Vulnerability Analysis of Farmers in Roodasht Region

Feasible Adaptation Strategies for a Sustainable Land Use in the Lower Reaches of the Zayandeh-Rud River

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Abstract

Over the past years, water resources depletion by various water users in the basin in combination with climate change have resulted in extreme water shortage and ongoing desertification in Roodasht, a region in Central Iran highly dependent on agriculture and harbouring a fragile ecosystem. Consequently, tensions among different water users increase. In order to develop and implement feasible approaches for sustainable land use that help stakeholders preventing or reversing land degradation and using water resources efficiently, a vulnerability assessment was necessary. Using Füssel's (2007) vulnerability framework, 16 factors for assessing the vulnerability of farmers to water scarcity in Roodasht have been classified. Data collection and analysis have been done based on a mixed method approach using both qualitative and quantitative methods. As a result, the main aspects of vulnerability could be identified as (1) exposure to poor and uncertain water availability, (2) low agricultural production with poor land management and low diversification of products, (3) high risk of pauperization with limited investment capacities and a risk of abandoning agriculture followed by migration, (4) inhibited regional entrepreneurship restricting development of local employment options and markets, and (5) poor efforts on environmental conservation in the region. As a result, there is a high risk of further desertification and social conflicts. Access to knowledge and information, promotion of collaborative networks, access to economic resources and availability of adapted infrastructure and technology could be drivers of an sustainable land use -management and -policy in the region.We hope that this document can make a first important contribution for implementing sustainable land use concepts in the Roodasht area that help prevent land and environmental degradation and enable an efficient use of water resources, safeguarding a sustainable development of this beautiful region with its people.

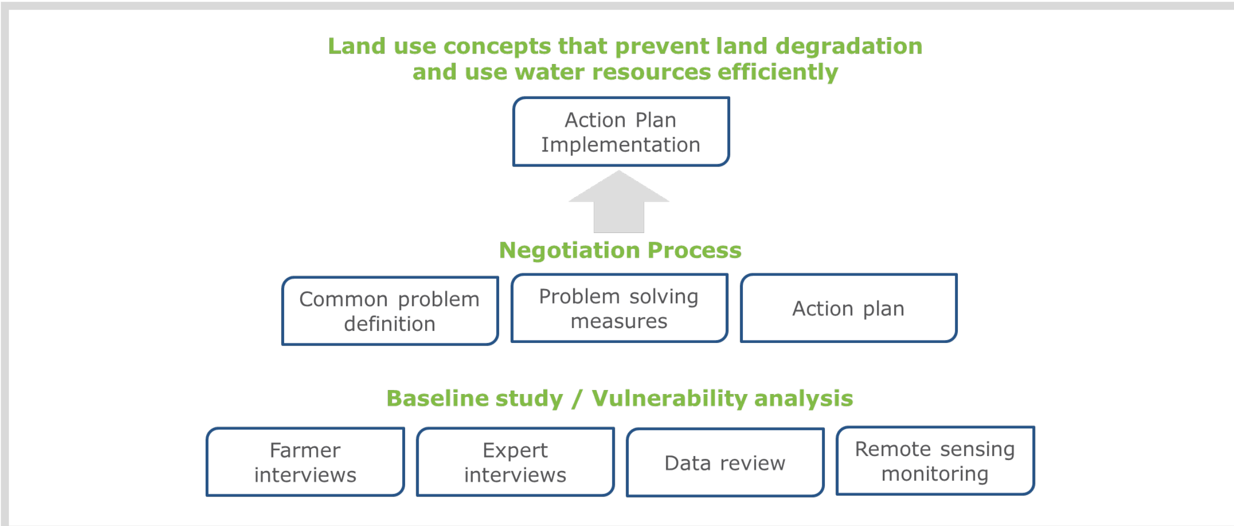
Preface

This report at hand analyses the situation in the lower reaches of the Zayandeh Rud river basin in Central Iran. In the past years, increased water extraction in the basin, climate variability and depletion of groundwater resources have resulted in extreme water shortage and ongoing desertification particularly in the arid downstream area of the basin. Ironically, cultivation has prevented the expansion of the desert at the same time. Drought periods have brought the government to rationalize and even prohibit water withdrawals for irrigation again and again during the last decade. As a result, farmers started to dig deep wells which again led to lowering groundwater tables. Tensions between different water users have increased. Though farmers have received some financial aid for their crop losses, all these measures are in no way sustainable and able to substitute a long-term strategy for land and water management.

To address these problems, the “Feasible Adaptation Strategies for a Sustainable Land Use in the Lower Reaches of the Zayandeh-Rud River” project (August 2015- April 2017) was launched. It is part of the "Policy dialogue and knowledge management on low-emission development strategies, in particular on renewable energy, in the MENA region” focus of the International Climate Initiative which is supervised by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and commissioned and funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB).

The aim of the project has been to develop and implement feasible and acceptable approaches for a sustainable land use concept that help stakeholders preventing or reversing land degradation and using water resources efficiently. Not only affected people (farmers) have been involved, but also staff of governmental institutions shall be motivated and supported in improving the general framework conditions in such a way that they provide incentives for a sustainable resource management. The project wants to promote mutual learning between decision-makers and target groups in order to achieve an outcome as sustainable as possible.

The project has three stages: In a first step, information and data about the main stakeholders, the status quo and changes in land use and management have been collected and are presented as a baseline study / vulnerability analysis in this document (see also project design below). This report presents an analysis of the complex cross-sectoral problem situation in the lower reaches of the Zayandeh-Rud river basin. The draft version of this report was revised based on various comments of a range of relevant experts and stakeholders in 2016.



Project design with vulnerability analysis and used elements (this report) on the bottom, the negotiation process (stage 2 presented in the Action Plan report) with related elements in the middle and the goal of implementation of land use concepts in the top (source: inter 3).

This vulnerability study provides the basis for stage 2, a series of participatory workshops with stakeholders that address land and water management issues more in depth. Therefore, a participatory, intermediate approach was chosen based on the Harvard Negotiation Project. This approach is divided into three steps: (1) creation of a common problem perception, (2) discussion of possible methods of problem resolution and selection of feasible problem resolution measures, and (3) sketching of an action plan. The Harvard principle implicates the aim of reaching an acceptable solution for all conflict partners as this is understood as the only way to guarantee a sustainable outcome. The results of the second project phase are presented in a separate “Action Plan” report (April 2017).

The third stage, the implementation of the action plan which includes land use concepts for preventing land degradation and using water resources efficiently, is a responsibility of the Iranian partners and decision-makers. We hope that the project results provide a useful basis for achieving the goals of improving farmers’ resilience and adaptation capacity in the face of water scarcity and climate change.

Acknowledgements

We would like to thank the Isfahan Regional Water Board Company for the dedicated coordination of the project in Isfahan. In addition, we would like to thank the colleagues at the Isfahan Agricultural Organization and Isfahan Department of Environmental Conservation as well as the Iranian experts from other institutions who have helped us immensely in the project implementation and the development of ideas. In particular, we would like to thank the farmers in Roodasht, who have welcomed us warmly and communicated their ideas and thoughts to us.

Further great thanks go to the German Federal Ministry of the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) for funding the project and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH for supervising the activities.

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1 Introduction

The Zayandeh-Rud in central Iran is one of the country's most important rivers, providing water for more than 4 million inhabitants. Originating in the Zāgros Mountains, the river passes big agricultural areas, large scale industry sites and the city of Isfahan, before it ends in the Gav Khuni wetland, an area recognized by the Ramsar Convention on Wetlands (Figure 1-1).

The exceptional geostrategic location of the Zayandeh-Rud basin has been the driving force for socio-economic, cultural and political growth of the region since early history. With technical innovations it has also been a hub not only for culture and trade but for regional water resources management with inter-basin water transfers from elsewhere into the basin and from the basin to other regions (e.g. Chaharmahal va Bakhtiyari). During the younger history the region has enjoyed a socio-economic development with flourishing urban growth, a thriving industrial development and expanding agricultural areas. These parallel developments have led to an extraordinary increase of water users and water demand in the basin, backed by the distribution of legal water entitlements of the government challenging the historic water distribution rationales (Sheikh Bahaei Tomar share scroll).

Consequently, water resources of the Zayandeh-Rud have not been able to meet the demand of all stakeholders in the basin in recent years. The responses to this situation have been technocratic in nature, altering the natural hydrology of the region: The government has increased control over scarce water resources by building the central dam and extracting more water from other basins, and water users have increased their water availability by intense exploitation of groundwater resources.

Disregarding all efforts to change this situation, water resources remain scarce in the region and the situation gets worse due to climate change characterized by global warming, less precipitation and higher climate variability (IPCC, 2014). The perspective of decreasing water availability and increased water demand as a result of rising temperatures also applies to the Zayandeh-Rud basin (see Eslamian et al. 2016 and Gohari et al., 2013).

This puts high pressure not only on the environment but on sectors with high water consumption, like agriculture in particular. Emerging conflicts between and within the water using sectors as well as increasing pollution of the water bodies have forced the Iranian government to spring into action, but so far measures have still rather been reactive in nature. Up to date, political leaders and decision makers have failed to foster a sound discourse on an integrated water management approach for the whole basin with universally accepted development goals.

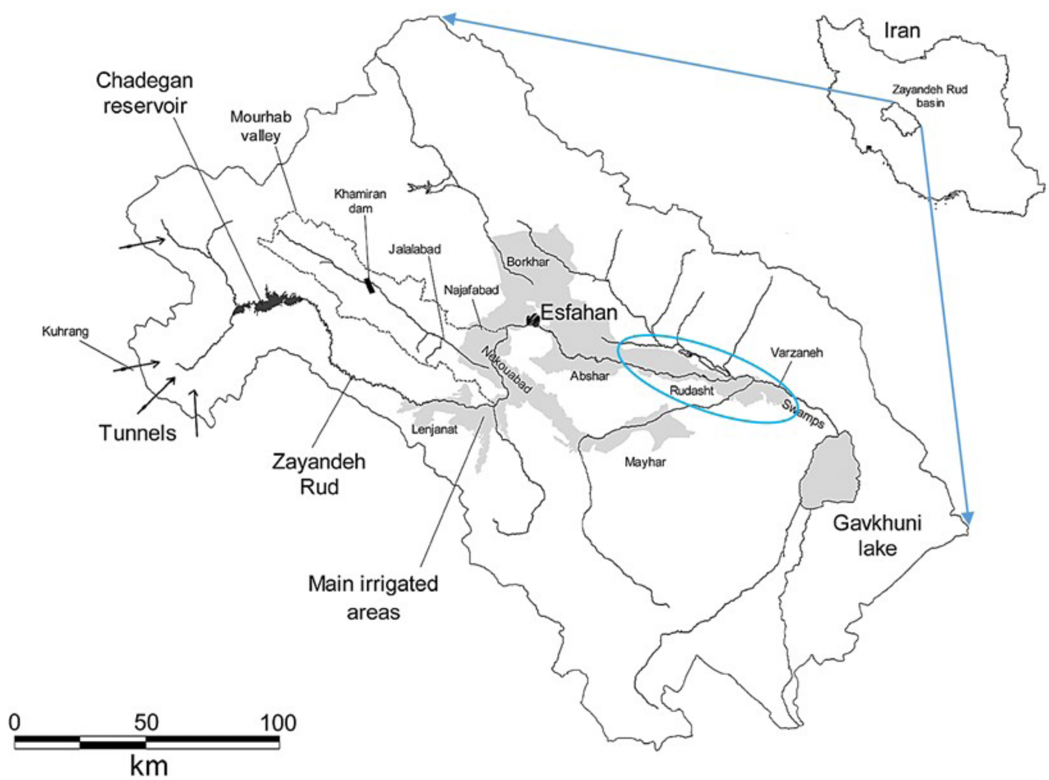

Figure 1 - 1: Location of the Zayandeh-Rud basin and Roodasht project area (source: Molle et al. 2009).

In the lower reaches of the Zayandeh-Rud River, most people live from agriculture. After the Iranian revolution modern irrigation systems (Abshar and Roodasht network) were built to increase agricultural production, and in years with sufficient water resources the canals provide water for around 70,000 ha of cultivated area. Together with the Gav Khuni wetland the Roodasht irrigation network are the tail-enders of the Zayandeh-Rud Basin and are therefore highly affected by water scarcity, water user conflicts and poor management of water resources (Molle and Mamanpoush, 2012).

The report at hand studies the Roodasht region, which comprises the cultivated and populated area within the Roodasht irrigation network up to and including the Gav Khuni wetland. Roodasht region is located in Isfahan county in the districts Jolgeh (western, upstream part of Roodasht), Bonroud (eastern, downstream part of Roodasht), and small parts of neighbor districts. Based on official data from Isfahan Agricultural Organization, the population of the area is more than 52.000 people in 8800 households inhabiting about 50 small cities and villages, Varzaneh (Bonroud district) being with more than 10.000 inhabitants the largest city in the region. There are more than 12.500 active farmers in Roodasht.

Historic development of Roodasht Region

Historic records indicate human settlements around Varzahneh in Roodasht Region already 5000 years ago. Farming activities are indicated already by the word Varzaneh which, according to linguists, has a connection to the verb Varzidan meaning farming in old Persian. Bonroud as one of the main districts in Roodasht has been a historic centre producing grains and cotton products for neighbouring desert cities (Nasle farad, 2017). For newer history, Whitton (1982) described the Roodasht plain comprising around 20,000 ha of irrigated land in 1972. Back than it was one of the least favoured agricultural area in the Isfahan region because of extensive areas of saline soils, limited quantities of poor-quality surface water, salty ground water and harsh climatic conditions. The plain was largely barren and treeless and by 1977 many farms and houses had been abandoned. The very simple cropping patterns of the area were based mainly on rotation of irrigated wheat, barley and cotton, and fallow land was used for grazing animals. In 1977, the farmers of these areas specialized in livestock husbandry and most of the wheat grown was used as a feed for cattle, sheep and goats. Some flour was milled and used for making unleavened bread. Already back then, the tail end position of Roodasht and increased water consumption upstream let the agricultural area of the Roodasht plains received only small volumes of poor quality water for the leaching of salt accumulations. Poor drainage and arid conditions also accentuated the processes of salinization in the saline-alluvial soils of this area.

Data of the Isfahan Water Board Company indicate that the modern irrigation channels have been inaugurated in 2003 and 2006 respectively (north and south Roodasht). Satellite images of cultivated areas in Roodasht in 1994 and 2007 presented in Figure 1 - 2 indicate that the modernization of irrigation networks did not expand the cultivated area significantly.

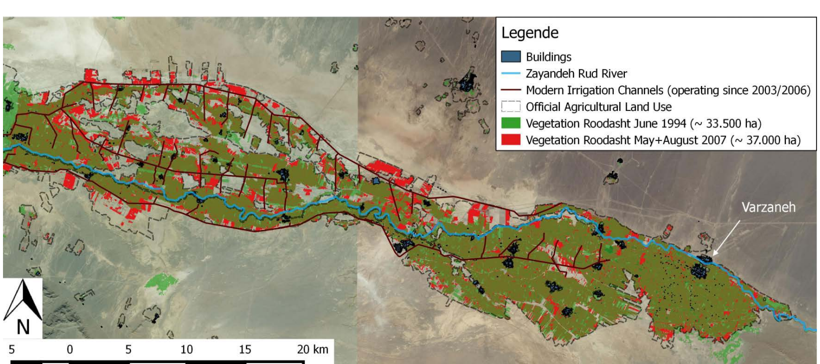

Figure 1 - 2: Satellite analysis of cultivated areas in Roodasht before and after construction of modern irrigation network (source: inte 3/TU Berlin).

2 Problem statement and research question

Apparently water availability in Roodasht decreased in the past years and at the same time social conflicts and ongoing desertification could be observed. There are no integrated, sustainable land use concepts established to cope with the ongoing crisis situation.

Information about how basin wide water scarcity influences water availability and impacts on local farmers and the process of desertification is available only dispersed in different sectors (agriculture, water, environment and social) and on different levels (national, provincial, county, districts and field level). However, a comprehensive understanding of the relevant dimensions and interaction of factors is currently missing.

Agriculture is the dominant form of land use in the Roodasht region. Therefore farmers are the main actors determining environmental conditions and development in the region. Devising sustainable land use concepts that stop or reverse environmental degradation and enable efficient and socio-economic valuable use of limited water resources is only possible though a profound understanding and strategic integration of farmers.

It is therefore necessary to assess the vulnerability of farmers in Roodasht towards water scarcity, which is closely interwoven with the fate of the environment. In the assessment it is important that the key factors of vulnerability are identified and characterized to serve as entry points for further works.

Mainly, this report intends to answer the question: ***How is the current vulnerability of farmers in the Roodasht region towards water scarcity?***

- How is water availability characterized in Roodasht during the past water scarce decade?
- What are relevant aspects and thematic fields being impacted by water scarcity?
- What may be the negative impacts of these conditions on farmers and local environment?
- How is the adaptive capacity of farmers towards these impacts and risks?

3 Theoretical framework, methods and concepts

3.1 Theoretical framework

Vulnerability is often conceptualized as the degree to which a system is susceptible to be harmed when exposure to hazards and risks (Turner et al, 2003, Adger, 2006, Füssel 2007). However, in most cases, vulnerability itself is a consequence, resulting from underlying social and environmental conditions which need to be understood (Voss, 2008).

Given this, the theoretical framework used to analyze the vulnerability of farmers to water scarcity in Roodasht is based on a comprehensive approach to vulnerability presented by H.M. Füssel (2007). In Appendix I a literature review on available approaches for conceptualizing and assessing vulnerability is being presented including the applied approach by Füssel (2007). According to Füssel, the term of vulnerability is conceptualized by distinguishing among the internal and external spheres (or scale) and the two knowledge domains: socio-economic and biophysical. The internal sphere includes factors describing the properties of the vulnerable system or community itself, whereas, factors from the external sphere describe aspects beyond the local community (Füssel, 2007). By adapting Füssel´s classification scheme in total 16 factors considered to assess vulnerability of farmers to water scarcity in Roodasht have been classified in the mentioned four dimensions (see Figure 3 - 1). A brief definition of the used vulnerability factors can be found in Appendix II, whereas the detailed discussion of these factors is presented in chapter 5 of this report.

The biophysical and socio-economic vulnerability factors from the internal and external sphere are closely interconnected and brought together and integrated in the vulnerability assessment presented in chapter 4.1. During this step the main aspects determining vulnerability of farmers and contesting a sustainable land use and farmers livelihoods are presented and discussed.

Furthermore, the adaptive capacity of farmers to adjust to the negative effects of water scarcity is derived from the vulnerability factors and presented in chapter 4.2. Adaptive capacity is an important aspect of vulnerability (IPCC, 2001, Smit and Wandel, 2006).

The overall structure of the vulnerability framework is presented in Figure 3 - 1.

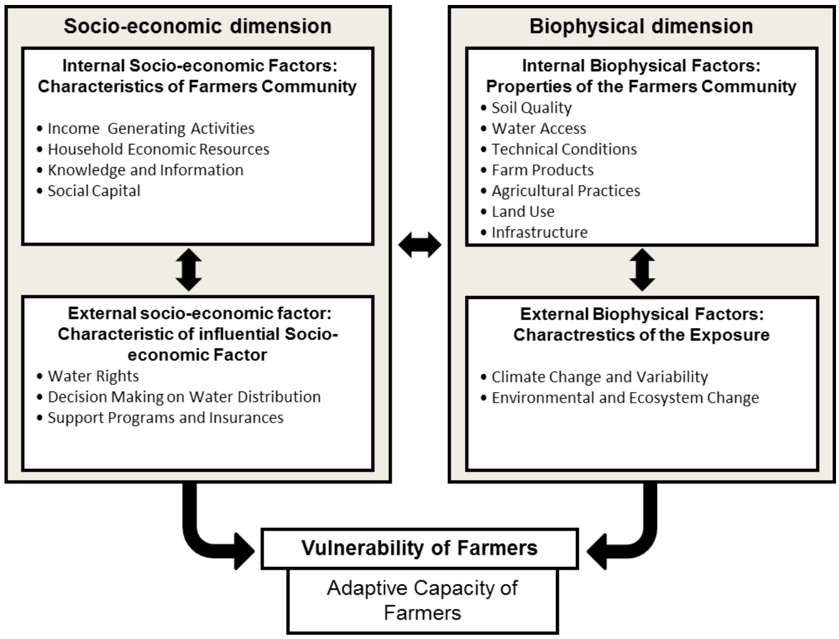

Figure 3 - 1: Applied vulnerability framework (adapted from Füssel, 2007).

3.2 Methods

Data collection and analysis are based on a mixed method using both qualitative and quantitative data which include (1) site visits, (2) literature review, (3) gathering of official data series, (4) interviews with farmers, (5) workshops and interviews with experts and (6) a remote sensing analysis which was performed by the BMBF IWRM Zayandeh Rud Project. The data collection between October 2015 and March 2016 allowed for integration of a vast range of perspective and points of views from affected farmers to local and provincial experts and different stakeholders, as well as official datasets and remote sensing data.

The process of data collection from Iranian organizations was done by coordinating with IWRM office in Isfahan. The quality and validity of the received data series and information was checked by the research team and different types of data were compared to assure the integrity of the data. Preliminary results of data analysis have been presented in a workshop with the Isfahan Regional Water Company and Isfahan Agricultural Organization which lead to revision of a basic dataset by the Isfahan Agricultural Organization.

Specifically data collection was done by:

- 30 on-site interviews with farmers in the Roodasht region. A questionnaire including more than 150 open-ended and closed-ended questions was used in in-depth interviews with farmers at different locations in the Roodasht irrigation network (Focus regions for Interviews are presented in Appendix III and an anonymized example questionnaire is attached in Appendix IV). The applied iterative development of non-theory based qualitative questionnaires until saturation of information is based on the Grounded Theory (Glaser and Strauss, 1967). During the interview mission it was found that after the first 20 performed interviews, no gain in understanding of the local situation was experienced, since answers repeated. After finishing 30 interviews this impression was confirmed and the performance of more interviews was found to be not adequate or useful in regard to the time investment.

- 7 workshops with experts from (1) the agriculture sector (provincial: Isfahan Agricultural Organization and Agricultural Research Center, county/district: Agricultural Service Centers, consulting companies and cooperatives, local: farmers and farmer representatives) (2) the water sector (provincial: Isfahan Regional Water Company, regional: Mirab company) and (3) environmental sector (provincial: Department of Environment, local: environmental NGOs);
- More than 30 expert interviews with representatives from (1) Agricultural Organization, Agricultural Research Center and Agricultural Service center, (2) Mirab company, (3) local NGOs, (4) Department of Environment, (5) Forest, Rangelands and Watershed Management Organization, (6) Agricultural Bank, (7) Agricultural Trade Union, (9) Rural Cooperative Organization, Cooperative Companies, (10) Imam Relief Fund, (11) international Research center ICARDA and (12) Technology Development council of Water, Drought , Erosion and Environment;
- Several datasets from Isfahan Agricultural Organization, Isfahan Regional Water Company;
- More than 20 site visits;
- A flanking literature and media analysis on different topics.
- A remote sensing mission by the BMBF IWRM Zayandeh-Rud Project, performed by the Technical University of Berlin with data from the Landsat satellite mission.

Data series analysis was performed by numeric quantitative analysis to identify trends and changes and to derive charts and figures.

Qualitative data of Farmers interviews and meetings with the experts is thematically analyzed. Regarding selected internal and external factors, the data is subsequently analyzed coded and categorized to identify relevant themes and issues. Furthermore, extensive field notes collected during the on-site interviews was used through analysis and coding in this research step.

3.3 Used concepts

In the following report, two basic concepts of desertification and water scarcity will be used which are defined in this paragraph.

Desertification

To describe environmental degradation in the study region the definition of desertification by the United Nations is being used. "Article 1 a: Desertification means land degradation [...] resulting from various factors, including climatic variations and human activities;

Article 1 f: land degradation means reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:

(i) Soil erosion caused by wind and/or water;

(ii) Deterioration of the physical, chemical and biological or economic properties of soil; and

(iii) Long-term loss of natural vegetation;" (UN, 1994: 337).

Water scarcity

To describe the phenomenon of reduced availability and access to water resources, the concept of water scarcity with the following definition is being used.

"Water scarcity is a gap between available supply and expressed demand of freshwater in a specified domain, under prevailing institutional arrangements [...] and infrastructural conditions. [...] considering three main dimensions of water scarcity, which can be summarized as follows:

- Scarcity in availability of water of acceptable quality with respect to aggregated demand, in the simple case of physical water shortage;
- Scarcity due to the lack of adequate infrastructure, irrespective of the level of water resources, because of financial , technical or other constraints; and
- Scarcity in access to water services, because of the failure of institutions (including legal rights) in place to ensure reliable, secure and equitable supply of water to users." (FAO, 2012: 5ff).

Climate Variation

Next to 'unique or singular phenomena' and 'complex extremes', IPCC (2001) defines 'simple extremes' as "Individual local weather variables exceeding critical level on a continuous scale [like for example] heavy rainfall" or drought. (IPCC, 2001:92) In this work 'simple extremes' according to IPCC (2001) like droughts are subject of study.

4 Vulnerability assessment

This section analyzes and presents the current state of vulnerability of farmers towards water scarcity in the Roodasht area. The goal of this section is to characterize factors and conditions connected to water scarcity, which currently impact negatively on farmers and may ultimately lead to environmental degradation/desertification and social conflicts. Subject of the report is not to quantify and compare vulnerability of different groups or locations or to sketch possible solutions, but to define the complex and multilayered current situation of vulnerability of local farmers.

At first, the main thematic fields of vulnerability will be introduced, followed by a detailed discussion of the identified topics. In chapter 4.2, adaptive capacity of farmers to cope with water scarcity will be characterized and discussed.

The presented vulnerability analysis has been derived by analyzing the different vulnerability factors discussed in detail in chapter 5. In the text several linkages to specific vulnerability factors are placed where the corresponding statements are developed in detail. The report structure was chosen for the sake of rapid readability of this chapter and the option to go deeper in specific aspects of interest in chapter 5.

4.1 Thematic fields of vulnerability

The main cause for vulnerability of farmers in the region is poor and uncertain **water availability in Roodasht** during the past water scarce decade. Coupled with a range of connected factors, this leads to significant cuts in local **agricultural production**, impacting negatively on **farmers' livelihoods**. Under these conditions, **regional entrepreneurship** stagnates and activities on **environmental conservation** are restricted. Vice versa, the absence of ecologic and sustainable regional development affects on-farm activities and livelihoods of farmers negatively.

In general it can be concluded that farmers have become increasingly vulnerable toward water scarcity in Roodasht mainly because:

- Water availability in Roodasht is low and uncertain, due to (1) little and unstable diversion of surface water to the region and (2) the connected reduction of quality and availability of local groundwater resources;
- Agricultural production is diminishing, with ongoing salinization and alkalinity of soils, little modern and efficient farm management and insufficient irrigation water;

- Farmers have no capacity to invest in adaptation measures, since they consumed their economic resources during the past dry years and currently carry a burden of debt, and at the same time they rely entirely on currently unproductive agriculture;
- Alternative local employment or occupation options are quasi nonexistent, since regional entrepreneurship is stagnating;
- Environmental conservation is not practiced, since both on- and off-farm conservation activities (also Gav Khuni wetland) are no attractive activities for farmers and not fostered by the government. Consequent ongoing desertification is impacting negatively on agricultural production.

The mentioned conditions create two main risks. Since (1) no structured and powerful measures have been taken to change the situation of farmers in Roodasht, and (2) the adaptive capacity of farmers (chapter 4.2) is low, the already observed symptoms of the two risks below are expected to grow and come to a crisis in the near future:

- A high risk of desertification and environmental degradation is implied by (1) soil salinization/alkalinity and wind erosion under water scarce conditions, (2) abandoned agricultural lands that turn to desert and get lost for agricultural practice, (3) limited application of measures for desertification control and environmental conservation and (4) drying out of Gav Khuni wetland with its central function in avoiding desertification and stabilizing the local microclimate.
- A high risk for social conflicts, tension or unrest is the short and long term effect of a feeling of farmers to be deprived by decision makers and the high risk of poverty of farmers' households. The traditional form of farming and livelihood is eroding and the only options seem to be to migrate to cities or remain in poverty in the area. This setting already caused several, also violent, protests but may escalate further in future.

The established thematic fields of farmers' vulnerability in Roodasht with associated conditions in green boxes above and characteristics in Roodasht in blue boxes beneath, are presented in Figure 4 - 1 and discussed in detail in the subsequent text.

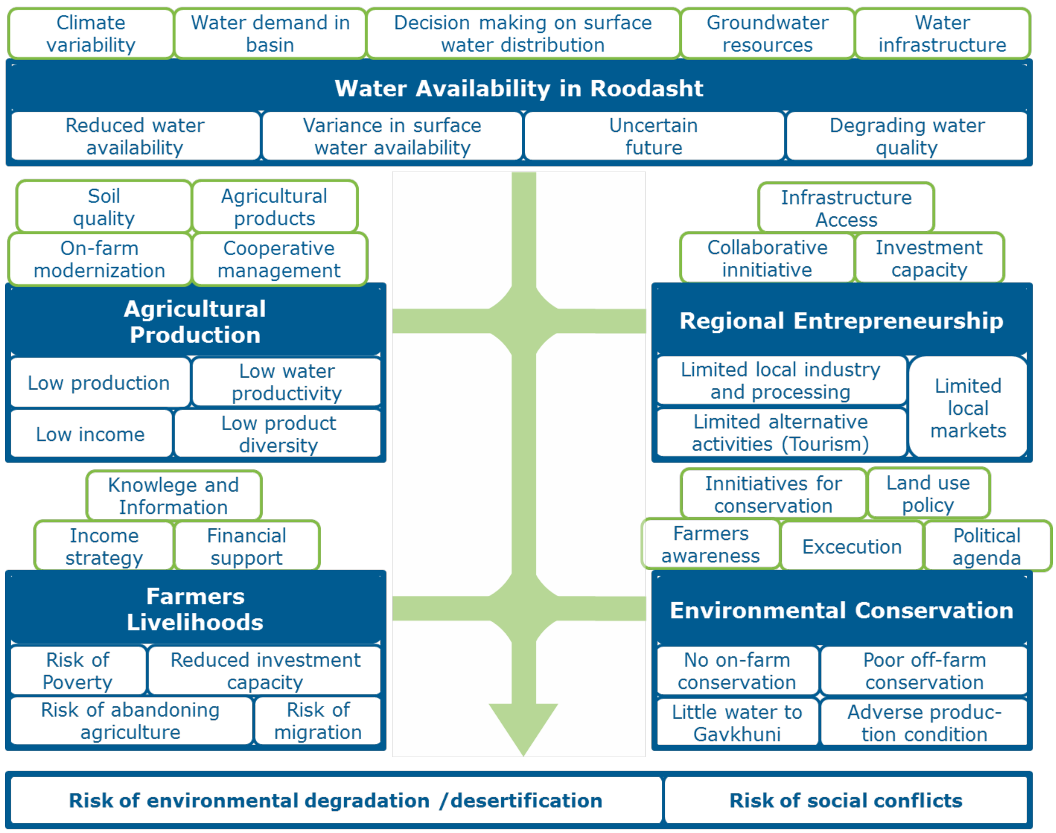

Figure 4 - 1: Thematic fields of farmers vulnerability in Roodasht (source: inter 3).

4.1.1 Water availability in Roodasht

Conditions

In younger history the number of water users in the basin increased by population growth, economic development and intensified agricultural activities as well as inter-basin water transfer (see chapter 1 and 5.2.1). In the past decade, the effects of **climate variability** and climate change have led to variance in precipitation and higher temperatures in the Zayandeh-Rud basin, which is expected to continue in future (see chapter 5.4.1).

These two factors lead to an increased **water demand** and competition for water on the one hand and on the other hand to less available surface water in the Zayandeh-Rud basin. The trend of basin wide water scarcity is reflected by a drop of over 40% of water stock in the central Zayandeh-Rud dam between the years 2007 and 2015 (see chapter 5.3.2). Historically Roodasht receives water twice per year, but in some of the past years Roodasht did not receive any water at all or only once a year due to limited water availability in the basin (see chapter 5.3.2).

