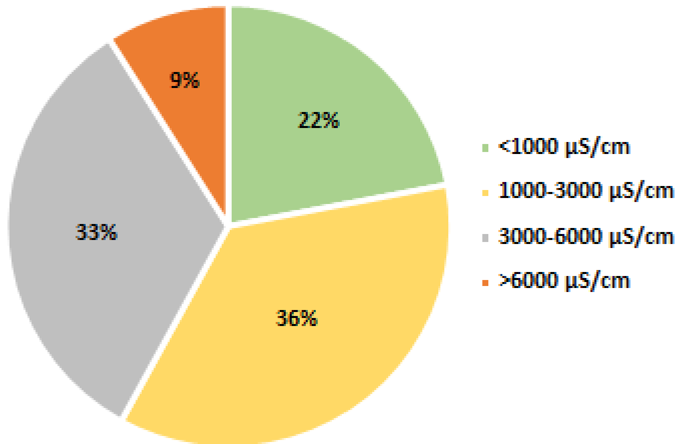


Figure 22: Percentage of salinity ranges in the study area

It is noticed that 22% of the farms have low salinity ranges, and from Table 8 it can be seen that 7% of the farmers expressed that the water situation is excellent and 12% expressed that it is very good. By combining these two categories from Table 8, it can be concluded that 19% of the farms are in excellent/ very good water situation. This means that there is a strong relationship between the answers in Figure 20 and the answers in Table 8. Similarly the farms of high salinity ranges, the two categories of high salinity ranges (3000-6000µS/cm) and (>6000µS/cm), which has more impact on farm production, are represented by 42% in Figure 20 and the bad/very bad water situation in Table 8 is represented by 39%.

In general, the water situation is assessed by farmers to be good in the form of quantity only, but the quality is affected by salinity and the situation is getting worse every day. Many farmers (40%) expressed that the water situation by saying; "the *water is available, but salty*". This indicates that farmers are not fully aware of the limitation of the natural system, especially in form of quantity. They think that water is available and have no idea about water shortage. They are only concerned about quality. In this respect, some participant noted:

> 'The water quality is very bad, it is saline and the water situation is at risk' (15 farmers)
>
> '*The water situation is at risk and it is not suitable for cultivating vegetables and fruit' (1 farmer)*
>
> *'The water quality is very bad and there is over pumping in the neighboring farms' (2 farmers)*
>
> *'It depends on rainfall, during rainy seasons the situation is better' (1 farmer)*

Some farmers refer the reasons of this situation to be the construction of roads, bridges, hotels, and industrial areas. One farmer argues:

> *'The construction of roads, bridges, hotels, and industrial areas played a major role in wasting water (why don't they find other sources of water for such activities!)'*

One farmer pointed to the commercial wells to be the reason behind threatening the water resources, as he mentioned:

> *'There are commercial wells selling water to residents near the coast, those wells have not been stopped after the desalination projects'*

In order to explore the knowledge of farmers regarding the irrigation water use in the region, farmers were provided with a list of statements and asked to specify if they agree with or not. Table 9, below, is representing the results.

Table 9: Farmers' knowledge regarding the existing irrigation water use in the study area, (n=64)

Statements	**No. of agree farmers (%)**	**No. of disagreeing farmers (%)**
The water is used efficiently without wastage	58%	42%
The water is limited	64%	36%
The water is over pumped	63%	37%
The salinity is increasing	88%	12%

From the results it is noticed that more than 50% of the farmers think that the water is used efficiently without any wastage, which is not true. This gives an indication that farmers are not aware of being consuming water for crop irrigation without taking into account crop water requirements. Moreover, it is not fully clear to them, that the quality in the coastal plain aquifer is gradually deteriorating through time because of salt-water intrusion, which is taking place because of excessive fresh water abstraction.

On the other hand, 64% agree that the water is limited and 63% agree that the water is over pumped. Additionally, they totally agree that the rates of salinity are increasing, as 88% of them said that this is the case.

In related to water shortage, the group of farmers was asked if they are ready to pay for a new water service, which provides water of a good quality, in order to reduce the withdrawal from groundwater aquifer. Around two thirds (67%) of them said 'Yes' and one third (33%) of them said 'No'.

Farmers were also asked to identify if they sell some of the pumped water or not. All of them (100%), said that they are not selling the water to others. However, this might not be the case, it was obvious that farmers were reluctant to answer this question. It can also be the case, as the groundwater quality is getting worse and not suitable for selling. In the results obtained by Al Shaqsi (2004), it was mentioned that 70% of the farmers admitted that they are selling some of the water produced from wells.

From the high levels of salinity in the farms, it is obvious that there aren't many options for short-term improvement in the region. In regard to the evaluation of groundwater salinity ranges in Al Batinah, Zekri (2010), stated "*The situation induces us to live with salinity problem and approach it scientifically focusing on its effects on plant growth*".

Farmers are dealing with the problem of saline water in different ways, around 48% of them are doing nothing and they mentioned that they are getting less yield. Some of them (30%) reported that they reduced the pumping hours per day, and some (around 40%) reduced the cultivated area in the farm. 44% of them said that they installed modern irrigation systems and 11% of the farms reported that they build their own desalination units in their farms. Following are some other expression of farmers regarding dealing with saline problem:

> *'I tended to animal husbandry (Bulls and sheep)' (3 farmers)*
>
> *'I plant only during winter seasons between September and February; this is in order to keep my farm in good situation, as well, I changed my agricultural behavior; I started cultivating part of the farm for a period of the year and keep a part to recover, and then the other way around' (2 farmers)*
>
> *'I started using greenhouses in order to reduce water consumption' (1 farmer)*
>
> *'I changed the irrigation times, now I only irrigate during early mornings and late in the nights' (1 farmer)*
>
> *'I started changing locations, which means I plant different types of crops in each part of the farm periodically, to protect the quality of the forage' (1 farmer)*
>
> *'I changed the type of fertilizers' (1 farmer)*

5.2.4 Farm Management

Regarding the issues that play a role in farmers' agricultural management, a list of options was provided to the farmers. They were asked to rate up what level they think each option is important. They were asked to mark one option for each issue, as either ‘extremely important’, ‘moderately important’, ‘neutral important’, ‘low important’ or ‘not important’ the answers are presented in Table 10.

Table 10: Issues that play a role in farmers’ agricultural management, n=64

Issues	Extremely important	Moderately important	Neutral important	Low important	Not important
To get a high income	72%	23.5%	3%	1.5%	0
To protect the environmental	84%	6.5%	8%	1.5%	0
To conserve water	81%	14%	5%	0	0
To have a long term perspective of the farm	69%	23%	8%	0	0
To produce good and high quality products	75%	15.5%	8%	1.5%	0
To have good marketing options	67%	26.5%	6.5%	0	0

From the above table it can be concluded that, all of the listed issues are rated as important, by at least 69% of the total respondents. The highest rated issues are; “to protect the environment’’, “to conserve water” and “to produce good and high quality products”. Overall, nothing actually was rated as not important as a very low percentage (1.5%) is observed under the ‘low important’ option.

During the survey, more than one third (39%) of the farmers reported that water management in the farms is the responsibility of both the owner and the foreign labourers (Figure 23). while 36% of the farmers reported that they are taking care of water management themselves. On the other hand 23% of the farm owners reported that foreign laborers are responsible for the water management in the farms.

Many farm owners employ foreign labourers, to work and take care of their farms. The reason might be that some owners are employees in the governmental or private organizations and don’t have enough time to take care of the farms. The second reason is that those laboruers are excepting a low salary (62-77 OR/month (Zekri et al., 2010)) , so it is cheap to employ them.

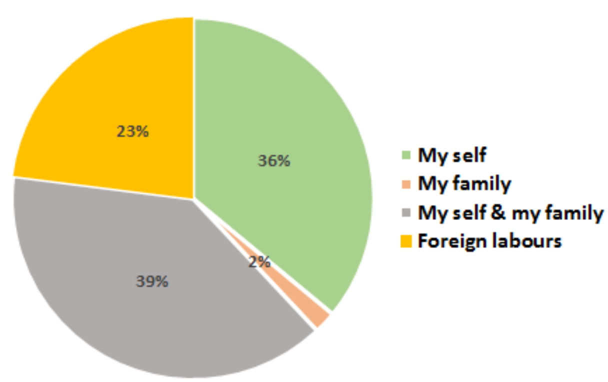


Figure 23: Water management responsibilities in the farms

The majority of the farmers (78%) indicated that they are aware of the daily amount of water used to irrigate their farms, but they expressed this in the form of pumping hours and not the exact amount of water abstracted via the wells. Here it is worth mentioning that the majority of the farmers (95%), reported that they do not have water meters in their wells.

Regarding the irrigation hours, many farmers in the region are not aware of the suitable time for irrigation. They are pumping at different times during the day, and some of them (13%) are pumping for more than 12 hrs/day (Figure 24). In this regard, Al-Shaqsi (2004), pointed out that some farmers are cultivating crops like Rhodes grass and pump unlimited amount of water without any restriction from water authorities.

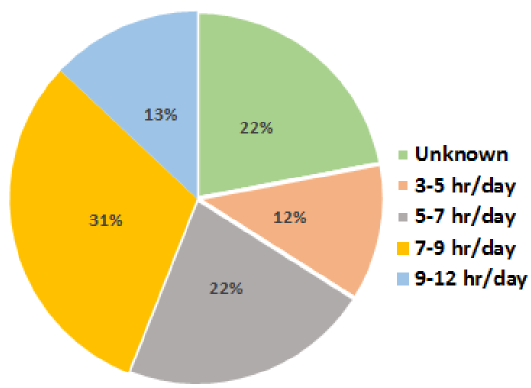


Figure 24: Percentage of irrigation pumping hours in the farms

Around 75% farmers also added that they receive support from their family members in taking care of the farms. As well, farmers rely mostly on foreign labor, as 92% of them mentioned that they have foreign labourers working in their farms. Of those, 62% reported that they have between 1-5 labourers, only 8% of the farmers reported that they don't have any (Figure 25). Compare these results to the results obtained from Figure 17 (see Section 5.2.1), it can be concluded that the farms of small areas which represent 52%, might be the same farms, with 56% of low number of foreign labourers in Figure 24 and so on with the farms of large areas.

This gives an indication that there is a relationship between farm sizes and the number of foreign labourers working in the farms. In addition to this, some farmers (3%) reported that they are renting their farms to those labourers.

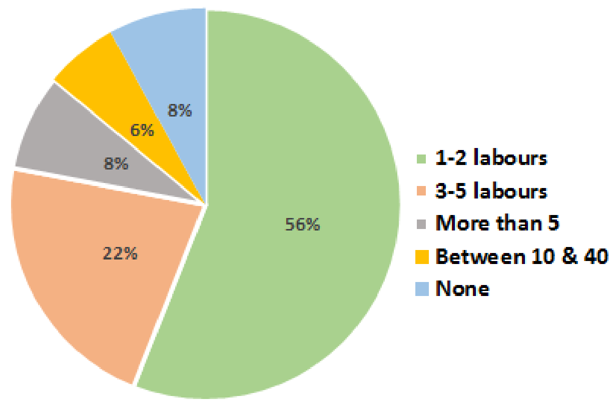


Figure 25: Percentage of foreign labourers in the farms

In order to investigate if those foreign labourers care about water management, farmers were asked to specify if those foreign labourers have knowledge in water conservation. 69% of the farmers believe that those labourers have no idea about conserving water.

Farmers were asked also to specify ways of promoting labourers to conserve water. This was an open question and the farmers answered it in different ways. Following are some remarkable statements from the farmers;

> *'I follow them myself and encourage them to repair the irrigation pipes periodically to prevent leakage' (7 farmers)*

> *'I monitor them and control the irrigation time by myself' (32 farmers)*

> 'Labourers *in my farm do not have any idea about conserving water, I have to direct them myself and I'm very strict in that' (3 farmers)*

> *'They have experience in crop water requirements' (1 farmer)*

> *'I teach them how to conserve water and give them instructions about crop water requirements' (13 Farmers)*

> *'I have to take care of that myself, because it is not only the matter of conserving water, but I also care about the electricity costs' (1 Farmer)*

> *'It is very difficult to control those foreign* labourers*, I do my best but, still they are wasting a lot of water' (1 Farmer)*

The last statement is very true because usually those labourers come from countries like Bangladesh, Pakistan or India, which are not really suffering from water shortages. Therefore, they are not aware of water problems and water deficit in the region and it is very hard to convince them about the importance of water saving. All this proves that those labour are also playing a role in threatening the groundwater aquifer in the coastal line of South Al Batinah region.

Farmers were asked to identify if they receive any training in water conservation, 91% of them answered 'No', and 9% only mentioned that they received some training from the government. Those 9%, were given a list of options (Table 11) and asked to specify in which field they received the training. Some farmers chose more than one option.

Table 11: Field of training farmers' received, n=6

Field	Number of farms (%)
Using and maintain modern irrigation systems	3 (50%)
Reducing water losses from irrigation channels	4 (67%)
Timing of irrigation, in order to avoid high temperature impacts	4 (67%)
Training on how to maintain water during dry seasons	1 (17%)

They were also asked to rate how good their experience with the training was. One third said that it was excellent, the second third mentioned that it was very good and the remaining third said it was good.

From the answers of farmers, it is concluded that training programs are not widely taking place in the region. This might be due to the shortage of the training programs implemented by the government or due to that some farmers are not willing to attend those programs.

5.2.5 Economic Situation

Regarding the level of farmers' dependence on farm income and how far it affects their behavior and opinions, 70% of the farms admitted that their farms are not the only source of income. They rely on employment in government or private organizations rather than farming. This fact is also underlined by Zekri (see Zekri et al., 2010). On the other hand, 30% of them mentioned that they don't have any other sources of income rather than their farms.

In this issue and in order to explore how far they rely on the farms as a source of income, farmers were given a list and asked to select the percentage of their total farm production sold. The results are summarised in Figure 26.

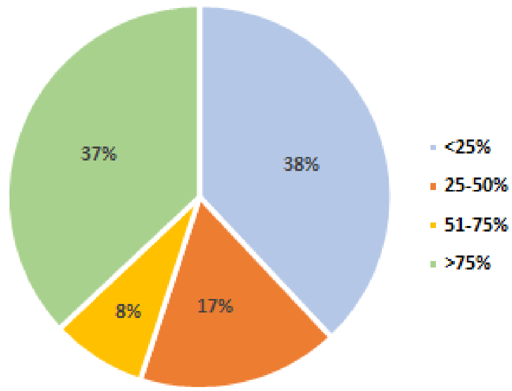


Figure 26: The percentage of total farm production sold

From the answers, it can be concluded that one third of the farmers are selling only a low percentage of their farm production which does not exceed 25%. While another one third is selling more than 75% of their farm production. The remaining one third of the farmers is selling between 25% and 75%. Another question asked to farmers, regarding economic situation, was to identify the amount of income from the farm if it is above or below 1000 Omani Reals (OR) per month. Around two thirds (62%) of the farmers answered that they receive less than 1000 OR/month, only 14% of them said that they get more than 1000 OR/month and 24% said that they don't sell any. Farmers were asked to identify if they have already received subsidies from the government. 53% (34 farmers) indicated 'Yes' as they have already received subsidies and 47% indicated 'No'. For those who indicated 'Yes' they were asked to specify the type of subsidies they received. Following (Table 12) are the types mentioned, some farmers selected more than one type:

Table 12: Type of subsidies received from the government- mentioned by farmers, n=34

Type	No. of Farmers (%)	Share from government %
Modern irrigation system	10 (16%)	50% - 100%
Green houses	10 (16%)	50%
Forage grainer or cutter	9 (14%)	50%
Financial support	1 (2%)	20-30%
Fertilizers and pesticides	5 (8%	Not mentioned
Water pump	1 (2%)	Not mentioned
Milk mixer	1 (2%)	Not mentioned

5.2.6 Experience with Ministries

Farmers were requested to identify the governmental organizations they deal with, and were asked to specify the level of cooperation with these organizations as either 'very good', 'good 'or 'very bad'. The results (answers of the farmers) are represented in Table 13:

Table 13: Governmental water and agricultural organizations mentioned by farmers, n=64

Name of the organization	**n**	**Level of cooperation**				
		Excellent	**Very good**	**Good**	**Poor**	**Very poor**
Ministry of Agriculture and fisheries (MAF)	60	3%	15%	50%	22%	10%
Ministry of Regional Municipalities and Water Resource (MRMWR)	30	3%	7%	50%	30%	10%
Ministry of Manpower	53	0%	4%	51%	34%	11%
Ministry of Housing	7	0%	0%	43%	28.5%	28.5%
Muscat Municipality-Farmer Markets	4	0%	25%	75%	0%	0%
Ministry of Commerce and Industry	4	25%	25%	25%	25%	0%
Ministry of Environment and Climatological Affairs (MECA)	1	0%	0%	0%	100%	0%

60 Farmers out of 64 mentioned that they are dealing with Ministry of Agriculture and Fisheries (MAF). 50% of them rated the level of cooperation as 'good'. The second highest rated organization was Ministry of Manpower; it was mentioned by 53 farmers. The level of cooperation was rated as 'good' by 51% of the farmers. The third rated organization was Ministry of Regional Municipality and Water Resources as 30 of the farmers (almost 50%) mentioned it. The level of cooperation was rated as 'good' by 50% of the respondent. Only one farmer mentioned that he is dealing with Ministry of Environment and Climate Affair, and he rated the level of cooperation as 'poor'.

Experience with government organizations, representing how the level of trust between farmers and governmental water and agricultural organizations is. In general, 17% of the farmers rated the level of cooperation with Ministries as 'very good', and 47% rated it as 'good' while 30% rated it as 'very bad'. 6% of the farmers did not know what to rate.

5.3 Ideas and Opinions

5.3.1 Opinions of Farmers and DM's Regarding the Future of Agriculture in Al Batinah

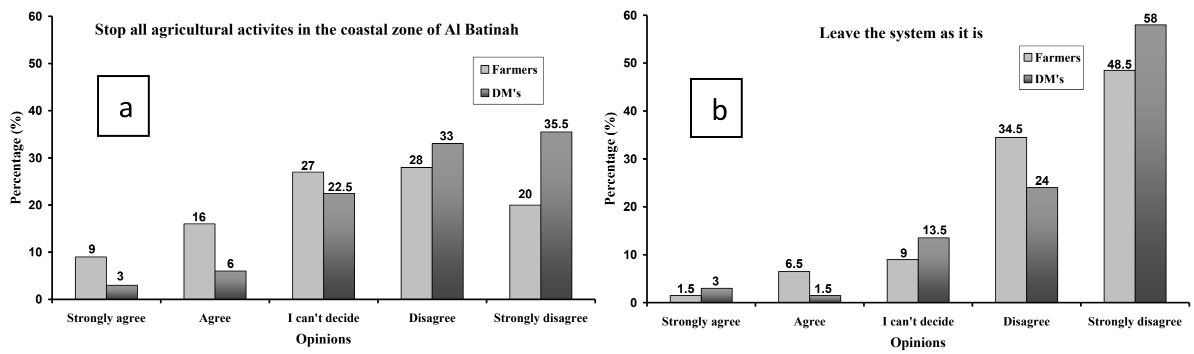


Figure 27: Opinions of farmers and DM's regarding the sustainability of agriculture in Al Batinah

Through the survey, one of the missions was to explore the opinions of farmers and DM's regarding the existing situation of water resources and agriculture in the region. Respondents were asked to rate (according to their opinions) if they prefer to "stop all agricultural activities in the coastal zone of Al Batinah". This question was asked as an option for water conservation and as a choice for the aquifer to recover. The results in Figure 27 (a) showed that very small proportions of respondents from both groups rated 'strongly agree' or 'agree' as their choices for the issue "stop all agricultural activities in the coastal zone of Al Batinah", 25% of the farmers and 9% of DM's. The majority selected 'disagree or 'strongly disagree', 48% of the farmers and 68.5% of the DM's. Around 27% of the farmers and 22.5 % of DM's couldn't decide what to choose.

For the continuation (future) of the agriculture in the region, respondents were asked to rate to what level they agree to "leave the system as it is without any changes". The rating levels were either 'strongly agree', 'agree', 'I can't decide', 'disagree' or 'strongly disagree'. For the issue Figure 27 (b), 8% farmers only and 4.5% DM's only chose 'strongly agree' and 'agree', while 83% farmers and 82% DM's chose 'disagree' and 'strongly disagree'. Some, like 9% of the farmers and 13.5% of the DM's couldn't decide what to choose.

Moreover, there was an agreement between the groups that the agriculture should have future, but changes are required for development.

Farmers know that the salinity is increasing with time and the water situation is getting worse every day. They mentioned that the water is not suitable any more for cultivating vegetables and fruits. For the water experts and water professionals, the problem of water shortage and saline water intrusion in South Al Batinah coastal area is understandable very well. They expressed that it is important that new strategies be implemented to deal with this problem. On the other hand, they think that if the development continued without any appropriate interventions, most probably farmers will sell their lands to be used for constructing buildings and other commercial projects.

Additionally, both groups agreed that the choice of “leaving the system as it is” is not acceptable. This gives an indication that the stakeholders, in general, believe that there is a need for improvement which could be achieved by implementing new management strategies.

5.3.2 Requirements Needed to Improve the Agricultural Productivity

Survey respondents were asked to indicate the requirements needed by farmers to improve the productivity of their farms. They were asked to rate each issue in the list as either ‘strongly agree’, ‘agree’, ‘I can’t decide’, ‘disagree’ or ‘strongly disagree’. The mean score ranges between 1 for ‘strongly agree’ and 5 for ‘strongly disagree’

The results are presented in Table 14; by the mean, standard deviations (SD) and P-values. The degree of significant differences is based on independent sample T-test. The shaded, in gray, P-values, in Table 14, are considered to be significant.

Table 14: Comparison of opinions between Farmers and DM’s regarding requirements needed to improve farm productivity, N=131

Requirements	Farmers (n=64)		Decision makers & Water professionals’ believe about farmers (n=67)		P-value
	Mean	SD	Mean	SD	
Guidance & Training in agricultural management	2.05	1.007	1.23	0.459	0.000
Subsidies for modern irrigation equipment	1.69	0.957	1.86	0.913	0.309
More water	2.56	1.052	3.64	1.096	0.000
Better quality of water	1.61	0.847	2.59	1.086	0.000
More labourers	2.90	1.146	3.60	0.914	0.000
More income	1.51	0.738	2.46	0.886	0.000
Better marketing facilities	1.62	0.906	1.58	0.615	0.782
Guidance & information farming centers	1.78	0.899	1.53	0.590	0.065
More cooperation with other farmers	1.81	0.941	1.71	0.812	0.530

Farmers are more interested in “more income”, “better quality of water”, “better marketing facilities” and “subsidies issues”. They are also interested in “more water” but the mean is approaching 3 which is the level of ‘I can’t decide’ answer or the neutral option. Moreover, farmers are more concerned about the quality of water compared to quantity. The difference in mean between the option of “more water” and “better quality of water” is 0.95. In fact, regarding water quality and quantity, these are the same results obtained in evaluating the water situation in the farms in the previous section (see Section 5.2.3).

The highest rated requirements by the group of decision makers are; “guidance and training in agricultural management”, “guidance and information farming centers”, “better marketing facilities” and “more cooperation with other farmers”. Additionally, it can be noticed in the group of DM’s that the mean for “more water” is approaching 4.

There are significant differences between opinions in the group of farmers and the group of DM’s in 5 out of 9 items. Differences are less obvious between the two groups in the rest 4 items. Most respondents (from both groups) rated the requirement of “better marketing facilities” as a strongly needed; the mean is less than 2 in each group.

Although, the level of significance is high for the option of “more labourers”, it can be noticed that among all the requirements there is an agreement between the two groups that this item is less important. It has the highest mean, in the group of farmers, and second highest mean in the group of DM’s, compared to the other requirements. Moreover, DM’s are proposing that farmers need more incentive issues. For example guidance and training. Incentives for water conservation in agriculture, considered to be a key water management tool to improve water use efficiency.

Standard deviation describes the variation around the mean values. High values stand for high variations, which indicate that the spread in opinions within a group is high. For example, within the DM’s group there is a high variation in opinions regarding the option “more income” and “better quality of water” the SD is 1.096 and 1.086 respectively. The variation in opinions is less in “guidance and training in agricultural management” (SD=459) and “guidance and information farming centers” (0.590). While there is a high variation in the opinions of farmers in “more labourers” (SD=1.146) and “more water” (SD=1.052). The variation in opinions is less in “more income” and as the SD 0.738.

