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Water Scarcity under Climate Change:
Impacts, vulnerability and risk reduction in the agricultural regions of Central Asia

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Water Scarcity under Climate Change: Impacts, vulnerability and risk reduction in the agricultural regions of Central Asia

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Table of Contents

List of Tables

List of Figures

Abbreviations

ASVI	Agricultural Systems Vulnerability Index
CA	Conservation Agriculture
CCA	Climate Change Adaptation
CO_2	Carbon Dioxide
DRR	Disaster Risk Reduction
EHW	Equal Hierarchical Weighting
EU	European Union
GAP	Gross Agricultural Production
GDP	Gross Domestic Product
IBSMA	Irrigation Basin System Management Authorities
IPCC	Intergovernmental Panel on Climate Change
MAWR	Ministry of Agriculture and Water Resources (of the Republic of Uzbekistan)
NGO	Non-governmental Organization
SAW	Simple Additive Weighting
UNFCCC	United Nations Framework Convention on Climate Change
WCA	Water Consumer Association
WSSI	Water Scarcity Severity Index

Summary

This doctoral dissertation is inspired by the major climate change risk to human security in many parts of the globe, namely water scarcity. The analysis is built upon the concept of vulnerability in order to explore those factors, which shape the climate change risk in the agricultural regions of Central Asia. More specifically, using Khorezm region of Uzbekistan as a case study, the thesis looks into the agro-ecological, socio-economic and institutional aspects of vulnerability to climate change and hazards. The main methods applied include participatory research (which represents a key informants survey and a focus-group discussion) and a statistical analysis (which represents descriptive statistics and a multi-criteria analysis).

The major scientific outcome of this work is the development of holistic vulnerability assessment method for agricultural systems, applicable to explore policy-relevant scenarios considering three pillars of sustainability (environment, society, economy). The proposed approach aggregates agro-ecological and socio-economic information into a composite indicator of vulnerability, namely Agricultural Systems Vulnerability Index (ASVI). The ASVI tool allows integrated, spatial and comparative assessment of local vulnerability to climate change and hazards, and could facilitate the discussion of local stakeholders for identification of priority regions and areas for policy interventions.

This dissertation also contributes to the knowledge of climate risks in Central Asia, by analysing the impacts of severe water scarcity, identifying the determinants of vulnerability and exploring the role of the institutions in reducing the vulnerability to water scarcity in the Khorezm region of Uzbekistan. The findings from the spatial vulnerability assessment suggest that various agro-ecological and socio-economic factors make the region vulnerable to water scarity, such as share of cotton and wheat production in the total agricultural output, level of environmental degradation and water productivity. In addition, several challenges to vulnerability reduction to water scarcity in Khorezm region and Uzbekistan are identified, such as need of engaging local institutions to play proactive role in vulnerability reduction and accounting for spatial vulnerability differences in the planning process.

Chapter 1 Introduction

The impacts of climate change on agriculture go beyond the impacts on crop yields, by affecting also the environment, rural income and food prices stability (IPCC, 2014b). The negative impact of climate change on freshwater availability at a global scale could be tremendous, altering the hydrological systems in terms of quantity and quality of the water resources (IPCC, 2014b). Meanwhile, water scarcity is among the most threatening hazards, which has already brought disastrous losses, particularly in the world's most arid regions.

From a geographical point of view, the analysis focuses on Central Asia, referring to five states in this region, namely Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. The regional focus is motivated by: (i) the expected high risk of water scarcity; (ii) the present socio-economic and political challenges in the above transition countries; (iii) the limited number of studies on impacts, vulnerability and policy options especially at a sub-national level; and (iv) existing data constraints. Furthermore, the importance of agriculture, and particularly the irrigated production, and the high share of the rural population in Central Asia, has led to focusing this dissertation on exploring climate change – irrigated agriculture nexus.

Looking into climate-related risks, early studies on climate change and hazards dealt with the assessment of the direct and indirect impacts. Later, the analysing approaches shifted to the emerging concept of vulnerability, recognizing the need of understanding the factors behind the scale of these impacts on the human and environmental systems. Today, the general perception is that along with the climatic factors, the environmental, social, economic, cultural, political and institutional characteristics also create vulnerabilities and limit, or facilitate, adaptation and mitigation responses (IPCC, 2014b).

These have formed the major guidelines for the layout of this dissertation which is therefore built upon the concept of vulnerability, integrating views of the schools of climate change adaptation and disaster risk reduction. The latter is the most recent stream of thought in the international research community and the basis for the development of the latest climate change policy frameworks.

This chapter provides regional background information and synthesis of the knowledge of climate change for the five Central Asian countries. Additionally, the notability of the concept of vulnerability in climate change and hazards science is emphasized (Section 1.3). Section 1.4 sets the key research objectives of this dissertation. The last two sections outline the selected materials and methods, and the thesis structure.

1.1. Central Asia: regional background

Figure 1-1. Map of Central Asia

Source: http://www.nationsonline.org/oneworld/map/central-asia-map.htm

1.1.1. Geopolitics

Bordering with China, Russia, Afghanistan, Iran and the Caspian Sea (Fig. 1-1) Central Asia lies thus on the geo-strategically important cross-roads between Asia and Europe. This vast territory of 399 million hectares is covered with huge mountains (Tian Shan and Pamir mountains), deserts (Kara Kum, Kyzyl Kum, Taklamakan), and steppes. The largest water bodies within the region are the (disappearing) Aral Sea and Lake Balkhash, while a number of big rivers (the largest of which are the Amu Darya and Syr Darya) support the life in Central Asia for centuries.

The early settlements in today's Central Asian borders date back from 4500 BC. The region was a major section of the Silk Road, and consequently, trade became an important factor for the regional development. After centuries of vibrant history, in the early years of the 20th century, the Central Asian states became part of the territory of the Soviet Union. Some of the annexed republics are rich in natural resources, such as oil and natural gas, and minerals (e.g. gold, copper, iron),others in water, but all being a root cause for past and present conflicts and political interests.

About seven decades of Soviet era brought significant development of the agricultural sector, notorious for the mass expansion of the irrigated land for the cultivation of cotton, often called the "white gold" of Central Asia. After years of agricultural production growth, however, the unsustainable resource utilization was blamed for many human-induced disasters of which the "Aral Sea disaster" is probably the most well-known. Today, the on-going environmental degradation and the depleting water resources, challenge not only the agricultural sector, but also the food and nutritional, water and energy security in this region. With the break-up of the Soviet Union (1991), the five Central Asian states took their own directions of development. Economic, social and political transition processes have left some of them in a state of high poverty, especially Tajikistan, while other more developed nations have installed highly centralized political systems, such as Uzbekistan and Turkmenistan.

1.1.2. Socio-economic context

Uzbekistan is the most populous country in Central Asia, despite its smaller territory in comparison to some of the other Central Asian states (Table 1-1). Tajikistan has the highest rural population ratio, but all five countries have predominantly rural population. The total population in Central Asia has increased from 51 million in

1991 to over 66 million in 2013, which has accelerated the overexploitation of land and water resources to meet its population's food, water and energy demands.

According to the World Bank's categorization, Uzbekistan, Kyrgyzstan and Turkmenistan belong to the lower middle income countries, while Kazakhstan is an upper middle income state. Tajikistan is a low income country and among the poorest states worldwide.

Table 1-1. Key development indicators for the Central Asian states

Indicator	UZB	KYR	KAZ	TAJ	TUR
Population (million, total in 2013)	30	5.7	17	8.2	5.2
Rural population (% of total population in 2013)	64	64	47	73	51
GDP per capita (2013, constant 2005 US$)	899	625	5425	480	3557
GDP growth (annual %, 2013)	8	11	6	7	10

Source: World Development Indicators (available at: http://databank.worldbank.org/data/; accessed on 14/08/2014).

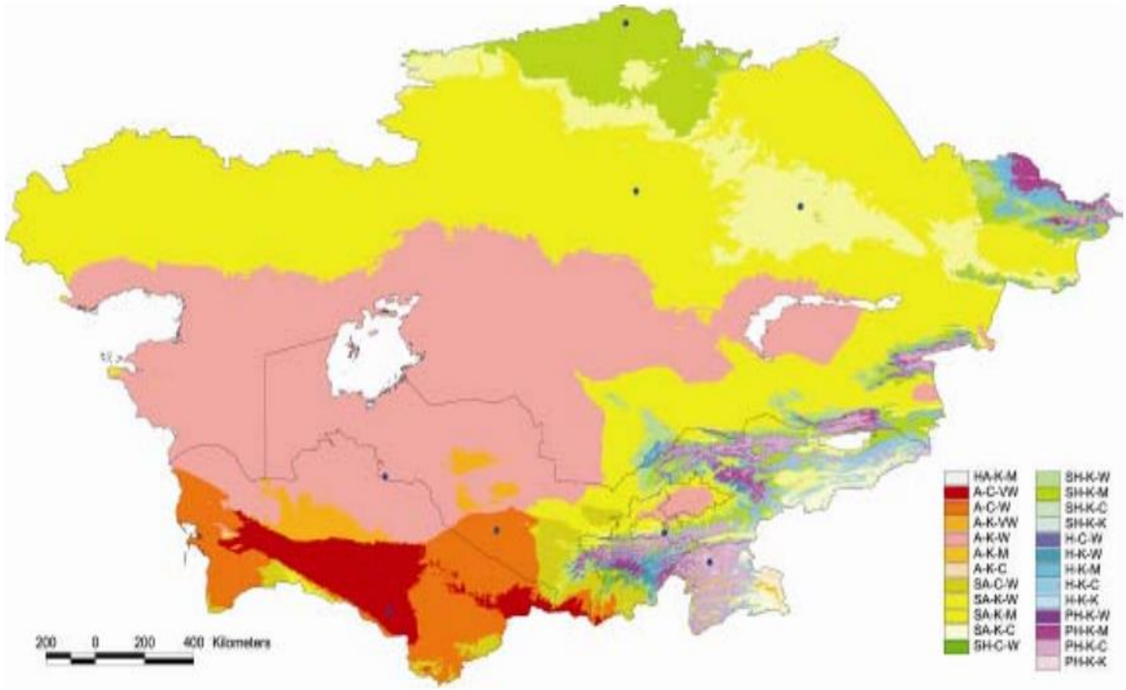
Due to the exposed differences in endowments and dependency on the water resources, the impacts, vulnerability and risk reduction in the Central Asian countries' agricultural sectors is likely to differ, but this can be confirmed only after the development of a concept that allows for this, such as the concept of vulnerability.

1.1.3. Agriculture

The Central Asian region has 21 agro-climatic zones (Fig. 1-2), however 76% of its total area is located in the arid and semi-arid zones, characterized with very cold winters and hot, dry summers. A big part of the agricultural lands are used as permanent pastures and only 12.3% are arable (Table 1-2).

Most of the countries utilize huge amounts of their freshwater resources for agricultural purposes, but receive a low return from the sector compared to the amounts used (Table 1-2). The irrigated production dominates in all of the five states, while Uzbekistan ranks first in terms of share of irrigated areas (Table 1-2).

Figure 1-2. Agro-climatic zones of Central Asia



Zone	Description	AI*	Max temp.	%
SA-K-W	Semi-arid, cold winter, warm summer	0.2-0.5	20-30^{0}C	37.9
A-K-W	Arid, cold winter, warm summer	0.03–0.2	20–30^{0}C	30.8
SA-K-M	Semi-arid, cold winter	0.2–0.5	10–20^{0}C	6.6
SH-K-M	Sub-humid, cold winter	0.5–0.75	10–20^{0}C	5.9
A-C-W	Arid, cool winter, warm summer	0.03–0.2	20–30^{0}C	4.9
A-C-VW	Arid, cool winter, very warm summer	0.03–0.2	>30^{0}C	2.9
PH-K-C	Per-humid, cold winter, cool summer	>1	0–10^{0}C	2.0
H-K-M	Humid, cold winter, mild summer	0.75–1	10–20^{0}C	1.6
SA-C-W	Semi-arid, cool winter, warm summer	0.2–0.5	20–30^{0}C	1.5
SH-K-W	Sub-humid, cold winter, warm summer	0.5–0.75	20–30^{0}C	1.4
A-K-VW	Arid, cold winter, very warm summer	0.03–0.2	>30^{0}C	1.2
PH-K-M	Per-humid, cold winter	>1	10–20^{0}C	1.2
SH-K-C	Sub-humid, cold winter, cool summer	0.5–0.75	0–10^{0}C	0.5
SA-K-C	Semi-arid, cold winter, cool summer	0.2–0.5	0–10^{0}C	0.5
H-K-C	Humid, cold winter, cool summer	0.75–1	0–10^{0}C	0.5
H-K-W	Humid, cold winter, warm summer	0.75–1	20–30^{0}C	0.2
SH-C-W	Sub-humid, cold winter, warm summer	0.5–0.75	20–30^{0}C	0.1
A-K-M	Arid, cold winter, mild summer	0.03–0.2	10–20^{0}C	0.1
PH-K-K	Per-humid, cold winter, cold summer	>1	<0^{0}C	0.1
PH-K-W	Per-humid, cold winter, warm summer	>1	20–30^{0}C	0.0
A-K-C	Arid, cold winter, cool summer	0.03–0.2	0–10^{0}C	0.0

*AI – Aridity index representing the ratio of the mean annual precipitation divided by the mean annual potential evapotranspiration.

Source: (de Pauw, 2007)

Due to a lack of investments over the last two decades, the irrigation and drainage systems have very low efficiency, high water loss ratios and urgent need of rehabilitation. As a result, the cost of the environmental degradation is much higher than the generated income from agriculture (Christmann et al., 2009). Nevertheless, the agricultural sector provides employment opportunities for a high share of the population (Table 1-2), and is of a great importance for the rural poor. Hence, the fate of the water resources plays a crucial role also in the future.

Following the independence from the Soviet Union, cotton, wheat, rice, potatoes, legumes, fruits and vegetables, and meat became major agricultural products in Central Asia (Christmann et al., 2009). Turkmenistan and Uzbekistan still maintain state regulated production of cotton and wheat. Both countries are economically dependent on cotton export and target grain self-sufficiency. The latter is conditioned by the growing uncertainty of the agricultural commodity prices at a global scale.

Table 1-2. Selected agricultural indicators for the Central Asian states

Indicator	UZB	KYR	KAZ	TAJ	TUR
Agricultural land (% of land area, 2012)	63	55	77	35	70
Arable land (% of agricultural land, 2011)	16.1	12	11.5	17.5	5.8
Agriculture, value added (% of GDP, 2012)	19	19	5	27	15
Employment in agriculture (%)	44	-	31	67	48
Annual freshwater withdrawals, agriculture (% of total freshwater withdrawal)	90	94	66	91	94
Rainfed areas (x 10^3 ha, 2008)	419	238	18994	208	400
Irrigated areas (x 10^3 ha, 2008)	4213	1072	2082	722	1800
Salinized irrigated area (%, 2008)	50	11	33	16	96

Sources: World Development Indicators (available at: http://databank.worldbank.org/data/); FAOSTAT (available at: http://faostat.fao.org) Christmann et al. (2009); Kienzler et al. (2012).

Aside from increasing land-degradation, the agricultural production is challenged by the future availability of water resources which have a strong impact on the land resources. On average, 48% of the irrigated land in Central Asia is salinized (Kienzler et al., 2012), with extremely high salinization in Turkmenistan, followed by Uzbekistan (Table 1-2). Cotton yields have already decreased due to worsening soil conditions (Gupta et al., 2009).

Another major issue in the Central Asian region are the agrarian reforms launched in 1991. The land reforms e.g. have focused on privatization of state-owned farm enterprises. Private land tenure has been granted in Kazakhstan and Kyrgyzstan, while the farmers in Turkmenistan, Tajikistan, and Uzbekistan operate on leased state land (Gupta et al., 2009). Household plots for cultivation of variety of fruits, vegetables and grain, as well as livestock production by individual small herders, are an important safety net for the rural population to cope with the economic transition (Gupta et al., 2009).

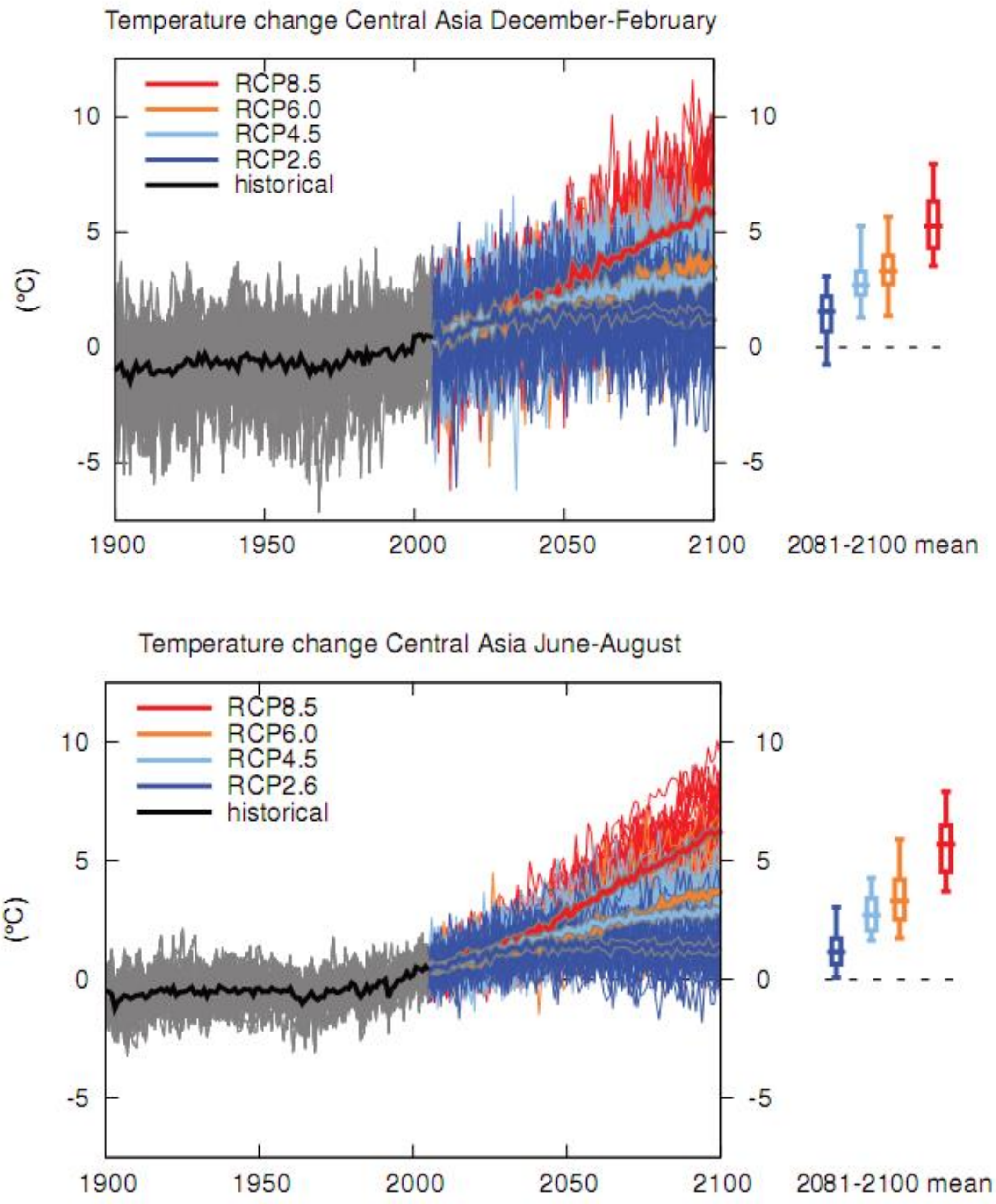
In the future, the challenge for the Central Asian agriculture in the context of the global change will be even bigger. The population is projected to increase to 79.9 million by 2050, which would lead to an increase in the food demand, and consequently, to even higher pressure on the land and water resources.

1.2. Climate change in Central Asia

1.2.1. Observed and expected climate change trends

The key features of the climate in Central Asia are the high degree of aridity, low precipitation (in most of the region) and large temperature fluctuations between the summer and winter seasons (de Pauw, 2007). Summer temperatures range from 20°C to 40°C (Fig. 1-2), while winter temperatures can reach -20 °C, and up to -45°C in the mountain areas (Gupta et al., 2009). Nearly 70% of the region receives precipitation in the range of 100-300 mm annually, and 90% has very cold winters with high frequency of frost occurrences (de Pauw, 2007).

Figure 1-3. Temperature change in Central Asia (1900-2100)



Notes: Time series of temperature change relative to 1986–2005 averaged over land grid points in December to February (Top) and June-August (Down) in Central Asia (30°N to 50°N, 60°E to 75°E). Thin lines denote one ensemble member per model, thick lines denote multi-model mean. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2081–2100 in the four Representative Concentration Pathways (RCPs) scenarios. The RCPs are four greenhouse gas concentration trajectories adopted in the AR5. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, relate to possible range of radiative forcing values in the year 2100 relative to the pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2).

Source: (IPCC, 2013)

The average annual temperature in Central Asia has increased by 1.2°C - 2.1°C since the 1950s (Gupta et al., 2009), which is above the global average increase of 0.72°C, over the period 1951–2012 (Stocker et al., 2013). The regional mean temperature is expected to increase by 2°C - 5°C until 2081-2100, depending on the Representative Concentration Pathways scenarios, with higher values for the summer period (Fig. 1-3). Furthermore, it is likely that many mid-latitude and subtropical arid and semi-arid regions will experience less precipitation, whereas the largest precipitation changes over northern Eurasia are projected to occur during the winter season (Stocker et al., 2013).

The latest National Communications under the United Nations Framework Convention on Climate Change (UNFCCC) outlines similar temperature patterns across the five Central Asian countries with variability in terms of precipitation. The observed warming rates in **Uzbekistan** have exceeded more than twice the global average since 1951, with the highest warming rates during the autumn season. Overall, an intensive warming is observed on the territory of Uzbekistan, while the projections of the average annual temperature rise under different scenarios are in the range of 3°C to 4°C by 2080 (Government of Uzbekistan, 2008). The temperature rise in **Kyrgyzstan** is expected to be higher during the summer and insignificant during the winter period. Similarly, the most significant reduction in the precipitation is expected during the summer period, and the highest increase is projected for the winter season. Nonetheless, the expected changes in the total annual precipitation compared to the basic period (1961-1990), would be insignificant (UNDP, 2009b). The analysis for **Kazakhstan** reveals that for the period 1936-2005, the climate in the country has become much warmer, with recorded rise in the temperatures during all seasons. Significant trend in the annual and seasonal rainfall has not been observed, yet, the results indicate an increasing climate aridity in the areas of deserts and semi-deserts of Kazakhstan (Ministry of Environment Protection of Kazakhstan, 2009). **Tajikistan**, which is predominantly mountainous region, experienced an increase in the temperatures in the plain regions by 0.1-0.2ºC per decade, while in the mountain areas by 0.3-0.5ºC during 60-year period. Alarmingly, there is an observed trend of warming during winter season, especially in November and December, with about 1-3ºC. Projections point out to an overall increase in the annual temperature of about 0.2-0.4ºC by 2030 (Government of the Republic of Tajikistan 2008). Finally, the projections for the rise of the temperatures in **Turkmenistan** by 2100 are in the range of 2-3ºC according to the best-case scenario, and 6-7ºC under the worst-case scenario (Ministry of Nature Protection of Turkmenistan, 2010).

The predicted climate changes are likely to have a significant impact on the hydrological cycle in entire Central Asia but in particular in the regions depending on water for livelihood security.

1.2.2. Regional impacts of climate change

The observed and expected climate changes have and would have significant impacts on the hydrological cycle in Central Asia. Projections for 2050 suggest potential decrease in the water flow in the Syr Darya River basin by 2-5% and by 10-15% in the Amu Darya River basin (Government of Uzbekistan, 2008). Furthermore, during extremely warm and dry years, vegetation flow in the Syr Darya and Amu Darya Rivers basins might decrease by 25-50% (Government of Uzbekistan, 2008). This would significantly affect Turkmenistan, since Amu Darya represents 90% of its surface water resources (Ministry of Nature Protection of Turkmenistan, 2010). In a short-run, the melting of the Central Asian glaciers would lead to an increase in the water flow in some rivers, however in a longer term, the water flows will reduce and adversely impact the vegetation period (Ministry of Environment Protection of Kazakhstan, 2009). In addition, the climate change may significantly affect the state of the lakes, especially in the Aral Sea basin (UNDP, 2009b).

There are observed and expected negative impacts on the environment and biodiversity. The climate change and anthropogenic factors have already intensified the desertification and water resources depletion processes, which affect the biodiversity in Central Asia. For instance, fishing in Uzbekistan has decreased 4.5 times in comparison with 1980s, due to the biodiversity loss in the Aral Sea (Government of Uzbekistan, 2008). The trend towards more dry and hot conditions is leading to a decrease of the desert forests productivity (Government of Uzbekistan, 2008). Furthermore, the projections for Kyrgyzstan indicate possible increase in the proportion of the arid desert and the semi-arid areas from approximately 15% in 2000 to 23-49% in 2100 (UNDP, 2009b).

The combined impacts of climate change, the water resources depletion and the environmental degradation will challenge in particular the agricultural sector and the livelihoods depending on it. While the expected increase in the growing degree days and in the concentration of the carbon dioxide (CO_2) might have positive effect on the crops productivity, the rising temperatures will significantly change the options for cultivating various crops and negatively influence the plant growth (e.g. Government of Uzbekistan, 2008, Ministry of Environment Protection of Kazakhstan, 2009, UNDP, 2009b). The expected water deficit and the poor state of the irrigation system infrastructure could lead to critical water scarcity in many sub-regions, and hence, are likely to bring huge agricultural losses. Furthermore, an additional water loss in the irrigation zones can result from the increased evaporation due to the warmer climate. For example, this would lead to an increase in the irrigation norms in Uzbekistan of about 5% by 2030 and 12-16% by 2080 (Government of Uzbekistan, 2008).

1.2.3. State of the climate change adaptation planning in the Central Asian states

The five Central Asian countries are at an early stage of developing long-term strategies on adaptation to climate change. Kazakhstan has only recently prepared National Concept of Climate Change Adaptation, Programme to Fight Desertification (2007-2017) and introduced several sectoral policies (Bizikova et al., 2014b). Kyrgyzstan has already incorporated climate risk reduction actions in several areas, including the agricultural sector (UNDP, 2009b), but does not have a national strategy on climate change yet. In 2003, Tajikistan developed its National Action Plan for Climate Change, with provisions on improved water and agriculture management. Turkmenistan adopted its National Strategy on Climate Change in 2012, while Uzbekistan has introduced several programmes since 2012, with focus on agriculture, water and biodiversity.

According to the national reports of the five countries to the UNFCCC, major interventions are needed in the following areas, as concerning the agricultural areas:

- Technological improvement
- Development of economic mechanisms for adaptive agriculture

- Establishment of state support mechanisms and institutions
- Improvement of the national hydro-meteorological monitoring systems
- Research on the impacts of and vulnerability to climate change and hazards, and evaluation of adaptation and mitigation policies
- Education and public awareness on climate change issues

Among the critical spheres of action in regards to climate change in Central Asia, is the need of more in-depth scientific research, which however is constrained by: lack of national experts; shortage of funds for research activities; data and methodological restrictions; organizational barriers. It must be recognized that the number of the Central Asian regional studies on climate change is growing over the recent years. However, scientific evidence on the regional climate change impacts and vulnerabilities, including the agricultural sector assessments, are still limited. Furthermore, institutional aspects of the adaptation of the agricultural sector to climate change and hazards are reflected in a relatively low number of published articles (Bizikova et al., 2014b). Particularly, studies at a Central Asian regional level and at a river basin scale (e.g. Glantz, 2005, Sommer et al., 2013, Sorg et al., 2014) are better represented in the literature, than sub-national and local level research.

1.3. Why the concept of vulnerability

A recent paradigm shift occurred in the scientific approaches from viewing climate change and disasters primarily as physical events, towards a holistic analysis of the complex interaction between a potentially damaging physical event (e.g. climate change, hazard) and vulnerability of the human-environmental systems (Birkmann, 2006b). Today, the concept of vulnerability is central in the international policy documents on climate change and hazards (UNFCCC, Hyogo Framework for Action 2005-2015), including in the reports of the IPCC. Similarly, among the prime cross-cutting principles and approaches of the European Union (EU) Strategy on adaptation to climate change for agriculture (European Commission, 2013) is the integrated research on regional and local vulnerabilities.

Furthermore, quantifying vulnerability through indicators is increasingly being seen as a milestone for an effective climate change adaptation and hazards risk reduction (Birkmann, 2006b). The assessment and ranking of vulnerability serves to inform policy- and decision-makers. Various international development programmes and funding agencies refer to prior vulnerability assessments to allocate funds for CCA and DRR (e.g. the special funds under the UNFCCC). Consequently, a vulnerability approach to climate risk reduction adopted in this dissertation meets the demands of the current climate change governance regime.

1.4. Problem setting and objectives

As mentioned above (section 1.3), the concept of vulnerability in exploring the interaction between the climate and human systems has received growing attention. Major challenges in Central Asia in the context of global change, and particularly the risks to agriculture are also well-known (section 1.2). Undoubtedly therefore, it is important to explore those factors, which shape the regional vulnerability. To date, however, there is a significant knowledge gap on the local determinants of vulnerability in the agricultural regions of Central Asia.

Against this background, the prime objectives of this dissertation are twofold:

- to support the climate risk reduction efforts in Central Asia, by exploring the impacts of and the vulnerability to a major climate hazard in this region – i.e. the water scarcity. To achieve this, the vulnerability analysis will consider not only the agro-ecological and socio-economic factors, but also the potential for vulnerability reduction through policy interventions and the capacity of the institutions to facilitate these policies;
- motivated by the need of developing a holistic methodology for vulnerability assessment for agricultural systems at a sub-national level, which would allow sustainability analysis of feasible adaptation scenarios.

These overarching research objectives frame a series of research questions, taking a case study from Uzbekistan. More specifically, the study seeks to answer:

- What is the state-of-the-art of the knowledge on vulnerability for Central Asia?
- What are proven to be feasible climate risk reduction measures and which are the prime barriers to their implementation?

- What are the current research gaps in vulnerability assessments for agricultural systems and how can these gaps be addressed from a methodological point of view?
- How can vulnerability assessment studies inform risk reduction policy development (such as agricultural adaptation planning), considering the issue of sustainability?
- How much was the case study region affected from severe water scarcity in the past and what were the spatial and temporal determinants of the associated impacts?
- What is the current spatial distribution of vulnerability within the case study region and how can the findings support the national adaptation planning?
- What is the role of national and local institutions in reducing the vulnerability of the Uzbek agriculture?

Overall, the conceptual framework, methods and findings of this dissertation could be valuable reference for both, academics and policy-makers.