Decisions on basin wide distribution of the limited surface water resources are done since 2014 by the Coordinating Council for Integrated Management of Water Resources (RBO) in the Zayandeh-Rud Basin. The water scarce situation, but also (1) little political and economic power of the Roodasht region and (2) little participation of farmers and environmental representatives, in an (3) intransparent decision making process (from farmers perspective) (see chapter 5.2.2), lead to a reduced amount of surface water distributed to the Roodasht area during the past decade. Water entitlements in the basin have become so complex and intransparent that farmers in Roodasht feel deprived of their water rights illegitimately by decision makers, which lead to a perception of exclusion and fraud causing **social conflicts**, with protests and a fading trust in governmental institutions (see chapter 5.2.1, 5.2.2 and 5.1.4).

In Roodasht area, the presence of surface water in (1) the Zayandeh-Rud River, (2) traditional irrigation channels, which are not lined with concrete and (3) percolating water from agricultural fields as well as (4) precipitation, is of upmost importance for groundwater recharge (see chapter 5.3.2 and 5.3.4). Therefore, the fate of local **groundwater resources** is directly dependent on surface water delivered to the region and the type of installed **water infrastructure** (e.g. lined channels and efficient irrigation methods may reduce groundwater recharge). Reduced surface water throughput in river and irrigation networks, as well as dropping groundwater tables due to limited recharge and over-extraction are central factors for **degrading quality of (ground-) water** resources (chapter 5.3.2). To a large extend, groundwater is being recycled for irrigation over and over again, accumulating salt and pollutants.

Outcome

The mentioned factors of (1) reduced basin wide water availability, (2) little recognition of Roodasht region in the completion for scarce surface water resources, and (3) interaction of surface and groundwater have led in the past decade to the following outcomes for Roodasht:

1. Overall reduced water availability for farming and environmental preservation (Gav Khuni wetland) from surface- and groundwater (see chapter 5.3.2);

2. Strong variance in surface water availability, in terms of (1) fluctuation of water diversion over different years, as well as (2) seasonal variance (spring and fall irrigation) (chapter 5.3.2);

3. An uncertain long term development of surface water distribution and the therewith connected fate of agriculture in the Roodasht region (see chapter 5.3.2, 5.2.2, 5.3.5, 5.3.7).

4. Degrading water quality of surface water and particularly groundwater resources which is closely connected to surface water distribution to Roodasht (see chapter 5.3.2).

The presented complex of problems around water availability in Roodasht is the main root cause for all below discussed thematic fields of vulnerability.

4.1.2 Agricultural production

Conditions

Long term degrading **soil quality** of farmland in Roodasht is a threat to agricultural production and fosters desertification.

The main parts of agricultural soil in Roodasht have high clay contents, little organic carbon and are saline as well as alkaline. Particularly when soils are dried out, these conditions imply a high risk of reduced productivity of soils and (wind) erosion, fostering the process of desertification (see chapter 5.3.1 and 5.4.2).

Reduced availability of surface water forces farmers with groundwater access to irrigate excessively with saline groundwater to sustain their production (see chapter 5.3.2, 5.3.4), which leads on a long run to (1) depletion and salinization of groundwater resources and (2) accumulation of salts and sodium ions in the soil. Soil degradation by salinization as well as alkalinity has an adverse effect on agricultural yields and may lead to abandoning agricultural activities due to economic inefficiency, which increases the risk of desertification and further loss of productivity of soils (see chapter 5.3.1, 5.3.4 5.4.2).

Dropping quality and fertility of the soil is supported by unfavorable agricultural practices like:

- Poor biomass management; Mostly farmers sell crop residuals to livestock keepers or use it for feed of own livestock, which removes biomass from the fields. Manure as soil conditioner is only applied to a limited extend due to its high market price. (chapter 5.3.5). Consequently soil organic matter which lowers the pH (organic and humic acids) and increases the cation-exchange capacity (buffering salinity) and improves drainage capacity may not build up;
- Limited application of conservation land management practices; Conservational tillage with a chisel plow is known in Roodasht but access to modern equipment is a limiting factor for application. Also the knowledge and skills of farmers attached to conservational tillage and further conservational agriculture practices like permanent soil cover and crop rotation are limited and not applied widely in Roodasht (chapter 5.3.5). Deep soil disturbance though plowing hampers biological process in the soil and oxidizes organic matter which increases alkalinity;
- High fertilizer inputs; Application of mineral fertilizer is the conventional land management approach in Roodasht practiced widely. The fertilizer application boosts yields on a short

term but also adds salts to the soil and pollutes the environment by nutrient rich drainage water (chapter 5.3.5).

The choice of **agricultural products** is strongly dependent on local biophysical and infrastructure conditions, but determines income generation capacity, options for local entrepreneurship and resilience of farmers towards water scarce conditions.

Crop choice is limited in Roodasht and dominated by wheat and barley, covering around 80% of the cultivated area. These grains have comparably (1) long cultivation periods which makes them dependent on irrigation water for several months (implying a high vulnerability to cuts in irrigation water particularly in spring time), and (2) low productivity and income generating potentials under water scarce conditions (chapter 5.3.4). Popularity of grains arises mainly from (1) a historical background, (2) matching water distribution patterns with water demand of grains, (3) valorization of precipitation of the planted winter grains, (4) a relative drought and salt resistance, and (5) governmentally guaranteed prices for grains. Alternative crop choice is restricted due to:

- Little Reduced water availability, as well as limited control on timing of irrigation water, particularly concerning farmers without or with poor groundwater access (chapter 5.3.4);
- Cultivation of other crops like high value, drought- or salt resistant crops requires access to equivalent seeds and seedlings which is limited in Roodasht (see chapter 5.3.4). It has to be noted that cultivated grains are comparably salt tolerant;
- Missing necessary receiving markets to sell the alternative products. There is hardly any local entrepreneurship to develop such markets by, for example, setting up local commodity chains. Wheat and barley have governmentally guaranteed prices and can be sold easily, through coordination of cooperative companies for marketing wheat and barley and exit the region as raw product (see chapter 5.3.4,5.3.7);
- Changing the cultivation to new cultivars requires know-how, access to adapted equipment as well as a certain willingness of farmers which is found to be low in Roodasht particularly amongst old farmers (see chapter 5.3.4 and 5.1.3).

The production costs of livestock are directly dependent on agricultural forage production. During water scarce conditions in the past decade, several livestock owners were forced to sell their animals, since they could not produce their own fodder or access cheap fodder on the marked (chapter 5.3.4). This action sustained their livelihoods during water scarcity but also sacrificed their liquid asset and reduced future coping capacity to drought (chapter 5.1.2).

Besides livestock, also some of the formally existing old orchards in Roodasht region could not be sustained during water scarcity, which lead to further decrease in diversity of farm products (chapter 5.3.4).

On-farm modernization to modern and water-efficient agricultural production systems in Roodasht is restricted due to a range of factors. Hence, traditional agricultural production manners with high water demand, high dependency on surface water and limited crop choice don't change. Nevertheless mechanization with old tractors is high and the government invests in mechanization and equipment projects (chapter 5.3.3).

Missing permanent availability of surface water, special characteristics of the soil and (high level) saline groundwater resources in Roodasht hinder the application of modern pressurized irrigation methods. These technologies require a stable water source and efficient water application of untreated groundwater would boost salt concentrations in the top soil (chapter5.3.3 and 5.3.2).

The conditions of water resources availability, as well as poor coverage with electric energy, liquid gas and drinking water infrastructure in rural areas lead to a high investment demand for larger modernization projects. Hence cases of, for example, greenhouse developments are rare in Roodasht (chapter 5.3.3 and 5.3.2). Farmers don't dispose of sufficient investment capacity, since their savings have been depleted during the past water scarce conditions with limited incomes (chapter 5.1.2). Also the uncertainty in water distribution and future development of the agricultural sector in the region makes investments into on-farm modernization risky and not rational for farmers and entrepreneurs (chapter 5.3.2, 5.3.3 and 5.3.7). Another critical aspect is the coverage of required, local technical consultancy services for modernization, which decreased in quantity and quality in the past dry years, when only little investment has been done by farmers (chapter5.3.3). In addition, considering the attachment to traditional knowledge of particularly older farmers, there is little motivation to change the farming system (chapter5.1.3).

Cooperative management in terms of shared investment and joint action is a way for farmers to reduce production costs and increase agricultural productivity and incomes. A strong cooperative management can foster the (1) defragmentation of agricultural lands, (2) facilitate sharing of farming equipment, and (3) stipulate collaborative marketing or processing approaches. In Roodasht, while farmers are members of a range of cooperative companies, the lack of successful collaborative "team work" amongst farmers was observed. Reasons may be mistrust and conflicts amongst farmers as well as missing know-how and effective management structures (see chapter 5.1.4).

Agricultural lands, in particular those of small holders, are often fragmented in several small parcels. In comparison to larger plots, these conditions lower efficiency of mechanized farming, on-farm water management and ultimately productivity of the arable land (chapter 5.3.6). Defragmentation of agricultural land requires a strong collaborative approach, which is only happening in rare exceptions in Roodasht.

Farming equipment is partly owned by small scale farmers but has to be rented to a large extend from large farmers that own more equipment (chapter 5.3.3). Sharing equipment is not typical in the region (chapter 5.1.4). These conditions increase production costs particularly of small scale farmers.

Local approaches for collaborative marketing of farm products or local value creation by, for example, cooperative commodity chains are limited (chapter 5.3.4, 5.3.7). Only few examples of functional and powerful cooperative structures that grant good incomes for its members could be observed (chapter 5.3.7 and 4.2).

Outcome

The mentioned factors of (1) ongoing degradation of agricultural soils, (2) restricted crop choice and (3) insufficient on-farm modernization as well as (4) inefficient cooperative farm management, coupled with the (5) poor conditions of water availability in Roodasht area have led to the following outcomes:

1. In the past decade **agricultural production** in Roodasht was cut down by more than half. The dynamic of cultivated areas and supplied surface water in the years 2006 until 2015 as well as a trend of abandoned agricultural plots is discussed in chapter 5.3.4 and 5.4.2.
2. **Water productivity**[1] is comparably low due to adverse soil conditions, land fragmentation, crop choice and application of traditional irrigation and farming methods (chapter5.3.1, 5.3.3 and 5.3.4);
3. **Diversity of farm products** was reduced during dry years, due to loss of livestock and orchards as well as restrictions in crop choice (chapter5.3.4);
4. Reduced agricultural production and high production costs (due to poor cooperative management) and water scarcity lead to a considerable **reduction of income** generation from farming (chapter5.1.1, 5.1.2 and 5.3.4).

1 We use the concept of water productivity as "the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits" (Molden et al. 2007)

The reduced agricultural production implies the risk of social unrest of traditional farmers in Roodasht whose livelihoods depended on farming for generations (chapter 5.1.1, 5.1.2 and 5.3.4). The pressure for agricultural production under adverse conditions fosters unsustainable land and water management and if agricultural lands are fallow for several successive years, there is a high risk of (1) desertification and (2) loss of soil fertility (chapter 5.3.1 and 5.4.2).

4.1.3 Farmers livelihoods

Conditions

Historically, farming is the main occupation of people in Roodasht. To a substantial part, **knowledge** and skills of farmers have been inherited through generations of farmers' families. Formal education is found to be low, particularly with old farmers (chapter5.1.3). Farmers get **informed** about aspects on farming by their social networks, media or agricultural service centers (chapter 5.1.3 and 5.1.4). In general, knowledge and information of farmers is restricted to traditional farming and does not empower them to approaching other forms of income generating activities or to modernize or change their agricultural production.

Income strategies for sustaining livelihood of most of the farmers in Roodasht (particularly old and small-scale farmers) are mainly limited to traditional farming (chapter 5.1.1). This restriction of income strategies origins next to missing knowledge and information from a lack of alternative local employment options for farmers and their household members (e.g. industry/processing facilities or activities like tourism) (chapter 5.3.7 and 5.1.1).

Financial support in terms of credits, aid, loans and also insurances that farmers receive are generally limited and not adequately adapted to water scarce conditions and vulnerability of farmers in Roodasht. The existing programs are rather a poverty relive than tools to empower farmers to invest and adapt their agricultural system or livelihood income strategies (chapter 5.2.3).

Outcome

The focus of income strategies on traditional farming in combination with the cut agricultural production of the past years caused significant reductions of income for farmers' livelihoods from 2009 onwards.

With the limited income for sustaining their livelihoods, farmers' households have been forced to (1) rely on support programs and insurances to cover their basic household needs, (2) consume their savings, (3) sell their liquid assets like livestock, equipment or even land, and to (4) access loans from the agricultural bank (chapter 5.2.3, 5.1.1 and 5.1.2). However, the high interest rate of loans, strong inflation and the permanently depressed farming income restrict repayment of loans which caused the financial burden to pile up over time for farmers (chapter 5.1.2).

This tensed financial situation coupled with the low agricultural production and uncertainty on future development of water distribution has the following outcomes for farmers' households in Roodasht:

1. A **risk of poverty**, with massive financial obligation but no household income or assets (chapter 5.1.2). Poverty within this large population group of the downstream region of the Zayandeh-Rud river will on the short or long run lead unavoidably to social conflicts;
2. A **reduced investment capacity** that does not render farmers capable or willing to fund projects of agricultural modernization or regional entrepreneurship (chapter 5.1.2, 5.3.3 and 5.3.7). This causes a vicious circle as sustainable livelihood alternatives are diminishing over time;
3. A **risk of abandoning agriculture** at least partly in order to (1) gain some income through selling land and equipment, (2) reduce running costs for sustaining agricultural lands, and (3) reduce the dependency of the uncertain future of water availability in Roodasht. After few years, fallow lands lose their agricultural productivity by soil degradation and foster desertification of those areas (chapter 5.1.2, 5.3.4, 5.4.2);
4. This desperate situation for farmers' livelihoods in Roodasht triggers particularly young farmers and household members to **migrate** elsewhere and to start a new life. Since cities are expected to be the major destination for migration, there is the requirement for a certain degree of financial resources to cope with the higher livelihood expenses in cities. Migration of larger numbers of farmers to cities entail the risk of segregation of this poor and poorly educated group in slums, leading to social tensions with vast impacts on cities as seen in many examples around the world.

4.1.4 Regional entrepreneurship

Conditions

Particularly in rural areas, poor access to production means like energy, water and gas **infrastructure** hinders local industrial development. This counts particularly for processing industries (commodity chains) connected to the agricultural sector where uncertainty on future water availability makes large investments of entrepreneurs risky and not rational (chapter 5.3.2 and 5.3.7).

Commodity chains in form of processing and marketing facilities for agricultural products could also be implemented collaboratively by farmers in form of cooperative companies. This type of farmers' entrepreneurship was found in some cases particularly with livestock keepers (chapter 5.3.7). Establishing farmer owned processing facilities requires (1) local know-how and (2) a powerful **collaborative initiative** by farmers, which is rare in Roodasht. Apparently, water scarcity also pressurizes and complicates farmers' networks (chapter 5.1.4). Moreover farmers' households need to dispose of a certain (3) **investment capacity** to set up a business, which has yet diminished over the past dry years (chapter 5.1.2).

Collaborative initiatives, in the form of NGOs and later as syndicates or cooperative companies could also develop alternative non-farming related activities like local (eco-) tourism. But touristic development requires an intact eco-system, particularly of the Gav Khuni wetland as one of the regional highlights which degraded in the past decade (chapter 5.3.7 and 5.4.2).

Outcome

The described local conditions of poor (1) infrastructure access, (2) collaborative initiatives and (3) investment capacity among farmers cause:

1. Restricted development of **local industry and processing facilities**, leaving agriculture as the only option of income generation for farmers' households (chapter 5.1.1);
2. Hindered development of **alternative activities like tourism**, gives no long term transformation perspective for farmers households to a regional development with an intact eco-system (chapter 5.3.7, 5.3.6);
3. The above aspects limit the development of **local markets** for agricultural products, where farmers could sell alternative products and thus would have an incentive for changing the dominant crop pattern to adapted products with higher revenues (chapter 5.3.7, 5.3.4).

4.1.5 Environmental conservation

Conditions

In Roodasht, **initiatives for environmental conservation** on private land in form of (1) financial incentive, (2) bids or bans or (3) targeted information or training on conservative i.e. alternative agriculture could not be observed (chapter 5.3.6). Changing land use from agriculture to, for example, planting halophyte shrubs for rangeland stabilization and conservative biomass and fodder production or solar or wind farms for energy production and erosion control is hindered by a complicated administrative process for changing land use, intending to preserve productive agriculture (chapter 5.3.6). In the tensed livelihood situation of the past decade, farmers have no option than to exploit their conventional agricultural system to a maximum.

In general, **farmers' awareness** on environmental preservation is low in Roodasht region, also due to little participation of farmers in local planning. The high dependency on income generating agriculture makes farmers and environment rather competitors for scarce water and natural resources than farmers agents of a sustainable land use (chapter 5.3.6, 5.1.1).

Little **executive** control on environmental issues like damaging range lands by free grazing livestock, uncontrolled mining activities or illegal water extraction from wells or from the Zayandeh-Rud river, give farmers no initiative to practice environmental conservation (chapter 5.3.5, 5.3.6, 5.4.2). A reason for little execution power on the field is also that interest groups such as environmental NGOs, who could fulfill this task, have no strong legal embedment and support (chapter 5.2.2). However experts state that the conditions of NGO developed positively in the past years.

Nevertheless, in the recent past it could be observed that an environmental focus in the **political agenda** established and enforced an environmental water right for the Gavkuhni wetland, which was fulfilled in 2015 for the first time (chapter 5.2.1 and 5.4.2).

Outcome

Outcomes of the mentioned conditions under water scarcity are:

1. **On-farm conservation** measures are rarely practiced by farmers. Conservation practices could reduce the irrigation water use in Roodasht and contribute to environmental protection, desertification control and alternative income generation potentials (chapter 5.3.6);

2. Only few **off-farm conservation** measures like governmentally funded implementation of natural vegetation cover in the bordering region of Roodasht exist. Local people are not aware of the importance of these initiatives for desertification control and vegetation is often destroyed by free grazing livestock (chapter 5.3.6). Such measures could preserve the environment and control further desertification.

3. After many dry years, water diversion to **Gav Khuni** wetland was enforced just recently (chapter 5.4.2). Sustaining this initiative in order to avoid desertification and support the local microclimate strongly depends on the decision making and capacities to enforce environmental interests locally.

The resulting ongoing desertification and changed micro climate leads to **adverse production conditions** for local farmers in terms of degrading soil quality, sand storms, increased evapotranspiration, less vegetation for range land grazing and even potential health impacts by polluted micro-dusts (chapter 5.4.2). Furthermore, environmental degradation limits opportunities to develop local tourism.

4.2 Adaptive capacity

tourism Any kind of external stress always triggers a reaction of farmers. If these reactions are short term coping strategies or long term sustainable adaptation strategies, depends mainly on adaptive capacity of farmers. Adaptive capacity can be defined by the capacity of farmers to adapt to external factors like climate change and water scarcity, which is determined by a range of internal factors (Smit and Wandel, 2006, Füssel 2006).

The following list presents (1) classic aspects of adaptive capacities (Rancoli, et al. 2001, Keil et al. 2005, Voss 2008 and Greenhill et al. 2009), (2) its function in an adaptation process, and (3) the current state of the capacity with the farmers' community in Roodasht.

Table 4 - 1: Aspects of adaptive capacity in Roodasht.

Adaptive Capacity	Function in adaptation process	Current state of capacity in Roodasht
Economic Resources	Empowers farmers to sustain livelihoods under water scarce conditions and allows them to invest in, and sustain adapted agricultural production or alternative income activities.	Economic Resources and investment capacity of farmers in Roodasht degraded heavily over the past decade. Economic resources, particularly of small farmers, can be considered as low in Roodasht.
Collaborative Networks	Required to conduct cooperative management or collaborative initiatives such as functional cooperative companies which facilitate for example modernization of agriculture, increasing economic productivity, income diversification as well as participation in regional planning.	Collaborative networks are present mainly as informal networks in Roodasht. Only few functional and powerful formalized cooperative companies could be found, which enable farmers to undertake organize collaborative initiatives and to follow common interests (e.g. land defragmentation, shared equipment).
Knowledge and Information	Key factor to understand the exposure to a certain pressure and to develop adaptation measures towards this pressure.	Knowledge and information of farmers is to a large extend limited to traditional know-how and information from small informal networks. Targeted information and training on adaptation strategies towards water scarcity are not present in Roodasht.
Infrastructure and Technology	Requirement to change traditional customary forms of agriculture to modern water efficient and income generating agriculture, or other forms of sustainable land management and income generation.	Availability of adapted technologies and necessary infrastructure to adapt livelihood strategies of farmers towards sustainable land management measures is not sufficiently present in Roodasht.

As presented in Table 4 - 1 the capacity of the majority of farmers in Roodasht to adapt to water scarce conditions can be considered low. Nevertheless in times of increasing pressure on farmers' livelihoods by the past decade's water scarcity, the pressure to develop adapted problem solutions is increasing.

Few successful examples of adaptation to water scarcity can be found in Roodasht region of which two are highlighted in the following.

Ghurtan Village example

There are about 220 farmers living in the three villages, Ghurtan, Balan, and Abolmaali in the east of Roodasth irrigation network. In former times, their water productivity and technical efficiency was low since their plots have been fragmented in small parcels over a large area. Every farmer owned their individual farming equipment. In general, production costs have been high and yields rather low generating only small incomes for farmers' households.

In a motion of collaborative action, a formal cooperative company has been established in 2006 out of a strong collaborative network amongst local farmers. The formal goal of the cooperative company was to consolidate fragmented lands in order to increase the quality of this natural resource. It was also intended to increase the access to modern farming equipment by collective ownership. Enough knowledge and information have been present within the cooperative company to maintain a trustful and productive environment and to access governmental funding for implementing the cooperative structure in the framework of an equipping and modernization plan supported by Isfahan Agricultural Organization.

With participation of all members, the cooperative company (1) converted 1.480 parcels to 280 parcels on about 750 ha, (2) lined 26 km of irrigation channels and adapted their irrigation method to increase water efficiency and (3) acquired modern farming equipment shared amongst its members. With these approaches, crop productivity was increased from 3.5 tons/ha to 8 tons/ha while production costs decreased (for example seed requirements for wheat from 350 kg/ha to 180 kg/ha).

Husbandry commodity chains example

Due to water scarcity and diminished economic resources in recent years, more than 50% of the local small scale livestock husbandries in Roodasht sold their livestock. Having sufficient knowledge and information on the availability and possibility of required infrastructure and technology, have persuaded 360 farmers in Bonroud district two years ago to take the first steps in funding and establishing a formal cooperative company for implementing a Livestock Production Chains Management Plant. The goal of the plant is to (1) provide feed for livestock,

(2) to process dairy products and (3) to process pack and marked meat. Based on the statement of the head of the cooperative, the trust and a strong collaborative network among the farmers have been playing a key role in planning this project. Funding for the intended plant is secured by about 180 B IRR, provided by farmers (15%) and agricultural organization (85%).

5 Detailed description of vulnerability factors

Based on the adapted analytical framework for the vulnerability analysis of local farmers, four major classifications of vulnerability factors have been considered. The detailed description of these factors is presented in this chapter structured according to the main classes:

- Internal socio-economic factors refers to characteristic of the local farmer community (chapter 5.1);
- External socio-economic factors show characteristics of influential socio-economic conditions (chapter 5.2);
- Internal biophysical factors include biophysical, technical and natural properties of Roodasht area and local farmers (chapter 5.3);
- External biophysical factors show characteristic of environmental based hazards which the Roodasht area is exposed to (chapter 5.4).

5.1 Internal socio-economic factors

As internal socio-economic factors we consider income generating activities, household economic resources, knowledge and information and social capital of farmers. These are factors which could impact the ability of the farmers to cope with the effects of water scarce conditions. These four different factors are discussed in detail in the following sub-chapters.

5.1.1 Income generating activities

Non-farm income opportunities in Roodasht are rare and farmers mostly rely on income generating farming which causes significant cuts in income under water scarce conditions. This creates a desperate situation for farmers, often leaving them with no other option than to abandon farming and to migrate to cities.

Farmers in Roodasht origin mainly from local farming families and operate according to handed-down skills and knowledge on farming (chapter 5.1.3). The livelihoods of 3/4 of the interviewed farmers are entirely dependent on income generating farming.[2] For farmers with alternative sources of income, farming still accounts for more than 50% of the household income. Consequently, during water scarcity and as they could not farm, they suffered from adverse conditions regarding their livelihood.

2 Farmers state to earn gross around 180-60 M IRR (4.500-1.500€) per ha and year.

Options for income diversification through working in non-farm occupations as in local manufactories, processing facilities, industry or tourism are rare in Roodasht, due to the absence of such facilities and limited formal education of farmers (chapter5.3.7,5.1.3). Farmers who do non-farming activities, particularly younger household members, usually work as building workers or drivers in the city.[3] Nevertheless these jobs are mainly seasonal occupations and imply low long term income stability.

Due to severe cuts in income through farming during the past water scarce decade and the restricted diversification of income opportunities in the region, migration to cities for finding a new job is a way of sustaining livelihood. However it becomes another challenge for smallholders and farmers with limited resources to cope with the higher cost of living in cities.

Meanwhile, some of the farmers, particularly older ones, stated that they had worked on their lands for most of their lives and thus are not willing to leave their land and migrate to cities or to work for another person.

5.1.2 Household economic resources

Under water scarce conditions with cut income from farming, household economic resources of farmers deplete over time. In this situation, farmers are highly dependent on governmental financial support, loans and cash borrowing for agricultural activities sustaining their livelihoods.

Diminished agricultural incomes, financial burden of loans and debts as well as limited liquid assets and heavy inflation make farmers prone to poverty and cause a lack of investment capacity to fund modern, adapted agricultural production systems or alternative non-farming activities.

The majority of the interviewees stated that their household economic capital is mainly composed of (1) income from farming activities, (2) limited financial subsides by the government or insurances during drought, as well as (3) liquid assets like their land, farming equipment and livestock.

Water scarce conditions with depressed agricultural activities (chapter 5.3.4) cause farmers to experience sensitive cuts in household income (chapter 5.1.1). At the same time heavy countrywide inflation increased costs of living. As primary coping mechanism towards reduced household income farmers consumed their savings in the successive dry years. Furthermore farmers receive some financial support from the government as well as minor compensation

3 There were two among farmers who worked with their tractors on the land of other farmers. Only one of the interviewees stated that he works as a public school administrative with an annual salary around 80 M IRR (2000 euro), which helped him to sustain his household livelihood effectively in time of water shortage.

from agricultural insurances which helps them to sustain their basic livelihood needs during water scarce conditions (chapter 5.2.3).

Liquid assets like land, farming equipment and livestock describe household economic capital in form of owned objects, which may be sold when cash is needed.

Considering land ownership, apart from one farmer stating that he has no land, all of the farmers are landowners. Regarding the size of the lands, the majority of the interviewees were smallholder farmers with fewer than 5 ha land. In normal years with water availability, about one third of the interviewed farmers rent lands on which they work as a partner and receive parts of the net income. Most of the farmers noted that the size of their lands hasn't changed in the last ten years. In order to generate income some farmers long to sell a part of their lands, also since the lack of enough irrigation water doesn't allow them to cultivate all of it. However, they state that there is a weak market for land sales in this region which is even more depressed in dry years and by the uncertainty on future development of water availability in Roodasht. Thus, lands cannot serve as a liquid asset under water scarce conditions.

Regarding farming equipment ownership, greater numbers of the interviewed farmers have their proper equipment including agricultural implements and tractors, but all of them rent combines. The investment in equipment is however generally low due to 1) the limited household economic capital, 2) an uncertain future development in the region and 3) lack of financial support from the government (chapter5.2.3). However, in comparison with land, agricultural equipment has more potential to be a liquid asset even under conditions of high water stress and there were farmers among interviewees, who sold their equipment to compensate for their decreased income and sustain their livelihood.

Livestock is another important asset for farmers in Roodasht. Around 1/3 of the interviewees stated that they own livestock. However, water shortage impedes farmers from providing the necessary forage for their livestock from their lands and raises production costs of keeping animals. Due to increased production cost and dropping prices of the instable livestock market, many livestock keepers sold their whole livestock during the past years and can no further liquidize this asset. (Chapter 5.3.4).

As stated by the majority of the farmers, since most of the household´s savings has been spent to compensate for the lack of stable farming income, they don't dispose of sufficient economic capital to sustain and enhance their farming systems. As a consequence, taking formal loans from the agricultural bank "Bank Keshavarzi" is a way to provide capital for sustaining and investment in agricultural activities. However, farmers stated that these kinds of loans were not sufficient and had too high interest rates for investment in developing modern agricultural systems. Meanwhile, due to depressed income in dry years and the poor loan repay condition with typical interest rates of 7 - 21% and payback times of 5 years, as well as due to the negative effects of high inflation, farmers are not able to repay their loans which has caused heavy financial burdens of loan debts.

The above mentioned conditions of (1) decreased farming income, (2) the loss of household savings, (3) the limited governmental supports, (4) high inflation rate, and (5) heavy financial burdens for loan debts cause:

- Livelihood insecurity and the risk of poverty of farmers, not being able to cope with their piled up financial obligations;
- A lack of investment capacity of farmers in Roodasht to fund modernization and development of adapted agricultural system and equipment or other non-farming activities;
- Risk of abandoning agriculture and migration to cities.

5.1.3 Knowledge and information

Agricultural activities are the traditional occupation of local people in Roodasht region. Knowledge of farmer households is thus focused on farming; deeply rooted in everyday practices, concrete experience and information and skills acquired over time. Information on agricultural practices are furthermore attained through local institutions such as agricultural service centers and exchange with successful pioneer farmers in their community.

Meanwhile, the practical knowledge of the farmers shape their environmental concerns and awareness. Through concrete and every day farming practices, they slowly realize that how environmental problems such as drying out of Gav Khuni wetland, soil salinization, and desertification have been impacting their farming activities as well as their livelihood.

The majority of the farmers stated that they have been working as farmers since childhood. Know-how is not necessarily related to their formal education, as most of the interviewees had elementary school education and only one of them disposes of a bachelor degree. By the majority, the interviewees don't perceive themselves as sufficiently skilled to changing their income activities and to following other occupations as traditional farming. However, young farmers perceive themselves as more capable and willing to take up knowledge and information to change and adapt their agricultural practice or cope with a different type of income generating activity.

To receive specific farming information that goes beyond their own practical experiences e.g. on new techniques for land management or irrigation, or to improve agricultural practices, farmers use the services by rural agricultural service centers and consulting companies through attending in training workshops or bilateral talks. Furthermore, communicating with farmers and especially neighbors plays an important role for access to information. Most of the interviewees stated that they get in touch with more experienced pioneer farmers in their community to enhance their on-farm knowledge. In general it could be observed that uptake of alternative or innovative forms of modern or adapted agriculture was relatively low in Roodasht.

General access to information is particularly gained through (1) local TV and radio, (2) farmers representatives or agricultural service centers, (3) other farmers and people in their community (chapter5.1.4), as well as through (4) religious persons from their mosque community. The use of new media is however limited and only two of the farmers stated that they get information on the internet and virtual social networks. Information about times of water availability is also given through representatives of the farmers who communicate with Mirab, Agricultural Service Centers and Isfahan Regional Water Company on this issue.

Meanwhile, according to the interviews, practical knowledge of farmers acquired through their concrete farming practices shape their environmental concerns and awareness. For instance, some of the farmers explained that the decrease in humidity caused by drying out of the Gav Khuni wetland negatively affected on their yield. From farmers' point of views, water scarcity is the main problem which threatens their livelihood to the extent that it changes their environment negatively.

5.1.4 Social capital

Water scarcity triggers degradation of trust between farmers and governmental institutions. A certain degree of resignation amongst farmers for not being able to participate in decision making can be observed.

Meanwhile, informal social networks like family or religious communities play an important role in farmers' every day live and during times of crisis. But apparently, structuring and formalizing these networks in form of successful cooperatives or collaborative initiative to follow common interests is happening only rarely in the region.

Two major aspects of social capital are (1) trust amongst farmers as well as between farmers, (governmental) institutions and other stakeholders and (2) informal and formal social networks. It shapes the way how farmers respond individually or collectively to risks associated with water scarcity.

Among the majority of interviewed farmers, the level of trust in government organizations and also farmers' institutions is dependent on the perceived performance of the organizations in servicing farmers to cope with water scarcity. Among a range of organizations considered in the interviews, trust in the Isfahan Regional Water Company and Mirab is very low since reduced water availability in Roodasht is mainly attributed to their actions (chapter 5.2.2). Meanwhile, medium trust was expressed in agricultural organizations including Agricultural Service Centers. Trust in the representative of Imam was the highest and most of the interviewees stated that representatives of the Imam from rural mosque communities are important, trustworthy contact persons for farmers to speak about their problems as well as mediators for social conflicts. Religious representatives are considered as influential on authorities and decision makers.