5.3.3 Opinions Regarding Potential Management Interventions

5.3.3.1 Opinions of farmers

Table 15: Opinions of farmers regarding possible interventions which could be implemented. N=64

Interventions	Options				
	Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
Introducing water quota	6	13	7	19	19
	(9%)	(20%)	(11%)	(30%)	(30%)
Introducing water quota with subsidies (guidance & training in agricultural management)	12	20	6	20	6
	(19%)	(31.5%)	(9%)	(31.5%)	(9%)
Introducing water quota with subsidies (equipment for modern irrigation)	7	21	7	23	6
	(11%)	(33%)	(11%)	(36%)	(9%)
Use treated waste water for irrigation.	16	32	6	7	3
	(25%)	(50%)	(9%)	(11%)	(5%)
Reduce the withdrawal of groundwater pumped per day with the help of guidance & training.	8	40	4	11	1
	(12.5%)	(62.5 %)	(6.5%)	(17%)	(1.5%)
Use good quality of water for irrigation purposes, from a centralized well field water distribution system (if implemented).	13	30	4	14	3
	(20%)	(46.5%)	(6.5%)	(22%)	(5%)
Change the type of crops to crops of lower water requirements.	9	33	6	14	2
	(14%)	(52%)	(9%)	(22%)	(3%)
Improve the irrigation methods in the farm.	18	36	3	5	2
	(28%)	(56%)	(5%)	(8%)	(3%)
Improve the irrigation methods in the farm with subsidies in form of equipment for modern irrigation systems.	26	36	0	2	0
	(41%)	(56%)		(3%)	(0%)
Improve the irrigation methods in the farm with subsidies in form of guidance and training in agricultural management.	18	42	0	3	1
	(28%)	(65.5%)		(5%)	(1.5%)
Construct injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	15	31	12	3	3
	(23%)	(48%)	(19%)	(5%)	(5%)
Encourage the construction of more desalination plants for brackish and seawater, in order to use it for irrigation.	15	34	3	11	1
	(23%)	(53.5%)	(5%)	(17%)	(1.5%)
Increasing the effectiveness of water use by public awareness.	28	34	2	0	0
	(44%)	(53%)	(3%)		
Introducing water prices for pumped groundwater.	2	9	5	19	29
	(3%)	(14%)	(8%)	(30%)	(45%)
Introducing special energy tariffs for agricultural purposes.	19	34	7	2	2
	(30%)	(53%)	(11%)	(3%)	(3%)
Forming water managers groups.	20	32	8	4	0
	(31%)	(50%)	(12.5%)	(6.5%)	(0%)
Forming helpful guidance & information water centers to support farmers in farm & water management.	18	19	25	2	0
	(28%)	(30%)	(39%)	(3%)	(0%)
Farms need to be evaluated and the government should take a decision to close some of them and change the land use.	21	29	7	5	2
	(33%)	(45%)	(11%)	(8%)	(3%)

A list of management interventions (see Section 4.2.2.2) was presented to the group of farmers to expose their opinions regarding each item in the list. The results are presented in Table 15.

Around two thirds (60%) of the farmers, disagree with the idea of water quota. Farmers were more enthusiastic regarding improving the irrigation methods with subsidies in the form of equipment (41%). On the other hand, the training and education was not considered as a strong priority for them. This proves that farmers are not interested in training (see also Section 5.2.4, Table 11). They also agreed much about increasing the effectiveness of water use by public awareness (44%).

Farmers were more enthusiastic regarding improving the irrigation methods with subsidies in form of equipment compare to the other two options regarding improving irrigation methods. Moreover, they did not reject the idea of using treated waste water for irrigation. It is interesting to see that 75% of them have chosen 'strongly agree' and 'agree'.

Additional Opinions

Within the survey and before providing the respondents with the list of proposed interventions, farmers were asked for possible interventions which could be implemented in effective manner to protect the groundwater system from depletion and to control salt water intrusion.

Many of them were directing the issue of solving these types of problems to the responsible organizations and they were more likely to the water availability solutions especially of good quality. Regarding this opinion, two farmers said:

> *'Rationalization of water consumption is the duty of the responsible organizations'*

Another farmer said:

> '*The responsible Organization should take action against water shortage'*

At the same time many farmers were encouraging the implementation of new irrigation systems, but not without subsidies from the government. For example three farmers mentioned the following:

> *'Government should encourage farmers to go for more modern irrigation systems and support them by subsidies in the form of equipment and desalination units. Farmers should be forced, in a way or another, to use modern irrigation systems'*

While one of the farmers said:

> '*Agriculture must be improved by new techniques (follow new irrigation systems, stop flood irrigation, use of greenhouses), it should be an integrated activity and focusing on vertical expansion and not horizontal expansion'*

Another interesting suggestion from farmers was to control the amount of forage in the area. It is important to mention here that according to the survey and other sources of information e.g. Al Shaqsi (2004), in many cases the biggest part of the cultivated area in each farm is forage or palm trees (see Section 5.2.2). Farmers are making good profit from forage. At the same time, forage is consuming a large amount of water which remains the same during dry and wet seasons (Al Shaqsi, 2004).One of the farmers described the situation by the following expression;

> '*Forage cultivation is a double-edged sword, it is profitable but at the same time consuming a lot of water. I think we need some training and guidance in cultivating and irrigating forage'*

Regarding the same issue, five farmers said:

> '*Stop cultivating forage because they consume a huge amount of water'*

Other farmers said:

> '*Agriculture is the second source of income in the country; we should not abuse it or replace the food crops by forage'*
>
> *'The best solution is to transfer or reduce the amount of forage in Al Batinah'*
>
> *'If we want to conserve water in this area, then we need to stop cultivating forage, it is the main water consumer'*

About this matter as well, some farmers are worried about implementing the idea of shifting the farms to another region (e.g. Najd-in Southern Oman). This idea is one of the proposed actions suggested earlier by some decision makers. One farmer expressed this by saying:

> '*Agriculture is the back bone of al Batinah, I'm against reducing the cultivated area or shifting the farms. That action will raise the prices of the products (food stuff)'*

Some farmers argued about renting farms to foreigners. Farmers believe that those foreigners are not aware about the core of the water problems in the area or even about the importance of conserving water. Farmers insisted the importance of establishing new rules for controlling the situation. About this issue, eight farmers said:

> *'Keep watching the farms which are rented to foreigners, water meters and special new rules should be used with those types of farmers'*

Regarding the same idea, one farmer rose up the issue but he was worried that it will not be accepted by the rest of the farmers. He also talked about subsidies. He said:

> '*I have some ideas, but they might not be good for some farmers, for example; stop renting farms to foreigners, and evaluate the existing farms, and support farmers with new irrigation systems (not less than 50%)'*

Farmers also mentioned the importance of improving management strategies, following are remarkable statements from farmers regarding this issue:

> '*Stop permitting car wash stations, they are so many now in the region and they are consuming a lot of water. If there is no way to stop them, then we have to find other source of water and stop over pumping'*
>
> *'Encourage farmers to use treated waste water for irrigation'*
>
> '*Suggest suitable crops for farmers and introduce water management competition programs between farmers and allocate rewards to motivate them for a better water management'*
>
> '*We need periodically meetings with decision makers from the relevant organizations to express our problems and opinions'*

The last statement gives an indication that farmers are supporting the idea of introducing the participatory approach.

5.3.3.2 Opinions of DM's

Similar list of management interventions was presented to the group of DM's to express their opinions regarding each item in the list. The results are presented in Table 16.

Table 16: Opinions of DM's regarding possible interventions which could be implemented. N=67

Interventions	Options				
	Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
Introducing water quota	23	31	7	4	2
	(34.5%)	(46%)	(10.5%)	(6%)	(3%)
Introducing water quota with subsidies (guidance & training in agricultural management)	23	33	10	1	0
	(34.5%)	(49%)	(15%)	(1.5%)	
Introducing water quota with subsidies (equipment for modern irrigation)	32	26	8	1	0
	(47.5%)	(39%)	(12%)	(1.5%)	
Use treated waste water for irrigation.	38	20	6	3	0
	(56%)	(30%)	(9%)	(5%)	
Reduce the withdrawal of groundwater pumped per day with the help of guidance & training.	34	26	5	2	0
	(50.5%)	(39%)	(7.5%)	(3%)	
Use good quality of water for irrigation purposes, from a centralized well field water distribution system (if implemented).	19	26	11	7	4
	(28%)	(39%)	(16.5)	(10.5%)	(6%)
Change the type of crops to crops of lower water requirements.	23	25	11	7	1
	(34.5%)	(37%)	(16.5%)	(10.5%)	(1.5%)
Improve the irrigation methods in the farm.	40	25	1	1	0
	(60%)	(37%)	(1.5%)	(1.5%)	(0%)
Improve the irrigation methods in the farm with subsidies in the form of equipment for modern irrigation systems.	29	32	2	4	0
	(43%)	(48%)	(3%)	(6%)	(0%)
Improve the irrigation methods in the farm with subsidies in form of guidance and training in agricultural management.	30	31	5	1	0
	(45%)	(46%)	(7.5%)	(1.5%)	(0%)
Construct injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	17	29	15	4	2
	(25.5%)	(43%)	(22.5%)	(6%)	(3%)
Encourage the construction of more desalination plants for brackish and seawater, in order to use it for irrigation.	6	17	19	12	13
	(9%)	(25.5%)	(28%)	(18%)	(19.5%)
Increasing the effectiveness of water use by public awareness.	40	24	2	1	0
	(60%)	(35.5%)	(3%)	(1.5%)	
Introducing water prices for pumped groundwater.	8	30	15	11	3
	(12%)	(45%)	(22.5)	(16.5%)	(5%)
Introducing special energy tariffs for agricultural purposes.	11	26	17	9	4
	(16.5%)	(39%)	(25%)	(13.5%)	(6%)
Forming water managers groups.	21	35	5	6	0
	(31%)	(52%)	(8%)	(9%)	(0%)
Forming helpful guidance & information water centers to support farmers in the farm & water management.	30	28	8	0	1
	(45%)	(41.5%)	(12%)		(1.5%)
Farms need to be evaluated and the government should take a decision to close some of them and change the land use.	9	33	9	10	6
	(13.5%)	(49%)	(13.5%)	(15%)	(9%)

DM's were significantly more likely to the idea of increase the effectiveness of water use by public awareness, encourage farmers to improve irrigation methods with subsides in form guidance and training, introducing using treated wastewater for agricultural use, encourage the farmer to reduce the withdrawal of groundwater pumped per day by guidance and training. However, they were less likely to the idea of introducing more desalination plants. Only 35% of them agreed with the idea, 28% they couldn't decide, and 37% disagreed.

It is obvious that the DM's (83.5%) are more likely to agree to the regulation issues combined with incentives in form of education and training as well as forming guidance and information centers (86.5%).

Additional Opinions

DM's also were asked for possible interventions which could be implemented in effective manner, to protect the groundwater system from depletion and to control salt water intrusion.

Around 60% of the DM's said that, if there is no action taken to solve the problem, the water table will continue to decline, seawater intrusion will increase, more farms will be abandoned and farmers will tend to sell their lands to be developed for housing or other projects rather than agriculture.

The decision makers came up with a lot of views and suggestions, policies and techniques. These can be classified as following (the percentage is representing the number of DM's);

- Changing practices and application of IWRM (36%)
- Improving the irrigation systems (30%)
- Adaption of water quotas and water pricing (24%)
- More infrastructures (e.g. dams, desalination plants, etc.) (22%)
- Awareness through Media (22%)
- Changing crop patterns (21%)
- Laws and Regulations (18%)
- Incentives, Training and Guidance (9%)
- Control land use (6%)
- Find other water sources for irrigation (5%)

In general decision makers and water professionals accepted implementation of water quotas and many other demand management solutions. They also insisted incentives, education, appropriate training and awareness programmes. In their opinions, those programmes are important to encourage farmers to accept new water conservation techniques and policies. Following are some remarkable statements from the DM's:

‘*The most important factor is optimization, which can be achieved by better management for water resources’*

‘*There must be a national plan with clear steps and a clear action time frame for integrated water resources management in the area, which should be approved from the highest decision makers. All the other aspects have to be combined together to achieve this goal, such as work with all stakeholders, regulations and laws, including the economic and social aspects, implementing the optimum and integrated solutions, seeking for the other alternative resources to reduce the groundwater depletion, etc.’*

‘*Groundwater is a very limited resource. Slowing down the agricultural pressure by changing crop type or finding other sources of irrigation water can be a good solution for the problem’*

‘Introduce water metering system and water quotas. Water quota must be implemented’

‘Describing the problem and alternatives through Media, and educate people about the consequences of over consuming’

‘To stop water consuming activities, such as car wash, rods grasses and recreational gardens that are scattered along Al Batinah coast’

‘Start using desalination plant for agriculture’

Others said *‘Water used in the residential areas should be from desalination plants’*

5.3.3.3 Irrigation methods

Farmers were asked to identify if they have experience in modern irrigation systems. 78% of them answered ‘Yes’ and the rest 22% answered ‘No’. However, it is noticed that the modern irrigation techniques are not widely used or implemented within the farms in the region. This agrees with the findings in chapter three (see Section 3.3.2), that modern irrigation systems have not significantly contributed to water saving.

In this regard, farmers were provided with a list of obstacles and they were asked to specify the obstacles facing the implementation of modern irrigation techniques in the farms. They were allowed to choose more than one option. The results are presented in the following table (Table 17).

Table 17: Obstacles facing the implementation of Modern Irrigation Systems, (n=64)

Obstacle	Percentage (%)
Modern irrigation systems are expensive	62.5 %
Modern irrigation systems are complicated & need maintenance	15.5 %
I don't believe in efficiency of modern irrigation	17 %
No Idea	8.5 %

Around 63% of the farmers believe that the modern irrigation systems are so expensive. Regarding this issue Al-Shaqsi, (2004) ,as well, mentioned that 48% of his surveyed population pointed out that because modern irrigation systems are expensive, they are still retaining traditional irrigation approaches.

Additionally, around 15% of the farmers proposed other types of obstacles. The following are some statements from the farmers:

> *'The maintenance is difficult, especially with the salinity problem and the leakage of Calcium. Modern irrigation is not conserving water without a good management' (5 farmers)*
>
> *'Some farmers have no idea about the efficiency of modern irrigation systems and some do not have good skills in farm management' (9 Farmers)*
>
> *'The trees are not well irrigated by such type of systems. Modern irrigation is not suitable for some type of crops' (2 Farmer)*
>
> *'Farmers can't afford modern irrigation without subsidies from the government' (2 Farmers)*
>
> *'Some farmers believe that there is no reliable income from the farms, so no need to spend more money on them' (2 Farmers)*

Some farmers in the coastal area think that they have enough water to irrigate their farms and no need to implement modern irrigation systems to save water, regardless the water quality. While some others, think that improvement is important, but at the same time, they believe that equipment together with training should be provided. This is also noticed in the analysis of opinions (see Section 5.4.1,Table 21), that farmers have rated the two options of improving irrigation methods "encouraging farmers to improve irrigation methods with subsidies in the form of equipment" and "encouraging farmers to improve irrigation methods with subsidies in the form of guidance and training" as the mean is 1.66 and 1.86 respectively. This gives an indication that there is a relationship between implementation of modern irrigation and subsidies in the form of equipment and training.

Modern irrigation systems might not be as expensive as they are with the saving in foreign labourers and the increase in the farm productivity. Therefore awareness and training are needed to convince farmers about the viability of modern irrigation systems.

Finally it is worth mentioning, here as well, that 20% of the farmers of the survey are using greenhouses in their farms.

5.3.3.4 Water Quota

Going back to the proposed list of interventions (Table 15), it is clearly noticed that the decision makers are strongly supporting the idea of implementing water quotas. 80% of their answers were lying between 'strongly agree' and 'agree' [see also Appendix A.3, Table A.1]. This is close to the result obtained by Al Shaqsi (2004), for the issue of implementing water quotas in Al Batinah region. He mentioned that, water specialists see quotas as an important tool for water management and 96% believed that water quotas should be implemented.

On the other hand, farmers do not really supporting the idea as much as DM's do. Only 29% of them agreed with the idea [Appendix A.3, Table A.1]. This percentage rose to 44% when subsidies were offered in the form of guidance and training, and to 50% with subsidies in the form of irrigation equipment. Here it is clear again, as mentioned earlier (see Section 5.3.2), that incentives and subsidies are considered as important factors for encouraging farmers to accept new water conservation techniques and policies. However, Al Shaqsi (2004) came out with a different result. He mentioned that 84.5% of the agricultural water users were interested to have water quota (Al Shaqsi, 2004). The reason, in his opinion, is that farmers prefer to get a certain amount of water every day to enable them to plan for the crop type, season and cultivated area. On the other hand, he mentioned that, according to his results, some farmers are unfamiliar with the concept of quotas.

5.3.3.4.1 Allocation of Water Quota

In this regard, the groups of stakeholders were provided with a list of options to identify if water quota is going to be implemented, how much amount of water can be allocated from the current use. The results are presented in Table 18 with the percentage of stakeholders' chosen options.

Table 18: Amount of water to be allocated from the current use, (N=131)

Amount of water to be allocated from the current use	No. of Farmers (%)	No. of DM's (%)
No water quota	61 %	9 %
Cutting 25% of current use	14 %	18 %
Cutting 50% of current use	5 %	17 %
Cutting 75% of current use	0 %	7%
Cutting, but no idea about the amount	20 %	40 %
Water quota should be allocated based on crop patterns in the farms	--	7%
Quota should be linked to the price unlimited, but higher price for higher consumption	--	2%

Around two thirds (61%), of the farmers, selected "no water quota" should be implemented. This is the same percentage (60%) of farmers who 'disagreed' and 'strongly disagreed' with the first option of adopting water quota in Table 15 [see more in Appendix A.3, Table A.1]. 14% selected "cutting 25% of current use", 5% selected 'cutting 50% of current use" and no one selected "cutting 75% of current use". While 20% agreed with the idea of cutting from the current amount of water use, but did not know how much amount of water can be allocated.

DM's were not so sure about the amount to be allocated for water quota. This is obvious from the results, as 40% of them did not know how much should be allocated from the current water use. 18% selected it to be "25% from the current water use", 17% chose it to be "50% from the current water use", and 7% prefer it to be "75% from the current water use". While 9% selected "no water quota" should be implemented. Some DM's suggested two more options to be added to the list; "water quota should be allocated based on crop patterns in the farms" this is mentioned by 7% of the DM's, and "quota should be linked to the price unlimited, but higher price for higher consumption" which is mentioned by 2% of the DM's.

5.3.3.4.2 Water Metering

As metering has a direct connection with water quota, farmers were asked about their opinion regarding installing water meters in their wells, especially those who agreed with the idea of water quota. They were requested to indicate if they are ready to install water meters, for every well in their farms, or not.

Only 11% of the farmers supported the idea. Many (59%) of them did not support it at all. While, some (30%) of them expressed that they are ready to agree, but under conditions. For those who were ready to agree, but under conditions, their worries mostly were about the amount of water to be allocated for irrigating their crops. Following are the expressions of farmers about the mentioned conditions:

'*The amount of water to be allocated for my farm should be enough for the growing seasons, because I don't grow crops along the year, I only do that during particular seasons, so the monthly amount might not work with me'*

'There should be a balance in allocating water quotas for seasonal crops, quotas should be allocated based on season requirements'

'The allocation rates should be fair and enough for the farmer and free of charge'

'The allocated water has to be enough for my crops'

'*Evaluate my water requirements first and sign an agreement, then if I use more, I can be charged'*

Moreover some farmers, their condition is just to implement the idea of water quota and water metering to the big commercial farms, as one of the farmers mentioned:

'*The idea of water quotas should be implemented only in the big farms which employ foreign labourers and produce high amounts of forage'*

This was also mentioned by Al Shaqsi (2004), he argued that, there are some concerns that large commercial farms employ a huge number of foreign labourers who may not be familiar with the water situation in the country and make no effort to conserve water. For this reason, some farmers, with a smaller farm in size (mostly vegetable farms) suggest that, the idea of water quotas should be only implemented in big farms.

DM's were asked, as well, to indicate if installing water meters is important or not. 91% of them strongly supported the idea, because they believe in metering as a good indication of amount of water abstraction. For those (9%) who said no, they were asked to propose other suggestions for monitoring. Following are the mentioned suggestions:

'Monitoring can be done through electricity bills'

'I think the best way is to use storage tanks, and follow them (farmers) how they use the water'

'Through farmers' awareness about crop water requirements and irrigation efficiencies'

Some of them believ that there is no way for monitoring and installing water meters, is not a good idea. They expressed the following:

'*There is no way to monitor water quotas, installing water meters is not a practical idea'*

'Never think about monitoring the wells, because farmers will violate the rule by a way or another. Just use awareness to encourage farmers to use water more efficiently'

Although water meters in general are essential to figure out the amount of water abstracted and necessary for implementing water quotas, there can be some obstacles facing this issue. Zekri (2008) explained the difficulties of installing water meters in individual wells in Al Batinah. He insisted that installing water meters is only possible in the case of tube wells. In fact, the number of wells registered in Al Batinah is very large and only 5% of them are tube wells. He also mentioned that there are possibilities of adding and removing a non-metered pump to the dug wells, which could be easily done by farmers.

Another factor which might be a challenge is the cost of installation of water meters, which might be very high. Regarding this, some DM's came up with the idea of monitoring the rates of abstractions through electricity consumption. This idea was also suggested by Zekri (2008).

Figure 28 represents the answers of the DM's regarding responsibilities for purchase and maintain the water meters.

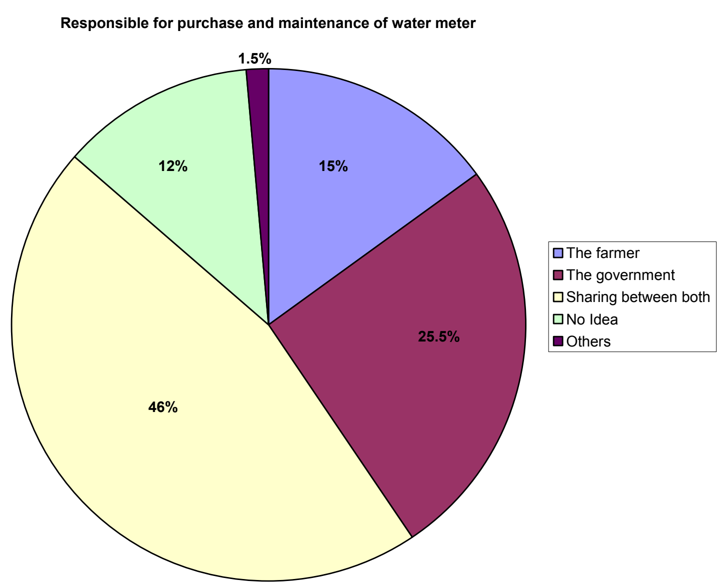


Figure 28: Answers of DM's regarding responsibilities for purchase and maintenance of the water meters

Many of the DM's (46%) agree that purchase and maintenance of the water meters should be shared between both, government and farmers. While, 25.5% of them insist that it should only be done by the government.

There was only one respondent who said:

> '*Purchase and installation from the government, and then maintenance could be done by farmers'*

In general, it is clear that the DM's believe that the biggest part of the process should be under the responsibilities of the government, although 15% of them indicated that it should be under the responsibility of farmers. Additionally, DM's are aware of the importance of subsidies, which was obvious earlier when they were answering the question (see Table 16) of possible interventions, for the options combined with subsidies.

5.3.3.4.3 Ways to Promote the Idea of Water Quotas

Looking forward to ways to promote the idea of water quotas among farmers, DM's were asked about best ways to encourage farmers to accept the idea of water quotas. They suggested several tools; following are the most remarkable ones and the percentage of DM's who mentioned the idea:

- Through subsidies in the form of modern irrigation equipment (15%)

  They referred this to that irrigation water will be automatically reduced by subsidising farmers with irrigation equipment and the idea of water quotas will be accepted by farmers. They added that it should be clear to farmers that sustainable supply is important and better than no supply at all in future. DM's ended this issue by saying: *'The government must show the available economic alternatives to compensate the farmers. Particularly those who are totally depend on agriculture'*.

- Through workshops (13.5%)

  Some water professionals and decision makers preferred arranging workshops to introduce the idea of water quota and explaining to farmers the benefit of it.

- Through pilot projects and step by step strategies (13.5%)
- Through awareness (12%)
- Through guidance and training (7.5%)

- Provide the farmers with new sources of irrigation. E.g. using of treated waste water or construction of new well fields (5%)
- Through religions and social commitments (2%)

Moreover, some of the respondents (6%) were reacting negatively, mentioning that farmers will never be convinced and it should be a governmental decision. Others said that only farmers who are affected by salinity might agree with the idea. In this regard, one respondent expressed the following:

'Farmers will never be convinced. Only farmers who are affected by salinity might agree'

Finally around (5%) of the DM's mentioned that they have no idea of the best way for the water quotas to be implemented, but they know it's a challenging task.