1.5. Materials and field research methods

1.5.1. Case study selection

The analysis focuses on the case study of the Khorezm region of Uzbekistan. Among the factors which motivated the selection of Uzbekistan, and particularly Khorezm, are the downstream location of this region along the Amu Darya river and the strong socio-economic dependence on irrigated agriculture. In the meantime, the dominant cultivation of highly water-demanding crops, such as cotton, wheat and rice, together with the significant soil salinization, are common characteristics of the countries in Central Asia. Furthermore, Khorezm was one of the most severely affected areas in Central Asia from the drought disaster in 2000-2001. Hence, the region is not only representative of many agricultural spots in Central Asia, but also highly vulnerable to climate change and water scarcity.

1.5.2. Field research methods

During the filed research over the period April-May 2013, secondary data was collected from the Khorezm Regional Statistical Department and the Ministry of Agriculture and Water Resources (MAWR) in Urgench city, the capital of the Khorezm region. Additionally, in order to obtain qualitative data, semi-structured interviews have been conducted. This approach has several advantages, including flexibility in the interpretation of the lead questions, particularly useful in cases when the respondents have different field of expertise and decision-making status (Damm, 2010). In addition, open-ended questions were used, which provide in-depth understanding of the issue, because respondents are not restricted in their answers, as in the case of close-ended questionnaire.

The survey was divided into three sections, according to the main topics of the dissertation. The interviews started with general introduction of the interviewer with the respondent. The objectives of the research were briefly explained to the informant and he/she was asked to describe his/her responsibilities in the respective organization. *Section 1* of the survey contained questions relevant to explore the severe drought impacts over 2000-2001, 2008, 2011. The respondents were questioned about his/her experience with the droughts and personal observations on the impacts during and after these events. *Section 2* added more questions relevant to explore the determinants of the agricultural vulnerability in Khorezm. The information obtained from the first two sections was used in Chapters 3 and 4. The last *Section 3* questioned the institutional dimensions of vulnerability and existing adaptation responses, used in the analysis in Chapter 5.

The sampling frame was tailored to present diverse points of view, thus built upon an interdisciplinary approach (see Table A-1). For instance, the key informants sample included a representative of an international development organization, regional and local level governmental officials, farmers' association and insurance company personnel. They are referred to as '*experts*' and defined as representatives of decision structures, responsible for development, implementation or control of certain policies (Damm, 2010). Different questions from the survey were selected for each respondent, depending on his/her field of expertize.

The major difficulties and challenges encountered during the field research are related to the difficult access to data, due to the strict state control on the information dissemination. Particularly problematic was to obtain social information, such as labour migration data, which was identified as a major issue, not only following severe droughts, but resulting from the overall economic situation in Khorezm. In addition, questions requiring more critical view on the governmental policies were answered in a modest manner.

1.6. Thesis outline

The sequence of the chapters of this thesis follows the objectives outlined in Section 1.4. Each chapter is either being published, under review or intended as an individual article. Therefore, some chapters include repetitions of the prime definitions, case study description and field research details.

Chapter 2 reviews the key determinants of vulnerability in Khorezm and identifies options for climate change adaptation and mitigation in rural areas. *Chapter 3* assesses the severity of the experienced water scarcity in the case study region and explores the associated impacts, and the dynamic factors of vulnerability. Drawing upon some of the findings from Chapters 2 and 3, *Chapter 4* assesses the spatial vulnerability within Khorezm under different scenarios, by proposing and applying an alternative holistic vulnerability assessment method for agricultural systems. *Chapter 5* identifies the network of formal institutions in Uzbekistan (national and local) related to the agricultural sector, highlights key institutional challenges and provides policy recommendations on strengthening the institutional capacity in the country. *Chapter 6* summarizes the thesis findings, draws conclusions and policy implications of the work, and suggests directions for future research.

Chapter 2 Rural vulnerability to environmental change in the irrigated lowlands of Central Asia and options for policy-makers: A review

This chapter is based on:
Aleksandrova, M., J. P. A. Lamers, C. Martius, B. Tischbein (2014). "Rural vulnerability to environmental change in the irrigated lowlands of Central Asia and options for policy-makers: *A review*." *Environmental Science & Policy 41(0): 77-88*.

Abstract

Climate change, land degradation and drought affect millions of people living in drylands worldwide. With its food security depending almost entirely on irrigated agriculture, Central Asia is one of the arid regions highly vulnerable to water scarcity. Previous research of land and water use in the region has focused on improving water-use efficiency, soil management and identifying technical, institutional and agricultural innovations. However, vulnerability to climate change has rarely been considered, in spite of the imminent risks due to a higher-than-average warming perspective and the predicted melting of glaciers, which will greatly affect the availability of irrigation water. Using the Khorezm region in the irrigated lowlands of northwest Uzbekistan as an example, the study identifies the local patterns of vulnerability to climate variability and extremes. The analysis looks at on-going environmental degradation, water-use inefficiency, and barriers to climate change adaptation and mitigation, and based on an extensive review of research evidence from the region, the chapter presents concrete examples of initiatives for building resilience and improving climate risk management. These include improving water use efficiency and changing the cropping patterns that have a high potential to decrease the exposure and sensitivity of rural communities to climate risks. In addition, changes in land use such as the afforestation of degraded croplands, and introducing resource-smart cultivation practices such as conservation agriculture, may strengthen the capacity of farmers and institutions to respond to climate challenges. As these can be out-scaled to similar environments,

i.e. the irrigated cotton and wheat growing lowland regions in Central Asia and the Caucasus, these findings may be relevant for regions beyond the immediate geographic area from which it draws its examples.

Key words: adaptation, climate risk, governance, irrigated agriculture, transformation countries, Uzbekistan, Aral Sea Basin, vulnerability

2.1. Introduction

Today, over 2 billion people are living in drylands (FAO et al., 2011). Furthermore, the economic impacts of regular droughts in these drylands during the past two decades exceed 60 billion USD (EM-DAT, 2009), while the costs of on-going land degradation has amounted to 40 billion USD annually (FAO, 2013). Droughts and land degradation are increasingly being associated with the worldwide climate change, which is expected to aggravate the situation in Central Asia above global averages and to reduce snow and glaciers reserves in the mountains (IPCC, 2014b). The glacier and snow reserves are virtually the only source of water for most of the irrigated croplands in the Aral Sea basin. Given that future climate projections indicate increasing water supply-demand gaps, crop production is endangered, accompanied by decay of socio-ecosystems (Chub, 2000, Christmann et al., 2009).

A vulnerability approach is often applied in the context of climate change analysis. It relates to the concepts of resilience, exposure and susceptibility (Smit and Wandel, 2006, Adger, 2006, IPCC, 2014b, IPCC, 2012a) defined as: (i) *vulnerability* as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes; (ii) *exposure* as the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social and cultural assets in places that could be adversely affected; (iii) *susceptibility* as the degree to which a system could be negatively affected (harmed) by climate variability or change; and (iv) *resilience* as the ability of a system and its components to absorb or recover from the effects of a hazardous event (Parry et al., 2007, Birkmann et al., 2013, IPCC, 2012b).

While evidence on climate risks in Central Asia has been reported (Sommer et al., 2013, Beek et al., 2011, Lioubimtseva et al., 2005, Mannig et al., 2013b), few studies explore the determinants of vulnerability and provide policy-oriented synthesis of suitable risk reducing measures in the Central Asian context (e.g.Lioubimtseva and Henebry, 2009, Thomas, 2008). To reduce this gap, the objectives of this chapter are to examine the rural vulnerability to climate changes and extremes, basing the analysis on the case study of the Khorezm region of Uzbekistan. This region exemplifies many of the environmental, socio-economic and governance challenges of the 21st century in Central Asia and the Caucasus.

Methodologically, this work is based on operationalizing a conceptual framework (Section 2.1.2), through a review of interdisciplinary scientific evidence. The study relies strongly – but not solely – on evidence amassed through long-term research in Khorezm, where innovative concepts and technologies for improved and sustainable agricultural production and rural livelihood have been developed (Martius et al., 2012). The investigated practices could be applicable also to regions with similar conditions such as the traditionally cotton- and wheat-dominated irrigated lowland regions of Central Asia and the Caucasus.

The policy-relevant research findings are grouped into adaptation/ mitigation[1] measures, while underlining their potential effects on the vulnerability components. The prospects of implementation are assessed while considering the expected benefits, and existing constraints (based on scientific evidence). The discussion suggests further practical options derived from global experience.

2.1.2. Conceptual framework of the analysis

Various vulnerability frameworks (e.g. Birkmann et al., 2013, Turner II et al., 2003) provide guidance for a holistic vulnerability analysis in the field of natural hazards and climate change. Yet, they need to be adapted to the case-specific context (i.e. region, sector, hazard) (Birkmann et al., 2013). Considering the Central Asian environmental, socio-economic and governance specifics, an integrated vulnerability-resilience-climate risk management analytical framework is suggested (Fig. 2-1). Nonetheless, while recognizing the multi-dimensional nature of "vulnerability", which includes for instance cultural aspects (Birkmann et al., 2013), only those elements have been included, that are relevant to identify how to counter climate change and extremes and environmental degradation with feasible options for action in irrigated areas.

Since the rural population makes up 60–70% of the total people in Central Asia and a high share is employed in irrigated agriculture (Christmann et al., 2009), the rural livelihoods (social systems), the ecological components (agro-ecosystems) and their interactions provide the key to resilience. These have therefore been emphasized

[1] *Adaptation* is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. *Mitigation* with respect to climate change, means implementing policies to reduce greenhouse gas emissions and enhance sinks (IPCC, 2014)

here. Human activities in Central Asia, such as agricultural intensification (resource utilization arrow), may exacerbate the environmental degradation (impacts arrow) and consequently increase climate vulnerability (Fig. 2-1). The social susceptibility factors include, for instance, rural livelihoods reliance on irrigated agriculture. Resilience *per se* is comprised of ecosystems resilience and social systems capacity[2] to cope with (e.g. access to information) and adapt to (e.g. land tenure) changes and shocks (Birkmann et al., 2013). This has barely been analysed previously.

A major climate change risk[3] in a rural area dominated by irrigated agriculture is water scarcity[4], which is considered in the analytical framework and elaborated as a function of climate change/hazard and vulnerability (Birkmann et al., 2013). Further, it was assumed that through adaptation and mitigation measures the vulnerability could be reduced while concurrently the resilience of the rural socio-ecological systems could be increased. The combination thereof could decrease the overall climate risks in the region.

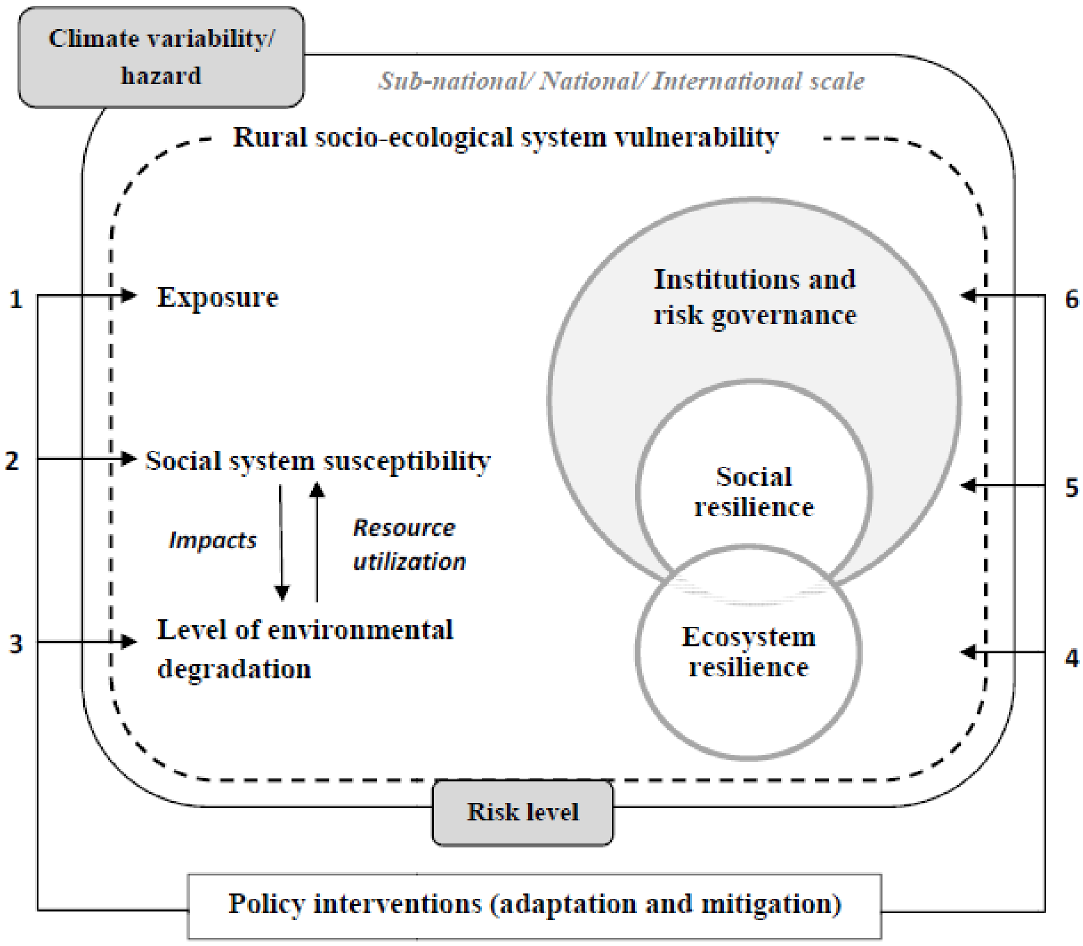
The proposed framework suggests furthermore that a single adaptation/mitigation measure (shown by the arrows 1-6, Fig. 2-1) could address more than one vulnerability component. For instance, practices which preserve ecosystem functions (i.e. build resilience shown by arrow 4) could bring social benefits such as income diversification (i.e. reduced social susceptibility).

Due to the strong grip of the state on irrigated crop production, evidenced by state order quotas for cotton and wheat (Rudenko et al., 2012), it is particularly important that institutional and governance[5] aspects are included in the analysis. These regional characteristics are crucial for mainstreaming climate change policies into local and national development plans. Moreover, an integration of sub-national, national and international perspectives is needed given the present trans-boundary

[2] *Coping capacity* is the ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome adverse conditions (IPCC 2012);and *adaptive capacity* is the whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures (IPCC 2014).
[3] *Risk* refer to the probability of harmful consequences (IPCC 2014).
[4] *Water scarcity* refers to a situation where the absolute quantity of water availability is insufficient to meet the demand.
[5] *Governance* is comprised of mechanisms, processes and institutions involved in climate risk management at a local, national and regional level.

water conflicts on one side (Martius et al., 2009, Sehring and Giese, 2011) and the existing international climate change programmes and funds on the other (e.g. Clean Development Mechanism (CDM)). Both however, create opportunities for risk reduction and development.

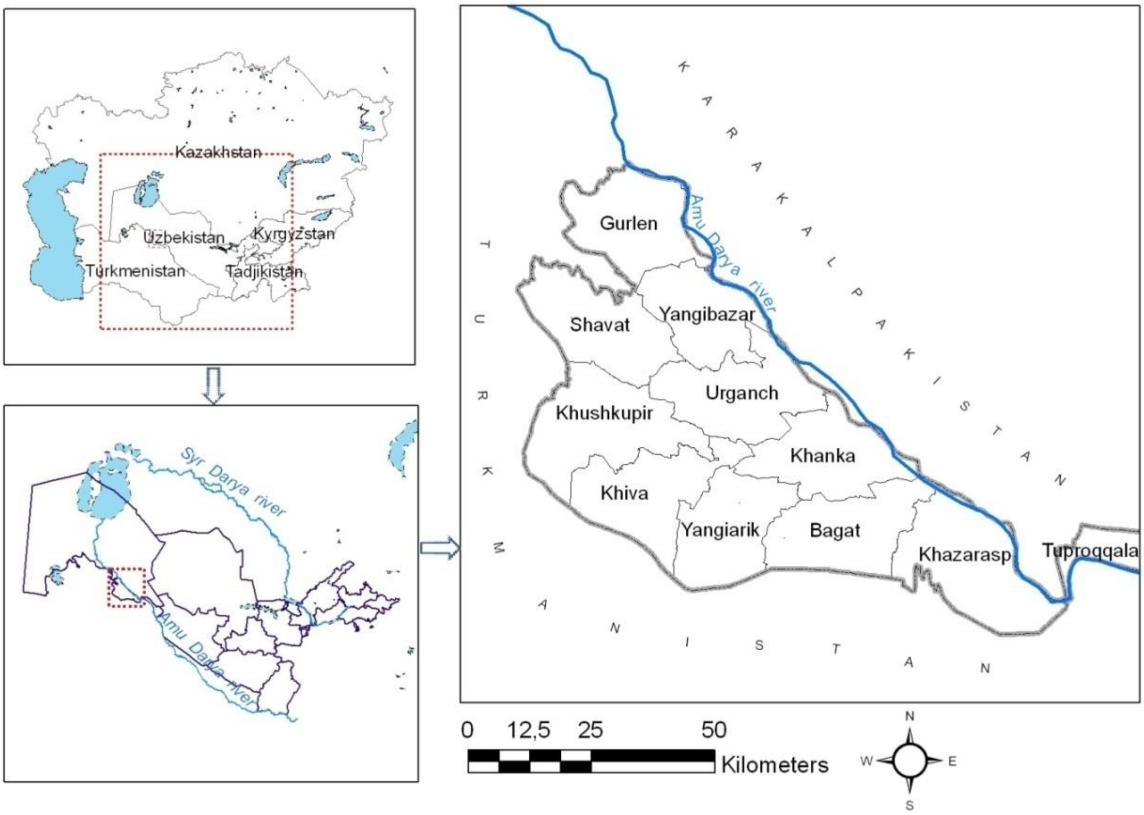
Figure 2-1. Integrated vulnerability-resilience-climate risk management framework



Notes: The figure highlights the relationship between climate pressures, social and ecological systems and the role of adaptation/mitigation and institutions. Source: developed by the lead-author based on the frameworks of Birkmann et al. (2013),Turner II et al. (2003), Ostrom (2009).

2.2. Climate change, water scarcity and land degradation in Khorezm: a vulnerability perspective

Figure 2-2. The Khorezm region in Uzbekistan



Notes: Top left: regional map. Bottom left: map of Uzbekistan. Right side: Map of Khorezm with its political districts. (source: ZEF/ UNESCO GIS Lab, 2013).

2.2.2. Climate risks and exposure

The Khorezm region of Uzbekistan is situated in the downstream part of the Amu Darya river basin. It is part of the inner Aral Sea Basin. Annual precipitation is ca. 100 mm (Conrad et al. 2012) and the Amu Darya river, the only water source for irrigated agriculture, is fed by meltwater from the snow and glacier reserves in the Pamir and Tien Shan mountains. These are therefore vital for the livelihoods in Central Asia. The decrease in surface and volume of these reserves, and consequently changes in quantity and timing of Amu Darya discharges, have often been attributed to climate change (Siderius and Schoumans, 2009). Even though glacier-melt runoff is predicted to increase the water volume in the short and perhaps even mid-term (Cruz et al., 2007), the reserves are ultimately limited and water scarcity is likely to occur more frequently sooner or later (Trenberth et al., 2007).

Conflicts over water between upstream and downstream countries and within country water allocation, could further reduce downstream water availability (Martius et al., 2009), adding an international and national dimension that needs to be analysed (Fig. 2-1). Also water quality is of concern, e.g. the average water salinity in the Tuyamuyun reservoir, upstream of Khorezm, has about doubled in 30 years as a result of diminishing flows from the Pamir and Tien Shan mountains and saline drainage water return flows (Siderius and Schoumans, 2009).

Changing climate has various risk-mitigating effects: the number of growing degree days is comparatively stable and suitable for cultivating the typical crops for the region (cotton, wheat, rice, maize, sorghum); high temperatures indicate increasing suitability for growing wheat; and climate-related crop water demands (i.e. the potential evapotranspiration) have only been slightly decreasing when analysing weather data of the past three decades (Conrad et al., 2012). But the arid climate, the high share of agricultural water use, the low water use efficiency and low irrigation water quality (salinity) all expose agriculture to risks from climate change.

Alternative water sources that potentially could be explored for agricultural purposes such as tapping local lakes (fed by groundwater and drainage system flows) have been examined, yet turned out to be insufficient in size (Shanafield et al., 2010). Also ground and drainage water resources have been considered, however groundwater recharge ultimately depends on the Amu Darya river flow (Ibrakhimov et al., 2007, Tischbein et al., 2012). Hence, while realizing now that such obvious options turned out to be not viable, the negative effect of climate change on water availability is much stronger than presently accounted for.

Table 2-1. Prime determinants of risk and vulnerability in the Khorezm region of Uzbekistan

Climate change, Hazards	Glacier-melt in Central Asia due to climate change Changes in quantity and timing of Amu Darya discharges Change in growing-degree days (temperature, precipitation) Extreme drought events
Exposure	Irrigated agriculture (crops, gross production) dominance

	Uncertainty over water availability (irrigation) High share of rural population
Socio-ecological systems' susceptibility	High socio-economic dependence on irrigated agriculture Low income diversification High water demanding crops *(cotton, wheat, rice)* dominance Irrigation system inefficiency Land/ soil / water deterioration (salinization)
Resilience, governance/ institutions	Coping capacity of the social system to deal with climate shocks (water scarcity) - concerns over: *Information availability, access and trust* *Water management response during droughts* Adaptive capacity of the social system *Restrictive water management with poor capacity* *Frequent land reforms and state tenure, farm restructuring* *Low diversification of cropping patterns* *Weak agricultural extension services* Ecological system resilience *Land typology of non-irrigated areas: desert land, forests, pastures* *Poor state of the irrigation and drainage system* *Unsustainable natural resources utilization*

2.2.1. Socio-ecological systems' susceptibility

Land degradation in Uzbekistan is associated with the enormous expansion of irrigated croplands due to the intensive development of large-scale irrigation systems since the 1960s (e.g. Saiko and Zonn, 2000, Beek et al., 2011). The soil organic matter (SOM), estimated at an average of only 7.5.g kg^{-1} in the topsoil (Akramkhanov et al., 2012) is reportedly falling since the 1950s, due to intensive soil tillage, high temperatures and intensive (over-) irrigation. Furthermore, the on-going soil degradation caused by secondary soil salinization is alarming (Tischbein et al., 2012). The share of highly saline soils increased from 6% in 1960 to 21% in 1990 whilst the total share of saline croplands in Khorezm has reached 40-60% (Akramkhanov et al., 2012).

An analysis of the government´s extensive groundwater monitoring datasets from 1990, 1994 and 2000 shows that during the irrigation cropping season about two thirds of the land in Khorezm had groundwater tables above the critical threshold level meaning levels triggering further soil salinization (Ibrakhimov et al., 2007). Remote sensing analysis based on the decline of NDVI over time shows that in the period 2000-2010 alone, about 33% of the Khorezm irrigated croplands experienced already various levels of degradation (Dubovyk et al., 2012).

Figure 2-3. Landscape

Irrigation from the Amu Darya river (left) is crucial for the life in the Khorezm region, while the high soil salinization (right) is a major problem in this region. (Source: author, 2013)

Human activities impact the level of land degradation and consequently the overall vulnerability of the system (Fig. 2-1). Apart from climate change and variability, main drivers of land deterioration in Khorezm are: (i) the tight governmental control of which agricultural crops are to be produced and with which methods (Djanibekov et al., 2012a); (ii) a government policy abiding by production maximization, rather than seeking sustainable agriculture through resource use optimization; (iii) the land tenure status (all land is owned by the state and only leased to farmers) combined with frequent land reforms, which both discourage long-term planning of land use and investments in resource-conserving measures amongst the farmers (Djanibekov et al., 2012a), and (iv) the lack of access to agricultural service providers which is indispensable for modernising irrigated agriculture in the region (Niyazmetov et al., 2012b).

Socio-environmental determinants of water scarcity. The agricultural sector in Khorezm utilizes up to 95% of the total water intake in the region (Schieder, 2011). The typical irrigation practices include furrow and basin irrigation – both characterized by low efficiency (approx. 40% according to field estimations) (Bekchanov et al., 2010b). A relatively high share of the delivered water (25% in 2004-5) is used for pre-seasonal leaching in spring (Tischbein et al., 2012):

The risk of water scarcity is determined not only by insufficient water availability due to climate change (exposure), but also by the factors of susceptibility, i.e. socio-environmental conditions (Fig. 2-1). Khorezm, similar to other regions in Central Asia and the Caucasus, experiences water scarcity, which is caused by: (i) the location along and the distance from the canal, for instance land located at the tail-end of the irrigation system suffers more frequent water shortages (Bekchanov et al., 2010a, Oberkircher, 2010); (ii) climate change, such as the observed more frequently occurring drought periods over the last decade; (iii) land elevation, insufficient levelling of croplands and low soil storage characteristics. However, the region also is exposed to economic/institutional water shortage that originates from: (i) maladaptive irrigation infrastructures after post-Soviet land reforms (Tischbein et al., 2012, Bekchanov et al., 2010a); (ii) insufficient and unequal water distribution amongst users, due to poor organisational structures and state policies (Abdullayev et al., 2008), and (iii) deteriorated infrastructure such as broken pumps or lack of electricity (Conliffe, 2009).

2.2.2. Social and ecological resilience

Coping with "drought" extremes. Khorezm experienced four major "droughts" since 2000, during which irrigation water inflow from the Amu Darya river amounted to not more then 40-60% of the long-term average (Abdullayev et al., 2008, CaWater-Info, accessed October 2012). In particular water delivery to the tail-end users had been insufficient during these periods of water scarcity. The 2000-2001 droughts are considered the one with the most adverse impacts on the agricultural sector, affecting concurrently the environment and rural livelihoods. The large scale of those impacts has been partly attributed to the insufficient drought preparedness of the national and local institutions (World Bank, 2005) including: (i) failure of drought early warning systems (such as inaccurate observations, poor data forecasting), and (ii) lack of *ex-ante* preparedness and adaptation planning. In addition, the farmers' lack of access to and/or trust in the provided information further exacerbated the negative drought effects (Conliffe, 2009).

The adaptive capacity in Khorezm is framed by the local and national socio-economic and institutional settings. About 70% of the population is rural, out of which 38% is directly employed in agriculture (OblStat, 2013b). Approximately 46% of the total agricultural land is annually used for cotton cultivation, followed by winter wheat and rice (Bekchanov et al., 2010a). Despite the growth of the agricultural sector in the past two decades, its share to GDP has gradually curbed from about 45% in the mid-90s to about 35% in 2012 (OblStat, 2013b) mainly owing to a faster growth of industry and services. At the end of 2008, after a series of intensive land reforms the share of private farms accounted for 82% with 24 ha as the average farm size (Djanibekov et al., 2012c). These frequent land reforms over the last two decades have affected the local adaptive capacity in several ways. Djanibekov et al. (2012c), but also Bobojonov et al. (2012), argued for instance that the present policy of state interventions disincentivizes efficient water use, distorts farming practices, hinders technical renovation and disfavours crop diversification and crop rotations.

Since 2000, the irrigation water management is organized through non-governmental Water Consumer Associations (WCAs), initially introduced to fill the gaps left after the reforms of state and collective farms which reduced the irrigation performance and sustainability. Mandated to regulate water distribution to the users and to maintain the infrastructure (Niyazmetov et al., 2012b), the irrigation water limits for each WCAs are still allocated by the State, based on criteria such as irrigated area, planted crops, and the respective static irrigation norms (Manschadi et al., 2010). However, the low human capacity, experience, skills and funds led to decreasing water use efficiencies and low water fee collection rates (Veldwisch et al., 2012).

Ecosystems resilience. The capacity to maintain ecosystem functions in the aftermath of external shocks is considerably determined by a human component (Fig. 2-1), for instance through natural resource utilization, such as land and water use. Irrigated land resources (42% of the total land area) in Khorezm are used predominantly for cropping, with a small share for livestock rearing, horticulture and gardens. The non-irrigated areas consist mainly of desert land, riparian forests (Tugai) and pastures (Akramkhanov et al., 2012, Khamzina et al., 2012). Given the prioritized production of cotton and wheat, irrigated fields suffer from increasing soil deterioration (Tischbein et al., 2012). The capacity to cope with climate hazards is further reduced by the current status and management of the irrigation and drainage system, which does not allow for controlling the groundwater table and soil salinity adequately, and in turn limits the options for improved irrigation and groundwater management (Tischbein et al., 2012).

Figure 2-4. Village in Khorezm

Scarceness is still wide-spread in the rural areas of Khorezm and livestock is an important security asset for the rural households. (Source: author, 2013)

2.3. Policy-oriented review of promising adaptation and mitigation practices

Suitable policy interventions for climate risk management should be implemented at national and local scale and benefit from the international climate regime (Fig. 2-1). Uzbekistan is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and has initiated the establishment of institutional capacities for assessing climate change impact and developing national plans for adaptation and mitigation. The prime institutions involved in drought risk management in agriculture at national level are: (i) the Ministry of Agriculture and Water Resources of Uzbekistan, responsible for planning, regulating and monitoring the agricultural activities, including the distribution of water and the dissemination of information; (ii) the Centre of Hydro-meteorological Service at the Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet), which is in charge of risk assessment, monitoring and forecasting; (iii) agricultural insurance companies. Following the severe droughts in 2000-2001, the Government has undertaken strategic actions to reduce future drought risks through: (i) large-scale introduction of water-saving technologies (e.g. a programme to implement drip irrigation over 2013-2017); (ii) institutional development for better water control; and (iii) improvement of runoff forecasting (Government of Uzbekistan, 2008). Yet, climate risk management remains a challenge ahead also because up-to-date findings on feasible measures are not available to policy and decision-makers.

2.3.1. Improved water resources management

Promising strategies for improving water-use efficiency (arrow 2, Figure 1) include tackling the demand side via (a) reducing the gross water requirements by more targeted and efficient irrigation without reducing yield, and (b) in case of severe under-supply, minimizing the impact of non-avoidable water stress on the yield production by controlled deficit irrigation. With improved irrigation scheduling, fulfilling the site-specific and time-depending needs of the crops (strategy a), water distribution can be optimized (Pereira, 1999) and this could raise the water productivity during drought seasons in Khorezm (Bekchanov et al., 2010a). Especially, replacing the existing static irrigation norms by an approach based on flexible modelling of surface and groundwater processes has a high potential to meet crop water requirements with lower water input (Awan et al., 2012). This can be supported by relatively simple measures for technical rehabilitation of the irrigation system (laser-guided levelling, introduction of equipment for water dosage at field level, lining of canals in reaches with high percolation) and by introducing modern irrigation techniques. The latter however, would require substantial investments (Rudenko and Lamers, 2010) and given the low capitalization levels of most farmers (Wehrheim et al., 2008), mainly low-cost methods seem currently appreciated. The latter include double-side irrigation on flat fields, short and alternate dry furrow techniques, optimizing application discharge under given field conditions, surge flow approach (Tischbein et al., 2012), although these are much less water-efficient (Bekchanov et al., 2010b).