Non-organized and informal social networks of for example family, neighbor and religious communities play a major role in farmers' everyday life and enjoy a high trust by farmers. These informal networks become particularly important in times of crisis, when farmer households need spiritual and material support in terms of borrowing money or sharing resources to cover basic household needs.

However, organized or even formalized social networks enabling a community of farmers to take collaborative actions for achieving common goals are rather rare in Roodasht. Instead, with the information from the interviews in mind, it could be concluded that (1) a perceived incapability of influencing decisions on water distribution (chapter 5.2.2) and (2) the high pressure on household economic resources and risk of poverty in the past years (chapter 5.1.2) created a certain degree of frustration, insecurity and general mistrust amongst farmers' households. This even corrupts the relationship amongst certain groups of farmers, making it particularly difficult to work together in a group of farmers successfully for common interests. The described setting might be one reason formal cooperative companies and associations for actions like land defragmentation or setting up commodity chains is rarely successful in Roodasht.

According to the law for cooperative companies which was approved in 1970s, in order to meet common needs and enhance the socio-economic conditions of the members, collaboration and self-helping of the members should be agreed principles for establishing a cooperative company (National parliament law, 1970)

However, studies show that the majority of cooperative companies in Iran have failed to construct a functional collaboration. The main reason are (1) mistrust amongst the members (2) inefficient human and financial resource management (3) the lack of skillful experts (4) the lack of adequate relationships and network with governmental organizations and rural communities, (5) absence of necessary equipment and facilities and (6) the lack of credits and vital agricultural inputs (Azkia, 1992, Azkia, Ghafari,2013). Figures on the whole Zayandeh-Rud basin show that with less than 6% agricultural exploitations with cooperative company are rather low compared to 94% individual farmers operation (Yekom, 2012). However, in the Roodasht area, there are 8 Rural Cooperative Company. 6 of them are currently active and more that 80% of the farmers are members of these companies in the region. The main duties of current Rural Cooperative Companies is to provide and distribute agricultural inputs and rural requirement like energy, water and financial support as well as collecting and selling rural and agricultural products.

Meanwhile, there are 6 active Rural Production Cooperative Companies in the region with around 3000 members and 16100 ha land covered. The main duties of Rural Production Cooperative Company are: (1) land defragmentation, (2) implementation of agricultural modernization plans, (3) provide farming requirement for members and supply, provide, distribute and selling of agricultural inputs.

However, disregarding the formal establishment of these institutions, the cooperative companies are facing several challenges in the region. In general operation and performance of these cooperative companies is highly dependent on the collaborative efforts of all members, which is stated by farmers and experts to be unsatisfactory. Besides decreasing governmental financial supports, problems with inefficient management structure and absence of skilled human resources, the lack of efficient farmers' collaboration is observed as one of the main problems of cooperative companies. Due to the loss of social trusts among the farmers and growing social conflicts in rural areas the potential for collaborative actions are becoming decreased.

Meanwhile, local participation and involvement in process of implementing agricultural plans and programs is influenced by the characteristic of social networks in local community. For instance, the 3rd and 4th level of irrigation networks have been successfully developed with participation of local farmers in rural areas where farmers could reach a collaborative approach for action (chapter 5.3.7).

With regard to common approaches to lobbying for water rights and influencing decision making on provincial or national level, a resigned sense of inability to participate in decision making was observed amongst farmers (chapter 5.2.2 and 5.2.2). Regarding this issue, most of the interviewees stated that organizations such as Agricultural Trade Union or environmental NGOs are not sufficiently influential to negotiate with authorities about farmers' needs. The great mistrust towards water authorities also supports this resignation and unbelief in possibilities for participation in decision making.

5.2 External socio-economic factors

External socio-economic factors could influence farmer´s vulnerability to water scarcity and its impact on environment. These include water rights, decision making on water on water distribution and support programs and insurance. These three factors will be elaborated in following.

5.2.1 Water rights

There are different water right holders in the basin. A historic development of water distribution in Zayandeh-Rud basin and national water right legalizations lead to existence of different types of entitlements, farmers may hold. Currently a customary water right principle is rehabilitated for distributing water within a region, since modern water rights approved by the government could not be sustained during water scarce conditions. Water allocation on basin scale appears to not happen entirely according to water rights, but other criteria.

This leads to uncertainty on water rights and entitlements amongst farmers.

Volumetric environmental water rights for the Gav Khuni wetland have been established in recent years but have not been enforced yet. Before that, natural resources have been the loser of the intense competition for scarce water resources that happened after changes on natural flow and allocation system in the basin, and even today water supply to Gav Khuni is fragile.

Water right holders in the Zayandeh-Rud basin are urban users, industry, agriculture and environment. In Roodasht, however, agriculture and environment with the Gav Khuni wetland are the two major water users. In Zayandeh-Rud basin, traditional distribution of water is based on Sheikh Bahaei Tomar share scroll, which reaches back to the Safavid Dynasty (1571-1629) and includes time and location of water distribution (Mehryar, 1999). The scroll is based on a crop calendar and share of available water, with two periods of water supply, (1) for agricultural purposes during 165 days (June 2th until November 14th); and (2) freely water withdrawal and water for the environment during 200 days (November 14th until June 2th).

According to Sheikh Bahaei, the Zayandeh-Rud river basin has 33 major shares, and for each major share, five days extraction right of the natural stream flow[4] of the Zayandeh-Rud River was determined. The major shares split to sub-regions with regards to local and regional specifics, the number of villages, traditional networks, ownership of lands and vast farming areas. The share scroll entitles Roodasht for 6 major shares of natural river flow, equivalent to totally 30

4 In historic travel reports the Zayandeh-Rud river is described as temporarily dry also before construction of the dam (Hoeltzer, E., 1975)

days of water extraction, roughly between June 2th and June 16th, as well as October 30th and November 14th.

In the younger history, socio-economic development, population growth, agricultural expansion, urbanization and industrialization have led to increasing water demand in the basin exceeding water availability. The high water demand has pushed the government to increase control over water resources by constructing the Zayandeh-Rud dam, inter-basin water transfers and improvement of water infrastructures. All these developments have changed the natural regime of the Zayandeh-Rud River in terms of volumetric as well as temporal water availability. Consequently, the historic Sheikh Bahaei share scroll has been superimposed by a range of political acts in the past.

With the enactment of the Iran Water Law and The Manner of Water Nationalization in 1968 all water resources had been declared as public property that the government may distribute according to public interests. Therefore, responsibility for maintaining infrastructure and supervision of water exploitation have been entrusted to the government. This was the legal fundament for the Water Equitably Distribution Law adapted in 1983 which formalized customary water entitlements as water rights, by (Article 18 – Note 1):

“Water right means the right of use of that water which has been specified and registered in records or ownership documents or orders of courts or other legal documents in the favor of the owners before the date of approval of this law”.

As an effect, farmers have been able to prove their water rights (HAGHABE) in the Zanyandeh Rud river basin according to: (1) Records or ownership documents that are ascribed to the historic Sheikh Bahaei share scroll; and (2) orders of courts or legal documents that are non-ascribed to the share scroll.

The priority of the HAGHABE water right was underlined later by the 13th meeting of the Supreme Council of Water that declared that the natural stream flow of river and first Kuhrang tunnel belongs to water right holders (HAGHABE) and environmental water requirement of the Zayandeh-Rud river and the Gav Khuni wetland. Furthermore, allocation of available water resources in dry years shall be decreased relatively by considering the share of water right holders.

However, after inauguration of the Zayandeh-Rud dam in 1970, control of the river stream removed the historic rationality of distributing water in time shares from the natural stream flow. Therefore, the Water Equitably Distribution Law suggested in Article 26 to calculating the volumetric amount of water rights by the following approach:

“According to the information by the Ministry of Agriculture on water requirement of crops in each area, for licensing water exploitation, the Energy Ministry is obliged to determine the amount of water consumption by considering the crop types and areas”.

Based on experts’ statements, however, after approving this article, the Ministry of Agriculture provided a document on the water demand of crops for each area, but the quantification of water right in volumetric means has never been made official. It is still a subject of ongoing discussions, what volumetric amount of water from the Zayandeh-Rud river should be allocated amongst water right holders, recently developed agricultural areas and how new water users in the urban and industrial sector should be considered, in particular during dry periods with low water availability.

The situation is particularly complicated since with the second and third national development plan, the government decided to develop modern irrigation networks in cooperation with the Agricultural Bank (Keshavarzi) with financial commitment of farmers which got rewarded with new water entitlement in form of water subscriptions (HAGHE ESHTERAKI). Important is that water subscription were documented by contracts between farmers and the Ministry of Energy in Zayandeh-Rud basin with the condition that water is allocated only allocated if enough water is available.

From the authors’ point of view, the historical evolution of water entitlements challenges water managers in the basin with two main problems amplified during dry years:

- The transition of water distribution patterns based on the natural stream flow to widely accepted and transparent water distribution patterns respecting control of the stream flow (by dam and inter-basin water transfer) did not succeed;
- Too many water entitlements for different stakeholders have been distributed over the decades, exceeding water availability (at least in dry years).
- As an effect a, for the authors (and many Iranian experts), in-transparent customary and rather reactive manner of water distribution was established. Currently the lawful and practiced water entitlements of farmers are unclear to farmers and most relevant experts in Roodasht. This cause a feeling of being deprived from their proper right, great uncertainty on future water availability and allocation and social unrest amongst farmers.

Apparently water distribution within an irrigation networks is practiced customary, loosely based on the traditional Sheikh Bahaei scroll (even though its outdated) which seems to be the most accepted rule of water distribution amongst farmers. On basin scale, however, water distribution seems to not being practiced according to water rights anymore but according to other criteria (chapter 5.2.2). In Roodasht, the conflict amongst water right holders (Haghabe) and Haghe Eshteraki holders is no major factor, because: (1) the distributed amount of Haghe Eshteraki is relatively low to actual water right in the region (approximately 20% of allocated surface water in Roodasht), and (2) most of the Haghe Eshteraki holders are farmers who have also water right.

Under water scarce conditions, the Gav Khuni wetland and the natural Zayandeh-Rud River have been suffering under the competition of different water users for the scarce resource. Nevertheless, the government has recently made rules and regulations on water allocation in terms of an environmental water right. However, water supply to Gav Khuni wetland is strongly dependent on the political agenda of decision making on water allocation (chapter 5.2.2).

5.2.2 Decision making on water distribution

Decisions on water distribution in the Zayandeh-Rud basin are being made centrally by the Coordinating Council for Integrated Management of Water Resources in Zayandeh-Rud Basin, which has been established in 2014 by the Supreme Council of Water. Under water scarce conditions of the past decade, water distribution is not happening entirely on the basis of water rights anymore but also according to further economic-political criteria.

Due to little political and economic power of the Roodasht region, little participation of farmers in the decision making and high pressure on limited water resources, surface water allocation to Roodasht got reduced and varied in the past years. As an effect, farmers feel deprived from their water rights, experience uncertainty of future water allocation and develop mistrust of the government as well as social conflicts.

Environmental water rights have been strengthened with the political agenda of the past years and the execution could be realized by the support of environmental advocates like NGOs.

Decision making structure

Decision making on water distribution in the Zayandeh-Rud basin is controlled by five main decision making bodies on different levels.

On national level, the Supreme Council of Water is the highest decision making entity. It is chaired by the President of Iran and includes members on national level from the (1) Ministry of Energy, (2) Ministries of Agriculture, (3) Ministry of Interior, (4) Ministry of Industries and Mines, (5) Department of Environment, (5) Management and Planning Organization etc. The Supreme Council of Water is deciding on the structure of water distribution on basin scale to different stakeholders, regions and inter-basin water transfer by setting priorities.

On basin scale, the Coordinating Council for Integrated Management of Water Resources in Zayandeh-Rud Basin is headed by the Ministry of Energy and has been established recently in 2014. It is supposed to improve the collaboration and coordination among the main stakeholders in different sectors and provinces. All authorities in the three involved provinces have to obey the decisions on water distribution made by the Coordinating Council for Integrated Management of Zayandeh-Rud Basin.

On the national and provincial scale, the Iran Water Resources Management Company (an agency of the Ministry of Energy) is responsible for enforcing policies and laws related to water resources. The Isfahan Regional Water Company in Isfahan is the provincial unit of the Iran Water Resources Management Company. The Iran Water Resources Management Company and Isfahan Regional Water Company have made decisions on water distribution on basin and provincial level before establishment of the Coordinating Council in 2014. However, today the Water Resources Management Company and Regional Water Company are responsible for implementing decisions on water distribution that have made by Coordinating Council for Integrated Management of Zayandeh-Rud Basin.

On provincial scale the Five-member Water Board Council is headed by the (1) Governor General of Isfahan and is composed of members from (2) the Isfahan Agricultural Organization, (3) Isfahan Regional Water Company Isfahan, (4) Mirab Company as well as a representative of the (5) Agricultural Trade Union. The Five-member Water Board Council is advising the Coordinating Council for Integrated Management of Zayandeh-Rud Basin and deciding on times of water release and supply to stakeholder and regions.

Criteria for decision making

During interviews with experts, it was found that water distribution on the basin scale seems to be determined based on the following criteria:

- Available water resources stored in Zayandeh-Rud dam and an estimation if inlet water to the dam from its catchment
- Water demand of different stakeholders and their water entitlements;
- Vulnerability and strategic importance of different sectors (e.g. Drinking water vs. irrigation water);
- Vulnerability and economic importance of different regions (e.g. upstream Zayandeh-Rud with industry and many water sensitive orchards vs. downstream with no industry and mainly grain cultivation);

- Political and economic power of stakeholder and regions to influence decision making, also social unrest as a pressure to be considered in decision making could be observed;
- Geopolitical importance of inter-basin water transfer.

Decisions on water distribution

During the past decade with water scarcity, available water resources stored in Zayandeh-Rud dam have not been sufficient to fulfill all formally allocated water rights in the basin.

The urban and industrial sector has been prioritized for water allocation by the Supreme Council of Water, leaving only very little water left for farming purposes. Furthermore the upstream region of the Zayandeh-Rud basin received apparently more water than the downstream region which is assumed by experts to have happened due to higher political and economic power and vulnerable orchard agriculture of this region. The environment of the Gav Khuni wetland did not receive any water during water scarcity.

With the change of the presidency in Iran but also social unrest of farmers and growing environmental awareness of people, the political agenda on water distribution of the Supreme Water Council changed. According to the decisions made in the 13th meeting of the supreme water council in 2014, the natural water of Zayandeh-Rud river should be only allocated to water right holders and also to environmental water right of Gav Khuni wetland and Zayandeh-Rud River. The industry and urban sectors should not further expand their water usage. Furthermore, in case of drought and water scarce conditions, if other sectors need to receive water they must compensate water right holders.

Although by the new priorities on water distribution, the environment has been considered as the third priority for water supply in this region, it took negotiations and lobbying of regional environmental stakeholders and local environmental NGOs to finally transfer water to the Gav Khuni wetland in 2015/2016.

Perspectives of farmers in Roodasht on decision making

In the past water scarce years, only little surface water with a (1) strong seasonal variation and (2) fluctuation over the years was allocated to Roodasht irrigation network (chapter5.3.2). The allocation of irrigation water did not meet the expectations of farmers referring to their formal water rights (chapter5.2.1).

During interviews with farmers and experts in the Roodasht area, the following issues on the current process of decision making on water distribution where brought forward:

- Formally decision making on water distribution was centralized with the Iran Water Resources Management on national level and Regional Water Companies on provincial level, supported by the provincial Five-member Water Board Council with only little chances for participation for local farmers (only Agricultural Trade Union);
- Since 2014 the Coordinating Council for Integrated Management of Water Resources in Zayandeh-Rud Basin is responsible for decision making, with more opportunities for participation of farmers and other stakeholder groups. Nevertheless it was found that farmers in Roodasht are not aware of this recent development and opportunities for participation in decision making;
- From a farmers' perspective the process of decision making and criteria for water allocation are not transparent and unknown;
- Farmers do not understand nor approve decisions on water allocation;
- Parallel institutions on local level which may be able, or even present themselves as capable to influence decision making are confusing for farmers;
- The Agricultural Trade Union is the only formal non-governmental representative of farmers participating in decision making on provincial level. Though there is a notion that adequate authorization and legal support are missing for the Trade Union. Furthermore local cooperative companies are not politically active and don't lobby in decision making;
- In the Five-member Water Board council, no representatives of the environmental sector are apparent;
- Political and economic power and lobbying seem to be crucial to be considered in decision making process. Both of these aspects are weak in Roodasht, making the region inferior in the competition with the upstream region of the Zayandeh-Rud or other sectors like industry.

The mentioned characteristics of, and farmers perception on, decision making on water distribution results in (1) a perception of exclusion and feeling of being deprived from proper rights in Roodasht, (2) a great uncertainty on future water distribution to the region as well as (3) mistrust and conflicts between farmers and government.

5.2.3 Support programs and insurances

Majority of current support programs and insurances on national or provincial level are not adapted to support farmers or vulnerable regions effectively in water scarce conditions.

Available programs secure farmers minimum livelihoods by poverty relieve, but do not enable farmers to sustain their livelihood situation or adapt or sustain their agricultural system during water scarcity.

Credits

The agricultural bank (Bank Keshavarzi) is a government-owned bank and the largest single source of agricultural credit in Iran and also in Roodasht region. Its mission is amongst other duties, to allot and distribute in a close coordination with Isfahan Agricultural Organization governmental credits such as loans, civil funds, and financial aids as well as some programs as for example farm modernization programs.

Figure 5 - 1 shows the volumes of credits (inflation corrected) given from the agricultural bank in Roodasht region between 2008 and 2014 as well as volumes of surface water distributed to the region. The high volumes of credits allocated in 2011 can be explained by the allocation of a large budget to the agricultural bank on national scale by the National Development Fund of Iran in 2011. Besides 2011, not a meaningful correlation between the surface water diverted and amount of given credits to Roodasht region can be observed.

In general it can be concluded that the amount of credits and loans, the return period, and the interest rates by the agricultural bank in Roodasht region have not be adapted and balanced with the water scarce conditions. No relive or "compensation" programs by the bank for intense crop losses in the farming sector during water scarce conditions could be identified.

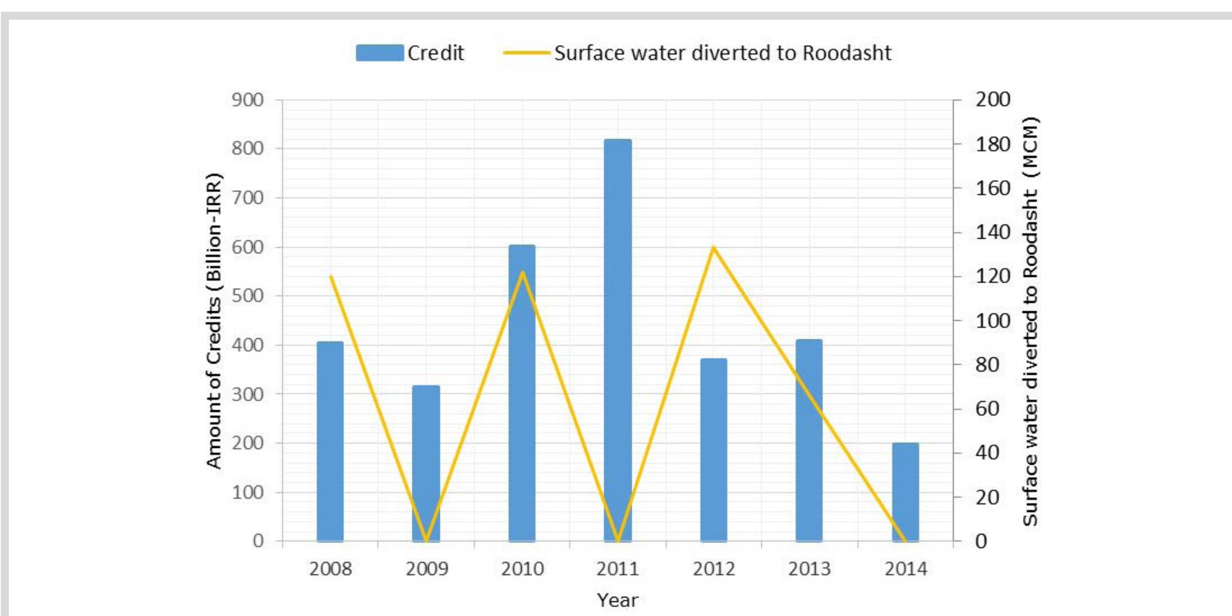

Figure 5 - 1: Time series of volume of credits distributed in Roodasht region and surface water diverted to Roodasht (inflation corrected data from the Isfahan Bank Keshavarzi and Isfahan Regional Water Company).

Governmental financial supports

Regarding governmental financial support program, only few specific and adapted financial support programs for the Roodasht region could be identified. Some limited aids have been paid for crop losses in Roodasht in the past dry years by government, since water scarcity is not a compensation criterion. Farmers affected by water scarcity received a single payment of 5 million IRR (120 euro) per person from the government in 2014.

Besides of this there is a basic monthly financial support of low income Iranian citizen of 455.000 IRR (12 euro) per person (information from 2015).

Imam Khomeini Relive Fund

The Imam Khomeini Relief Foundation (IKRF) is a national, non-profitable and welfare Foundation, supporting 2.300 needy families financially in Roodasht region. The number of rural family household that receive financial aid have increased according to the Foundation by 50% in last five years due to successive water scarce conditions. Beneficiaries receive a monthly payment of around 800.000 IRR and have access to a limited medical and health service. Based on the experts' statement, the IKRF budget is limited and couldn't take it to account as a supportive fund for needy farmers.

Social security insurance

Social security insurance including health insurance covers the medical expenses of the farmer households and it is based on paying premium by farmers. It is a general type of social security insurance in Iran which faces the problem of inefficiency to cover the high costs related to health and retirement in Iran.

In Roodasht, however, farmers who took this type of social security insurance were not satisfied by the insurance conditions. The Agricultural Trade Union in Isfahan province, as a pioneer agency in the country has been lobbying with policy makers to facilitate the farmers and agricultural employers' social insurance. The efforts yielded in a law in 2015 that gives about 20% exemption on payment for social security for local farmers. Apparently there are few additional charity centers in Isfahan that allocate funds to farmers, mainly for their medical expenses.

Agricultural insurance

The Agricultural Insurance Fund was established aimed at supporting farmers and livestock producers incurring losses and damages in their products due to unexpected natural disasters. It guarantees operations in maintenance period (from planting to harvest) against risks such as floods, hail, fire, and drought. Nevertheless water scarcity is no compensation criteria which made the insurance for farmers in the past decade partly ineffective. Figure 5 - 2 shows that, the amount of given insurance compensation to Roodasht region by applying inflation rate has been decreased in past years. This shows that insurances are no mean for most of the farmers to compensate for crop loss in water scarce conditions. No adapted insurance programs for vulnerable regions like Roodasht in down reaches of Zayandeh-Rud basin could be found.

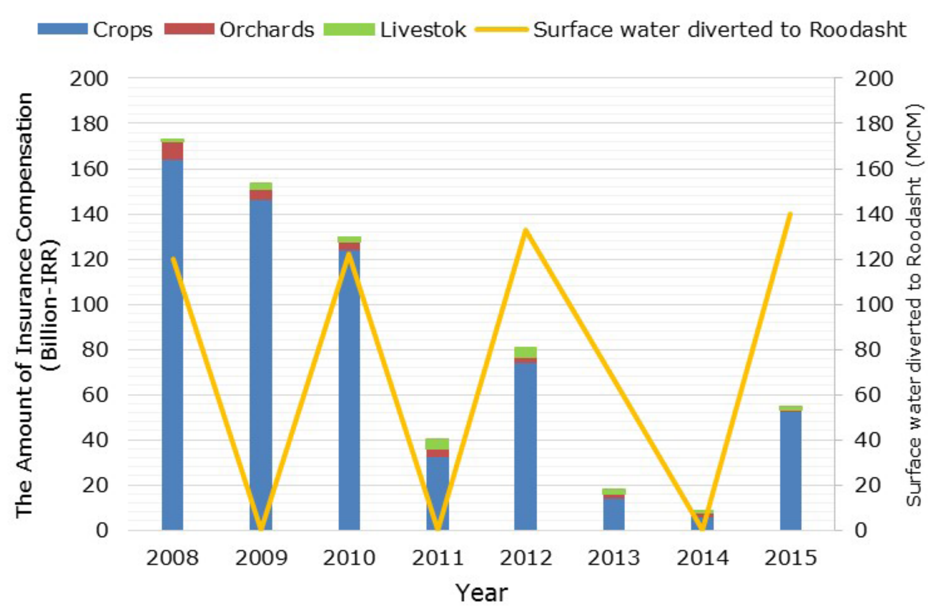

Figure 5 - 2: Time series amounts payed as insurances in Roodasht region and surface water diverted to Roodasht (inflation corrected data from the Isfahan Bank Keshavarzi and Isfahan Regional Water Company).

5.3 Internal biophysical factors

Internal biophysical factors refer to physical and technical characteristic and conditions of the farmers' community and area of Roodasht. These include soil quality, water access, technical conditions, farm products, agricultural practices, land use and infrastructure.

5.3.1 Soil quality

Soil in the region has a high clay content which is affiliated to risks like salinization and erosion particularly when dried out or fallow. Low organic carbon content, salinization and alkalinity of soils is a risk for agricultural productivity.

The main proportion of the Roodasht area is composed of soil type ESF25 (see Figure 5 - 3) according to a database on soil types of Isfahan County (source: IWRM Office). The soil is characterized by 4 layers[5] of clay loam and silty clay. The clay and silt content of the top layers in the whole area are relatively high with around 30 - 40% clay and approx. 45% silt. Clay and silt content increase by depth, whereas organic carbon content of the top soil is below 0.5% and decreases by depth. The soils are saline-alkaline.

It has to be noted that the presented information (soil database and map) are with more than 10 years of age partly outdated. Nevertheless it is the only readily available information for soil quality in Roodasht. According to experts there is a large quantity of new soil data with the Agricultural Research Center, Universities and other institutions, but these data are up to data not harmonized, merged and made available in new soil data bases or maps.

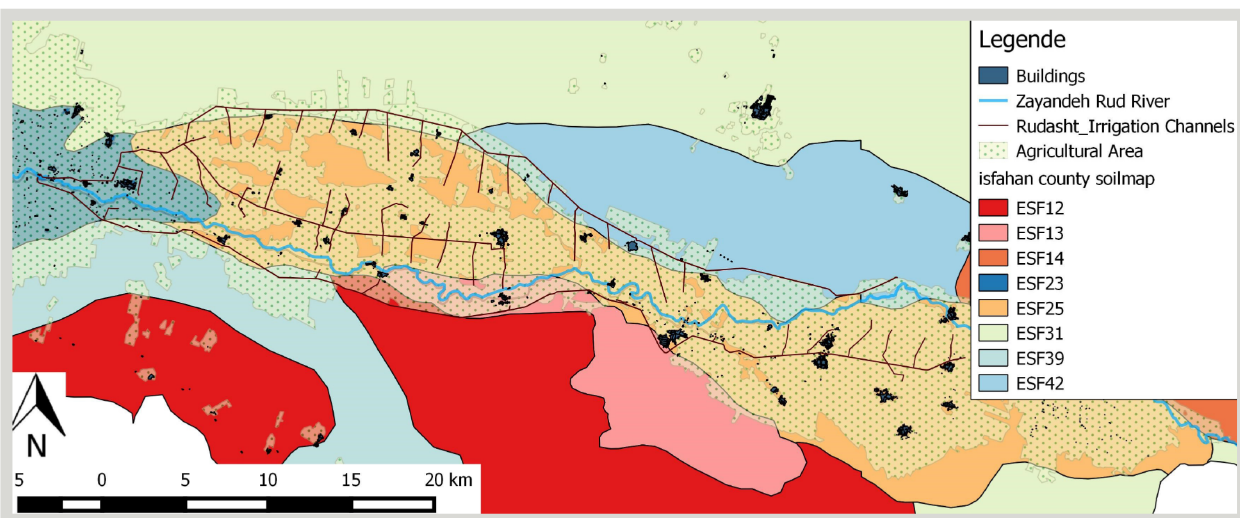

Figure 5 - 3: Soil types in the Roodasht area (source: Isfahan Regional Water Company).

Even though experts state that soil quality increased slightly in the past 20 years due to organic carbon enrichment by cultivation and irrigation with surface water, data from the database on soil types shows that salinity of the soil increases with its depth from 4 up to 11 dS/m. Salemi et al. (2000) and local experts report even higher salt concentrations of up to 14 dS/m for the Roodasht region. Salt potentially origin from (1) geological conditions of the alluvial plains of the Zayandeh-Rud river, (2) partly capillary rise from shallow, saline groundwater, (3) use of saline irrigation water and limited leaching (see chapter 5.3.2) and (4) high mineral fertilizer

5 The top layer is clay loam with 15% rock fragment and a soil organic carbon content of 0.4%. The given organic carbon of the topsoil equates to a humus content of approx. 0.65%. In 25 cm depth a silty clay loam layer with less rock fragment but similar soil organic carbon starts and is replaced in a depth of 70 cm by a silty clay layer with less rock and organic carbon fraction. From a depth of 120 cm there also is silty clay layer with even less sand but more clay and silt content and only 0.25% organic carbon and no rock fraction.

inputs (see chapter 5.3.5). Saline soils are expected to have an adverse impact on yields as presented in Figure 5 - 4. Detailed information on soil alkalinity and its effects on agricultural activities in Roodasht could not be found.

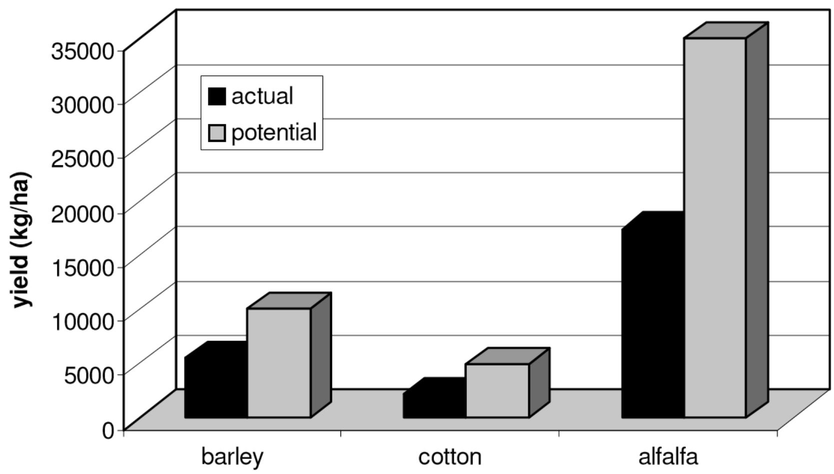

Figure 5 - 4: Yield gap of selected crops due to soil and water salinization in Roodasht Region (Salemi et al., 2000).

In general, besides of little organic carbon and high salt concentrations, the soil quality in the Roodasht region has a high agricultural potential. Nevertheless the following risks impacting on productivity are attached particularly to high clay content and soil salinization and alkalinity.

Low organic C content

- Very low humus content of the soil can reduce fertility and structural quality of soil.

High Clay content

- Risk of salinization and sodic soils with soil dispersion, clay platelet and aggregate swelling (poor soil structure);
- Risk of water logging, low aeration, drainage and poor root development;
- Risk of compaction by machinery;
- Risk of reducing availability of plant nutrients;
- High risk of water and wind erosion when soil is dry.

High salt and sodium ion content

- Risk of reduced agricultural productivity (see Figure 5 - 4),

- Risk of increase erodibility potential in terms of dispersion due to Sodium Ion (alkalinity) in topsoil (decrease in porosity, fertility and dispersity of soils particularly when not irrigated).

Furthermore an expert reports of dissemination of gypsum particles in the region due to wind erosion of traditional gypsum mines.

The chances and risks of local soil quality have been confirmed during farmer interviews, where most of farmers state that they are generally satisfied with the soil quality. Nevertheless the majority of farmers state that soil quality decreased in the past 10 years due to salinization, particularly by irrigation with saline groundwater which affects their productivity. A method to control salinization and alkalinity of soils is to have knowledge on groundwater quality and over irrigating fields when water resources are available to leach salt to lower soil horizons (see chapter 5.3.2). Also an elaborated drainage system on the field is perceived as important for soil management. Some farmers report erosion of soils and loss of natural vegetation cover in the past years. Furthermore the risk of drastically decreasing soil quality if a field is fallow for more than two years due to lack of irrigation water is reported by farmers.