In general, water quota is chosen for more analysis because it is a good tool for regulation, from the demand side, and it is a well-known intervention measure. It is a good way to identify how water is distributed, who is getting and how much, when and how. In addition to that, it is a practice followed from a long time in Oman with the *Aflaj* systems (see Section 3.1.3). The only difference is that water can be seen when it is flowing in the *Aflaj* systems, while groundwater cannot be seen and not easy to understand what is going on, in aquifers, under the ground. This is the reason why farmers are not aware of the limitation of the groundwater resource in the region. Therefore there is a high risk of losing this resource due to a decrease in water quality.

5.3.4 Towards Implementation of Water Management

5.3.4.1 Involvement of Relevant Stakeholders in Decision Making Process

Survey respondents in both groups were asked to indicate by 'Yes', 'No' or 'No idea' if water users should play a role in making decisions regarding environmental problems and selecting management options. For this question (Table 19) the group of water experts and water professionals were specified according to the organizations they belong to.

Table 19: Water users involvement in decision making process, N=130

Organization	n	Yes%	No%	No Idea%	No Answer%
Farmers	64	95.3%	1.6%	0%	3.1%
Ministries and Water issue Organizations	54	88.9%	5.6%	3.6%	1.9%
Research Organizations	12	83.3%	16.7%	0%	0%
Total	130	91.5%	4.6%	1.5%	2.4%

Majority of the respondents (91.5%) believe that involvement of water users in the decision making process is important. Only 4.6% of all respondents indicated that they are not agreeing with the idea. Most of the decision makers groups indicated that they agree with the idea, by at least 80% of the total respondents. Similar results obtained by Al Shaqsi (2004) where he mentioned that all surveyed water specialists supported the idea of water users' involvement in water management issue. However, researchers were more cautious about the idea, at least 16% of them thought that it is not a good idea.

Decision makers in ministries and water issue organizations supported the idea very well and they mentioned several reasons, according to their opinions, involvement of water users in decision making processes is important. First, users are the main source of water problems and environmental degradation and they should be familiar with some of the effects in their lands. Therefore, their suggestions will be based on their practical experience to the problem. The second reason was the implementation of proposed interventions which might be accepted easier, as users will be keen to protect their own lands. The third mentioned reason was that such a process will facilitate increasing the knowledge of water users regarding the water problems, which will increase, as well, the awareness and farmers will be more favorable to conserve water. Many of the mentioned reasons match the advantages of the participatory approach.

The respondents also pointed to an important note, as they were concerned about how smooth the process could be, so they insisted that for the process to take place smoothly, all this should be done without any financial stress on farmers.

For those who indicated ‘No’, they did not mention strong reasons for their choices. The only reason mentioned is that, it is difficult for farmers to understand technical issues.

In general the majority of the respondents supported the importance of introducing the participatory approach with contributions from relevant stakeholders.

5.3.4.2 Obstacles Facing Water Professionals and Decision Makers Regarding the Implementation of Different Interventions

Water professionals and decision makers were asked to assess the major obstacles regarding the implementation of different interventions for overcoming environmental problems and the problem of water shortage in South Al Batinah. They were asked to rate the importance of each issue listed in the following table (Table 20) as either ‘extremely important’, ‘moderately important’, ‘neutral important’ ‘low important’ or ‘not important’. Additionally there were some respondents who did not give answers to this question, those were classified as; No Answer (NA).

Table 20: Obstacles facing water professionals and decision makers, N=67

Obstacles	Extremely Important	Moderately important	Neutral important	Low important	Not important	NA
Financial problems (availability of funding or budgets)	46%	31%	10%	9%	3%	1%
Political commitments and regulations	43%	31%	21%	4%	0%	1%
Religious commitments	16%	20%	27%	27%	7%	3%
Absence of a clear mechanism for implementing the proposed solutions	35%	47%	13%	4%	0%	1%
Decentralization of the governmental institutions relevant to the decision-making with respect to water issues	25%	41%	23%	7%	1%	3%
Farmers attitude and opinions	42%	40%	15%	1%	0%	2%
Political willingness and support	46%	34%	13%	4%	0%	3%
The complexity of the problem	27%	38%	21%	9%	1%	4%
Being water priceless for farmers (Free access to water)	31%	43%	16%	9%	0%	1%

From the results (Table 20) and by combining ‘extremely important’ and ‘moderately important’, it is obvious that almost all of the listed obstacles were rated as important (8 out of 9), by at least 60% of the total respondents. The highest rated obstacles were; “absence of a clear mechanism for implementing the proposed solutions”, “farmers attitude and opinion” and “political willingness and support”. The lowest rated (as important) obstacle was “religious commitments”. By combing ‘low important’ and ‘Not important’, 34% of the respondents rated it as a less important issue.

From the opinions of the respondents it can be concluded that the “religious commitments” are not considered as a great issue concerning most of the DM’s.

Different other obstacles were brought forward by the DM’s, which were not included in the list. For example; facing new problems during implementation, shortage in the human resources and limitation of capacity building, the absence of future long term outlook, and absence of ways of cooperation with farmers.

5.3.4.3 Ways of Communication and Involvement

The different types of respondents were asked to specify, from a provided list, the best way of communication between farmers and decision makers. Results are presented in Figure 29 below.

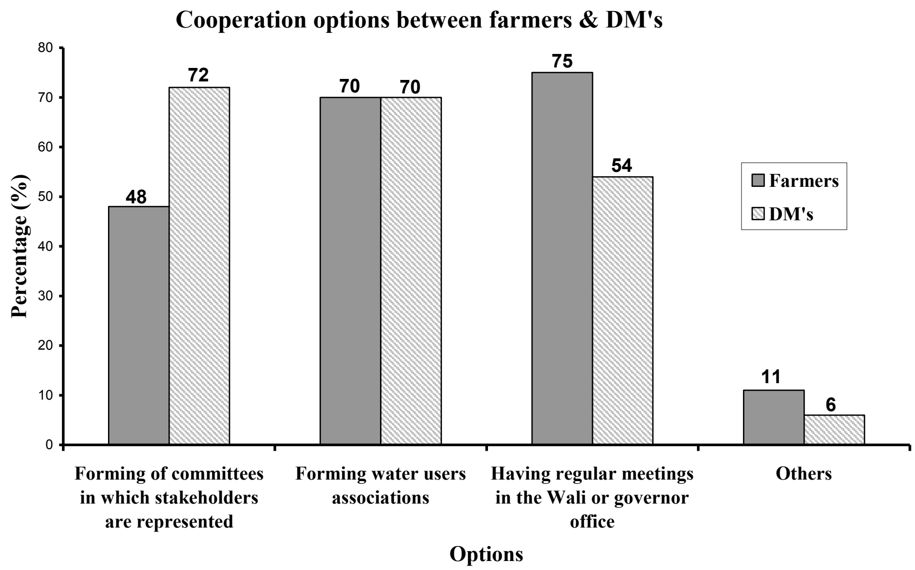


Figure 29: Communication ways between farmers and DM's

Most of the mentioned procedures are accepted by all respondents by at least 48%. Farmers (75%) are more likely to the idea of "having regular meetings in the *Wali* or Governor Office". While DM's (72%) are more likely to accept the option of "forming committees in which relevant stakeholders are represented".

Farmers were asked to identify if they are ready to be members of these meetings or associations. More than two thirds (78%) of them are interested in taking place in meetings and negotiations, while 22% are not interested to be involved in such type of meetings.

Many other ideas were brought forward by the different respondents. For example eight farmers suggested formulation of committees from the government that will visit them periodically and ask them about their opinions regarding the problem and the proposed interventions. They also suggested periodical meetings to be organized by the government in the agricultural centers in the regions.

Through this survey it was noticed that marketing facilities are very important to farmers. Most respondents rated the "requirement of better marketing facilities" as strongly needed (see Section 5.3.2, Table 14). In this context, five DM's suggested that, based on better marketing facilities, farmers can be convinced to adopt new water conservation techniques in their farms. Another way suggested by three DM's is to use new technologies to communicate with farmers, e.g. construction of special web sites via the internet to let farmers express their opinions. They even proposed to introduce intervention measures through the web site and ask farmers for their choices. However, for this issue, farmers are required to have knowledge of using computers and other new techniques.

Some of the decision makers and water professionals believe that Oman Agricultural Association or other forms of organizations of farmers should play a significant role to facilitate sharing ideas between farmers and other relevant organizations. This is supporting very well the importance of introducing the participatory approach with contributions from the relevant stakeholders. This was also underlined by the (MAF, 2012), that a coordinated response is needed between the relevant organization, farmers, as well as the media to help this message become part of local understanding.

5.3.4.4 Ways to Encourage Farmers to Change their Water and Agricultural Management Behaviours

DM's were asked to identify the best ways that could be used to encourage farmers to change their water and agricultural management behaviours. They suggested different and many ways which are summarised below. The percentage represents the number of DM's:

- Through training and pilot projects (39%)

  This option is mentioned by at least one third of the respondents. They insist that farmers should be trained and educated on the short and long terms. Some of the DM's added that training should start in school courses, to ensure the acceptance of the new generations in adopting better managements. Following are some remarkable expressions from DM's:

  'Through pilot projects, and use some farms to convince farmers with good methods of irrigation systems and new technologies in farming'.

  'Arrange training programs for farmers, and share with them some successful real farm experiments'.

- Through public awareness (18%)

  Some respondent indicated that "*awareness programs can particularly work with farmers; especially the educated ones*". However, they added that; "*these programs might not work with the greedy farmers, who only care about their short-term profits without paying any attention to the negative impacts caused by their behaviors*". Moreover, they mentioned that; "*the worse thing is that when educated farmers cut-down their groundwater abstraction rates themselves alone while greedy farmers still abstract it as they wish*". In this case, "*The former will eventually decide to return back to their earlier abstraction rates*".

Here it can be concluded (according to the expressions of the respondents) that, there is a relationship between the level of education of the farmers and their response to the awareness programs.

- Involving them in the decision making processes (18%)

  Some DM's insist that farmers should be involved in the decision making process. They expressed the following;

  'To *enrol them in the process of finding solutions*'

  '*By engaging them in decision making process and following up the implementation of intervention decided'*.

  '*Providing them with a list of possible solutions with a full list of advantages and disadvantages and allowing them vote for the best solution'.*

- Forcing them through rules and regulations (9%)

  Regarding this option, the following statement was mentioned by almost 7 DM's;

  '*The solution is to enforce all farmers to implement all regulations/ideas that would benefit the agricultural sector*'.

- Through incentives from the government (7%), and through better marketing facilities (7%)

  In this regard, it is noticed that the issues of incentives and marketing were combined together in most of the statements mentioned by the DM's;

  'Governmental support in the form of equipment and helping them marketing their products.'

  'Arranging meetings with farmers and supporting them economically/ by subsidies.'

  'Subsidies in agricultural materials. Subsidies in agricultural irrigation systems (material & installation). To find a market for the agricultural product'

- Through periodic supervision from the government (3%)

  In this regard, some DM's mentioned the following;

  '*The best way is periodically supervision from the government'*

5.3.5 Vision

Respondents, from both groups, were asked about their expectations for the future of agriculture and the availability of the water resources in the Al Batinah region. This was an open question and the respondents came out with different visions.

5.3.5.1 Vision of Farmers

Some farmers (19%) were optimistic about this issue. Following are some statements:

> *'I think the situation will be much better in the future'*
>
> *'I'm 90% sure, that there will be an improvement in the system. The agricultural productivity will be much better in future'*
>
> *'If good management strategies will be established, and farmers take good care of their farms with support from the government, the agriculture will improve and the productivity will increase'*

While some farmers (36%) had a different vision for the future of agriculture in the region. They think that, without a better management, the situation will be worse. This can be noticed from the following expressions:

> *'If no action is taken, there will be no more agriculture in future'*
>
> *'If no action is taken and the cultivation of forage increases, deterioration will also increase'*

Some farmers complained about foreign labourers, they suggested reducing reliance on foreigners for a better future. While others complained about the constructed dams, as they think those dams obscured the water. In this regard, one respondent expressed the following:

> *'With the existence of those dams and without new irrigation systems, the future will never be better'*

Some said that the situation depends on the climate change and the rainfall patterns. There were only few farmers who said that they have no idea how the future will be.

Regarding the personal situation of farmers if they will be still farming in future, they mentioned that they prefer to be still farming in their farms, but they doubt if their children will appreciate to be farmers.

5.3.5.2 Vision of Decision Makers

The vision of DM's about the future of agriculture in Al Batinah, in many cases (34%), is conditioned by interventions and strategies to be implemented. Following are some expressions from DM's regarding this issue:

> *'Without implementing good intervention measures, the sea intrusion will expand in land and the agriculture will be destroyed'*
>
> *'Without implementing any solutions; most of the farmers will be changing their lands use'*
>
> *'With the implementation of good strategy (e.g. cultivating more efficient crops which need less water and more economically); the farms can recover'*
>
> *'If new interventions will be implemented, the system will improve and the productivity will increase'*
>
> *'If the recent trend continues, more land will be abandoned'*

Additionally, some DM's (8%) insist that the solutions should be based on the participatory approach and stakeholders should be involved in the management issue. This can be noticed in the following expressions:

> *'For a better future of the agriculture in the region, the relevant stakeholders should be involved in the management issue and they should be ready to cooperate'*
>
> *'With a good cooperation and understanding of the problems between all stakeholders, the future of agriculture will be improved as well as the availability of water'*
>
> *'If the government act seriously and involve the farmers in the issue, the problem can be solved or at least reduced'*
>
> *'If the government and farmers cooperate to apply the integrated water resources management which is one of the logical solutions to improve the present situation, the future of agriculture will be better'*

Some DM's (4%) attribute the issue to the climate situation. They expressed this in the following way:

> *'The future depends on the rainfall events, but I think Oman is going into a different hydrological cycle where the quantity of the groundwater is due to increase as a result of heavy rains and storms'*

'The groundwater will raise again due to the climate change, where the water cycle will return to normal and more rainfall will occur'

In general, from the answers of the respondents, around 24% of the DM's are optimistic about the future. While 39% are not expecting a good future for the agriculture in the region.

5.4 Comparison between Opinions

5.4.1 Comparison of Opinions between Farmers and Decision Makers (DM's) Regarding Potential Interventions

Table 21: Results of the comparison in opinions of farmers and DM's regarding management interventions

No.	Intervention measures	Farmers (mean)	DM's (mean)	Farmers (SD)	DM's (SD)	P value	Direction
1	Introducing water quota	3.47	1.88	1.391	1.023	0.000	D
2	Introducing water quota with subsidies (equipments for modern irrigation)	2.75	1.70	1.309	0.779	0.000	D
3	Introducing water quota with subsidies (guidance & training in agricultural management)	2.94	1.58	1.233	0.762	0.000	D
4	Introducing using treated wastewater for agricultural use, if it is available and the quality is acceptable	2.17	1.61	1.092	0.834	0.001	R
5	Encourage the farmers to reduce the withdrawal of groundwater pumped per day by guidance & training.	2.31	1.63	0.974	0.756	0.000	D
6	Implementation of centralized well field water distribution system for agriculture which provides water in a good quality	2.42	2.27	1.193	1.162	0.458	R
7	Convince the farmers to change the type of crops to the ones with lower crop water requirements.	2.48	2.03	1.084	1.058	0.017	D
8	Encourage farmers to improve their irrigation methods	2.02	1.45	0.968	0.610	0.000	D
9	Encourage farmers to improve their irrigation methods with subsidies (equipment for modern irrigation systems)	1.66	1.72	0.648	0.794	0.636	D
10	Encourage farmers to improve their irrigation methods with subsidies (guidance & training in agricultural management)	1.86	1.66	0.774	0.686	0.115	D
11	Construction of injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	2.19	2.13	1.006	1.013	0.764	R
12	Construction of more desalination plants for brackish & seawater, to be used for irrigation.	2.14	3.09	1.082	1.311	0.000	R
13	Increase the effectiveness of water use by public awareness.	1.55	1.46	0.561	0.636	0.424	D
14	Introduce water prices for pumped groundwater.	3.92	2.48	1.276	1.133	0.000	D
15	Introduce special energy tariffs for agricultural water use.	1.86	2.49	0.957	1.146	0.001	D
16	Forming water managers groups	1.88	1.91	0.864	0.900	0.819	D
17	Forming guidance & information water centers to support farmers in farm & water management.	2.11	1.63	0.918	0.813	0.002	D
18	To evaluate the farms- government should take a decision to close some farms & change the land use	1.97	2.52	1.054	1.211	0.006	D

The list of management interventions was used to perform a comparison analysis between the two groups. The results are presented in Table 21. The mean score ranges between 1 for 'strongly agree' and 5 for 'strongly disagree'. The degree of significant differences is based on independent sample T-test. For the mean(s), items shaded in gray, are the highly rated by the respondents, while the P-value(s), items also shaded in gray are significant.

Differences between opinions of groups were examined by an independent sample T-test. When calculated P-values are next to zero, significant differences between opinions of existing groups is high.

The mean, is representing the degree of acceptance of each intervention by the groups. The results which are represented by standard deviation (SD) values in Table 21 are reflecting if the management options and interventions focus on water demand side (D) measures to reduce water consumption and use the resources more efficiently, or on water resources side (R) measures to increase the availability of water.

From the results, It is obvious that farmers are significantly more likely to accept the idea of "increasing the effectiveness of water use by public awareness", "encouraging farmers to improve irrigation methods with subsidies in the form of equipment", "encouraging farmers to improve irrigation methods with subsidies in the form guidance and training", "introducing special energy tariffs for agricultural purposes", and "forming water managers groups". They are more enthusiastic regarding "improving the irrigation methods with subsidies in the form of equipment" comparing to the other two options regarding "improving irrigation methods", as the mean is (1.66). It is also noticed that they did not reject the idea of using treated wastewater for irrigation, 75% of them have chosen 'strongly agree' and 'agree' [Appendix A.3, Table A.1], and the mean for this option is (2.17).

DM's are significantly more likely to accept the idea of "increasing the effectiveness of water use by public awareness", "encouraging farmers to improve irrigation methods with subsidies in the form guidance and training", "introducing using treated wastewater for agricultural use", "encouraging the farmers to reduce the withdrawal of groundwater pumped per day by guidance and training". It can be also noticed that DM's are less likely to accept the idea of introducing more desalination plants. Only 35% of them agreed with the idea, 28% couldn't decide, and 37% disagreed. [Appendix A.3, Table A.1]

In many cases (12 of 18 items) the opinions of farmers are very different from the group of DM's. On the other hand, differences are less obvious between the two groups in 6 of the 18 items. It is also worth mentioning here that although the results in some options showed differences in opinions between the two groups, it can be noticed that the differences are not absolutely in an opposite direction. Opinions in some cases are flowing in the same direction (e.g. ‘strongly agree’ and ‘agree’) but the level of differences is high. For example regarding introducing special energy tariffs for agricultural purposes, the mean for farmers is 1.86, while it is 2.49 in the case of DM’s. In other words, both groups did not disagree with the idea, but there are differences in the level of agreement between the two groups.

Almost both groups are significantly more likely to accept the ideas of “centralized wells”, “changing crop patterns”, “improving irrigation methods (with subsidies)”, and the “construction of injection wells”. However, opinions of farmers were mostly more diverse than DM’s opinions. Farmers were significantly less likely to accept the idea of water quota and to introduce water prices for pumped groundwater than the DM’s. Only 29% of farmers accepted water quota [See Appendix A.3, Table A.1]. Additionally, they are more enthusiastic regarding improving the irrigation methods with subsidies in the form of equipment (41%) [Appendix A.3, Table A.1]. On the other hand, the training and education are not considered as strong priorities for them. They also agreed much about increasing the effectiveness of water use by public awareness (44%) [Appendix A.3, Table A.1]. For the group of DM’s, it is obvious that in many cases they are more likely to accept the regulation issues combined with incentives in the form of education and training as well as forming guidance and information centers. While farmers are more likely to accept issues coupled with incentives in the form of equipment from the government.

5.4.2 Are DM’s Aware of Farmers’ Thinking and Behaviors?

During performing the pre-test survey and through the comparison between the opinions of farmers and decision makers, it was noticed that the opinions of farmers are very different from the opinions of decision makers. To improve the analysis and in order to investigate if DM’s know how the farmers think, a further analysis was required. For that, during the survey, the interventions’ question was repeated for the group of decision makers, but this time they were asked to rate to what level the interventions might be accepted by farmers. The purpose was to explore if there are any differences between the farmers’ actual opinions and what decision makers believe about farmers’ opinions. Having prior knowledge and understanding about the thinking, behavior, and needs of involved groups of users, helps in the selection processes of the appropriate option and the development of implementation strategies. The results are represented in Table 22.

Table 22: Results of the comparison in opinions of farmers and DM's believe about farmers' opinions regarding management interventions

No.	Intervention measures	Farmers (mean)	DM's believes about farmers (mean)	Farmers (SD)	DM's (SD)	P value (farmers & DM's believes about farmers	Direction
1	Introducing water quota	3.47	3.18	1.391	1.435	0.243	D
2	Introducing water quota with subsidies (equipments for modern irrigation)	2.75	2.18	1.309	0.984	0.005	D
3	Introducing water quota with subsidies (guidance & training in agricultural management)	2.94	2.34	1.233	1.136	0.005	D
4	Introducing using treated wastewater for agricultural use, if it is available and the quality is acceptable	2.17	2.30	1.092	1.168	0.523	R
5	Encourage the farmers to reduce the withdrawal of groundwater pumped per day by guidance & training.	2.31	2.45	0.974	1.158	0.472	D
6	Implementation of centralized well field water distribution system for agriculture which provides water in a good quality	2.42	2.76	1.193	1.244	0.114	R
7	Convince the farmer to change the type of crops to ones with lower crop water requirements.	2.48	2.70	1.084	1.155	0.270	D
8	Encourage farmers to improve their irrigation methods	2.02	1.87	0.968	0.776	0.329	D
9	Encourage farmers to improve their irrigation methods with subsides (equipment for modern irrigation systems)	1.66	1.58	0.648	0.678	0.523	D
10	Encourage farmers to improve their irrigation methods with subsides (guidance & training in agricultural management)	1.86	1.84	0.774	0.914	0.874	D
11	Construction of injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	2.19	2.19	1.006	0.941	0.969	R
12	Construction of more desalination plants for brackish & seawater, to be used for irrigation.	2.14	2.54	1.082	1.198	0.049	R
13	Increase the effectiveness of water use by public awareness.	1.55	2.03	0.561	0.797	0.000	D
14	Introduce water prices for pumped groundwater.	3.92	3.51	1.276	1.481	0.089	D
15	Introduce special energy tariffs for agricultural water use.	1.86	3.21	0.957	1.292	0.000	D
16	Forming water managers groups	1.88	2.13	0.864	1.086	0.134	D
17	Forming guidance & information water center to support farmers in farm & water management.	2.11	1.94	0.918	0.868	0.278	D
18	To evaluate the farms- government should take a decision to close some farms & change the land use	1.97	3.25	1.054	1.396	0.000	D

Similar to the previous comparison (Table 21), the mean score ranges between 1 for 'strongly agree' and 5 for 'strongly disagree'. The degree of significant differences is based on independent sample T-test. For the mean(s), items shaded in gray, are the highly rated by the respondents, while the P-value(s), items shaded in gray, also, are significant.

In this comparison, there are no significant differences in opinions between farmers and what DM's believe about farmers' opinions in 12 of 18 items, but the differences are obvious in the rest 6 items. Additionally, there are no significant differences between responses in each group regarding introducing water quotas when the option was not coupled with any subsidies. While the differences in opinions are significant in the other two options of introducing water quotas with subsidies. 44% of the farmers agreed with the ideas of water quotas with subsidies in the form of equipment for modern irrigation, while 57% of the DM's thought that farmers will be more likely to accept the idea. Similarly, 50% of the farmers agreed with the ideas of water quotas with subsidies in the form of guidance and training in agricultural management while 73% of the DM's thought that farmers will be more likely to accept the ideas. [Appendix A.4, Table B.1]. Here it is worth to point out that although the differences were significant in those two interventions, they were going to (toward agreeing) the same direction and not the opposite.

However, the level of significant differences in opinions is very high in ideas of "introducing special energy tariffs for agricultural purposes", "increase the effectiveness of water use by public awareness", and "farms need to be evaluated (government should take a decision to close some farms and change the land use)" the P-value is zero. DM's did not know that farmers could accept these idea.