The current irrigation practices based on static norms do not allow reacting adequately to severe supply-demand gaps (as was seen in the years 2000 and 2001). Adapting to severely reduced supply consists of controlled deficit irrigation (strategy b) which enables minimizing the impact of non-avoidable water stress on yield. Akhtar et al. (2013) combined the AquaCrop (Steduto et al., 2009) and the HYDRUS 1-D (Simunek et al., 2008) models to elaborate a tool to deal with deficit irrigation strategies. Considering the capillary rise from shallow groundwater, it was estimated that raising water productivity is feasible even under diminished water supply. Taking cotton as an example, simulations show that even up to a 20% reduction in water supply, a loss of (harvested) yield can be nearly avoided in case of optimized irrigation timing and amount. Furthermore, the impact of a 40% reduction in water supply on yield could be kept in the range of 14-29% in terms of yield loss (Akhtar et al., 2013).

Finding alternatives to increasing the storage capacity of the irrigation and drainage system (arrow 4, Fig. 2-1) would be a desirable option influencing the supply side mainly in terms of timing, including: (i) conjunctive use of surface and groundwater utilizing the buffer function of the groundwater; (ii) integrating the lakes, which are abundant in the region, into water management planning; and (iii) construction of small decentralized reservoirs to store canal water in case of oversupply and to use it during deficit periods (Tischbein et al., 2012). Currently, the farmers' preferences in response to water scarcity follow a certain sequence: first, tapping the groundwater reservoirs by partly blocking drainage discharge when possible and using them as a fall-back option during periods with water shortage; and second, cultivating alternative crops and/or abandoning part of the cropland. However, filling groundwater resources and maintaining shallow groundwater has the unwanted side effect of increasing secondary soil salinity. Since option (iii) requires huge investments and is not feasible in a short-run, options (i) and (ii) need to be further explored.

Studies on water use demonstrated that the poor performance of irrigation water management is not only a technical matter, but has an institutional dimension as well. Therefore, technical approaches for restructuring irrigation water supply must be flanked with institutional re-arrangements creating better management conditions and economic incentive-disincentive systems (arrow 6, Fig.2-1). For instance, water pricing schemes aiming at economically efficient allocation of the water resources have been suggested. However, several practical difficulties remain, such as "demand uncertainty" (uncertainty over the willingness to pay) and need of infrastructural modifications (Saleth et al., 2011). Djanibekov et al. (2012b) investigated the prospects of introducing irrigation water service fees and concluded that while this measure has the potential to generate sufficient funds to support the management of the irrigation network, positive effects can be expected only if additional policies aiming at water use reduction and farms income increase are introduced as well.

Figure 2-5. Cotton or gardens

Cotton fields (left) represent 85% of the total cropland in Khorezm. The increase in the garden areas (right) is beneficial risk reducing option. (Source: author, 2013)

2.3.2. *Considering alternative cropping patterns*

Bekchanov et al. (2012) argued that the long-term sustainability of the Uzbek economy, which is among others exposed to environmental degradation, water security risk and uncertain world commodity prices, requires switching to less water-intensive agricultural production procedures. For example, a change in the cropping patterns (arrow 2, Fig. 2-1) as an adaptation measure could have multiple benefits, such as improving soil quality while offering new opportunities for income generation. Relying on the combined information from field experiments, modelling and secondary sources, Bobojonov et al. (2012) show that higher water use efficiency combined with secured farm income is feasible through diversifying the crop portfolio.

2.3.3. Considering perennial crops and afforestation

Including perennial crops in the agro-ecological landscape has been practiced in Uzbekistan for wind erosion control, wood production and horticulture (Tupitsa, 2009). Although fruit trees have been part of the production systems as practiced over the Soviet Union era, their further promotion has hardly been part of the reforms during the past decade (Djanibekov, 2008). Concurrently, an assessment through aerial photographs illustrated an average annual deforestation rate of almost 1.5% and an even higher rate of conversion of the natural *tugai* forests (natural floodplain forests along the Amu Darya river) to cropland with only sparse tree cover. This change in land use impacted significantly soil greenhouse gas emissions which turned out to be much lower from different forest-based land uses compared to agricultural land uses (Scheer et al., 2012).

Afforesting marginal, salt-affected croplands (arrow 4, Fig. 2-1) is a well-known strategy for re-vegetation, land reclamation, income generation and diversification of the land use while capturing atmospheric carbon dioxide (CO_2) (FAO, 2001). For instance, after five years of afforestation, the amount of Carbon (C) sequestered in the above-ground woody biomass was in the order of U. Pumila (11 t C ha^{-1}) <*E. angustifolia* (17 t C ha^{-1}) < *P. euphratica* Olivier (23 t ha^{-1}) (Khamzina et al., 2012). Afforestation of such marginal cropland patches turned out to be an economically viable alternative compared to a series of crop cultivations including cotton (Djanibekov et al., 2012d), provided that land users will be ensured with long-term tenure security and have access to knowledgeable people for establishing and maintaining tree plantations on marginal cropland. It was argued therefore, that afforesting degraded croplands may open new financial opportunities in Central Asia through CDM projects. With reference to the framework used (Fig. 2-1), global initiatives can thus support the social-ecological resilience at a local scale as well.

On the other hand, the research outcomes indicated that the current global average price for CDM payments of 4.76 USD per temporary Certified Emission Reductions (tCER) is insufficient to induce farmers to participate in short-term afforestation projects (Djanibekow et al 2012d). However, the overall findings illustrated that afforesting degraded cropland has the potential of reducing the rural vulnerability to droughts through several pathways: (i) diversify income and relax food and energy insecurity (fruits, firewood, fodder and timber); (ii) provide amenities (shadow and shelter) for well-being; and (iii) provide ecosystems services and thereby build resilience of the environment (e.g. microclimate, bio-drainage, water efficiency) (Khamzina et al., 2012). Although, a periodic leaching (for instance once during 10-15 years) may be needed to counterbalance the slowly rising soil salinity under afforested areas. Given the high timber prices, such plantations could be transferred to timber production, yet financial benefits can be reaped only after longer periods (Khamzina et al., 2012). Additional benefits from a change from annual to perennial vegetation include a reduced average daily out-flux of CO_2 equivalents (Scheer et al., 2012) and an increased C sequestration in soils (Hbirkou et al., 2011).

2.3.4. Considering conservation agriculture

Conservation agricultural (CA) practices are highly potential means to build resilience of the ecosystems in relation to the human component (arrows 3 and 4, Fig. 2-1). CA consists of a basket of measures that are applied adaptively, but must follow three principles: (i) minimizing soil disturbance (e.g. direct seeding, decreased/no tillage); (ii) maintaining a permanent soil cover (e.g. use of cover crops, crop residues); and (iii) providing adaptive crop rotations (Milder et al., 2011, FAO, 2002). In this way, CA contributes to preserving soil moisture and sequester and maintain C; protects and enhances the biological functioning of the soil; decelerates salt accumulation due to a lowered evaporation; reduces soil erosion; maintains and improves crop yields and increases the resilience against droughts, salinization and other hazards (Derpsch and Friedrich, 2009).

Worldwide, CA practices have been introduced considerably in the rain-fed agricultural areas of South and North America, whilst recently they have been found promising under the irrigated conditions in Central Asia, although demanding various adaptations and improvements of legal frame-conditions (Kienzler et al., 2012). Yet, the combined benefits from CA practices that require much lower energy input per unit area (energy, machinery, labour, seeds, fertilizers), do not only cut on production costs (Kassama et al., 2012), which improves rural income, but also decrease greenhouse gas emissions.

2.3.5. Adapting agricultural production and trade

The entire cotton value chain plays a significant role in the national and regional economy of Uzbekistan, while wheat production was greatly promoted to support national food self-sufficiency (Rudenko et al., 2012). Therefore options which increase resource use efficiency and favour the processing industry must be explored (arrow 2, Fig. 2-1). Rudenko (2008) argued that in the cotton value chain, an increase in the in-country processing of cotton fibre and Khorezm regional production of textile products with higher value-added followed by their export, could double or maintain the present regional export revenues. Meanwhile, the lower water demand would decrease the vulnerability to droughts and reduce the present environmental burden provoked through cotton cultivation (Rudenko, 2008).

Although the diversification of agricultural commodity trade and the promotion of market participation could potentially make rural livelihoods more resilient to climate extremes (sections 2.3.2, 2.3.3), presently poor markets exist for fruits, vegetables and tree products (e.g. Bobojonov et al., 2012, Khamzina et al., 2012). Good economic practices for improving the market conditions (arrows 5 and 6, Fig. 2-1) should be adapted to the Central Asian context, including regional free trade as a measure against price volatility (Mirzabaev and Tsegai, 2012), better functioning of the processing sector, improved storage facilities and facilitation of export (Bobojonov et al., 2012, Rudenko et al., 2012).

Table 2-2. Summary of reviewed policy options, their potential effects on the components of vulnerability and prime constraints to implementation.

Climate change adaptation/ mitigation opportunities	Potential effect on the components of vulnerability					Constraints
	E	ED	SS	CAC	ER	
Improving water-use efficiency						
Improvement of the irrigation scheduling *(arrow 2, Fig.1)* (Bekchanov et al., 2010b)			-	+		Need of substantial investments (Rudenko and Lamers, 2010) Poor performance of irrigation water management institutions (Abdullayev et al., 2008) Need to improve storage capacity demands substantial infrastructural modifications (Tischbein et al., 2012) Current centralized water management (Djanibekov et al., 2012c, Manschadi et al., 2010) Ongoing land reforms and state land-tenure (Trevisani, 2009 cited in, Djanibekov et al., 2012a) Water pricing “demand uncertainty” (Saleth et al., 2011)
Replacement of the existing static with flexible, adaptive irrigation norms *(arrow 2, Fig.1)* (Awan et al., 2012)			-	+		
Increase in the storage capacity of the irrigation and drainage system *(arrow 4, Fig.1)* (Tischbein et al., 2012)	-	-		+	+	
Water pricing schemes/ water user fees and consequently prospects for economy efficient allocation of water *(arrows 2 and 6, Fig.1)* (Djanibekov et al., 2012b)			-	+		
Considering alternative cropping & processing patterns						
Crop diversification, change to less water-intensive production *(arrow 2, Fig.1)* (Bobojonov et al., 2012, !!! INVALID CITATION !!!)	-	-	-	+	+	Fixed state production quotas on cotton and wheat (Bobojonov et al., 2012) Poor linkages of farmers with markets for fruits, vegetables (Bobojonov et al., 2012) Under-developed, in-country cotton and wheat value chains (Rudenko, 2008)

Perennial crops and afforesting degraded croplands						
Re-vegetation and land reclamation, capturing atmospheric carbon dioxide *(arrow 4, Fig.1)* (Khamzina et al., 2012); CDM financial opportunities (Djanibekov et al., 2012d)	-	-	-	+	+	Lack of knowledge (Kan et al., 2008) Poor markets for tree products, insecure land tenure (Khamzina et al., 2012, Djanibekov et al., 2012d)
Conservation agriculture *(arrows 3 and 4, Figure 1)* (Kienzler et al., 2012)	-	-	-	+	+	Lack of farmer knowledge State production quotas on cotton and wheat Ongoing land-reforms and state land-tenure Insufficient legal framework (Djanibekov et al., 2012a, Kienzler et al., 2012)
Adapting agricultural production and trade						
Improved market conditions *(arrow 5, Fig.1)* (Mirzabaev and Tsegai, 2012)			-	+		Need of improved storage facilities and investments in the processing and refinement sectors (Bobojonov et al., 2012, Rudenko et al., 2012)
Development of the processing and refinement sectors (e.g. cotton value chain) *(arrow 2, Fig.1)*(Bobojonov et al., 2012, Rudenko et al., 2012, Rudenko, 2008)	-	-	-	+	+	

Notes: E=exposure, ED=environmental degradation, SS=social system susceptibility, CAC= coping and adaptive capacity, ER=ecosystem resilience. (-)/(+) refer to decreasing/increasing potential effect on the vulnerability components of each adaptation/mitigation option. The references in the table include only experience from Khorezm (global good practices described in Section 3 are excluded).

2.4. Outlook

Within the proposed vulnerability-resilience-climate risk management framework, institutional support and political awareness on climate risks are prerequisites for effective risk governance (highlighted by arrow 6, Fig. 2-1). The national administration of Uzbekistan plays a central and active role in the water and agriculture sectors. The current differential crop policies prioritizing cotton for export and wheat to support national food security through elevated levels of subsidies are nevertheless inconsistent with climate change mitigation and adaptation measures. This consequently reduces the resilience of the agricultural sector (at a local and national level) to the changing environment. To take advantage from all opportunities, Uzbekistan should reflect on discarding differential crop schemes altogether or give equal importance to all crops and sectors. This in particular would decrease the vulnerability of areas with poorer access to markets, storage and processing facilities (Bobojonov et al., 2012).

Furthermore, incentives should be orchestrated to facilitate sustainable resource management, social equity and environmental preservation. The highly needed decentralization of the water management in the country was only half-heartedly pursued. Combined with the on-going reversing of previous land reforms towards larger farms (Djanibekov et al., 2012a), the capacity of the rural population to take adaptation initiatives relevant to their needs and capabilities is restricted. Insecurity about land ownership could also explain the low incentives for investment in adaptation measures as frequently argued (e.g. Djanibekov et al 2012a). Similar challenges need to be overcome before introducing adaptation measures such as farm-forestry (Khamzina et al., 2012) and conservation agriculture (Kienzler et al., 2012). Further obstacles identified for the implementation of adaptation and mitigation measures are the lack of farmers' knowledge about the environmental benefits from measures such as afforestation (Kan et al., 2008), and cultural and religious aspects that affect water management at a local level (Oberkircher, 2010). Therefore, climate change adaptation and mitigation planning could benefit from a shift in governmental policies towards more equitable and participatory distribution of decision power among the involved stakeholders in agriculture and water management, together with social capacity building, such as awareness rising.

Chapter 3 Water scarcity and rural welfare in Central Asia: An integrated impact and vulnerability analysis

Abstract

Water scarcity is an imminent risk in Central Asia, conditioned by depleting glaciers reserves and unsustainable water resources management. With the break-up of the Soviet Union, the Central Asian states struggle to settle stable trans-boundary agreements for the management of the major rivers. These factors, coupled with national and sub-national vulnerabilities, resulted in significant losses from droughts especially since 2000. The rural areas were particularly affected, as they depend narrowly on the agricultural sector, which is very vulnerble. Based on a research in the Khorezm region of Uzbekistan as an example, which has been one of the most severely affected areas in Central Asia during the 2000-2001 disastrous droughts, this chapter presents the findings of an integrated drought impacts and vulnerability analysis. More specifically, this study analyses the severity of the droughts in Khorezm, which have occurred four times during 2000-2012 and were characterized by water availability in the range of 40-60% of the long-term average in this region. It further explores the associated direct and indirect environmental and socio-economic impacts and seeks to identify the regional determinants of vulnerability. The main methods applied include drought indexing, field-interviews and descriptive statistics. The findings suggest that particularly the 2000-2001 droughts affected not only the agricultural production, but also the environment and the social security in Khorezm. Despite the observed trend towards lower vulnerability, the region is still highly exposed and sensitive to water scarcity and lacks capacity to deal with climate related challenges.

Key words: agricultural sector, economic growth, hazard impacts, Uzbekistan, water scarcity severity index

3.1. Introduction

Over the last decade, regularly recurring droughts have turned into a global concern, bringing severe social, economic and environmental consequences. Central Asia is considered a region which is highly exposed to various natural hazards such as droughts, floods and landslides (UNDP/BCPR, 2011). The observed and expected climate changes indicate an increasing frequency and severity of the hydro-meteorological extreme events, including water scarcity in the major rivers of this region (IPCC, 2014b). At the same time, the post-Soviet transition process in the Central Asian states has created a challenging socio-economic and political environment for disaster risk governance.

The importance of water is exemplified through irrigated crop production, which remains a major contributor to: (i) foreign income earnings, such as cotton for Uzbekistan and Tajikistan; (ii) food security, given that irrigated wheat and rice are the two most important food staples in the region; and (iii) rural employment (Christmann et al., 2009). Droughts can also impact the hydro-electric power generation of upstream countries, which presently covers 97% of the electricity supply in Tajikistan and even up to 91% in Kyrgyzstan (World Bank, 2013).

Several major drought events have occurred in Central Asia since 2000 and some have been classified as *disastrous*[6] (see Table 3-1), with about 6,4 million people being affected directly (EM-DAT, 2009). Droughts have become a considerable challenge for the five countries in Central Asia since the break-up of the Soviet Union. The droughts in 2000-2001 were particularly severe in Tajikistan and Uzbekistan, leading indirectly to the loss of income, higher food prices, malnutrition and migration, thereafter followed by increased poverty rates and health decline (World Bank, 2005). The greatest source of direct losses for the regional economies has been the loss of agricultural production, which accounted for 16,8% in Tajikistan and 2,4% in Uzbekistan (expressed as percentage of the agricultural value added) as some estimations suggest (World Bank, 2005, World Bank, 2006). Indirect damages included furthermore environmental degradation, for example a loss of wetlands and desertification in some regions of Karakalpakstan (World Bank, 2005). The drought spell in 2007-2008, characterized by a very hot summer in 2007,

[6] Here '*disastrous event'* is defined according to EM-DAT criteria and definitions, available at: http://www.emdat.be/criteria-and-definition

followed by an unusually cold winter in 2008, has affected the water availability during the entire 2008. The most impacted countries were Tajikistan and Kyrgyzstan, because the water scarcity resulted in an energy crisis and a sharp rise in the food prices, with a particularly strong socio-economic impacts in the rural areas (UNDP, 2011, UNDP, 2009a).

Table 3-1. Drought disaster events in Central Asia and major impacts

Year	Country (main affected provinces)	Number of people affected	Major consequences/ associated impacts
2008	Kyrgyzstan (n.a.)	2,000,000	Energy crisis; food prices inflation (32% rise) and consequent food insecurity among the poorer strata of the population.
2007-2008	Tajikistan (n.a.)	800,000	Shortage of hydro-power electricity and associated energy price increase; damaged agricultural production and food insecurity due to increase in the food prices (26% in 2008).
2000-2001	Tajikistan (Khatlon)	3,000,000	Need of food-aid (relief aid delivered to about 58% of the rural population); increase in food prices; failure of rain-fed and irrigated crop production and associated unemployment in the agricultural sector (approx. 160 million USD losses); energy supply deficit; increase in waterborne diseases.
2000-2001	Uzbekistan (Karakalpakstan, Khorezm)	600,000	Critical need of drinking water supply; increase in the number of people affected by water-related diseases; lack/shortage of water for irrigation; significant impacts on crops and livestock (approx. 130 million USD impacts in the agricultural sector); unemployment rate growth (approx.. 100,000 farm households unemployed); increase in food prices; accelerated desertification in Karakalpakstan.

Notes: The table summarises information from various sources: EM-DAT (2009) (accessed 27.08.2013); ADRC (2013) (accessed 27.08.2013); World Bank (2005); World Bank (2006).

Despite water scarcity being a major threat to the sustainable development of Central Asia, a prime source of information on the impacts and determinants of disastrous outcome are mainly the few above mentioned reports (Table 3-1).

Regional assessment studies are limited and therefore the objective of this chapter is to fill in this gap by providing a detailed characterization of the severity of water scarcity, associated the underlying factors of vulnerability and observed impacts in the Khorezm region of Uzbekistan. The region, subject to this study, has been one of the most severely affected areas in Central Asia during the 2000-2001 disastrous droughts. The region is an example of the dominance of an irrigated agricultural area and the findings are therefore of relevance for drought risk management in similar contexts.

3.1.1. Scope of the study

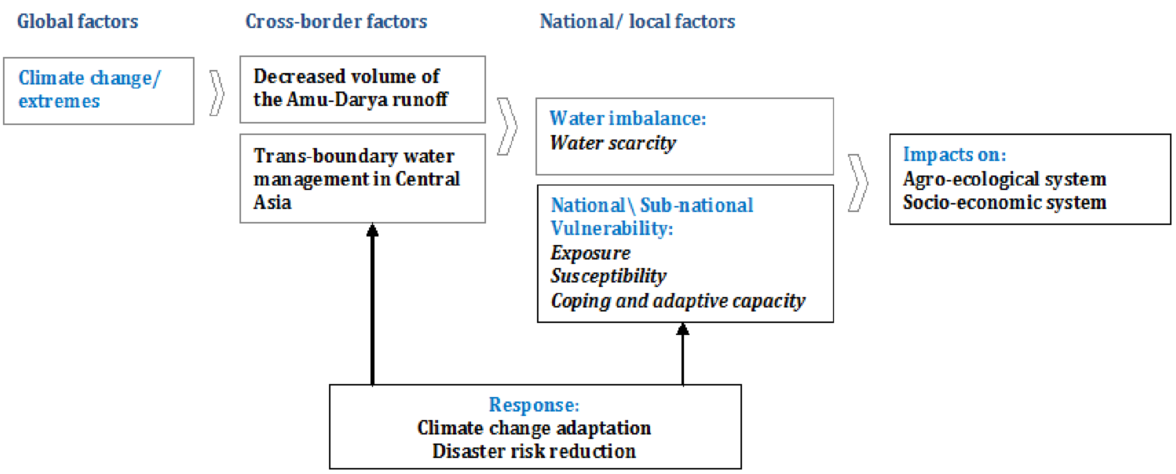
Droughts are hydro-meteorological hazards and the severity of their impacts is influenced by various environmental and socio-economic factors. Accordingly, drought events are classified as meteorological (precipitation deficit), hydrological (critical stream-flow and groundwater deficit), soil-moisture/agricultural (critical soil moisture deficit) and socio-economic (caused by pressure on water resources by human uses) (IPCC, 2012b). *Water scarcity* indicates insufficient water availability vs. water demand resulting in physical water shortage (e.g. due to hydrological drought) and poor natural resource management (Falkenmark et al., 1989, Kharraz et al., 2012), hence, the term is linked to the notion of socio-economic drought.

For the Central Asian countries, drought in a broader sense, is a relatively new risk, yet aggravated not only by the changing climate patterns (natural cause), but also by the water management and distribution among the newly-formed autonomous states (human cause). Therefore, *water scarcity* was identified as the most appropriate measurement of drought severity, compounded of: (i) *hydrological drought,* which represents the negative anomalies in stream-flow, and/or groundwater levels (IPCC, 2012b), and (ii) *socio-economic and institutional conditions* in the region, e.g. land and water management at a cross-border and local level.

Within the scope of this study falls also the view that the impact of hazards is conditioned by local vulnerabilities (Fig. 3-1). Among the various representations of *vulnerability*, the definitions of the Intergovernmental Panel for Climate change (IPCC) in the context of climate change adaptation (CCA) and disaster risk reduction (DRR) were adopted here, namely "the propensity or predisposition of a system to be adversely affected" (IPCC, 2012b).

According to the IPCC (2012b), *impacts* are generally defined as effects on natural and human systems. The scale of suffered losses is attributed to the vulnerability of the system, while responses such as CCA and DRR, could decrease the potential impacts. In relation to this, it is important to define: (i) *coping capacity*, which is "the ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome adverse conditions"; and (ii) *adaptive capacity,* which is "the combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for, and undertake actions to, reduce adverse impacts, moderate harm, or exploit beneficial opportunities" (IPCC, 2012b).

Figure 3-1. Conceptualization of the linkage between vulnerability, impacts and responses to water scarcity in the case study region



(Source: own compilation)

Valuing hazard impacts and accounting for direct and indirect linkages is challenging, also it is often restricted by the lack of data. Therefore, this chapter was built upon holistic and integrated analysis, using a combination of quantitative and qualitative methods to deal with insufficient data availability. First, the water scarcity severity index (WSSI) was developed as a proxy indicator for the drought severity

(Fig. 3-1). This allowed determining those years and districts in the Khorezm region, which had experienced extreme, severe or moderate droughts during the examined period 2000-2012. The findings formed in turn a basis for identifying those factors leading to higher drought impacts, capturing simultaneously the spatial and temporal aspects (Box *Vulnerability* of Fig. 3-1).

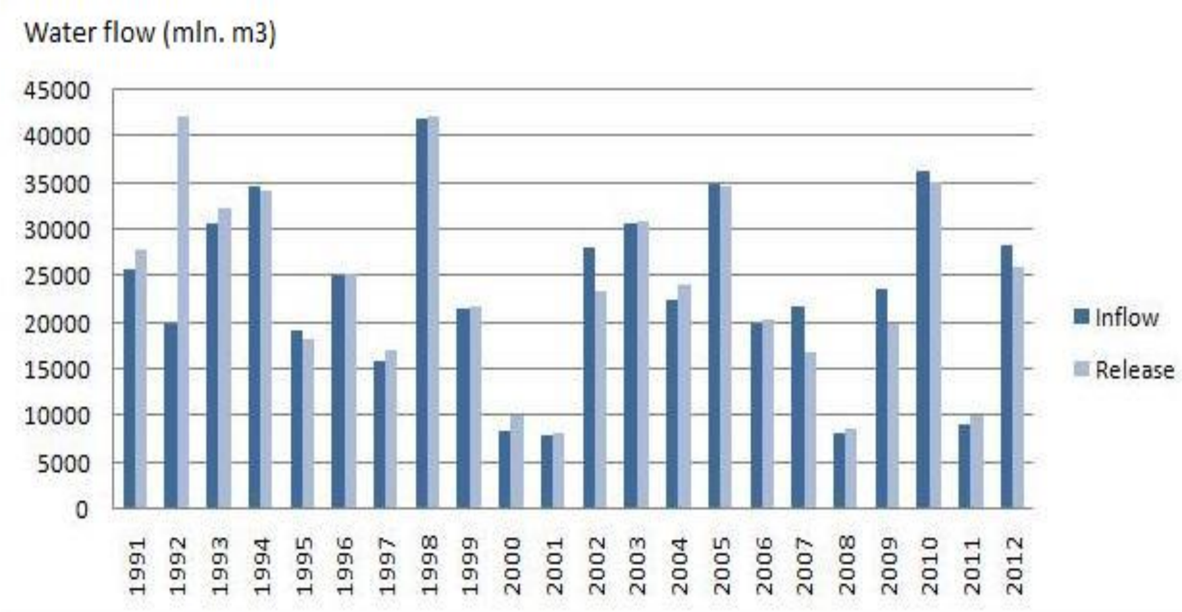
Next, to better understand the drought hazard, the multiple dimensions of the social, economic and environmental impacts were explored through surveys with key informants. Secondary data was collected from various sources to cross-check and triangulate the statements of the respondents, by conducting empirical analyses (Box *Impacts* of Fig. 3-1). More specifically, the analysis sought to explore the linkages between the hazard and the regional welfare, whereas two aspects were considered: (i) the effects of severe and extreme water scarcity on the environment, agricultural sector and regional economic growth; and (ii) temporal analysis of the observed changes towards higher or lower regional vulnerability. In addition, policy implications of the findings for CCA and DRR are discussed in Section 3.4 (Box *Response* of Fig. 3-1). Prior to the analytical part, Section 3.2 provides information for Khorezm and outlines the methods used in the work.

3.2. Materials and methods

3.2.1. Case study characterization

The Khorezm region of Uzbekistan covers about 680,000 ha from the down-stream lands of the Amu Darya floodplain in the inner Aral Sea basin. The average day temperature is 13-14°C, whilst precipitation does not exceed 100mm annually. Four major drought events have occurred in the region during the past 15 years in 2000-2001, 2008 and 2011, characterised with water availability in the range of 40-60% of the long-term average (Fig. 3-2). Khorezm has 11 administrative districts with a total population of 1.65 million, out of which 67% is rural (OblStat, 2013b). The GDP per capita in 2012 was 943 USD (current prices) (OblStat, 2013b), which is below the county's average of 1717 USD (World Bank, 2013).

Figure 3-2. Actual water flows to and from the Tyanumuyn reservoir in Khorezm during the vegetation period



(*Source: own elaboration based on data from CaWater-Info (accessed October 2012))*

Water and irrigation

The hydrological cycle in Khorezm is determined by the water availability in the Amu Darya, including ground-water recharge, which is a considerable source of drinking water in many rural areas and additional source for irrigated agriculture. Annual precipitation and temperature patterns do not contribute significantly to the water availability at a local level and together with the arid environment the development of a dense irrigation system was needed to pursue for agricultural production. The water streaming from the Amu Darya is first collected in the Tuyamuyun reservoir and next channelled to the irrigation system, which is comprised out of primary (inter-region), secondary (inter-farm) and tertiary (on-farm) canals. The excess surface and groundwater is drained out of the region through a network of laterals and collectors. The amount of water supply is regulated according to the state norms and depends on the planned irrigated land and crop varieties to be cultivated each season. Notable is the low irrigation efficiency due to an outdated infrastructure and poor management, with losses along the system suggested to be about 45% in 2004-2005 (Tischbein et al., 2012).

Agriculture

The value added of the agricultural sector to the regional GDP is 35%, while data for 2008 showed nearly 38% of the people being employed in this sector (OblStat, 2013b). The largest share of the agricultural output is represented by cotton, winter wheat and rice (OblStat, 2013a). Cotton and wheat farmers receive large subsidies and are obliged to meet certain production quotas, while their profits are restricted by the state-determined prices of cotton and partly those of wheat. Export of cotton accounted for about 98% of the total regional export revenues in 2006, while the Khorezm region provided 53% of the national rice production in 2007 (Bekchanov et al., 2010a). Importantly, the rice fields occupy barely 9% of the total cropland (OblStat, 2013a), however, paddy rice cultivation demands about five times higher amount of water than cotton (Müller, 2006). In addition, the free market conditions and high internal demand, make rice production highly profitable for farmers (Bekchanov et al., 2010a). Fruits and vegetables, as well as fodder crops (maize, clover, others), are an important component of the regional output, trade and households' nutrition. Animal husbandry comprises about 50% of the regional gross agricultural production, however only about 7% of the agricultural land is used for pastures. Of importance in the region is the presently small-scale agro-processing industry, such as cotton oil extracting, textile production, fruits, vegetables and wheat processing, which have however the potential to generate substantial profits and support the regional development (Rudenko, 2008).

Rural reforms

The severe drought events over the last 15 years went along with several farm-restructuring phases and institutional reforms. A nation-wide farm privatization process was initiated in 1998 and composed of a partial break-up and downsizing of production units. The final stage of privatization was reached at the end of 2007, when 82% of the farms had become private. The complete break-up of farms and land was promoted especially between 2005 and 2007, however afterwards the government assessed this process of being inefficient and which needed to be reversed. This has led to a land consolidation process initiated from 2008 onwards, which was focused on farm and hence production optimization. The latter was characterized with the reallocation of land from small farms (<30ha) to larger ones, with dominant type of producers private farms and household plots (Djanibekov et al., 2012a). Meanwhile, the state procurement system for cotton and wheat has been preserved during all reforms. However, in general, the privatization transformed the socio-economic structure of the rural livelihoods. For instance, the dominant form of labour has changed from family contracts up to 2002, to permanent and seasonal employment. Also, the shift from state to private farms opened more opportunities for the latter in terms of production diversification. Lastly, since 2000 WCAs were formed and mandated for water distribution among users, although frequently criticized for inefficient services provision (Veldwisch et al., 2012, Abdullayev et al., 2008).