5.3.2 Water access

Access to irrigation water resources can be distinguished in access to surface water and access to other water sources, particularly groundwater. Farmers in Roodasht mainly use both sources of these water sources. Furthermore natural precipitation is playing an important role for farmers for sustaining crops in between two irrigation periods. Nevertheless rainwater harvesting is not practiced by farmers in the region. As presented in chapter 5.4.1, natural precipitation in the Roodasht area is generally low (with less than 100 mm/a) and varying strongly over the years.

Surface water

Access to surface water is determined by water diversion to the Roodasht irrigation network, which is decided on by the Coordinating Council for Integrated Management of Zayandeh-Rud Basin and the 5 Member Water Board Council in dependency of water stocked in the Zayandeh-Rud dam and other criteria (chapter 5.2.2). Figure 5 - 5 shows the amount of available water in the Zayandeh-Rud dam, and water diverted to the Roodasht irrigation network in the period between 2006 and 2015. The data show that parallel to a downward trend of the water stock in the dam, surface water division to Roodasht irrigation network is decreasing and shows strong fluctuations with several dry years with no water supply at all.

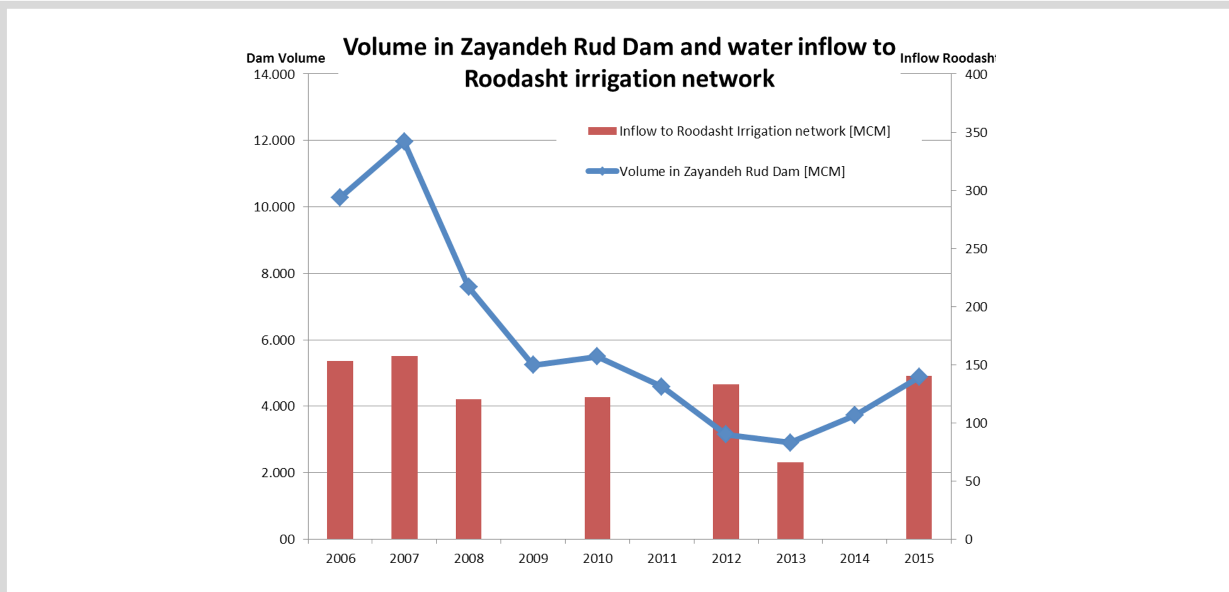

Figure 5 - 5: Time series on annual[6] water stock in the Zayandhe Rud dam and water supply to Roodasht irrigation network (source: Isfahan Regional Water Company).

Data on long term development of the surface water distribution to the downstream region of the Zayandeh-Rud from 1992 to 2012 shows that diversion of surface water has decreased with almost 50% extremely in Roodasht irrigation network, while the environmental flow in Zayandeh-Rud River close to Varzaneh decreased even by 90% (see Table 5 - 1). The reduced surface water availability is also observed further upstream in the Abshar irrigation network with more than 50% reduction of irrigation water and the Zayandeh-Rud River just downstream of Isfahan city (Choum Bridge) with 34% reduction of river flow.

Table 5 - 1: Long term development of surface water distribution, downstream region of Zayandeh-Rud (source: IWRM Office Isfahan, IKI Project Kick-off, 2015).

Registration time span	Pol-e-choum hydrometric gauge (Choum Bridge) average river flow [MCM/a]	Water diverted to Absahr irrigation network, average [MCM/a]	Water diverted to Roodasht irrigation network, average [MCM/a]	Varzaneh hydrometric gauge (Varzaneh) average river flow [MCM/a]
2002-1992	487	270	262	187
2002-2012	323	125	135	22
Reduction in time	%34	%54	%48	%88

6 A water year is presented with figures from September of the last year, until September of the given year. For example for a figure of the year 2015, data from September – December 2014 and January- September 2015 are presented.

Regarding timing of irrigation water availability, data from the Isfahan Regional Water Company shows that water is usually diverted to Roodasht irrigation network during two time periods: (1) between October and December, as well as between (1) March and June, whereas the later period has an overall higher water donation (see Table 5 - 2 and Figure 5 - 6).

Table 5 - 2: Surface water diversion in different month and different years[7] to Roodasht irrigation network (source: Isfahan Regional Water Company).

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
										Sep - Oct
■	■	■		■		■			■	Oct - Nov
■	■	■		■		■			■	Nov - Dec
						■				Dec - Jan
										Jan - Feb
	■								■	Feb - March
■	■	■		■		■			■	March - April
■	■	■		■		■	■		■	April - May
■	■	■		■		■	■		■	May - June
							■			June - July
										July - Aug
										Aug - Sep

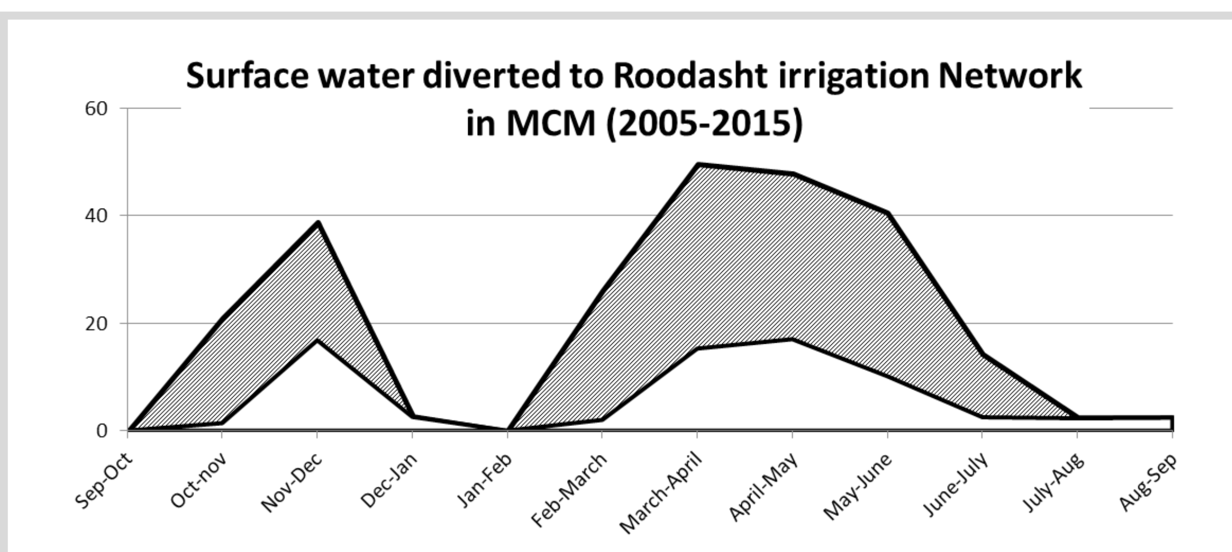

Figure 5 - 6: Monthly range of surface water diverted to Roodasht irrigation network in different month of the year. Years with no water distribution have not been considered in the figure (source: Isfahan Regional Water Company).

7 A water year is presented with figures from September of the last year, until September of the given year. For example for data of the year 2015, data from September – December 2014 and January- September 2015 are presented.

All interviewed farmers state to hold a water right which entitles them to receive a temporal share of irrigation water (time) from the network according to the Sheike Bahaei (HAGHABE) share principle. Two farmers in the upstream part of the region affirm to hold also water subscriptions (HAGHBE ESHTERAKI) in addition to their traditional water right (chapter 5.2.1). Some water right holders state to pay no fee and others annual fees with a variance in communicated fees. Farmers explain that the only way to increase the access to surface water is to rent agricultural lands with water rights attached or to "borrow" water rights from neighboring farmers.

Farmers state that they are generally satisfied with the quality of surface water, but that the uncertainty on water diversion to the Roodasht irrigation network implies insecurity on future development of the agricultural sector in the region (chapter 5.2.2). Agricultural experts state that little control on timing of water access in the irrigation network is a major restriction for optimizing irrigation efficiency and crop choice (see chapter 5.3.4).

Regarding quality of water, Droogers et al. (2000) report irrigation water quality of 2-6 dS m-1 (confirmed also by Salemi et al., 2000). In their work, a physically based, simulation model for crop growth, water and salt transport at field scale in Roodasht region was applied. They report for the example of cotton, that if water quality improves due to changes in water management upstream of Roodasht to 2 DS m-1 or even 1 DS m-1, yields can increase to 73% and 77%, respectively, of the potential value, with the same annual irrigation application (Droogers et al., 2000).

Ground water

Access to other water resources can only be granted by exploitation of groundwater with wells or by use of the few existing qanats and springs. For the hydrological unit (Kouhapayeh-Segzi plain) where the Roodasht irrigation network, but also parts of Abshar irrigation network are located, data from 2006/2007 suggest, that almost 99% of exploited "other water resources" origin from groundwater from deep and semi-deep/shallow wells. Furthermore, data shows that yield of wells decreased by around 42% even though the number of wells increased by 11% in 5 years between 2006/2007 and 2011/2012 (see Table 5 - 3). The limited extraction volume is expected to have a major reason in declining groundwater quality in terms of salinization, which makes wells partly unproductive for agricultural activities.

Table 5-3: Other water resources in Kouhpayeh-Segzi hydrological sub unit (source: IWRM Office Isfahan, IKI Project Kick-off, 2015).

	2007/2006		2012/2011	
	Amount of units	Extraction volume [MCM/a]	Amount of units	Extraction volume [MCM/a]
Deep wells	833	130	926	57
Semi-deep wells	15.193	959	16.835	576
Qanats	185	14,6	N/A	N/A
Springs	127	1,1	N/A	N/A

interviews, farmers confirm that groundwater tables have declined and water quality downgraded severely in the past years, particularly for shallow wells. In general groundwater access allows farming for a period of time independently of availability of surface water in the irrigation network. Although farmers report that groundwater has been becoming too saline (with extreme values of up to 20 dS/m) in last years to be used as the only source of irrigation water. Apparently deep wells with >100 m depth have less problems with salinity than shallow (semi-deep) wells of <20 m depth. In the most cases farmers have to balance surface and groundwater irrigation based on their experience and by regularly testing salinity of groundwater.

Some farmers report that wells are also being shared amongst farmers, or farmers with wells sell a proportion of their groundwater to farmers without groundwater access.

Regarding Figure 5 - 7, one can see that particularly in the region around Varzaneh and in Bonroud district, the largest amount of approx. 8.000 official agricultural wells in Roodasht (state 2011) are located (expert report high numbers of illegal wells in Roodasht). The figure also shows that around 98% of the identified wells are between 4-20 m deep, whereas only about 100 wells are up to 100 m deep and just 40 of them are deeper than 100 m. The abundance of a vast number of shallow wells supports the statement by experts that aquifers in the region are shallow and thin, meaning that they can usually be tapped easily, but are also highly reactive towards recharge, depletion and salinization. However, according to experts, in the eastern part of the plain also an artesian, confined aquifer can be found (tabbed by deep wells) which suffers from reservoir loss.

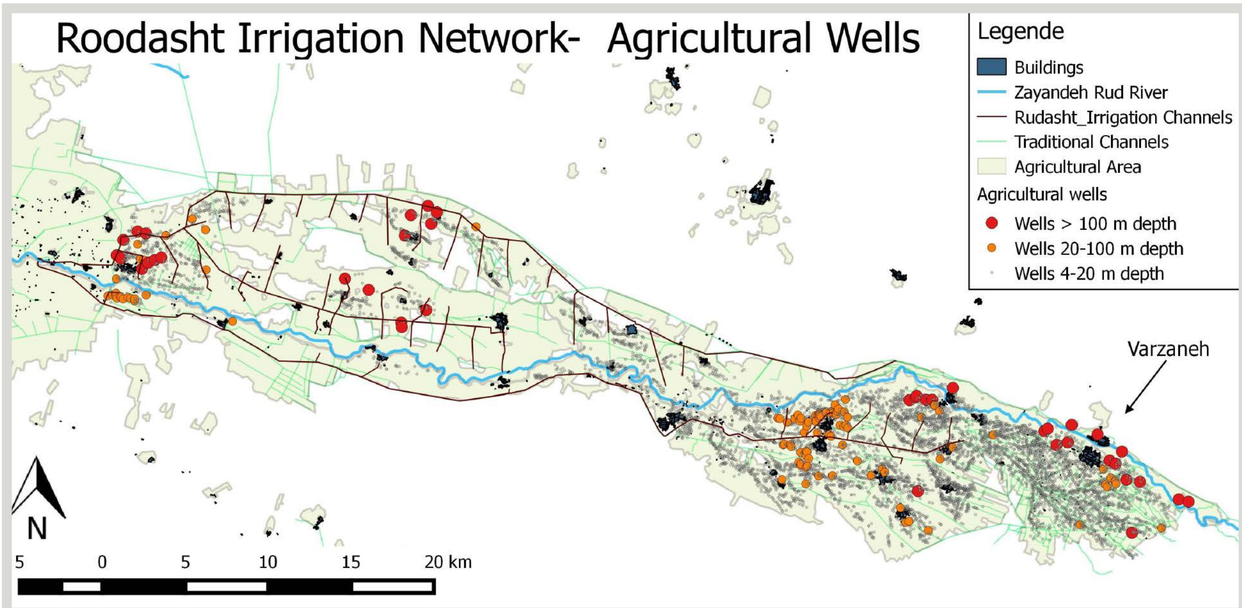

Figure 5 - 7: Roodasht Irrigation network with official agricultural wells (source: Isfahan Regional Water Company, 2011).

The high density of wells might be connected to geo-conditions, but also the use of traditional irrigation channels in this downstream region of the Roodasht irrigation network, which allow water to percolate and recharge groundwater. This phenomenon is seen as water loss and disadvantage when comparing to lined channels but has a vital function for groundwater recharge.

Experts also state that groundwater recharge is furthermore facilitated by (1) water flowing through the natural river bed of the Zayandeh-Rud, (2) percolating irrigation water by irrigation and application of "inefficient" irrigation methods as well as (3) natural precipitation in the area. Since most of the mentioned factors are reduced by the limited amount of surface water diverted to the downstream area of the Zayandeh-Rud during the past water scarce decade, groundwater tables are declining, which is further intensified by heavy groundwater extraction for agricultural purposes. Ground water dynamics in relation to recharge and abstraction in the Zayandeh-Rud basin are also described in Molle et al. (2009).

The major impact of declining groundwater tables is the analogue happening growing salinity of the groundwater resources, which is of upmost importance for agricultural production.

The expert appraisal of the relationship of groundwater tables and salinization with diversion of surface water to Roodasht is supported in the following by monitoring data from the Isfahan Regional Water Company. The following Figure 5 - 9 presents time series on depth of ground water tables and Figure 5 - 10 as well as Figure 5 - 11 present time series on groundwater salinity of selected monitoring wells in the Roodasht region. The location of the monitoring wells is being presented in Figure 5 - 8. Next to the depth of ground water wells in meters and salinity of groundwater in EC [dS/m] between Mehr 1385 (September 2006) until Shahrivar 1392 (September 2013), the charts also include monthly surface water diversion to Roodasht irrigation network [million m^3 or MCM] and precipitation in Varzaneh Region [mm].

For the following interpretation of the presented data it is important to note that for the sake of manageability and presentability of data, only a selection of existing monitoring wells are being presented. Furthermore a causal relationship of surface water supply and precipitation with groundwater dynamics should be confirmed by a further analysis of geological conditions and exploitation activities of specific aquifers. Nevertheless the conclusions below show a valid trend.

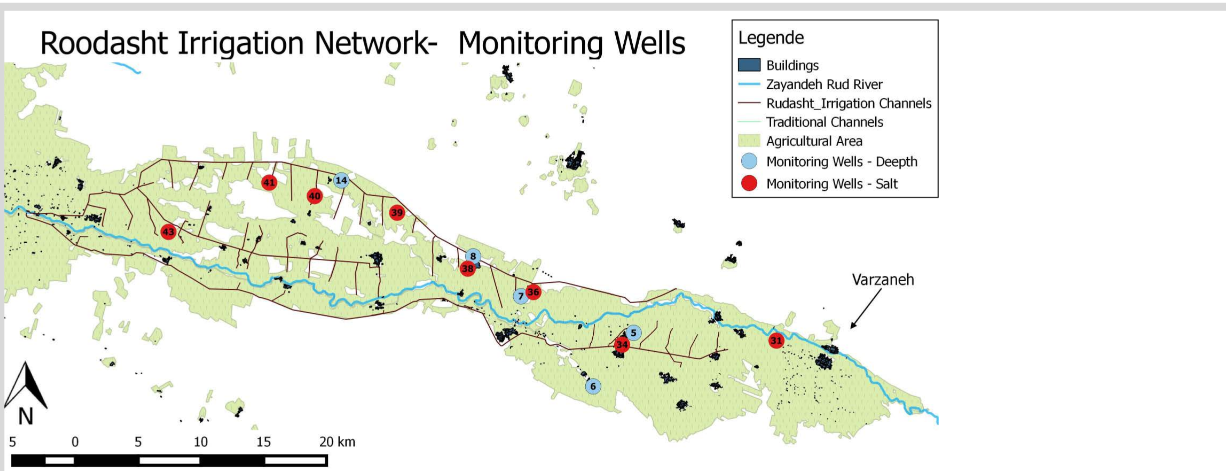

Figure 5 - 8: Roodasht Irrigation network with selected monitoring wells (source: Isfahan Regional Water Company).

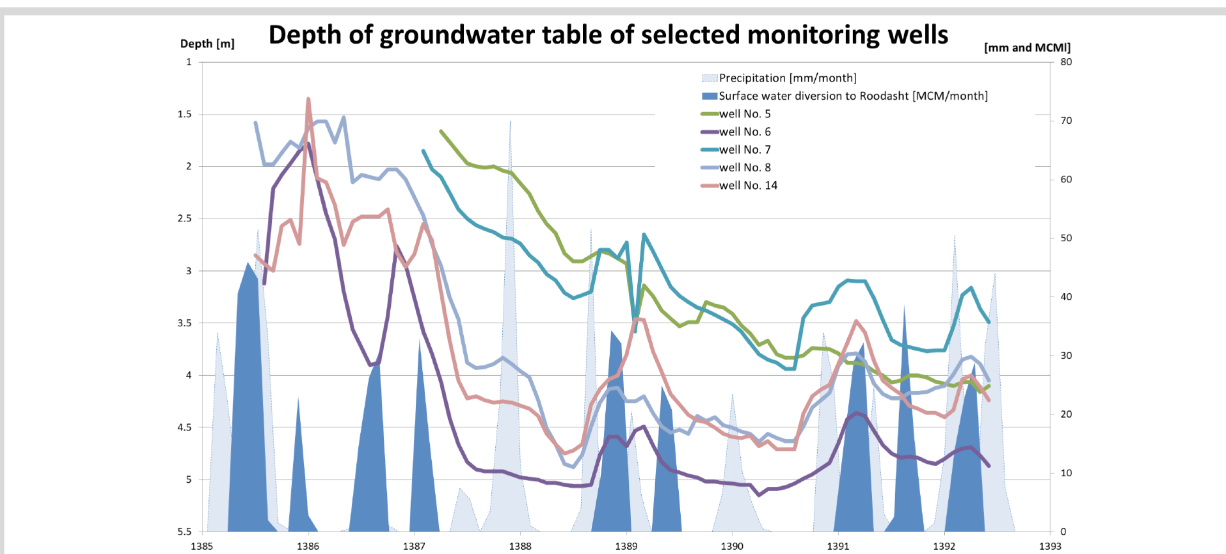

Figure 5 - 9: Depth of selected monitoring wells in Roodasht with data on water supply and precipitation (data source: Isfahan Regional Water Company).

The figure above shows an approx. 2 m decrease of groundwater tables of the five presented shallow wells within 7 years between 1385/86 (2006) until 1392/93 (2013). In general, the monitoring data from monthly measurements show fluctuations of the groundwater table. During the period with no surface water supply to Roodasht from Tir 1387 (June 2008) until Aban 1388 (October 2009), one can observe a drop (> 1m) of all presented groundwater tables. During this period (first month of 1388) an intense precipitation event of 70 mm in one month was recorded in Varzaneh. An effect of this event is only indicated weakly by a slight stabilization or even rising water table in well No. 8. In general the effect of precipitation on groundwater tables is not very clear in this figure.

When surface water started to be diverted to Roodasht again in the end of 1388, one can observe a gradual rise in ground water tables, followed by a drop of the tables in the next water scarce period until the beginning of 1391 where water tables start to rise again analogue to supplied surface water.

In general the dependency of ground water tables by on supplied surface water to Roodasht is obvious in the figure.

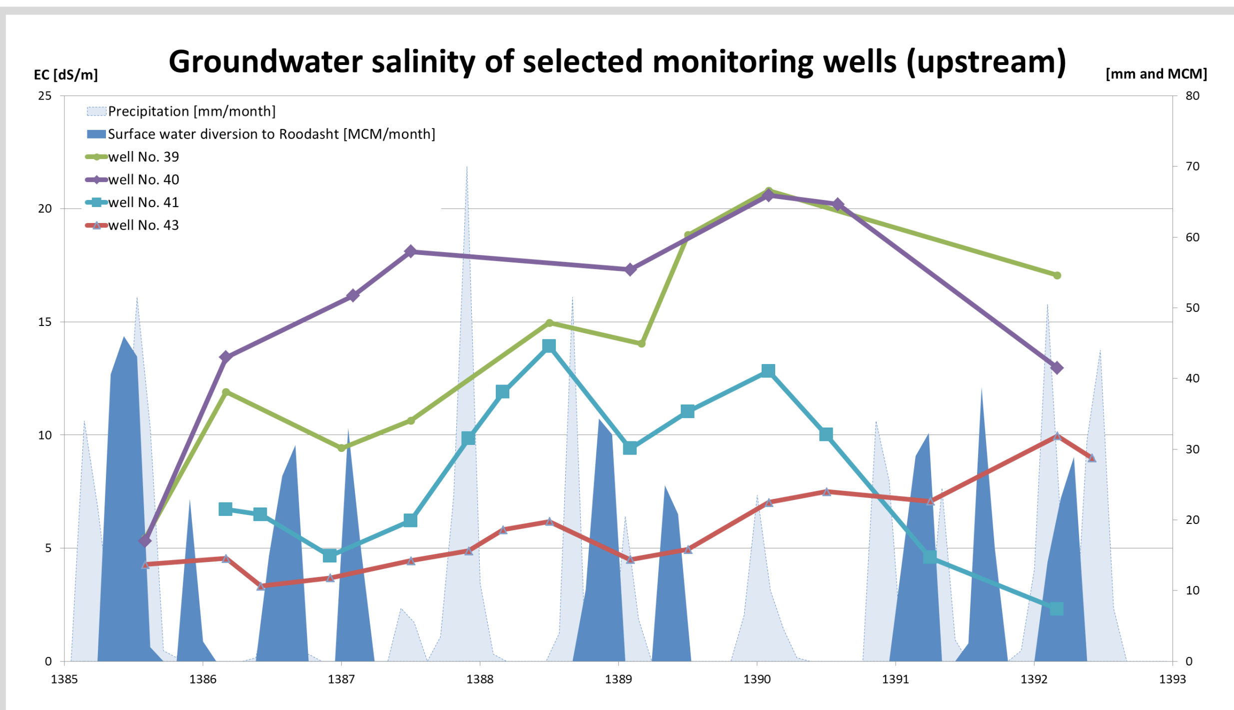

Figure 5 - 10: Salinity of groundwater from selected wells in the upstream part of Roodasht with data on water supply and precipitation (source: Isfahan Regional Water Company).

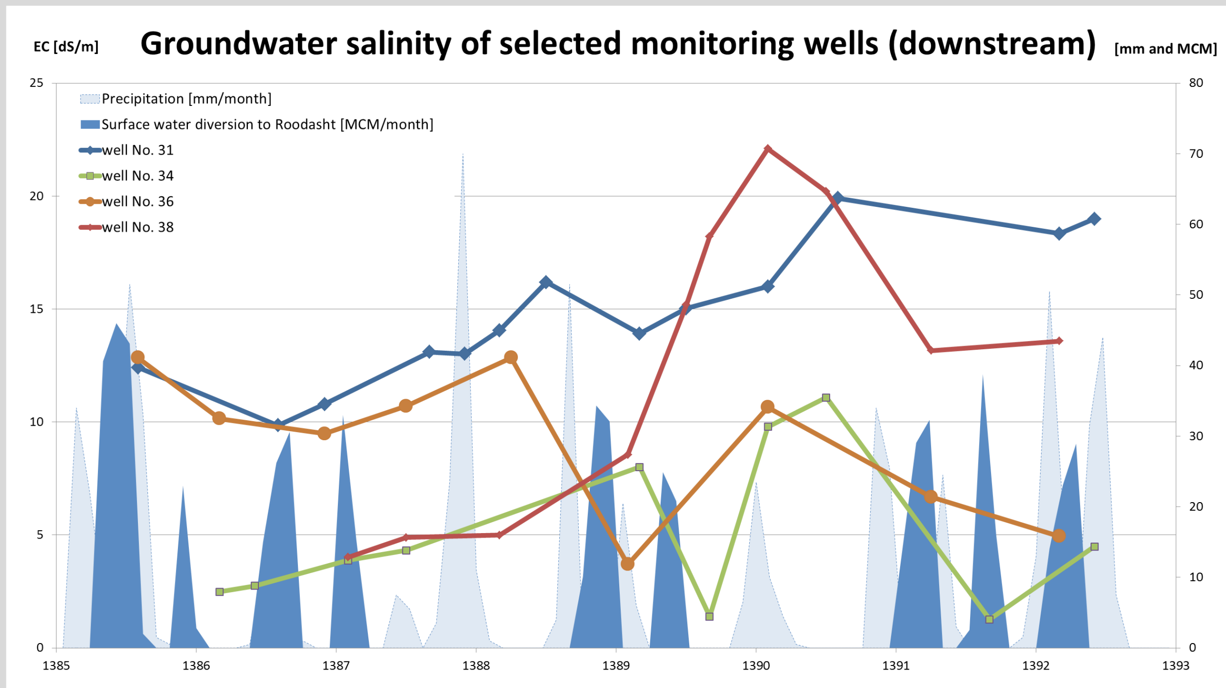

Figure 5 - 11: Salinity of groundwater from selected wells in the downstream part of Roodasht with data on water supply and precipitation (source: Isfahan Regional Water Company).

The Figure 5 - 10 and Figure 5 - 11 above show a strong fluctuation of groundwater salinity of the 8 presented monitoring wells during the period of 7 years. The interpretation of the monitoring data on salinity is challenging due to the long measuring intervals of several month. Besides of wells 36 and 41, all wells show an increase of salinity of up to 11 dS/m during the presented time period of 7 years. Analogue to the dynamic of groundwater depths discussed above, also the salinity of monitored well water increases during water scarce periods with no surface water diversion to Roodasht and gradually decreases when surface water is being supplied to the region.

The response of cultivated areas, to missing water diversion to the Roodasht irrigation network and the presented consequences on ground water quality, can also be observed in Figure 5 - 12 and is being discussed in chapter 5.3.4.

The majority of farmers apply surface water from the irrigation network and groundwater junctive. 1/3 of the interviewed farmers who are located in the upstream region, rely entirely on surface water and don't use groundwater. This is expected to be due to the absence of wells in this region because local aquifers are unproductive or too saline (see Figure 5 - 7). Farmers which are located next to the river downstream of Varzaneh rely entirely on groundwater, and one farmer close to Varzaneh city with a greenhouse uses tap water for irrigation (with a limitation in quantity per month). Farmers close to the river also own mobile pumps and it is likely that they partly extract surface water from the Zayandeh-Rud.

To sum up, decreased access to irrigation water though the irrigation network (1) is a threat for agricultural production (see chapter 5.3.4), (2) increases uncertainty of future development of the agricultural sector in the region, (3) limits possibilities to leach salt from soils (see chapter 5.3.1), (4) increases the risk that fields are fallow with a long-term adverse impact on soils and environment (desertification) (see chapter 5.3.1 and 5.4.2), (5) fosters over exploitation of groundwater and (6) decreases groundwater recharge resulting in sharp rise of salinity of groundwater.

A special form of water access is using the effluent of a wastewater treatment plant. The Isfahan Regional Water Company states, that the stabilization lagoon in Varzaneh services around 97% of the town and has an approximately effluent (including some infiltration of groundwater) of 2.600 m^3/day. The Isfahan Regional Water Company allocates the effluent to limited local users for urban and agricultural usages and the rest of effluent discharges to the river. But the effluent is emitted to the Zayandeh-Rud and used by some farmers illegally as continuous water source. The reuse of waste- or grey water for irrigation at other villages or cities in Roodasht is not practiced/unknown.

5.3.3 Technical conditions

Farmers own farming equipment or have to rent it at high prices, boosting production costs. Only one active cooperative company owning machinery collaboratively could be identified. Availability of modern machinery is limited.

The predominant irrigation method is traditional flood irrigation. Pressurized irrigation is only applicable to a limited extent due to timing of surface water availability and saline groundwater resources.

Only few farmers have the resources to build greenhouses due to the massive investment required for the necessary equipment. Required local, technical consultancy capacities decreased in the past years.

In general, investment of farmers in equipment and infrastructure is low due to limited financial resources and a perceived uncertainty of future development of the agricultural sector in the region.

Farmers use tractors, agricultural implements for farming and combines for harvesting wheat and barley. Some farmers with access to the traditional irrigation network in the down reaches of Roodasht region, as well as those located close to the river own mobile pumps for pumping irrigation water. Larger farms and farmers in the border region to the desert usually own all their equipment but rent the combine. Other farmers don't own any equipment at all but rent all of it, some only rent modern farming equipment like powerful tractors or special implements. Experts state that there are many tractors in the region, but most of them are too old and weak to drag modern farming implements, which is available only limitedly in the region, which forces farmers to rent modern tractors in order to apply modern farming techniques.

Renting equipment is paid usually as fee per hectare (approx. 2.7 M IRR/ha). Farmers (usually large scale farmers) that own machinery rent these out to other farmers. During interviews, only one active cooperative company could be identified (Ghurtan village) that successfully shares modern equipment amongst its members, decreasing the production costs of individual farmers. Experts state that cooperative companies have access to governmental support for mechanization, but that interests' rates of about 22% are not attractive for farmers.

As an adaptation to soil salinity the chisel plough was introduced about 3 years ago to till the land with limited soil disruption (conservational tillage). Local availability and acceptance is limited since farmers state that it can only be applied to leveled lands and its effectiveness on weed eradication is not satisfactory.

All farmers use flood irrigation and state to not be able to change their irrigation method to pressurized systems like tape or drip irrigation due to (1) discontinuous access to surface water (2) salinity of groundwater (see chapter 5.3.2). Only very few farmers in special circumstances, like the greenhouse close to Varzaneh that uses tap water or farmers with very deep wells, apply pressurized irrigation on a part of their land. The Ministry of Agriculture supports farmers with an allowance of 12 M IRR / ha for conversion to pressurized irrigation methods.

Farmers can adjust irrigation timing if they use groundwater and to a minor extend with water storage facilities. About half of the interviewed farmers own a pond for storing irrigation water temporarily which is partly funded by the government.