In general, in most of the cases, the decision makers were aware of farmer's opinions. This is very obvious in the options of water quotas. This gives an indication that the existing situation is not in a very bad condition, since DM's understand and are familiar with the opinions of farmers. On the other hand it is seen that regarding some options, farms evaluation, DM's did not know that farmers could accept the idea.

5.5 Drivers behind Opinions

5.5.1 Analysis of Frequency Curves

The obtained data were used for a more advanced statistical analysis in order to identify factors behind farmers' choices and opinions. By using frequency curves, differences were examined in opinions within the same group. Following (Figure 30) are the frequency curves obtained from the analysis of farmers' group (64 farmers). The score on the x-axis ranges between 1 for strongly agree and 5 for strongly disagree.

From Farmers' frequency curves, it is noticed that the percentage of farmers who agreed and the percentage of farmers who rejected the idea of water quota with subsidies, is similar (Figure 30 (f)). This can be seen more clearly at the additional two circles around the two groups within the same sample. Therefore, Cross-tabulation and DA are performed to identify the parameters which might be the reason behind.

For this work, three types of water quota (WQ) interventions, are used:

1. Water quota
2. Water quotas with subsidies in form of equipment and,
3. Water quotas with subsides in form of guidance and training.

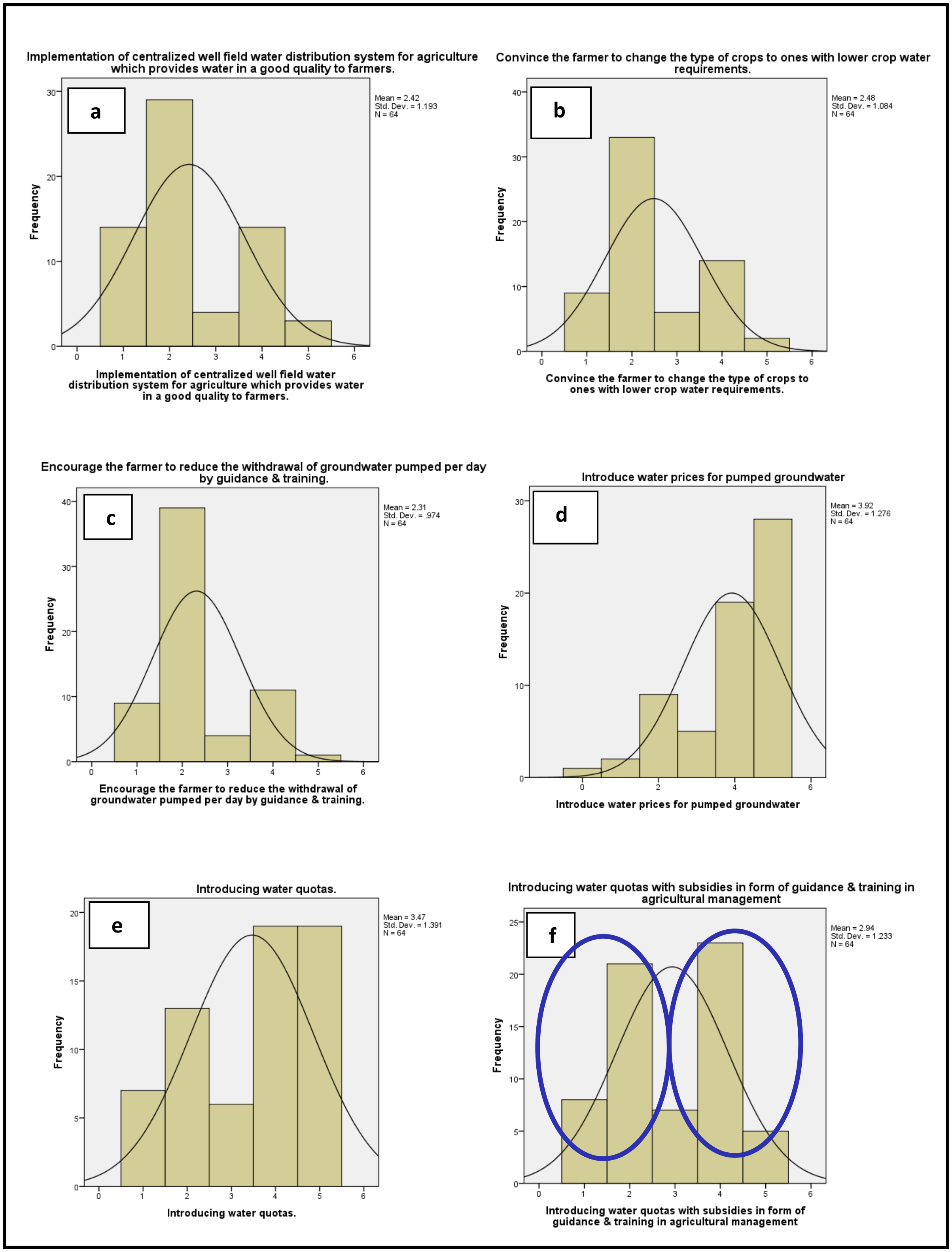


Figure 30: Frequency Curves of Farmers' opinions

5.5.2 Cross Tabulation Analysis

As an advanced test, a cross tabulation analysis was used to evaluate the influence of some factors (e.g. salinity ranges, farm size, age, and educational level) on farmers' opinions regarding the implantation of water quota. In evaluating the results 'strongly agree' and 'agree' were combined to be 'agree'. While the 'disagree' and 'strongly disagree' were combined to be 'disagree'.

The Influence of Salinity Levels on Farmers' Opinions

Table 23: The influence of salinity ranges on farmers' opinions regarding implementing water quotas. N=60

Salinity range	No. of Farmers	Implementation of water quotas	Options				
			Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
<1000 µS/cm	12	Adopt the idea of water quotas.	1 (8.33%)	0 (0%)	3 (25%)	2 (16.67%)	6 (50%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	2 (16.67%)	3 (25%)	2 (16.67%)	4 (33.335)	1 (8.33)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	2 (16.67)	3 (25%)	3 (25%)	3 (25%)	1 (8.33)
1000-3000 µS/cm	23	Adopt the idea of water quotas.	2 (8.70%)	4 (17.39%)	2 (8.70%)	11 (47.83%)	4 (17.39%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	4 (17.39%)	7 (30.43%)	2 (8.70%)	8 (34.78%)	2 (8.70%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	3 (13.04%)	8 (34.78%)	1 (4.35%)	10 (43.48%)	1 (4.35%)
3000-6000 µS/cm	20	Adopt the idea of water quotas.	3 (15%)	6 (30%)	1 (5%)	4 (20%)	6 (30%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	6 (30%)	4 (20%)	2 (10%)	6 (30%)	2 (10%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	2 (10%)	5 (25%)	3 (15%)	8 (40%)	2 (10%)
>6000 µS/cm	5	Adopt the idea of water quotas.	1 (20%)	2 (40%)	0 (0%)	0 (0%)	2 (40%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	1 (20%)	4 (80%)	0 (0%)	0 (0%)	0 (0%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	1 (20%)	3 (60%)	0 (0%)	0 (0%)	1 (20%)

In order to evaluate if there is a relationship between the level of salinity in the farms and the opinions of farmers regarding implementing water quotas, farmers were classified into groups according to the salinity ranges in their farmers. The results of each category are tabulated in Table 23.

It is noticed from the results that the ideas of implementing water quotas are accepted more by the farmers who are affected by high salinity ranges (Table 23). By combining 'strongly agree' and 'agree' 60 to 100% of the farmers who belong to the (>6000 µS/cm) category accepted all three options of water quotas. The (3000-6000 µS/cm) category, accepted the ideas by at least 45%. Moreover, around 48% of the farmers belong to the (1000-3000 µS/cm) category, accepted the ideas as well. For the category of (<1000 µS/cm), only 8% accepted the idea of the first option. While, The percentage increased to 41.5% with second and third options.

From the opinions of the respondents, it can be concluded that the salinity ranges (as a factor) have an effect on farmers' opinions regarding implementing water quotas.

The Influence of Farm Size on Farmers' Opinions

Another factor tested here is the farm size, to evaluate if there is any relationship between the farm size and the opinions of farmers regarding implementing water quotas. Farmers were grouped into different categories according to farm size. The results are tabulated Table 24.

From the results in Table 24, the highest rated option is "intoducing of water quota with subsidies in the form of equipment for modern irrigation systems". 61.3% of the opinions of the respondent belonging to the category of (<10fd) rated it as strongly agree and agree. The lowest rated option was "introducing of water quota, by the category of (>60fd), as they rated it as 100% disagree and strongly disagree. In general, all the farmers in the category of (>60fd) were less likely to accept the idea. In all three options, their opinions occurred between disagree and strongly disagree.

It can be concluded from the above results that the farm size, as a factor, play a major rule in farmers' opinions regarding the three options of water quotas implementation.

Table 24: The influence of farm size on farmers' opinions regarding implementing water quotas. N=63

Farm size in Feddan	No. of Farmers	Implementation of water quotas	Options				
			Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
<10 fd	31	Adopt the idea of water quotas.	5 (16.1%)	8 (25.8%)	2 (6.5%)	11 (35.5%)	5 (16.1)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	6 (19.4%)	13 (41.9%)	2 (6.5%)	9 (29%)	1 (3.2%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	4 (12.9%)	12 (38.7%)	3 (9.7%)	10 (32.3%)	2 (6.5%)
10-29 fd	22	Adopt the idea of water quotas.	1 (4.5%)	4 (18.2%)	3 (13.6%)	7 (31.8%)	7 (31.8%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	5 (22.7%)	6 (27.3%)	3 (13.6%)	8 (36.4%)	0 (0%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	2 (9.1%)	7 (31.8%)	2 (9.1%)	11 (50%)	0 (0%)
30-60 fd	8	Adopt the idea of water quotas.	1 (12.5%)	1 (12.5%)	1 (12.5%)	0 (0%)	5 (62.5%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	2 (25%)	1 (12.5%)	1 (12.5%)	1 (12.5%)	3 (37.5%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	2 (25%)	2 (25%)	2 (25%)	0 (0%)	2 (2%)
>60 fd	2	Adopt the idea of water quotas.	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (100%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	0 (0%)	0 (0%)	0 (0%)	1 (50%)	1 (50%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	0 (0%)	0 (0%)	0 (0%)	1 (50%)	1 (50%)

The Influence of Age on Farmers' Opinions

To evaluate the influence of age of farmers on their opinions regarding implementing water quotas, they were grouped into five categories according to their age. The results are illustrated in Table 25.

Table 25: The influence of age on farmers' opinions regarding implementing water quotas. N=64

Age	No. of Farmers	Implementation of water quotas	Options				
			Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
<30 yr	4	Adopt the idea of water quotas.	1 (25%)	0 (0%)	0 (0%)	0 (0%)	3 (75%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	1 (25%)	0 (0%)	0 (0%)	2 (50%)	1 (25%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	1 (25%)	0 (0%)	1 (25%)	1 (25%)	1 (25%)
30-45 yr	17	Adopt the idea of water quotas.	3 (17.6%)	3 (17.6%)	2 (11.8%)	6 (35.3%)	3 (17.6%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	4 (23.5%)	4 (23.5%)	3 (17.6%)	5 (29.4%)	1 (5.9%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	4 (23.5%)	3 (17.6%)	5 (29.4%)	4 (23.5%)	1 (5.9%)
45-55 yr	19	Adopt the idea of water quotas.	1 (5.3%)	6 (31.6%)	1 (5.3%)	5 (26.3%)	6 (31.6%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	7 (36.8%)	6 (31.6%)	0 (0%)	4 (21.1%)	2 (10.5%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	2 (10.5%)	10 (52.6%)	0 (0%)	5 (26.3%)	2 (5.9%)
55-65 yr	16	Adopt the idea of water quotas.	2 (12.5%)	1 (6.3%)	2 (12.5%)	7 (43.8%)	4 (25%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	1 (6.3%)	5 (31.3%)	2 (12.5%)	7 (43.8%)	1 (6.3%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	1 (6.3%)	4 (25%)	0 (0%)	10 (62.5%)	1 (6.3%)
> 65 yr	8	Adopt the idea of water quotas.	0 (0%)	3 (37.5%)	1 (12.5%)	1 (12.5%)	3 (37.5%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	0 (0%)	5 (62.5%)	1 (12.5%)	2 (25%)	0 (0%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	0 (0%)	4 (0%)	1 (0%)	3 (50%)	0 (50%)

The highest rated intervention is "intoducing of water quota with subsidies in the form of equipment for modern irrigation systems". 68.4% of the opinions of the respondent belonging to the category of 44-

55yr rated it as ‘agree’. The lowest rated intervention is “intoducing of water quota and adoption of water quota with subsidies in the form of equipment for modern irrigation systems” by the category of (>30yr), they rated it as 75% disagree.

The Influence of Educational Level on Farmers’ Opinions

To evaluate the relationship between farmers’ educational level and their opinions regarding the implementation of water quota, the group is classified into five categories according to the level of education. The results are illustrated in Table 26.

The results indicate that the category of ‘no read no write’ is more likely to accept all options of water quota by at least 54.6%. The highest rated option was “introducing of water quota with subsidies in the form of equipment for modern irrigation systems”. 66.6% of the opinions of the respondent belonging to the category of ‘secondary school’ rated it as ‘strongly agree’ and ‘agree’.

The lowest rated option was “introdicing of water quota and adoption of water quota with subsidies in the form of guidance and training” in agricultural management by the category of ‘read and write only’, as they rated it as 71.5% ‘disagree’ and ‘strongly disagree’.

Table 26: The influence of educational level on farmers' opinions regarding implementing water quotas. N=64

Education level	No. of Farmers	Implementation of water quotas	Options				
			Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
No read no write	11	Adopt the idea of water quotas.	2 (18.2%)	4 (36.4%)	0 (0%)	2 (18.2%)	3 (27.3%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	1 (9.1%)	5 (45.5%)	1 (9.1%)	3 (27.3%)	1 (9.1%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	1 (9.1%)	6 (54.5%)	0 (0%)	3 (27.3%)	1 (9.1%)
Read and write only	7	Adopt the idea of water quotas.	0 (0%)	0 (0%)	2 (28.6%)	3 (42.9%)	2 (28.6%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	1 (14.3%)	0 (0%)	3 (42.9%)	3 (42.9%)	0 (0%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	0 (0%)	0 (0%)	2 (28.6%)	5 (71.4%)	0 (0%)
Primary school	15	Adopt the idea of water quotas.	2 (13.3%)	2 (13.3%)	3 (20%)	5 (33.3%)	3 (20%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	4 (26.7%)	4 (26.7%)	1 (6.7%)	5 (33.3%)	1 (6.7%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	1 (6.7%)	5 (33.3%)	2 (13.3%)	6 (40%)	1 (6.7%)
Secondary school	18	Adopt the idea of water quotas.	3 (16.7%)	4 (22.2%)	0 (0%)	3 (16.7%)	8 (44.4%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	6 (33.3%)	6 (33.3%)	1 (5.6%)	5 (27.8%)	0 (0%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	5 (27.8%)	5 (27.8%)	2 (11.1%)	5 (27.8%)	1 (5.6%)
Graduated and post graduated	13	Adopt the idea of water quotas.	0 (0%)	3 (23%)	1 (8%)	6 (46%)	3 (23%)
		Adopt the idea of water quotas with subsidies in the form of equipment for modern irrigation systems	1 (8%)	5 (38%)	0 (0%)	4 (31%)	3 (23%)
		Adopt the idea of water quotas with subsidies in the form of guidance & training in agricultural management.	1 (8%)	5 (38%)	1 (8%)	4 (31%)	2 (15%)

5.5.3 Analysis of Drivers behind Farmers' Opinions

Farmers' frequency curves (see Section 5.5.1, Figure 29) showed differences in opinions in some interventions, while differences in opinions were not so high within the group of DM's [Appendix A.5, Figure A.1]. It is noticed that the percentage of farmers who agreed or rejected the idea of water quota with subsidies is similar. Therefore, it is of interest to identify the drivers influencing farmers' opinions. A Discriminant Analysis was conducted based on selected indicators from the data set, to identify parameters playing a role in opinions variations. The DA was applied by following the steps described in chapter 4. The results for each step are represented below:

Step 1: *Data preparation*

Discriminant Analysis was performed to identify the drivers (Discriminators) influencing farmers' opinions regarding the intervention measures of "water quota without any subsidies" and the other two options of; "water quota with subsidies in the form of equipment" and "water quota with subsidies in the form of guidance and training". By inspecting the group means which were obtained from the frequency analysis, two groups of farmers were defined[7]: The first group is of the farmers who agreed for water quota to be implemented, and the second group is of those who disagreed. The groups of 'strongly agree' and 'agree' were merged to be only 'agree', and the groups of 'strongly disagree' and 'disagree' were merged to be only 'disagree'.

Those who were not able to rate which option to choose, were excluded from this test. Therefore, the total number of farmers for this test is 40 farmers instead of 64.

Step 2: *Selection of indicators*

From the data set, nine (see Table 27) different indicators were selected with either continuous data (A) or categorical data (C). These are the independent variables (IV) that were considered to have great effects on choices of farmers regarding a particular intervention (the dependent variable (DV)). After that, significant mean differences were observed for all independent variables and a Discriminant Analysis (DA) test was performed to assess the contribution and level of importance of each selected indicator on farmers' opinions regarding the implementation of the interventions.

[7] Where the mean, within the sample, is between 3 and 4.

Table 27: List of selected indicators

No.	Indicator	Type
1	Age (A)	A
2	Farm size (fd)	A
3	Area used for agriculture (fd)	A
4	Area used for commercial (fd)	A
5	Salinity range (µs/cm)	A
6	Educational level	C
7	Level of cooperation with Ministries	C
8	Farm classification	C
9	Percentage of products sold	C

(A) continuous data and (C) categorical data, (fd) feddan

Step 3: *Application of the method*

For applying the DA, both options for independents were used: "Enter Independents Together" and "Use Stepwise Method", but each at a time. For evaluating the results, a Canonical Correlation Analysis (CCA) was used. If the canonical correlation approaching 1, it means that the suggested discriminator based on the list of indicators explains most of the variation between the groups of dependent variables. The results are summarized in Table 28.

Table 28: The suggested discriminators by Discriminant Analysis (n=40)

Analysing option	**No. of samples**	**Suggested discriminators**	**Canonical correlation**
Water Quota			
Stepwise	40	1.Salinity range	0.352
Independents together	40	1.Salinity range 2.Level of cooperation with Ministries	0.516
Water Quota with Equipment			
Stepwise	40	*No variables were qualified*	--
Independents together	40	1.Level of cooperation with Ministries 2.Area used for commercial 3.Farm size	0.448
Water Quota with Guidance & Training			
Stepwise	40	*No variables were qualified*	--
Independents together	40	1.Level of cooperation with Ministries	0.469

Investigations by DA, indicated that opinions are influenced by "salinity range" which describe the level of groundwater salinity in the farm, and "level of cooperation with Ministries" (Table 28). The later represents the level of trust between farmers and decision makers. In the list of indicators only 4 of them considered to be able to explain the differences in opinions. This gives an indication that the correlation is not very strong. However, the "level of cooperation" is selected in all cases which gives at least a qualitative hint on its importance.

5.6 Modeling with BN

For the validation of the structure of the BN, water quota was considered to be the intervention to be tested through the network. The reason is that there is a high variation in opinions regarding water quotas implementation within the group of farmers.

Variables were identified in three levels; the input, intermediate and output variables. Furthermore, an explanation of how these variables will be dependent on each other was identified, which is an important task in constructing a BN. Additionally, data were prepared and probability values of all input variables and conditional probabilities of the intermediate and output variables were calculated and determined.

5.6.1 Determination of the Variables and Validation of the Structure of the BN

The variables to be included in the network were decided based on knowledge obtained through the description and evaluation of the problem, the statistical results and by using expert opinions. A large number of variables were chosen to be representing factors thought to be contributing in shaping farmers' willingness and ability or capability to change and respond.

The structure of the BN (the map of variables and conditions) was reviewed by the stakeholders (decision makers and scientists) through meetings and workshops (see Figure 31). They were asked to discuss the key variables, and if adjustments were needed in the causal links represented in the framework.

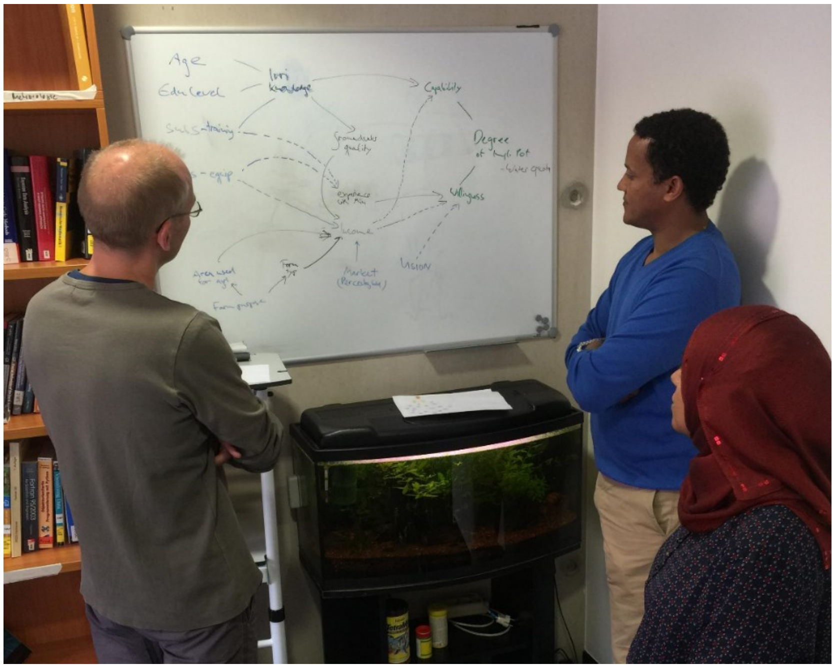


Figure 31: Asking for expert opinions during developing the structure of the BN

All suggested changes were marked down, for both, variables to be included and hypothetical connections between the variables. At the end, 18 variables were chosen to be transferred to the GeNIe software where the network was manually built (see Figure 12). It is worth mentioning here that expert opinions were only used to design the network and to decide the variables to be included and the links among them, but not to feed the network with data. The following table (Table 29) describes the assumption behind the structure of the BN.

Table 29: Assumptions behind the variables used in the structure of the Baysian Network model (BN)

Variable	Definition- the idea	Impacts on	Assumption	If the data is available or not (A/N)
Degree of implementation potential of water quotas	Water quota is defined to be, the allocation of the resources in an equitable way. Implementation of water quotas to the ground water used for irrigation in the study area is essential to control the problem of water shortage and saline intrusion in the coastal aquifer. The idea is to test the degree of implementation potential through evaluating variables affecting behaviors and opinions of different stakeholders.	N/A	N/A	A
Ability/ Capability/ Flexibility to respond	The ability and capability of the stakeholders In the matter of money.	1)degree of implementation potential	According to the factors influencing farmer's capability, to accept or reject the idea.	A
Willingness/Attitude	This is to test level of willingness of accepting or rejecting the idea.	1)degree of implementation potential	Increase the level of acceptance	A
Farm income/month	Net income from the farm (O.R/month)	1(ability/ capability/ flexibility to respond 2)Willingness	If there is an income from the farm, it means more money is available for adoption of better management activities.	A
Market- revenue	Farm production sold (percentage)	1)farm income/month	Increasing monthly income from the farm production	A
Ground water quality/Salinity range	The recorded salinity range for the ground water in the farm	1)ability/capability/ flexibility to respond 2)farm income/ month	Good water quality helps the farmer to increase the cultivated area and produce more products.	A
Crop pattern	Type of cultivated crops in the farms (Trees, Forage & Clover, Vegetables)	1)marketing	Deciding the percentage of total farm production sold and make profit.	A
Irrigation knowledge	If farmers have good irrigation skills	1) farm classification 2) ability/ capability/ flexibility to respond	This should alow farmers to manage their farms in a good way and adopt new irrigation methods. Also, farmers become more likely to respond	A
Farm type	Clasified by irrigation method used	1)farm income/month	A modern farm with new irrigation techniques is more likely to have more income compared to a traditional one.	A
Area used for agriculture	The percentage of the area used for agriculture in the farm.	1)crop pattern 2)farm type (by irrigation method)	Deciding the type of cultivated crops and type of irrigation methods to be used.	A
Distance from sea	The distance between the farm and the coast line.	1)ground water quality/salinity range 2)crop pattern	Near to the sea, more water salinity problems.	A
Subsidies	Government support (equipment). Farmers will be able to have new irrigation equipment in their farms and upgrade their farms from being traditional to modern ones.	1)farm type (by irrigation method) 2)farm income/month	Reduction in water used for agriculture	A
Training	Training and education in different aspects of water & agricultural management	1)irrigation Knowledge	1) By training, farmers can gain more information on farm and water management, then their irrigation skills will improve.	A
Educational level	Respondent's educational level	1)irrigation knowledge	A good education helps to introduce new technologies in irrigation.	A
Age	Age of the Respondents	1)irrigation knowledge	long experience in water management and farming, will impact the irrigation knowledge	A
Long term perspective	The vision and perspectives of the respondent about future alternatives	1)willingness	A respondent with a long term vision for the situation will be more willing to respond.	A
Experience with	The level of trust between farmers	1)long term	Experience with Ministries:	A

ministries	and governmental water and agricultural organizations.	perspective 2)willingness	Representing the level of trust between farmers and governmental water and agricultural organizations. Availability of good cooperation with water & agriculture organizations, farmers are more likely to respond. The more the farmers trust these organizations, the more willing to support optimization.	
Awareness about the problem	The awareness of the respondent about water management, limitation of resources and the environmental problems.	1)long term perspective	A respondent with a good awareness of the situation will be able to evaluate what is the best for the future.	A

5.6.2 Identification of States and its Potential Data and Sources

After the agreement of all the relevant factors, which are related to water resource management, the data were generated from the questionnaires and the statistical results [see more in Appendix A.6]. The data initiated in the network were directly formed from the answers of the responses to the survey questions. Almost all the collected data and information were useful and applicable even the qualitative ones. The missing data were very few in the data set, so the interpolation option was used to fill the gaps in the spreadsheet.