3.2.2. Empirical specification

The aim is to explore the direct and indirect impacts of water scarcity on the agricultural sector and regional economic growth, as well as on the dynamics of the rural resilience to water scarcity. For this purpose, descriptive statistical tools were used, in a combination with qualitative information gathered from key informants. Prior to the impact analysis, the severity of water scarcity was explored.

Constructing Water Scarcity Severity Index (WSSI)

Drought indexing is a common tool for drought measurement and forecasting. Various drought indices are suggested in the literature; however, most of them are developed for rain-fed agriculture (e.g. Standardized Precipitation Index (SPI); Percent of Normal (PN); Deciles). To estimate water scarcity in irrigated areas, similar methods for measurement have been used, but they are based on a different set of variables, e.g. the Surface Water Supply Index (SWSI) proposed by Shafer and Dezman (1982). The lack of available and reliable data for a full hydrological cycle in an irrigation-dominated region such as Central Asia, requires the development of simplified indices, such as the Groundwater Resource Index (Mendicino et al., 2008) and storage level of reservoirs (Gil et al., 2011). Therefore, taking into account the above described regional characteristics, and referring to the definition provided in Section 3.1, water scarcity was quantified by using values associated with the monthly water delivery to Khorezm, intra-regional distribution and groundwater level.

The purpose of this study was to define the spatial and temporal severity of the experienced drought events, rather than to focus on drought forecasting. Therefore, the Z-scoring method was used to construct the WSSI for the Khorezm region (Eq. 3.1). The proposed standardization approach is used for the computation of SPI (McKee et al., 1993), which permits determining periods with abnormally wet or dry conditions. The threshold level (class WSSI) was determined similarly to the Palmer Drought Severity Index (PDSI) (Palmer, 1965), which takes the 0 value for the normal state and +/- for wet or dry conditions. In this particular analysis that focuses on drought, consequently negative values were defined as -3 (extreme drought when WSSI≤-2.00), -2 (severe drought when -1.99≤WSSI≤-1.50), -1 (moderate drought when -1.49≤WSSI≤-1.00), and 0 (normal state, -0.99≤WSSI≤1.00).

$$z - score_j = \frac{x_{ij} - \mu_j}{\sigma_j} \qquad \text{Eq. (3.1)}$$

WSSI was estimated by using water use and groundwater level values separately in order to accurately identify those years and districts, which were exposed to extreme, severe and moderate droughts. In this way, the differences in time-series data availability (see Section 3.2.3) could be partly counterbalanced. The total water availability data for the entire six month vegetation period (April-September) was used to analyse the cumulative drought impacts. The leaching period (usually in March) was excluded due to a lack of reliable data. The index for each district was derived based on the statistics (mean, standard deviation) for the relevant districts. This is of importance, because some areas have received less water historically and, therefore have specific agro-environmental and technical characteristics, not related to drought hazards. For instance, since the distance from the water intake source restricts the access to water within Khorezm, previous studies have grouped its administrative districts into upper-end (i.e. upstream) (*Kushkupir, Khiva, Shavat, Yangiarik*), mid-tail (i.e. midstream) (*Urgench, Yangibazar*) and tail-end (i.e. downstream) (*Khazarasp, Bogot, Khonka, Gurlen*) (Bekchanov et al., 2010a). This classification was adopted in this study as well. Accordingly, the computed index represents the severity of water scarcity for each district. WSSI for the whole region was estimated using different dataset (see Section 3.2.3).

3.2.3. Data specification

Survey design and methodology

Semi-structured interviews have been conducted during April-May 2013 to collect information on the direct and indirect drought impacts. The informants were asked to describe the immediate and long-term impacts on the agro-ecological and social systems, and express their opinion as to what could be described as the worst drought years, why they thought so and what has changed over time. The key informants were representatives of formal institutions and are referred to hereafter as '*experts*' (see also 1.5.2 and Table A-1).

Secondary data sources

The data for drought indexing included: (i) water delivery and agricultural area datasets by district for the period 1998-2010 (source: MAWR, 2011); (ii) groundwater level data for 1991-2006 (2004 missing) (source: ZEF/ UNESCO Project Database); (iii) total water delivery values for the region over the period 1991-2012 (source: CaWater-Info, accessed October 2012).

The information for the impact analysis originated from different secondary datasets. Data on the gross domestic product (GDP) and gross agricultural production (GAP) in current prices (Uzbek soums, USZ) was collected from the Khorezm Regional Statistical Department (OblStat, 2013a, OblStat, 2013b) and corrected for annual inflation rates, considering respectively the GDP and GAP deflators reported to the World Bank (2013). Labour demand was calculated using the official labour norms per hectare (OblVodkhoz, 2013) and data for the area harvested of selected main categories (OblStat, 2013a). The datasets for population and agricultural value added to the regional GDP were obtained from the Statistical Department (OblStat, 2013b). The farm privatization data was taken from Djanibekov et al. (2012a). Land productivity was calculated by dividing gross agricultural production by the harvested area.

3.3. Results

3.3.1. Spatio-temporal distribution of the water scarcity

Summary statistics of the water availability values for the vegetation period (i.e. surface water and ground-water level) by district, are presented in Table 3-2. For the two drought indicators, the standard deviations are the highest for Kushkupir and Shavat districts, which are tail-end locations. The data points of the groundwater level tend to be closest to the mean values for Gurlen and Khazarsp (upper-end districts). The observed variations are likely caused by the districts' distance from the discharge points and by the direct access to river water, which is feasible for the upper-end districts (Bekchanov et al., 2010a, Oberkircher, 2010).

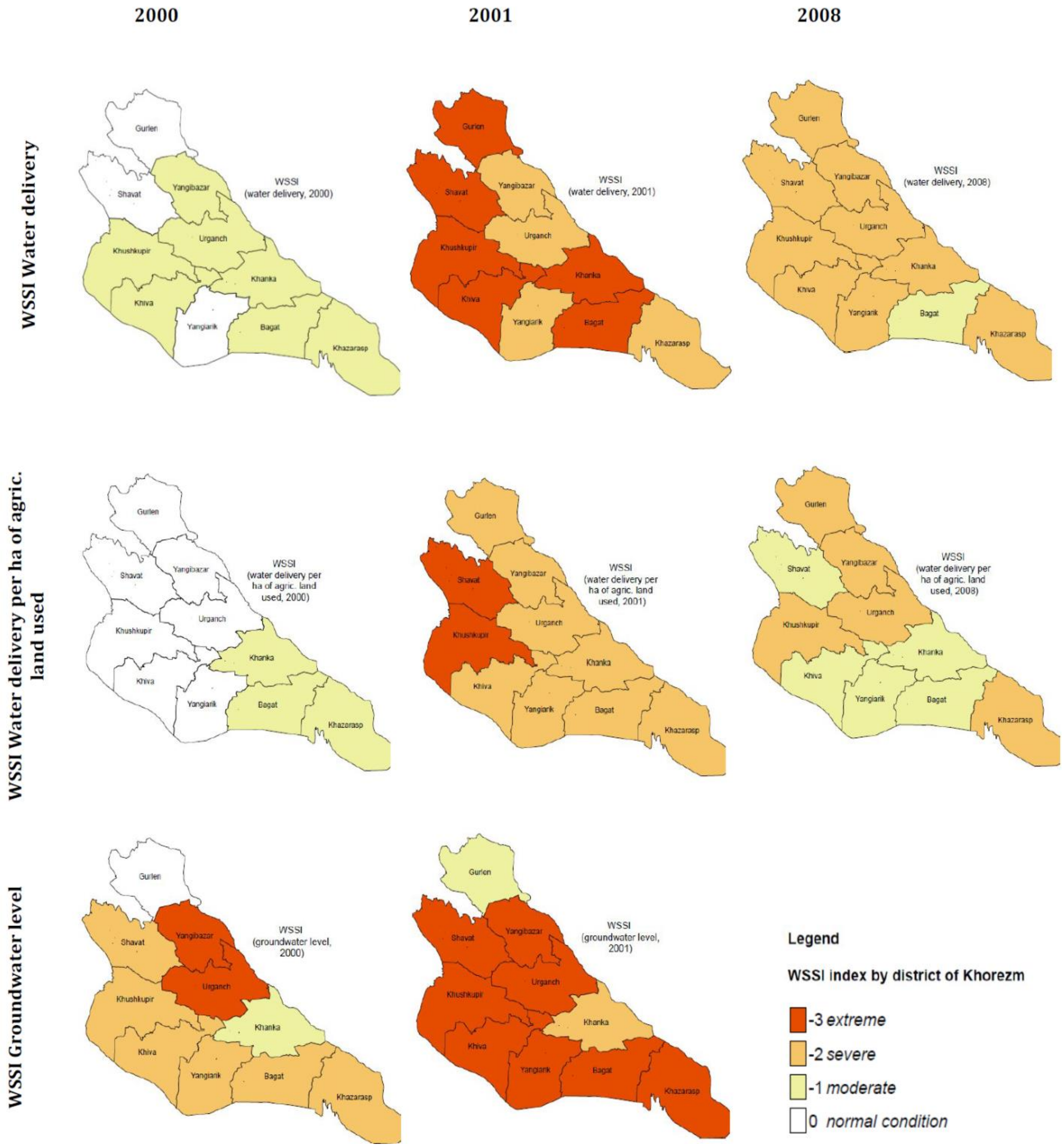
Table 3-2. Summary statistics and variation of water delivery (1998-2010) and groundwater level (1991-2006) across districts for the vegetation period

District/ Region total	Water delivery (mln. m^3)				Ground-water level (m)			
	Mean	Min	Max	St.dev.	Mean	Min	Max	St.dev.
Bogot	245.53	92.96	306.42	72.26	1.11	0.94	1.47	0.14
Gurlen	317.96	154.54	407.77	80.98	1.09	0.91	1.25	0.10
Khazarasp	204.70	108.67	254.57	51.98	1.10	0.97	1.37	0.11
Khiva	231.35	85.24	317.46	70.85	1.30	1.16	1.83	0.18
Khonka	265.52	114.61	337.68	74.50	1.24	0.98	1.53	0.17
Kushkupir	338.05	116.72	464.17	101.28	1.49	1.27	2.09	0.23
Shavat	282.85	89.59	391.66	86.89	1.28	1.13	1.89	0.21
Urgench	307.51	135.44	429.63	86.56	1.49	1.28	1.91	0.18
Yangiarik	222.12	84.98	326.97	69.28	1.11	0.85	1.70	0.22
Yangibazar	252.45	129.46	336.84	65.70	1.34	1.15	1.78	0.18
Khorezm	**2897.98**	**1301.48**	**3717.23**	**772.00**	**1.23**	**1.07**	**1.62**	**0.15**

Source: own elaboration based on data as reported in Section 3.2.3. The total water delivery data for the region captures longer time-span and originates from different source in comparison with district level values.

Fig. 3-3 visualises the spatial and temporal distribution of the severe drought conditions in 2000-2001 and 2008 (2011 is not presented due to unavailable data at a district level after 2010). The WSSI of three indicators is illustrated: water delivery, water delivery per agricultural land used and groundwater level. This division allows determining: (i) the districts with higher deviations of water availability values in comparison to their normal state, and (ii) the effects of land-use management on the severity of water scarcity, by taking water per ha values.

Figure 3-3. Spatial distribution of the Water Scarcity Severity Index (WSSI) among the districts of the Khorezm region for 2000, 2001 and 2008



Note: WSSI index values refer to: -3 (extreme drought when WSSI≤-2.00), -2 (severe drought when -1.99≤WSSI≤-1.50), -1 (moderate drought when -1.49≤WSSI≤-1.00), and 0 (normal state, -0.99≤WSSI≤1.00). (*Source: own elaboration)*

In 2000 and 2001, the groundwater level in the mid-tail districts Urgench and Yangibazar was abnormally low (extreme negative value), even though the water delivery to these regions was not severely impacted during 2001, which is the year with the lowest water availability in Khorezm on record. In 2001, only the end-tail Kushkupir and Shavat sub-regions generated extreme values as per ha of agricultural land used, evidenced by the highest standard deviation values for these districts. This result could be related to poorer land and water management. The spatial distribution of the droughts in 2008 seems more equal in comparison with 2000 - 2001; however, the lack of data does not allow further spatial comparison of trends over time.

The WSSI for the whole region was computed as well, based on the normalized data for the total water delivery to Khorezm. This regional-level dataset contains 21 observations, whilst the district-level data captured only 12 years. Therefore, the WSSI for the whole region gives a more accurate classification of the water scarcity but does not account for sub-regional variability. Slightly differing from the results mapped on Fig. 3-3, the regional WSSI point to a higher drought severity in 2008 (-3, extreme drought) and 2011 (-2, severe drought) (see also Fig. 3-2).

3.3.2. Impact analysis

The observed drought impacts identified through the surveys were categorized into direct and secondary (indirect) impacts (Table 3-3). The direct impacts are associated with the observed short-term changes in the environment and the immediate socio-economic losses. The indirect impacts are long-lasting consequences of the water scarcity, expressed by key informants. In order to structure the analysis, the impacts were divided into two categories: environmental and socio-economic.

Environmental impacts

Water scarcity is associated with higher soil salinization, caused primary by decreased groundwater level and direct usage of groundwater by farmers, as a coping strategy during drought periods. A common perception was that the environmental degradation would be effected over consecutive years, which in turn could have led to e.g. the need for more water for leaching, less harvest and additional production costs. A recent study for instance, has found evidence that the level and salinity of the groundwater are associated with the observed trend of increasing land degradation in Khorezm (Dubovyk et al., 2012).

Table 3-3. Survey results of the observed impacts listed by key informants during and after the droughts in 2000, 2001, 2008, 2011 in the Khorezm region of Uzbekistan

	Direct/Short-term impacts	Indirect/Long-term impacts
Environmental impacts	▪ Decreased groundwater level and consequent increase in its salinity; decrease in the volume of drainage water; increased groundwater direct usage with high salinity ▪ Loss of natural vegetation cover	▪ Soil quality deterioration (due to salinization) for at least 1-2 consecutive years ▪ More leaching water needed subsequent years
Socio-economic impacts	▪ Less/ lack of drinking water in some rural areas and health impacts ▪ Loss of income for farmers as a result of agricultural production loss (less harvest, loss of fruit trees, spread of new for the region pest species on melons and potatoes) ▪ Less demand for labour in the agricultural sector ▪ Livestock loss or need to sell, due to insufficient animal feed and water ▪ Personal conflicts over water allocation	▪ Less harvest and higher production costs in the consecutive 1-3 years ▪ Food price volatility (higher local markets prices of fruits, vegetables and rice; price fluctuations of animal products (dairy, meet)) ▪ Labour migration ▪ Slower economic growth/ decrease in GDP per capita in the region ▪ Decrease in nutrition intake by the people mainly in the rural parts (urban poor affected as well) and consequences on health

Impacts on the agriculture

Overall, there is a strong correlation between the WSSI and GAP growth per capita (Pearson correlation coefficient r=0.71). The majority of the informants stated that cotton, wheat and rice production have been highly sensitive to droughts, as well as the livestock, which also represents a security net for the rural households. Garden farms have been lesser affected than the large crop fields and some have even benefited from the higher local market prices during the drought years. However, the loss of fruit trees and increase in pest problems has impacted their income in the following years. Furthermore, tail-end districts, such as Kushkupir, have experienced periods with difficult access to drinking water (during 2000-2001) for household usage, including the provision of water for the cattle. Many farmers were forced to sell their livestock, which in turn destabilized the prices of animal products, such as meat.

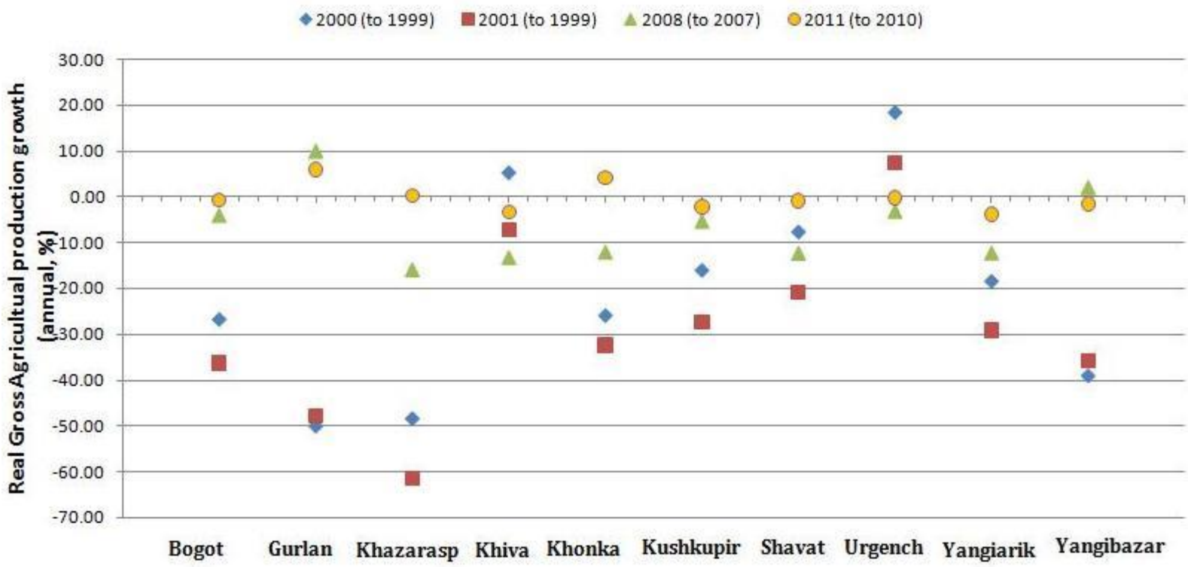
Spatially, gross agricultural output of each district depends on the access to water, crops-mix, proximity to markets and soil quality, as previously postulated (e.g. Bekchanov et al., 2010a, Müller, 2006). Drought impacts on the annual GAP growth which differs substantially from district to district and over time (Fig. 3-4). Overall, Bogot, Khazarasp and Yangibazar were the most affected areas by the droughts of 2000-2001, while the spatial distribution of the impacts of the water scarcity during 2008 and 2011 tended to be more equal, as already observed (Fig. 3-3).

Khazarasp was the district with the lowest growth rate during the drought years. This could be related to the high share of paddy rice produced in this region, being the most sensitive crop to water scarcity and additionally affected by the imposed state restrictions on rice cultivation during droughts. Additionally, previous assessments (Bekchanov et al., 2010a) indicated that Khazarasp had on average the lowest agricultural revenue per capita, also due to being the most densely populated district.

Conversely, Urgench illustrated a positive growth in 2000-2001, higher even in comparison to 2008 and 2011. Its mid-tail location, smaller share of cotton fields and higher share of fruits production could have been among the underlying factors of the lower vulnerability. In addition, more favourable agricultural commodity markets in the city of Urgench, the regional centre of Khorezm, existed, in comparison to the local markets in the rest of the sub-regions.

Gurlen and Yangibazar districts have historically received more water since they are located close to the water source (Müller, 2006). This explains that in Gurlen the largest portion in the agricultural gross value added came from rice cultivation and in Yangibazar from cotton (OblStat, 2013a, OblVodkhoz, 2013). This in turn resulted in high negative growth rates during 2000-2001, yet the impacts of 2008 and 2011 droughts in both districts were lower. Visibly, the rest of the districts in Khorezm showed smaller variations of growth rates over time, meaning that more stable conditions for agricultural production have been developed.

Figure 3-4. Spatial distribution of agricultural production growth rate over drought years by districts of the Khorezm region



Notes: The growth rate for 2000 and 2001 was calculated by using 1999 as the base year with no drought; the estimates for 2008 and 2011 were done in accordance with the respective previous year, when no droughts occurred.

Droughts have also affected the harvested area, crops-mix and agricultural labour demand (Figs. 3-5 and 3.6). The area harvested in 2000-2001 was much below the long-term average, mainly due to the lower rice, wheat and maize crop areas and yields. Labour norms per hectare used to be higher for fruit and vegetables production (0.7-1.8 people per hectare), followed by rice (0.68) and cotton (0.53). For that reason, the negative effect of droughts on the labour demand in some areas was related to the restricted rice production during the water scarce years. The little number of garden farms in 2000-2001, compared to later years, could also explain the lower employment opportunities, production and profits. In 2008 and 2011, total fruit and vegetables output was 0.70 and 1.06 times higher than in 2000. Cotton production is a major source of foreign currency and therefore cotton producing farms are given priority in terms of water supply by the state organisations. For that reason, the drought impacts on cotton production were less severe as compared to rice and cereal production. Wheat is, after cotton, the second strategic crop in Uzbekistan and there is a trend for increasing its production, related to the governmental policies towards food security (Rudenko et al., 2012) in response to the increaseof the global food prices and the diminishing water resources.

Figure 3-5. Agricultural production by crop type in the Khorezm region, 1998-2012

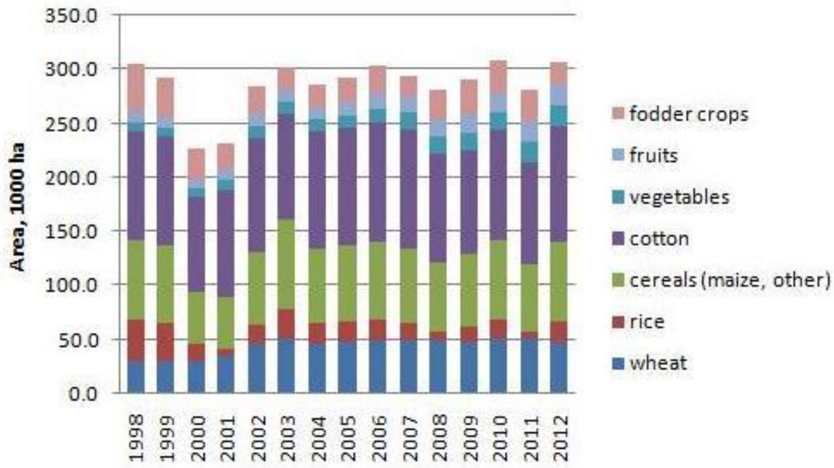
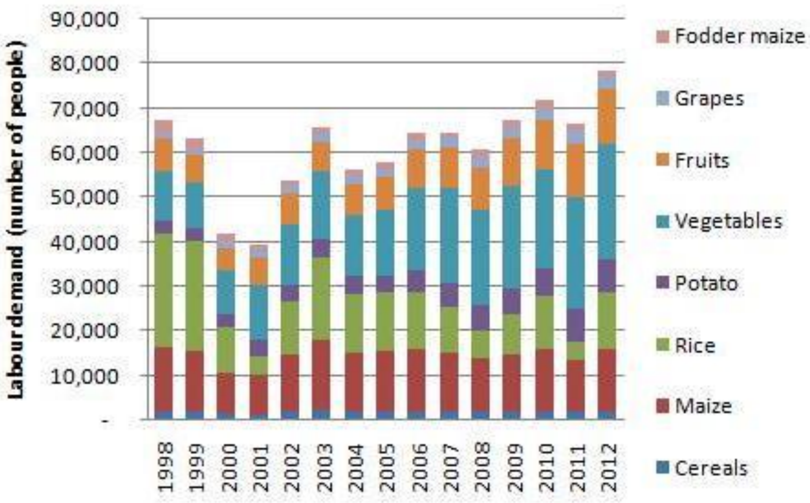


Figure 3-6. Agricultural labour demand for major agricultural crops in the Khorezm region, 1998-2012



Impacts on regional welfare

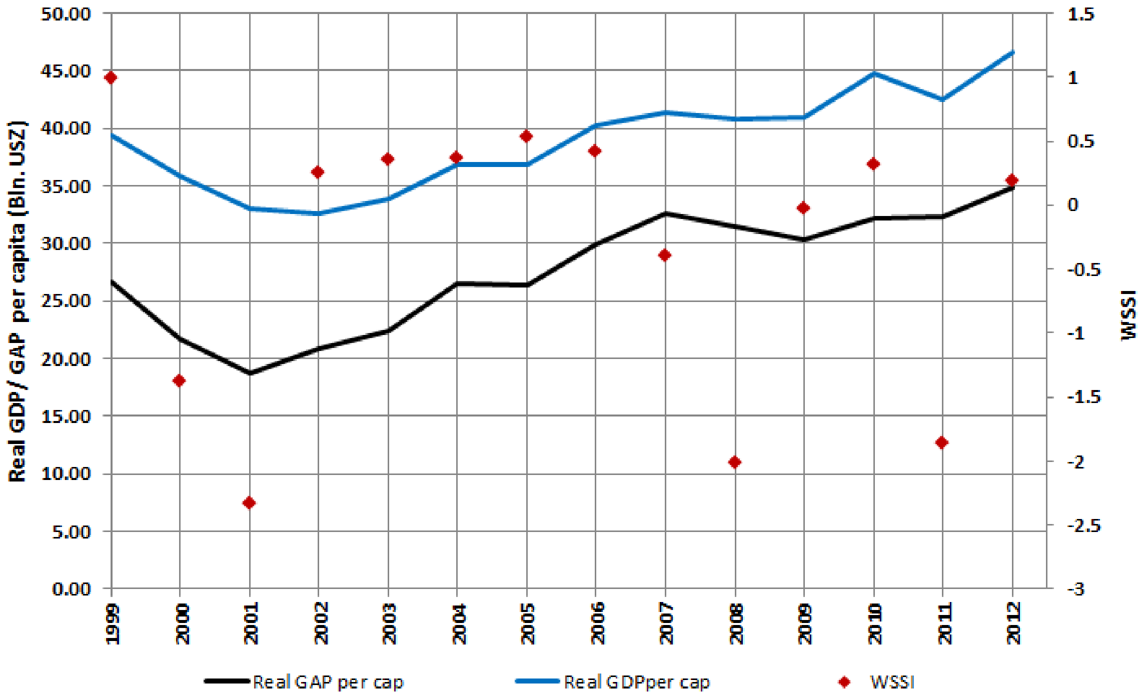
A number of key informants stated that in some areas, the difficult access to and the deteriorated quality of drinking water brought about negative health consequences for the population (Table 3-3). The situation was further aggravated by livestock loss, being a security asset for the rural households. Another major problem, raised from the severe water scarcity, was the struggle over the access to water, which created personal conflicts between farmers. Furthermore, the peasant farmers (*dehqons*) in Khorezm rely on own production for food and reaching self-sufficiency and additional income, by producing fruits, vegetables, rice and wheat on their small plots. Therefore, they could also be seriously affected as a result of increasing conflicts and claims during water scarce periods (Veldwisch et al., 2012).

The economic impacts estimated by the key informants include loss of income, labour migration and food prices volatility, with longer term consequences (Table 3-3). However, the statistical data available was limited and did not allow in-depth assessment of the drought impacts in monetary terms. Instead, Pearson correlation coefficient between the regional WSSI and GDP growth per capita was calculated. Its value is 0.78 (significance at 1% confidence level; 12 observations), pointing at a strong relationship between the regional economic development and water extremes. The GDP per capita indicator accounts for output from other industries and sectors in Khorezm. It also reflects the consumption in the region, thus, indirectly captures the ability of the population to purchase goods and services, and accounts for secondary effects on the rural welfare, such as labour migration.

3.3.3. Regional vulnerability over time

The general perception among the surveyed experts was that the most severe drought impacts were experienced during and after the 2000-2001 disastrous events mainly because the water scarcity was "*unexpected*", "*long-lasting*" (two consecutive years) and "*nobody knew what to do*". The respondents stated that the 2008-drought brought only moderate losses, although the water available was very much similar to 2000-2001, whilst the 2011-drought affected mainly the end-tail regions of the irrigation channels. Furthermore, according to the insurance expert, the droughts in 2000-2001 were recognized entirely by the authorities as a disaster, and hundreds of cotton and wheat farmers were consequently compensated. The statements of the key informants are consistent with the fact that only the 2000-2001 droughts were listed in the international disasters database EM-DAT, suggesting that human security had been affected. In this section, an additional analysis is performed, to question why, even though the absolute water scarcity in 2008 was similar to the values in 2001, the impacts were much lower (as described in Section 3.3.2 and visible on Fig. 3-7).

Figure 3-7. Water scarcity severity index (WSSI), real gross domestic product (GDP) and real gross agricultural production (GAP) growth per capita, 1999-2013

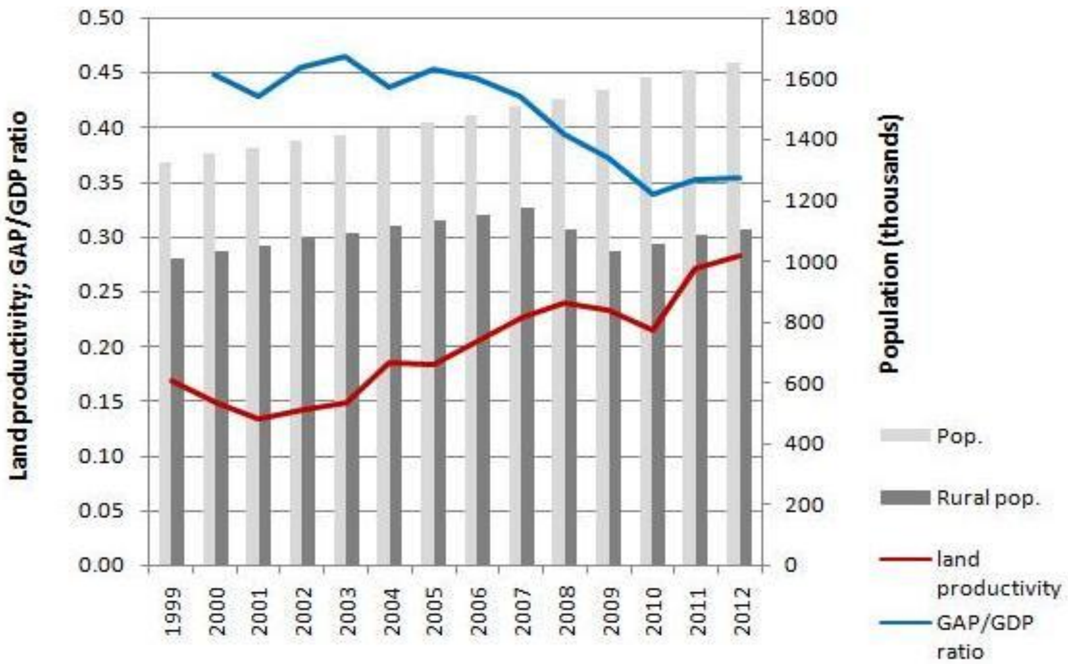


An analysis of the changes in the socio-economic patterns in Khorezm can be particularly informative, because it reveals the temporal determinants (including the dynamic factors) of regional vulnerability to water scarcity. The first observation (Fig. 3-8) is that up to 2007, the share of the rural population to the total population was growing, while since 2008 this indicator has dropped, which could be linked with the migration processes out of the rural areas. Reasonably, the indicator is negatively related with the GDP growth (correlation coefficient r=-0.13)as people employed in agriculture use to receive low and often non-monetary payments (Veldwisch, 2008). At the same time, the agricultural value added to the regional GDP kept falling after

2007, while the services and construction sectors have been expanding. These two opposite trends indicate that the dependency of the economic development rate on the water in Khorezm has apparently been decreasing since 2007. This could explain the lower sensitivity to the water scarcity during 2008 and 2011. Notably, the land productivity has been improved, which is an indicator for increased regional capacity to deal with the water scarcity.