There are only about 12 greenhouses with water efficient crop production on less than 8 ha in the region. Financial means and access to low interest rate credits to build and equip greenhouses are restricted for farmers (chapter 5.2.3, 5.1.2), even though there are governmental funds available for greenhouse development. Farmers also express a time consuming administrative process for implementing greenhouses as a restriction. Infrastructural requirements for greenhouses are (1) a stable water access with low salinity, (2) potentially desalinization facility, (3) pressurized irrigation equipment or hydroponic, (4) potentially air-conditioning, (5) access to adapted cultivars, (6) access to markets, (7) energy access and (8) technical consultancy. For tap water and electricity access, proximity to villages is desired for greenhouses (see chapter 5.3.7). Other forms of agriculture like fish breeding are restricted due to financial means of farmers and technical know-how available locally.

The Agricultural Organization offers investment projects like equipping and modernization plans up to 85% coverage of investment, focusing on concrete lining of irrigation channels and construction of secondary irrigation channels, repairing qanats and defragmentation of lands (chapter 5.3.6). For most of the plans a collaborative approach by implementing a functional cooperative structure is required by farmers, which is happening rarely and is a hindering reason for accessing these programs (chapter 5.1.4).

In general technical modernization is restricted due to (1) perceived irrationality to invest in the farming sector due to high insecurity of future water availability (chapter 5.3.2, 5.2.2), (2) limited household investment capacity (chapter 5.1.2, 5.1.2) and (3) limited motivation to change farming system intensively for traditional reasons and missing knowledge and skills, particularly among old farmers (chapter 5.1.3). Furthermore, experts state that due to limited capital and investment by farmers in the past dry years, the coverage and quality of required service provision by consultancy and technical service companies decreased.

5.3.4 Farm products

Agricultural production in Roodasht is strongly dependent on the availability of surface water in the irrigation network.

Wheat and Barley are the dominant crops in the region. The planted crop types have secure markets but their long cultivation periods imply a high dependency on water availability. Alternative crop choices are limited mainly due to irrigation water availability, availability of cultivars and markets as well as local know-how.

Farmers with groundwater access can diversify their cultivation and also cultivate in drought conditions. Also Orchards are an option for farms with groundwater access.

Livestock is a diversification strategy for farmers. Livestock diminished in the past dry years due to increased production costs and limited household capital. In Roodasht livestock has a high forage demand which cannot be covered locally in dry years.

Dependency of agriculture on water availability

Figures from the Isfahan Agricultural Organization on cultivated areas in Roodasht merged with data from the Isfahan Regional Water Company on water supply to the Roodasht irrigation network show that the total cultivated area is strongly dependent on water availability in the Roodasht irrigation network. The datasets on cropping patterns in Roodasht include all cultivated areas which have been harvested. Data from a separate information sheet from the Isfahan Agricultural Organization on areas which have been cultivated but could not be harvested due to limited yields, have been added to these data sets. In general farmers plant more crops than they can irrigate with expected irrigation water quantity. They (1) hope for rain in winter so crops would survive, (2) compensate lack of water with saline groundwater, (3) sell premature crops to livestock keepers or (4) hope for compensation for lost crops.

For each year between 2006 and 2015, Figure 5-12 shows the cultivated areas in Roodasht split in areas being harvested (black column) and areas being planted but not harvested (black and white column). Also the figure shows the annual water supply (orange line) to Roodasht irrigation network with a percentage of volume of annual water being supplied in spring time (February-July). Furthermore cultivated areas derived by an analysis of remote sensing data[8] by the BMBF IWRM Zayandeh-Rud project are included in the figure.

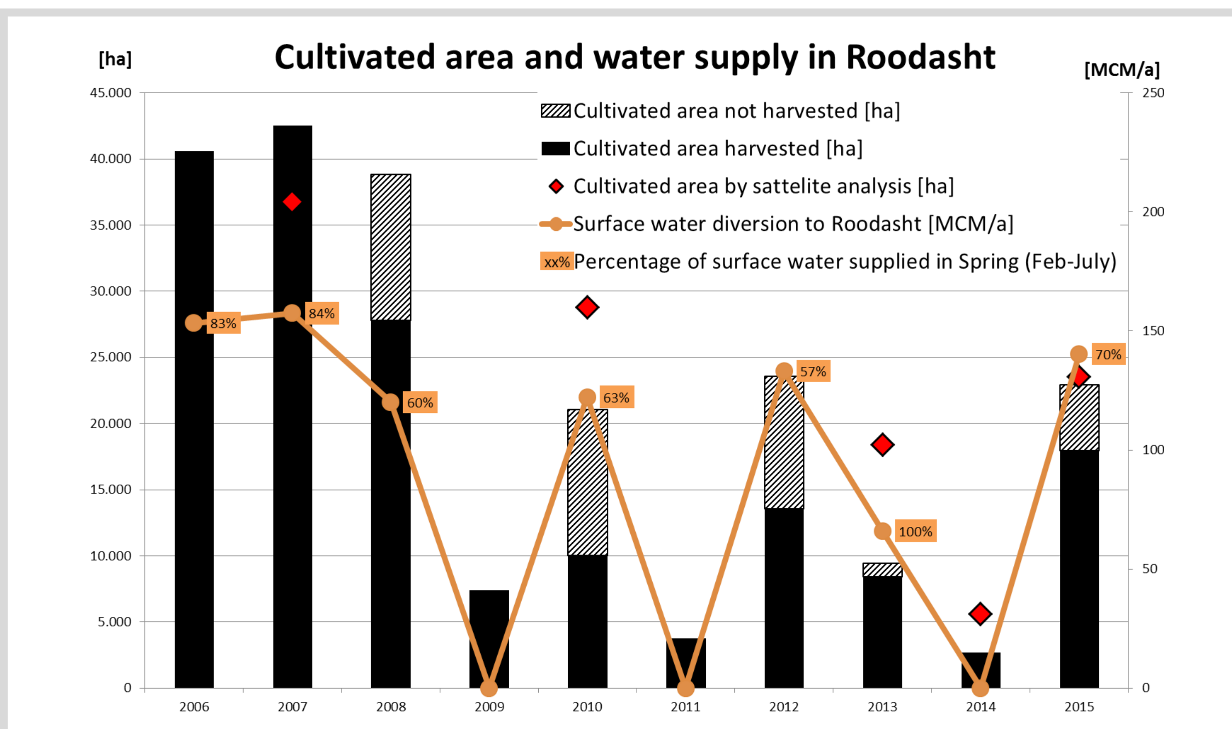

Figure 5-12: Time series, cultivated areas merged with data on water distribution to Roodasht irrigation network and remote sensing data. (sources: Isfahan Agricultural Organization and Isfahan Regional Water Company)[9]

8 Annual cultivated areas from the remote sensing mission have been derived by merging detected cultivated areas from the month April, May and August for each year.

9 An agricultural and water year runs from approx. 20.September-20.September and is named according to the year where the calculation ends. For example: Data on water supply and cultivation between 20.9.2014 – 20.9.2015 are presented with the year 2015.

The presented figure shows that:

- A proportion of cultivated areas could not be sustained and have not been harvested during the year 2008 when surface water supply to Roodasht irrigation network started to decrease. Another reason may be the decreased proportion of water being supplied during spring time (84% in 2007 and 60% in 2008) which is essential particularly for winter crops wheat and barley (Farmers have enough water to plant but not to sustain their crops over the year). This effect can also be observed with large areas being not harvested in 2010 and 2012 with only about 60% of the water being supplied in spring, whereas less crop loss can be observed in 2015 with 70% water being supplied in spring and in 2013 where all water has been supplied in spring. Furthermore the exceptional low natural precipitation during the year 2008 year might be the reason that crops could not be sustained until harvest time (see chapter 5.4.1).
- In the years 2009, 2011 and 2014 a limited cultivation could be sustained, also when no irrigation water was available in the irrigation network. The dataset indicates that these areas have been irrigated by groundwater only and are expected to be connected to wells in certain locations taping a productive aquifer that is resilient to limited recharge due to missing surface water in the region. Satellite images in Figure 5-7 indicate the cultivated areas (in green) of the year 2007 during the month April, May and August, which covers almost the entire area. Furthermore areas are included in red that have been cultivated in all of the years 2007, 2010, 2013, 2015 and also the year without any surface water access 2014. Comparison with the locations of agricultural wells in in the previous chapter shows that the cultivated areas match with areas where wells can be found. Therefore it can be concluded that some aquifers and wells have the capacity to sustain agricultural production also during several water scarce years. Nevertheless also for these areas a decreasing trend over water scarce years can be observed;
- In the years 2010, 2012 and 2015, the level of cultivated areas decreased by around 40% in comparison to the years 2006-2008 where similar amounts of surface water have been available in Roodasht. According to experts, the reason for this phenomenon is expected to be a strong increase in salinity and decline of (shallow) groundwater resources after a year without recharge by surface water (see chapter 5.3.2). This leads to heavy restrictions in application of junctive use of groundwater and surface water for agricultural production and reduces cultivated areas majorly. Furthermore agricultural areas which are not irrigated frequently by surface water are expected to have an increase in soil salinization, making them unproductive for agricultural purposes. In Figure 5-14 and Figure 5-15 staged transparent layers of remote sensing images of cultivated areas in Roodasht for the years

2007, 2010 and 2015 are presented. It can be observed that even though surface water diversion to Roodasht was similar agricultural areas particularly in the border regions to the desert in downstream Roodasht have not been cultivated anymore. It is assumed that these areas have been abandoned and experience a desertification process losing agricultural productivity entirely (see chapter 5.3.1).

Furthermore the comparison of cultivated areas and data from remote sensing mission shows that the trend is similar but also indicates that data on cultivated areas are rather estimative and may be supported by application of remote sensing. Particularly for the year 2010 and 2013 more cultivated areas than given by the Isfahan Agricultural Organization are detected. Considering this, the decrease of cultivated areas between 2007/2008 and 2010 might not be as drastic as the figure suggest.

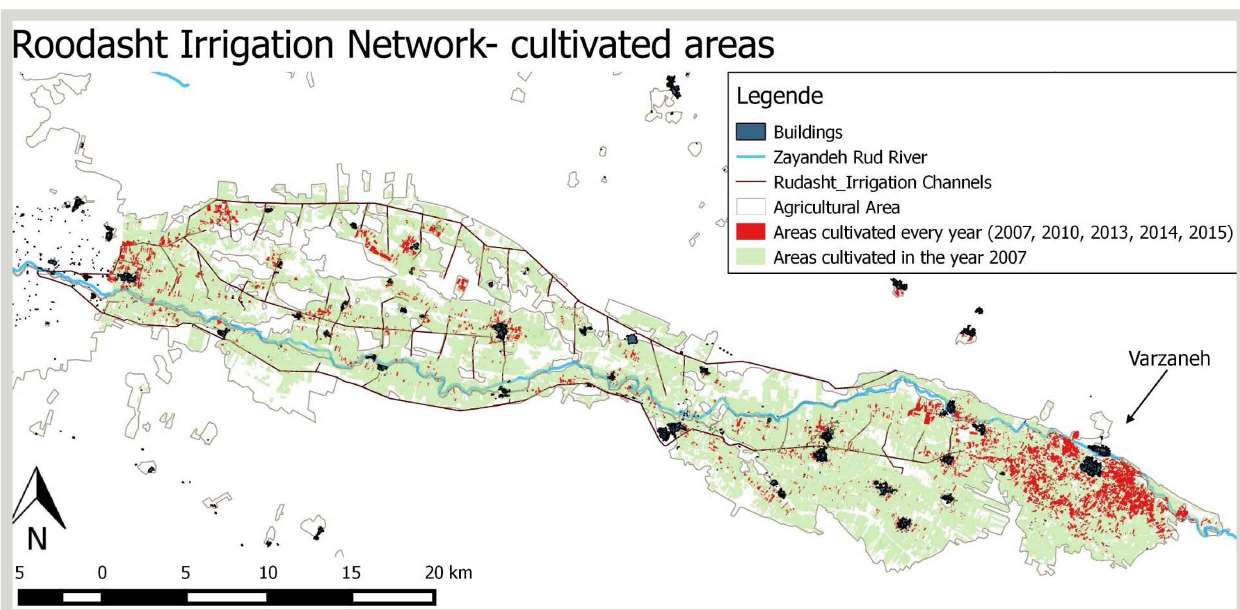

Figure 5-13: Roodasht irrigation network with area cultivated in 2007 and areas cultivated every year in 2007, 2010, 2013, 2014, 2015 detected by remote sensing (source: Technical University of Berlin, Hengsbach).

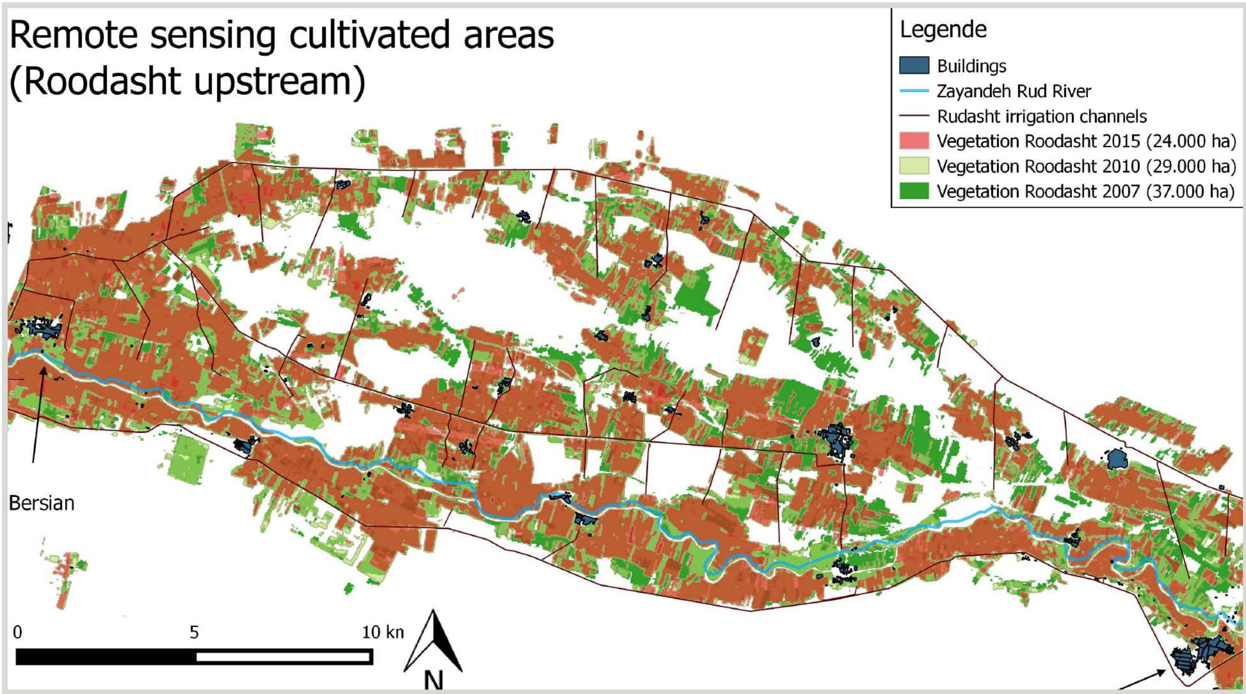

Figure 5-14: Upstream part of Roodasht irrigation network with stacked transparent layers cultivated in 2007, 2010 and 2015 detected by remote sensing (source: Technical University of Berlin, Hengsbach).

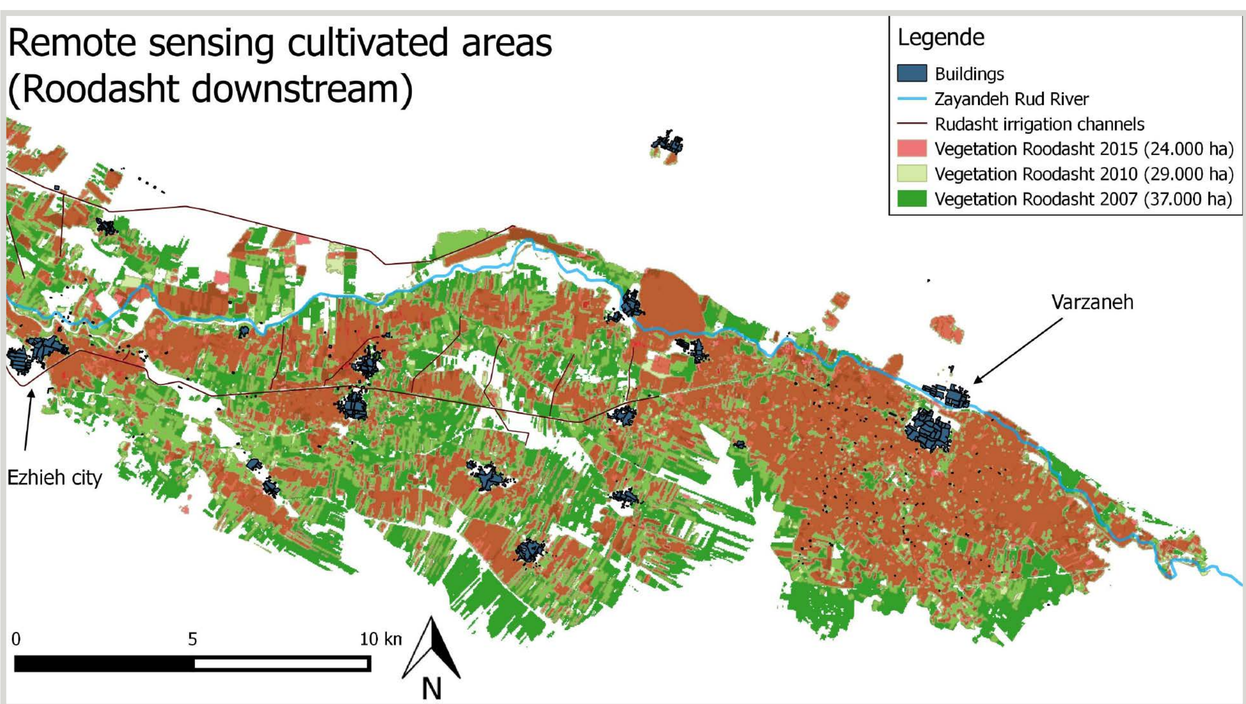

Figure 5-15: Downstream part of Roodasht irrigation network with stacked transparent layers of cultivated in 2007, 2010 and 2015 detected by remote sensing (source: Technical University of Berlin, Hengsbach).

Crop choice

All interviewed farmers dependent on surface water and shallow wells for irrigation state that they produce either wheat or barley or both of them (most farmers). Access to deep wells is an important factor influencing the cropping pattern. Most interviewed farmers having access to productive wells state that they plant on parts of their land also other crop types like Alfalfa, Cotton and Beet or to a small extend Safflower, Lettuce and Millet as well as Broom Sorghum, which according to experts is an alternative for water and cost efficient forage production and could compensate some wheat and barley cultivation.

Some farmers with access to deep wells are also planning to start orchards with Pistachios or Pomegranates. Currently, only one of the interviewed farmers has a pistachio orchard of 2.5 ha, which is located in the upstream region of Roodasht irrigation network. Apparently some orchards with Pomegranates, Pistachios, Grapes and Berries exist in the region, but farmers report that some old orchards (up to 200 years old) where lost in the past dry years.

Data on cropping patterns in Roodasht from the Isfahan Agricultural Organization confirm the limited crop choice on fields with access to surface water and shallow wells in comparison to farms with access to deep wells or very productive aquifers (Figure 5-16).

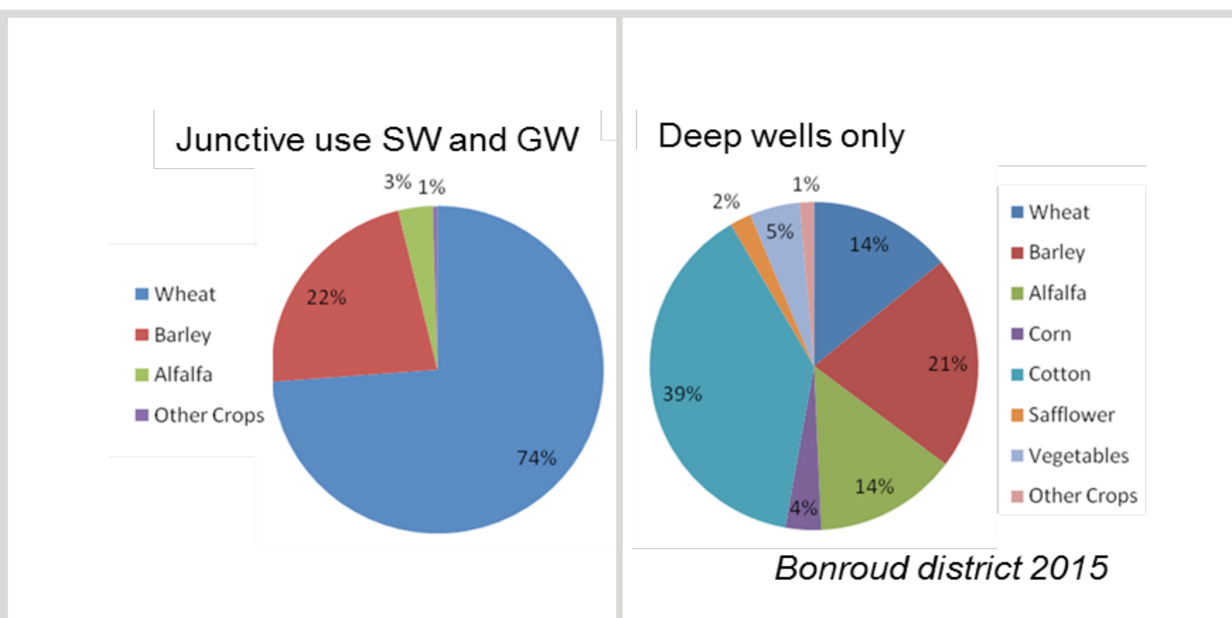

Figure 5-16: Percentage of cultivated crop types [ha] for Bonroud district in 2015, split into areas with surface water and shallow well access only and areas with access to deep wells (source: Isfahan Agricultural Organization).

Analogue to Figure 5-12, Figure 5-17 shows the cultivated areas for different crops in columns which are cultivated between 2006 and 2015 as well as water supply (orange line), with the datasets from Isfahan Agricultural Organization and Isfahan Regional Water Company. The figure indicates a dominance of wheat and barley (percent figure in the columns) in the crop patterns of Roodasht. It can be observed that the proportion of wheat and barley of the total cultivated and harvested area is around 75% between 2006 and 2008. In water scarce years with depressed overall production this percentage sinks down to 50% due to the fact that more diverse production, practiced by groundwater irrigation is happening. In the year 2015 wheat and barley accounts for 90% of the cultivated areas. Besides all fluctuations wheat and barley are the dominant crops in the region. It seems these grains are the "safe option", particularly for farmers relying on surface water and shallow wells.

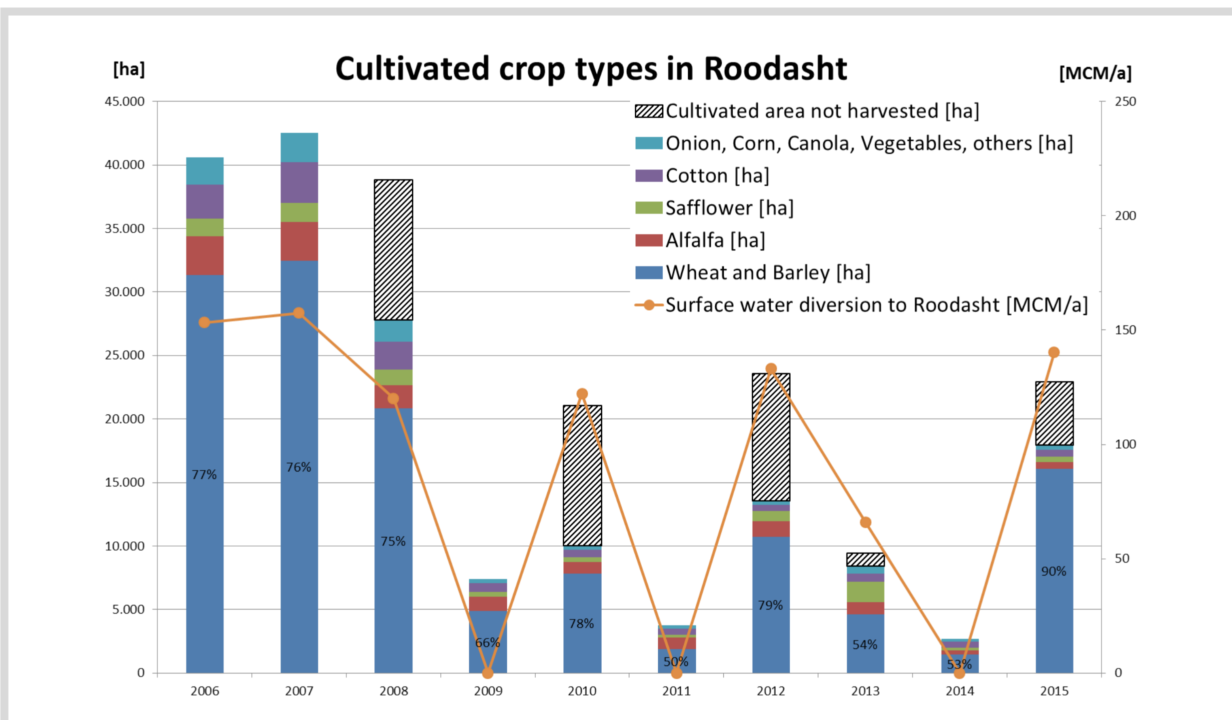

Figure 5-17: Time series, cultivated crop types, merged with data on water distribution to Roodasht irrigation network. Percent figures show the proportion of wheat and barley of the correlating column (sources: Isfahan Agricultural Organization and Isfahan Regional Water Company[10]).

Also regarding yields, wheat and barley are dominant in the region, followed by onion, corn, vegetables and other crops. Figure 5-18 shows, that yields are close to being analogue to cultivated areas and yields per ha (data are average values for whole Isfahan province) don't

10 An agricultural and water year runs from approx. 20.September-20.September and is named according to the year where the calculation ends. For example: Data on water supply and cultivation between 20.9.2014 – 20.9.2015 are presented with the year 2015.

change significantly over the years. Also, the figure shows that cultivation of vegetables allows much higher yields (25-80 ton/ha) than grains (4.5 – 5.5 ton/ha), whereas for grains, around the same yield of straw per hectare may be added (wheat 1:1 and barley 1:0.9).

Governmentally guaranteed prices for a range of crops presented in Table 5-4 show that grains reach higher marketing prices than vegetables and at the same time are expected to have lower production costs.

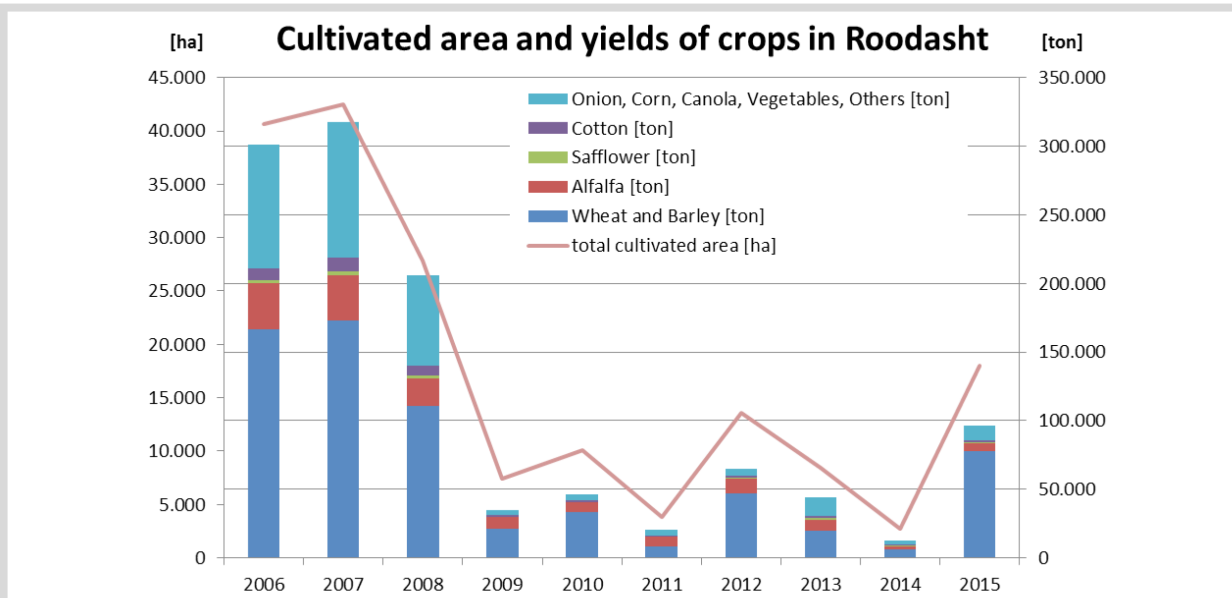

Figure 5-18: Total cultivated area (harvested) and yields of different crops in Roodasht (source: Isfahan Agricultural Organization).

Table 5-4: Governmentally guaranteed prices for different crops in Rial/kg (source: Isfahan Agricultural Organization).

2015	2014	2013	2012	2011	2010	2009	2008	2007	product
11550	10500	5500	1950	3600	3300	3050	2250	2050	wheat
9200	7800	4500	3400	2900	2600	2700	1650	1520	barley
9600	8700	4550	3500	3000	2760	2760	1750	1620	seed corn
2700	2100	1350	1050	900	750	620	500	460	sugar beet
25500	22000	14000	10500	9000	7500	6480	5400	5000	cotton
21500	18500	9500	6000						safflower
3600	3000	1950	1470	1450	1350	1080	910	883	potato
2400	2000	1350	1050	900	900	790	670	627	onion

Figure 5-19, an average cropping calendar for the Roodasht and Abshar region is presented for a range of different crops. Also the time period of an agricultural year and periods of typical surface water diversion to the Roodasht irrigation network are included. The figure is overlaid with average precipitation and temperature data, related to the time scale. Comparing irrigation water availability and possible crops, it becomes obvious that timing of irrigation water doesn't support the cultivation of certain crops (e.g. Saffron, Corn, Millet, Maize, etc.). The figure also shows that a large proportion of possible crops would be cultivated during the hottest period of the year (June-October), when almost any natural precipitation is available at all, and typically no irrigation water is being supplied to Roodasht irrigation network.

Due to an estimated irrigation water demand[11] for wheat and barley between November and May with a peak between March and May, the timing of surface water supply is optimal for these crops.

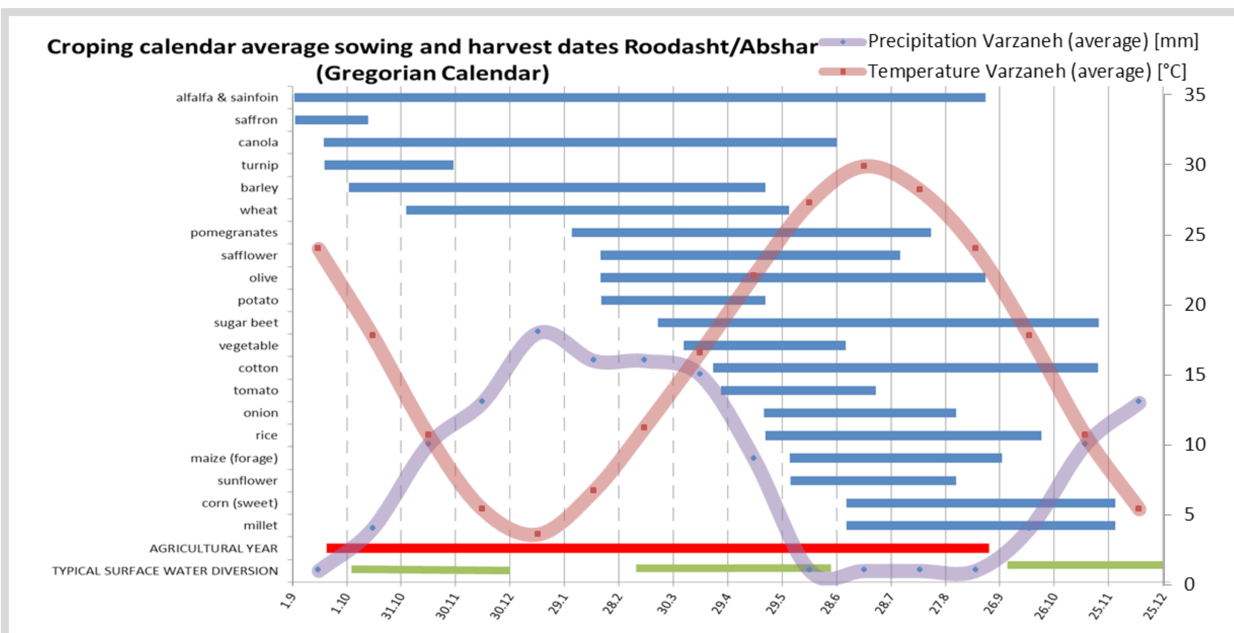

Figure 5-19: Crop calendar for Roodasht and Abshar region, with the time period of an agricultural year and typical periods of surface water diversion to Roodasht irrigation network and average precipitation and temperatures in Varzaneh (source: Isfahan Agricultural Organization, Isfahan Regional Water Company, climate-data.org).