The statistical approaches were used to identify the key variables influencing farmers' willingness and capability to change. These were represented as nodes in the BN, and described using states relevant to the survey responses. An initial representation of the causality links between the key factors was developed.

Table 30 is giving an overview of the questions used for each variable, and how data were decided for each variable.

Table 30: List of Variables, States and the question(s) compiled to each variable

Variable	States	Survey Question(s)
Implementation potential	1 (yes) 2 (No)	Introducing water quotas?(Agree, Disagree)
Ability	1 (yes) 2 (No)	Are you ready to pay for a new water service (which provides water of a good quality) to reduce the withdrawal from groundwater aquifer? (Yes/No)
Willingness	1 (yes) 2 (No)	The nearest question (from the questionnaire) to fit this variable was: Are you ready to install water meters for every well in your farm? (Yes/No)
Farm income	1 (I don't sell) 2 (<1000 O.R/month) 3 (>1000 O.R/month)	What is the monthly income from your farm production
Market- revenue	1 (<25%) 2 (25-75%) 3 (76-100%)	What percentage of your total farm production is usually sold?
Salinity range	1 (<1000µs/cm) 2 (1000-3000µs/cm) 3 (>3000µs/cm)	Is there any indication of salinity in your farm? (Yes, No), please specify the range (if possible)
Crop pattern	1 (Vegetables) 2 (Trees) 3 (Veg & trees) 4 (Veg & trees & Forage) 5 (Trees & Forage) 6 (all) (veg, trees, forage & cereals)	Which of the following crops do you grow or produce in your farm (Trees, Forage & Clover, and Vegetables)? Please select option(s)
Irrigation knowledge	1 (High) 2 (Med) 3 (Low)	For this variable, the data used is a combination of answers to two questions: 1. Do you know how much water do you use per day? (Yes/No) 2. Do you have water meters? (Yes/No) So if the farmer answered yes to both questions, it is considered that he has good knowledge about irrigation, if both answers are no, it means his irrigation knowledge is poor. Those are the criteria used to generate the data for this variable. [See more in Appendix A.6]
Farm classification (% of area irrigated by flood/ farm)	1 Modern (< 30 %) 2 Mixed (31-69 %) 3 Traditional (70-100%)	The question was: Please specify the method(s) of irrigation used in your farm; Flood, Bubbler, Sprinkler, Drip, Others? From the answers, farms were classified, according to irrigation methods, and merged to three categories [See Appendix A.6].
Area used for Agriculture & food production	1 (<5 fd) 2 (5-10 fd) 3 (10-15 fd) 4 (15-20 fd) 5(>20 fd)	What area (fd) used for agriculture and food production?
Distance from sea (km)	1 (<5 km) 2 (5-10 km) 3 (10-15 km) 4 (>15 km)	Do you know how far your farm is located from the sea? (Yes, No) please specify
Subsidies	1 (yes) 2 (No)	Have you received any support from the government-equipment? (Yes, No)
Training	1 (yes) 2 (No)	Do you already have any training related to water conservation? (Yes, No)
Education level	1 (No read no write)& (Read & write only) 2 (Primary school) 3 (Secondary school) 4 (Graduated level)	What is your educational level? No read no write, Read and write only, Primary school, Graduated level. Please select one option.
Age	1 (<45 yr) 2 (46-55 yr) 3 (>55 yr)	How old are you?
Long term perspective	1 (yes) 2 (No)	For vision and perspectives of the respondent about future alternatives, the data used is a combination of answers to four questions: 1) Do you know possible interventions which could be

		implemented in an effective manner, to improve the situation? 2) What are your expectations for future of agriculture and the availability of the water resources in the Batinah region in 2025? 3) Do you have a long term vision for improvement of your farm? 4) How do you see your personal situation in the future? According to the answers to these questions, the farmer was given marks, and then it was decided about him, as he has a long term perspective for future or not. The categories are (Yes, No).
Experience with Ministries	1 (very good) 2 (good) 3 (very bad)	Which Governmental and non-Governmental water organizations you deal with? Please specify the level of cooperation (very good, Good, very bad).
Awareness about the problem	1 (No idea) 2 (poor) 3 (Med) 4 (Good) 5 (very good)	Data for this variable were generated from some statements which were included in the questionnaire and farmers were asked to tick "Yes" or "No". that was done through the following question: What do you think about the following statements regarding irrigation water use? [See Appendix A.6].

5.6.3 Populating the Network, Assignment of Conditional Probabilities to Input/output Variables and Output Presentation

The data, for all the variables were prepared in a single spreadsheet as a text file, for each of the 64 farmers included in the survey. Then the BN was automatically learnt from the data set.

The algorithm used was clustering, which is the default algorithm of the software, and according to literature e.g. (Jongsawat et al., 2008), it should be sufficient for most applications.

During learning for the conditional probabilities, the normalisation is required to be non-zero with each state within a variable (Jones et al., 2010). The value should be of between 0 and 1 and a total value for each CPT should be 1. The software used in this study (GeNIe) automatically normalises any values entered. Each variable is assigned with its own CPT. Table 31 is showing the probability of the "educational levels".

Table 31: The probability table for the educational levels' node

Educational levels' node - States	Probability
Not educated or read and write only	0.28461538
Primary school	0.23846154
Secondary school	0.27692308
Graduated level	0.2

First round simulation

The BN structure and results of the first round simulation are presented in Figure 32. The variables are classified into 3 groups:

- The main inputs (interventions), these are green in color,
- The intermediate variables, which are blue in color
- And the output (objective) variables, these are divided to sub-outputs which are yellow in color, and main output which is orange in color.

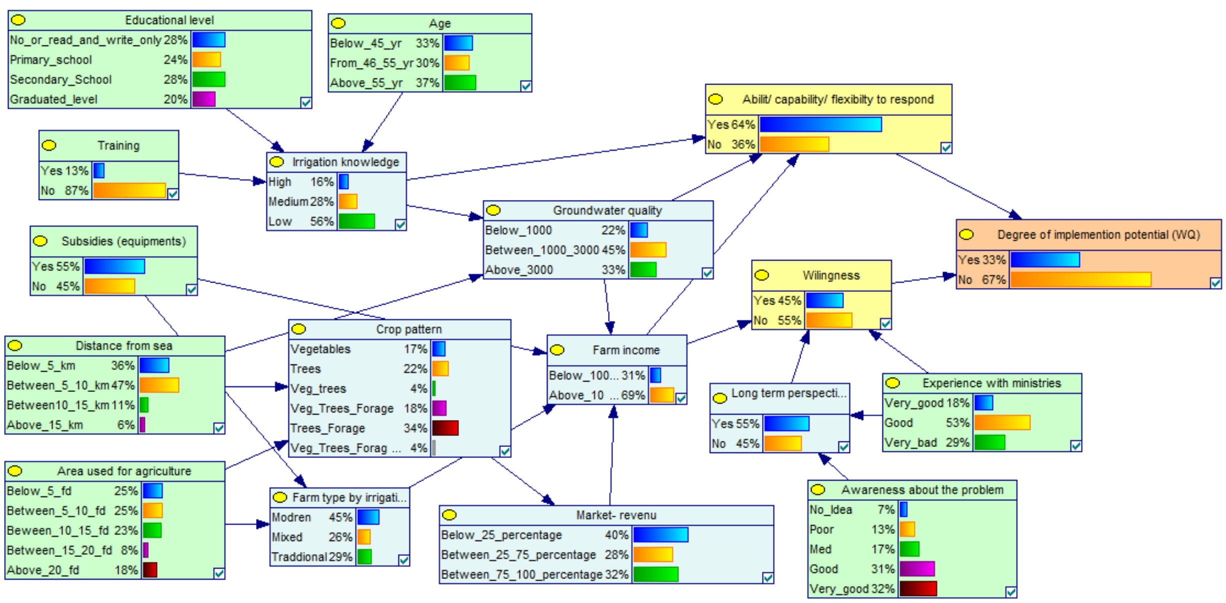


Figure 32: The structure of the BN (Implementation of water quotas)

5.6.4 Validation of the Performance of the BN

For the validation purpose a comparison of the BN model results to the actual data gathered from the survey was carried out. The results obtained from the BN should agree with the results of the social survey (the analysis of the list of interventions (see Section 5.3.3)).

The list of interventions (Section 5.3.3, Table 15) was reviewed and the number of farmers were classified to three groups: 'agree (19 farmers)', 'disagree (38 farmers)' and 'I can't decide' (7 farmers) for the issue of "introducing of water quota". The "I can't decide' group was removed out. Then the total number of participants (57 farmers) from 'agree' and 'disagree' groups was considered to be 100% of the participants. After that the parentage of each group was calculated. The results are presented in Table 32.

Table 32: Comparison between the results of social survey analysis and model with BN

Social Survey			Model with BN		
Intervention	**Opinon Analysis**		**BN Target Variable**	**BN Results**	
Introducing water quota	Agree (33%)	Disagree (67%)	Degree of implementation potential of water quotes	Yes (33%)	No (67%)

From Table 32, it is noticed that the results from the analysis of opinions regarding the implementation of water quota are similar to the results obtained from the BN model during testing the degree of implementation potential of water quota. Therefore, the re-production by using BN was considered to be performing well and other simulation can be carried out by doing some adjustment to the network.

5.6.5 Sensitivity Analysis

A sensitivity analysis was performed to create a set of scenarios. Those scenarios were then used to determine how changes in one variable(s) will impact the target variable. For example; if an update is made on one variable (say crop pattern), other variables in the BN might change probabilities after the update. This enables to check whether the output results of other variables in the BN make sense and are justifiable/realistic after the update of a particular variable. Then the variables, play a role in farmers' opinions can be ranked according to the level of influence on the target variables.

An increase/decrease in the probabilities of some parent nodes (input nodes) were made to explore the result in the effect of relative increase/decrease on the output nodes' probabilities. The results are presented as follow[8]:

Sensitivity analysis: The impacts of "training"

In the second round simulation the probability of "training" was increased to 100% for the 'Yes' state and decreased to 0% for the 'No' state. The impacts are represented in Figure 33.

[8] The adjusted variables are surrounded by blue circles and the influenced variables are surrounded by red circles

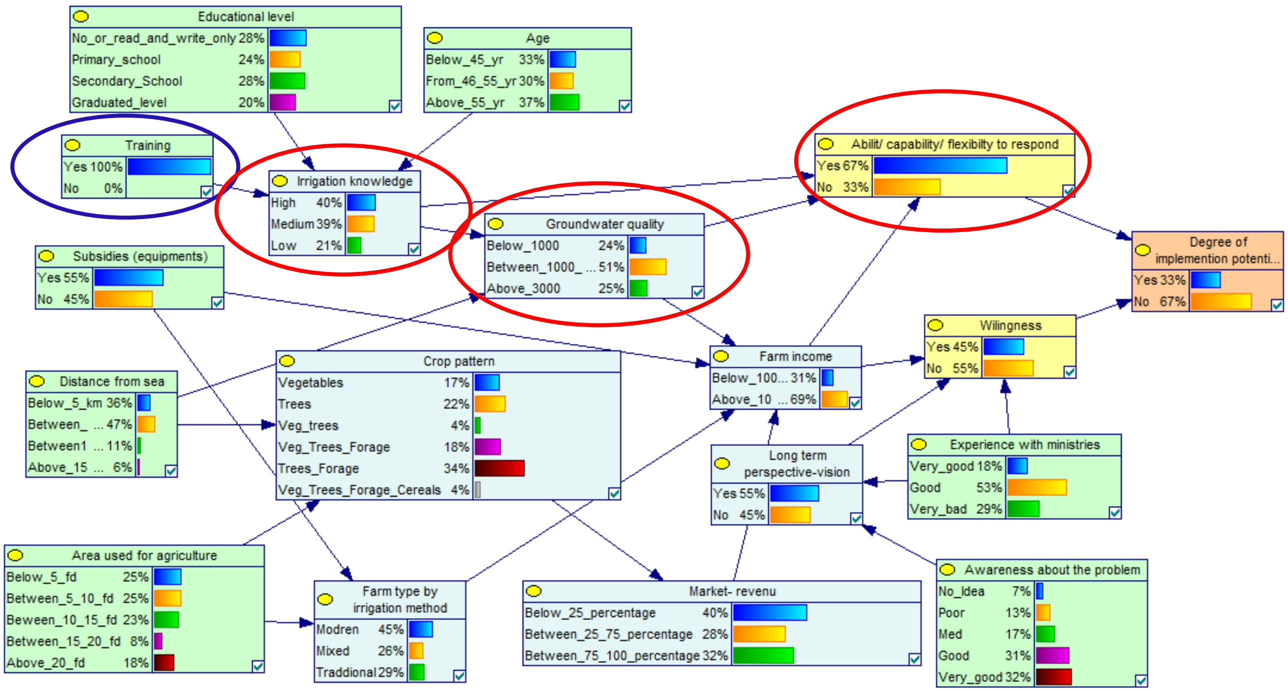


Figure 33: The impact of “Training” on the output variables

After running the second simulation (first scenario), the results showed that the node "training" is not influencing the target output node "degree of implementation potential" and regarded as having a less influencing effect on the sub-output node "ability/ capability/ flexibility to respond" .

Sensitivity analysis: The impacts of “subsidies”

In the third round simulation the probability of “subsidies” was increased to 100% for the ‘Yes’ state and decreased to 0% for the ‘No’ state. The impacts are represented in Figure 34.

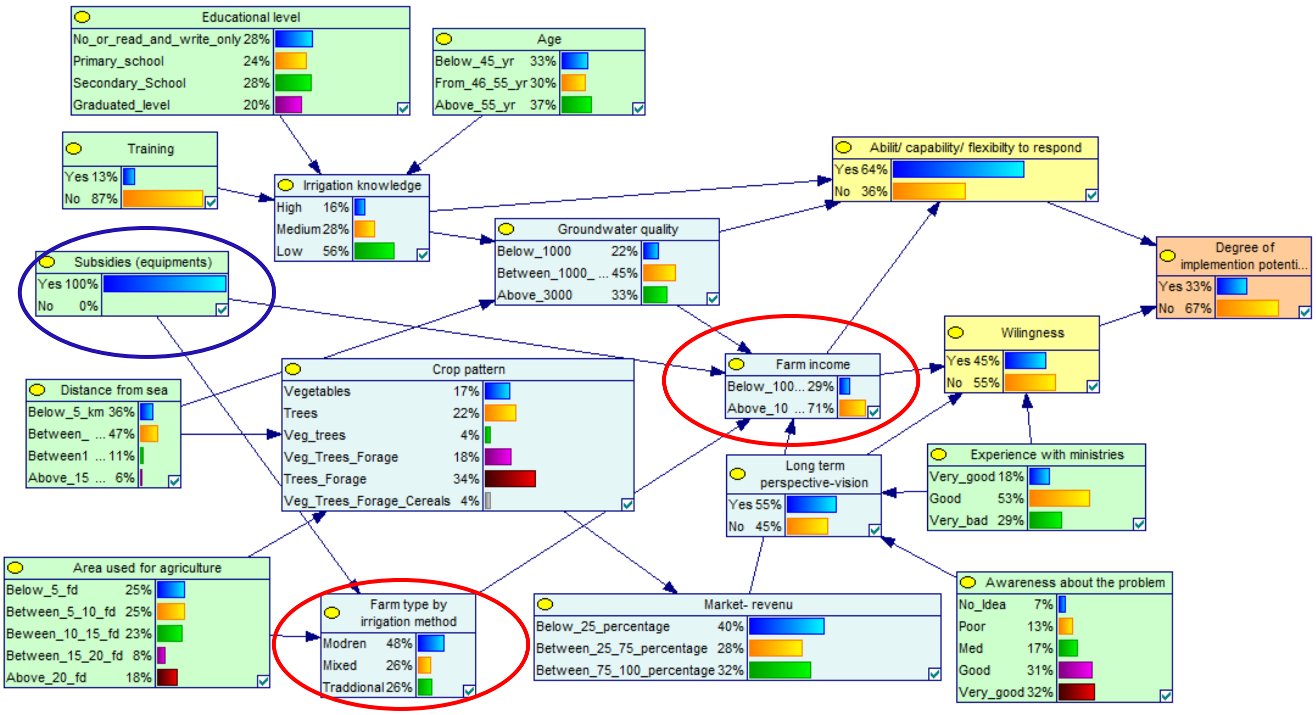


Figure 34: The impact of "subsidies" on the output variables

The results showed that the node "subsidies" is not influencing any of the output nodes. It has a slight impact on the node "farm income" and "farm type by irrigation method". The increase in the probability of "farm type by irrigation method" changed from 45% for 'modern' to 48%. Also, the "farm income" which is 'above 1000 Omani reals' increased from 69% to 71%.

Sensitivity analysis: The impacts of "training" and "subsidies"

In the fourth round simulation the probabilities of "training" and "subsidies" were increased to 100% for the 'Yes' state and decreased to 0% for the 'No' state. The impacts are represented in Figure 35.

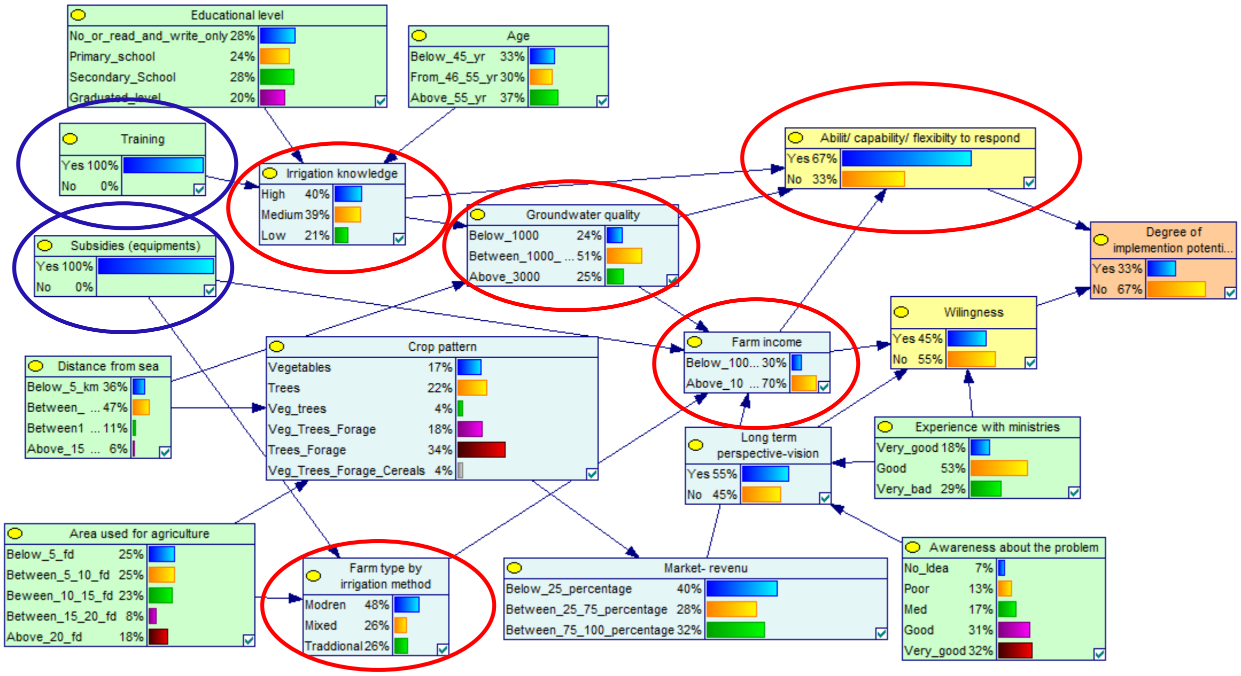


Figure 35: The impacts of "training" and "subsidies" on the output variables

In the fourth round of simulations (third scenario), the influenced variables were almost similar to what was observed in the second and third simulations. The combination of two variables did not change much in the output variables.

Sensitivity analysis: The impacts of "experience with Ministries"

In the fifth round simulation the probability of "experience with Ministries" was increased to 100% for the 'very good' state and decreased to 0% for the 'very bad' state. The impacts are represented in Figure 36.

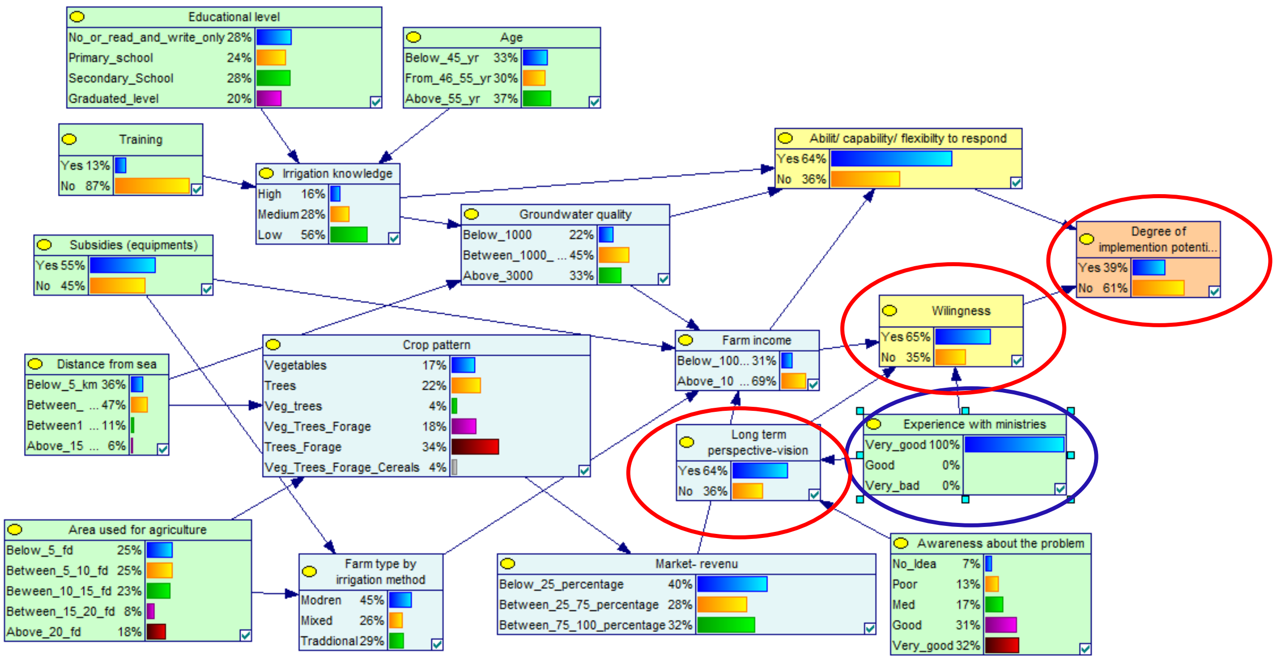


Figure 36: The impact of "experience with Ministries" on the output variables

After running the fifth round simulation (forth scenario), it was noticed that the "experience with Ministries" is the most influence factor that can cause changes on the output variable "degree of implementation potential". The 'Yes' state changed from 33% to 39%. There were also some changes in "willingness", the 'Yes' state changed from 45% to 65%. The changes were also obvious in the "long term perspective- vision". The 'Yes' sate jumped from 55% to 64%.

From this it can be concluded that, Variables which are directly linked to the end point of the BN are more likely to appear more significant. The "experience with Ministries" showed some impacts on "willingness" and "degree of implementation potential" because it is very close to the end point, and directly linked to the "willingness". These are similar results obtained by Ticehurst (2011), the variables which are directly linked to the variable of interest are more influential than those not directly linked.

Sensitivity analysis: The impacts of "training", "Subsidies" and *"experience with Ministries"*

In the sixth round simulation the probabilities of "training" and "subsidies" were increased to 100% for the 'Yes' state and decreased to 0% for the 'No' state and the probability of "experience with Ministries" was increased to 100% for the 'very good' state and decreased to 0% for the 'very bad' state. The impacts are represented in Figure 37.

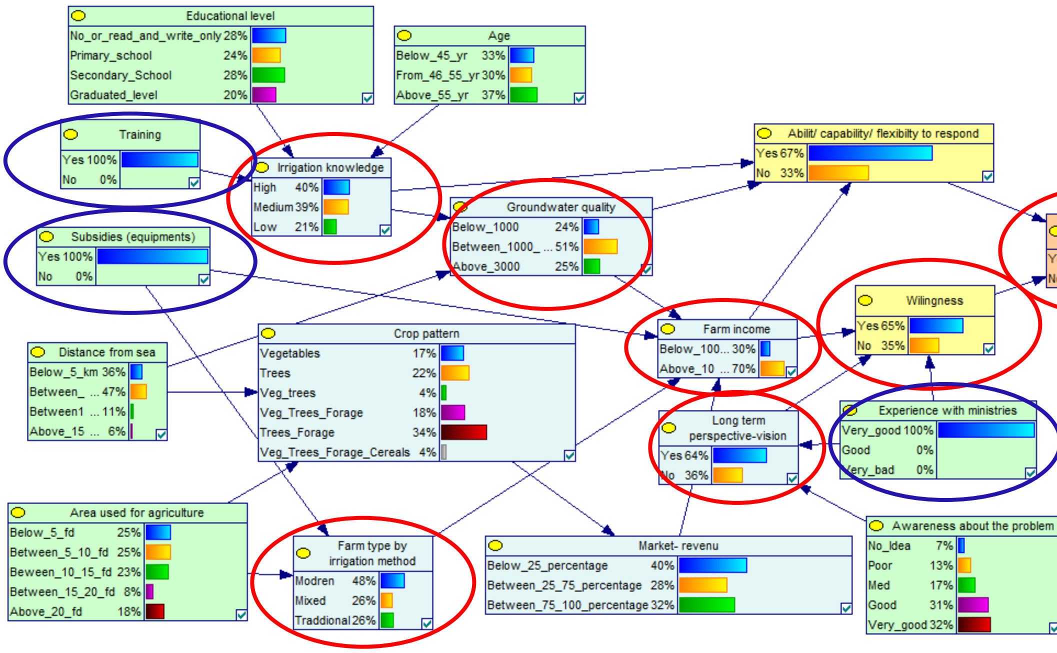


Figure 37: the impacts of "training", "subsidies" and "experience with Ministries" on the output variables

In the sixth round of simulations (fifth scenario), it was noticed that the combination of changes in "training", "subsidies" and "experience with Ministries" showed similar results of the simulations when those variables were changed individually. There is no much impacts of three variables on the implementation potential of water quota.

Preliminary results from the BN model were:

- The hypothesis for most of the variables worked logically.
- The impacts of the input variables on the implementation potential of water quota (the output variable) were limited.
- There are some variables (e. g. subsidies (Training and equipment) from the government) which might be related to the adoption of water quota.
- The variables which are very close to the variable of interest, have more influence than those variables which are far away from the output or the variable of interest.

It was also noticed that, if the BN is too big, there are no much effects on the output. The reasons might be that some variables are misplaced[9] or the sample size might be too small and an improvement of the database set is needed.

This spots the light on the importance of the care which should be taken during developing such a network in order to construct the best model from the data. In this regard, (NEIL et al., 2000) argued that although tools are available to construct large BN, there are no guidelines on building those networks. Therefore, it is important while building the network to keep in mind the following points:

- In each network there should be an input (it can be more than one variable) and an output (it can also be more than one variable).
- Variables should be related to each other together with knowledge about the probabilistic relationships among the variables.
- Ordering the variables is very important (e.g. cause should come before the effect).
- The parent node might have a set of children, and the child node as well might have a set of parents.
- The number of nodes and arcs should be minimal as much as possible (see the equation in Figure 10). It is good to have a higher number of samples and a simplified network.

[9] There might be more than one possible structure of the BN for the problem we are trying to solve.

6 Discussion and Recommendations

This study underlines the importance of a participatory approach with contributions from the relevant stakeholders in order to achieve a real IWRM implementation process. The new framework emphasizes participation as a critical approach in facilitating IWRM. More than 90% of the respondents who participated in the survey of this work, believe that involvement of water users in the decision making process is important. Only 4.6% of all respondents indicated that they are not agreeing with the idea. Al Shaqsi (2004) argued that the reason stated by 30% of water specialists, regarding non-involvement of water users in water management, in the study he performed in Oman, is that decision makers are not aware of the importance of users' participation. Additionally, he mentioned that 25% of them expressed that the fact is that decision makers think that others might view to users' involvement as weakness and misunderstanding of decision makers.

The situation is too complex in Al Batinah, and needs more knowledge and concerted efforts from the different stakeholders together with a combination of different management interventions, to be improved. Farmers are playing a major role in deteriorating the groundwater quality in South Al Batinah region. They are not aware of the water source limitation. 58% of the farmers, in this study, think that the irrigation water is used efficiently without wastage, however this is not true. More than 50% of the farmers, in the study area, are still using flood irrigation method to irrigate their farms regardless of the crop water requirements. This method of irrigation allows a considerable waste of water via evaporation and deep percolation. Moreover, 92% of the farmers mentioned that they have foreign labourers working in their farms, and 69% of the farmers believe that those labourers have no idea about conserving water.

In this Thesis, participants were asked about their opinions regarding the existing situation in South Al Batinah, as well as regarding the suitable interventions to be implemented. In general, results showed that the need of improvement and implementing new management strategies is supported by all groups of stakeholders. In most cases, farmers were more likely to accept interventions of increasing water availability (e.g. construction of more desalination plants, and artificial recharge (injection wells), while decision makers (DM's) were more likely to demand management (e.g. an implementation of water quotas, and subsidies). Opinions of farmers are mostly more diverse than DM's opinions.

The differences in opinions is highly visible in the question of water quotas. The majority of water professionals and decision makers (96%) believe that water quotas, on groundwater, should be implemented, while only (29%) of the farmers accepted the idea. The percentage of farmers rose to 44% when subsidies were offered in the form of guidance and training, and to 50% with subsidies in the form of irrigation equipment. This indicates that farmers could be persuaded by incentives and subsidies to accept new water conservation techniques.

Moreover, the installation of water meters as a monitoring tool, for the amount of water abstracted by farmers, was supported by the majority (over 90%) of the decision makers but, was rejected by more than 50% of the farmers.

DSS tools are essential for building a bridge between involved ministries and other relevant organizations and stakeholders. This confirms what was mentioned by (Pannell et al., 2006) regarding the level of trust between stakeholders in a system. He argued that level of trust is one of the useful indicators to be taken into account under the consideration of elements of a framework for exploring the adoption of a practice by landholders.

The application of BN approach, in this Thesis, is a matter of transfer the statistical results to an explanation model. Such models, should be useful to predict and see the impacts in order to conclude future scenarios. The scenarios should form the basis to increase the acceptance of different interventions. Therefore, the network can be used as a DSS enabling DM's to identify what is possible to be implemented from the social point of view.

The BN model, in this Thesis, showed that the variables which are directly linked to the variable of interest are more influential than those not directly linked. For example, during the sensitivity analysis, the adjustments in "training" and "subsidies" did not show major changes in the output variables. While the adjustments in "experience with Ministries", which was near to the output variables, showed some remarkable changes in the output variables.

The future forecasting ability was quite limited by the structure of the BN. The evidences were very low (not so clear) and the limitation was high. BNs are complex and sometimes consist of too many connections and relationships, dependency and CPT are not strong enough, or even the sample size is not enough. The level of missing data, has also a large impact on the results of a BN. Therefore, the improvement of the database (extension of the survey) is a potential future task.

Just to cope with these limitations, further researches are needed. Another BN model can be developed with different connections and relationships. But one should be aware that if there are major changes, over time, in the structure of the institutions, then the BN cannot deal with such evolution of the behavior.

It is very hard to understand the behaviors of people, the techniques used can be limited to the type of data available, characteristics of the selected region, sample size.

In this Thesis, the implementation of cost and law and regulations issues were not considered. Therefore, additional research, taking into consideration those issues, is required to support more informed decision-making as well as the understanding of relationships between hydrological processes and socio-economic dependencies of complex hydrosystems. Moreover, attributes such as the cost of the alternatives, who would be paying and who will be benefit, time frame for implementation, the role of farmers and the role of Government…etc. could be taken in consideration during performing further researches. This would be helpful in obtaining more realistic views and opinions from stakeholders.

For the case of South Al Batinah, both groups agreed that the water situation is at risk. However, there are difficulties in implementing the intervention and it is not easy to predict which one is the most suitable with a good chance to be implemented from the social point of view.

Following are some recommendations related to the methodology and some related to the South Al Batinah case:

Recommendations related to the methodology (approaches, models, tools)

- Development of new integrated approaches which can deal with the interaction of society and water resources and the public feedbacks. Decision makers and all other stakeholders should play a role in implementing appropriate changes.
- The application of the principles of integrated water resources management in all watersheds (catchments) and the involvement of water users in the preparation and implementation of these principles and concepts are necessary.
- Evaluation of management options should be supported by models and pilot projects in nature to monitor how they work.

Recommendations related to results (the case of South Al Batinah)

- Continuing to introduce modern irrigation systems and knowledge to the farmers.
- Find new alternatives to minimize dependence on foreign laborers coming from rainy countries, or to enhance their knowledge in water and agriculture management in Oman.

- Address training programs. Farmers should be trained to understand what water scarcity means and what is needed from their side to improve the management of water resources
- Continuing to monitor and study changes in the salinity of groundwater. Periodic monitoring programs should be allocated for the groundwater recharge and depletion.
- Assess the impacts of the implemented measures on the improvement of the water situation in South Al Batinah region. This should be done with the help of models.
- Persuading farmers by incentives and subsidies to accept new water conservation techniques.
- Continued stakeholder feedback (public information) and interview evaluations.
- Increase awareness and knowledge (especially with farmers) about water resources systems and their interaction with agricultural production.

7 Summary and Conclusion

The contribution of this work is to introduce a new framework for dealing with the irrigation water problems in South Al Batinah region in Oman, which should support decision makers in taking more informed decisions. The challenges facing the implementation of integrated approaches in Oman, can be confined to; the scattered in responsibilities, as well as, in the sectoral structure and decisions. Omani water specialists admitted that there is a deficiency in water users' involvement in the management of water in Oman. Decision making should not be limited (only) to considering information collected from public. Users should be treated as DM's and must negotiate about the alternatives. Moreover, guidance is needed in this field to provide information about the best possible and sustainable management practice for maintaining natural systems. Additionally, formal approaches are essential to support the analysis of management alternatives with the involvement of the relevant stakeholders and communicate results in a transparent way.

From the available data and information of the salinity in Al Batinah, it is noticed that the intrusion is increasing, and it takes a long time to recover. Over 70% of the farmers reported that their farms are affected by saline water intrusion and 33% of them have a high range of salinity (3000-6000 µS/cm), as a fact, it is very hard to find a short-term solution for improvement. Therefore, the intervention which is applied now to improve the situation, might show its results after a long period of time, which might extend to 20 years or longer. This is also clearly underlined by Zekri (2008). He mentioned this by saying: "*The partial recovery of the aquifer quality would take several decades of zero pumping*" (Zekri, 2008). In this regard Walther (2014), as well, concluded the recovery time of the water levels, in Al Batinah, is supposedly more than 100 years and even longer for the salinity (see Walther et al., 2014).

A good solution as a result of just thinking through conventional methods between decision makers, without analysing the consequences of implementation, can come out with negative results and might be rejected by the different stakeholders or even generate conflicts between them. For example, if a farmer with a high salinity range, in his farm, received incentives from the government and his upstream neighbor, with a low salinity range, did not, a lot of conflicts might start to occur regarding this issue. It was obvious from the results that farmers, with small farms, suggested that the implementation of water quotas is only suitable for big commercial farms. Because they think that, in these farms there are a lot of foreign labourers and those could be the main perpetrators of the problem of water depletion. It should be clear to the farmers that they are using a common-pool limited resource. Therefore, solutions should not be only for individual profit and immediate satisfaction. They should be from a holistic perspective and aim to satisfy all relevant stakeholders, as well as ensure the sustainability of the resource for the future generation. For this, farmers should be educated to understand what water scarcity means and what is needed from their side to improve the management of water resources. The majority (91%) of farmers, in the study, area reported that they did not receive any training in water conservation. Farmers can be educated through training programs, awareness programs, or a combination of training programs and incentives from the government. This step is important in order to avoid the negative consequences, and make the use of water resources be more efficient as well as avoiding failure and wastage of money. This supports the idea of evaluating and analysing the intervention is important before the implementing process. On the other hand, the development of adequate water related institutions (e.g. Water User Associations) and information exchange is also fundamental for the successful of water management processes.

In this Thesis, evaluation of opinions showed that in most cases, farmers were more likely to accept the interventions of increasing water availability, while decision makers (DM's) were more likely to accept the demand management options. Opinions of farmers are mostly more diverse than DM's opinions. However, decision makers, in many cases, are aware of the needs of farmers, which is a good sign for reaching an intervention that satisfies most of the stakeholders and facilitates the implementation process. The results also emphasized that farmers could be persuaded by incentives and subsidies to accept new water conservation techniques. As well, around two thirds (67%) of the farmers showed their readiness to pay for a new water source or service in order to reduce threatening the groundwater aquifer in the region. This proves that understanding of behavior and drivers behind opinions offers the opportunity to trigger the acceptance of management interventions.

It is also obvious from the results, that there is a lack of knowledge in water and agriculture management from the farmer side, as well as a lack of awareness. Farmers are very good in evaluating the saline problem but not aware of the problem of water shortage. Additionally, they are dealing with the problem of saline water intrusion in totally different ways. 48% of them are doing nothing and they reported that they are getting less yield. The rest did more than one action at a time. 30% reported that they reduced the pumping hours per day, and at the same time some of the farmers (40%) reduced the cultivated area in the farm. 44% of them said that they installed modern irrigation systems and 11% of the farmers reported that they built their own desalination units in their farms. This insists the importance of the participatory approach to be implemented in Al Batinah region, which also matches with the results of Zekri (2008) when he underlined that the establishment and implementation of law and regulations to improve groundwater management require the consensus of all the relevant stakeholders.

Investigations through the DA indicated that farmers' opinions are influenced by "levels of groundwater salinity in the farm" and "levels of cooperation with relevant organizations". The later represents the level of trust between farmers and decision makers.

The need to improve the situation is supported by all groups. This shows that there is a consensus between the groups about the need of improvement in the management strategies. Moreover, the idea of the participatory approach is not rejected by the different groups of stakeholders. Water users appreciate participating in decision making processes, regarding environmental problems, and would like to be involved. The participatory approach allows people to get involved in the evaluating process and see the advantages and disadvantages of management options. Additionally, it allows the communications in both directions; between relevant decision makers and between decision makers and water users, and raises the level of trust between them. It was obvious from the results that trust between water users and decision makers has an impact on the level of acceptance of a particular intervention by the farmers. This should be taken into account under the consideration of exploring possible intervention measures.

Modeling approaches (quantitative tools and decision support tools) that can integrate different system processes, are considered to be very useful to water managers and decision makers. They help to process the data and enabling understanding of the impacts and consequences of potential management interventions. Moreover, they are powerful tools for capturing the uncertainty of a complex system and enabling quantification of social and human inputs.

In general, water management in coastal areas requires combined efforts of many sectors and stakeholders including farmers. The relevant stakeholders should be aware of the importance of water conservation and optimal utilization and the need to reduce the depletion of the aquifer in those areas.

Water management strategies should not only focus on the technical means, but should also be directed to improve management practices and social behavior changes. The government and decision makers should believe that it is important to involve stakeholders in management processes.

Finally, evaluation of the management options should be supported by models and experiments in nature to monitor how they work. For a successful evaluation process to occur, both a support from the relevant stakeholders and (coupled with) appropriate models are required. Stakeholders including farmers, decision makers and water professionals could play a role in providing needed information for evaluating the best possible interventions to be implemented. Ideas and opinions collected from the different stakeholders are considered to be an important source of information to be used in feeding the selected supporting model.

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List of Messages

Message 1: The pressing problems, in the field of water resource management, have to be tackled from an integrated perspective taking into account environmental, human and technological factors and in particular their interdependence.

Message 2: The conventional approaches being currently used to study water resources management lack to reflect the mutual relationship between water resources and societies.

Message 3: There is a great need to move towards a real IWRM, taking into consideration the importance of involving stakeholders in the management processes.

Message 4: In water resources management domains, the competition for water in areas with high demands causes conflicts of interests among various water actors with mostly contradicting objectives.

Message 5: Many environmental problems basically are social and behavioral problems, especially in the form of failure of human decision making.

Message 6: Environmental and natural resources managers and decision makers need models which help them to understand the effectiveness of alternative management decisions.

Message 7: Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.

Message 8: The management option which suits many relevant stakeholders might not be the best in the scientific point of view.

Message 9: Understanding landholder decision –making is now acknowledged as fundamental to achieve better policy outcomes.

Message 10: Dealing with natural systems is very complex and surrounded by some ambiguity. Integrated approaches are required, which can facilitate communication and knowledge transmission between the relevant stakeholders of a system.

Message 11: Sea water intrusion into the coastal aquifer systems is one of the major sources of concern in many coastal areas in arid and semi-arid countries. The problem has impacts on agricultural and the economic basis of farmers in such regions.

Message 12: The imbalance between the abstraction rates and recharge rates led to: (1) dryness of Aflaj in the interior region of Al Batinah and (2) a dramatic decline in groundwater levels accompanied with saltwater intrusion into the coastal aquifer of the region.

Message 13: Farmers are playing a major role in threatening the groundwater aquifer in South Al Batinah region.

Message 14: The challenges facing the implementation of integrated approaches can be confined to the scattered responsibilities, sectoral structure and decisions.

Message 15: Water use management is not adopted in Oman - more water efficiency regulations are required.

Message 16: Omani water specialists admitted that there is a deficiency in water users' involvement in the management of water in Oman.

Message 17: The main challenge facing water sector in Oman, is to formulate water resource management strategies that will make better use of the available water resources.

Message 18: The situation is too complex in Al Batinah, and needs more knowledge and concerted efforts from the different stakeholders together with a combination of different management interventions, to be improved.

Message 19: Many farms (54%), in the survey, are located between 1 and 5 km only from the sea, this means that the farms are highly subjected to be affected by salinity problems.

Message 20: More than 50% of the population, in the survey, is still using flood irrigation method to irrigate their farms.

Message 21: Farmers are not aware of the water source limitation. They are very good in evaluating the saline problem but not aware of the problem of water shortage.

Message 22: 58% of the farmers think that the irrigation water is used efficiently without wastage, however this is not true.

Message 23: Around two thirds of the farmers are ready to pay for a new water source or service in order to reduce threatening the groundwater aquifer in the region.

Message 24: Over 70% of the farmers reported that their farms are affected by saline water intrusion and 33% of them has a high range of salinity (3000-6000 µS/cm), so there aren't so many options for short-term improvement.

Message 25: Farmers are dealing with the problem of saline water in totally different ways.

Message 26: 92% of the farmers, in the survey, mentioned that they have foreign labourers working in their farms, and 69% of the farmers believe that those labourers have no idea about water conservation.

Message 27: The majority of the farmers (95%), reported that they do not have water meters in their wells.

Message 28: The majority of the farmers (91%) did not receive any training in water conservation.

Message 29: Agriculture has not been found to be the main source of income for many (70%) of the selected farmers of the survey. The main income source for the farmers is employment rather than farming.

Message 30: Decision makers (68%) strongly refused the idea of stopping the agricultural activities in Al Batinah compared to farmers (48%)

Message 31: The majority (over 80%) of the relevant stakeholders prefer the sustainability of agriculture in the region.

Message 32: Stakeholders believe that there is a need of improvement which could be achieved by implementing new management strategies.

Message 33: Farmers are more concerned about quality of water compared to quantity.

Message 34: Most respondents (from both groups) rated the requirement of better marketing facilities as strongly needed to improve the agriculture productivity.

Message 35: Incentives for water conservation in agriculture, considered to be a key water management tool to improve water use efficiency.

Message 36: Although more than 70% of the farmers have experience in irrigating by using modern irrigation techniques, it can be noticed that modern irrigation techniques are not widely used or implemented within the farms in the region.

Message 37: The majority of water professionals and decision makers (96%) believe that water quotas, on groundwater, should be implemented, but only (29%) of the farmers accepted the idea. The percentage of farmers rose to 44% when subsidies were offered in form of guidance and training, and 50% with subsidies in form of irrigation equipment.

Message 38: Farmers could be persuaded by incentives and subsidies to accept new water conservation techniques.

Message 39: The installation of water meters as a monitoring tool, for the amount of water abstracted by farmers, is supported by the majority (over 90%) of the decision makers but rejected by more than 50% of the farmers.

Message 40: Some farmers, with a smaller farm in size, suggest that the idea of water quotas and water metering should be only implemented to the big commercial farms. The reason, in their opinions, is that the big farms employ a huge number of foreign labourers who consume a lot of water without efficiency.

Message 41: The idea of the participatory approach was not rejected by the different groups of stakeholders.

Message 42: Religious commitments are not considered as a great issue concerning most of the DM's regarding implementing intervention options.

Message 43: Water users appreciate participating in decision making processes regarding environmental problems and would like to be involved in selecting suitable management interventions.

Message 44: Around one third (36%) of the farmers believe that if no good management strategies are implemented, the situation in south Al Batinah will be worse in future.

Message 45: More than one third (39%) of the decision makers believe that the agriculture in Al Batinah region will be worse in future.

Message 46: Farmers are significantly less likely to accept the idea of water quota and introducing water prices for pumped groundwater than the DM's.

Message 47: The need to improve the situation is supported by all groups. This indicates that there is a consensus between the groups about the need of improvement in the management strategies.

Message 48: Farmers are more likely to accept the solutions of increasing water availability especially of good water quality, while decision makers are more likely to accept the management issues especially demand management.

Message 49: Decision makers, in many cases, are aware of the needs of farmers. This is a good sign for reaching an intervention that satisfies most of the stakeholders and facilitates the implementation process.

Message 50: Salinity ranges (as a factor) have an effect on farmers' opinions regarding implementing water quotas.

Message 51: Level of trust between users and decision makers has an impact on the level of acceptance of farmers regarding implementing a particular intervention and it should be taken into account under the consideration of exploring possible adoption options.

Glossary of the Arabic Terms

Falaj /Aflaj (plural):	Channel systems that access groundwater by gravity flow from underground gallerias or surface springs on neighboring mountain slope.
Khareef:	Seasonal south-western monsoon which brings occult precipitation to the southernmost coast of Dhofar. (Literally translation: Autumn)
Sabkha:	salt flat, playa.
Share'ah	A water collecting point within the Falaj system.
Wadi(s)	Valley or a small river or drainage channel in an arid region, which carries flash floods. The flow in such river, last only for few days during the year, usually after heavy rain. (s) used with plural.
Wali:	Local governor.
Wilaya(t)*:*	An administrative area within the sultanate. (t) used with plural.

Appendix

A.1 Questionnaire of Farmers

A.2 Questionnaire of Decision Makers

A.3 Opinions of Farmers and Decision Makers regarding possible interventions (Table A.1-A.2)

A.4 Comparison in opinions of farmers and Decision Makers regarding possible interventions which could be implemented (Table B.1-B.2)

A.5 Decision Makers' Frequency curves

Appendix A.1

Questionnaire for the Stakeholders on Water Resource Management in South Al Batinah Governorate in the Sultanate of Oman (Questionnaire for Farmers)

Introduction

These questionnaires were designed to explore how we can introduce a better management for water recourses in South Al Batinah Governorate. Your cooperation and knowledge is very important for understanding which are the suitable ways and solutions for the water deficit problem in the region.