In addition, during the same time-span, the farm privatization process was completed (in 2007). As mentioned earlier, the land reforms and farm restructuring processes have been undergoing since 1991, including farm privatization, and was characterized by several stages. Presumably, the transition from state to private farming would affect not only the agricultural production, but also the structure of the social system and household sources of income and food (Veldwisch et al., 2012).

Figure 3-8. Trends over time of selected vulnerability indicators



Improvements in the institutional capacity have also played a role in reducing the vulnerability to water scarcity in Khorezm (Response Box of Fig. 3-1). Key survey informants (governmental officials) stated that supplementary water usage regulations were put in place after the 2000-2001 droughts, addressing drinking water supply for the population and irrigation for the agriculture. The dissemination of hydro-meteorological information from Tashkent to Khorezm was highly improved. Schlueter et al. (2010) provide similar evidence for disaster response, namely that drought prevention measures were introduced by the state after 2000-2001, including better drought forecasting. Importantly, in 2003 the water management system based on administrative boundaries was transformed to basin-based management system (i.e. hydrological boundaries), and Irrigation Basin System Management Authorities were established.

3.4. Discussion and conclusion

3.4.1. Limitations of the analysis

The performed impact analysis aimed to identify relationships and trends in the context of vulnerability to water scarcity, rather than to quantify the economic losses, given the limited data. Several limitations of this study are acknowledged. First, the available dataset for computation of WSSI for each district was not sufficient to obtain robust insights in regard to trends in the intra-regional water management. This is however of importance, since tail-end districts receive less water and suffer higher impacts over water scarce years. Second, the analysis of drought impacts is based on relatively short time-series does not provide strong empirical evidence. Nevertheless, the findings based on the statistical analysis are consistent with the survey outcome and past studies.

3.4.2. Underlying factors of vulnerability and policy implications

Previous research in the Khorezm region of Uzbekistan examined the effects of water availability on the economic performance of the agricultural sector, employing descriptive statistics, regression analysis and general equilibrium models (e.g. Bekchanov et al., 2010a, Müller, 2006, Bekchanov et al., 2010b). However, a broader perspective of the nexus of climate hazards and rural welfare in the region has not been explored so far. The integrated approach applied in this study allows for a multi-dimensional impact analysis (presenting environmental, socio-economic and governance aspects) and identification of the main determinants behind the associated losses, drawing upon the concept of vulnerability. In this manner, the study could serve as a reference for selection of indicators, which might be of relevance to assess the risk of climate change and hazards in Khorezm or similar regions.

The 2000-2001 droughts brought not only crops-failure, but also environmental degradation and social insecurity. The low coping capacity during that period was due to the fact that the disaster was an unexpected and unexperienced before. The response of the people to it included abandoning part of the land, blocking the drainage system and using small mobile pumps (Conliffe, 2009), which further could have worsen the situation at the tail-end regions. But some studies reported that the institutional failure was to be blamed for the severity of the impacts, such as failure of drought early warning systems (including inaccurate observations, poor data forecasting); policies that focused on drought response and relief, rather than on preparedness and mitigation; the farmers' lack of access to and/or trust in the received information (Conliffe, 2009, World Bank, 2005).

The results also demonstrated that over time the vulnerability in the region has decreased due to various other factors, apart from water distribution (Table 3-4). Among them, farm privatization could have played a significant role. Whilst the state quota for the strategic cotton and wheat crops has been preserved after the reforms (Djanibekov et al., 2012a), the opportunities for profit generation have increased, supplementing the regional economic growth, and thus indirectly fostering improved adaptive capacity.

Still, the coping and adaptive capacities of the Uzbek farmers are limited unless the state land tenure system is relaxed. For instance, research on technical efficiency at a farm level suggests that the current reform of new consolidation (which started in 2008), would improve the productivity and efficiency only in a short run, unless extension services are not strengthened, as well as land property rights are allocated to farmers (Karimov, 2012). Therefore, a shift to private ownership may increase the resource utilization efficiency (e.g. Djanibekov et al., 2012a) which would be an incentive for climate adaptation and risk mitigation investments.

Among the water and agricultural sector-specific positive changes in Uzbekistan is the recognized importance of a better forecasting of and information dissemination on water availability at a national level, indicated by the improved hydro-meteorological monitoring and forecasting capacities (World Bank, 2006). Ineffectively however, the early warning information has been used mainly for cotton and wheat production planning (World Bank, 2006), and not yet fed into a complete and multi-sectoral drought early warning system.

Another major point is the need for knowledge building of the farmers. Karimov (2012) underlines, that the more educated farmers achieve higher production efficiency. From this point of view, in a region such as Khorezm, facing regular constraints of water availability, farmers could benefit from trainings on how to deal with severe droughts. Thus, the inclusion of drought risk management into farmers' services provision would form a path towards mainstreaming of climate change adaptation and risk reduction in those rural areas.

Table 3-4. Summary of identified key underlying factors of regional vulnerability and consequent policy recommendations

Underlying factors of regional vulnerability		Response: policy recommendations	
Spatial	**Temporal**	**Local level**	**National level**
Population density District's GDP structure Access to river water determined by the distance from the discharge points Share of cotton and wheat farms Share of rice production in the district's output Share of garden farms	Rural-urban population ratio Regional GDP structure Intra-regional water management Hydro-meteorological monitoring and forecasting capacities State regulations Land productivity Experienced before disaster (i.e. learning capacity)	Trainings of farmers to cope with severe droughts Shift from water-intensive production to water-saving processing industries (e.g. cotton-value chain) Irrigation and drainage system rehabilitation Introduction of water saving technologies	Strengthening the national early warning systems Land property rights allocation Liberalization of cotton and wheat production Decentralization of the water management

The GDP diversification, together with the observed urbanisation processes, could have reduced the sensitivity of the region to water scarcity. The development of the cotton value chain in Khorezm, for instance, offers significant job opportunities (30-40% of the total regional labour force), additional export revenues and a shift to a less water-demanding economy (Rudenko et al., 2012). Both the agricultural production mix and the change in the GDP structure are of significant importance. The presented analysis, for example, showed that the number of garden farms has increased over time – a factor which points at income diversification and lower production sensitivity to water scarcity. Assessments of the various benefits from policy change to crops diversification have been made (e.g. Bobojonov et al., 2012), although being based on bio-physical criteria (including water usage efficiency) and potential for income generation.

Despite the shortcomings of this chapter, the analysis provides a holistic view of the Khorezm regional vulnerability over time and across districts. The findings show that even though the economic development of Khorezm has changed from a very high to a much lower water dependency, agriculture and the water-intensive crops remain of vital importance for the region and its rural population’s welfare. Furthermore, water scarcity is not a threat to agriculture alone, but to the rural livelihoods, affecting the quality of and access to drinking water and sufficient nutrition, bringing social insecurity issues such as health deterioration, migration and personal conflicts. Lastly, the ecological impacts following the droughts have had long-lasting effects and the expected, more frequent and severe, future droughts could lead to irreversible consequences.

Chapter 4 Assessing agricultural systems vulnerability to climate change to inform adaptation planning – operational method and case study application

This chapter is based on:
Aleksandrova, M., A. Gain, C. Giupponi (2014). "Assessing agricultural systems vulnerability to climate change to inform adaptation planning – operational method and case study application"*. Mitigation and Adaptation Strategies for Global Change, Springer (under review).*

Abstract

Agriculture is one of the most vulnerable sectors to climate change. Beside the climatic change, the population growth, economic development, poverty, land use changes and management practices have direct impacts on agriculture. Combined effects of these factors increase the vulnerability in the agricultural sectors. The current vulnerability assessments through traditional fragmented disciplinary methods are insufficient to capture the combined effects of factors impacting agriculture and therefore need to be replaced by integrated approaches. A holistic vulnerability assessment method for agricultural systems is presented that aggregates agro-ecological and socio-economic information into one composite indicator of vulnerability. The outcomes of the proposed methodological approach are: (i) a classification of administrative units according to their vulnerability; (ii) an identification of key determinants of vulnerability for each unit; (iii) a comparison of adaptation policy scenarios, considering their effects on the sustainability of the agro-ecological and socio-economic systems. The proposed method is examined in the Khorezm region of Uzbekistan – a representative irrigated agricultural region in the Lower Amu Darya river basin. A decision support tool is applied to facilitate multi-criteria decision analysis. The assessment for Khorezm reveals significant spatial differences of vulnerability levels due to a variation of various contributing factors, e.g. natural resources, water productivity, rural-urban ratio. Feasible land and water management policies could reduce the vulnerability, particularly in the

regions with the poorest agro-ecological conditions. Considering the vulnerability assessment in the local context, the findings can contribute to the development of vulnerability reduction policies in the study region and areas with similar socio-economic and agro-ecological patterns.

Key words: adaptation, vulnerability, Amu Darya, integrated indicators, sensitivity, sustainability, irrigated agriculture

4.1. Introduction

Agriculture remains a key economic sector for many low-income countries, accounting on average for 28% of their GDP (World Bank, 2013). Sustainable management of the agricultural systems therefore has become of an international priority for achieving world food security. Undoubtedly, climate change poses a significant threat to agriculture, particularly in arid regions, through more frequent hydrological extreme events and changes in the seasonal agro-meteorological conditions, along with land degradation and desertification (IPCC, 2014b, Gain and Wada, 2014).

Numerous methods for the assessment of climate change impacts on agriculture have been proposed (e.g. Morton, 2007, Howden et al., 2007, Molua, 2009, Calzadilla et al., 2013, Mendelsohn, 2014). A vast body of literature has shown that socio-economic factors, along with environmental change, negatively contribute to the scale of the impact (e.g. Antwi-Agyei et al., 2012, Sommer et al., 2013, Harvey et al., 2014, Lindoso et al., 2014). Some of these studies (Luers et al., 2003, Berry et al., 2006, Harvey et al., 2014, Lindoso et al., 2014) are framed within the concepts of risk and vulnerability.

The various existing definitions of *risk* and *vulnerability* create heterogeneous understanding of the terms, bringing disagreement within the scientific community, concerning in particular how to measure imprecisely defined variable (Birkmann, 2006b, Füssel, 2007, Gain et al., 2012). Nevertheless, there is common understanding that vulnerability is a component of risk and a condition for a system to be adversely affected (IPCC, 2014b).

Recent vulnerability assessment frameworks conceptually integrate the research streams of CCA and DRM (IPCC, 2012b, Birkmann et al., 2013, Gain et al., 2012, Giupponi et al., 2014). The Fifth Assessment Report (AR5) of the IPCC recognizes that “vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt”(IPCC, 2014b). However, *exposure* is considered in the AR5 as an external element while assessing risk. Alternatively, Birkmann et al. (2013) suggest that vulnerability is a function of exposure, susceptibility and (lack of) resilience. Of relevance to the agricultural systems analysis under global environmental change is the vulnerability framework proposed by Turner II et al. (2003), which is in line with the CCA stream of thoughts and has strong emphasis on the human-environmental linkages.

When referring to vulnerability assessment for agricultural systems, three distinctive research streams are highlighted in the literature:

- The research stream on *agro-ecological assessments* (e.g. Liu et al., 2013, Srivastava et al., 2010) considers the sensitivity of crop production to climatic shocks. The methodological approaches of this stream include statistical and multi-criteria analysis of agro-ecological indicators;
- The *economic assessments of the agricultural sector* analyse the effects of climate change on the economic performance of this sector (e.g. Calzadilla et al., 2013, Molua, 2009). Key performance indicators are agricultural productivity and farm income. The assessments are based primarily on econometric analysis using partial or general equilibrium models.
- The *assessments on social aspects* (e.g. Morzaria-Luna et al., 2014, Antwi-Agyei et al., 2012, Harvey et al., 2008) present social vulnerability perspective. This research stream analyses the relationship between the agricultural performance and climatic hazards, through incorporating indicators of adaptive capacity.

The interactions among agro-ecological, economic and social aspects within the agricultural systems are complex across spatio-temporal scales. Therefore, holistic vulnerability assessments for agriculture, reflecting the multi-dimensional nature of the concept have received less attention (e.g. Monterroso et al., 2014, Zarafshani et al., 2012, Balbi et al., 2013). Such approach requires: (i) an integrated consideration of cross-disciplinary indicators; (ii) a suitable normalization or standardization procedure, and (iii) aggregation methods (Gain and Giupponi, 2014). For reducing vulnerability, an evaluation of possible adaptation strategies also need to be included in the assessment (Giupponi et al., 2013, Balbi et al., 2013). Notwithstanding, vulnerability reduction in the agricultural sector should be approached in a sustainable mode. The IPCC (2014a) defines sustainability as “a dynamic process that guarantees the persistence of natural and human systems in an equitable manner”. However, this aspect is poorly reflected in the existing vulnerability assessment methods for agriculture.

Looking across disciplines, the most common method for quantification of vulnerability is the indicator-based assessment. Despite the existing concerns over actual quantification of vulnerability, the vulnerability assessment tools could have significant positive impact towards scientifically sound and socially coherent adaptation planning (Giupponi et al., 2013). Furthermore, the vulnerability indicators appear to be useful tools for communicating complex state-of-affairs (Hinkel, 2011).

In line with the above expose, the objective here is to provide a comprehensive assessment of vulnerability for agricultural systems at a sub-national scale, through aggregation of agro-ecological and socio-economic information into one Agricultural Systems Vulnerability Index (ASVI). Furthermore, the effect of a set of climate change adaptation measures on the regional vulnerability is evaluated, while accounting for the sustainability of the agro-ecological and socio-economic systems. The methodological framework is applied to the case study of Khorezm region of Uzbekistan. The case study is a proper example of: (i) an irrigated agricultural system in an arid/ semi-arid region, which is threatened by significant reduction of (Amu Darya) river water flows during the vegetation period, also caused by global change (Schlüter et al., 2013); (ii) a sub-national vulnerability assessment in a country with an agricultural sector under strong and close surveillance of the national administration, including the provision of state production quotas for cotton and wheat; (iii) a centralized water management system (Veldwisch et al., 2012); and (iv) limited data availability. The proposed methodological approach could be suitable for studies in similar, or adapted to diverse, contexts. As well, the findings can support the development of vulnerability reduction policies in the case study region.

Following this introduction, Section 4.2 describes the conceptual and methodological framework, and Section 4.3 presents the applicability of the framework, exemplified through the case study. The findings of this study are discussed in Section 4.4.

4.2. Methodological framework

4.2.1. The conceptual model for vulnerability assessment

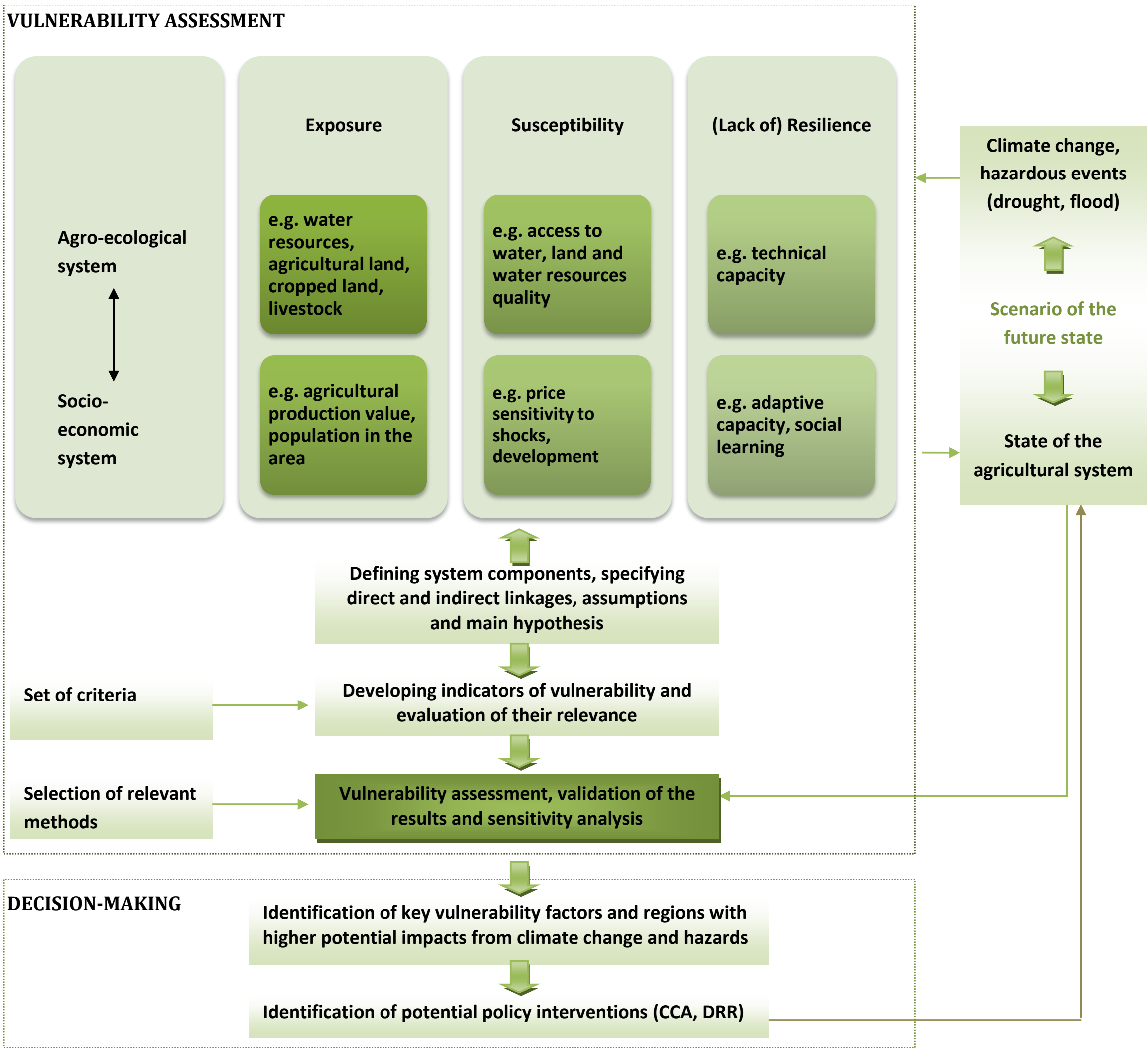
According to Spedding (1988), “the operational units of agriculture may be described as *agricultural systems*, including all the variations in size and complexity of a unit that are called enterprises, farms, plantations, regional and national agricultures”. Here, the *regional and national agricultural systems* are referred to, which consist of cropping/livestock and ecological (i.e. natural resources such as land and water) systems. In a broader context, the regional and national agricultures have agrarian structure which combines those economic, social, technical and political factors and processes that affect the agricultural production. The agrarian structure therefore, describes the socio-economic and technological factors of vulnerability.

To structure this complex analysis, the components of the agricultural systems are grouped into those with an agro-ecological (AE) dimension (e.g. soil properties, cropping-patterns, irrigation network) and socio-economic (SE) dimension (e.g. economic activities and social relations) (Fig. 4-1). This approach allows further analysis of the results in terms of environmental and socio-economic sustainability.

To conceptualize the vulnerability, the analysis draws upon the vulnerability frameworks of Birkmann et al. (2013) and Turner II et al. (2003), and refer to the definitions specified in the Glossary of Terms of the AR5 of the IPCC (IPCC, 2014a) (see Fig. 4-1). The exposure is examined through indicators which reflect the presence of agro-ecological and socio-economic assets or resources that could be adversely affected by climate change (or hazard event). Hazards due to global climate change are considered an external pressure (or shock) with a degree, magnitude and probability of occurrence, without necessarily being in direct contact with the system. Framing the exposure in this way allows evaluating climatic scenarios and linking the vulnerability assessment with further risk analysis. Similarly, the Climate Vulnerability Index (CVI) (Sullivan and Meigh, 2005) and Water Vulnerability Index (WVI) (Sullivan, 2011) contain indicators, among others, of surface water availability and climate impact on water resources.

Factors that determine the susceptibility of the system are its properties, which predispose the elements at risk to suffer harm (Birkmann et al., 2013). Resilience is related to factors which shape the ability of the system to cope with and adapt to shocks or gradual changes, such as functional efficiency, capacity, diversity, accessibility.

Figure 4-1. Conceptual model for vulnerability assessment for agricultural systems



Operationalizing vulnerability assessment should facilitate decision-making through: (i) the identification of key vulnerability factors and regions with higher potential impacts of climate change and hazards, and (ii) *ex-ante* evaluation of climate change adaptation and risk reduction policies. To serve this purpose, it is essential to provide an explicit analysis of vulnerability that can be useful for improved planning and decision-making in the agricultural sector. In addition, the development of policy scenarios should be an integral part of the analysis (highlighted in Fig. 4-1). The proposed methodological framework (Fig. 4-1) also suggests that adaptation and risk mitigation efforts increase the resilience and decrease the susceptibility and exposure of the agricultural system. Furthermore, the conceptual model for vulnerability assessment for agricultural systems highlights the importance of achieving balance between the two agricultural sub-systems (agro-ecological and socio-economic) through sustainable climate policies.

4.2.2.Selection of agro-ecological and socio-economic indicators

Appropriate indicators for vulnerability assessment can be developed in a systematic way through: (i) defining the system boundaries; (ii) understanding the direct and indirect linkages between the system components and outlining the main assumptions and hypotheses; (iii) preparing preliminary list of indicators based on existing literatures on relevant indicators; (iv) selecting final set of indicators based on stakeholders involvement (Gain et al., 2012). The final list of vulnerability indicators should contain the most sensitive factors related to the agricultural system – climate change nexus.

The available literature is rich on guidance for indicators selection (e.g. OECD, 2008, Birkmann, 2006a), however, here are incorporated tangible criteria considering the specific vulnerability assessment context. Firstly, both the agricultural systems and vulnerability have a dynamic nature and therefore evaluators should account for “slow-changing” variables such as soil-properties (Luers, 2005). Specifically, agricultural systems are composed of human and environmental components, both of which change over time but at a different pace. For example, agricultural productivity in a certain region might increase in a relatively shorter period; however, unsustainable resource utilization could lead to land degradation in a longer period. Similarly, the concept of vulnerability implies change over time, not only due to changes in the systems components, but also as a result of adaptation responses to climate change (Birkmann et al., 2013). Secondly, given the strong grip of the national administration on the lower level administrations, including the case study, the proposed methodological framework refers to multi-level analysis, i.e. national, regional and even sub-regional. However, differences between the data availability at these levels may restrict this intention necessitating a re-scaling of the assessment from sub-regional to national assessment, and vice versa. Most often, lager sets of statistical data for socio-economic variables are available at national and regional level, while agro-ecological information is accessible mainly at a local level. Thirdly, selected indicators should capture the effects of the intended policy scenarios for providing robust information to decision-makers.

Indicators used for the agro-ecological system

The vulnerability of the agro-ecological systems is determined by factors of exposure, susceptibility and resilience. Following the definitions provided (Sections 4.1 and 4.2), the level of exposure of an agro-ecological system could be measured through "*natural resources*" indicators such as water availability and cropland. For example, it is assumed that regions with higher share of cropland are more exposed to climate change and shocks, because they have more assets that could be adversely affected. Susceptibility is related to the properties of the agro-ecological system which make the system more fragile and sensitive, here grouped into "*environmental quality and degradation*" and "*agricultural production sensitivity*" respectively. Soil and water quality (including groundwater and irrigation), for example, are among the main environmental compartments in agro-environmental assessments (Giupponi and Carpani, 2006). Agricultural production loss is an indirect output measurement of the agricultural sector sensitivity to climate pressures.

Resilience is shaped by "*agricultural diversity*" and "*productivity, technical efficiency and capacity*". Diversity is a well-recognized pre-condition for resilience (Schouten et al., 2012). Thus, it is assumed that agricultural production differentiation suggests a higher ability of the agro-ecological system to cope with changes and shocks. Aspects such as water and land productivity, the efficiency and capacity of the irrigation system are factors used to reflect resilience and overall capacity of the production process.

Indicators used for the socio-economic system

Exposure of the socio-economic system is composed of "*economy (agricultural output) and people*". It is assumed therefore that regions with higher agricultural output or regions with higher population density will be more exposed to climate effects. The factors that shape the sensitivity of the human component are "*dependence and development*" and *"access to resources"*. It is assumed that regions which are highly dependent on the agricultural sector or have a low rate of production growth, would be at a high risk to water scarcity (Gain and Giupponi, 2014). Furthermore, social vulnerability studies include indicators for "*access to resources*" such as access to water for irrigation (e.g. Sullivan and Meigh, 2005). Finally, to measure the resilience of the socio-economic system, indicators of *“socio-economic agrarian structure*” were used. The latter characterize the coping and adaptive capacity of the regions, which is limited or enhanced by system’s properties, such as land ownership, farm typology and labour organization.

4.2.3. Aggregation and policy evaluation method

A preliminary step for the aggregation of diverse indicators is normalization to deal with the different measurement units. Several normalization techniques exist in literature (OECD, 2008) and the best choice depends on the indicators under consideration, and the preferences of the decision maker (Gain and Giupponi, 2014). After normalising the indicator values (i.e. transforming them into real numbers between zero and one), the final outcome (in this work the *ASVI*) is the result of a hierarchical combination of several indicators that need to be aggregated. The necessity of aggregation of multi-dimensional information constitutes a challenge for the selection of methodological approach. Suitable aggregation algorithms need to be selected in accordance with the logic of the conceptual framework, but also according to the elicited preference of the decision makers (Giupponi et al., 2013). Statistical and participatory methods could be applied for composite indicator development. For instance, large datasets are often aggregated through a combination of multivariate statistical techniques, such as principal component and factor analysis. As well, widely applied are simplified methods such as simple additive weighting (SAW) with equal weights.

The proposed assessment method provides flexibility in terms of analytical approaches, according to the desired outcome. For example, the method can be applied for: participatory or data-driven vulnerability assessment; spatial or aggregated analysis; multi-criteria decision analysis of climate change and policy scenarios. The framework can also integrate external models’ output. The vulnerability assessment is performed in a decision support tool called *mDSS*, developed within the NetSyMod framework (Network Analysis – Creative System Modelling – Decision Support) (Giupponi et al., 2008). The *mDSS* software was initially developed as a Multi-sectoral Integrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale (Giupponi, 2007). The tool has been used in several cases as a tool to facilitate the involvement of stakeholders and experts in environmental decision making (Giupponi, 2014). In this study the *mDSS* tool is applied for: (i) normalization and aggregation of the spatial data; (ii) ranking within and across scenarios and mapping of the results; (iii) sensitivity analysis of the obtained ranks of scenario options.

4.3. Application to the case study of irrigated agriculture in Khorezm region of Uzbekistan

4.3.1.System of agro-ecological and socio-economic indicators for Khorezm

Khorezm is located in the northwest, arid/semi-arid parts of Uzbekistan. The livelihoods of the majority of the people highly depend on the Amu Darya river waters as the region is characterized by irrigated agriculture. Local water distribution management includes storage of water in Tuyamuyun reservoir and sub-regional distribution through primary (inter-region), secondary (inter-farm) and tertiary (on-farm) canals. Chapter 2 previously summarized the determinants of regional climate change vulnerability for the study area, to which it is referred here.

Climate change threatens the Khorezm region through changes in quantity and timing of Amu Darya discharges (Schlüter et al., 2013). As a consequence, more frequent drought events occur. Environmental deterioration, including groundwater salinization and land degradation, has become a major concern in Khorezm. The average groundwater salinity value for Khorezm falls nevertheless still in the moderately saline waters (Rhoades et al., 1992), meaning that it does not directly affect the performance of crops. However, the increasing groundwater salinity combined with the high temperatures driving evapotranspiration, enhance secondary soil salinization (Tischbein et al., 2012), which has become a wide-spread problem in this region. In addition, soil degradation has increased significantly during water-scarce periods, which requires consequently more water for leaching the accumulated salts.

The sensitivity of the agricultural production is determined by: (i) the dominance of high water demanding crops, mainly cotton and rice, and to a lesser extend wheat; (ii) a high dependence on irrigated agriculture; and (iii) low diversification of farmers' income (see Chapter 2). In addition, the rural population surpasses the number of people living in urban areas. The inefficiency of the irrigation system and the restrictive water management by the national and regional administration have a particular high impact. The existing policies prioritize water distribution to cotton and wheat fields and restrict rice cultivation in case of expected water scarcity. Furthermore, national policies affect the resilience in the region through frequent land reforms, state land tenure and production quotas for cotton and wheat (Chapter 2). Dominant is cotton/wheat farming, whereas the agricultural diversity varies within districts of Khorezm. Karimov (2012) found that crop diversification is positively related to higher technical efficiencies of the farmers in Khorezm.

Table 4-1. Key vulnerable groups and factors identified by key informants

Vulnerable group	Vulnerability factors
Population (urban and rural)	▪ Both urban and rural population could be negatively affected from water scarcity, because Khorezm is agricultural region and local food markets react to the environmental change through prices. ▪ Rural population is more sensitive to water scarcity due to the high employment in the sector and the households' food self-sufficiency on own production.
Farmers	▪ Cotton and wheat farmers are more vulnerable because: - they have to meet state production quotas and the price of their output is fixed; - cotton fields require much more water and cotton is more sensitive to the timing of irrigation, in comparison to garden fields; ▪ Rice farmers generate good profit if there is enough water, but at the same time rice production is restricted from the government during water scarce years. ▪ Farmers from the tail-end (downstream) districts receive less water especially during drought years. ▪ Some of the fruit and vegetables producing farmers can generate sufficient profit during water scarce years due to the higher market prices. ▪ All of the farmers face higher risk due to the frequent land reforms, state land tenure and poor irrigation infrastructure and management. ▪ Soil properties and high salinization are major problem.

Table 4-2. Components of vulnerability and selected indicators

Component	Category	Relation with VI*	Selected indicator	Acronym
AE Exposure	Natural resources	**-**	*water flow to district*	**WF**
		+	*crop area (% of total for Khorezm)*	**CA**
SE Exposure	Economy and people	**+**	*population (% of total for Khorezm)*	**PPL**
		+	*gross agricultural production district share*	**GAP**
AE Susceptibility	Environmental quality and degradation	**+**	*groundwater salinity (average)*	**GS**
		+	*low quality cropland (% of district's cropland)*	**LQCL**
	Agricultural production sensitivity	**+**	*cotton/wheat area (share in the total district area)*	**CWA**
		+	*rice area (share in the total district area)*	**RA**
SE Susceptibility	Dependence and development	**+**	*rural population share (% for the district)*	**RPPL**
		-	*compound rate of agricultural growth per cap*	**GRAG**
	Access to resources	**-**	*access to irrigation*	**AI**
AE Resilience	Productivity, efficiency and capacity	**-**	*economic water productivity*	**EWP**
	Diversity	**-**	*agricultural diversity index*	**ADI**
SE Resilience	Agrarian social structure	**-**	*share of non-cotton/wheat farms in the district*	**SNCWF**

Notes: Indicators specification, descriptive statistics and correlation analysis are presented in Appendix B (Tables B1 and B2). VI refers to vulnerability index.