11 Calculated Evapotranspiration in Varzaneh Plain with NETWAT software.

As presented, crop choice of farmers is not very diverse in the region. During interviews, all farmers state that the choice for wheat and barley is mainly due to:

- Low water demand of the crops as well as their stress tolerance to drought and saline conditions of water and soils;
- Valorization of autumn precipitation of winter grains;
- Possibility of marketing at governmentally guaranteed prices with cooperative companies, whilst other products are usually sold to "Middlemen" to fluctuating prices which is difficult to plan with;
- Practical knowledge to plant the grains and production of own seeds, if the quality of the harvest is satisfactory;
- Sort of traditional attachment to Wheat and Barley;
- Household consumption of produced wheat for baking bread.

Regarding crop choice, experts state that:

- The seed market controlled by Isfahan Agricultural Organization has the following shortcomings:
  - approved and improved seeds and cultivars are only available for 1/3 of farmers in the whole catchment;
  - Requirement to expand portfolio and availability of adapted cultivars with (1) less water demand, (2) higher salt and water stress tolerance, (3) cultivation periods adapted to the wet and colder periods of the year. To this point it has to be noted that already successful developments of adapted cultivars are present in the province and region, nevertheless the wide on-farm application and uptake of farmers is relatively low. In general research and adaptation of seeds is a process with no end point.
- Nursery facilities are not existent locally that propagate and produce seedling which can be planted before the hot season of the year and require less time till harvest. For planting seedlings, it is expected that farming methods and machinery might have to be adapted.
- In Roodasht, no stable marked or local demand is apparent for alternative (dry land) crops with high economic return like medical plants (for example thyme)[12], saffron, pistachios or rhubarb.

12 Local people state that there is a small medical factory in Kafroud Village near to Varzaneh.

- No local processing facilities (for example oil production from oil seeds like safflower) are in place locally that would generate a demand for these crops.
- Soil and water salinity is hindering application of medical herbs (Expert state that eucalyptus, fennel seeds and madder might be options).
- The know-how, availability of adapted equipment but also motivation of farmers for cultivation of alternative crops is lacking.

expertsSome alternative crops like Chamomile, castor seed and dill are planted on experimental farms by the Agricultural Research Center and Agricultural Service Centers, which are used for presentation and training on these new crops. Pioneer farmers may also experiment with these crops or saffron or cumin seed.

Livestock

1/3 of interviewed farmers own livestock but mainly state that it is not economically beneficial for them due to increased production costs and decreased product prices. Other farmers state they had to sell their livestock due to water scarcity and financial problems in the past dry years (chapter 5.1.2). If water is available for farming, farmers produce around ¾ of their feeding for livestock on their own fields. The feed is mainly straw, barley, beet scum, beet, corn and alfalfa. In times of water scarcity when agricultural cultivation is limited, livestock keepers have to buy feed which is increasing the production costs.

In the interviews, farmers owning livestock are medium scale 10-20 ha and usually have single or few (up to 20) cows, sheep or chicken for household consumption. The largest interviewed livestock keepers are one farmer with 40 sheep and 40 chickens close to the river and one farmer with 200 sheep in the upstream part of the Roodasht region. Livestock from small holders is mainly marketed locally, whereas large husbandries sell in the province or on national markets.

In general, farmers perceive livestock as a way to diversifying income when agricultural activities are limited due to water scarcity.

Experts state that in Bonroud district, there are approx. 1.650 livestock husbandries, of which about 60% are inactive due to economic reasons. There are some livestock husbandry cooperative companies in place, servicing its members with feeds, and marked products jointly (e.g. milk collection stations).

Figures from the Isfahan Agricultural Organization (see Table 5-5) suggest that there is a large quantity of livestock apparent in the region with an increasing trend on heads and feed requirement of around 30% between 2006 and 2014. Chicken for egg and meat production are the dominant form of livestock, more than doubling the capacities between 2006 and 2014. The main part of livestock is expected to be located in few industrial livestock breeding facilities mainly around Varzaneh. According to experts, drinking water demand of livestock is mainly supplied with groundwater.

The presented forage demand shows high values compared to presented figures on crop yields in Figure 5-18. For example in 2014, total yields of wheat, barley, alfalfa, corn and others in Roodasht have been approx. 11.000 tons being only 1/3 of the local demand on forage. Nevertheless it has to be noted that for grains, approx. the same amount of straw has to be added to the harvested grains given in Figure 5-18. In general it can be concluded, that in dry years with low agricultural production in the region, either forage for industrial livestock breeding has to be imported to the region, or livestock (particularly sheep) are kept free range and risk to degrade the natural vegetation cover. Experts state that range lands in Bonroud district have a capacity for 24.000 livestock, but that the natural vegetation cover for grazing is very weak. Furthermore experts state that the productivity and efficiency of livestock production in Isfahan is not very high.

Table 5-5: Livestock in Roodasht between 2006 and 2014 (source: Isfahan Agricultural Organization).

Forage (Ton / Year)	Head of livestock			Year
	Poultry	Sheep	Cow & Calf	
51.264	280.000	80.500	22.700	2006
54.140	309.500	87.300	23.720	2007
56.234	325.900	90.920	24.610	2008
57.055	411.700	91.880	25.010	2009
59.234	459.800	93.910	26.130	2010
61.569	496.800	65.630	27.380	2011
62.586	524.900	98.850	27.650	2012
66.055	632.200	100.750	29.580	2013
68.094	671.000	102.900	30.600	2014

5.3.5 Agricultural practices

Agricultural practices in the region include only poor biomass management of soils since manure is expensive and crop residuals are largely being sold or used for feeding livestock. Application of manure is restricted due to high costs and mulching as well as conservational agriculture methods are not practiced. High temperatures and low humidity of soils require large amounts of organic material for humus buildup. Productivity is sustained by application of mineral fertilizer and chemical pesticides.

Measures for controlling salinization of soils are available to certain extend but have a limited uptake.

Land leveling and improving on-farm irrigation conveyance efficiency have a certain uptake in the region.

Farmers have access to training on technical measures primarily in Agricultural Service Centers.

The low organic carbon and humus content of soils (chapter 5.3.1) poses a threat to productivity of soils in the long run. Regarding biomass management, more than half of the interviewed farmers state that they leave some part of the crop residuals on the field before plowing it, in order to increase soil organic carbon. According to local experts' the high temperatures and low soil humidity limits the decomposition rate of organic matter in Roodasht and complicates humus buildup[13]. Most farmers state that they started to apply this type of conservation tillage just recently (earliest 3 years ago). This technique is more popular in the upstream region of Roodasht than in the downstream region. Nevertheless the main part of the crop residuals is being sold as feeding for livestock owners or is being fed to own livestock. Consequently the amount of crop residuals on the field and integration of organic carbon in soils is expected to be little. About 1/3 of interviewed farmers use manure as additional fertilizer either from own livestock or from the market. The high costs for manure and limited availability are practical restrictions for farmers to apply it, even though most of them are aware of potentially positive effects on their fields.

In general, sustainable conservation agriculture with (1) minimal soil disturbance, (2) permanent soil cover and (3) crop rotations (4) intercropping are not practiced in Roodasht.

All farmers state that they use mineral fertilizer and pesticides/herbicides on their fields to sustain productivity. Figures from the Agricultural Organization shows that the relative amount of applied herbicides per ha did not change over the past years, but applied pesticides increased slightly, relative to cultivated areas. Applied fertilizers do not show a strong correlation to

13 Detailed information on the effects of temperature and dryness on decomposition of crop residuals and privileges of non-tillage or low tillage practices could not be included in the report due to missing scientific reports regarding this matter for Roodasht.

cultivated areas. In general, experts state that fertilizer application is not very efficient, due to limited knowledge on soil-water-plant relationships.

Regarding control of salinization of soils, the application of the so called chisel plow is supposed to avoid turning the soil excessively (conservational plowing) and allowing salts to slowly leach from topsoil. Farmers state that there are limitations on available machinery for conservational plowing and that they are not satisfied with the results in terms of weed control.

Land leveling is an on-farm measure to increase water productivity and avoid soil erosion, which has a high uptake in the past three years. The Agricultural Organization has apparently given some financial support for the application of the measure. Other technical measures and approaches for improvement of irrigation efficiency are conveying water on-farm by pipe, lining traditional canals in collaboration with Agricultural Organization, or experimenting with drip or tape irrigation (see chapter 5.3.2). Other approaches to improve water efficiency, like the use of plastic foils to reduce evaporation losses on fields, subsurface irrigation or mulching have very little uptake in Roodasht.

Farmers get informed about new land management and farming approaches by Agricultural Service Centers, Consulting Companies, the TV or by visiting successful farmers in their neighborhood. 2/3 of the interviewed farmers have attended farming workshops by Agricultural Service Centers on a large variety of topics like: seed plantation, livestock keeping, irrigation methods, mechanized farming, land leveling and application of herbicides (Chapter5.1.3)

5.3.6 Land use

Land use changes have to be confirmed officially though an intense administrative process. Natural conservation is not a supported form of land use. Also stabilization of range lands is limited and efforts get compromised by free grazing livestock and other reasons.

Land defragmentation has a high potential for farmers that take up collaborative action. Nevertheless these measures have a limited uptake in Roodasht.

Cultivated area in Roodasht is classified officially as agricultural land use (see agricultural area in Figure 5-7). Changing utilization of agriculture land to environmental conservation or other productive forms like solar farms (which also prevents soil erosion), is considered a change in land use[14].

14 Apparently few farmers in the upstream region of Roodashts, in proximity to Isfahan City try to set up orchards and get permission to build a house inside the orchard and fence the area. The land price multiplies for such plot and it’s likely that land would rather be used as green weekend domicile for people from Isfahan, than for income generating farming. This would be an informal land use change.

According to the "Act to preserve agricultural land use" (1/8/1385), land use changes of arable lands have to be requested and are decided on by a committee composed of provincial representatives of the Isfahan Agricultural Organization, Housing and Urban Development, Environment agency, the Governor and is chaired by the department of Land Affairs in Isfahan Agricultural Organization.

In general, preservation of agricultural land use and maintaining their productivity is the main objective of this committee in order to reach the ambitioned agricultural development goals of Ministerial plans and maintain employment capacity of agricultural land use.

Nevertheless the "Act to preserve agricultural land use" doesn't consider the construction of greenhouses, livestock, poultry, fish, other agricultural products and complementary industries as land use change, but as improvement of rural food production and agriculture. When complying with environmental regulations these types of land use change can be approved directly from the Isfahan Agricultural Organization.

In general no programs or efforts for natural conservation on private lands are in place in Roodasht. Conservative agriculture, mulch farming, environmental conservation approaches or plantation of live wind breaks around the fields to avoid wind erosion could not be found in Roodasht.

In the border areas of Roodasht, on governmental land, few approaches have been made to increase natural vegetation of range lands for erosion and desertification control. Experts discuss the plantation of native consistent plants as Haloxylon, Calligonum Seidlitzia rosmarinus, Nitraria Schoberi, Artemisia Sp. flanked by rain water harvesting and storage, irrigation of range lands as well as mulching for desertification control of range land. Experts state that these efforts in rangeland are subverted by water scarcity, wind erosion as well as grazing of free range livestock (high numbers) and mining activities in the region.

The defragmentation of agricultural land is a sub-form of land use change, supported by the Isfahan Agricultural Organization (with 85% of funding). A large part of farmers in Roodasht own small farms that are fragmented to different plots, which is typical for Iran (Ahmadpour et al. 2013). Kalantari et al. (2008) and Soltani (1978) point out, that the size and fragmentation of plots is an important factor for yields and production costs. Arsalanbod (2000) shows that for wheat production a 1% increase in farm size or 1% decrease in fragmentation of plots, both causes a 0.4 % decrease in production cost.

The uptake of land defragmentation measures is, besides of few examples like Ghurtan Village, generally low in Roodasht, since it requires an intense cooperation and collaboration amongst farmers, establishment of a cooperative company (see chapter 5.1.4) as well as a certain extend of know-how and investment capacity of farmers' households (see chapter 5.1.2).

5.3.7 Infrastructure

Irrigation networks are partly modern and partly traditional in unlined channels.

Drinking water, energy and other infrastructure is mainly available in cities and villages but in rural areas.

There are only limited processing industries and no other industries in the region. Processing industry has a focus on livestock and vegetable packing and is heavily challenged by drought conditions.

Touristic infrastructure and eco-tourism infrastructure and activities are not present in the region.

Irrigation conveyance infrastructure in Roodasht was modernized with lined primary and secondary channels in 2002 for Roodasht left (north) and 2005 for Roodasht right (south). However, the terminal section of Roodasht right is not yet modernized and particular in the region around Varzaneh, traditional earthen channels are still in use (Figure 5-20). The Isfahan Agricultural Organization is putting effort into supporting farmers to line channels or to pipe water on Village/tertiary/Sahra level.

According to data from the Isfahan Regional Water Company, conveyance efficiency (delivered water/Inflow at Headwork) of the irrigation network ranges from 74-85% between 2004 and 2015[15].

The drainage system has a vital function for agricultural productivity in the region, due to apparent 1) low water infiltration rates, 2) partly high ground water levels, and 3) low quality of irrigation water. According to local experts, the modernization of the irrigation network was not accompanied by sufficient revision of the drainage systems which was one factor for ongoing salinization of soils. Due to limited data availability, no specific information on the design of drainage networks could be included in the report.

15 Analyzing the effects of modernized irrigation channels on the water transfer efficiency is beyond the scope of this report. When doing so, the effects on groundwater recharge by concrete lining of channels should be considered.

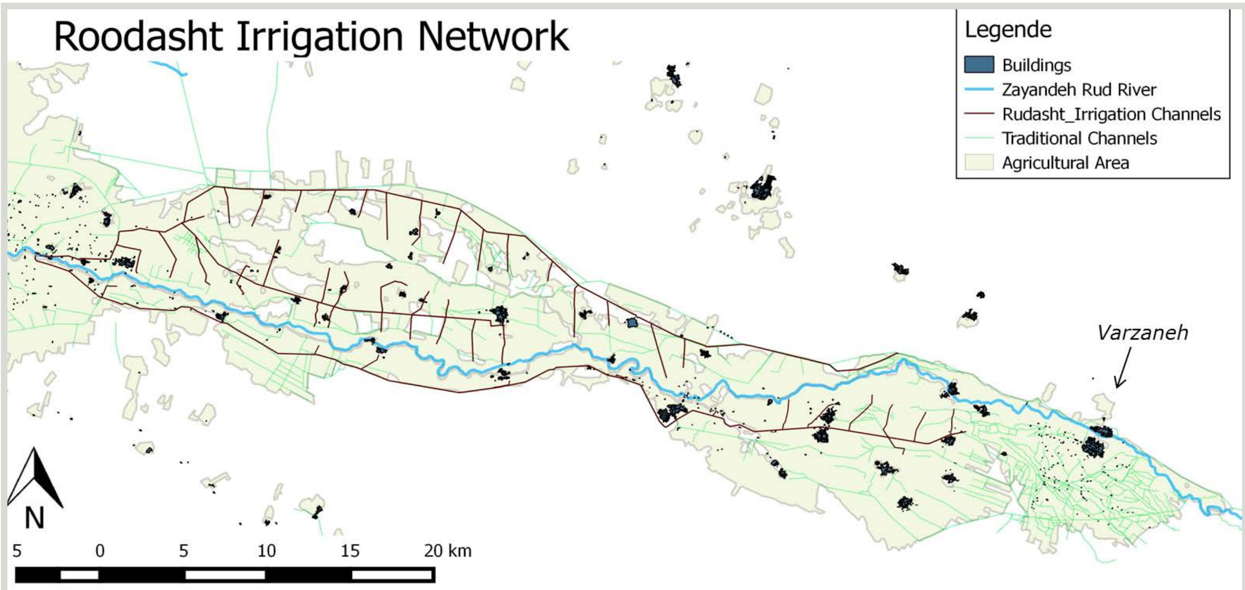

Figure 5-20: Irrigation network Roodasht area.

Experts state that investments in roads, gas pipelines, power supply lines, drinking water supply and sanitation are restricted to the larger villages and cities of the region. Farmers state that they have to construct electric conveyance poles with own capital if requiring electricity on the field (e.g. Greenhouses). Experts state that missing infrastructure (particularly power and drinking water supply) in areas out of industrial settlement is restricting small-scale industrial development in the region. Relying on the statement of an expert from industrial settlement company, however the industrial settlement of Varzaneh has sufficient infrastructures for industrial development. But in practice there is no interest for industries to develop and invest their activities there, because (1) the settlement is located relatively far from Isfahan city and product marketing may be difficult, (2) local people dispose not of sufficient how-know for operation of processing facilities and training or extension facilities are missing, and (3) lack of adequate financial supports or incentives to attract investors.

Industrial sites and processing industry are limited in Roodasht area. Table 5-6 presents units of agricultural processing industries in the Region. 2/3 of the 13 identified units are located in Jolgeh District, which is located closer to market facilities and transportation hubs at Isfahan city. Only one facility is a cooperative operation and only one has more than 120 employees, the others are with 5 to 32 employees relatively small with only limited employment opportunities for local communities. One facility produces organic fertilizers, two livestock feeds and four other process livestock products (milk and egg). The other 6 processing industries mainly dry and pack various vegetables with a total demand of raw vegetable of almost 30.000 tons.

Figures on crop production presented in Figure 5-18 show that this demand could only be fulfilled locally in years with high agricultural production between 2006 and 2008. In dry years, processing facilities are expected to import raw vegetables from other regions or are forced to diminish their production. Experts report, that some dairy processing facilities have closed down in the dry years.

This situation highlights the uncertainty affiliated to the agricultural sector in the region, with the effect, that investors and entrepreneurs perceive investment in agriculture and processing facilities as not attractive. Nevertheless at least one cooperative company for livestock production with 360 members, creating 160 additional jobs and reviving of about 700 inactive husbandries, is currently being developed in the region as a partnership project of around 150 billion IRR volume with 85% governmental funding.

In general the types of processing industry show that there is no processing for high value and alternative crops like medical plants, saffron or oil production from safflower present in the region.

Table 5-6: Active processing Industry in Roodasht area (source: Isfahan Agricultural Organization).

District	Brach	Nr. of employees	produts	Nominimal prodution [tom]	Raw material	Raw material amount [ton]
Bon roud	milk	10	dairy production	3000	raw milk	3000
Bon roud	livestock feed	5	poultry & livestock feed	4800	agriculture products	1752
Bon roud	fertilizer	9	enriched manure of poultry & Livestock	9600	-	0
Bon roud	livestock feed	17	varius poultry & livestock feeds	24000	1wheat, Barley, maze, ...	17100
Jolgeh	milk	20	dairy products	14600	raw milk	15000
Jolgeh	milk	12	dairy products	7650	raw milk	6000
Jolgeh	vegetable	32	dry vegetables production & packing	200	vegetables	3500
Jolgeh	egg	30	egg	12096	egg	14400
Jolgeh	vegetable	8	dry vegetables	46	vegetables	120
Jolgeh	vegetable	13	dry vegetables packing	350		5250
Jolgeh	vegetable	10	dry vegetables production & packing	100	vegetables	2000
Jolgeh	vegetable	17	dry vegetables packing	150	various vegetables	1800
Jolgeh	vegetable	121	freezing & packing fruits vegetable & meats	16950	various vegetables &meat	16962

Next to the processing industry experts state that there are around 70 active (partly traditional) mines present alone in Bonroud district.

The Gav Khuni wetland and surrounding area has potentials as a touristic areas with various attractions, such as sand dunes, wetland, the traditional and historical monuments and rare fauna and flora. This area is well suited for traditional and modern touristic activities such as observing animals, camping, staying in traditional motels, motocross and dune buggying on the sand hills, as well as camel and horseback riding and various possibilities for day trips. The region has historical heritages and attractions like the Ghurtan citadel, Jame mosque of Varzaneh, historic bridge crossing Zayandeh-Rud river, Kabutar Khaneh (pigeon house), wind towers, Gav-chah (traditional water extractions method) and other attractions.

Nevertheless, the basic touristic infrastructure is weak in the area, but generally the potentials for attracting domestic and foreign tourists to Roodasht region and Gav Khuni area are not enough to provide secure income source for significant number of local people. Besides, the ecotourism in the region is depended of water flowing into the Gav Khuni wetland since recent water scarce conditions have been damaging severely its ecosystem and natural biodiversity. There are few NGOs that are concern about tourism industry in the region. These NGOs state that their goal is to create a cooperative company for tourism in Roodasht and that environmental conditions are crucial for future development of the sector.

5.4 External biophysical factors

External biophysical factors refer to characteristic of biophysical conditions that could influence farmer´s vulnerability. These include climate change and variability as well as environmental and ecosystem change.

5.4.1 Climate change and variability

Climate change and variability are reported in the region. Temperatures are expected to increase, causing a higher water demand with increased evapotranspiration in agriculture.

At the same time variability of precipitation is expected to increase which can be observed already in the past decade in Roodasht. Basin wide precipitation is in sum expected to decrease.

Climate change and variability coupled with increasing water demand, is expected to intensify the current water scarcity in the basin stressing particularly agriculture and the environment. Gohari et al. (2013) project a 1.1 to 1.5 °C increase in monthly temperature and 11–31 % reduction in annual precipitation causing higher irrigation water demand by crops in the Zayandeh-Rud basin during the near-term future (2015–2044).

A climate change Report of the Technical University of Isfahan (Eslamian et al. 2016) predicts the change in temperature and precipitation in the Zayandeh-Rud basin according to two scenarios[16] for all weather stations in the basin. The report projects a 0.6-1.1°C increase in average temperature and a change in annual precipitation from -0.53 to +0.42% during the near-term future (see Figure 5-21) (2015–2044). Based on the figure, the average monthly temperature is increased for both of two emission scenarios. The maximum and minimum temperature increase occurs in summer (September) and winter (January) respectively. The January, February and March are found to have the maximum precipitation decrease in comparison with other months whereas in fall between October and November, a relative increase of precipitation is expected. The A2 emission scenario shows more annual precipitation decrease than the B1 emission in Zayandeh-Rud basin.

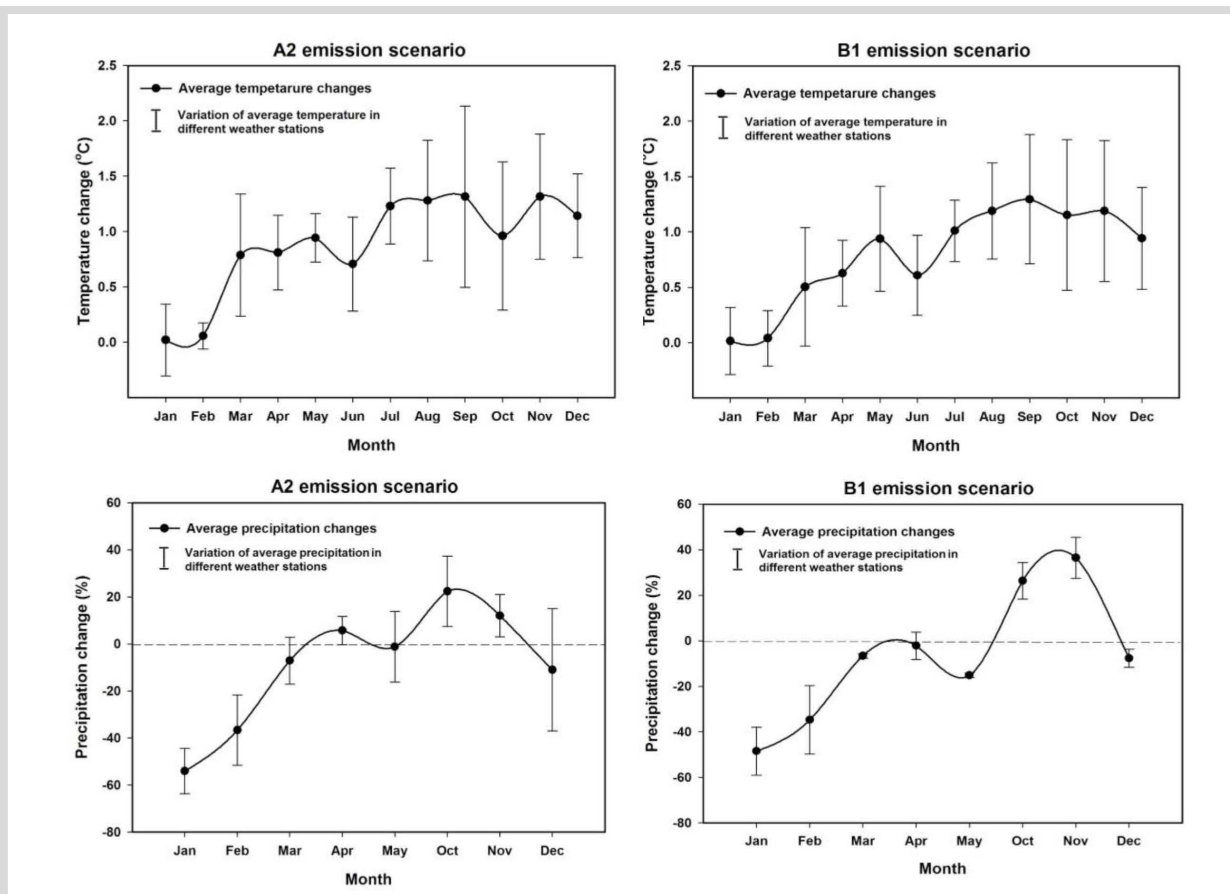

Figure 5-21: Average monthly temperature and precipitation changes in different weather stations for A2 and B1 emission scenario during the near future (2015-2044) in Zayandeh-Rud basin (source: Eslamian et al. 2016)

16 IPCC (Intergovernmental Panel on Climate Change) Scenario A2: Population growth, regionally oriented economic development of self-reliant nations. Scenario B1: population growth, less material intense industry, more service and information economy, emphasis on ecologically friendly global solutions.

For Roodasht region the climate change report suggests the change in temperature and precipitation between the cities of Isfahan and Varzaneh. The study presents an increase in temperature of all seasons during the period 2015-2044 with the least increase in winter (0,3-0,4 °C) and the highest increases in summer (1.4 °C) and autumn (1,2 °C) respectively. The amount of rainfall is predicted to decrease in the winter (0.16-0.20 mm) and to increase in Fall (0.1-0.4 mm) (Table 5-7).

Table 5-7: Climate Change scenario for Roodasht region until 2044 (IUO, 2014).

	Winter		Spring		Summer	Fall	
	T [°C]	PPT [mm]	T [°C]	PPT [mm]	T [°C]	T [°C]	PPT [mm]
Scenario A2	+0.38	-0.2	+0.83	+0.03	+1.42	+1.16	+0.11
Scenario B1	+0.28	-0.16	+0.73	-0.18	+1.05	+1.2	+0.42

The highest increase in monthly rainfall is predicted for October (A2: 0.17 mm and B1: 0.69 mm) in Varzaneh and the most significant decrease in rainfall is predicted in January (A2: 0.36 mm and B1: 0.41 mm) (see Figure 5-22).

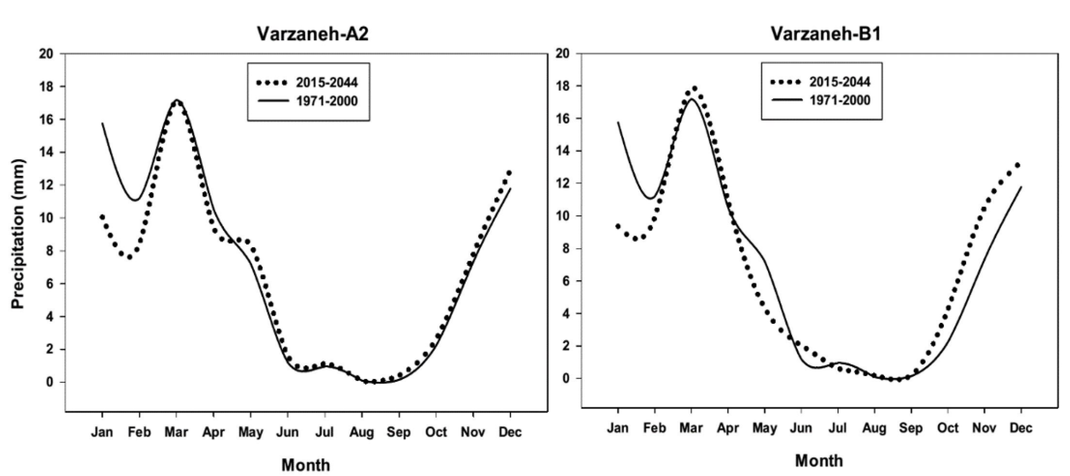

Figure 5-22: Monthly precipitation in Varzaneh region in 2044 according to Scenario A2 and B1 (IUO, 2014).

In the past decade, strong variance in natural precipitation was experienced in the whole catchment but particularly in the area around Roodasht. Figure 5-23 presents the variance of precipitation at Varzaneh climatology station ranging from 10-180 mm/a. The figure shows that variance of precipitation has been increased in the past decade, but that a slight long term upwards trend can be found in annual precipitation.

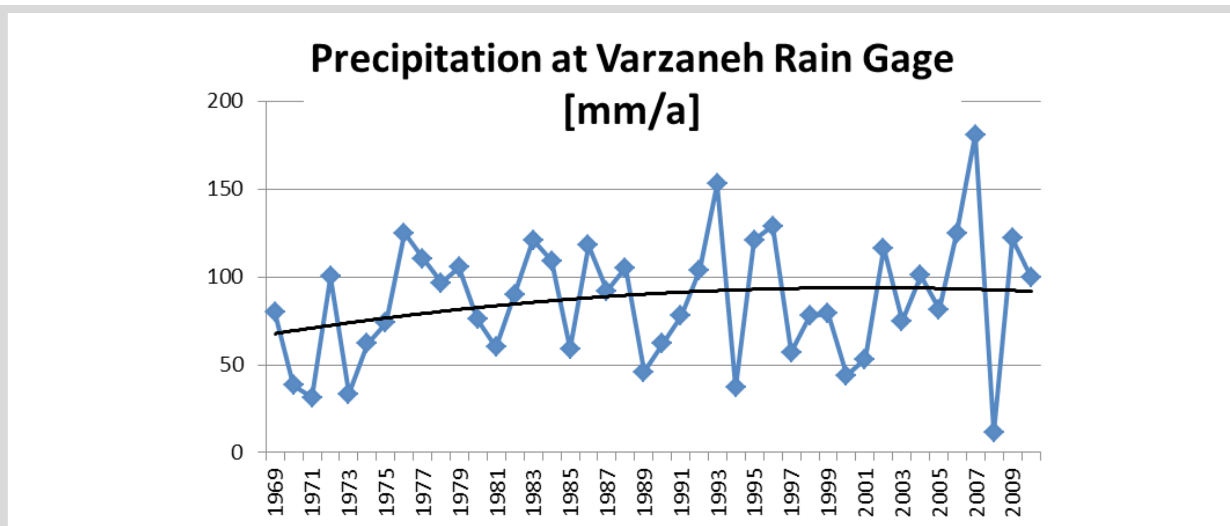

Figure 5-23: Annual precipitation in Varzaneh [mm/a].

The combination of rainfall deficiency and high temperature in Roodasht, creates a serious risk of drought when there is no distributed surface water to supply water requirement of cultivated crops. In order to investigate the rainfall variance and deficiency in the region, the Standardized Precipitation Index (SPI) has been computed for the Varzaneh climatology station for the 12 month time scale covering 1968-2014 (see Figure 5-24).

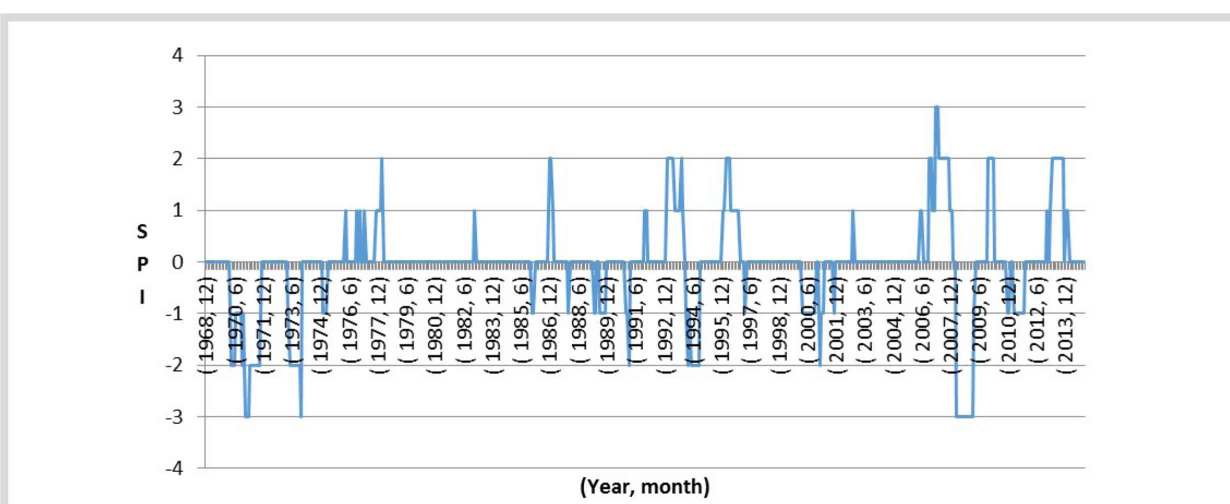

Figure 5-24: Standardized Precipitation Index (SPI) for Varzaneh climatology station.

Applying the method of drought classification based on the SPI suggested by McKee et al. (1993) presented data for Varzaneh weather station indicated that the region has faced severe to extreme droughts in the years 2001, 2008 and 2011. However during the past decade more wet years have been recorded than dry years.

5.4.2 Environmental and ecosystem change

Environmental degradation though desertification is an ongoing process in Roodasht. Loss of natural ground cover, limited agricultural activities, strong wind, and salinization of soils are drivers of further desertification. Gav Khuni wetland is drying out and makes micro climate worst and hazardous dust storms probable.

As on can see in Figure 5-25, the land cover and environment around Roodasht irrigation network is dominated by desert and poor vegetated range lands. This environment makes the Roodasht area particularly prone to heavy impacts by the harsh environment.

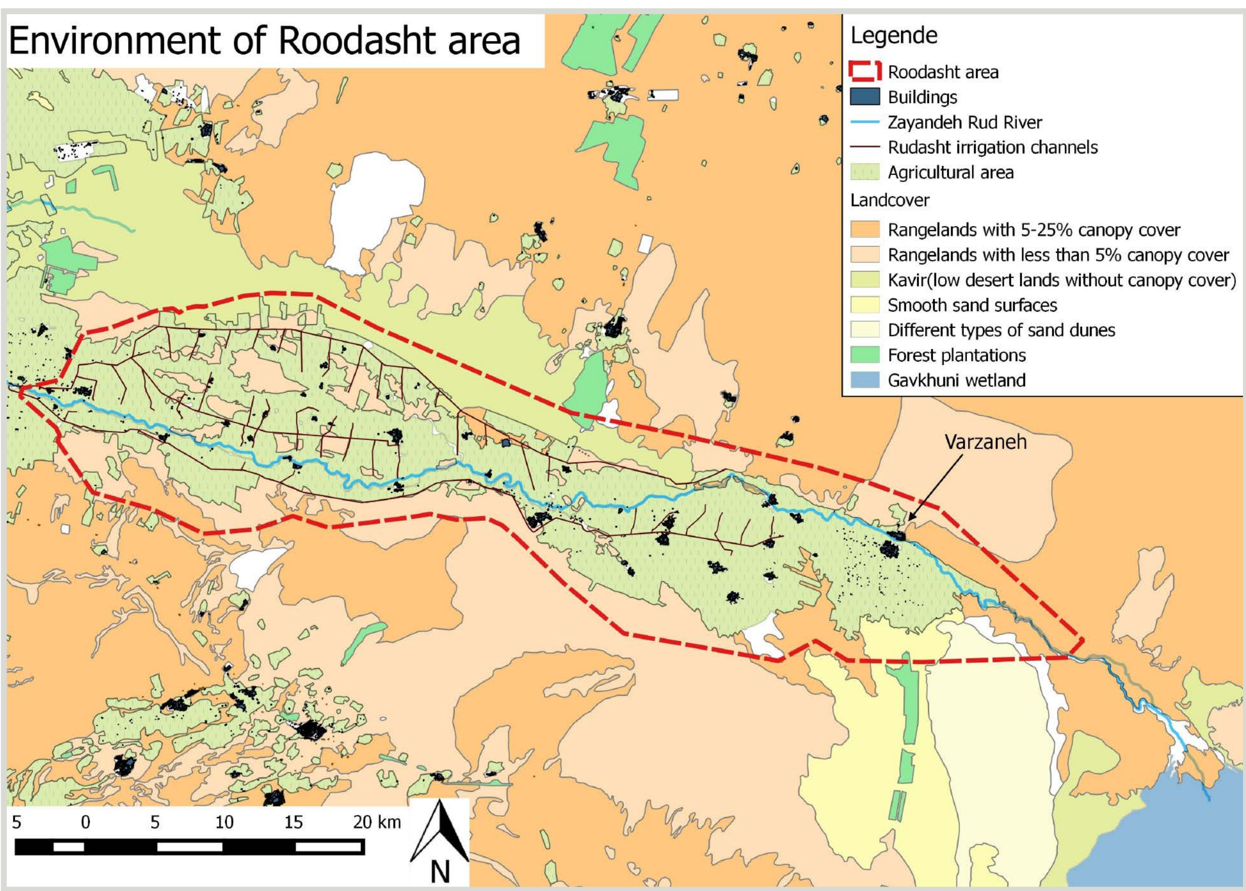

Figure 5-25: Land cover around Roodasht irrigation network (data source Isfahan Water Company).

Environmental change in the region is characterized by an ongoing desertification process with rapid land degradation, triggered mainly by erosion and deterioration of soil quality. Furthermore dropping groundwater tables are a fact in the region.

Land degradation

Land degradation is driven mainly by the following 5 processes:

1. The available amount of water for agriculture and the environment in the project area at the tail end of the Zayandeh-Rud catchment decreased in the past decade;
2. The water quality of the Zayandeh-Rud river has downgraded in the past years due to population growth, industrial and agricultural development in the basin. Also the Ground water quality decreases;
3. Absence of conservative agricultural practices with permanent crop cover, mulching or low tillage as well as excessive application of mineral fertilizers on agricultural fields;
4. No wide application of conservation or stabilization projects for desertification control;
5. The transformation of natural areas into urban or agricultural areas, free livestock grazing as well as mines also degrades the quality of remnant range land patches (Bateni et al., 2012);
6. Strong winds and dust storms of up to 16 m/s foster wind erosion.

These processes affect the land resources particularly in the border areas to the desert in the following ways.

Soil erosion:

- Wind erosion leads to a loss of the fertile top soil layer. The regionally typical soils with high clay content and soil dispersion due to Sodium Ions (alkalinity) are very prone to wind erosion when dried up and no natural vegetation breaks the wind. Wind erosion of the fine textured clay soils also lead to the environmental hazard of dust storms with micro dust;
- Plots are not arable anymore if farmers pause cultivating them due to water scarcity. Coverage with desert sand and wind erosion makes fields uncultivable;
- Irrigated plots which are not leveled as well as natural areas around drainage channels are affected by water erosion and show gullies.

Natural Vegetation Cover:

- Due to overgrazing, wind erosion and decreased water availability in the region, the natural vegetation cover has been diminished and conservation projects are contradicted.

Soil Quality:

- Soils are getting saline (up to 14 ds m-1 in Roodasht) as well as alkaline and loose productivity (see chapter 5.3.1). Polluted surface can have high salt concentrations (up to 6 ds m-1 in Roodasht) (Salemi et al., 2000), Groundwater has even higher salt concentration (up to 25 dS m-1), irrigating with it and adding mineral fertilizers (nutrient salts) coupled with a lack of rain or irrigation water for leaching salts to the groundwater makes a salinization of soils inevitable.

The severe outcomes of the land degradation process could be observed particularly in the border areas to the desert in the downstream region of Roodasht. Large agricultural areas have been abandoned due to poor soil and water quality in the past decade. This phenomenon is highlighted by a photo of the border region in Figure 5-26 and satellite images with diminished agricultural areas of the past decade in Figure 5-15.

Figure 5-26: Abandoned agricultural fields in the border area to the desert south east of Varzaneh (Photo: Raber).

Next to agricultural fields, the degradation of rangelands and ongoing desertification process is also reported by local and provincial experts. “Dryness, salinity, alkalinity, gypsum bearing soils and man-made factors, have worked together to remove and degrade the vegetation and plantation cover” are words used by an expert to describe the conditions of the natural range land around Roodasht. Also Barzani and Salleh (2015) present a high desertification hazard of the arid and semi-arid Roodasht region. Iranmehr et al. (2015) underline natural degradation and development of saline soils during the past decade in the eastern part of the Zayandeh-Rud Basin as well as a shrinking Gav Khuni wetland.

River’s water quality

The river water quality in the downstream region of the Zayandeh-Rud has decreased analogue to urban, industrial and agricultural activities in the basin, threatening the ecosystem and water users in Roodasht.

In order to evaluate water quality in the Zayandeh-Rud river in Roodasht area, the IRWQIsc[17] index was used by Isfahan Department of Environment. The index is considered the most suitable indicator for evaluation of surface water quality in Iran.Table 5-8 presents the classification of water quality according to the IRWQIsc in different years on five stations along the Zayandeh-Rud river, in Abshar and Roodasht region, from Poli Choom to Pole Varzaneh station. It can be seen that the water quality is in general rather poor and dropped over time and along the flow path of the river. It is expected that reasons for deterioration of water quality are discharge of agricultural drainage water and domestic as well as industrial waste water.

Table 5-8: Classified water quality for different years along the Zayandeh-Rud river according to the IRWQIsc (Source: Data from Isfahan Department of Environment)

Year	Abshar region		Roodasht region		
	Pole Choom	Pole Ziar	Pole Eghie	Pole Oshkohran	Pole Varzaneh
2010	Rather bad	Rather bad	Bad	Bad	Bad
2011	Rather bad	Rather bad	Rather bad	Rather bad	Bad
2014	Bad	Bad	Bad	Bad	Bad
2015	Bad	Bad	Bad	Bad	Very bad

17 Iran Water Quality Index for Surface Water Resources-Conventional Parameters, computed from 11 water quality factors including COD, BOD, Oxygen, EC, total Coliforms, Nutrients (N&P), pH, Hardness and Turbidity

a b

Figure 5-27: Photos of the situation of the Gav Khuni wetland: (a) in the past (normal regime state), and (b) at present (abnormal regime state) (Sarhadi and Soltani, 2013).

The natural function of the wetland by the complex interactions of soils, water, plants and animals, particularly for stabilization the shoreline and erosion control, groundwater recharge and purification as well as stabilization of the local micro climate conditions in terms of rainfall and temperature have been diminished in the past years (NWCSAP, 2011). Wind erosion in dried out Gav Khuni wetland was reported by several presenters in the World Wetlands Day (2.2.2016 in Isfahan).

Wind erosion and dust storms in Roodasht area are currently discussed amongst experts as a serious hazard for environment, agriculture and people. Due to the drying out of the Gav Khuni wetland in last several years, experts believe that wind carries away micro dusts from fine silt deposits of the formerly wet area. These silts may contain dangerous heavy metals or other toxic materials origin from polluted water that evaporated or infiltrated in the wetland over decades. Relying on the experts' statement, the annual dust fall rate in areas near to Gav Khuni wetland is about 50 tons/km2 and micro dustry may be carried over large distances up to Isfahan. Particularly respiratory and cancerogenic diseases are feared by this dangerous phenomenon. Interviews with experts and researcher on health issues indicated that local people in Roodasht have experienced mental and physical diseases with an upward trend. Unfortunately during research, no official data or investigation in the regard could be found.

The ongoing drying out of the wetland can be observed with satellite images from the BMBF IWRM Zayandeh-Rud project which present the development of the Gav Khuni wetland from 2007 till 2016. Figure 5-28 shows the wetland in May 2007 with water being present in the wetland. In Figure 5-29 the dried out wetland in May of the years 2010, 2014 and 2015 can be observed. And finally Figure 5-30 presents a time series with inflow of water to the wetland between December 2015 and March 2016 where an environmental water right hast been enforced (see chapter 5.2.2).

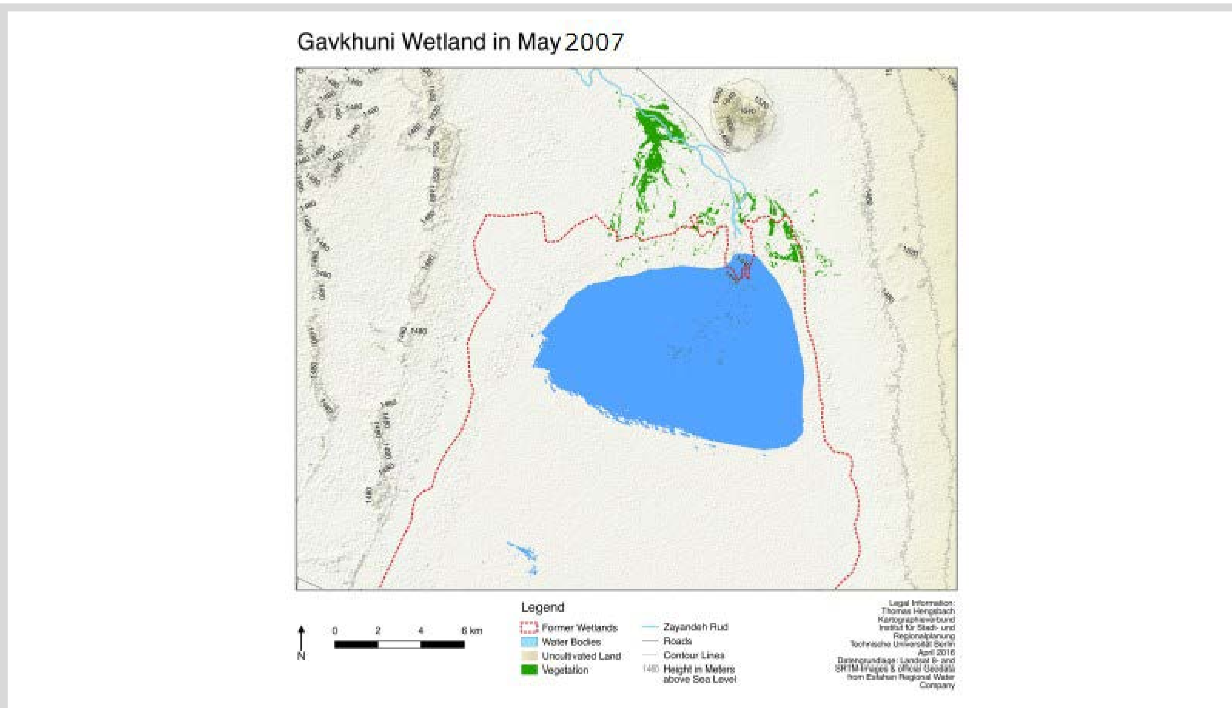

Figure 5-28: Gav Khuni wetland in May 2007 detected by remote sensing (source: Technical University of Berlin, Hengsbach).

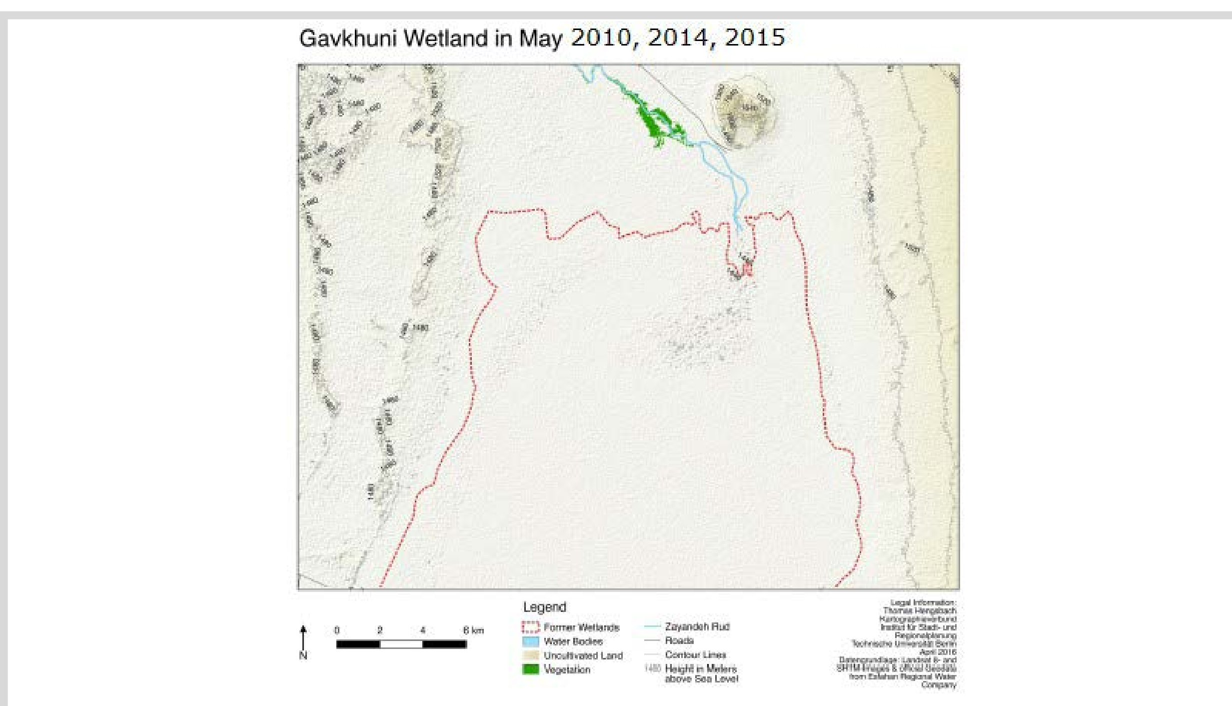

Figure 5-29: Gav Khuni wetland in May 2010, 2014 and 2015 detected by remote sensing (source: Technical University of Berlin, Hengsbach).

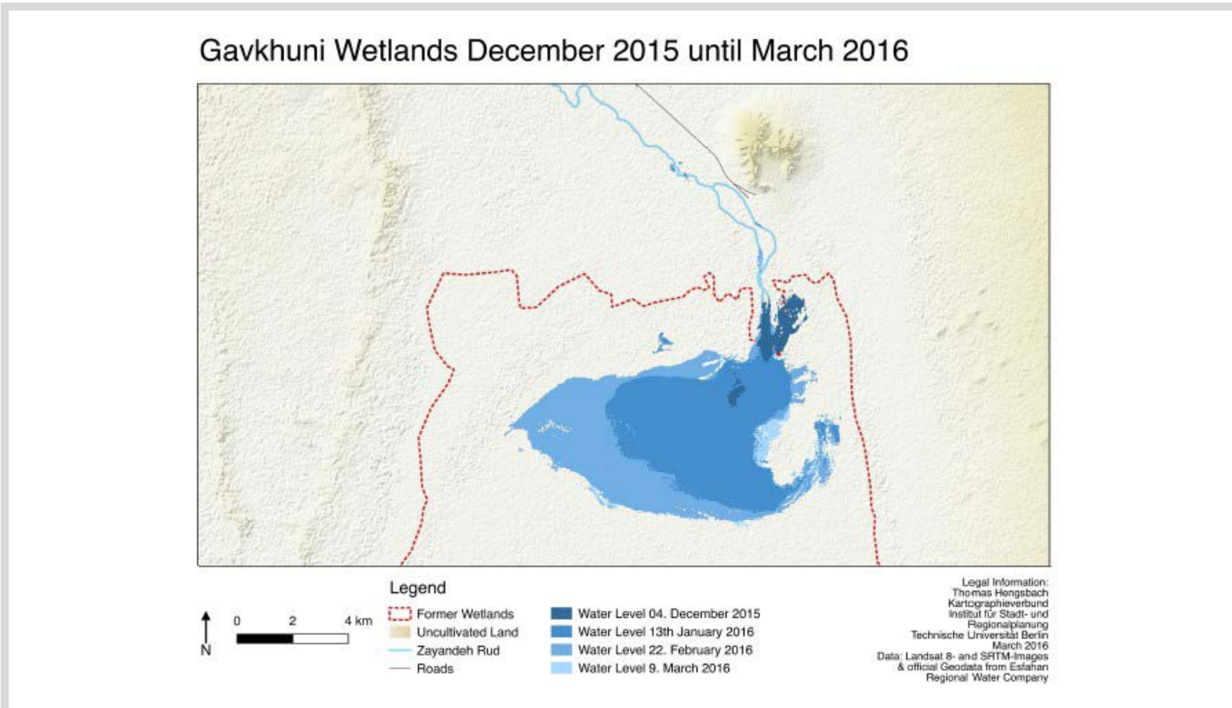

Figure 5-30: Gav Khuni wetland from December 2015 till March 2016 detected by remote sensing (source: Technical University of Berlin, Hengsbach).

6 Conclusion

The study at hand assesses the vulnerability of farmers in the Roodasht region towards water scarcity.

With the application of an adapted conceptual framework from Füssel (2007), 16 socio-economic and biophysical vulnerability factors have been classified. By an integrated analysis of these factors, a growing vulnerability could be found in interconnected fields:

1. Poor and uncertain **water availability** in Roodasht during the past water scarce decade, caused by little and unstable diversion of surface water to the region and a connected reduction of quality and availability of local groundwater resources;
2. Low **agricultural production** with little diversification of products, mainly driven by limited availability of irrigation water, ongoing salinization and alkalinity of soils as well as missing modern and efficient farm management;
3. On farming dependent **livelihoods** with high risk of poverty, limited investment capacities and a risk of abandoning agriculture followed by migration.
4. Inhibited regional **entrepreneurship** limiting local employment options and markets. Main causes area uncertainty in future water availability, poor infrastructure as well as missing collaborative initiatives and investment capacity of local farmers;
5. Poor efforts in on- and off-farm **environmental conservation** in the region, due to lacking initiatives, local execution, hindering policies and little environmental awareness of farmers.

Since the mentioned factors and conditions have till now not been targeted with powerful measures or actions plans, two main risks could be identified which are expected to grow and come to a crisis in the near future: desertification/land degradation and social conflict.

- A high risk of desertification is founded in soil erosion and salinization, abandoned agricultural lands, little desertification control and environmental conservation, and drying out of Gavkhuni with its central function of stabilizing the local microclimate. This may have severe impacts on agricultural activities and human settlements in the whole region, risking the regional environment to degrade and making the region uninhabitably. Long term effects on the neighbouring Abshar irrigation network and even Isfahan city, with increasing sand and dust storms, carrying polluted micro-dust from the wetlands sediments and changing microclimate are possible.

- A high risk for social conflicts is the short and long term effect of a feeling of farmers to be deprived by decision-makers and the risk of impoverishment. The traditional form of farming is eroding and the only options seem to be to migrate to cities or remain in poverty in the area. This setting already caused several, also violent, protests but may escalate in the future.

In the study, could be concluded that the adaptive capacity of farmers to cope and adapt successfully to given conditions: economic resources, collaborative networks, knowledge and information, and infrastructure and technology are currently low in Roodasht, but may serve as possible entry point to develop strategies for a sustainable land use and management concepts in Roodasht (see Figure 6-1). The authors believe that as important precondition for any adaptive capacity to unfold, water distribution on basin level must be rehabilitated in a reliable and transparent way.

- **Knowledge and information** dissemination are key factors for farmers for understanding the drivers of their current vulnerability and to developing adapted solutions. Informed local people can also participate in regional planning with governmental institutions. Participation of farmers, focused information and training campaigns could for example be implemented for developing and promoting changes of farm products, to enable farmers to follow other jobs and develop local business or to increase farmers' awareness on environmental conservation and show opportunities for their livelihoods though these practices.

- Access to **economic resources**, e.g. by targeted funding, public private partnerships or governmental incentives might empower farmers to invest in farm modernization and water efficient agriculture or to set up local processing facilities collaboratively. Furthermore, financial incentive could empower farmers to follow less water intense conservative (agricultural) activities.

- Support and facilitation of **collaborative networks** e.g. by targeted coaching and information campaigns may enable farmers to create powerful cooperative companies. Functional cooperative companies may lead to higher uptake of land defragmentation projects, sharing farming equipment or even establishment of cooperative commodity chains which create jobs and income for farmers' livelihoods as well as markets for alternative crops. Furthermore, strong collaborative networks may empower local people to implement alternative income activities like eco-tourism.Improved access to adapted **infrastructure and technology** may empower farmers to adapt their farming system to more soil conserving and water efficient farming practice. Introducing environmental technologies such as decentralized energy production, flanked by some logistic infrastructure could enable development of local processing industry and give new adapted land management options for local people.

In Appendix V a comparison of the presented results with previous studies is presented.

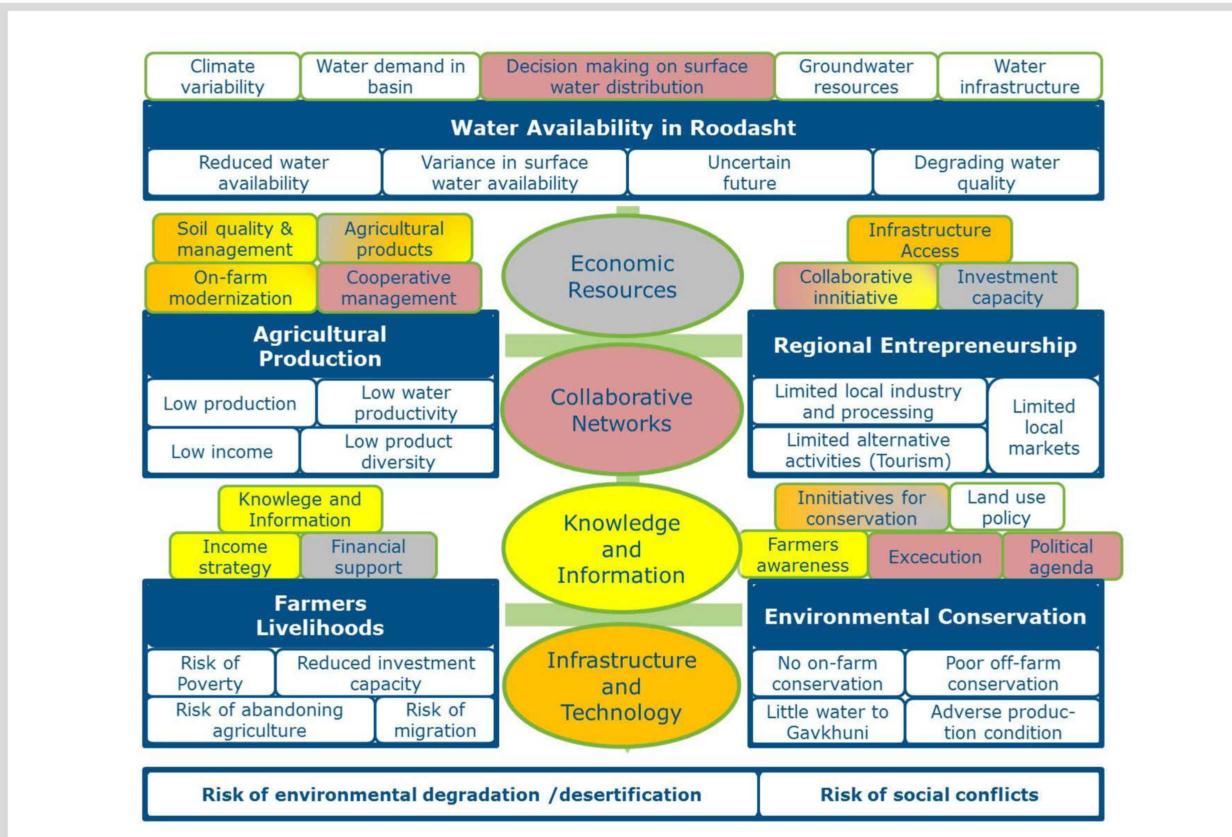

Figure 6-1: Concept scheme on potential influences of adaptive capacity on different aspects of vulnerability (source: inter 3).

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Appendix I: Literature review vulnerability assessment

The conceptualization of vulnerability varies significantly across research domains, and has evolved for each research domain over time. In this section the different academic research approaches towards vulnerability to climate change are characterized, but the evolution of conceptual approaches over time is not discussed in detail, (Kasperson et al. (2005) provide a review of this evolution). Regarding the various roots and conceptualizations of the vulnerability research, Füssel (2007) concludes that there is no single 'correct' or 'best' conceptualization that would fit all assessment contexts and needs, and that concepts have to be adapted locally according to specific objectives.

Adger (2006) classifies reviewed vulnerability research approaches in disaster research and research on entitlements. The disaster literature focuses on vulnerability and adaptation of social-ecological systems to natural hazards, whereas the term social-ecological system refers to a linked system of ecological and social system as defined in Carpenter, et al. (2001) ."…the term 'social-ecological' system to emphasize the integrated concept of humans in nature and to stress that the delineation between social and ecological systems is artificial and arbitrary." (Folke et al., 2005: 443)

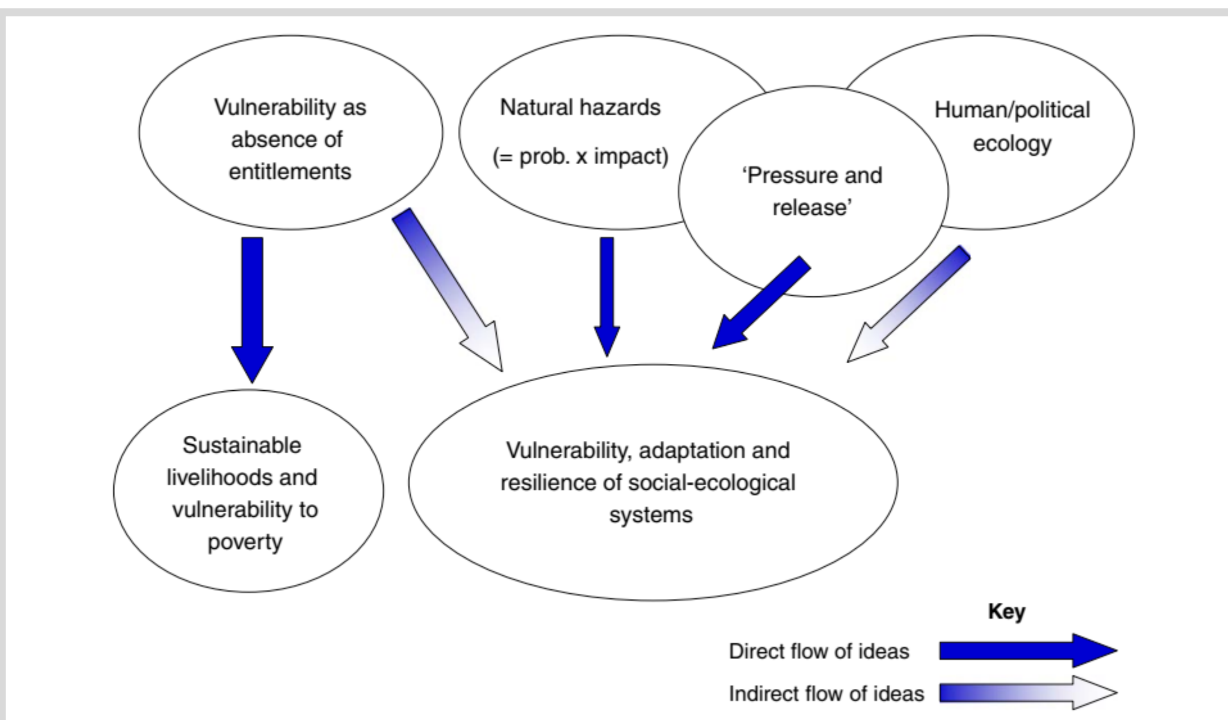

Figure 1: Traditions in vulnerability research and their evolution (source: Adger, 2006:271).