There are different types of question:

- Selective question: For these types of questions, please select one or more possible answers (according to the content of the question).
- Open questions (very few): the questions require your personal opinions; please give a short and clear answer.
- Rating questions: Used to find out your prioritization regarding different answers. Please mark the order of the options according to your opinion.
- Filling gap questions: Those questions are included to collect some figures and information. Please fill the gap according to your knowledge and the level of care.

The questionnaire consists of four sections as follow: *Please start answering the questions*

Section one: General information

1. In which village is your farm? *Please specify the name of the village*

____

2. What is your education level? *Please select one option*
    a. No read and write
    b. Read and write only
    c. Primary school
    d. Secondary school
    e. Graduated level
    f. Post graduated

3. How old are you? *Please select one option*
    a. Below 30
    b. 30-45
    c. 45-55
    d. 55-65
    e. Above 65

4. What is your gender? *Please mark the right answer*

    a. Male b. Female

Section two: Farm survey

5. Are you taking care of your own farm? *Please select one option*
    a. Yes, I'm the owner of the land
    b. No, it belongs to one of my relatives
    c. I'm renting the land for Agricultural use
    d. Other,________________________________

6. What is the size of your farm? *Please specify*
    a. <10 fd
    b. 10-29 fd
    c. 30-60 fd
    d. >60 fd

The total size of my farm is ______________ (fd)

7. Does your farm exist for:
    a. Only food production
    b. Only gathering with family and friends during weekends and vacation seasons?
    c. Both
    d. Others, *Please specify*

____

8. What area (fd) used for agriculture and food production? ______________ (fd) or (%)

9. What is the overall situation of water resources of your farm? *Please select one option*

    a. Excellent, I'm happy with my farm
    b. Very good, It is ok but improvement needed
    c. Good
    d. Bad
    e. Very bad, I'm not happy with my farm

10. Who is responsible for water management in your Farm?
    a. My self
    b. My family
    c. Foreign labours
    d. Others, *please specify*____

11. What are your Irrigation sources? *Please select all types of sources you use for irrigation*
    a. Well(s) how many_______
    b. Falaj
    c. Tanker
    d. Others (please specify____)

12. a) Do you know how much water do you use per day : *please select one option*
    a. Yes b. No

    b) If the answer is yes, *please specify*______________________m3/day

    c) Do you have water meter? a.Yes b. No

d) Do you sell some of the pumped water? *Please select one option*
    a. Yes b. No

13. Which of the following crops do you grow or produce in your farm? *Please select option(s)*

crop type		**Area (fd) or (%)**
a.	Vegetables	
b.	Fruit	
c.	Palm tree	
d. Clover	Forage &	
e.	Cereals	
f.	Other, *please specify*	
g.		
h.		

Note*: you can use the empty cells for more crop types*

14. Please specify method(s) of irrigation used in your farm and specify the area in (fadan) and crop type for each method? *Please select all methods used in your farm*

Irrigation type	Area (fd) or (%)	Crop type (if possible)
a. Flood		
b. Bubbler		
c. Sprinkler		
d. Drip		
e.		
f.		

Note*: you can use the empty cells for more types of irrigation methods and crop types*

15. Do you use greenhouses?

a. Yes b. No

If the answer is yes, what is the area and type of crops (if possible?)

____

16. According to your information about groundwater salinity problem:

a) Is there any indication of salinity in your farm? *Please select one option*
   a. Yes b. No
b) If the answer is yes, please specify the range (if possible): *Please select one option*
   a. <1000 µS/cm
   b. 1000-3000 µS/cm
   c. 3000-6000 µS/cm
   d. >6000 µS/cm

c) Do you know how far your farm is located from the sea (km)?
   a. Yes b. No

d) If the answer is yes, *please specify*______________________(km)

e) Does the saline water affect your agricultural management? *Please select one option*
   a. Yes b. No

f) If your answer is yes, specify which action you took from the following: *you can select more than one answer*

a. I use more water for irrigation
b. I changed the crop types
c. No action, but I get less yield
d. I reduced the cultivated area in my farm
e. I reduced the pumping hours
f. I installed modern irrigation systems
g. I build my own desalination unit in my farm

Others *please specify*:

____

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17. Do members of your family helps you in taking care of the farm?
    a. Yes b. No

18. a) Do you have foreign labour in your farm? *Please select one option*
    a. Yes b. No

b) If the answer is yes, how many do you have in your farm? *Please select one option*

a. 1-2
b. 3-5
c. More than 5

19. a) Do those foreign labours have knowledge in water conservation? *Please select one option*
    a. Yes b. No

b) What do you do to encourage them conserving water?

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20. a) Is your farm the only source of income you have?

a. Yes b. No

b) If the answer is No, to what percentage does your income relay on your farm? *Please specify*

a. <25%
b. 25-50%
c. 51-75%
d. >75%

c) What percentage of your total farm production is usually sold?

a. <25%
b. 25-50%
c. 51-75%
d. >75%

d) Where do you sell your farm products? *Please select option(s)*

No.	**Places**	**(√)**	**(%) if possible**
a	Farmer's markets		
b	Large grocers		
c	Small grocers		
d	Individual customers		
e	Local hotels and Restaurants		
f	Export		

Others, *please specify*____

e) What is the income from farm production?

a. <1,000 O.R /month
b. >1,000 O.R /month

Section three: Ideas and Opinions

21. What does the farmer need to improve the productivity of his farm? *Please mark one option for each point*

No.	Requirements	Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
a.	Guidance & Training in agricultural management					
b.	Subsidies for modern irrigation equipment					
c.	More water					
d.	Better quality of water					
e.	More labour					
f.	More income					
g.	Better marketing facilities					
h.	Guidance & information farming centres					
i.	More cooperation with other farmers					

Others, *please specify*

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22. a) How do you assess the current water situation in your region? *Please specify*

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b) What do you think about the following statements regarding irrigation water use?

No.	Statement	Agree	Disagree
a	The water is used efficiency without wastage		
b	The salinity is increasing		
c	The water is limited		
d	The water is over pumped		

23. Do you know possible interventions which could be implemented in an effective manner, to improve the situation? *Please specify*

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24. For the sustainability of agriculture in the area and conservation of groundwater, to what extent would you agree with the following interventions? *Please answer from "a' to "t" by marking only one option for each intervention*

No.	**Interventions**	**Options**				
		Strongly agree	**Agree**	**I can't decide**	**Disagree**	**Strongly disagree**
a.	I adopt the idea of water quotas.					
b.	I adopt the idea of water quotas with subsidies in form of equipment for modern irrigation systems					
c.	I adopt the idea of water quotas with subsidies in form of guidance & training in agricultural management.					
d.	If treated waste water is available for agricultural use, I would purchase it for irrigation.					
e.	I'm ready to reduce the withdrawal of groundwater pumped per day with helpful of guidance & training.					
f.	I'm ready to use good quality of water for irrigation purposes, from a centralized well field water					

	distribution system (if implemented).					
g.	I'm ready to change the type of crops to crops of lower water requirements.					
h.	I'm ready to improve the irrigation methods in my farm.					
i.	I'm ready to improve the irrigation methods in my farm with subsidies in form of equipment for modern irrigation systems.					
j.	I'm ready to improve the irrigation methods in my farm with subsidies in form of guidance and training in agricultural management.					
k.	I'm with the idea to construct injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.					
l.	I encourage the construction of more desalination plants for brackish and seawater, in order to use it for irrigation.					
m.	I'm with the idea of increasing the effectiveness of water use by public awareness.					
n.	I'm with the idea of introducing water prices for pumped groundwater.					
o.	I suggest to introduce special energy tariffs for agricultural water use.					
p.	I support forming water managers groups.					
q.	I support forming helpful guidance & information water centre to support farmers in farm & water management.					
r.	Farms need to be evaluated and the government should take a decision to close some of them and change the land use.					

s.	Stop all agricultural activities in the coastal zone of Al Batinah					
t.	Leave the system as it is					

25. a) Are you ready to pay for a new water service (which provide water of a good quality) to reduce the withdrawal from groundwater aquifer? *Please select one option*
    a. Yes b. No

b) If the answer is yes how much are you ready to pay: _____________O.R/m3

26. a) Do you already have experience with modern irrigation systems? *Please select one option*
    a. Yes b. No

b) In your opinion, what are the obstacles of not using modern irrigation techniques? *You can select more than one option*

a. Modern irrigation systems are expensive
b. Modern irrigation systems are complicated and needs maintenance
c. I don't believe in efficiency of modern irrigation

Other (please specify____)

27. a) If you are ready to adopt the idea of water quotas, are you ready to install water meters for every well in your farm? *Please select one option*
    a. Yes b. No c. Yes under conditions

b) If your answer is "Yes under conditions" what are they? *Please specify*

____

____

____

28. If water quota is going to be implemented, how much can be the amount of water to be allocated? *Please select one option*
    a. No water quota
    b. Cutting 25% of current use
    c. Cutting 50% of current use
    d. Cutting 75% of current use
    e. Cutting, but I have no idea about the amount

29. In your opinion, to what extent do the following issues play a role in your agricultural management? *please mark one option for each criteria*

No.	**Issues**	**Extremely important**	**Moderately important**	**Neutral important**	**Low important**	**Not important**
a.	To get a high income					
b.	To protect the environmental					
c.	To conserve water					
d.	To have a long term perspective of my farm					
e.	To produce good and high quality products					
f.	To have good marketing options					

Others, *please specify*

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30. Which Governmental and non-Governmental water organizations do you deal with? *Please specify the name and cooperation level.*

No.	**Name of the organization**	**Level of cooperation**				
		Excellent	**Very good**	**Good**	**Poor**	**Very poor**
1						
2						
3						
4						
5						
6						
7						
8						

31. a) Did you already get subsidies provided by the government? *Please select one option*
    a. Yes b. No

b) If the answer is yes, please specify which one and what is your experience?

____
____
____

32. a) Did you already have any training related to water conservation? *Please select one option*
    a. Yes b. No (*Note: if the answer is No, go to question no. (e)*)

b) If the answer is yes, in what field? *You can select more than one option*
    a. In using and maintain modern irrigation systems

b. In reducing water losses from irrigation channels
c. In timing of irrigation, in order to avoid high temperature impacts
d. In how to maintain water during dry seasons
e. Others, please specify____

c) What was your experience?

a. Excellent
b. Very good
c. Good
d. Bad
e. Very bad

d) Who organized the training program? *Please select one option*

a. Governmental organization b. Non-Governmental

e) Do you like to have some (more) training, in which field? *You can select more than one option*

____
____
____

33. a) Do you think that water users should play a role in making decisions regarding environmental problems and water management issues? *Please select one option*

a. Yes b. No

b) If the answer is yes, please explain how:

- Forming of committees in which stakeholders are represented
- Forming water users associations
- Having regular meetings in the Wali or governor office
- Others, please specify____

34. Are you ready to be a member in these meetings or associations? *Please select one option*

a. Yes b. No

Section four: Vision for future

35. What are your expectations for future of agriculture and the availability of the water resources in the Batinah region in 2025?

36. How do you see your personal situation in the future?

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Appendix A.2

Questionnaire for the Stakeholders on Water Resource Management in South Al Batinah Governorate in the Sultanate of Oman (Questionnaire for Decision Makers)

Introduction

The problem of over abstraction and sea water intrusion in the Batinah coastal area was addressed by the Government in the beginning of 1990s. However, it is more than 20 years and the Region is still suffering and the sea water intrusion is expanding more and more.

This is a research project about possibilities of implementing integrated water resources management measures in south Al Batinah region. For this project you will be kindly asked to complete a questionnaire as a part of data collection for the research.

The questionnaire was designed to explore the opinion of all water issue stakeholders (SH's) regarding the possibility of implementing interventions measures to control the problem of water shortage in south al Batinah Governorate.

Your answers will not be released to anyone and will remain anonymous. Your name will not be written on the questionnaire or be kept in any other records.

Your cooperation and knowledge is very important for a better understanding of what are the suitable interventions to be implemented.

There are different types of question:

- Selective question: For these types of questions, please select one or more possible answers (according to the content of the question).
- Open questions: the questions require your personal opinions; please give a short and clear answer.
- Rating questions: Used to find out your prioritization regarding different answers. Please mark the level of the options according to your opinion.

The questionnaire consists of four sections as follow: *Please start answering the questions*

Section one: Back ground information

1. What is your field of interest? *You can select more than one option*
    a. Groundwater
    b. Agriculture
    c. Water resources management and planning
    d. Surface and subsurface hydrology
    e. Climate change

f. Environmental Protection
g. Others, please specify____

2. What is your educational level? *Please select one option*
   g. Below secondary school
   h. Secondary school
   i. Graduated level
   j. Post graduated
3. Your gender is? *Please mark the right option*
   a. Male   b. Female

4. How old are you? *Please select one option*
   a. Below 30
   b. 30-45
   c. 45-55
   d. 55-65
   e. Above 65

Section two: Ideas and Opinions

5. The farming and water resources in South Al Batinah Governorate has been deteriorated a lot during the last two decades, what is your expectation for future if the development continuous without any interventions? *Please specify*

____

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6. In your opinion, what are the possible interventions which could be implemented in an effective manner, to protect the groundwater system from depletion and salt water intrusion? *Please specify a list of options and put them in order according to which one can be more applicable and accepted by all stakeholders*

____

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7. In your opinion, which of the following interventions are suitable to be implemented to solve the problem of water shortage in South Al Batinah? *Please specify to what extent you would agree with the following interventions.*

No.	Intervention	Options				
		Strongly agree	Agree	can't decide	Disagree	Strongly disagree
a.	Introducing water quotas.					
b.	Introducing water quotas with subsidies in form of equipments for modern irrigation systems.					
c.	Introducing water quotas with subsidies in form of guidance & training in agricultural management					
d.	Introducing using treated wastewater for agricultural use, if it is available and the quality is acceptable.					
e.	Encourage the farmer to reduce the withdrawal of groundwater pumped per day by guidance & training.					
f.	Implementation of centralized well field water distribution system for agriculture which provides water in a good quality to farmers.					
g.	Convince the farmer to change the type of crops to ones with lower crop water requirements.					
h.	Encourage farmers to improve their irrigation methods.					
i.	Encourage farmers to improve their irrigation methods with subsides in form of equipments for modern irrigation systems.					
j.	Encourage farmers to improve their irrigation methods with subsides in form of guidance and training in agricultural management.					
k.	Construction of injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.					
l.	Construction of more desalination plants for brackish and seawater, in order to					

	use it for irrigation.					
m	Increase the effectiveness of water use by public awareness.					
n.	Introduce water prices for pumped groundwater.					
o.	Introduce special energy tariffs for agricultural water use.					
p.	Forming water managers groups.					
q.	Forming guidance & information water centre to support farmers in farm & water management.					
r.	Farms need to be evaluated and the government should take a decision to close some of them and change the land use.					
s.	Stop all agricultural activities in the coastal zone of Al Batinah					
t.	Leave the system as it is (No action).					

8. In your Opinion, which of the following criteria is taken into account when you measure an intervention to be adapted? *Please add more criteria and specify how you would rate them. Mark one option for each criteria,* ***1*** *is" more important"* ***5*** *is "less important"*

No.	**Criteria**	**Extremely important**	**Moderately important**	**Neutral important**	**Low important**	**Not important**
a.	Customs, norms and inherited values					
b.	Religion and sharia law					
c.	Financial costs					
d.	Environmental impacts					
e.	Economic recovery					
f.	Society reaction					
g.						
h.						
i.						

9. In your opinion, to what level do you think, the following interventions can be accepted by Farmers? *Please specify the level*

No.	Intervention	Options				
		Strongly agree	Agree	He can't decide	Disagree	Strongly disagree
a.	Introducing water quotas.					
b.	Introducing water quotas with subsidies in form of equipments for modern irrigation systems.					
c.	Introducing water quotas with subsidies in form of guidance & training in agricultural management					
d.	Introducing using treated wastewater for Agricultural use, if it is available and the quality is acceptable.					
e.	Encourage the farmer to reduce the withdrawal of groundwater pumped per day by guidance & training.					
f.	Implementation of centralized well field water distribution system for agriculture which provides water in a good quality to farmers.					
g.	Convince the farmer to change the type of crops to ones with lower crop water requirements.					
h.	Encourage farmers to improve their irrigation methods.					
i.	Encourage farmers to improve their irrigation methods with subsides in form of equipment for modern irrigation systems.					
j.	Encourage farmers to improve their irrigation methods with subsides in form of guidance and training in agricultural management.					
k.	Construction of Injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.					
l.	Construction of more desalination plants for brackish and seawater, in order to use it for irrigation.					

m	Increase the effectiveness of water use by public awareness.					
n.	Introduce water prices for pumped groundwater					
o.	Introduce special energy tariffs for agricultural purposes.					
p.	Forming water managers groups.					
q.	Forming guidance & information water centres to support farmers in farm & water management..					
r.	Farms need to be evaluated and the government should take a decision to close some of them and change the land use.					
s.	Stop all agricultural activities in the coastal zone of Al Batinah					
t.	Leave the system as it is (No action).					

10. In your opinion, what are the major obstacles facing water professionals and decision makers regarding the implementation of proposed interventions for overcoming the problem of water shortage in south Al Batinah Region? *Please add more obstacles and specify how you would rate them*. *Mark one option for each obstacle*

No.	**Obstacles**	Extremely important	Moderately important	Neutral important	Low important	Not important
a.	Financial problems (availability of funding or budgets)					
b.	Political commitments and regulations					
c.	Religion commitments					
d.	Absence of a clear mechanism for implementing the proposed solutions					
e.	Decentralization of the governmental institutions relevant to the decision-making with respect to water issues					
f.	Farmers attitude and opinion					
g.	Political willingness and support					
h.	The complexity of the problem					
i.	Being is water priceless for farmers					

Others, *please specify*

____

____

11. a) Do you think that water users should play a role in making decisions regarding environmental problems and water management issues? *Please select one option*
    a. Yes b. No

    b) If the answer is yes, *please explain how* and if the answer is No, *please explain why*

    ____

    ____

    ____

    c) In your opinion, which of the following options can used to involve Farmers in the management issue, *you can select more than one option*:
    - Forming of committees in which stakeholders are represented
    - Forming water users associations
    - Having regular meetings in the Wali or governor office
    - Others, please specify____

    ____

Section three: Water resources and agricultural management

12. From your opinion what is the best way that can be used to encourage farmers to change their agricultural management behaviours? *Please explain how*

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13. If water quota is going to be implemented, how much can be the amount of water to be allocated? *Please select one option*
    f. No water quota
    g. Cutting 25% of current use
    h. Cutting 50% of current use
    i. Cutting 75% of current use
    j. Cutting but no idea about the amount

14. How can farmers be convinced to agree with the idea of water quotas?
    ____

    ____

    ____

15. a) Implementing water quota necessities the installation of meters for every well, do you think there is a need to do that? *Please select one option*
    a. Yes   b. No

    b) If the answer is yes, who has to pay for purchase and maintenance? *Please select one option*
    a. The farmer or
    b. The government?
    c. Sharing between the Government and Farmers
    d. Others, please specify____

    c) If the answer is No, do you have other suggestions for monitoring? *Please explain*

    ____

    ____

    ____

16. Why do you think farmers are not attracted to use modern irrigation techniques? *You can select more than one option*
    a. They are expensive and farmers cannot afford them
    b. The techniques are complicated and farmers are not familiar of how to use and maintain them
    c. The Farmers don't believe in efficiency of modern irrigation systems
    d. Absence of legislation enforcement
    e. Others, please specify____

17. a) Most of the Farmers rely on foreign labour. Do you think those labour increases the wastage of water used for irrigation? *Please select one option*

    1) Yes   b. No

    b) If the answer is yes, *please explain why* and if the answer is No *also explain why:*

    ____

    ____

    ____

18. If you think foreign labour have contribute to water deficit problem, how do you think this problem can be solved? *Please give your suggestions*

    ____

    ____

    ____

19. In your opinion, What does the farmer need to improve the productivity of his farm? *Please mark one option for each point.*

No.	**Needs**	**Strongly Agree**	**Agree**	**No opinion**	**Disagree**	**Strongly Disagree**
a.	Guidance & Training in agricultural management					
b.	Subsidies for modern irrigation equipment					
c.	More water					
d.	Better quality of water					
e.	More labour					
f.	More income					
g.	Better marketing facilities					
h.	Guidance & information farming centres					
i.	More cooperation with other farmers					

Others types of needs, *please specify*

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Section four: Vision for future

20. What are your expectations for future of agriculture and the availability of the water resources in the Batinah region in 2025?

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Appendix A.3

Table A.1: Opinions of farmers and DM's regarding possible interventions which could be implemented. N=131

Interventions	n1=64 n2=67	Options				
		Strongly agree	Agree	I can't decide	Disagree	Strongly disagree
Adopt the idea of water quotas.	Farmers	6	13	7	19	19
	%	(9%)	(20%)	(11%)	(30%)	(30%)
	DM's	23	31	7	4	2
	%	(34.5%)	(46%)	(10.5%)	(6%)	(3%)
Adopt the idea of water quotas with subsidies in form of equipment for modern irrigation systems	Farmers	12	20	6	20	6
	%	(19%)	(31.5%)	(9%)	(31.5%)	(9%)
	DM's	23	33	10	1	0
	%	(34.5%)	(49%)	(15%)	(1.5%)	
Adopt the idea of water quotas with subsidies in form of guidance & training in agricultural management.	Farmers	7	21	7	23	6
	%	(11%)	(33%)	(11%)	(36%)	(9%)
	DM's	32	26	8	1	0
	%	(47.5%)	(39%)	(12%)	(1.5%)	
Use treated waste water for irrigation.	Farmers	16	32	6	7	3
	%	(25%)	(50%)	(9%)	(11%)	(5%)
	DM's	38	20	6	3	0
	%	(56%)	(30%)	(9%)	(5%)	
Reduce the withdrawal of groundwater pumped per day with helpful of guidance & training.	Farmers	8	40	4	11	1
	%	(12.5%)	(62.5 %)	(6.5%)	(17%)	(1.5%)
	DM's	34	26	5	2	0
	%	(50.5%)	(39%)	(7.5%)	(3%)	
Use good quality of water for irrigation purposes, from a centralized well field water distribution system (if implemented).	Farmers	13	30	4	14	3
	%	(20%)	(46.5%)	(6.5%)	(22%)	(5%)
	DM's	19	26	11	7	4
	%	(28%)	(39%)	(16.5)	(10.5%)	(6%)
Change the type of crops to crops of lower water requirements.	Farmers	9	33	6	14	2
	%	(14%)	(52%)	(9%)	(22%)	(3%)
	DM's	23	25	11	7	1
	%	(34.5%)	(37%)	(16.5%)	(10.5%)	(1.5%)
Improve the irrigation methods in my farm.	Farmers	18	36	3	5	2
	%	(28%)	(56%)	(5%)	(8%)	(3%)
	DM's	40	25	1	1	0
	%	(60%)	(37%)	(1.5%)	(1.5%)	(0%)
Improve the irrigation methods in my farm with subsidies in form of equipment for modern irrigation systems.	Farmers	26	36	0	2	0
	%	(41%)	(56%)		(3%)	(0%)
	DM's	29	32	2	4	0
	%	(43%)	(48%)	(3%)	(6%)	(0%)
Improve the irrigation methods in my farm with subsidies in form of guidance and training in agricultural management.	Farmers	18	42	0	3	1
	%	(28%)	(65.5%)		(5%)	(1.5%)
	DM's	30	31	5	1	0
	%	(45%)	(46%)	(7.5%)	(1.5%)	(0%)
Construct injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	Farmers	15	31	12	3	3
	%	(23%)	(48%)	(19%)	(5%)	(5%)
	DM's	17	29	15	4	2
	%	(25.5%)	(43%)	(22.5%)	(6%)	(3%)
Encourage the construction of more desalination plants for brackish and seawater, in order to use it for irrigation.	Farmers	15	34	3	11	1
	%	(23%)	(53.5%)	(5%)	(17%)	(1.5%)
	DM's	6	17	19	12	13
	%	(9%)	(25.5%)	(28%)	(18%)	(19.5%)