In order to explore the underlying vulnerability factors of the Khorezm region for the last fifteen years, a survey of key informants was performed (see Table A1). The survey has been conducted based on semi-structured questions. The summary of survey results is presented in Table 4-1. On the basis of the survey findings, a preliminary list of indicators was presented in a focus group discussion among scientists who have substantial research experience (4 to 10 years) in the Khorezm region. A total of nine researchers participated, with backgrounds in agricultural economics, water management, environmental monitoring, agronomy and afforestation. Building upon the survey findings, focus group recommendations and previous research results (Chapters 2 and 3), the proposed vulnerability assessment method for agricultural systems was operationalized upon data availability. The final set of selected indicators is listed in Table 4-2 and described in details in the Table B1.

4.3.2. Scenario specification

Impact of climate change on water flow for irrigation

The latest assessment of the impact of climate change on the water flow to the midstream Kerki gauging station (upstream from the Tuyamuyun reservoir, which discharges water to Khorezm), suggests a reduction of the average multi-year seasonal discharge in 2030 by 13% and in 2050 by 22% (Schlüter et al., 2013). Various assumptions underlie these findings, such as about greenhouse gas concentrations according to the SRES A1B, and future institutional and technical conditions. Here, the case of 80% water availability during the vegetation season in respect to the long-term average is considered (i.e. a reduction of the average water flow to each district of Khorezm by 20%). Even though the expected climate changes and land degradation in the Central Asian region are significant *(IPCC, 2014b, Mannig et al., 2013a)*, to simplify this feasibility study, the case of reduced water flow in the current environmental conditions was explored.

Adaptation policy scenario

According to the available statistical data, the environmental pressures are higher in the three downstream districts of Khorezm, namely Kushkupir, Shavat and Yangiarik. More specifically, these districts share the following characteristics: the lowest access to irrigation; the lowest cotton yield (Ruecker et al., 2012); high share of poor quality soils; the highest groundwater salinity. Therefore, adaptation scenario was explored only for those districts as follows:

- reduction of the use of the low quality cropland for cotton production (defined in the Table B1) by 50 % as a water saving measure. The existing estimations suggest that eliminating marginal areas from the irrigation plan could save 15-20% surface water (Awan et al., 2012). Therefore, is was assumed that with 50% reduction in the use of low quality cropland, each of the three districts could save about 10% water;

- reduction of the cotton area by 20%, in addition to the reduced low quality cropland;
- reduction of the rice areas by 100 %, which could save up to 1% water (Awan et al., 2012);
- replacement of the reduced cotton area with fruits/vegetables. This could save about 9% water (Awan et al., 2012) and increase the farmers' income (Bobojonov et al., 2012).

This set of adaptation measures could bring several additional socio-economic benefits. For example, recent analysis on the prospects for afforestation of the Khorezm marginal croplands, reveals that trees plantation is an applicable option for income diversification, soil salinity improvement and decrease in the regional water demand (Khamzina et al., 2012). Furthermore, an overall reduction of the cotton cropland in the range of 17-69 % (i.e. reduction of raw cotton production) is expected to preserve the same level of cotton export revenues, if cotton value chain offers better conditions for investments in the processing sector, such as cotton fibre and fabrics production for export (Rudenko et al., 2012, Rudenko et al., 2013).

Building upon these findings, it was assumed that the *GAP* and *CRAG* indicators will not be negatively affected after the adaptation, therefore those elements were kept at the baseline state. However, the *ADI* and *SNCWF* values were increased in accordance with the adaptation scenario, referring to increased resilience and capacity. As well, the *EWP* should increase, whereas it was assumed again constant gross agricultural production, however less water demand due to the set of measures.

The developed adaptation scenario seeks to explore adaptation options at a sub-regional scale in Khorezm. Imposing water saving measures only in those districts, with the highest environmental degradation and the lowest access to irrigation is more feasible near-future scenario. Given the governmental policies of prioritization of raw cotton production, the explored set of measures could hardly be introduced across all districts. Furthermore, the proposed ADAPT scenario is used for sensitivity tests of the spatial multi-criteria analysis.

Developing upon the above specifications, two scenarios were explored in this study: (i) 20% reduced water flow under business-as-usual conditions, referred to as

“BAU -20%”; and (ii) 20% reduced water flow with imposed adaptation measures in three districts (as described above), referred to as “ADAPT -20%”.

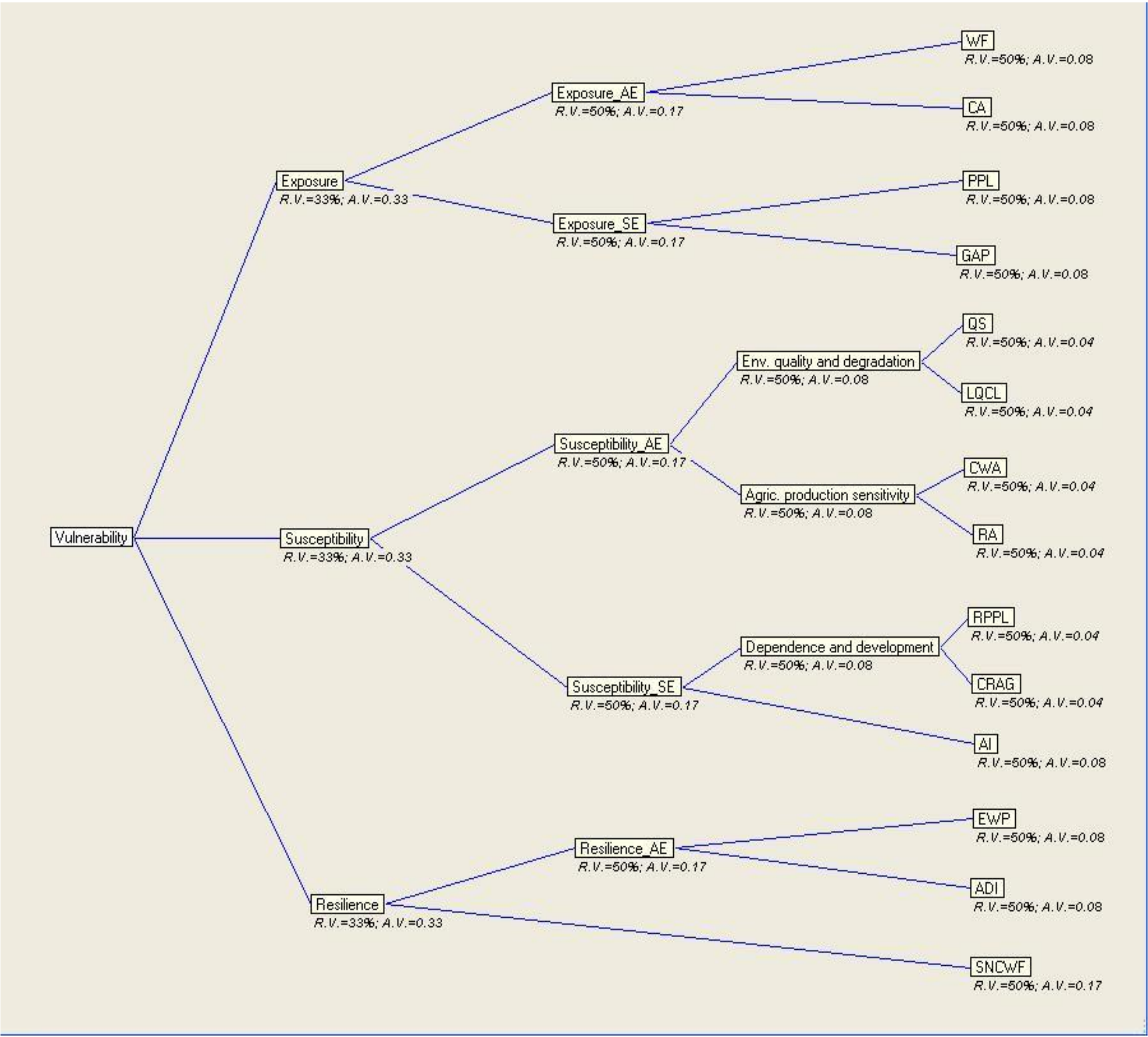
4.3.3. ASVI computation and results

Descriptive statistics are derived to explore the baseline dataset (Table B1). The original data (n=10) is composed of 14 indicators with diverse measurement units. All of the variables are quantitative, except *AI* which is categorical. Given this structure of the dataset, Pearson correlation analysis was performed to verify the relationships between the indicators (Table B2). The sign of the correlation coefficient *r* is consistent with the theoretical knowledge, except in some cases (such as r of AI and CRAG), in which however, *r* is very low and not statistically significant. Since the sample size is small, the variables with $r>0.8$ were considered with caution during the robustness tests of the baseline results. High correlation (i.e. $r>0.8$) exists between: *GAP* and *PPL*; *GAP* and *RPPL*; *CWA* and *ADI*. However, these indicators belong to a different sub-components of the index (except *GAP* and *PPL*), and therefore were preserved during the first run of the model.

The full dataset, containing the baseline data and two scenario matrices (“BAU -20%” and “ADAPT -20%”) (i.e. 30 observations and 14 indicators), was normalized (min-max method) and aggregated with mDSS using SAW. Equal hierarchical weights (EHW) were assigned. The ranking algorithm was based on the surface area of each district. The hierarchical design allowed us to group the indicators into sub-indices that share the same dimension of vulnerability (Fig. 4-2). The index values were divided into 3 classes (low, medium and high vulnerability) within the range of minimum and maximum scores for each scenario. In the baseline assessment, the index values were in the range 0.45-0.65.

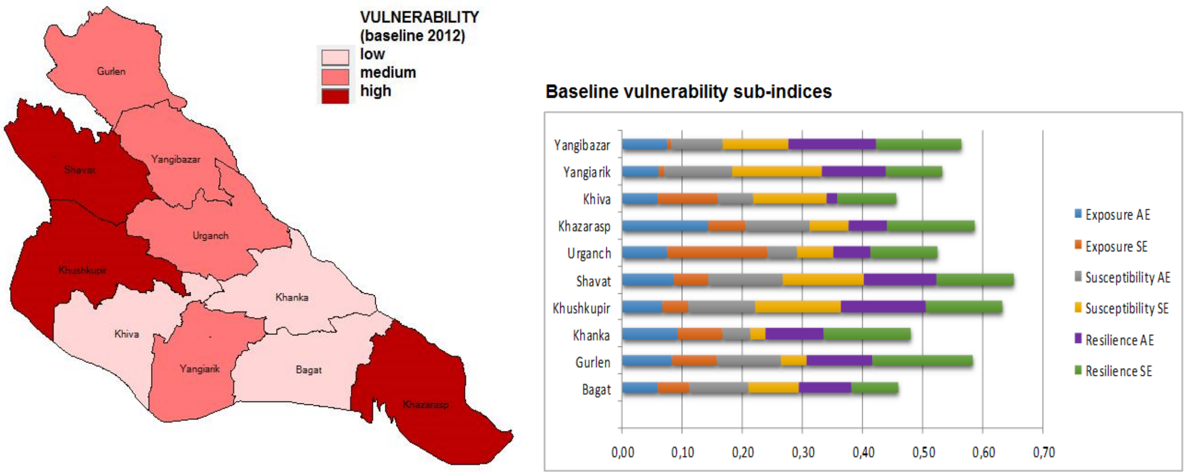
The summary of the results, including the level of vulnerability and the associated dominant factors, are provided in Fig. 4-3 and Table 4-3. The most critical elements, which shape the vulnerability within the region, differ across the districts. The indicators related with cotton and wheat farming are set into the sensitivity and resilience sub-indices, and the districts with the lowest share of their production fall in the low and medium vulnerability classes. The state of the natural resources (soil, water) and the water productivity are also major determinants of the districts’ vulnerability to climate pressures. In addition, the population size, rural-urban ratio and gross agricultural output within the region, supplement the spatial variability of the vulnerability index and its sub-components.

Figure 4-2. Structure of the Khorezm Agricultural Systems Vulnerability Index (ASVI)



Note: applied simple additive aggregation method and equal hierarchical weights.

Figure 4-3. Baseline (2012) agricultural systems vulnerability index for Khorezm (left) and sub-indices by district (right)



Notes: The ASVI values for each class are in following range: low 0.45-0.51, medium 0.52-0.58, high 0.59-0.65. AE refers to agro-ecological; SE refers to socio-economic.

Table 4-3. Summary of the results of the baseline agricultural systems vulnerability assessment for Khorezm

District	Level of vulnerability and key factors
Bagat	**Vulnerability: low**. The baseline scenario rank of Bagat is 9, suggesting one of the lowest levels of vulnerability in the region. Overall, Bagat has low exposure and high resilience in comparison with the other regions. Meanwhile, the susceptibility falls in the mid-class, shaped primary by the highest for Khorezm dependence and development, i.e. RPPL and CRAG indicators.
Gurlen	**Vulnerability: medium**. Gurlen, even though located close to the river, has medium exposure, susceptibility and very low resilience. To this contribute the high values of the indicators CA, GAP and the huge land used for cotton and wheat, including the lowest share of non-cotton farms. Major susceptibility factor is also the largest share of the land used for rice cultivation.
Khanka	**Vulnerability: low**. Khanka district has the lowest susceptibility in Khorezm, associated with the lowest environmental deterioration, the highest value of CRAG indicator and its upstream location. Despite the medium exposure and the high lack of resilience as a result of the low agricultural diversity and the high share of cotton and wheat farms, the low susceptibility place the district in the low vulnerability class.

Khazarasp	**Vulnerability: high**. Khazarasp is the largest district and has the largest share of crop land which contributes to the high exposure. Susceptibility of the region, however, is medium, shaped by the low CRAG value and the high agricultural production sensitivity due to the intense cropping of cotton and rice (Khazarasp and Gurlen are the largest rice producers in Khorezm). Even though the district has the highest economic water productivity within the region, the low agricultural production diversification places the region in the mid-range of the resilience class.
Khiva	**Vulnerability: low**. Khiva is the district with the highest resilience in Khorezm due to the high agricultural diversity and economic water productivity. Meantime, the district has the smallest share of land used for cotton and wheat cultivation.
Kushkupir	**Vulnerability: high**. Kushkupir holds a big share in the Khorezm crop land, and the same time has the lowest water availability and contributes little to the regional GAP. The high exposure and the medium susceptibility and lack of resilience, make Kushkupir the second most vulnerable district. Together with Shavat, the region has the highest environmental degradation and poorest land and water resources quality – a situation aggravated by the high share of cotton production. Importantly, the region has the lowest economic water productivity.
Shavat	**Vulnerability: high**. Shavat share the same environmental and water access challenges as Kushkupir, as well as the high scale of cotton production given the poor state of its natural resources. Water flow to the district however is higher in comparison to Kushkupir, which places Shavat in the mid-class of exposure component.
Urgench	**Vulnerability: low to medium**. Urgench is the Khorezm regional centre, with the highest values of PPL and GAP indicators, and at the same time it holds a large share of Khorezm's crop land. All of those factors contribute to the highest value of exposure within the region. However the district have very low susceptibility related to the better state of land and water resources and highest share of urban population in comparison with the rest of the districts. The lack of resilience sub-index of Urgench is in the lower range of mid-class.
Yangiarik	**Vulnerability: medium**. Yangiarik is a downstream district, with the highest regional susceptibility sub-index, main determinants of which are the poor environmental quality, the high share of cotton and wheat fields, as well as the dominance of the rural population and the lower agricultural development rate. However, Yangiarik is the least exposed district, having the lowest CA and GAP indicators values. The district has medium resilience.
Yangibazar	**Vulnerability: medium**. Similarly to Yangiarik, Yangibazar has very low level of exposure, primary determined by the lowest socio-economic exposure component (PPL and GAP indicators). Meantime, the region has high susceptibility and lack of resilience, with the following most critical factors: the highest share of cotton/wheat area, very high share of rural population, mid-stream location and the lowest agricultural production diversity.

4.3.4. Sensitivity analysis of the baseline ASVI

Following the baseline estimations, the robustness of the vulnerability index was carried out through analysing its correlation with the input parameters. Four indicators (*CA, CWA, ADI, SNCWF*) were significantly correlated, with coefficient value *r*>0.6. Given this result, and the high correlation between the *GAP* and *PPL* indicators, which belong to a same sub-component of the index, several robustness checks of the weighting method were performed, whereas the results are summarized in Table 4-4.

Table 4-4. Sensitivity of the class ASVI due to a change in the assigned weights

Changes in the assigned weights	Bagat	Gurlen	Khanka	Khushkupir	Shavat	Urgench	Khazarasp	Khiva	Yangiarik	Yangibazar
EHW	1	2	1	3	3	2	3	1	2	2
PPL=0,25, GAP=0,75	1	3	1	3	3	2	3	1	2	2
CA=0,25, WF=0,75	1	2	1	3	3	1	3	1	2	2
ADI=0,25, EWP=0,75	1	2	1	3	3	2	2--3*	1	2	2
CA=0,25, WF=0,75; ADI=0,25, EWP=0,75	1	2	1	3	3	1--2*	3	1	2	2
SNCWF=0,5	1	2	1	3	3	2--3*	3	1	2	2
E=0,25, S=0,50, R=0,25	1	2	1	3	3	1	2	1	3	2

Note: 1 - low vulnerability class; 2 - medium vulnerability class; 3 - high vulnerability class; * - value at the border between two classes.

First, the weight of the indicator *PPL* was reduced in favour of that of *GAP* indicator, since it has very high values in Urgench and Khiva - two urban-dominated districts. The effect of the change in the vulnerability class, however, is reflected only from the rank of Gurlen, which has the second highest *GAP* in Khorezm after Urgench. Next, the weights of the *CA, ADI* and *SNCWF* indicators were reduced separately and jointly, since those indicators showed higher correlation with the *ASVI*. Change in the vulnerability class occurred solely for Urgench. The last run of the robustness test accounted for change in the weights of the vulnerability sub-components (exposure, susceptibility, lack of resilience). The latter addressed the correlation problem within the exposure component, and between the exposure, lack of resilience and *ASVI*, through assigning lower weights. Those modifications changed the classes of three districts, which have the highest exposure indices among all. Lastly, lowering the weight of the *SNCWF* indicator significantly changed only the class of Urgench towards much higher vulnerability. Given that the class volatility under alternative weighting scheme affects primary Urgench district, EHW approach was used throughout the analysis.

4.3.5. Spatial vulnerability under different scenarios

The change in the aggregated *ASVI* values under the explored scenarios is given in Table 4-5. The results show that the lowest vulnerability values are obtained under the scenario ADAPT -20% (values range 0.30 – 0.61), while the highest vulnerability is observed under the scenario BAU -20% (values range 0.47 – 0.68). Changing only one indicator equally across all districts (WF under scenario BAU -20%), leads to a higher overall vulnerability, but preserves the original rank order.

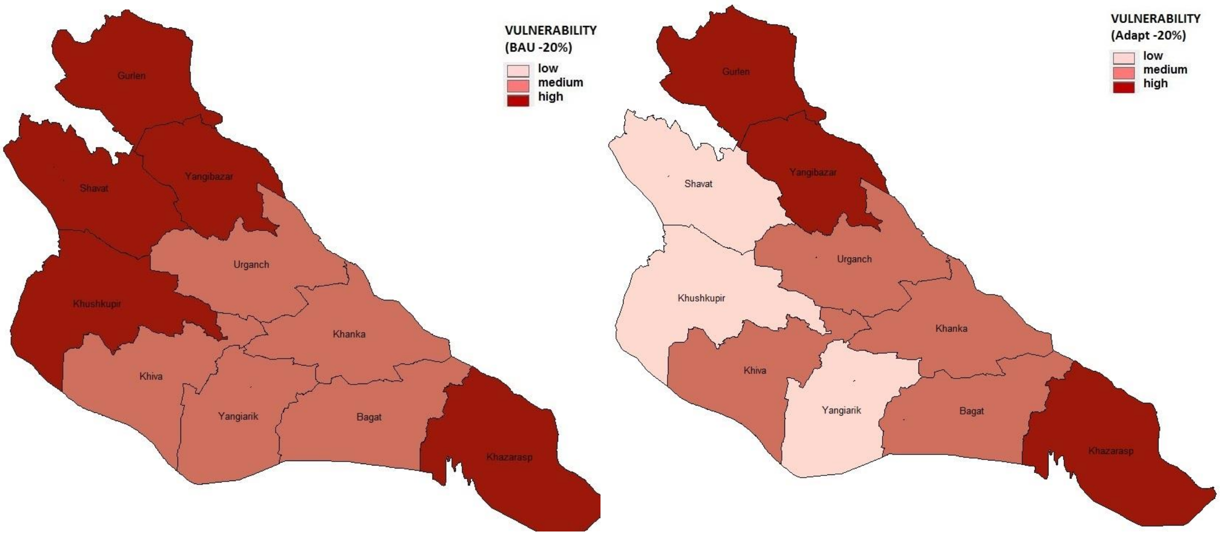
Table 4-5. Vulnerability index values under different scenarios

District	Baseline2012	BAU -20%	ADAPT -20%
Shavat	0.65	0.68	0.38
Khushkupir	0.63	0.66	0.41
Khazarasp	0.59	0.60	0.61
Gurlen	0.58	0.61	0.61
Yangibazar	0.56	0.59	0.59
Yangiarik	0.53	0.55	0.30
Urgench	0.52	0.55	0.55
Khanka	0.48	0.50	0.50
Bagat	0.46	0.48	0.48
Khiva	0.45	0.47	0.47

Notes: BAU -20% refers to business-as-usual scenario with reduction of water flow by 20%; ADAPT refer to the case of introducing the set of adaptation measures as described in Section 3.2.in response to the expected 20% less water availability.

The spatial sensitivity of the index to a change in several indicators related to adaptation is high. This is confirmed by the change of the classes of the districts in which the adaptation was imposed (Yangiarik, Kushkupir, Shavat) (Fig. 4-5). According to the sensitivity analysis performed through mDSS, the *most critical* *criterion*[7] for rank volatility for the three districts is the agro-ecological exposure sub-component. The most vulnerable districts identified in the baseline assessment (Shavat and Kushkupir), are those with the highest volatility of the classes. However, the rank order of the rest of the districts follows the same pattern.

Figure 4-4. ASVI for Khorezm under two scenarios (“BAU -20%” and “ADAPT -20%”)



Note: The ASVI values for each class are in the following range: low 0.30-0.42, medium 0.43-0.56, high 0.57-0.68.

4.3.6. Adaptation policy evaluation

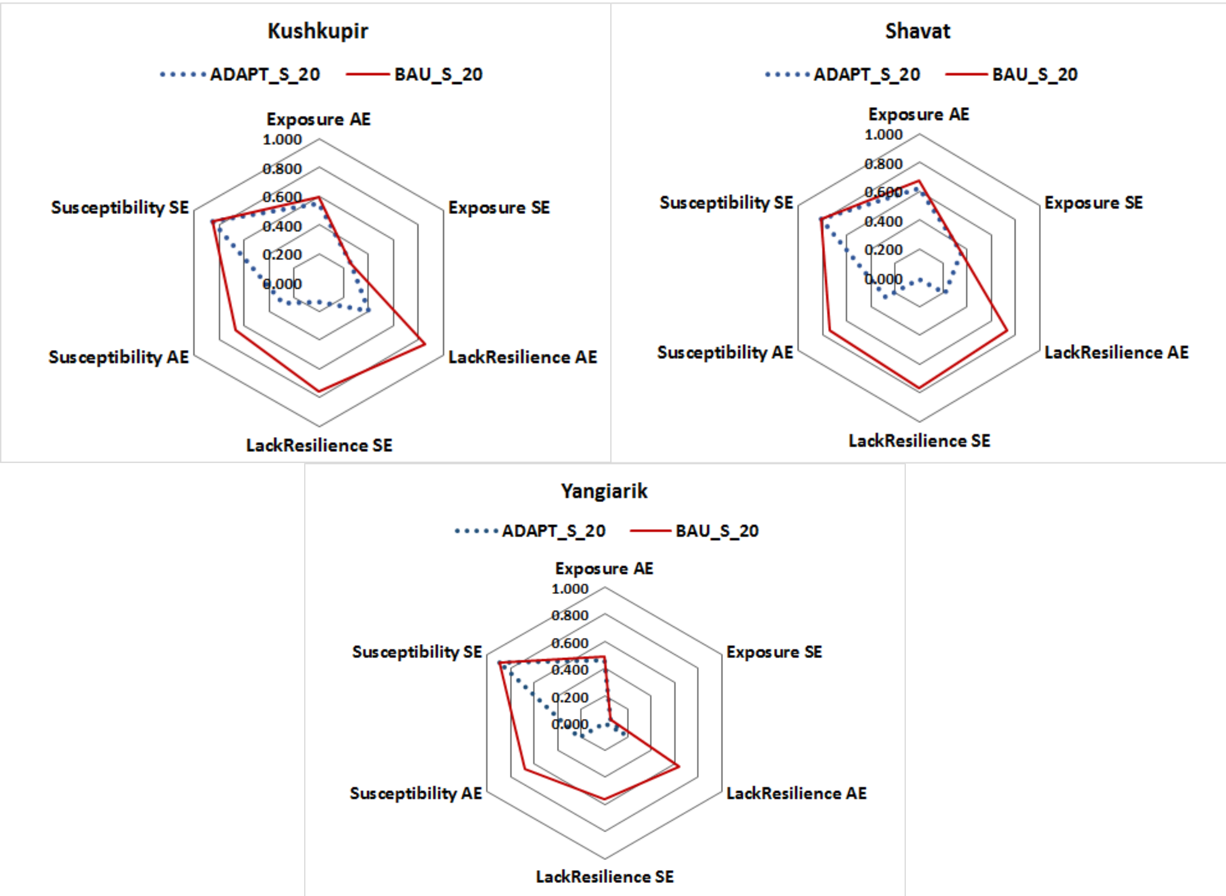
The results presented in the previous sections, demonstrated how local actors can apply the proposed method, not only to assess the current vulnerability in Khorezm, but also to explore the effects of plausible scenarios on the spatial distribution of vulnerability. However, in order to support the development planning, the analysis should also explore the effect of adaptation on the AE and SE systems, as a means to integrate adaptation policies evaluation with sustainability analysis. For this purpose, the vulnerability sub-indices (Exposure AE and SE, Susceptibility AE and SE, Lack of resilience AE and SE) for the three districts, in which adaptation measures were imposed were used (Fig. 4-5). A change in the values of the sub-

[7] *Most critical criterion* is part of the sensitivity analysis performed in mDSS. It shows the criterion which could reverse the ranking of the options given the smallest change in its weight.

indices under the explored scenarios occurs only in four components, namely Exposure AE, Susceptibility AE, Lack of resilience AE and SE.

The sustainability patterns for Kushkupir and Shavat are similar since the two districts share common vulnerabilities. Significant reduction of the agro-ecological susceptibility and overall lack of resilience is observed in all districts. The socio-economic resilience, determined by the indicator for farm-type, has very strong influence on the overall vulnerability reduction.

Figure 4-5. Comparison of the sub-component scores of the Agricultural Systems Vulnerability Index (ASVI) for the three districts under the explored scenarios



4.4. Discussion and conclusion

4.4.1. The Khorezm region vulnerability

Global change, and water availability in particular, are of major concern over achieving food security and enhancing rural development in Central Asia. Djanibekov et al. (2013a) assessed, that the pressure on the water resources in Uzbekistan is expected to rise significantly due to increasing economic growth, unless policy actions take place. Looking into these pressing needs, the vulnerability assessment for Khorezm could serve as a model for the analyses of policy implications at a sub-national level. While previous research in the case study region looked into the benefits of potential options for improved land and water management (e.g. Rudenko et al., 2013, Djanibekov et al., 2013b, Martius et al., 2012), a multi-dimensional assessment of the regional vulnerability to climate change at a sub-national level was performed here, linking multiple dynamic factors and policy responses into aggregated information for policy-makers.

This study found that there are significant spatial differences between the agro-ecological and socio-economic determinants of the districts' vulnerability, which should be considered in the rural development and climate change policies. For this reason, the explored adaptation scenario targeted the districts with the poorest agro-environmental conditions. Such a differential approach to adaptation planning, which considers the spatial differences, could be feasible pathway to initiate adaptation, given the constraints in the region, such as the state production quotas and the need of substantial investments in the irrigation infrastructure (Chapter 2), while contributing to a more equal development. Bekchanov et al. (2010a) already discussed the importance of equal water distribution to improve the low water productivity in the tail end districts. Similarly, Dubovyk et al. (2012) recommend prioritized mitigation planning in the low-fertility lands which are located close to the natural sandy desert, since land degradation in those areas is significantly high. To this, trees plantation, as it was already mentioned, is a suitable risk mitigation, water saving and income diversification policy (see Section 4.3.2). Importantly, the districts with the highest environmental susceptibility have a high share of land for cotton cultivation. Therefore, the agricultural production diversification is crucial for the regional resilience, especially in the most vulnerable districts.

The vulnerability analysis for Khorezm could be further extended to risk assessment, considering future environmental and socio-economic change. The presented case study is an example of data constrained vulnerability assessment.

Therefore the analysis would benefit from involvement of key stakeholders in the *ASVI* and scenario development process. Adaptation policy impact assessments from external models could be linked with the framework through the *mDSS* tool for multi-criteria analysis of various policy options.

4.4.2. Performance of the ASVI, uncertainties and limitations

The vulnerability assessment for agricultural sector requires an integrated approach, coupling agro-ecological and human systems. The concept should relate also to dynamic processes before becoming suitable for scenario analysis. The proposed approach bridges the vulnerability assessment with policy decision-making, which makes it a useful supplementary methodology for identifying hazard prevention policies and climate change adaptation measures.

The *ASVI* tool allows integrated, spatial and comparative assessment of local vulnerability to climate change and hazards. Furthermore, the *ASVI* incorporates indicators which reflect the global change (such as land degradation) impacts at a regional scale, which makes it compatible with further risk analysis. The proposed method is suitable for evaluation of adaptation scenarios, considering three pillars of sustainability (environment, society, economy). In this sense, the ASVI tool adds several features in the vulnerability assessment methods for agricultural systems which are not common in the current literature. In addition, the tool could facilitate the discussion of local stakeholders for identification of priority regions and areas for policy intervention. Therefore, policy-makers working in the field of agriculture can adopt the framework in order to identify sustainable solutions of local issues under climate change.