Entitlement research has origins in development economics and sees vulnerability as absence of entitlements, threatening sustainable livelihoods and susceptibility to poverty and famine (Adger, 2006). The pure entitlement research branch will not be discussed in further detail. The disaster research tradition includes the fields of (1) natural hazards research (also called Risk-hazard approach in Füssel (2007)) mainly shaped by Burton et al. (1978 & 1993) and (2) political economy (or human ecology) (see figure above).

Natural hazard research explores the biophysical aspects of vulnerability by conceptualizing the impact of a hazard as a function of exposure to the exogenous hazard event and the dose-response (sensitivity) of the entity exposed and its adverse effects. Vulnerability is the amount of (potential) damage caused to a system by exposure to frequency and severity (or probability of occurrence) of a specific climate related event or hazard. The approach is concerned with the damage (outcome) experienced by a system with a specific sensitivity via exposure to hazards. This type of vulnerability is sometimes referred to as internal or biophysical vulnerability (Füssel, 2007). It is defined as the "nature of the hazard and its first-order physical impact, and a biological or social component associated with the properties of the affected system that act to amplify or reduce the damage resulting from the first-order impact." (Adger et al., 2004:29)

Adger et al. (2004) and Brooks et al. (2005) conceptualize risk (biophysical vulnerability) as a probabilistic occurrence of climate-related disasters comprising meteorological (physical) hazard events that are then mediated by the vulnerability of the exposed system.

Biophysical vulnerability = f(hazard, social/inherent vulnerability) (Adger et al., 2004:40)

This descriptive approach provides insight as to the distribution of hazardous conditions, effects on people and structures and an estimation of potential damages (Füssel and Klein, 2006; Hebb and Mortsch, 2007; Turner et al., 2003). However, the ability of people to cope with hazards receives only minor attention. Hence the role of political economy, institutions and social structures of the system in shaping exposure, sensitivity and adaptive capacity are relatively ignored in this framework (Turner et al., 2003). Indicators in this biophysical approach might include: monetization of damages, human mortality figures, reconstruction costs, or ecosystem damage (Adger, 2004).

The political ecology approach applies an explanatory model of socioeconomic vulnerability to multiple stresses. Vulnerability is the internal state (inherent property) of a system that makes human society susceptible to damage from external hazards whereas the nature of hazard is not specified (Adger, 2004). This 'social science' definition is often referred to as social vulnerability because it describes and characterizes the conditions of a system as being composed of socio-economic factors like socioeconomic inequality among and within a social system, and the ability of different groups to anticipate, cope with, resist, recover from or adapt to an external stress (Adger, 2006; Fuessel and Klein, 2006; Hebb and Mortsch, 2007; Turner et al., 2003). In this conceptualization, vulnerability is determined by factors such as poverty and inequality, marginalization, food entitlements, access to and the ability to mobilize resources, which links political ecology to research on entitlements (Füssel, 2007). It is essential to stress that vulnerability of a specified system or exposed unit is critically dependent on the nature of the system and the specific hazard or range of hazards (Adger et al. 2004; Brooks et al., 2005). In this concept hazards refers to physical impacts.

Recently, scholars from both research traditions have attempted to combine internal factors of a vulnerable system with its exposure to external hazards in more or less integrated vulnerability frameworks. Examples of this blended conceptualization include the 'pressure and release model' by Blaikie et al. (1994), the 'hazard of place model' by Cutter (2003) and the 'coupled vulnerability framework' presented in Turner et al. (2003).

The pressure and release model addresses the shortcomings of hazard research by conceptualizing the vulnerability of a social group as a product of physical or biological hazards (i.e. the external dimension of vulnerability or exposure) with an internal dimension (sensitivity and adaptive capacity), which is the cumulative progression of inherent social characteristics of the exposed unit (root cause, dynamic pressure, unsafe condition). This internal dimension makes the system either susceptible or able to cope with external stresses (Adger, 2006; Blaikie et al., 1994; Fuessel and Klein, 2006; Hebb and Mortsch, 2007; Turner et al., 2003; Wisner et al., 2003).

The need to address the unique physical and social conditions of different social-ecological systems has led to creation of 'place-based' vulnerability assessments, also known as hazard of place models (Cutter, 1996; Cutter et al., 2000; Fuessel and Klein, 2006; Hebb and Mortsch, 2007; Turner et al., 2003). "Distributive patterns of hazards and the underlying processes that give rise to them" are analyzed for a large array of different hazards for a specific location at the same time (Cutter et al., 2000:714). A particular strength of this place-based analysis is its ability to engage public involvement and collaborative assessment by multiple stakeholders in defining vulnerability problems (Turner et al., 2003).

Füssel (2007) recognizes the problems posed in science and policy development by competing conceptualizations and terminologies of vulnerability and thus attempts to build a shared conceptual framework to enable clear communication and transparency. Reviewing a diversity of frameworks of vulnerability assessment towards climate change he constructs a general applicable conceptualization of the term vulnerability by distinguishing among the dimensions: sphere (or scale) and knowledge domain of vulnerability factors. The sphere is separated into (1) internal vulnerability factors that describe properties of the vulnerable system or community itself, and (2) external factors that refer to some stressor outside the vulnerable system, depending on the scope of vulnerability assessment. The knowledge domain distinguishes among (1) socioeconomic vulnerability factors typically investigated by social science (human/political ecology), and (2) biophysical factors which are focus of physical research disciplines (natural hazard research) (see figure below). Categories of the knowledge domain can overlap (Füssel, 2007) and the term 'coupled human-environmental' (i.e.socio-ecological) system describes the interconnectedness of the system (Turner et al., 2003; Adger, 2006).

This coupled vulnerability concept provides "a minimal structure for describing the multitude of vulnerability concepts in the literature," which can be further broken down in order to describe relevant factors in a more in-depth manner (Fuessel, 2007:158). Internal social vulnerability factors could be distinguished as either generic factors (such as poverty, inequality, health etc.) or factors that are specific for a particular hazard (such as the situation of dwellings in relation to river flood plains) (Füssel, 2007). "Factors such as poverty and inequality are representing 'generic' vulnerability and adaptive capacity, i.e. those are factors that determine vulnerability and the capacity to adapt to a wide range of hazards." (Adger et al., 2004:39).

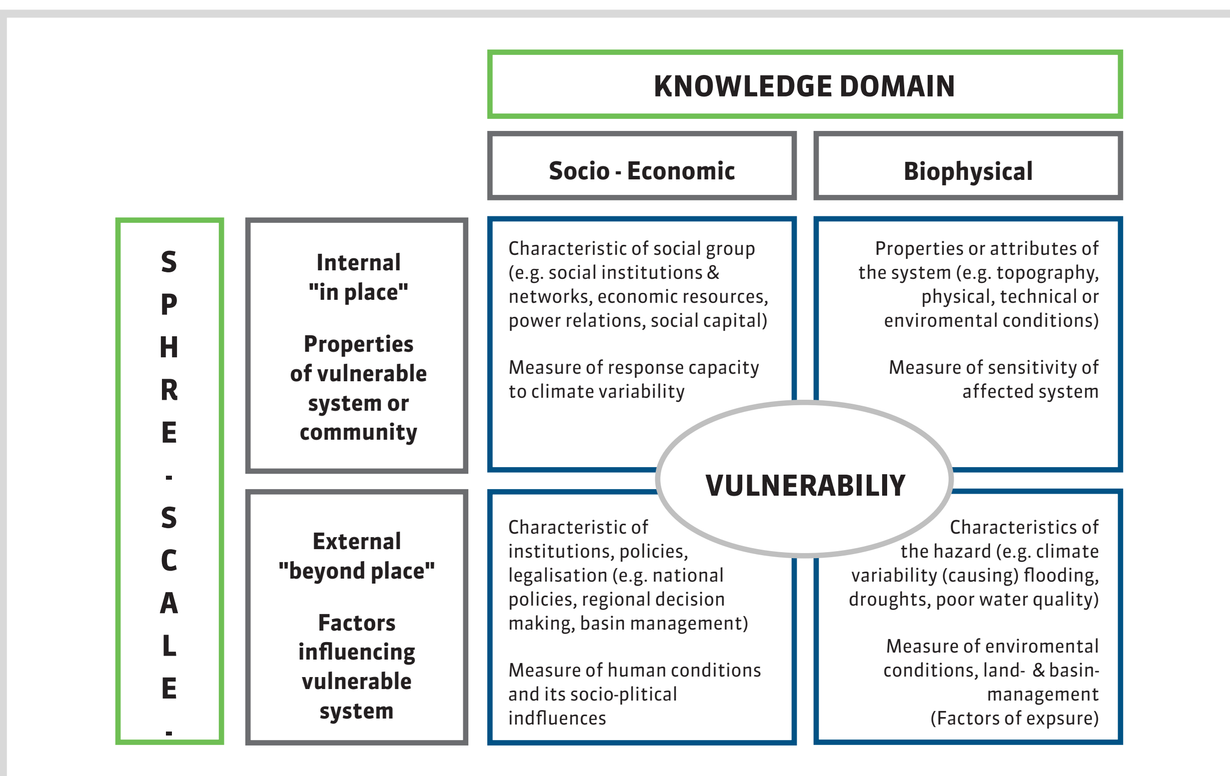

Figure 2: A conceptual diagram of the four key components that can be used to define vulnerability (modified from Füssel, 2007).

Distinguishing the scale dimensions has particular importance in vulnerability assessment of a single sector or area in river basins. Cumming et al. (2006) emphasizes that when the jurisdiction of management institutions fails to match the environmental or ecosystem scale of the natural system, mismanagement, inefficiency and loss of adaptive capacity of the social-ecological system can result (Cumming et al., 2006). Also Turner et al., (2003) mention in relation to 'place based' vulnerability assessments that local analysis must always simultaneously consider places and scales of study beyond the primary system boundaries in order to capture the range of stakeholders, feedbacks and spatiotemporal processes that define vulnerability of complex and hierarchical coupled systems. In their 'coupled vulnerability framework' for vulnerability analysis in sustainable science, Turner and colleagues link external human-environmental conditions and dynamics with the internal human-environmental system of concern in which vulnerability resides. The external conditions shape hazards to which the internal system (place of analysis) is exposed to. Consequently, adaptation mechanisms of the vulnerable subsystem might affect or target spatiotemporal dimensions transcend the system or location of analysis (Turner et al., 2003).

Appendix II: List of vulnerability factors.

Table: List of used socio-economic and biophysical vulnerability factors.

Vulnerability Factor	Definition
Internal Socio-economic (Properties of the Community)	
Income generating activities	On-farm and off-farm activities of farmers to sustain their livelihoods.
Household economic resources	Financial income, capital and liquid assets that household farmers have.
Knowledge and information	Types of knowledge, skills and information which farmers acquire through education, practice, experience or communication.
Social capital	Characteristic of social networks and trust in the region.
External Socio-economic (Characteristics of the Exposure)	
Water rights	Types of water rights entitled to farmers and environment.
Decision making on water distribution	Characteristic of decision making structure involving different organizations and stakeholders which can influence water distribution in Roodasht.
Financial Support programs and insurances	Types of financial aids, credits and insurances allocated to support farmers.
Internal Biophysical (Properties of the Community)	
Soil Quality	Properties and characteristics of the agricultural soils.
Water Access	Conditions and ways, farmer access irrigation water.
Technical Conditions	Technical equipment and conditions of modernization of agriculture.
Farm Products	Types and amount of agricultural product farmers produce.
Agricultural Practices	On-Farm measures farmers take for management of their land.
Land Use	Conditions of land use and change in the region.
Infrastructure	Infrastructure present in the region
External Biophysical (Characteristics of the Exposure)	
Climate Change and Variability	Current and future climatic conditions in the region.
Environmental and Ecosystem Change	Environmental and Ecosystem changes in the region.

Appendix III: Map Roodasht cultivated area

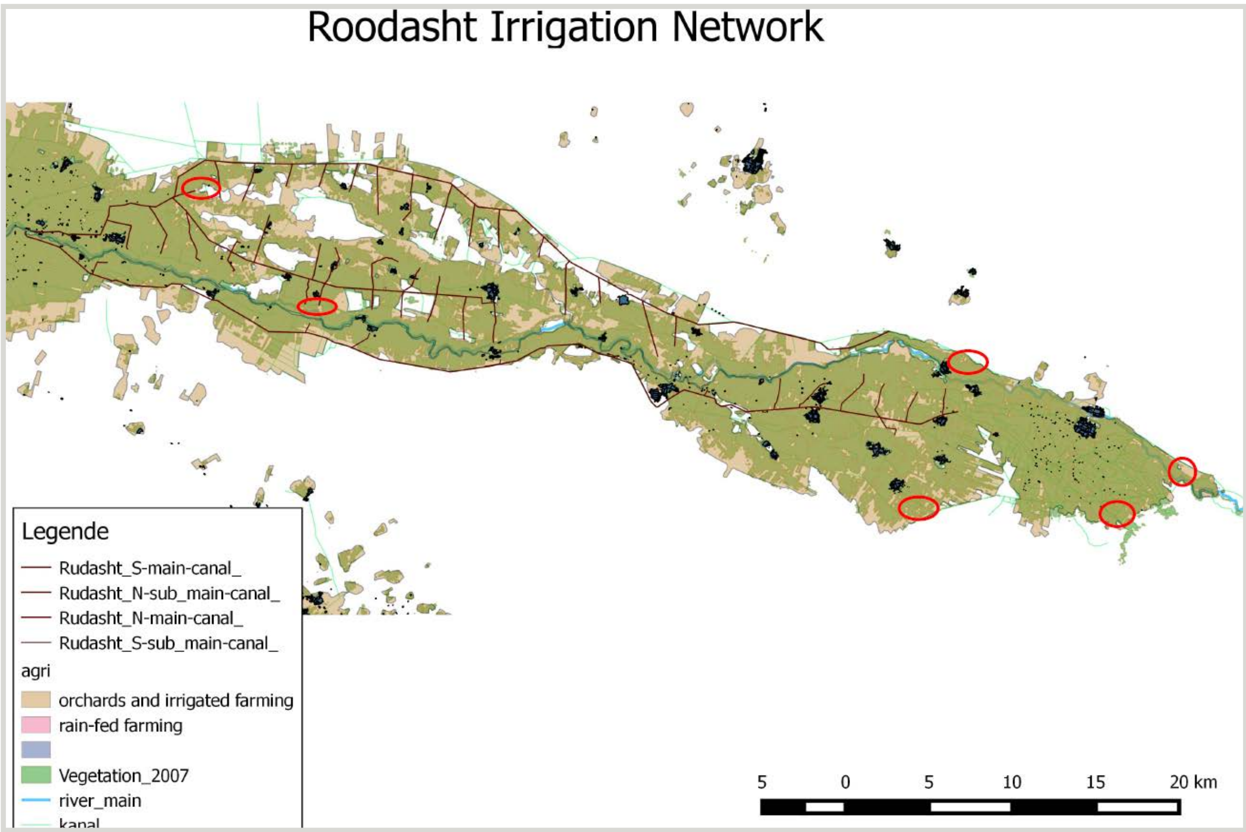

Figure 3: Roodasht irrigation network with interview locations marked with red circles (source: inter 3).

Appendix IV: Sample of Farmers Interview

Farmers Interview 10.11.2015

He is a large scale farmer, and he has a passion about farming. He began farming since his childhood. Farming is the best way that he could earn money. He thinks farmers are depending on water and farming. If there is no water it means no farmer. He thinks because of over-consumption in the whole basin, the amount of available water downstream of the Zayandeh-Rud River is reduced. But he thinks that if the water is not available, everything will breakdown and also if the current policies followed by authorities the conditions will get the worst. He is a young man, he has knowledge about farming. He doesn't see opportunities for himself and his family in the city.

Location:

Interview questions

1. General Information

Age:38 years old	How long have you worked as a farmer? For 22 years	Formal education: able to write and read
place you live in: Esfina (North Baaran) farm☐ village ■ city☐	number of persons in your family household: 12 people(with his brothers family who work on the same land)	number of household members who work on your farm: 3 people (two brothers with the one of nephew)

1.1. How large is your farm?30 hectares plus 20 rented hectares (but he could not plant all of them last year)

1.2. Does the farm you work on belong to you? Yes☐ No ■
(If no, please answer question 1.2.1)

For how long is your land already in your ownership? For 37 years	Did it belong to your father? Yes☐ No☐
Do you think your children will work on it in the future? Yes☐ No☐ If no, why? His daughter is really interested in farming; He supports her if the conditions will get better! One of his brother migrated to the city after water scarcity starting12 years ago! Mr. Akbari spoke about drought years as years of injustice! He thought that if the conditions get better his brother will come back	Was it the same size in last 10 years? Yes☐ No☐ If no, why? but if the farming conditions does not get better he has to sell his lands to pay back his bank debts(loans he got with the high interest rate which he cannot be able to repay. He did not work for 3 years. So he borrowed bank loans to be able to live when he could not be able to farm

1.2.1 For how long have you rented the land? He has rented around 20 hectares land for 10 years

- How much do you pay for rent per year? Last year he paid 500 euros per hectare, he said that if he had enough economic capital he would prefer to buy more lands.

2. Resource and livelihood

2.1. What is the average income you earned from farming annually in a normal year? Gross income: 120000 euros, net incomes 50000 euros, (he said that to continue farming I have to cut my family expenses to be able to spend enough money on my land!)

2.2. Is farming the only source of income for your household livelihood? Yes■ N o □
If no, answer the following table;

Other source of household income (e.g. other jobs...):he used to be have an animal husbandry, but it was no longer beneficial	How much of your livelihood income comes from farming in a normal year? 1/4□ 1/2□ 3/4 □other

2.3. In your household, what are the women working_ Household activities ■ farming activities□ others□
(in Jolgeh and Bonroud women also work on farms.)

2.4. Please answer the following questions about the energy resources you use :

The types of energy resources you use in household activities: gas ■ gas oil□ electricity ■ firewood□ other□	The types of energy resources you use in farming: gas□ gas oil ■ electricity ■ firewood□ other□
The monthly average amount you pay for each type of energy? The gas oil prices increased dramatically in recent years, he spent 5000 lit/month gasoil, his tractor was not energy efficient! 10 cent/lit (with subsidies) Electricity 7500 euros/year	If firewood, where do you get it from?

2.5. Please answer the following questions about family household needs:

Where do you get your drinking water? Drinking water network ■ well□ water tank□ other□	Do you provide your household needs from your farm products? 30% provided form his farm, wheat, onions, vegetables, poultry, Yes□ No□ If yes, which?

2.6. Please answer the following questions about family household needs: Did your livelihood situation change in the past 10 years? Yes■ No□

- How and what are your responses to changes so far and in the future? he had several problems,
  He thinks that if the current policies followed by authorities the conditions will get the worst.

3. Labor and equipment

3.1. Please answer the following questions about the labor in your farm:

Number of people working on your land: fixed 4 people , and 3 people for 2 month,20 women workers coming from another city(Shahreza) are employed to work on cucurbits for 15 days	average salary you pay annually(per person):2000 euros/ year (per fixed worker)

3.2. Please answer the following questions about farming equipment:

Type of equipment you use on your farm: one tractor and agricultural implements. Tillage, but he needs more advanced tractors!	Do they belong to you? Yes□ No□ If no, how do you provide the equipment you need? Under what conditions He also rents new Holland tractor. He rents pesticides sprayer, combine

3.3. Where do you get capital needed for investments in your farm (e.g farming equipment) with the high interest rate, he got husbandry loan and aslo he got loan to buy agricultural equipment and implements.

Household capital□ Loan■ Subsidies□ other

- please tell us about your experience he should repay the loan in 5 years with the high interest rate (17% to 24%)he got 10000 euro loan and 15000 euro loan . and he regretted. Because repaying condition is not good

- If loan, how much of the money you use on the farm comes from loans
  1/4□ 1/2□ 3/4■ other 1%
  Where does the loan come from? Agricultural Bank

3.4. If you had enough money, what farming equipment would you buy? New Holland tractor, combine, auto-planting machine it costs total 250000 euros

4. Farm Products

4.1. Do you have livestock? Which? Yes□ No ■
If yes, please fill the following table:

Where does the livestock feed:	What type of feeding:	amount of feeding per day:
where does livestock drink?	type of animal product and livestock you sell:	average production cost per animal unit:

If you sell your livestock or their products, Where do you sell livestock (and/or products) and to what price? (per each type of product)

4.2. Do you have orchards? Yes ■ No□
If yes, please fill the following table:

type of orchard: pistachios	The size of the orchard and the number of trees:2.5 hectares with 2500 trees.
How old is it?2 years	How are trees irrigated: Pressurized□ flood irrigation ■

4.3. Which crops did you plant in the last year? Wheat, barley and Alfalfa

- Why did you plant these types of crop? (Economic, practical knowledge, available facilities and resources,...) because of water shortage . Wheat is high demanding and low risk. If the conditions got better he would plants saffron. He needs animal fertilizer. Saffron is more economically beneficial than wheat

- Can we fill out the table (Appendix) for different crops you planted in the last year?

4.4. Can you also indicate on the calendar (Appendix) when your main crops were planted and harvested?

- In between cropping periods, was the field fallow? If the water would be available, he would plant twice a year but in recent years he couldn't plant more than 10 hectares per year.

  - If it was not fallow, what do you plant (indicate in Appendix)

4.5. Please answer the following questions about where you get the necessary inputs and to what price

	source	Price
Seeds(per the type of crop):	-Production Cooperative (70%) -Market	40 cent/kg wheat
Fertilizers(per type of fertilizer):	Cooperative union	Chemical fertilizer750kg/h Phosphate12 euro/kg urea 9 euro/kg
Pesticides(per type of fertilizer):	cooperative, service center	4 euros/ lit

4.6. How and where do you sell your crops? And to what price? (please indicate the average price for each type of crop)
Cooperative associations, wheat 25 cent/kg, barley 20 cent/kg

4.7. Do you have any problems with selling your farm products?
Yes ■ No □
If yes, please explain there is a bite delay in paying money

4.8. Did you change your crop management in the past 10 years?
Yes ■ No □
If yes, please explain he tried to use crops with higher value like pistachio or saffron.

5. Irrigation water

5.1. What kind of water resources do you use for irrigation?
Surface water ■ groundwater ■ rain relevant□

- If you use groundwater? How deep is your well? 60 m
- Do you use water resources of the irrigation network?
  Yes ■ No□
- Do you have any water storage facilities?
  Yes ■ No□
- If yes, what kind? Earthen pool for storing water

5.2. What kind of water right do you hold?
Water right ■ water share□ shared water right□

5.3. On what does the amount of water you get supplied dependent on? It's not depend on the condition. That is fixed.
owned area□ planted area□ Cropping pattern□ other□

- Could you sell your water or water right? How?
  Yes□ No□
  If yes, how? Selling and buying the water or water right is attached to the land.

5.4. How much do you pay for irrigation water annually? About 750 euro annually

5.5. How often did you need to irrigate the different crops in the last year? (calendar in Annex with planting and harvest dates)

- Have you ever tried to optimize water efficiency?
  Yes ■ No□
  If yes, how? Land leveling

5.6. Does the irrigation water you use have good quality?
Yes ■ No□
If yes, please explain it. He thinks Mirab couldn't manage distribution of water resources in network.

5.7. Did the quality of water resource you use for irrigation change in the past 10 years?
Yes□ No ■
If yes, please explain it. In past 10 years, the quality of groundwater is reduces.

5.8. How do you get informed about the time water is available? Representative of the farmers who are connected with Mirab

5.9. Do you always receive the water you need?

Yes□ No ■

- Have you ever tried to optimize water efficiency?
  If not: Why do you receive sometimes too little water?
  Because of problems in the consumption in the basin, the amount of available water for downstream of the Zayandeh-Rud river is reduced.

6. Soil and Land Management

6.1. Please fill the following table regarding your land and soil management practices:

Biomass management: what do you do with crop residues and waste from livestock on your farm? Feeding the livestock	Soil preparation: tillage - conventional (plowing with no crop residue on the surface) ■ conservation (no or minimum till with crop residue on the surface) ■ tillage to conserve water □
Fertilizer: None□ mineral ■ manure □	Weed management: None □ Mechanical □ pesticides/herbicides ■

6.2. Do you have to follow any land use regulations by the authority?

Yes□ No ■

Like what? There is no regulations for land use

6.3. How is your soil quality? The soil quality is perfect but the land which has been planted for several years is better.

6.4. Did your soil quality change in the 10 past years?

Yes ■ No□

If yes, which? Why? It became better. In some areas because of overusing of salty groundwater, there are problems with soil salinization.

Soil erosion□ soil salinization□ loss of organic matter□ loss of natural vegetation□ others□

- How does that affect your farming activity?

6.5. What do you do to stop degradation?
Prevent to use groundwater too much, cultivation management.

6.6. Please fill the following table about the activities you could be able to change your farming system to:

Changing crops to higher value crops: Yes ■ No□ He planted pistachio	Changing to agroforestry system: Yes□ No ■
Changing to fish or livestock breeding: Yes□ No ■ It's not economically	Changing to greenhouses: Yes□ No□ That needs money

Please explain your answers.

6.7. How do you get informed about new farming, irrigation technology and land management practices? Agricultural service center

- Have you attended in farming workshop regarding water and soil related issues?
  Yes ■ No□
  If yes, what kind of workshops?
  Crop pattern, new irrigation methods, plantation, applying pesticides.

6.8. Did you change your land and soil management practices in the past 10 years?
Yes ■ No□
If yes, please explain it (how and why)
Land leveling to prevent soil erosion and increase in irrigation efficiency

7. Coping and adaptive strategies

7.1. Did you still farm when there was little water in 1392 -1393 (2013/14)?
Yes□ No□
Please explain
(when he could not be able to farm he had to borrow some loans to survive! he said that

he worked for himself for several years and could not imagine to work as a worker for another employer!

7.2. Did it led to changes in your livelihood?

Yes☐ No■

Please explain

7.4. What kind of insurance do you have?

Social insurance■ agriculture insurance■

Other☐ none☐

7.5. Have there been any special farming regulations in times of water shortage by the authority?

Yes☐ No■

If yes, what kind?

7.6. Do you know any other Farmers that cope better with water shortages than you (on farm management and livelihood generation)?

Yes☐ No■

- If yes, how did they do it?
- Why didn't you copy them?

7.6. To cope with water shortage what kinds of option could you apply? Why?

Change crop pattern: Yes☐ No■ Because schedule for water distribution is restricted and groundwater's quality is not suitable.	Change irrigation system and water resources: Yes■ No☐ That needs money
Change your land management practices: Yes☐ No■	Alternative source of income: Yes☐ No■

8. Natural environment

8.1. How does natural environment impact on your life? (e.g. Gav Khuni wetland and river)

- Did the conditions of the ecosystem change in the past years? How?
  In last 10 years, the conditions of environment changed totally. Before that there were not any problems.

  - How did impact on your life? Why? mental health

9. Visioning Questions

9.1. Why do you do farming? Please explain shortly.
He has a passion about farming. He began farming since his childhood. Farming is the best way that he could earn money.

9.2. What makes you happy/satisfied (or not) about the following items? What do you think can hold you back from achieving your goals/expectations in the short, medium and long term?

Family: having healthy life with happiness, earning Halal money
Farming: being successful, applying new methods
Your community: help each other and wants to change their old way of thinking

9.3. What do you think about the conditions regarding the following items will be better in future?

Family: will be better, he has a positive view
Farming: it will be better.
Your community: their connection and support will get weak.

9.4. How could local farmers help themselves to tackle with the problems in dry years? What would you need to do that?
He thinks farmers are depend on water and farming. If there is no water means no farmer. Most of the farmers that he know couldn't do any activity. If there wouldn't be any financial support everything will get worse.

9.5. If you had to abandon agriculture, what would you do and how would you make a living?
He is a young man, he has knowledge about farming. He couldn't survive in the city. It would be really hard for him.

To 3 and 4
Year: 1393 -1394 (2014/15)

Crop				How much input required						Comments
type	Area	Yield	Irrigation method	Irrigation water	Days of work	Machinery (Which kind?)	Fertilizer (which kind, how much?)	Pesticides (which kind, how much?)	Seeds (how much?)	
wheat	20 hectares		Flood irrigation	Per ha 30lit/sec for 12 -14hours(7 times)but he thinks that because of the inefficient irrigation method water is wasted		Tractor, farming implements, Combine	Chemical fertilizer750kg/h Phosphate12 euro/kg urea 9 euro/kg	1 lit/h Delta methrin	220 kg/ha	
barley	10 hectares		Flood irrigation			Tractor, farming implements, Combine	Chemical fertilizer750kg/h Phosphate12 euro/kg urea 9 euro/kg	Delta methrin	250/h	
Other (alfalfa, lettuce)	10 hectares		Flood irrigation			Tractor, farming implements, Combine			Once for 7 years 200 kg/h	

Crop	Farvardīn	Ordībehešt	Khordād	Tīr	Amordād	Shahrīvar	Mehr	Ābān	Āzar	Dey	Bahman	Esfand
wheat	* *	*	+	+ + +				# *#	*			
Barley	* *		+	+ + +				# #	* *			
Alfalfa	+	+	+ +	+		+	+ #	*	*	*		*

Plant# Irrigate* Harvest+

Appendix V: Comparison of results with previous studies

Results of the study at hand are comparable with previous studies in the region as well as in regions similar to Roodasht, which focus on water scarcity, drought and vulnerability.

Safavi et al. (2014) present an integrated index for vulnerability assessment in both spatial and temporal dimensions in Zayandeh-Rud catchment using multiple drought factors. As result, he found growing vulnerability towards drought and presents meteorological, hydrological, agricultural, socio-economic and environmental drought-indicators for decision makers.

Hosseini et al. (2009) analyzed causes and effects of drought as well as related management mechanisms in rural and nomadic communities in southeastern of Iran. They found five main components as causes for drought vulnerability including socio-economic, livelihood, and hydrological, agricultural and meteorological factors. In conclusion, they suggest fife management mechanisms as drought response: integrated water resources management, institutional capacity building, targeted economic support programs, systemic planning and sustainable development of agriculture and livelihoods.

Comparing results of these studies with the current vulnerability assessment in Roodasht highlights the power of integrated and comprehensive vulnerability approaches to analyze and present the multi-faced factors determining vulnerability. Comparison also shows that determined relevant factors have similar characteristics and that economic support programs may play a crucial role for adaptation: Nikouie et al. (2012) analyzed least cost measures for securing the environmental flow of the Zayandeh-Rud river. By applying an integrated basin framework, they examine two types of policies including (a) reduced agricultural diversions without a water conservation subsidy, and (b) reduced agricultural diversions with a water conservation subsidy. Results of the study show that water conservation subsidies can provide incentives for farmers to change their irrigation method and use adapt water-saving irrigation technologies.

Zamani Nouri et al. (2015) analyzed agricultural drought vulnerability in Isfahan Province by using rainfall data. The results revealed that agricultural vulnerability to drought in Isfahan County is the highest. Thus, it proves the importance of assessing vulnerability in local scale to understand the impacts of internal and external socio-economic and biophysical factors and their effects on local farmers.

Keshavarz et al. (2010) investigated farmer´s drought management strategies in Fars province using cluster analysis and found three main drought management approaches among the farmers which include “technical drought management”, “economic drought management” and “integrated drought management” as combined of technical and economic strategies. Similar to what has been found in Roodasht, the result of this study indicate that adaptive strategies are shaped mainly by farmer´s knowledge and their socio-economic and environmental resources.

In another study Keshavarz et al. (2013) focused on social impacts of drought in two villages in Fars Province Iran using qualitative interview methods. The study presents social impacts on fulfillment of basic needs, marriage, education, conflicts and dependencies as well as psychological and emotional impacts. Similar aspects could also be found during research to this vulnerability study in Roodasht.

Drought vulnerability studies conducted in different regions in the world confirm the vital role of local assets (especially economic resources and sources of income) as adaptive capacity to mitigate the risks of drought and water shortage (Eakin 2003, Alston 2007, Greenhill et al. 2009). Meanwhile the results of various studies indicate how farmers use their practical knowledge to cope with drought. A study on farmers adaption to drought in western Nile delta in Egypt shows how farmers apply various practical methods to adapt with water scarcity, which include changing cropping patterns, crafting collective irrigation rules, reusing agricultural drainage water and practicing deficit and night irrigation (Ghazounai, et al. 2014). Similar to what analyzing agricultural practices and crop choice in Roodasht has shown, the finding of the study in Egypt reveals how crop choice is shaped and constrained by water availability and short term economic profitability.

The results of international examples underline that it is essential to have a integrated approach to assess the complex factors defining farmers´ reality and the risks of environmental degradation. This is the starting point for finding measures striving for sustainable adaptation to water scarcity and environmental degradation.