Increasing the effectiveness of water use by public awareness.	Farmers	28	34	2	0	0
	%	(44%)	(53%)	(3%)		
	DM’s	40	24	2	1	0
	%	(60%)	(35.5%)	(3%)	(1.5%)	
Introducing water prices for pumped groundwater.	Farmers	2	9	5	19	29
	%	(3%)	(14%)	(8%)	(30%)	(45%)
	DM’s	8	30	15	11	3
	%	(12%)	(45%)	(22.5)	(16.5%)	(5%)
Introducing special energy tariffs for agricultural purposes.	Farmers	19	34	7	2	2
	%	(30%)	(53%)	(11%)	(3%)	(3%)
	DM’s	11	26	17	9	4
	%	(16.5%)	(39%)	(25%)	(13.5%)	(6%)
Forming water managers groups.	Farmers	20	32	8	4	0
	%	(31%)	(50%)	(12.5%)	(6.5%)	(0%)
	DM’s	21	35	5	6	0
	%	(31%)	(52%)	(8%)	(9%)	(0%)
Forming helpful guidance & information water centre to support farmers in farm & water management.	Farmers	18	19	25	2	0
	%	(28%)	(30%)	(39%)	(3%)	(0%)
	DM’s	30	28	8	0	1
	%	(45%)	(41.5%)	(12%)		(1.5%)
Farms need to be evaluated and the government should take a decision to close some of them and change the land use.	Farmers	21	29	7	5	2
	%	(33%)	(45%)	(11%)	(8%)	(3%)
	DM’s	9	33	9	10	6
	%	(13.5%)	(49%)	(13.5%)	(15%)	(9%)
Stop all agricultural activities in the coastal zone of Al Batinah	Farmers	6	10	17	18	13
	%	(9%)	(16%)	(27%)	(28%)	(20%)
	DM’s	2	4	15	22	24
	%	(3%)	(6%)	(22.5%)	(33%)	(35.5%)
Leave the system as it is	Farmers	1	4	6	22	31
	%	(1.5%)	(6.5%)	(9%)	(34.5%)	(48.5%)
	DM’s	2	1	9	16	39
	%	(3%)	(1.5%)	(13.5%)	(24%)	(58%)

Appendix A.3

Table A.2: Comparison of opinions of farmers and DM's regarding possible interventions which could be implemented. N=131 (Statistical data)

Intervention measures	Farmers (n=64)				DM's (n=67)				P-value
	Mean	Median	Std. Deviation	Skew.	Mean	Median	Std. Deviation	Skew.	
Introducing water quotas.	3.47	4	1.391	-.463	1.88	2	1.023	1.122	.000
Introducing water quotas with subsidies in form of equipment for modern irrigation systems.	2.75	2	1.309	.131	1.70	1	.779	.186	.000
Introducing water quotas with subsidies in form of guidance & training in agricultural management	2.94	3	1.233	-.035	1.58	1	.762	.668	.000
Introducing using treated wastewater for irrigation, if it is available and the quality is acceptable.	2.17	2	1.092	1.082	1.61	1	.834	1.329	.001
Encourage the farmer to reduce the withdrawal of groundwater pumped per day by guidance & training.	2.31	2	.974	.923	1.63	1	.756	1.182	.000
Implementation of centralized well field water distribution system for agriculture which provides water in a good quality to farmers.	2.42	2	1.193	.626	2.27	2	1.162	.824	.458
Convince the farmer to change the type of crops to ones with lower crop water requirements.	2.48	2	1.084	.621	2.03	2	1.058	.729	.017
Encourage farmers to improve their irrigation methods.	2.02	2	.968	1.379	1.45	1	.610	1.443	.000
Encourage farmers to improve their irrigation methods with subsides in form of equipment for modern irrigation systems.	1.66	2	.648	1.197	1.72	2	.794	1.308	.636
Encourage farmers to improve their irrigation methods with subsides in form of guidance and training in agricultural management.	1.86	2	.774	1.735	1.66	2	.686	.857	.115
Construction of injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	2.19	2	1.006	1.058	2.13	2	1.013	.713	.764
Construction of more desalination plants for brackish and seawater, to be used for irrigation.	2.14	2	1.082	.799	3.09	3	1.311	-.045	.000
Increase the effectiveness of water use by public awareness.	1.55	2	.561	-.190	1.46	1	.636	1.421	.424
Introduce water prices for pumped groundwater.	3.92	4	1.276	-1.27	2.48	2	1.133	.315	.000
Introduce special energy tariffs for agricultural purposes.	1.86	2	.957	1.187	2.49	2	1.146	.423	.001
Forming water managers groups.	1.88	2	.864	.706	1.91	2	.900	.823	.819
Forming guidance & information water center to support farmers in farm & water management.	2.11	2	.918	-.097	1.63	2	.813	1.142	.002
Farms need to be evaluated, government should take a decision to close some farms & change the land use.	1.97	2	1.054	1.072	2.52	2	1.211	.633	.006
Stop all agricultural activities in Al Batinah coast	3.28	3	1.315	-.413	3.79	4	1.320	-1.311	.029
Leave the system as it is (No action).	4.09	4	1.205	-1.760	4.19	5	1.305	-2.014	.649

Note: 1) Mean score ranges between 1 for strongly agree and 5 for strongly disagree
2) The degree of significant differences is based on independent samples T-test
3) Those shaded are significant

Appendix A.4

Table B.1: Opinions of farmers and DM's believe about farmer's opinion regarding possible interventions which could be implemented. N=131

Interventions	n1=64 n2=67	Options				
		Strongly agree	**Agree**	**I can't decide**	**Disagree**	**Strongly disagree**
Adopt the idea of water quotas.	Farmers	6	13	7	19	19
	%	(9%)	(20%)	(11%)	(30%)	(30%)
	DM's	6	14	13	21	13
	%	(9%)	(21.5%)	(19%)	(31.5%)	(19%)
Adopt the idea of water quotas with subsidies in form of equipment for modern irrigation systems	Farmers	12	20	6	20	6
	%	(19%)	(31.5%)	(9%)	(31.5%)	(9%)
	DM's	10	39	9	8	1
	%	(15%)	(58%)	(13.5%)	(12%)	(1.5%)
Adopt the idea of water quotas with subsidies in form of guidance & training in agricultural management.	Farmers	7	21	7	23	6
	%	(11%)	(33%)	(11%)	(36%)	(9%)
	DM's	11	27	16	12	1
	%	(16.5%)	(40.5%)	(23.5%)	(18%)	(1.5%)
Use treated waste water for irrigation.	Farmers	16	32	6	7	3
	%	(25%)	(50%)	(9%)	(11%)	(5%)
	DM's	14	28	13	9	3
	%	(21%)	(42%)	(19%)	(13.5%)	(4.5%)
Reduce the withdrawal of groundwater pumped per day with helpful of guidance & training.	Farmers	8	40	4	11	1
	%	(12.5%)	(62.5 %)	(6.5%)	(17%)	(1.5%)
	DM's	11	27	12	16	1
	%	(16.5%)	(40.5%)	(18%)	(23.5%)	(1.5%)
Use good quality of water for irrigation purposes, from a centralized well field water distribution system (if implemented).	Farmers	13	30	4	14	3
	%	(20%)	(46.5%)	(6.5%)	(22%)	(5%)
	DM's	5	26	18	10	8
	%	(7.5%)	(39%)	(26.5%)	(15%)	(12%)
Change the type of crops to crops of lower water requirements.	Farmers	9	33	6	14	2
	%	(14%)	(52%)	(9%)	(22%)	(3%)
	DM's	6	28	15	13	5
	%	(9%)	(42%)	(22.5%)	(19%)	(7.5%)
Improve the irrigation methods in my farm.	Farmers	18	36	3	5	2
	%	(28%)	(56%)	(5%)	(8%)	(3%)
	DM's	16	41	7	3	0
	%	(24%)	(61%)	(10.5%)	(4.5%)	(0%)
Improve the irrigation methods in my farm with subsidies in form of equipment for modern irrigation systems.	Farmers	26	36	0	2	0
	%	(41%)	(56%)		(3%)	(0%)
	DM's	29	31	7	0	0
	%	(43.5%)	(46%)	(10.5%)		(0%)
Improve the irrigation methods in my farm with subsidies in form of guidance and training in agricultural management.	Farmers	18	42	0	3	1
	%	(28%)	(65.5%)		(5%)	(1.5%)
	DM's	24	28	11	4	0
	%	(35.5%)	(42%)	(16.5%)	(6%)	(0%)
Construct injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	Farmers	15	31	12	3	3
	%	(23%)	(48%)	(19%)	(5%)	(5%)
	DM's	17	21	25	4	0
	%	(25.5%)	(31.5%)	(37%)	(6%)	(0%)
Encourage the construction of more desalination plants for brackish and seawater, in order to use it for irrigation.	Farmers	15	34	3	11	1
	%	(23%)	(53.5%)	(5%)	(17%)	(1.5%)
	DM's	11	22	18	13	3
	%	(16.5%)	(33%)	(27%)	(19%)	(4.5%)

Increasing the effectiveness of water use by public awareness.	Farmers	28	34	2	0	0
	%	(44%)	(53%)	(3%)	(0%)	(0%)
	DM's	12	42	10	2	1
	%	(18%)	(62.5%)	(15%)	(3%)	(1.5%)
Introducing water prices for pumped groundwater.	Farmers	2	9	5	19	29
	%	(3%)	(14%)	(8%)	(30%)	(45%)
	DM's	3	10	13	20	21
	%	(4.5%)	(15%)	(19%)	(30%)	(31.5%)
Introducing special energy tariffs for agricultural water use.	Farmers	19	34	7	2	2
	%	(30%)	(53%)	(11%)	(3%)	(3%)
	DM's	4	15	16	21	11
	%	(6%)	(22.5%)	(23.5%)	(31.5%)	(16.5%)
Forming water managers groups.	Farmers	20	32	8	4	0
	%	(31%)	(50%)	(12.5%)	(6.5%)	(0%)
	DM's	10	31	20	4	2
	%	(15%)	(46%)	(30%)	(6%)	(3%)
Forming helpful guidance & information water centre to support farmers in farm & water management.	Farmers	18	19	25	2	0
	%	(28%)	(30%)	(39%)	(3%)	(0%)
	DM's	16	37	11	2	1
	%	(24%)	(55%)	(16.5%)	(3%)	(1.5%)
Farms need to be evaluated and the government should take a decision to close some of them and change the land use.	Farmers	21	29	7	5	2
	%	(33%)	(45%)	(11%)	(8%)	(3%)
	DM's	7	12	12	23	13
	%	(10.5%)	(18%)	(18%)	(34.5%)	(19%)
Stop all agricultural activities in the coastal zone of Al Batinah	Farmers	6	10	17	18	13
	%	(9%)	(16%)	(27%)	(28%)	(20%)
	DM's	5	3	7	18	34
	%	(7.5%)	(4.5%)	(10.5%)	(27%)	(50.5%)
Leave the system as it is	Farmers	1	4	6	22	31
	%	(1.5%)	(6.5%)	(9%)	(34.5%)	(48.5%)
	DM's	1	14	15	17	20
	%	(1.5%)	(20.5%)	(22.5%)	(25.5%)	(30%)

Appendix A.4

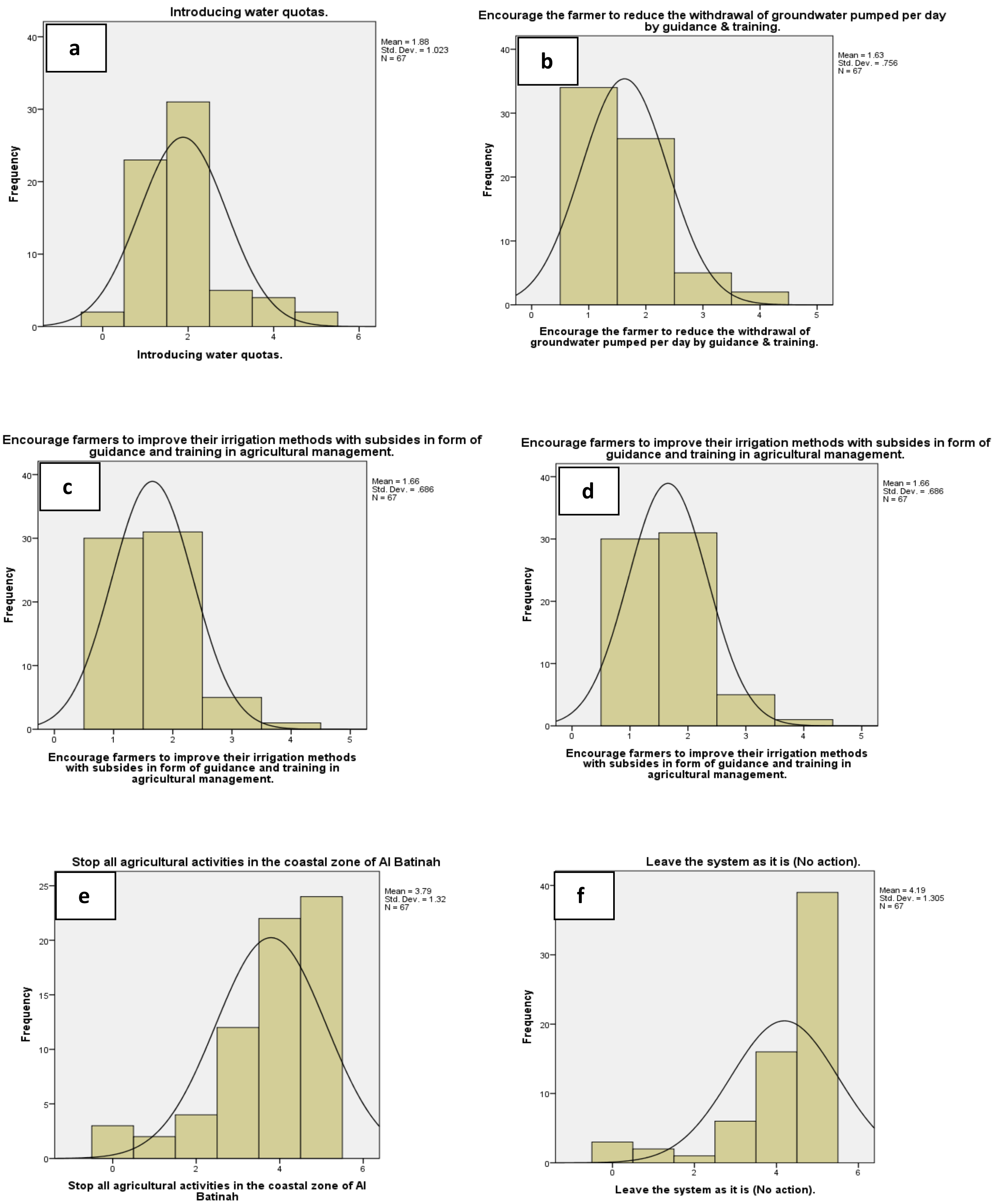
Table B.2: Comparison of opinions of farmers and DM's believe about farmer's opinion regarding possible interventions which could be implemented. N=131 (Statistical data)

Intervention measures	Farmers (n=64)				DM's believe about farmers (n=67)				P-value
	Mean	Median	Std. Deviation	Skew.	Mean	Median	Std. Deviation	Skew.	
Introducing water quotas.	3.47	4	1.391	-.463	3.18	4	1.435	-.483	.243
Introducing water quotas with subsidies in form of equipment for modern irrigation systems.	2.75	2	1.309	.131	2.18	2	.984	.612	.005
Introducing water quotas with subsidies in form of guidance & training in agricultural management	2.94	3	1.233	-.035	2.34	2	1.136	.114	.005
Introducing using treated wastewater for agricultural use, if it is available and the quality is acceptable.	2.17	2	1.092	1.082	2.30	2	1.168	.506	.523
Encourage the farmer to reduce the withdrawal of groundwater pumped per day by guidance & training.	2.31	2	.974	.923	2.45	2	1.158	.131	.472
Implementation of centralized well field water distribution system for agriculture which provides water in a good quality to farmers.	2.42	2	1.193	.626	2.76	3	1.244	.228	.114
Convince the farmer to change the type of crops to ones with lower crop water requirements.	2.48	2	1.084	.621	2.70	2	1.155	.310	.270
Encourage farmers to improve their irrigation methods.	2.02	2	.968	1.379	1.87	2	.776	.440	.329
Encourage farmers to improve their irrigation methods with subsides in form of equipment for modern irrigation systems.	1.66	2	.648	1.197	1.58	2	.678	.144	.523
Encourage farmers to improve their irrigation methods with subsides in form of guidance and training in agricultural management.	1.86	2	.774	1.735	1.84	2	.914	.582	.874
Construction of injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	2.19	2	1.006	1.058	2.19	2	.941	-.066	.969
Construction of more desalination plants for brackish and seawater, to be used for irrigation.	2.14	2	1.082	.799	2.54	2	1.198	.100	.049
Increase the effectiveness of water use by public awareness.	1.55	2	.561	-.190	2.03	2	.797	.871	.000
Introduce water prices for pumped groundwater.	3.92	4	1.276	-1.27	3.51	4	1.481	-.881	.089
Introduce special energy tariffs for agricultural water use.	1.86	2	.957	1.187	3.21	3	1.297	-.445	.000
Forming water managers groups.	1.88	2	.864	.706	2.13	2	1.086	.238	.134
Forming guidance & information water center to support farmers in farm & water management.	2.11	2	.918	-.097	1.94	2	.868	.690	.278
Farms need to be evaluated, government should take a decision to close & change land use.	1.97	2	1.054	1.072	3.25	4	1.396	-.540	.000
Stop all agricultural activities in Al Batinah coast	3.28	3	1.315	-.413	4.04	5	1.308	-1.468	.001
Leave the system as it is (No action).	4.09	4	1.205	-1.760	3.52	4	1.318	-.602	.001

Note: 1) Mean score ranges between 1 for strongly agree and 5 for strongly disagree
2) The degree of significant differences is based on independent samples T-test
3) Those shaded are significant

Appendix A.5

Figure A.1: Decision Makers' Frequency curves



Appendix A.6

Data preparation for the Beysian Network

(Questions for each variable)

After the agreement of the network, the following step is data preparation for each variable. The data are generated from the questionnaires as described below:

Questions of each variable and how was the data decided for each variable.

Age: Age of the Respondent. The data were taken from the questionnaires and categorized to three categories:

1. (<45 yr)
2. (46-55 yr)
3. (>55 yr)

This was a direct question: How old are you?

Educational level: Respondent's educational level. The data were taken from the questionnaires and categorized to four categories:

1. No read no write
2. Read and write only
3. Primary school
4. Graduated level

This was a direct question: What is your education level? Please select one option

Training: Training and education in different aspects of water & agricultural management. The data were taken from the questionnaires and categorized to two categories:

1. Yes
2. No

This was a direct question: Do you already have any training related to water conservation?

Subsidies: Subsides provided by the government (equipment). The data were taken from the questionnaires and categorized to two categories:

1. Yes
2. No

This was a direct question: Have you received any support from the government-equipment?

Distance from Sea: This is the distance between the farm and the coast line, the data were taken from the questionnaires and categorized to four categories:

1. (<5 km)
2. (5-10 km)
3. (10-15 km)
4. (>15 km)

This was a direct question: Do you know how far your farm is located from the sea? (Yes, No) please specify

Area used for Agriculture: This is the area (fd) used for agriculture in the farm. The data were taken from the questionnaires and categorized to five categories:

1. (<5 fd)
2. (5-10 fd)
3. (10-15 fd)
4. (15-20 fd)
5. (>20 fd)

This was a direct question: What area (fd) used for agriculture and food production?

Awareness: Data for this variable was generated from some statements which were included in the questionnaire and farmers were asked to tick yes or no. that was done through the following question:

What do you think about the following statements regarding irrigation water use?

Table2:

No.	Statement	Agree	Disagree
a	The water is used efficiency without wastage	*	
b	The salinity is increasing	*	
c	The water is limited	*	
d	The water is over pumped		*

If the farmer chooses the to tick the boxes with *, it means he got the full marks, out of 4, then his awareness about the problem is classified as following (five categories);

1. Very high (for 4 points)
2. High (for 3 points)
3. Medium (for 2 points)
4. Low (for 1 point)
5. Very low (for 0 points)

Experience with Ministries: Representing the level of trust between farmers and governmental water and agricultural organizations. The data were taken from the questionnaires and categorized to three categories:

1. (very good)
2. (good)
3. (very bad)

This was a direct question: Which Governmental and non-Governmental water organizations do you deal with? Please specify the level of cooperation (very good, Good, very bad)

Irrigation Knowledge: for this variable, the data used is a combination of answers of two questions:

1. Do you know how much water do you use per day? (Yes/No)

2. Do you have water meter? (Yes/No)

So if the farmer answered yes for both questions, it is considered that he has good knowledge about irrigation, if both answers are no, it means his irrigation knowledge is poor. Those are the criteria used to generate the data for this variable.

And then the farmer get a marks for his answers according to the following table:

Table3:

Options	Water pumped(Yes=1/No=2)	Water meter(Yes=1/No=2)	Marks/ Knowledge
First option	Yes=1	Yes=1	1= High
Second option	Yes=1	No=2	2=Medium
Third option	No=2	No=2	3=Low

The answer for both questions should be yes to get High as both answers were positives. If the answer for the first question is yes and the second one is no, then his irrigation knowledge is medium. Finally, if both answers are no then his irrigation knowledge is poor or low.

Note: This led us at the end, to come out with a conclusion of being, 12 frames are considered to be having high irrigation knowledge, 15 Medium and 47 Poor o low. (See Table 1, will be in the appendix)

Crop Pattern: Type of cultivated crops in each farm. Each farmer specified the type of crops cultivated in his farm, and then the data were categorized as following;

Farms cultivated by:

1. (Vegetables)
2. (Trees)

3. (Veg & trees)
4. (Veg & trees & Forage)
5. (Trees & Forage)
6. (all) (veg, trees, forage & cereals)

The question was: Which of the following crops do you grow or produce in your farm (Trees, Forage & Clover, and Vegetables)? Please select option(s)

Farm Classification: Farms were classified according to irrigation methods (table 4), then the classes were merged to three categories:

1. Modern (< 30 %)
2. Mixed (31-69)
3. Traditional (70-100%)

Table 4:

% of Area irrigated by flood /Farm	No. of Farms (69)	Farm classification	%
< 10%	24	More Modern	39 %
10-30%	6	Modern	15%
30-70%	13	Mixed	16 %
70-90%	4	Traditional	6 %
90-100%	17	More Traditional	24%

The question was: Please specify method(s) of irrigation used in your farm; Flood, Bubbler, Sprinkler, Drip, Others?

Salinity Range: The recorded salinity range for the ground water in the farm (µs/cm). In most of the farms, groundwater salinity was measured by the government and the farmer was provided by this information. The data were taken from the questionnaires and categorized to three categories:

1. (<1000µs/cm)
2. (1000-3000µs/cm)
3. (>3000µs/cm)

The question was: Is there any indication of salinity in your farm? (Yes, No), please specify the range (if possible)

Farm income: The monthly income from farm production. The data were taken from the questionnaires and categorized to three categories:

1. (I don't sell)
2. (<1000 O.R/month)
3. (>1000 O.R/month)

The question was: What is the monthly income from farm production?

Market: The data were generated from the percentage (%) sold from the farm production. The data were taken from the questionnaires and categorized to three categories:

1. (<25%)
2. (25-75%)
3. (76-100%)

The question was: What percentage of your total farm production is usually sold?

Vision: For vision and perspectives of the respondent about future alternatives, the data used is a combination of answers of four questions:

1) Do you know possible interventions which could be implemented in an effective manner, to improve the situation?

2) What are your expectations for future of agriculture and the availability of the water resources in the Batinah region in 2025?

3) Do you have a long term vision about improvement for your farm?

4) How do you see your personal situation in the future?

According to the answers of these questions, the farmer were given marks, and then it was decided about him, as he has a long term perspective for future or not. The categories were:

1. Yes
2. No

Ability: The ability and capability of the stakeholders. (E.g. In the matter of finance). The data were taken from the questionnaires and categorized to two categories:

1. Yes
2. No

The question was: Are you ready to pay for a new water service (which provide water of a good quality) to reduce the withdrawal from groundwater aquifer? (Yes/No)

Willingness: This is to test his level of willingness of accepting or rejecting the ideas (e.g. adoption of water quota). The data were taken from the questionnaires and categorized to two categories:

a. Yes

b. No

The nearest question (from the questionnaire) to fit this variable was: Are you ready to install water meters for every well in your farm?

Implementation potential: Implementation of water quotas to the ground water used for irrigation in the study area is essential to control the problem of water shortage and saline intrusion in the coastal aquifer. The idea is to test the degree of implementation potential through evaluating variables affecting behaviours and opinions of different stakeholders. The data were taken from the questionnaires and categorized to two categories:

1. Agree
2. Disagree

The information was taken from a direct question within the table of intervention included in the questionnaire. The question was: For the sustainability of agriculture in the area and conservation of groundwater, would you agree with the idea of Introducing water quotas? (Agree, Disagree)

Note: Water quota is defined to be, the allocation of the resources in an equitable way.