The methodology is transferable to other case studies, providing flexibility in terms of weighting and aggregation methods. Non-participatory techniques were explored here, however the selected *mDSS* software is a proven tool for policy evaluation with stakeholders' involvement (Giupponi, 2007, Giupponi et al., 2008, Giupponi, 2014). While further work is required to refine the methodology upon wider applicability, the approach proposed herein could facilitate dialogues among local and national actors.

The performed analysis aimed at exploring the applicability of the proposed method in assessing the impact of the potential reduction of the irrigation water availability and set of adaptation measures on the Khorezm regional vulnerability. The application in the case study considers min-max linear scaling for normalization, which is commonly used method in hierarchical models. The hierarchical approach for configuration of social vulnerability indices has very high accuracy, however a certain level of uncertainty originates at the weighting stage (Tate, 2012). Special attention was paid therefore, on the weighting algorithm of the case study assessment. The robustness tests through change in the weights of the baseline *ASVI* showed that the index is highly sensitive to the agro-ecological exposure and resilience indicators. However, the vulnerability class of only one district reflected those changes, which is most likely related to the highest values of several exposure indicators for the district. The sensitivity tests showed satisfactory stability of the ranks under different scenarios.

There are several other acknowledged shortcomings of this study. First, the method has been exemplified only through the case study of Khorezm. Even though the indicators development involved local stakeholders, a backward communication of the final results to the key policy-decision makers was not feasible.

Second, the developed adaptation scenario is based on literature review findings. Therefore, it is limited by the assumed changes in, or preserved constant values of, the agro-ecological and socio-economic parameters. For instance, climate change would affect crop production through a change in the seasonal agro-meteorological conditions, not only through the irrigation water availability. Nevertheless, the incentive behind the scenario analysis was to demonstrate the applicability of the vulnerability assessment approach for policy evaluation, and to explore the uncertainty in the use of the developed *ASVI*.

Third, the assessment was concentrated on a district scale analysis within a region. Spatial up-scaling of the vulnerability approach, however, is associated with several challenges, such as: (i) possible loss of information during the process of transferring the approach from local to higher level; and (ii) assumptions suitable for one spatial level could not be adequate for other (Fekete et al., 2010, Eriksen and Kelly, 2007). In addition, the choice of scale yields different relationships between the indicators (Tate, 2012).

Finally, the proposed assessment method should be perceived as a generalized operational method for aggregation of multi-dimensional spatial information, relevant to describe local determinants of vulnerability and upon which scenarios of future conditions can be applied. Hence, the derived ASVI could be useful for informing adaptation planning. Yet, the vulnerability indicators reduce complexity, which could lead to misinterpretation of information, and therefore they should serve as entry-points for adaptation planning and allocation of resources, rather than as a prime criteria (Hinkel, 2011).

Chapter 5 The role of the institutions in climate change vulnerability reduction: The case of Uzbek agriculture

Abstract

Climate change threatens agriculture worldwide. While the scientific literature is rich on technical solutions for responding to the various risks, practitioners often face major barriers to their implementation, often posed by the institutions. At the same time, the institutions are those organizations, rules and processes, which create the mechanisms that turn the technical solutions into practical actions. The objective of this analysis is to explore the role of the institutions in reducing the agricultural vulnerability to climate change in Uzbekistan, which is a country in transition governed by a highly authoritarian, top-down system. The study gives national and sub-national perspectives by taking the Khorezm region as a case study. This region is challenged by a significant risk from water scarcity and land degradation, while being highly dependent on irrigated agriculture. Specifically, the chapter provides a state-of-the-art analysis of the national and local institutions related to the agricultural sector. Key messages of particular concern for vulnerability reduction in Khorezm are discussed. The study further provides policy recommendations which can support the development of national adaptation strategies. The analysis is a combination of a review of literature and formal institutional settings and interviews with key informants from Khorezm. The findings highlight major institutional challenges to climate risk reduction, such as: lack of vertical and horizontal distribution of institutional power; and limited opportunities for participation of the private sector in vulnerability reduction.

Key words: adaptation, Aral Sea, Amu Darya, water scarcity

5.1. Introduction

The concept of vulnerability is widely applied in studies on climate change and hazards, whereas *institutions* (see Table 5-1 for definitions) are an integral part of the analysis in many vulnerability assessment frameworks (e.g. Turner II et al., 2003, Birkmann et al., 2013, Giupponi et al., 2014). For instance, according to Birkmann et al. (2013), the "institutional vulnerability" could shape the risk to climate change and hazards. Similarly, Turner II et al. (2003) include institutions in the human component of vulnerability, because they could be either stressors or factors of sensitivity and resilience. To this, Adger et al. (2005a) claim that the distribution of power within institutions that manage resources, could create vulnerabilities.

Institutions not only drive environmental changes, but they also may confront them (Young, 2002). Through their structures, rules and processes, institutions are the key mechanism to respond to the negative impacts of climate change. Consequently, weak institutional capacity in terms of organizational structure, legislation, scientific knowledge and financial mechanisms, is a major obstacle to vulnerability reduction. Berman et al. (2012) suggest that institutions facilitate the process of transforming coping capacity (the capacity to cope with current climate variability) into adaptive capacity (the capacity for long-term and sustainable adaptation planning), particularly important for natural resources dependent communities in the developing world. The efficiency of the actions for vulnerability reduction, such as adaptation, is highly dependent on the institutional architecture. For instance, individual adaptation actions are constrained by institutional processes, such as regulatory structures and property rights (Adger et al., 2005b).

The role of the institutions in vulnerability reduction in transition countries is scarcely explored by scholars. The agriculture in the Central Asia region contributes substantially to the states' economic development, employment and food security (Christmann et al., 2009). Climate risk management in the Central Asian states is at its early stage of development, suggesting lack of national and local institutional capacities in the face of global change. Meanwhile, together with the institutional transformation in all sectors, the region faces significant climate risks (IPCC, 2014b, Agal'tseva et al., 2011), land degradation (Saiko and Zonn, 2000) and irrigation water insecurity and conflicts (Martius et al., 2009, Sehring and Giese, 2011). An emerging issue in Central Asia is how institutional transformation can facilitate climate change vulnerability reduction policies. Previous studies have identified several challenges to adaptation planning for agriculture in this region, such as limited integration and cooperation between stakeholders, and insufficient regional and local level institutional capacities (Bizikova et al., 2014b).

Uzbekistan remains the most centralized state in Central Asia, which makes it a special case for exploring the role of institutions in reducing the agricultural vulnerability to climate change. This chapter investigates the issue at a regional scale, through a case study of Khorezm, which is an important agricultural region of Uzbekistan. The specific objectives which guided this study were: (i) to identify the *formal institutions* in Uzbekistan and Khorezm, involved in climate change management and with a particular reference to agriculture; (ii) to analyse how they shape the regional vulnerability to climate change and water scarcity through a discussion on the challenges and key issues; (iii) to provide recommendations on strengthening the institutional capacity.

5.1.1. Scope and methods

Within the broader definition of *institutions* adopted in the Fifth Assessment Report (AR5) of the IPCC, in this analysis the term refers to formal organizations (actors), legal frameworks and policies (see Table 5-1). Hence, the focus is on institutions operating at national, regional and district level. Among various possible ways to categorize (local) formal organizations, the classification proposed by Agrawal (2008) is used in this work, i.e. *state, private and civic* institutions. The state institutions are local agencies of higher levels of government. The civic institutions include membership organizations (e.g. associations with membership fees), while the private ones refer to businesses and non-governmental organizations (NGOs).

Major climate change issues in the case study region are the expected more frequent drought events and consequently, the higher risk of water scarcity for irrigation (Schlüter et al., 2013). Therefore, the term *vulnerability reduction* covers not only climate change adaptation, but also disaster risk reduction policies in response to water scarcity.

Methodologically, the analysis and the discussion were built upon: (i) a review of literature and formal institutional settings (organization, policies and strategies, legislation); (ii) field research. Semi-structured interviews were conducted with formal state institutions (e.g. Ministry of Agriculture and Water Resources in Khorezm), associations (e.g. farmers associations), financial organizations and extension services providers operating in the Khorezm region (Table A1). The interviews focused on exploring various issues (depending on the respondents' field of expertize):

- main institutions involved in climate risk management in agriculture in the region, their role and collaboration with other actors;
- existing structures at regional and district level for information dissemination and prevention of droughts;
- priorities in the national and local plans for rural development and how climate risk reduction measures (such as adaptation) are being incorporated;
- existing financial mechanisms to deal with climate risks and to support adaptation;
- private business participation in climate risk reduction.

Table 5-1. Glossary of key terms adopted

Term	General definitions as defined by the Fifth Assessment Report of the IPCC (IPCC, 2014a)	Definitions used in this study
Vulnerability	Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.	The propensity or predisposition of a system to be adversely affected. Vulnerability has three components: exposure, susceptibility and resilience (including adaptive capacity).
Vulnerability reduction	**Adaptation** is the process of adjustment to actual or expected climate change and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. **Disaster risk reduction** denotes both a policy goal and an objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, a hazard, or a vulnerability; and improving resilience.	**Vulnerability reduction** could be achieved through adaptation and disaster risk reduction measures (relevant to the high water scarcity risk in Khorezm).

Institutions	Institutions are **rules and norms** held in common by social actors that guide, constrain, and shape human interaction. Institutions can be **formal**, such as laws and policies, or **informal**, such as norms and conventions. **Organizations** – such as parliaments, regulatory agencies, private firms, and community bodies – develop and act in response to institutional frameworks and the incentives they frame. Institutions can guide, constrain, and shape human interaction through direct control, through incentives, and through **processes** of socialization.	**Formal (local) institutions** include: (i) organizations (state, private, civic); (ii) legal frameworks, policies, strategies;

5.2. Institutional and policy context in the Uzbek agriculture

5.2.1. National and regional actors

State organizations

- **Ministry of Agriculture and Water Resources**[8]

The Ministry of Agriculture and Water Resources (MAWR) was established in 1997, after an in-depth governance reform in Uzbekistan following the independence from the Soviet Union in 1991. The establishment of the MAWR marks two significant organizational changes in the structure of the water governance in the country. First, the newly established MAWR is a single centralized organization which unites two previous ministries - the Ministry of Agriculture and the Ministry of Melioration and Water Resources (Veldwisch et al., 2012). Second, the water resources management system is transformed from an administrative-territorial-based[9] into a basin-based management system[10], involving the creation of the Irrigation Basin System Management Authorities (IBSMA) in 2003 (Veldwisch et al., 2012). The latter are directly responsible for the Water Resources Unit of the MAWR in Tashkent, and are therefore independent from the regional and district offices of the

[8] In Russian: Министерства сельского и водного хозяйства Республики Узбекистан.
[9] System based on administrative boundaries.
[10] Systems based on hydrological boundaries.

MAWR. According to Veldwisch et al. (2012), this transformation was characterized with:

- Extension of a highly centralized water management system, with a control base located in Tashkent;
- Remaining dominance of the agricultural planning, i.e. maintenance of the centralized political control;
- Reducing the previously existing dependency on local actors and avoiding conflicts of interest between farmers, *hokims*[11] and the MAWR.

The priorities for the MAWR are related to the optimization of cotton and wheat production through setting annual production targets and prioritizing water delivery to wheat and cotton fields. Furthermore, the MAWR is in charge of issuing technical specifications for water intake from the irrigation basin systems, as well as technical rehabilitation of the latter. Together with other agencies, the ministry develops agricultural and rural development plans and policies. At a regional level, in addition to its main functions (agro-practices, economic reforms, water management), the Khorezm Regional Department of the MAWR performs other activities, relevant to climate risk management:

(i) Information dissemination. The system of planned agricultural production in Khorezm requires the dissemination of climate and hydrological data from the responsible state organizations to the cotton and wheat farmers. The central office of the Centre of Hydro-meteorological Service (Uzhydromet) in Tashkent provides weather forecast information, prior to planting and harvesting seasons, which helps the optimization of the cropping calendar by the Regional Department of the MAWR in Khorezm.

The hydrological data is jointly analysed by the Uzhydromet in Tashkent and the Department for Lower Amu Darya Basin Irrigation Systems (which operates under the MAWR). Then, the information on water availability (including forecasted values) and instructions for water distribution are sent to the representatives of the MAWR (including to the Irrigation Department) in the Khorezm's regional centre in Urgench. From there, the information is further distributed to each district's branches of the MAWR, Water Consumer Associations (WCAs), *hokims* and Farmers' Council. The

[11] Local governors, e.g. of a village. They are responsible for overseeing that the cotton and wheat targets, imposed by the state, are met by the farmers.

farmers are informed about the planned water delivery volumes to their fields by the WCAs (mainly), and are provided with further instructions/ orders by the local representatives of the MAWR. The information on water availability is distributed at least once per week to the districts' *hokims* and MAWR representatives (interview code 01, Table A1).

(ii) Advisory services and training activities. Despite the significant progress in terms of information dissemination in Khorezm, since the severe droughts of 2000-2001 (see Chapter 3), to date, many farmers are ill-prepared to face climate variability and water scarcity:

> *"Farmers don't know what to do when it rains unexpectedly or when there is no water when needed. Most of them wait orders from the ministry."* (interview code 01, Table A1).

This can be seen as a cause for and a consequence from the MAWR's ongoing grip on the cotton and wheat farmers, who have to meet the state production quotas. The ministry also organizes free compulsory training for cotton and wheat farmers. This training is annual (held in winter) and is conducted in each district. It is carried out by working staff of financial institutions, the tax administration, the MAWR and universities, and usually covers a variety of topics, including introduction to agricultural laws and regulations. Nevertheless, the training does not cover topics such as drought preparedness and response (interview code 01, Table A1).

- **Centre of Hydro-meteorological Service at Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet)[12]**

Uzhydromet is a state organization, governing the state system of hydro-meteorological observations and services provision, including scientific research on climate change impacts and risks. It is the designated body responsible for the development of the Uzbekistan National Communications under the UNFCCC. Importantly, the centre prepares short- and long-term forecasts for water regimes of the basins of Amu Darya and Syr Darya rivers. The monitoring and analysis of agro-meteorological parameters in support to the work of the MAWR is among the key activities of Uzhydromet.

[12] In Russian: Центр гидрометеорологической службы при Кабинете Министров Республики Узбекистан.

The Khorezm regional administration of Uzhydromet is authorized to collect hydro-meteorological information from Khorezm and to communicate it to the national central administration. There are three hydro-meteorological stations in Khorezm located in Urgench, Khiva and close to Tuyamuyun reservoir[13]. The data collected from the three stations is sent hourly, directly to the central administration in Tashkent, while the regional office in Urgench receives information from the stations on a daily basis (interview code 04, Table A1). As mentioned earlier, the central administration of Uzhydromet provides the collected and analysed information to the MAWR, used later on for the regional agricultural production planning. The administration in Khorezm also makes observations of the state of the crops in case of frost, dry or cold conditions, and reports to the central base in Tashkent (interview code 04, Table A1).

Overall, the hydro-meteorological monitoring, forecasting and information dissemination capacities of Uzhydromet have been improved significantly over the last decade, which increases the agricultural resilience to climate change and hazards at a national and sub-national level. For instance, inaccurate observations and poor data forecasting were among the main reasons for the state’s failure to respond to the severe droughts in 2000-2001 (see Chapter 3).

- **State Committee of the Republic of Uzbekistan for Nature Protection[14]**

The Committee regulates, monitors and controls issues related to the environmental protection and rational utilization and reproduction of the natural resources within the national borders. Additionally, it has direct responsibility for ensuring good environmental quality and improved ecological conditions (State Committee of the Republic of Uzbekistan for Nature Protection, 2014). The Regional Committee for Khorezm has policy implementation, controlling and monitoring functions, and more specifically: monitoring of the quality of air, water and land resources; wild fires protection; re- and afforestation activities (interview code 03, Table A1). In Khorezm, the Committee collaborates with the Forestry Department of the MAWR on projects for trees plantation on non-agricultural land. Afforestation activities aim at the

[13] Water from Amu Darya river is first collected in the Tuyamuyun reservoir and then distributed through the irrigation network to the Khorezm region.
[14] In Russian: Государственного комитета по охране природы Республики Узбекистан. The Ministry of Finance of the Republic of Uzbekistan holds 75,6% share.

protection of the agricultural land from dry winds, which increase the soil erosion and soil moisture deficit (interview code 03, Table A1).

Generally, the role of the Regional Committee for Nature Protection in reducing the agricultural vulnerability to climate change (including to water scarcity) is indirect. The committee's office in Khorezm has no power over agricultural policies and its activities seem rather isolated from the management of the agricultural sector. Yet, the environmental restoration activities of the organization can improve the agro-ecological resilience in the region. For example, the Committee for Natural Protection is the designated body for controlling the implementation of the new Programme of Action for Protection of the Environment 2013-2017 (described further in Section 5.2.2.).

- **"Uzagrosugurta" State Joint-stock Insurance Company (JSC)**[15] holds the largest share in the Uzbek agricultural insurance market, working with the state system of insuring cotton and wheat farmers. The interview with a regional bank representative who is in charge of the insurance reimbursement requests, focused primary on understanding the process of covering losses from natural disasters, and droughts in particular. Declaring a drought disaster event is in the authority of Uzhydromet, which provides the insurance company with the necessary data. In addition, the WCAs are required to report on the differences between the fixed water-use norms[16] and the real volume of water used by the farmers as evidence that the yield losses are due to the water scarcity. If declared a disaster event, a special commission assesses the losses from the natural disaster. Members of the commission include regional representatives of the MAWR, Farmers' Council, banks (if the farmer has credit), and the insurance company. Finally, the commission decides on the amount of reimbursement.

The above described scheme suggests significant state control over the amends of disaster losses. According to the interviewed insurer, only 2000-2001 droughts were recognized by the authorities as a disaster and in total 436 cotton and wheat farmers were reimbursed (interview code 05, Table A1). However, for the following water scarce seasons (in 2008, 2011), the government provided tax benefits to the affected farmers (interview code 01, Table A1). Both the insurance and the state

[15] Государственно-акционерная страховая компания "Узагросугурта" , http://www.agros.uz/
[16] These norms are determined for the major crops by the MAWR.

support are higher for farmers whose land has low soil quality in accordance with the state cadaster's records.

Civic organizations

- **Farmers' Council of the Republic of Uzbekistan**[17]

The Farmers' Council is a para-civic organization, established with a presidential decree to support the establishment and development of civic institutions, which provide services to farmers and stimulate the development of farm enterprises and small businesses. Among the main activities of the Council in Khorezm are trainings, developing local markets for agricultural producers and information dissemination (interview code 06, Table A1). Climate risk management (including water scarcity) is not among the priorities of the organization, which are rather business-oriented and state-order dependent. Nevertheless, the activities related to the development of markets for non-cotton and wheat production increase the economic resilience in the region and stimulate the diversification of farms' production. Thus, the Farmers' Council also supports the vulnerability reduction to climate change in Khorezm.

- **Water Consumer Associations** [18] exist officially since 2000 as a voluntary, non-governmental and non-profit entities, established by the state (Veldwisch et al., 2012). Officially formed and managed by a group of water users, the WCAs are self-financing irrigation organizations, "still heavily controlled by the government for the purpose of regulating agricultural production" (Veldwisch et al., 2012). The latter include state control of water inflows to and outflows from each WCA. The representatives of each WCA are required to monitor and report the water quantities delivered to their members on a regular basis. WCAs are used as sub-units for norm-based water distribution within the Khorezm region. Membership in WCAs is gained through the payment of consumer fees. However, the low capacity, the tight state control and the low efficiency of the WCA are disincentive for the farmers to make payments (Veldwisch et al., 2012).

[17] In Russian: Совету Фермеров Узбекистана. Previous name: Farmers' Association, changed with Presidential Decree 4495/30.12.2012.
[18] WCAs are known as Water User Associations (WUAs) until 2009.

Three representatives of village WCAs[19] were interviewed during the field research with the objective to explore their capacity to deal with severe water scarcity. All of them stated that they receive enough information on water availability from the Irrigation Department of the MAWR, however, they can do nothing if there is no water (interview code 07-09, Table A1). The water availability in their villages, determined by the state-ordered distribution and informal arrangements, especially during water scarce reasons, is of general concern for them (interview code 07-09, Table A1).

Private organizations

- **Agricultural services providers**

There are various organizations in Uzbekistan which provide *elements* of agricultural extension services. Still, major gaps in infrastructure and institutional arrangements exist (IWMI, 2008). In part, the above mentioned civic organizations, together with technology transferring organizations (e.g. Machinery Tractor Parks) (Niyazmetov et al., 2012a) and public knowledge providers (e.g. MAWR), compose the main body of extension service structures in Khorezm.

In order to explore if climate risk is raised as an issue in the trainings offered by private organizations, an interview with the representative of the **Regional Centre for Information and Innovation**[20] was conducted. The centre is a non-profit organization, working under the authority of the Farmers` Council of Uzbekistan, which operates in Khorezm since 2010. It collaborates with NGOs in the region. There is only one person working in the Khorezm regional centre, and two trainings for 60 farmers (mostly cotton and wheat producers) were organized in total in 2012. The trainings were designed to serve the farmers' interests and needs (e.g. the organizers asked the farmers what they would like to learn). The trainings were carried out by experts from Tashkent, as well as local specialists. The courses included knowledge building on heat-resilient crops and less water intensive varieties, which are relevant to climate change vulnerability reduction. Yet, there is a general lack of experts on climate change (interview code 11, Table A1). Major obstacles to the further development of the centre are lack of financial resources

[19] Most often, they are farmers themselves.

[20] In Russian: Хорезмской отделение Центра информации и инноваций при Республиканском Совете фермеров Узбекистана.

and the fact that the farmers are used to have access to free training services, such as those offered from the state (interview code 11, Table A1).

- **Bank (financial) institutions**

Open Joint Stock Commercial Bank (OJSCB) "Agrobank" is the largest bank of the Republic of Uzbekistan[21]. Despite its private status, there is a strong state representation among the bank's council members, and the Chairman of the Council is the Prime Minister of the Republic of Uzbekistan. The bank was selected for this survey in order to explore the status of the private investments in climate change adaptation in Khorezm.

Among the various banks operating in Khorezm, 70% of the farmers are clients of OJSCB "Agrobank" (interview code 10, Table A1). The bank supports rural development initiatives in Khorezm, by providing credits to: (i) cotton and wheat farmers through a state programme; (ii) farmers to process their own agricultural products (fruits and vegetables, fish); and (iii) rural households for housing needs. However, the respondent of the survey stated that there are no private investments in, and special programmes for, financing climate adaptation projects in Khorezm (interview code 10, Table A1)[22].

Table 5-2. Summary of the activities performed by key organizations operating in Khorezm, and related to the reduction of the agricultural vulnerability to climate change and water scarcity

Institution	Activities at a regional level in Khorezm
State organizations	
Ministry of Agriculture and Water resources of the Republic of Uzbekistan (MAWR)	Agro-practices, implementation of economic reforms, water management; information dissemination; Advisory services and training activities.
Khorezm regional branch of the State Committee for Natural Protection	Implementation, control and monitoring of state policies in the field of environmental protection, ecological conservation and

[21] Further information is available at: http://www.agrobank.uz/en/.
[22] The interviews were conducted in April-May 2013. The new state programme on promotion of drip irrigation, described in Section 5.2.2, has not yet been started in Khorezm.

	restoration.
Centre of Hydrometeorological Service at the Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet)	Climate, water and crops monitoring (data collection and monitoring).
Insurance company ("Uzagrosugurta")	Assessment and coverage of natural disaster losses in the agricultural sector.
Civic organizations	
Farmers' Council of the Republic of Uzbekistan	Farmers' support services: information dissemination, trainings, market access
Water Consumer Association (WCA)	Water distribution within the WCA members; collecting and reporting water delivery data.
Private organizations	
OJSCB AgroBank	Credits for various rural development projects.
Regional Centre for Information and Innovation under Farmers` Council of Uzbekistan	Trainings of farmers, including knowledge building on heat-resilient crops and less water intensive varieties.

- **Farm enterprises**

Djanibekov et al. (2012a) has described in detail the ongoing since 1991 farm restructuring process in Uzbekistan. The first phase (1991-1998) was re-designation of state-owned farms to collective farms, through transformation of all *sovkhozy*[23] into *kolkhozy*[24]. During that period, the state procurement system covered cotton, wheat and most of the other agricultural products. Between 1998 and 2013 three additional phases of farm restructuring and privatization occurred, each of which brought significant changes in the labour organization, farm-size and the state procurement system (Djanibekov et al., 2012c). The fourth and last phase started in 2008 and was characterized with an optimization of the recently formed private farms (*fermers*), with the requirement of a minimum farm size of 30 ha for cotton and wheat producers and 5 ha for horticultural/gardening farms. Along with the establishment of private farming, the state supported the rural households (i.e. the peasants) by providing small plots of land. These farms, *dehqons,* produce food for home consumption, barter or sale on the local markets, which make about 70% of the total population (Veldwisch et al., 2012).

[23] Large size farm, financed by the state budget.
[24] Smaller, self-financed farms.

The type of production of the private farms (Table 5-3) shapes the vulnerability to climate change and water scarcity of the *fermers* (see Chapters 3 and 4). Most vulnerable are considered cotton, wheat and rice producers (see Chapter 4). In January 2013, the share of cotton and wheat farms in Khorezm was 43%, corresponding to 85% of the arable land (OblVodkhoz, 2013).

Table 5-3. Characterization of private farms (*fermers*) in Khorezm

Production	Cotton and wheat Rice Gardens (fruits, vegetables) Livestock farms Other (e.g. fisheries, honey and silk producers)
Minimum farm size (ha)	Cotton and wheat farms – 30 ha Gardens – 5 ha
Land ownership	The state leases to *fermers* land; non-transferable; the state keeps the right to deprive the land.
State procurement system	Cotton and wheat production quotas.
State support and agricultural services	Special credit programme for cotton and wheat framers; State support to cotton/wheat farmers in case of significant droughts; WCA, Farmers' Council, some technology transferring and training agricultural services providers.
Dominant form of labour	Permanent and seasonal employment.

5.2.2. Policies and programmes linked to agriculture[25]

Land, water and agricultural production regulations

The "Land Code of the Republic of Uzbekistan" (No. 598-I, 1998) specifies that the agricultural land is a state property and not a subject to sale. It contains special provisions for the protection of the irrigated croplands. The latter can be transformed to non-irrigated in exclusive cases only. The agricultural land is categorized into productivity classes according to the soil *bonitet*[26] (Karimov, 2012), used to

[25] This section contains review of selected key legislation and programmes' documentation, which are publicly accessible. Additional information obtained from interviews with key informants is included as well.
[26] This is qualitative measurement of the soil fertility. It is index value, with scale range 1-100, whereas index=100 suggests the highest soil fertility.

determine the potential yields, regional cropping patterns, irrigation norms and state subsidies for cotton. *Fermers* have lease contracts for cultivation with the state. The state preserves the right to deprive the land, which has been used in the latest land consolidation reform.

The state order covers two strategic crops, i.e. cotton and wheat production. Farmers sell almost 100% of the produced cotton and 50% of the wheat to the state (the rest can be sold on the market). The price of the cotton is determined by the state and the payments are made to state-controlled accounts. The money can be used only for the state-determined production inputs and services, bought from state/semi-state organizations (Veldwisch et al., 2012). The price for the wheat production quota is fixed by the state, according to the minimum market price (Karimov, 2012). Both, cotton and wheat production are subject to strict production regulations, subsidies and credit support programmes.

A state resolution from 2011[27] frames the financing mechanism for cotton and wheat farmers. According to the resolution, cotton farmers can receive a credit for a period of 18 months, while wheat farmers for 12 months. The total amount of the credit is 60% of the state contract for cotton and wheat production (interview code 10, Table A1). The state also ensures low interest rates for cotton and wheat farmers (3% annual interest rate in 2013). The credit is used for covering the production costs (fuel, labour, fertilizer, seeds, and machinery) and other expenses (taxes, insurance). The financial resources supporting this mechanism come from a special governmental fund (i.e. Appraisal of Agricultural Production for State Needs Fund).

Agricultural production in Khorezm is entirely dependent on irrigation and the policies for optimal production of the strategic crops direct the water distribution regime. Cotton producers have access to water with priority after drinking water demands are fulfilled (Veldwisch et al., 2012) in comparison with rice and garden farmers (*dehqons*). The water delivery to each district (and within the district) is determined on the basis of the planned area for cropping, crops-mix and soil *bonitet* (interview code 01, Table A1). During water scarce seasons, the rice production is banned or decreased, while priority is given to irrigating the cotton fields.

[27] The text of the resolution was not available for this study and some of its provisions were quoted by a bank representative (interview code 10, Table A1).

Policies on promoting adaptation to climate change relevant to the agricultural sector

The governmental plans for the development of Khorezm in the period 2013-2015 and 2015-2017 prioritize the improvement of irrigation and drainage systems, and the optimization of agricultural production (interview code 01, Table A1). These plans were not publicly available at the time of the field research, and therefore, the concrete actions remain disclosed. However, the “Presidential Decree on Measures for Optimization of Cropland and Increase of the Food Crops Production (2008)”[28] addresses the increased risk of water scarcity in the country, and enacts a reduction of the cotton fields by 6,2 thousand ha in Khorezm, starting from 2009. The same decree sets an increase of the area allocated for cultivation of cereals, oil, fruits and vegetables. According to the available data, fruits and vegetables fields were 31 thousand ha in 2008 and 39 thousand in 2012 (OblStat, 2013a). As it was shown in Chapter 3, the increase in the number of garden farms since 2008 is among the major factors of the increased resilience in Khorezm. Yet, the high production targets for cotton and wheat are preserved, evidenced by: (i) the ongoing land consolidation reforms, and (ii) the statistical data, which shows that 100,7 thousand ha with cotton were harvested in 2009, against 106,6 thousand ha in 2012 (OblStat, 2013a).

Significant technical interventions in the water sector have taken place since 2012. The “State Programme for Improvement of the Irrigated Lands and Rational Use of the Water Resources for the period 2013-2017”[29] aims at the rehabilitation of the existing irrigation and drainage systems, and introduction of drip irrigation and other innovative water-saving technologies. More specifically, the programme stipulates the installation of drip irrigation systems on 25 thousand ha arable land nationwide by 2017, provided for orchards, vineyards and vegetable fields. The construction of a drip irrigation system in Khorezm is planned to cover 200 ha in total by 2017, and the installation of other water-saving technologies additional 950 ha. The programme further sets plans for the provision of new water use measurement equipment for the WCAs and farmers.

[28] Указ Президента Республики Узбекистан “О мерах по оптимизации посевных площадей и увеличению производства продовольственных культур”, Ташкент, 20 октября 2008 года № УП-4041.
[29] In Russian: “Государственной программы по улучшению мелиоративного состояния орошаемых земель и рациональному использованию водных ресурсов на период 2013-2017 годы”.

The implementation of the above mentioned programme is regulated by several decrees (see Table C1, *in Russian*), which contain provisions regarding the institutional aspects. First, the decrees set measures for advancing the procedures for planning, implementation and financing of drip irrigation and other innovative water-saving projects. Second, the decrees necessitate the development of regional programmes on land improvement and rational utilization of water resources. Third, the acts list measures for the improvement of the existing systems for monitoring the quality of water and soils of the irrigated fields. Forth, the plans provide for trainings of specialists on how to install and maintain the new irrigation technologies.

The new legislation also frames the funding mechanism for the drip irrigation projects from the Fund for Irrigated Lands Improvement to the Ministry of Finance. Farmers, who wish to apply for drip irrigation project can invest own sources or apply for credit from the programme fund. The interest rate for the credit from this fund is fixed by the state on 6%, out of which 3% is the bank margin. Regional working groups are in charge of collecting and evaluating the project documentation of interested farmers.

Since the programme is at an early stage of implementation, open questions remain, such as the acknowledgment of an interest from the farmers in the programme, given the state land tenure, and the availability of sufficient institutional capacity at a local level to facilitate the process.

Environmental policies

The Uzbek “Law on Environmental Protection” (No 754-XII, 1992) regulates the use of natural resources in a sustainable manner and sets the establishment of Environmental Protection Fund. At present, the “Resolution to the Programme of Action for Protection of the Environment 2013-2017” (Cabinet of Ministers of the Republic of Uzbekistan, 2013) directs the national policies for the sustainable use of natural resources, including land and water. The resolution further prioritizes the development of regional and international cooperation in the environmental field. An important provision of the resolution is the rehabilitation and improvement of the ecological situation in the Aral Sea basin through agro-forestry measures. The control over the implementation of the resolution is designated to the State

Committee for Nature Protection, while the MAWR is in charge of planning the agro-forestry activities. There are no other concrete actions on adaptation to the changing environmental conditions, such as more sustainable utilization of the depleting water resources in the Aral Sea basin.

Over the last decade, a number of strategic activities for improving the ecological resilience in Uzbekistan have taken place. According to the Second National Communication to the UNFCCC, these include: (i) the Programme of Action on Improvement of the Ecological and Socio-Economic Situation in the Aral Sea Basin (2003-2010); (ii) National Strategy and Action Plan for Conservation of Biodiversity (1998); (iii) Regional Environmental Action Plan for Central Asia; (iv) the development of institutional structures and mechanisms for preparation and implementation of Clean Development Mechanism (CDM) projects; (v) Strategy for Improvement of the Living Standards of the People of Uzbekistan (2005-2010).

5.3. Institutional challenges and issues involved in reducing the agricultural vulnerability to climate change in Khorezm

Notably, policy interventions in response to the increased risk of water scarcity in Uzbekistan have taken place since 2008. Yet, up to 2013 there was no planned adaptation action for agriculture in Khorezm, but just several measures for coping with droughts during water scarce seasons. In 2013, the government adopted programmes, which have the potential to improve the agro-ecological and agro-technical conditions in this region. However, the institutional state-of-the-art analysis provided in Section 5.2 raises several issues of particular concern for the vulnerability reduction in Khorezm.

First, and above all, there is a ***lack of vertical and horizontal distribution of institutional power***. Some early adapters, such as Germany and the United Kingdom, have strong top-down leadership in the adaptation planning by the ministries responsible for agriculture (Bizikova et al., 2014a). Similarly, the power for climate risk reduction responses in Uzbekistan is concentrated primarily in the MAWR in Tashkent. There is also a certain level of horizontal cooperation on climate risk response for agriculture between the MAWR and other state agencies. However, unlike the early adapters, vertical cooperation (e.g. stakeholder consultations) with regional and local state actors in Uzbekistan is limited. Yet, integrating local knowledge into adaptation responses is a key principle for sustainable adaptation (Eriksen et al., 2011).

In addition, the highly centralized water and agriculture management system in Uzbekistan has been criticized for creating vulnerabilities and posing barriers to risk reduction (e.g. Schlueter et al., 2010, Aleksandrova et al., 2014). Furthermore, the presence of malfunctioning institutions in the water distribution system of Uzbekistan, such as the WCAs, remains a major element with a negative impact on the adaptive capacity of the institutions in the country.

Another major issue resulting from the top-down planning process in Uzbekistan is the lack of a long-term outlook on bigger issues such as climate change by local state and civic organizations. The Khorezm region is located in an arid/ semi-arid region and the key informants were rather concerned about the climate variability and the resulting water scarcity. The state prescribes the near-future development plans for the region on which the institutions in Khorezm rely. Consequently, long-term and proactive incentives for climate risk management at a sub-national scale are missing.

The review also showed that the greatest advances in adaptation are linked to policies for the reduction of the water demand for irrigation, mainly through the rehabilitation of the irrigation and drainage systems, and for building institutional and human capacity to introduce these measures. The plans target some shifts in the cropping patterns towards less cotton and more food crops. However, ***the current policies and regulatory frameworks do not deal with the climate risk (and water scarcity) in a holistic manner***. Much more significant shift in the Uzbek agriculture is needed to face the increasing risk of water scarcity (Chapter 2). It should be also highlighted that the policy responses to climate change in the Uzbek agriculture are isolated from the other economic sectors, e.g. the processing industries. Furthermore, there are no synergies between the existing adaptation programmes and the policies for sustainable development, such as rural poverty reduction and climate change mitigation (i.e. reduction of greenhouse gases in agriculture).

The current policies on climate risk reduction account for agro-environmental parameters (e.g. soil properties, crop type) at a farm-level in order to prioritize sites for the implementation of adaptation measures. However, they ***do not consider the socio-economic and environmental vulnerabilities at a district level,*** which should be the entry point for policy planning. For example, the climate risk within Khorezm is shaped by various factors, such as the rural population ratio, agricultural diversity and productivity (see Chapter 4). Additionally, the equal access to water is still problematic in Khorezm and the issue is not addressed in the latest policy plans. However, previous studies emphasize the importance of equal water distribution among the districts in Khorezm (Bekchanov et al., 2010a, Wegerich, 2007).

The preservation of the state land tenure and the continuation of the farm reforms in the future could slow-down the process of adaptation in Khorezm. Several authors have claimed so far that these two factors disincentive the farmers in Khorezm to invest in technological innovations (Chapter 2). With the new programme on the introduction of drip irrigation, the farmers have to invest without having property rights on the land and long-term security. This in turn, questions the sustainability of the adaptation programme.

There are also partnership principles embedded in the strategic plans of Uzbekistan, such as the involvement of research institutions and commercial banks in the adaptation. Nevertheless, there ***are limited opportunities for the private sector to participate*** in the vulnerability reduction. Most of the farmers are cotton and wheat producers, and the state controls the entire process of their production, regulating the agro-practices, water distribution and training activities. In this regard, during the interviews, some of the key informants were asked if there are any private investment projects for rehabilitation and innovation of the irrigation system, and the answer was that only the government can promote such activities. This limits the opportunities for participation of other actors, such as private extension services providers. Similar is the case of the new state programme on introduction of drip irrigation and water saving technologies according to which the implementation of the project is designated primarily to state companies (e.g. construction works, trainings).

5.4. Recommendations on strengthening the national and regional institutional capacities

The authoritarian, top-down system of governance of Uzbekistan cannot integrate the internationally recognized key principles of developing national climate change risk reduction policies, such as involving the local communities in the decision-making process, and promoting community-based adaptation. Yet, there are several entry points for strengthening the institutional capacities at a national and sub-national level, which donot require significant shift in the current political regime. More specifically:

- ***Local institutions should play a proactive role.*** The analysis has shown that there are structural disincentives for proactive vulnerability reduction action at a sub-national level. Even in the highly centralized Uzbek governance system, the state could still create an environment for a public-private partnership, which would empower local actors and encourage the private sector's participation in climate risk mitigation.
- ***The national and sub-national adaptation planning should be approached in a holistic manner.*** Climate risk management should cover a broader area of intervention without being fragmented into isolated measures, such as infrastructural innovation, but should rather be framed as a set of various policies. Therefore, a broad spectrum of adaptation measures should be explored (e.g. Chapter 2) and integrated into the development plans of multiple sectors. Additionally, the mitigation of greenhouse gases emissions in agriculture has to be embedded in the national adaptation plans.
- ***The regional plans should consider the local vulnerability patterns within Khorezm.*** The regional climate risk mitigation plans should be developed upon the principles of equal intra-regional sustainable development. For instance, the districts with predominant cotton and rice production are more exposed to the risk of water scarcity, and therefore crop-diversification policies in these particular districts should be prioritized (see Chapter 4). The same principles of bottom-up planning should be merged with the existing top-down governance at a national level.

- ***More research on how the informal institutions affect the vulnerability, and how they can be engaged in increasing the region's resilience, is necessary.*** The role of the informal institutions was excluded from the scope of the present analysis. Still, it is worth noting that the informal arrangements in Khorezm, particularly in the water management, strongly influence the outcome of the policy processes from the planning through to the implementation phases (Schlueter et al., 2010).

5.5. Conclusion

The climate change risk is a new issue in rural Uzbekistan, although over the last decade, dealing with water scarcity has raised awareness of this challenge. There is a substantial experimental evidence on suitable measures for reducing the climate change risk in the agriculture in Khorezm (Chapter 2)(Aleksandrova et al., 2014). It has been established that institutions could either limit or enhance the ability of the agricultural sector to cope with and adapt to the change and extremes. The institutions and their capacity to facilitate climate change vulnerability reduction policies in Uzbekistan are therefore a key.

While national adaptation planning is at an early stage of development, the example of the Khorezm region raises a number of critical issues for the designing of effective climate risk policies. These issues relate primarily to the highly centralized agriculture and water management system in the country. Considering that a significant change in the Uzbek political context is not foreseen in the near future, the chapter attempts to provide policy recommendations, which may be feasible in the current political environment, namely: (i) empowering more local actors and encouraging public-private partnership; (ii) using holistic approach for the formulation of policies; (iii) accounting for spatial differences in terms of vulnerability at a sub-national and sub-regional level.

Chapter 6 Conclusion

This thesis compiles four articles (main chapters), which are interrelated and address the objectives identified in *Chapter 1*. This concluding chapter summarizes the key findings but also the limitations of the work presented in the previous chapters. It draws together the main conclusions and policy implications of the thesis and proposes directions for future research.

6.1. Summary of the research

Chapter 2 reviewed the key determinants of vulnerability in Khorezm region and identified options for climate change adaptation and mitigation in rural areas, which further allow extrapolation in similar environments (e.g. irrigated areas of Central Asia and the Caucasus). More specifically, the chapter summarized extensive research evidence on measures for improved land and water management in the region, considering the changing climate. These measures include: (i) improving water use efficiency; (ii) changing the cropping patterns that have a high potential to decrease the exposure and sensitivity of rural communities to climate risks; (iii) changes in land use such as the afforestation of degraded croplands; and (iv) introducing resource-smart cultivation practices such as conservation agriculture. The chapter further outlined the prime barriers to the implementation of these measures in Khorezm, such as limited technical capacity and strong governmental grip in the agriculture and water sectors.

Chapter 3 provided a detailed characterization of the severity of water scarcity in Khorezm, which has been one of the most affected areas in Central Asia during the 2000-2001 disastrous droughts. A *Z-score* indexing method was used to measure the severity of the water scarcity. The study also explored the direct and indirect agro-ecological and socio-economic impacts of the droughts, combining qualitative survey results with quantitative statistical data. The overall aim of the analysis was to derive a set of spatial and temporal determinants of vulnerability to water scarcity, partly used later on in *Chapter 4*. The results indicated a trend towards higher resilience in Khorezm since the worst droughts in 2000-2001. The major limitations of this study are related to the relatively short time-series data available for the analysis. However, the identified relationships and trends through statistical techniques were consistent with the survey outcomes and past studies.

In ***Chapter 4*** a holistic operational method for a vulnerability assessment of climate change and hazards for agricultural systems is proposed. The approach allowed an aggregation of agro-ecological and socio-economic information into one composite indicator of vulnerability, suitable to: (i) perform spatial comparative analysis at a sub-regional level; (ii) identify key factors of vulnerability for each administrative unit; (iii) compare adaptation policy scenarios, considering their effects on the sustainability of the agricultural systems in Khorezm. The assessment results showed that various socio-economic and agro-ecological factors shape the spatial distribution of vulnerability, and hence the regional climate risk reduction policies should be based upon differential and holistic approach. This study was limited by sufficient data availability and the lack of opportunity for backward communication of the results to local actors.

In ***Chapter 5*** the role of institutions in reducing the vulnerability in the agricultural sector is analysed. This component reviewed the existing formal institutions (state, civic and private) and explored the horizontal and vertical distribution of institutional power. The institutional analysis included to what extent the present governmental policies facilitate efforts to the climate change risk reduction in Khorezm. A key argument was that there are various challenges to reducing the agricultural vulnerability to climate change in the study region, originating primary from the centralized, state-procurement agrarian system. A number of entry points is suggested to enhance climate risk reduction in the current political environment.

6.2. Significance of the methodological approach and future research

The notion of vulnerability is central in the international policy frameworks on climate change and hazards. The multi-dimensionality of the vulnerability concept allows for an approach that captures complex relationships and translates cross-disciplinary information into concise, policy relevant messages. In this context, the findings demonstrate how the concept of vulnerability can be used to explore agriculture – climate change and hazards nexus, in a comprehensive manner. More specifically, the concept was used to:

- understand locally specific processes within agricultural systems, in relation to climate change and specific hazard;
- assess the risk-prone administrative units and quantitatively measure the effect of a set of vulnerability reduction policies on the overall sustainability of the human and environmental systems;
- explore how institutions shape the risk to climate change and to what extend they can facilitate climate change policies.

Building upon the existing vulnerability assessment frameworks and methods, the most commonly used approaches to vulnerability assessment for agriculture could be complemented (Chapter 4). The suggested assessment method aggregates agro-ecological and socio-economic information at one level of administrative unit. This permitted to extend the theoretical model to a wider applicability in the spatial vulnerability analysis for agriculture. Future research can concentrate on extending the elaborated conceptual model with a risk assessment perception.

Furthermore, it was shown that the vague usefulness of the results in policy evaluation is a major limitation of many vulnerability assessment methods for agriculture. In addition, vulnerability assessments are rarely linked to sustainability analysis. Consequently, a distinct advantage of the proposed method is its applicability in the evaluation of climate policies regarding their effect on the sustainability of the socio-economic and agro-ecological systems.

An extension of the work on a vulnerability assessment for the Khorezm region could address a participatory validation of the baseline results and an evaluation of the concrete policies suggested under different climate and water scenarios. Furthermore, future research could link the vulnerability assessment with dynamic models in order to assess how future changes in the institutional, socio-economic and environmental settings would affect the vulnerability of the Khorezm region.

6.3. Policy implications of the findings

The rivers in Central Asia are vital for the life in the entire region, while the risk of water scarcity is increasing under the pressures of climate change and human activities. Central Asia is presently one of the largest irrigated regions worldwide, and several of the five Central Asian states strongly rely on irrigated agriculture for food self-sufficiency and gaining export revenues. The massive irrigation expansion of cotton cultivation in the past decades, and the ongoing post-Soviet transition period, has led to a tremendous environmental degradation and a nowadays deteriorated irrigation infrastructure. Climate change is already impacting the Amu Darya and Syr Daria river flows, and an anticipated decrease in water availability is of a particular concern to the downstream countries, including Uzbekistan, which was addressed in this dissertation.

The Uzbek government has already recognized the need of taking actions against the imminent climate risks. Yet, the development of national climate change policies is at a very early stage. Designing policies for the reduction of climate risk requires prior impact and vulnerability assessments and especially of key economic sectors, as well as strong institutional capacities for climate change risk management. The literature review revealed several recent studies, which explore the impacts of climate change on the Central Asian agriculture and environment. A significant body of literature proposes innovative solutions for improved land and water management in Central Asia, based on the example of Khorezm. Still, most of these studies are fragmented to sectoral or single-policy analysis. Therefore, this study complemented the previous analyses by drawing a comprehensive picture on vulnerability to climate change and water scarcity in the agricultural regions of Uzbekistan. The thesis further sought to provide scientific basis and policy relevant information for the development of climate change policies for agriculture in Uzbekistan. In line with the findings, several policy recommendations for improved climate change action are provided.

First, effective climate risk policies require a diverse portfolio of agro-ecological and socio-economic measures. For example, a basic principle of the latest EU Adaptation Strategy (2013) is the principle of ‘diversity’ related to the exploration of cross-sectoral and a diverse set of measures. Similarly, such a set of diverse actions is proposed (*Chapter 2*), namely:

- Improving water-use efficiency, through:

    - An improvement of the irrigation scheduling;
    - A replacement of the existing static regime with flexible, adaptive irrigation norms;
    - An increase in the storage capacity of the irrigation and drainage system;
    - An introduction of water pricing schemes/ water user fees and consequently increasing the prospects for economy efficient allocation of water;
- Crop diversification, change to less water-intensive production;
- Including perennial crops as an alternative land use of degraded land;
- Introducing conservation agriculture practices on the croplands presently still fertile;
- An adaptation of the agricultural production and trade, through:
    - Improved market conditions;
    - Development of the processing and refinement sectors.

Second, most of the above interventions require an action at a field or regional level. However, any relevant regulations and mechanisms for climate change management must be embedded within the national legislative framework. Furthermore, the national and local institutions must be able to facilitate the whole process, from the planning to the implementation and monitoring. As discussed (*Chapter 5*), the institutions for climate risk reduction could be strengthened through empowering more local actors and enhancing public-private partnerships, which in turn would facilitate pro-active local level responses to climate change.

Third, the national policies should be built upon in-depth understanding of spatially-differentiated vulnerabilities. The example of Khorezm showed that the variability in terms of vulnerability at a sub-regional level is determined by various socio-economic and agro-ecological factors (*Chapter 4*), which if not considered, could create higher vulnerabilities and inequality between the regions in Khorezm.

Finally, by accepting the vulnerability concept as a means of preparing regions better for climate change and variability as well as consequent hazards (such as water scarcity), Uzbekistan will have a tool and hence the opportunity to set a precedent in Central Asia region, where many similar agro-ecological sub-regions occur.

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Appendices

Appendix A. Surveys information

Table A1. List of the key informants included in each of the survey sub-sections

CODE	Institution and key informants expertize	Impacts	Vulnerability	Institutions
	International organization			
12	**United Nations Development Programme/ Global Environmetal Facility (UNDP/ GEF), Tashkent** (one representative working on projects in Khorezm)	✓	✓	×
	State organizations			
01-02	**Ministry of Agriculture and Water resources of the Republic of Uzbekistan** (two representatives for Khorezm, with background in agronomy and economics)	✓	✓	✓
03	**Khorezm regional branch of the State Committee for Natural Protection** (one informant with expertise in environmental protection, ecological conservation and restoration)	✓	✓	✓
04	**Centre of Hydrometeorological Service at the Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet)**, Khorezm Administration on Hydrometeorology (one informant with expertise in climate and water monitoring)	✓	✓	✓
05	**Insurance company (“Uzagrosugurta”)** (one representative with expertise in natural disaster losses in the agricultural sector (assessment and coverage)	✓	✓	✓
	Civic organizations			
06	Khorezm representative of **Farmers’ Council of the**	✓	✓	✓

	Republic of Uzbekistan (one person)			
07, 08, 09	**Water Consumer Association** (three local representatives from Gurlen, Shavat and Kushkupir districts)	✓	✓	✓
	Private organizations			
10	**AgroBank** (one representative working in the credit department)	×	×	✓
11	**Regional Centre for Information and Innovation under Farmers` Council of Uzbekistan** (one representative).	×	×	✓

Notes: ✓/× denotes that the respondent was/ was not questioned on the sub-topic of the survey (Section 1 – Impacts; Section 2- Vulnerability; Section 3 – Institutions).

Appendix B. Data description and other statistical specifications

Table B1. Indicators specification and descriptive statistics

Indicators: description, relevance and data source	Min	Max	Mean	St. dev.
WF (water flow to district, mln. m^3) Water flow (WF) represents the long-term average water supply to each district which is planned by the government and determined by the water availability and annual crop planning. The values of the average water flow to each district during the vegetation period (1998-2012) were calculated based on data obtained from MAWR (2011) and OblVodkhoz (2013). The indicator is assumed to be negatively related to the district's vulnerability.	203,13	337,21	266,89	43,28
CA (share of the crop area in the total area of Khorezm, %) The indicator presents the land planned for 1-year cropping as of January 2013 (e.g. fruit trees gardens are multi-year plants thus are not included) and the data is taken fromOblVodkhoz (2013). The indicator reflects which district has higher share cropland within Khorezm, thus is more exposed to climate change and water scarcity.	6,50	12,80	10,00	2,29
PPL (population share in the total population of Khorezm, %) The indicator takes into consideration which districts are more populated and therefore more vulnerable. The data is for 01.01.2013 and originates fromOblStat (2013b).	4,66	18,65	10,00	4,12
GAP (district's gross agricultural production share, %) This indicator shows the average gross agricultural production share of each district in the total	7,34	14,11	10,00	1,96

GAP of the Khorezm, being a proxy for the exposure of the region. The source is OblStat (2013a). Remark: Even though the available data is for 1999-2012, the rate is calculated using data from 2009 onwards, due to the following factors: (i) new land consolidation reforms towards farm optimization were initiated in 2008, which would have affected farm efficiency and profits; (ii) 2008 was also severe drought year; (iii) even though 2011 was moderate drought year, the links between land reforms and drought impacts are reflected in the growth rate under current land reforms.				
GS (average groundwater salinity, g/l) The indicator shows the long-term average (1990-2004, no later data exists) ground-water salt content for each district. The dataset (ZEF/ UNESCO Project Database) contains in total 1970 collecting points (observation wells) in Khorezm and on average 197 points per district. The samples were taken each year during April, July and October.	1,47	2,26	1,80	0,24
LQCL (share of the low quality cropland in the total district's cropland, %) Official numbers are taken from OblVodkhoz (2013). Low quality cropland is defined as area with soil infertility and the indicator reflects which district has higher share of poor quality soils as of January 2013, which suggests higher susceptibility.	6,93	18,70	13,55	4,08
CWA (share of the cotton/wheat area in the total district's area, %) Official numbers are taken from OblVodkhoz (2013) and the indicator reflects which district has higher share of land used for cotton cultivation, thus sensitive to water scarcity (Remark: the values show jointly cotton and wheat area, since separate data for cotton area was not available, however big part of the cotton fields are rotated with winter wheat and therefore is considered suitable indicator variable).	69,43	90,67	83,98	5,64
RA (share of the rice area in the total district's area, %)	4,30	19,59	8,90	5,08

The data source is OblVodkhoz (2013). During a drought year, rice production is significantly reduced and therefore normal water availability year 2012 is taken to derive the indicator values. Our assumptions suggest that high share of rice areas makes the districts more vulnerable.				
RPPL (share of the rural population in the total for the district, %) The values show the districts with dominating rural population, thus more linked with agriculture. The data is as of 01.01.2013 and originate from theOblStat (2013b).	48,04	82,45	69,58	10,44
CRAG (compound rate of agricultural growth per capita) The indicator takes 2009-2012 annual gross agricultural output per capita and measures the agricultural development of each district, whereas higher values reflect lower susceptibility. The data specification is same as GAP, including the reasoning for taking 2009-2012 series only. The formula used is as follows: $CRAG = \left((GAP\ per\ cap_{2012} / GAP\ per\ cap_{2009})^{\frac{1}{3}} \right) - 1$	0,02	0,07	0,03	0,02
AI (access to irrigation, category) The districts are first divided into 3 categories (upper-tail, mid-tail, end-tail) based on previous research (Bekchanov et al., 2010a). The indicator reflects the location along the main irrigation canals which determines the access to water of each district. Therefore the category variables in this code refer to: 1- low access at the end-tail location (downstream); 2 - medium access at the mid-tail location (midstream) and 3 - high access at the upper-end location (upstream).	1	3	2	
EWP (economic water productivity, USZ/m^{-3}) The indicator distinguishes which district has higher gross agricultural output per unit of water flow for the period 2009-2012 (i.e. it reflects land use, water use, technical efficiency and capacity). It is	9,35	18,65	14,31	2,86

expected that the indicator will be positively related to the capacity of the district to optimize the water-use. The calculations are based on the data for WF and GAP, being specified above. The calculated values are similar to previously obtained results fromBekchanov et al. (2010a) for districts' water productivity for the period 2000-2007. Difference is observed mainly in the productivity of Urgench and Khazarasp, however the datasets used in this study differ.				
ADI (agricultural diversity index, index) The index is calculated using Shannon's diversity index: $APDI\ (Shannon\ diversity\ index)_i = -\sum_{j=1}^{s} p_j * \ln p_j$ where, i – district in the Khorezm region, p_j – proportion of land (ha) used for j specialization, s – total land. The main specialization categories included are (the classification is made according to the data obtained from (OblVodkhoz, 2013)): cotton and wheat; livestock; fruits and vegetables (horticulture; viticulture; watermelon; potatoes; other vegetables); other (silk; poultry; honey makers; fishery). Higher ADI suggests more diversity, thus less vulnerability to climate change and water scarcity.	0,41	0,93	0,58	0,14
SNCWF (share of non-cotton/wheat farms for each district, %) Using the same dataset as ADI, this indicator is a proxy for land tenure and freedom in decision-making, since cotton and wheat farmers are under state quota production system, including strict requirements on the production techniques (fertilizers use, tillage, etc.), as well as lower opportunities for making profit. Therefore, SNCWF is assumed to be negatively related with vulnerability.	46,41	68,51	57,20	6,94

Table B2. Pearson correlation coefficients for the baseline dataset for vulnerability assessment

	WF	CA	PPL	GAP	GS	LQCL	CWA	RA	RPPL	CRAG	AI	EWP	ADI	SNCWF
WF	1,00													
CA	0,47	1,00												
PPL	0,17	0,08	1,00											
GAP	0,38	0,43	0,80	1,00										
GS	0,43	-0,10	-0,36	-0,42	1,00									
LQCL	-0,37	-0,30	-0,49	-0,61	0,59	1,00								
CWA	0,25	0,48	-0,65	-0,25	0,15	-0,01	1,00							
RA	-0,13	0,42	-0,18	0,26	-0,25	0,01	0,16	1,00						
RPPL	-0,38	-0,47	-0,70	-0,89	0,34	0,62	0,20	-0,34	1,00					
CRAG	0,16	-0,04	0,50	0,27	-0,32	-0,55	-0,33	-0,43	-0,29	1,00				
AI	-0,07	0,40	-0,05	0,32	-0,64	-0,48	0,31	0,56	-0,15	-0,18	1,00			
EWP	-0,45	0,08	0,62	0,63	-0,74	-0,24	-0,46	0,41	-0,51	0,03	0,43	1,00		
ADI	-0,26	-0,54	0,60	0,18	-0,08	0,07	-0,99	-0,19	-0,13	0,31	-0,35	0,40	1,00	
SNCWF	-0,25	-0,76	0,24	-0,14	0,26	0,33	-0,52	-0,49	0,31	-0,10	-0,38	0,07	0,59	1,00

Appendix C. Legislative acts

Table C1. List of legislative acts concerning the “State Programme on the Improvement of the Irrigated Lands and Rational Use of Water Resources (2013-2017)”, including the introduction of drip irrigation systems *(in Russian)*

1	Постановление Кабинета Министров Республики Узбекистан от 24 февраля 2014 года № 39 “О дополнительных мерах по обеспечению безусловного выполнения Государственной программы по улучшению мелиоративного состояния орошаемых земель и рациональному использованию водных ресурсов на период 2013-2017 годы”
2	Постановление Президента Республики Узбекистан от 19 апреля 2013 года N ПП-1958 "О мерах по дальнейшему улучшению мелиоративного состояния орошаемых земель и рациональному использованию водных ресурсов на период 2013-2017 годы"
3	Постановление Кабинета Министров Республики Узбекистан от 21 июня 2013 года N 176 "О мерах по эффективной организации внедрения и финансирования системы капельного орошения и других водосберегающих технологий полива"
4	Постановление Кабинета Министров Республики Узбекистан от 05.06.2013 г. N 158 "О мерах поэтапного обновления насосно-силового оборудования водохозяйственных организаций Министерства сельского и водного хозяйства Республики Узбекистан в период 2014-2018 годы"

Remark: The texts of the above legislative acts are available at www.lex.uz (accessed and reviewed on 22.07.2014).

Estratto per riassunto della tesi di dottorato

Studente: Mariya Ivanova Aleksandrova**, matricola:** 955941
Dottorato: Scienza e Gestione dei Cambiamenti Climatici
Ciclo: 27

Titolo della tesi : Water Scarcity under Climate Change: Impacts, vulnerability and risk reduction in the agricultural regions of Central Asia

Abstract

English

This doctoral dissertation is inspired by the major climate change risk to human security in many parts of the globe, namely water scarcity. The analysis is built upon the concept of vulnerability in order to explore those factors, which shape the climate change risk in the agricultural regions of Central Asia. More specifically, using Khorezm region of Uzbekistan as a case study, the thesis looks into the agro-ecological, socio-economic and institutional aspects of vulnerability to climate change and hazards. The main methods applied include participatory research (which represents a key informants survey and a focus-group discussion) and a statistical analysis (which represents descriptive statistics and a multi-criteria analysis). The major scientific outcome of this work is the development of holistic vulnerability assessment method for agricultural systems, applicable to explore policy-relevant scenarios. This dissertation also contributes to the knowledge of climate risks in Central Asia, by analysing the impacts of severe water scarcity, identifying the determinants of vulnerability, and exploring the role of the institutions in reducing the vulnerability to water scarcity in Khorezm. This thesis further translates the results into policy recommendations for the reduction of the vulnerability to climate change and water scarcity in Uzbekistan.

Italiano

Questa tesi dottorale si occupa della carenza idrica, un importante rischio per la sicurezza umana in molte parti del mondo provocato dai cambiamenti climatici. L’analisi è costruita sul concetto di vulnerabilità, per esplorare quei fattori che compongono il rischio nelle regioni agricole dell’Asia Centrale. Più specificamente, usando la regione di Khorezm in Uzbekistan come caso studio, la tesi approfondisce gli aspetti agro-ecologici, socio-economici e istituzionali della vulnerabilità ai cambiamenti climatici e agli *hazards*. Tra i principali metodi applicati vi sono una ricerca partecipata (che include un questionario ad esperti ed una discussione *focus-group*) ed un’analisi statistica (che include statistiche descrittive e un’analisi multi-criterio). Il principale risultato scientifico di questo lavoro è lo sviluppo di un metodo olistico di valutazione della vulnerabilità per sistemi agricoli, applicabile per l’esame di scenari rilevanti per nuove *policy*. Questa ricerca contribuisce anche alla conoscenza dei rischi climatici in Asia Centrale, analizzando gli impatti di una forte carenza idrica, identificando le principali cause della vulnerabilità ed esplorando il ruolo delle istituzioni nella riduzione della vulnerabilità alla carenza idrica in Khorezm. La tesi inoltre fornisce *policy recommendations* per uno sviluppo agricolo sostenibile e climaticamente resiliente in Uzbekistan.

Firma dello studente: