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Natural Resources and Human Welfare in Central Asia

Ira Pawlowski (ed.)

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CONTENT

INTRODUCTION

IRA PAWLOWSKI

This book summarizes the main findings of the multidisciplinary research and post-graduate education project “Land use, ecosystem services, and human welfare in Central Asia (LUCA)” (2010-2014) conducted by Giessen University and its partners in Germany and Central Asia[1], funded by VolkswagenStiftung. The project combined research activity and scientific education with emphasis on the intrinsic interaction of people and their environment in the vulnerable region of Central Asia. The principal theme of the project has been the interrelation between ecosystems, land use, and human activity. Ecosystems provide supporting, provisioning, regulating, and cultural services that sustain human wellbeing but that are in turn also affected by human activity. The issue of land use and its natural and socio-economic drivers is of particular scientific interest when analysing the region of Central Asia with its extremely diverse ecosystems and with its societies and systems in transition. The increasing scarcity of natural resources – particularly water and fertile soil – together with conflicts over their use endanger the welfare of the people in the region and potentially could lead to political conflict.

With these issues in mind, a multidisciplinary and cross-national approach has been chosen by Giessen University and its partners to investigate this broad topic while in particular utilizing and enhancing the research capacity of the region. Within several subprojects young academics from Kyrgyzstan, Kazakhstan, Uzbekistan, and Tajikistan have concentrated their PhD research activities on the assessment of past and current land use structures and their interrelation with physical processes of the biogeosphere, economic development, and human welfare. Senior researchers from Germany and Central Asia have guided the research of the PhD students. Capacity building has therefore been an integral component of the LUCA project targeting three areas: the improvement of the methodological expertise of the young researchers, the promotion of multidisciplinary thinking and transnational cooperation, and the (re)connection with the international scientific community. Alongside the

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1 Partner institutions of the project have been: Marburg University, Dept. of Geography (Germany); Helmholtz-Centre Potsdam GFZ, German Research Centre for Geosciences (Germany); Central Asian Institute of Applied Geosciences (CAIAG), Bishkek (Kyrgyzstan); Hydrometeorological Research Institute (NIGMI), Tashkent (Uzbekistan); Academy of Sciences, Institute of Economy and Demography, Dushanbe (Tajikistan); Scientific Information Center of Interstate Coordination Water Commission (SIC ICWC), Tashkent (Uzbekistan); National Space Agency, National Center of Space Researches and Technologies, Almaty (Kazakhstan); Scientific Research Institute of Ecology and Climate, Almaty (Kazakhstan); Agricultural University, Tajik Agricultural Economics Institute, Dushanbe (Tajikistan).

research activities, the project has focussed on education and has conducted summer schools, training courses, a conference, and has facilitated the presentation of research outcomes in international symposia and publications.

This book, organized in two parts, presents abstracts of the research of the subprojects. The first part focuses on dimensions of earth and environmental sciences and demonstrates on how and to what extent (man-made) changes of biogeographic conditions have occurred and how they will influence land use in the future. The study of Duishonakunov/King on a mountain range of Southern Kyrgyzstan measures substantial glacier retreat of more than twenty percent on average as well as changes in permafrost due to climate change over a period of 45 years. This has serious implications for natural hazards and the economic development of the region. Another natural disaster is described in the work of Aslanov et al: the drama of the anthropogenic desertification process of the former Aral Sea. The authors have studied spatial and temporal ways of dust deposition, the composition of the deposited material containing pesticides, heavy metals and salt, and its potential impacts on arable land and human health. The research of Teshebayeva et al deals with the hazard of earthquakes and landslides. The researchers developed a special remote sensing technique for the analysis of such surface displacements in Southern Kyrgyzstan in order to help in the understanding of active tectonic processes and their spatio-temporal consequences. The improvement of irrigation and drainage systems in order to minimize water loss and return flow is the underlying idea of the work of Kenjabaev et al. By modifying a special hydrological model, they were able to predict and compare groundwater levels for various crops in the Fergana province of Uzbekistan and thus assess the efficiency of local irrigation and drainage management practices.

The second part of the book describes project research on socio-economic and institutional aspects of land use and their interrelation with human wellbeing. The working group of Khakimov et al evaluated the macroeconomic drivers of the agricultural sector of Tajikistan and explained that current income growth in the country, mainly caused by a continuously high inflow of remittances, will translate only marginally into an increase in domestic production but will lead to an increase in food imports. The case study of Gojenko et al investigated food consumption in two districts of Eastern Uzbekistan and revealed a considerable level of food insecurity, amounting to forty percent of surveyed households. This showed a direct relationship between the area of household plots, the number and variety of crops cultivated, the number of household members, and the education level of the head of the household. The contribution of Zhunusova/Herrmann investigated the impact of both direct agricultural policies and changing macroeconomic conditions on agricultural incentives in Kyrgyzstan. The authors found out that the production of food crops was preferred over tradable agricultural products due to food self-sufficiency needs, a lack of market access for export products, and a protected home market for importable goods such as energy sources and machinery. A different type of research has been undertaken by the working group of Sabitova et al who looked at the implementation of the Kyoto Protocol in Kazakhstan and its legal implications for land-use, land-use change, and forestry (LULUCF). The argument of the authors is that a domestic emissions trading scheme together with participation in Joint Implementation projects may be employed for Kazakhstan's quantified emissions limitation and reduction commitment under the Kyoto Protocol. The final contribution of Avazov et al looks at the issue of efficient pasture management in Tajikistan's mountains. Applying a bio-economic, linear programming model the authors determine the economic impact of various grazing management strategies. They show how a concentrated pricing will impact on the system by improving inventories over the season and promoting the production of fodder crops to reduce pressure on pastures.

Although each subproject has been very specific in its research question, the overall observation is that land use has been continuously changing in Central Asia, being influenced by and influencing human welfare. Understanding the extent and the drivers of that change is crucial for the further development of the region. The LUCA project has been contributing to this analytical process through its research. Probably the most important outcome of the project has been, however, the enhanced personal and institutional scientific relationships that will sustain further investigations in the future.

The editor thanks the contributors for presenting their research, VolkswagenStiftung for funding the project including this book, and the team of the Center for International Development and Environmental Research (ZEU) at Giessen University for its assistance in publishing.

Giessen, in July 2014

Part I:
Natural Resources and Environment

CLIMATE CHANGES IN THE NARYN CATCHMENTS: CONSEQUENCES FOR GLACIERS, PERMAFROST AND THE ECONOMIC DEVELOPMENT IN KYRGYZSTAN

M. Duishonakunov and L. King

0 ABSTRACT

The recent glacier conditions in the Naryn catchments were investigated using topographic maps and satellite imagery. The results show, that during the 45-year period 1965–2010, the glacier area decreased in the mountain ranges by 17 to 29%. The glacier shrinkage will affect not only irrigation water availability during summer but also the potential of hydropower stations once numerous smaller glaciers will have disappeared. In addition massive ground ice in permafrost may also melt in a warming climate. This will create natural hazards, especially slope instabilities. Glacier changes may lead to catastrophic glacier lake outburst floods, a common phenomenon in Kyrgyzstan. The effects of climate change on water resources are of paramount importance because of the high dependency of Kyrgyzstan on fluvial water originating from the mountains. Monitoring water resources and planning water use at a balance between water use and water resources belong to the most important issue in this region. In spite of this well-known imbalance, water demand may increase in the future due to food- and energy-security concerns in the region, and this might even lead to severe conflicts among nation states.

1 CLIMATE CHANGE AND WATER AVAILABILITY IN KYRGYZSTAN, AN INTRODUCTION

Naryn basin has the largest river catchment area in Kyrgyz Republic and many mountain glaciers. It is a huge “water tower” for the Kyrgyz Republic and Uzbekistan. Thus, the glacier conditions in the Naryn catchment have a large impact on the available water resources for the arid flat plains below. They provide water for residents, irrigation, and energy in the Kyrgyz Republic but also other parts of Central Asia.

Scientific discussions suggest that, regardless of whether climate change has natural or anthropogenic causes, it will have strong effects on glacier recession, regional hydrological balance, and economic sustainability in arid and semi-arid regions of Central Asia (Alamanov et al., 2006; Fujita et al., 2011). The probable potential effects of climate change on water resources are of paramount importance because of the high dependency on fluvial water originating from mountains. Monitoring water resources and planning water use and the balance between water use and water resources are very important issues in this region because the majority of the water supplied from Central Asian mountains is used within the irrigation zones of the arid flat plains (Report of Eurasian Development Bank, 2009; Agrawala et al., 2001). This study therefore intends to deliver valuable data for estimating the magnitude of glaciological changes and their future effects for the water availability in this region.

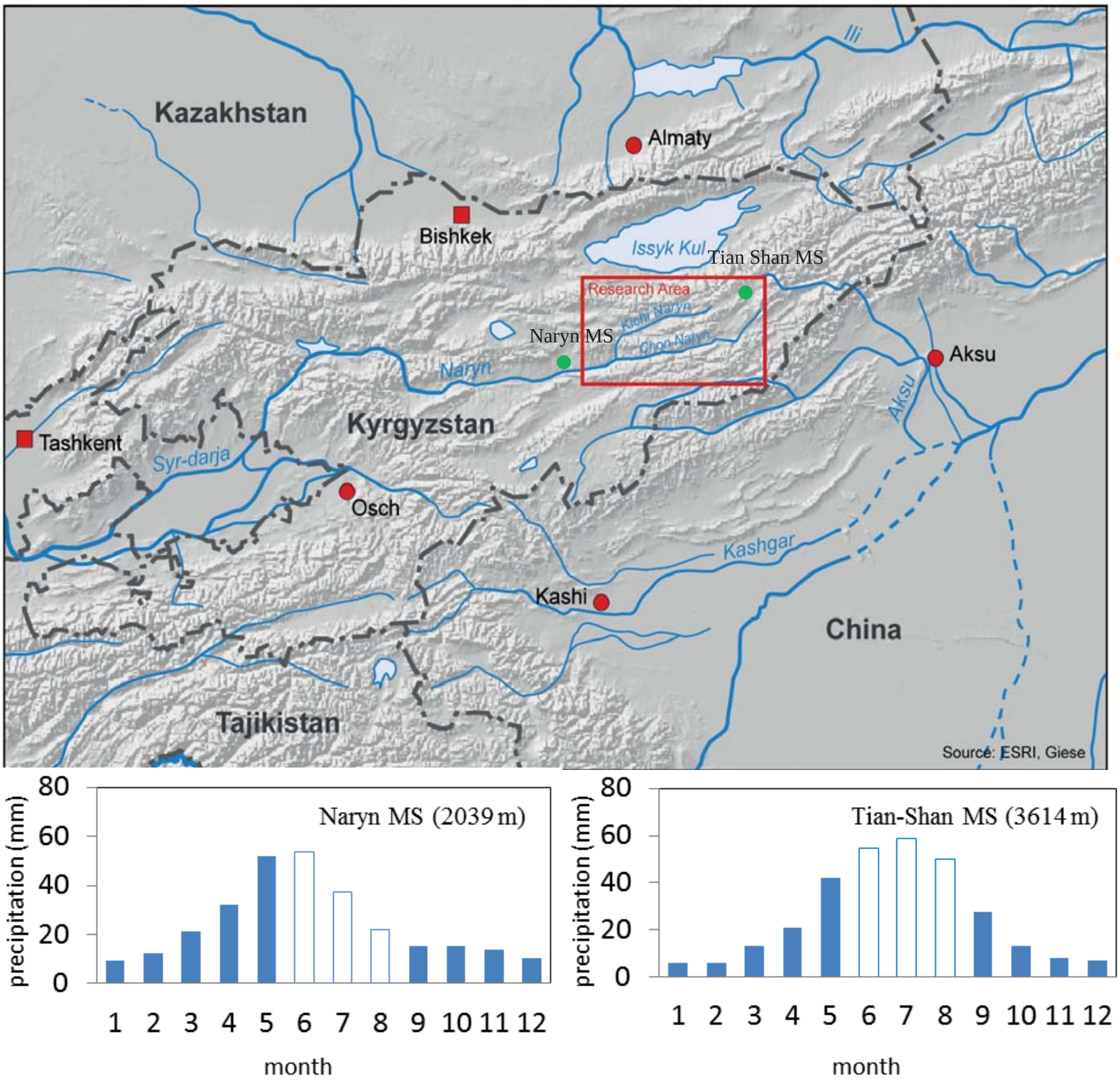
In addition to the glaciological study, the extent of frozen ground and its characteristics are also researched, as the occurrences of widespread massive ground ice in permafrost has to be assumed. This ground ice will melt in a warming climate and thus not only contribute to the water balance. More important, it will create hazards as e.g. slope instabilities by many thawing and freezing (periglacial) processes. At the same time, also glacier changes may create hazards, as e.g. catastrophic glacier lake outburst floods (GLOFs) that are very common and dangerous in Kyrgyzstan. Glacier changes (glaciology) and changes in the periglacial environment (geocryology) are therefore strongly connected by many interrelations. The hazards involved may influence and hinder the development of Kyrgyzstan. Selected glaciological and periglacial aspects will be presented in this paper.

2 THE STUDY AREA

The Naryn basin flow runs from east to west across the territory of Kyrgyzstan, and its length, before merging with the Syr-Darya, is more than 700 kilometers. The major water resources of the Naryn basin are fluvial water from rain and snow and glacier melt in the upstream area. There are 654 identified glaciers in the Naryn basin (Glacier Inventory of USSR, 1973, 1977). We investigated the recent condition of glaciers in the Chon Naryn and Kichi Naryn river catchments in the eastern part of the Naryn basin (Figure 1). These catchments include 69% of the glacier area in the Naryn basin, including 607.9 km2 (10.8% of the basin) in the Chon Naryn and 344.7 km2 (8.9% of the basin) in the Kichi Naryn. The catchments include eight mountain ranges: the Akshyirak, Borkoldoy, Naryn, Sook, Jetim, Jetimbel, Terskey, and Uchemchek.

Two meteorological stations are shown in Figure 1, along with the seasonal variation in monthly precipitation for 1930–2010 for selected stations. The climatic conditions in the upper Naryn basin are very severe, and all locations within it show an average annual air temperature below freezing point. In the lower part of the upper Naryn basin, annual precipitations are 292 mm at the Naryn meteorological station (2039 m) and 311 mm at the Tian Shan meteorological station located at an altitude of 3614 meters (Figure 1, cp. Figure 10 for climate values).

Figure 1: Location of the Naryn basin. The red rectangle shows the study area. Green dots show the locations of the two meteorological stations. Figures at the bottom show the seasonal variation in monthly precipitation for 1930–2010 for selected stations (white bar: JJA).



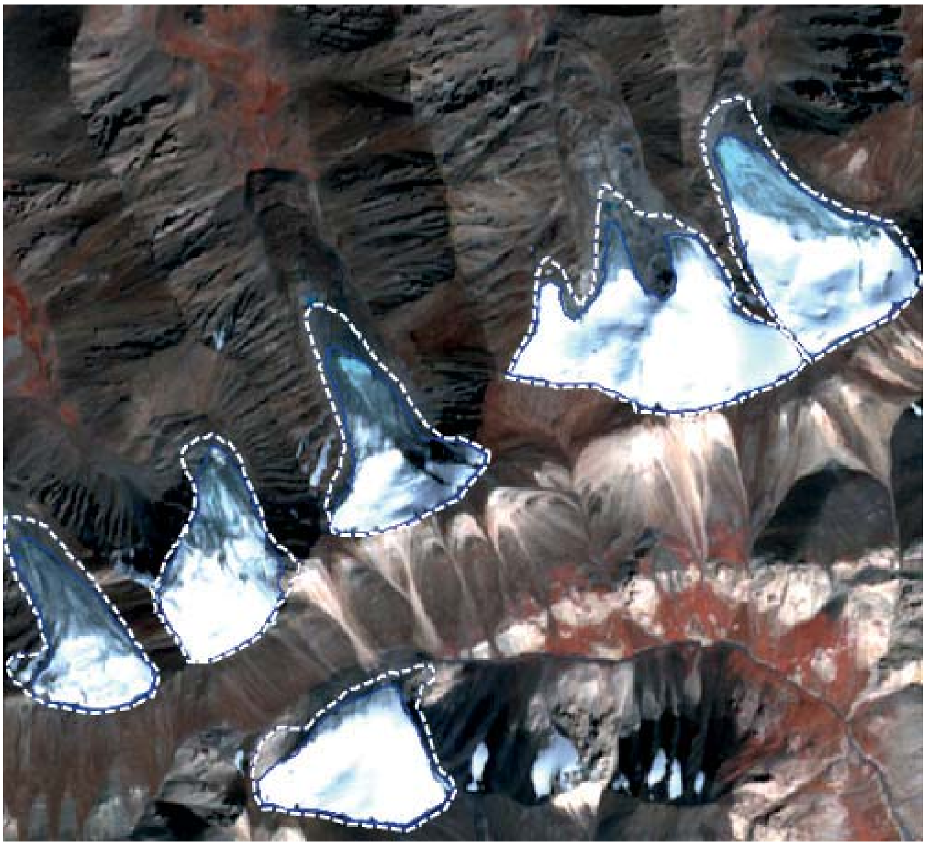
Annual precipitation is low, and the maximum precipitation occurs during summer (May to August) because of the topographical complexity of the Tian Shan Mountains and the complex interactions between the Westerlies and the Siberian High that affect the precipitation in the Tian Shan Mountains (e.g., Aizen et al., 1995, 1997). The basin has clear cloudless weather with little precipitation during winter, and this allows the use of the Arabel Kumtor, and Chon Naryn catchments as winter pastures. In this paper, local Kyrgyz geographic names are used according to Baratailiev (2004) and Barataliev et al. (2004).

3 DATA AND METHODOLOGY FOR GLACIER AND PERMAFROST STUDIES

3.1 Available data and data processing

To clarify recent glacier changes in the two catchments, glacier boundaries were delineated on 1:25,000 topographic maps based on aerial photography collected in the 1960s and with “Advanced Land Observing Satellite” and “Advanced Visible and Near Infrared Radiometer type 2” satellite datasets acquired during 2008–2010. This ALOS/AVNIR-2 (70 × 70 km) data used consists of four bands, three visible (0.42–0.69 µm) and one near infrared (0.76–0.89 µm), and have a spatial resolution of 10 m (JAXA, 2009). We used orthorectified ALOS/AVNIR-2 products by JAXA in this study. To reduce the potential uncertainty in glacier mapping with satellite data, we selected satellite imagery acquired during the glacier ablation period that had minimal cloud cover or nearly cloud-free conditions. The topographic maps were scanned at 700 dpi and were projected by georeference on ArcGIS 9.2.

Figure 2: Extraction of glacier outlines in the Borkoldoy range from ALOS/AVNIR satellite images and topographic maps (1:25,000). Dark-blue glacier outlines of 2010, and white dotted outlines of 1965.



3.2 Glacier outline extraction

The outlines of glaciers were extracted manually by visual interpretation of the 2008–2010 ALOS/AVNIR-2 images (Figure 2). The areas of the extracted glacier polygons were computed using ArcGIS 9.2, with omission of glacier areas smaller than 0.1 km2. We added the glacier polygon data to attribute data such as mean altitude, minimum altitude, maximum altitude, area, and aspect in each glacier-area class. Changes in the terminus position of some glaciers were observed and measured during fieldwork from 2010 to 2012 using GPS instruments.

3.3 Permafrost research methodology

In addition to the glacier studies, we also investigated the conditions of Permafrost and ground ice. In Kyrgyzstan, only a few researchers are currently dealing with this topic. However it is studied here, as the melting of massive ground ice and perennial snow patches (as indicators for actual permafrost conditions) may contribute to the regional water balance in a much greater magnitude than assumed today.

For the current study we investigated frozen ground upon upstream Naryn catchments, during August 2010 to August 2013. We measured near-surface ground temperatures in 18 locations at different altitudes and slopes. The objectives of this study are to estimate the distribution of permafrost, and its active layer, and to discuss the permafrost environment in the upstream Naryn catchments. The general features of mountain permafrost such as permafrost distribution and temperatures, active layer thicknesses within the upstream Naryn catchments, Tian Shan Mountains are described. The area of permafrost studies in the Naryn basin is located within the two upstream river basins (Chon Naryn and Kichi Naryn). The mountain permafrost zone in our study area belongs to the Asian mountain permafrost area, the largest in the world.

In the field we used steel rods and a hammer to knock holes up to 1.5 m deep in order to install our thermistor strings, thus measuring continuously ground temperature profiles for the coming study years. Ground temperature measurements were carried out in 18 locations between altitudes 3007 and 4043 meters. These measurements were performed using wireless mini thermistor sensors and loggers (M-Log5W). They have a high memory capacity (2048kB), a very low energy consumption and a waterproof cover (Figure 3). The temperature sensor has a high resolution of 0.01°C and an overall accuracy of ± 0.1°C. This thermistor can work more than 5 years without changing batteries depending on temperature conditions of the logger instrument and the batteries. The temperature recording started in August 2010 at an hourly interval. At all locations the observation period was up to end of August 2013.

Figure 3: M-Log5W wireless mini data logger

(http://www.geoprecision.com/)

4 GLACIOLOGY OF THE NARYN CATCHMENTS

4.1 General glacier characteristics

A total of 654 glaciers were studied in the two researched catchments: 15 glaciers in the Akshyirak massif, 126 in the Borkoldoy range, 130 in the Jetim range, 89 in the Jetimbel range, 80 in the Naryn range, 41 in the Sook range, 95 in the Terskey range (south slope glaciers), and 78 in the Uchemchek range (Table 2). Of these, 513 glaciers (435.2 km2) in the northwest, north, and northeast sectors of the eight mountain ranges account for 74.3% of the total glacial area. The characteristics of the glacier distribution in the study area were analyzed in relation to the statistical relations among topographic parameters of the attribute data (mean altitude, minimum altitude, maximum altitude, area, and aspect in each size class; Tables 1 and 2).

Table 1: Basic information on investigated glaciers (1965)

Class (km²)	Number	Total area (km²)	Total area (%)	Minimum elevation (m)	Maximum elevation (m)	Mean elevation (m)
0.1 – 0.5	395	98.1	16.8	3580	4960	4187
0.5 – 1	177	186.6	31.9	3510	4960	4214
1 – 2	40	70.9	12.1	3580	5020	4232
2 – 5	30	120.6	20.6	3720	4880	4222
5 >	12	109.2	18.6	3600	5170	4258
Total	654	585.4	100	3510	5170	4223

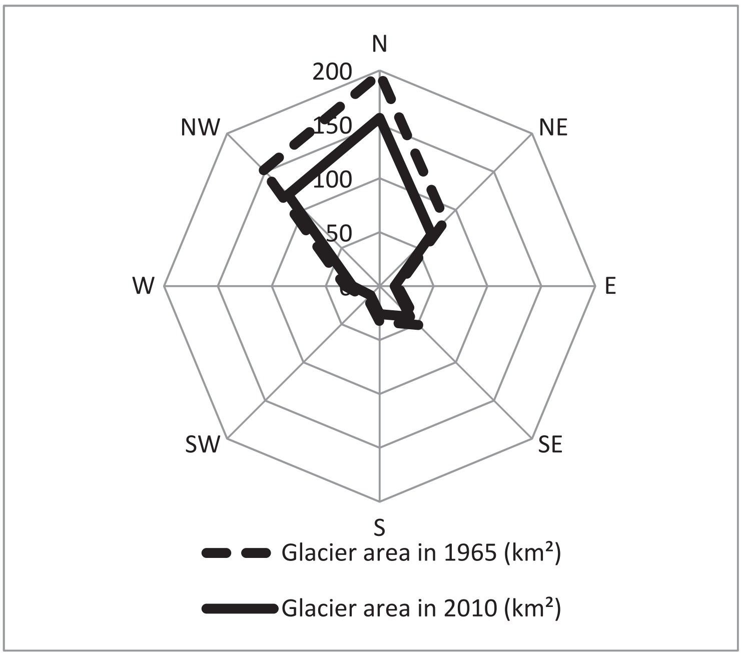
Table 2: Derived glacier parameters (~2010) for eight mountain ranges

	range	Akshyirak	Borkoldoy	Jetim	Jetimbel	Naryn	Sook	Terskey	Uchemchek
Area (%)	0.1 – 0.5 (km2)	2	11	15	**24**	**46**	14	18	19
	0.5 – 1 (km2)	10	**27**	**30**	**54**	**38**	72	**22**	**30**
	1 – 2 (km2)	18	14	6	17	0	14	8	**24**
	2 – 5 (km2)	**23**	**26**	**29**	5	16	0	**24**	13
	5 > (km2)	**47**	**22**	**20**	0	0	0	**28**	14
Aspect (%)	N	2	**32**	**48**	**55**	**39**	**58**	3	40
	NE	0	**20**	15	16	**33**	16	7	12
	E	0	0	2	6	4	6	9	0
	SE	0	5	5	0	0	4	**39**	0
	S	0	2	1	0	0	0	**32**	0
	SW	9	2	3	1	0	6	3	0
	W	9	8	2	2	6	4	2	14
	NW	**80**	**31**	**24**	**20**	18	6	5	**34**
Total glaciers measured		15	126	130	89	80	41	95	78

A majority of the parameters clearly showed evidence of changes in the regional characteristics of the glacier distribution. Figure 4 shows that the relationship between glacier area and aspect, indicating that large glaciers are concentrated on northern aspects. A majority (74.3%) of the total area is located in the sectors northwest, north, and northeast. Table 2 shows the distribution of glaciers classified according to area class (0.1–0.5 km2, 0.5–1 km2, 1–2 km2, 2–5 km2, and >5 km2) for the eight mountain ranges. In three mountain ranges, the distributions of glacier size classes are similar: glaciers with areas of less than 1 km2 occupy 78% in the Jetimbel range, 86% in the Naryn range, and 84% in the Sook range.

There are there are no glaciers larger than 5 km2 in these ranges. In the Akshyirak massif, small glaciers of less than 1 km2 occupy 11.5%, and larger glaciers of more than 5 km2 occupy 48%. In the other (Borkoldoy, Jetim, Terskey, and Uchemchek) ranges, the distribution of glacier size classes is different; glaciers with areas of less than 1 km2 occupy 39–50% and those larger than 5 km2 occupy 14–28%. The glacier termini altitudes in these four mountain ranges are quite different: 5170 m in the Borkoldoy range, 4840 m in the Terskey range, 4825 m in the Jetim range, and 3510 m in the Uchemchek range. The average glacier termini altitude in the study area is 4223 meters.

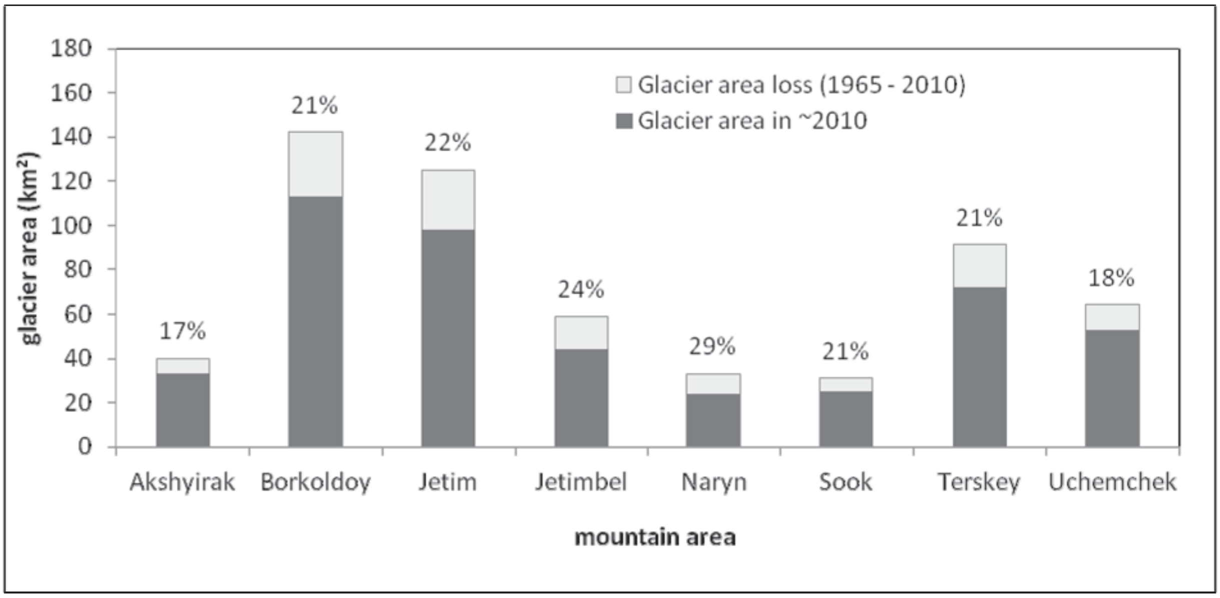
Figure 4: Distribution and area change of glaciers with different aspects.



4.2 Glacier area changes from 1965 to 2010

We investigated the glacier shrinkage in the two catchments using 1:25,000 topographic maps (~1965) and ALOS AVNIR-2 satellite data (~2010). The total area of the 654 studied glaciers decreased by 21.3% (from 585.4 km² to 460.5 km2) during the period 1965 to 2010 (Table 3). The glacier area decreased by 17.4% in the Akshyirak massif, 20.8% in the Borkoldoy range, 21.9% in the Jetim range, 24.6% in the Jetimbel range, 28.9% in the Naryn range (north slope), 20.8% in the Sook range, 20.9% in the Terskey range (south slope), and 17.8% in the Uchemchek ranges (Figure 5). The greatest area reductions occurred in the Naryn (28.9%), Jetimbel (24.6%), and Jetim ranges (21.9%).

Figure 5: Changes in total glacier area in eight mountain regions for the period ~1965 and ~2010



Additionally, the percentages of glacier loss in the different size classes were investigated. Small glacier areas are sensitive to local climate changes and local glaciological factors (Johannesson et al., 1989; Kuhn, 1995; Nesje and Dahl, 2000). The relative abundances of glaciers in the different size classes strongly affected the total glacier-area loss percentage. The regions dominated by small glaciers are more sensitive to change because of the shorter response time of small glaciers to climate variability (Bahr et al., 1998). In the study area, 89% of glaciers have an area of less than 1 km2. A comparison of glacier size class distributions and glacier shrinkage amounts revealed that the Naryn range with its many small glaciers (<1 km2) experienced large glacier shrinkage (28.9%), whereas, the Akshyirak massif with its large glaciers (>5 km2) had less shrinkage (17.4%; Tables 2 and 3). Figures 6 and 7 show specific glacier changes related to the glacier size class. There were also dramatic change differences between glaciers located on northern and southern slopes. On northern slopes, 513 glaciers decreased by 19.7%, but on southern slopes, 78 glaciers were reduced by 24.1%.

Figure 6: Specific glacier changes related to the glacier size class (Akshyirak, Borkoldoy, Naryn and Sook mountain ranges)

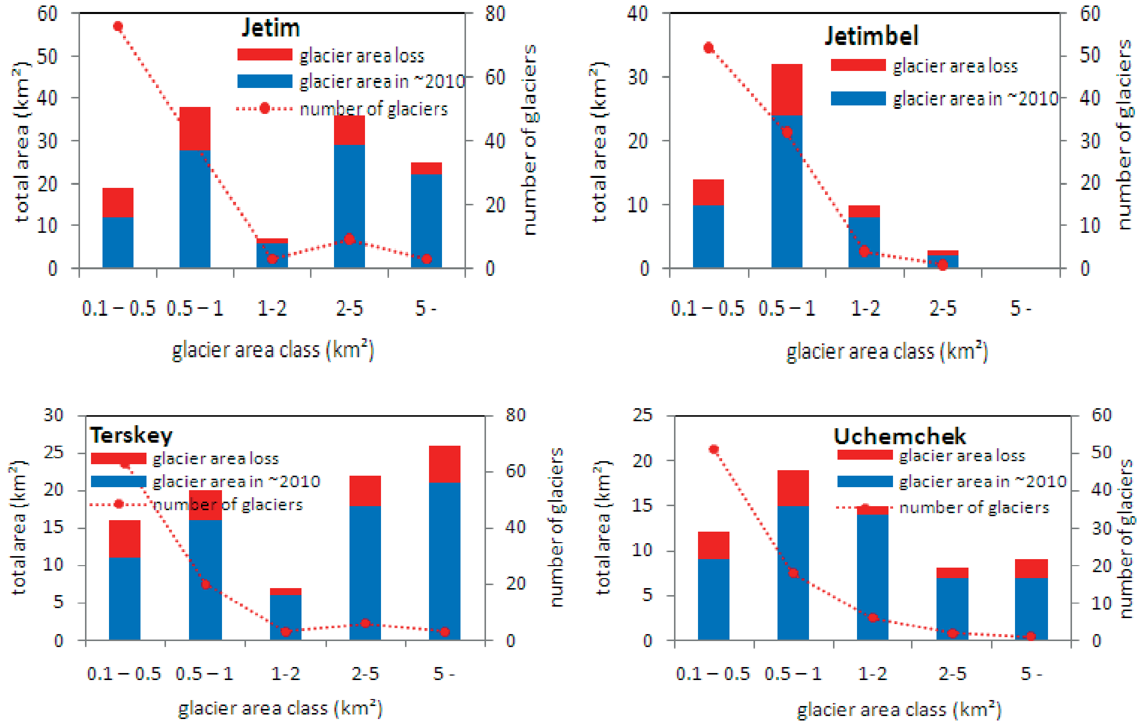


Figure 7: Specific glacier changes related to the glacier size class (Jetim, Jetimbel, Terskey and Uchemchek mountain ranges)

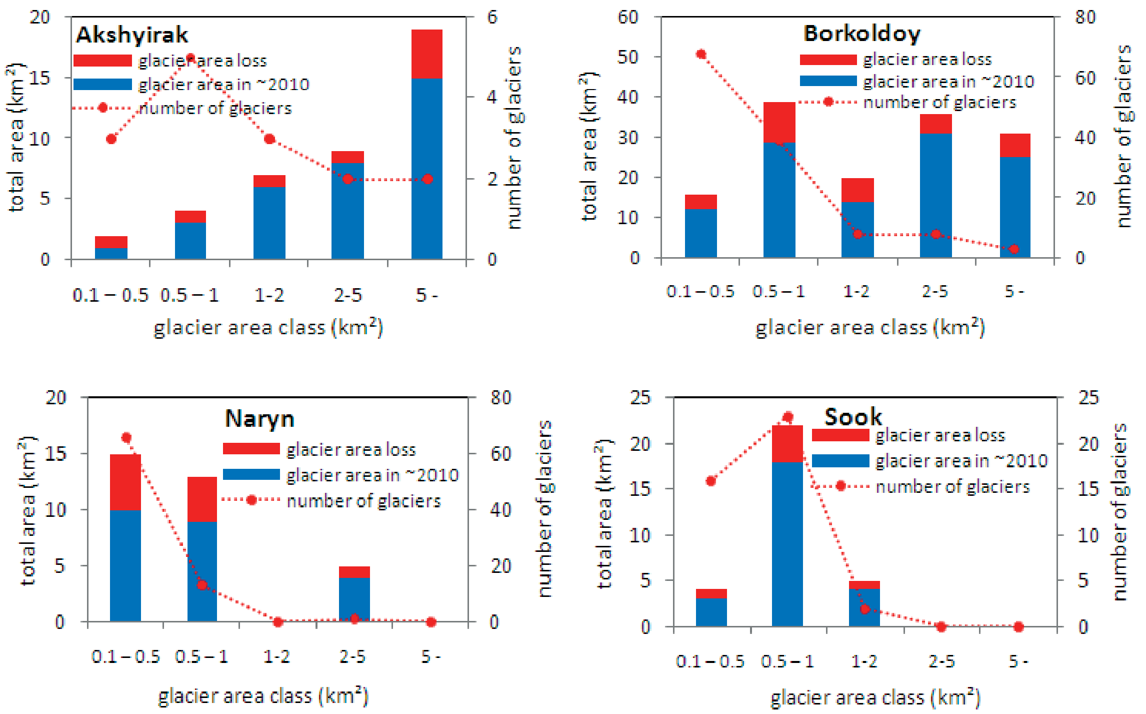


Table 3: Summary of glacier area change in eight mountain ranges

Mountain area	Average area (km^2)	Area (km^2) 1965	Area (km^2) 2010	Area change (%) (1965 - 2010)
Akshyirak	2.66	39.9	32.96	- 17.4
Borkoldoy	1.13	142.0	112.50	- 20.8
Jetim	0.96	125.1	97.75	- 21.9
Jetimbel	0.66	58.7	44.25	- 24.6
Naryn	0.42	33.3	23.65	- 28.9
Sook	0.76	31.4	24.86	- 20.8
Terskey	0.96	91.0	71.96	- 20.9
Uchemchek	0.82	64.0	52.61	- 17.8
Total	0.90	585.4	460.54	- 21.3

5 IMPACTS OF GLACIER CHANGES ON WATER RESOURCES

The total area of glaciers of the Chon Naryn and Kichi Naryn catchments of the Naryn basin decreased significantly between about 1965 and 2010, with a total glacier retreat of 21.3%. This is due to increasing summer temperatures and decreasing precipitation. This glacier shrinkage varied with regional climate and differed among glaciers of different sizes and according to altitude. The largest amount of glacier shrinkage occurred in the Naryn range (28.9%) because of the dominance of small-scale glaciers on north-facing slopes. Strong glacier retreat can produce large quantities of water in a short time period, which may cause hazards in downstream areas. Continuing glacier shrinkage will result in water and energy deficiencies in the region. The present state of these glaciers needs to be evaluated and monitored scientifically for reasonable development and use of regional water resources and water cycle models, and for regional economic planning.

It is important to understand the impact of glacier shrinkage on water resources in lowland arid areas. Any change in the glacier regime has a severe impact on Naryn River tributary water entering the Syr-Darya, which is important for Kyrgyzstan and Uzbekistan. Hagg et al. (2007) estimated significant changes in seasonal runoff volume related to glacier area loss in the Tian Shan using a special CO2 scenario from 2050 to 2075. Decreased glacier area leads to a decrease in summer glacier-melt discharge. The distribution of glaciers among the main tributaries of the Naryn basin is extremely uneven, and the contribution of glacier water to the total runoff also varies among the tributaries. In this paper, based on identified regularity of spatial distribution of rainfall, relations of melting ice and snow on the temperature (Dikih, 1999) determined the volume of glacial runoff in the Chon and Kichi Naryn rivers. Table 4 contains the values of runoff norm. The share of glacier melt water is analyzed using Dikih's method. The contribution of glacier runoff to the summer discharge is large in both catchments.

Table 4: Total and glacier runoff of the Chon Naryn and Kichi Naryn catchments

Hydrological station	Average annual discharge, 1930-2010 (m^3/sec)	Runoff volume (mln m^3)	Glacier runoff (mln m^3)			Share of glaciers in total runoff (%)	Share of glaciers in summer runoff (%)
			From snow melting	From ice melting	Total		
Chon Naryn	46.5	1479	196.5	258.5	455.0	30.7	51.3
Kichi Naryn	41.1	1340	201.6	119.7	321.3	23,9	36.5

6 PERMAFROST AND GROUND ICE AS ADDITIONAL RUNOFF PARAMETERS

6.1 Permafrost

Permafrost is defined as ground that remains at or below 0°C for at least two consecutive years. Mountain permafrost regions are traditionally divided into several zones based on estimated geographic continuity in the landscape. A typical classification recognizes continuous permafrost (underlying 90-100% of the landscape); discontinuous permafrost (50-90%); and sporadic permafrost (0-50%) (www.ipa.arcticportal.org). In the Tian Shan Mountains at altitudes of more than 3300 m a.s.l. there is permanently frozen ground spread almost everywhere.

The permafrost – is the product of climate and heat-flux from the earth. Its origin and preserving is promoted by the low average annual and winter temperatures and the insignificant snow cover, which favour the cooling off in winter. Permafrost has been identified as one of the cryospheric indicators of global climate change within the monitoring framework of the WMO Global Climate Observing System (GCOS) (Harris et al., 2003 a, b; Cihlar et al., 1997; Mackay, 1972). In a permafrost area, the so-called active layer thaws in summer and freezes in winter. Accordingly, any underground ice must lie in permafrost below the depth of summer thaw. Underground ice can only persist in permafrost, but not all permafrost has underground ice, because permafrost is defined solely upon a temperatures basis (below 0 °C) and not upon the presence or absence of ice. King et al. (1992) remind the following: Whereas practically all water is frozen in permafrost material at temperatures of about -15 C, a considerable amount of water remains unfrozen at temperatures between 0 °C and -5 °C, especially in materials with high clay content. This is important when using geophysical (seismic) properties in order to find and characterize permafrost. Permafrost may exist in soils or other surficial materials (from peat or clay to boulders) or even in bedrock (King L., 1986). Mountain permafrost is known from many high altitude regions, such as the Rocky Mountains in North America (Janke, 2005), the Alps in Europe (Harris et al, 2003; King, 1990, 2000), the mountains in Scandinavia (King, 1986; King et al., 1988), the Himalaya in Asia (Jin et al, 2000).

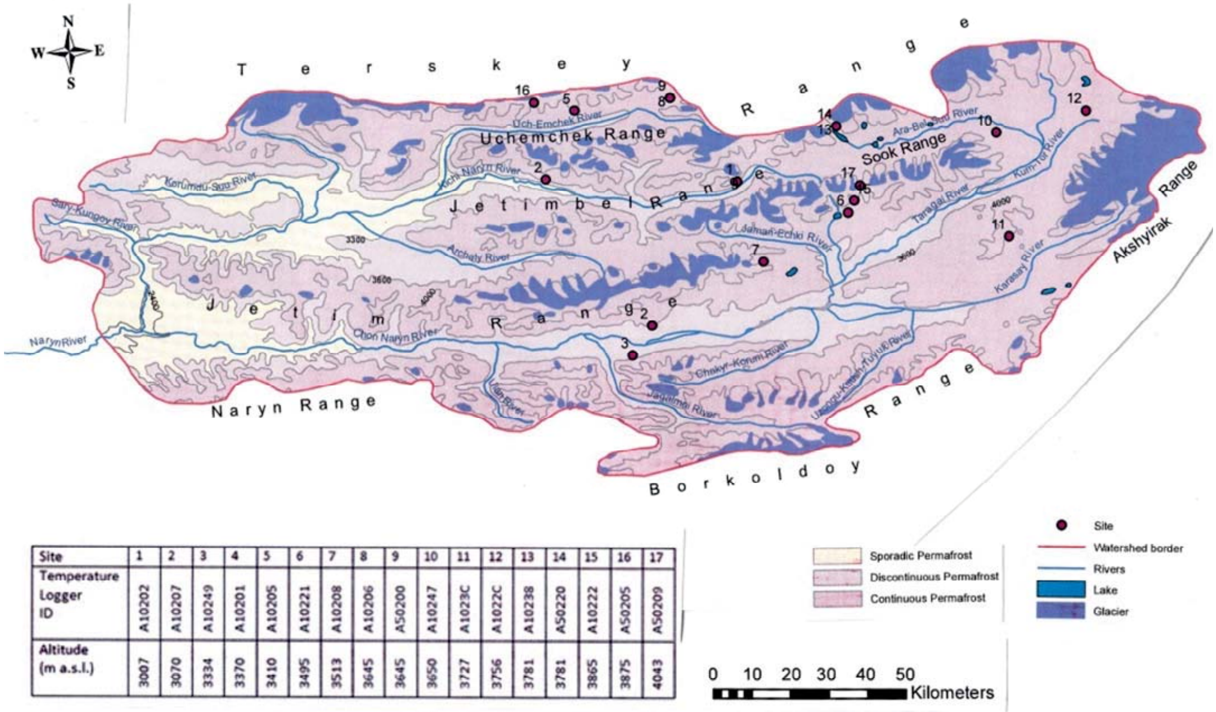
Recent studies have reported warming of permafrost temperatures in many places of the world (e.g. Marchenko et al., 2007; Gruber et al, 2004; Ostercamp, 2003). Under climate change, the temperature increase and the distribution of permafrost in the mountain areas get more and more in the focus of the scientific community especially because of its impact on the water balance, but also concerning slope instabilities and many natural hazards involved with slope failures.

6.2 Periglacial processes and phenomena

The study of periglacial environments is very important for Kyrgyzstan with its vast mountain areas. By definition, the term “periglacial” means “the conditions, processes and landforms associated with cold, nonglacial environments”. The term was originally used to describe the climatic and geomorphic conditions of areas peripheral to Pleistocene ice sheets and glaciers. Modern usage refers, however, to a wider range of cold climatic conditions regardless of their proximity to a glacier, either in space or time. Many, but not all, periglacial environments possess permafrost; all are dominated by frost action processes. Therefore the periglacial environment does not include glacier areas, but ground ice and consequently freezing and thawing processes. This is important to understand, because ground ice in permafrost, in contrast to glacier ice, does not contribute to the annual runoff, hence the water level in the rivers (French, 2007). However, the ground is frozen, which means that the water stays frozen within these grounds. But, in the future the ground ice which is stored in permafrost can be a significant water source. That is why it´s important to study the differences between the glacial and the periglacial environment.

Periglacial processes include frost jacking, frost sorting, frost wedging, cryoturbation, and the development of cryotextures, cryostructures and cryogenic fabrics in soils. Its phenomena include landforms like seasonal and perennial frost mounds, as well as the cryotextures, and cryogenic fabrics found in soils. Special landforms exist in areas with frost, although only some indicate proofs of permafrost presence. Surface features formed under cold, nonglacial conditions are known as periglacial landforms (Washburn, 1980; French, 1996). Many researchers were fascinated by the wealth of periglacial forms, and many well illustrated textbooks on periglacial processes and “cryology” exist (e.g. Washburn, 1973; 1979).

Figure 8: Permafrost distribution map for the two river basins Chon Naryn and Kichi Naryn (Inner Tian Shan)



Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Temperature Logger ID	A10202	A10207	A10249	A10201	A10205	A10221	A10208	A10206	A50200	A10247	A1023C	A1022C	A10238	A50220	A10222	A50205	A50209
Altitude (m a.s.l.)	3007	3070	3334	3370	3410	3495	3513	3645	3645	3650	3727	3756	3781	3781	3865	3875	4043

6.3 Distribution and temperature of ground ice

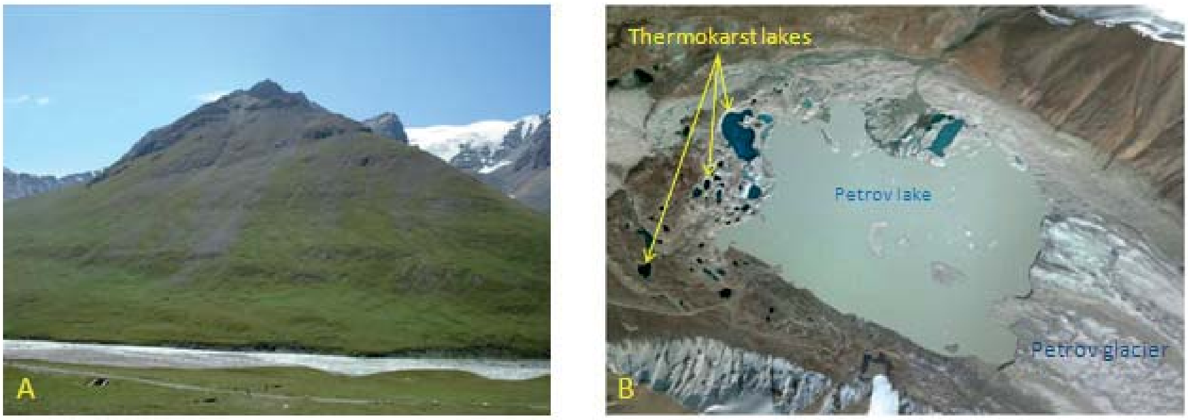
In the investigated area permafrost is developed above 3300 m a.s.l. (Figure 8). The definition of the lower permafrost limit in mountains is not an easy task. The point is that physical-geographical conditions here are extremely variable: exposure and steepness of slopes is changed over short distances, bedrocks are replaced by soft sedimentary masses, vegetative ground cover and ground moisture contents are very variable. Winter air temperature inversions and extremely variable depth of snow cover are usual for mountainous areas. All these factors have influence on the permafrost development. Moreover, it is necessary to distinguish between the lower limits of sporadic, discontinuous and continuous permafrost.

Table 5: Altitudinal location of permafrost

Logger ID	Altitude (m a.s.l.)	Slope (^{0})	Aspect	Vegetation cover	Mean annual ground surface and ground Temperature (^{0}C); depth from surface (01.09.2010—31.08.2013)					
					0 cm	10 cm	31 cm	52 cm	82 cm	132 cm
A10202	3007	15	S	VC1		4.38	4.30	4.40	4.26	4.45
A10207	3070	8	S	VC2		3.01	2.96	3.02	3.10	3.00
A10249	3334	25	N	VC2		-1.04	-1.32	-1.34	-1.36	-1.72
A10201	3370	23	SW	VC1		2.52	2.54	2.31	2.15	2.50
A10205	3410	7	S	VC1		2.26	1.98	2.13	2.08	2.26
A10221	3495	7	SW	VC2		0.08	-0.22	-0.24	-0.21	-0.31
A10208	3513	11	S	VC2		-0.32	-0.30	-0.54	-0.56	-0.60
A10206	3645	12	N	VC1		0.29	0.43	0.33	0.15	0.06
A50200	3645	12	N	VC1	-1.44					
A10247	3650	4	W	VC2		-1.10	-1.28	-1.48	-1.63	-1.85
A1023C	3727	8	W	VC1		-1.86	-1.87	-2.31	-2.02	-1.98
A1022C	3756	9	N	VC2		-1.34	-1.06	-1.38	-1.22	-1.24
A10238	3781	18	SE	VC1		-0.11	-0.12	-0.11	0.06	0.23
A50220	3781	18	SE	VC1	-0.36					
A10222	3865	14	SE	VC3		-1.67	-1.62	-1.80	-1.88	-1.90
A50205	3875	5	S	VC3	-2.80					
A50209	4043	6	W	VC3	-4.27					

The lower altitudinal limit of sporadic permafrost in the Naryn basin is as low as 2700 m. We have data at our disposal (Table 5) on location of permafrost on northern slopes at altitudes between 3334 and 3756 meters (Akshyirak, Uchemchek and Sook mountain ranges), on southern slopes at altitudes between 3007 and 3875 meters (Terskey, Sook, Uchemchek, Jetim mountain ranges), on western slopes at altitudes of 3650 to 4043 meters (Akshyirak and Sook mountain ranges) and on eastern slopes at altitudes of 3781 to 3865 meters (Terskey and Sook mountain ranges). The sporadic permafrost area is increasing with altitude, and the area of discontinuous permafrost starts somewhere near the hypsometric line of 3300 meters. Here the area with permafrost is larger than the non-permafrost area. Permafrost is wide-spread throughout, at altitudes above 3200-3400 meters. We propose the isohypse at 3300 meters as the lower limit of discontinuous permafrost in the upstream Naryn basin. Different forms and phenomena that in many cases may be connected with the occurrences of permafrost (frost mounds, solifluction formations, thermokarst etc.) also indicate to a probable position of such boundary near 3300 meters (Figure 9).

Figure 9: Solifluction lobes in the north slope of Jetimbel Mountain (A) and thermocarstic lakes on the Petrov lake moraine dam, north-west slope of Akshyirak mountain (B)



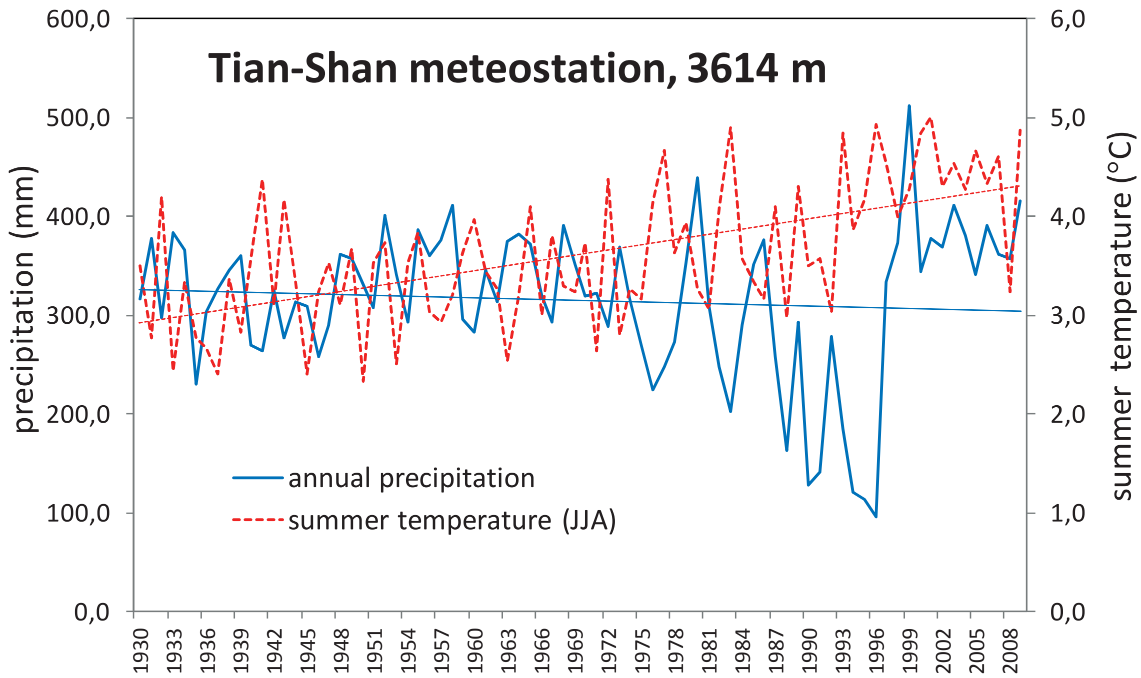
(A) M. Duishonakunov, 25 July, 2010); (B) Google earth imagery; date: 10/4/2002

Thus, permafrost in the Naryn basin is wide-spread mainly above an altitude of 3300 meters. Above 3600 m the continuous permafrost zone starts. However, isolated permafrost islands and their “tongues” on steep slopes with northern exposure and at their foots exist as low as 2700 m, and maybe, even slightly below.

As a general rule, the MAAT, the precipitation characteristics and the summer air temperatures give a good first indication for a typical periglacial environment. This is certainly the case for the Tian Shan meteorological station (Figure 10).

Mountain permafrost and periglacial landforms may contain large quantities of fresh water in the form of ice. Especially glacier moraines and rock glaciers have high ice ontent. Rock glaciers are ice-rich periglacial landforms, ice can occupy up to 80% of the volume. A more suitable descriptive definition of a rock glacier (Washburn, 1979) is “a tongue-like or lobate body, usually of angular boulders, that resembles a small glacier, generally occurs in mountainous terrain and usually has ridges, furrows, and sometimes lobes on its surface, and has a steep front at the angle of repose.” Most of the active and inactive rock glaciers are located in the south-west slopes of the Akshyirak mountain massif, in the west part of the Jetimbel and in the Borkoldoy mountain ranges.

Figure 10: Annual precipitation amount and mean summer air temperature (JJA) at the Tian Shan meteorological station

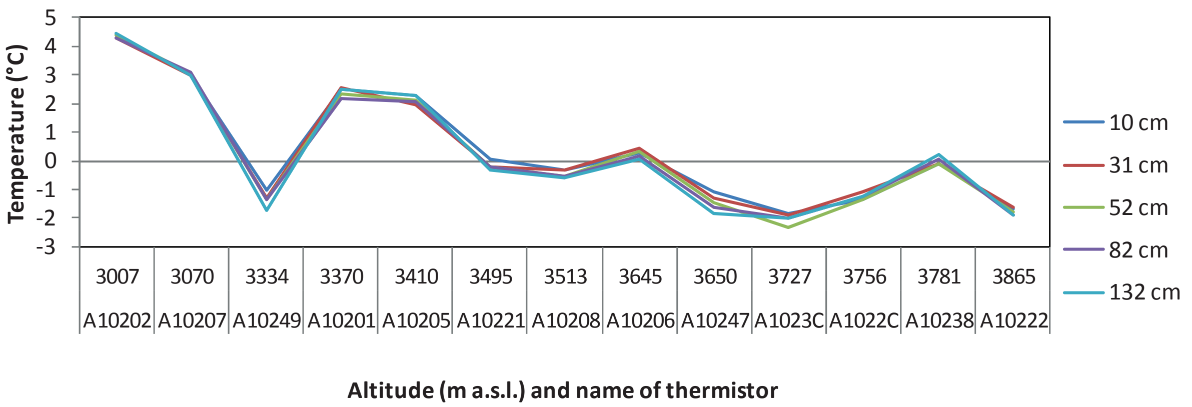


Our data in the Kumtor catchment during 2001-2011 show that the ten years mean annual ground temperatures (MAGT) were between -0.2°C (at the depth of 5 cm) and -1.3°C (at the depth of 300 cm). This is considerably warmer than the mean annual air temperature (MAAT = -5.730C). Annual average temperatures during the last ten years at the depth of 100, 150 and 300 cm never were above 0°C. Other measurements in 18 locations during August 2010 and August 2013 show that the mean annual ground temperatures (Figure 10) at the depth of 10 cm ranged between +4.4°C (south slope of Uchemchek Mountain, 3007 m a.s.l.) and -4.3°C (north slope of Sook mountain, 4043 m a.s.l.).

The data in Figure 10 show that MAGTs at similar depths are significantly lower at Tian-Shan Station. Larger temperature amplitudes are observed at the Tian-Shan Station than at the other 17 locations.

The MAGT at the permafrost table is one main thermal characteristic of permafrost, and is very important for estimating the distribution and thicknesses of permafrost. Ground temperature measurements (2001-2011) in the Kumtor catchment (3659 m a.s.l.) showed that the mean annual permafrost table temperatures vary from -1.1 °C to -1.9 °C and the active layer thicknesses reached 2 to 3 meters. The MAGT usually decreases by about 0.5 - 0.6 °C per each 100 m of altitude (Gorbunov, 1986). The differences in MAGT between north and south slopes at the same altitude vary from 1.0 to 5.0 °C depending on factors as vegetation, snow cover etc. Our data on geothermal observations during 2001-2011 indicates that permafrost has been warming in the Kumtor catchment area (Tian Shan meteostation area, 3659 m a.s.l.) during the last 10 years. The increase in these permafrost temperatures varies at the depth of 5 cm from -2.23 0C (2001) to -0.49 °C (2011) and at the depth of 300 cm from -1.94 °C to -1.09 °C. Marchenko S. (2007) also notes that “Permafrost is warming in the Inner Tian Shan. Permafrost temperatures increased by 0.1 °C over 1986-1993 both in the valley and on the mountain slopes”. The geothermal gradient in the Tian Shan changes from 0.01 °C /m at the mountain ranges up to 0.02 – 0.03 °C /m at the valleys (Schwarzman, 1985).

Figure 11: Mean annual ground temperature variability at the depth of 10 cm, 31 cm, 52 cm, 82 cm and 132 cm, at different altitudes between 3007 m and 3865 m a.s.l. (2010-2013).



6.4 Thickness of Permafrost and Ground ice content

Changes in permafrost thickness in different places in connection with increase of altitudes seem to be of great practical interest. Unfortunately, data on its thickness in the Inner Tian-Shan are very limited. Besides, some of them are obtained by poll that is why they are not always sufficiently reliable. However, we try to summarize the knowledge.

Data collected by Gorbunov (1967) shows that the permafrost thickness at altitudes of 2800 m to 3000 m makes up several meters, but hardly exceeds 20—25 meters. For example, permafrost thickness in the area of the Kara-Keche brown coal field on the northern slope was equal to 6-7 m. Permafrost thickness increases at altitudes of 3100—3200 meters. At the same Kara-Keche coal field it amounts to 29 m on the northern slope at an altitude of 3180 meters. Apparently, the thickness of permafrost on northern slopes at altitudes of 3100 m to 3200 m does not exceed 50-60 meters (Gorbunov, 1967).

At altitudes of 3300—3400 meters the permafrost thickness is known for several locations of the Inner Tian-Shan. According to data of A.P. Kasymkhodzhoev (1952), the thickness of permafrost at the bottom of Ak-Sai depression at the confluence of Terek and Ak-Sai rivers achieves 107 meters. In another area of the Inner Tian-Shan, on slopes of Baidulu range the permafrost thickness at the same altitudes was significantly less. On a steep windward slope of the north-western exposure a permafrost thickness in fractured rocks appeared to be equal to 60 meters. On a downwind more snow-covered slope on the eastern exposure in the same area it decreased at the altitude of around 3400 m to 10—15 meters (Atakanov, 1963).

Massive ground ice with dimensions typically from a few meters to tens of meters also occurs in permafrost. For example, we have found outcrops of massive ground ice in the Akshyirak area on altitudes of 3753 meters, confirming the very high ground ice content in the region.

Thus, the maximum thickness of permafrost at altitudes of around 3000 meters can amount to 20 - 25 m, at 3100 to 3200 meters to 50 - 60 m; at the altitude of 3300 to 3400 meters to 100 - 110 m, at 3500 to 3600 meters to 150 - 160 m, and at an altitude of 4000 meters to more than 200 m. At altitudes above 5000 meters, it is likely that the permafrost thickness makes up several hundred meters (Gorbunov, 1967).

There are gradient values of permafrost thickness increasing alongside with the increase of altitudes. Several factors influence its thickness. Some factors contribute to the earth surface cooling, others, on the contrary, prevent it. This is complicated also by the fact that one and the same factor within different seasons of the year changes its direction. Thus, a snow cover in winter prevents soil freezing, and in summer, delays its warming up. A steep slope of the southern exposure in summer receives less heat at the expense of direct solar radiation, than a horizontal site. These effects have always to be kept in mind when estimating the permafrost pattern and its estimated thickness.

7 IMPACT OF PERIGLACIAL ACTIVITIES AND PERMAFROST CHANGE ON LANDSCAPES

There are general facts to call when considering the impact of permafrost on landscape components. First of all, permafrost acts as a more or less impermeable screen, preventing substance exchange from deep layers with the earth surface. Some active exchange is possible only through taliks (unfrozen islands within the permafrost), which stipulates a strict localization of this process. Permafrost with its cold reserves inevitably makes certain thermal influence on the lithosphere surface and surface air layers.

In general, permafrost of the Naryn basin slackens landscape dryness to some extent. As a matter of fact, ground ice as a water-tight stratum prevents filtration of surface and atmospheric water, and contributes to increase ground moisture. Besides, dew (condensation of water vapours from air) penetrating into the soil, and thawing in summer also contributes to the increase of moisture. Disappearance of permafrost on Tian-Shan syrts would result in disappearance of bogged areas and in a significant reduction of the meadow area. From this point of view, availability of permafrost is a positive phenomenon.

Any evident direct correlation of vegetation with permafrost in the Tian-Shan was not reported, with some minor exceptions. It is caused by the fact that usually a permafrost level (except for bogged areas and peatlands) occurs at the depth of more than 1.2-1.5 m, and a root system of vegetation penetrates only at the depth of several tens of centimeters.

Permafrost has influence on mountain vegetation in two ways. On the one side, it contributes to some increase of soil moisture and, accordingly, is favourable for vegetation development. On the other hand, heaving processes and thermokarst in this extremely dry region often lead to soil salination and vegetation dieback. There is no doubt, that a dependence between permafrost and vegetation cover is much more diversified, but it requires special investigations.

Permafrost influences the fauna of the Tian-Shan mountain areas as well. It is recorded that marmots select warm areas for their burrows, where active permafrost is missing (or relict permafrost may exist in greater depth). This is usually in depressions with fine sediment accumulation and with snow cover in winter. Thus, ground-ice of the Tian-Shan mountains has influence on the development of many specific landscape components and their dynamics.

8 IMPACT OF CLIMATE CHANGES ON WATER AVAILABILITY AND ECONOMIC DEVELOPMENT OF KYRGYZ MOUNTAIN AREAS: CONCLUSIONS AND FUTURE PERSPECTIVES

8.1 Glaciological conclusions

As shown in the earlier chapters, the recent glacier conditions in the Chon Naryn and Kichi Naryn catchments were investigated using topographic maps at the 1:25,000 scale and ALOS/AVNIR-2 satellite imagery. In summary for the 45-year period 1965–2010, the glacier area decreased by 17.4% in the Akshyirak massif, and by 20.8% in the Borkoldoy, 21.9% in the Jetim, 24.6% in the Jetimbel, 28.9% in the Naryn, 20.8% in the Sook, 20.9% in the Terskey (south-slope glaciers), and 17.8% in the Uchemchek mountain ranges. The shrinkage was more dramatic for south-facing than for north-facing glaciers, with respective area losses of 23.6% and 19.8%. The glacier shrinkage might affect not only irrigation water availability during summer but also the planning of four cascade power stations to be constructed in the Chon Naryn and Kichi Naryn catchments.

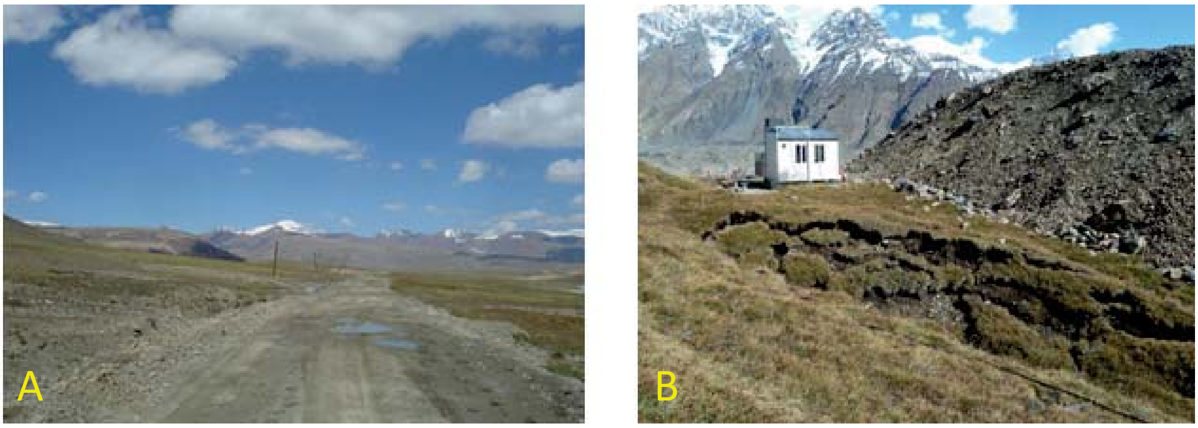
After the Chon Naryn, the Kichi Naryn catchment is the second major tributary of the Naryn River by amount of glacier coverage. The reductions of the glacier areas are partly due to decreased precipitation, which not only affects the availability of water for irrigation but also has a cascading effect on the hydropower works in the Toktogul, Kurpsay, Tashkumyr, Shamaldysay, and Uchkurgan parts of the Kambarata-2 project. At present, the upper Naryn hydropower cascade is planned as part of four consecutive steps, the Akbulun, Naryn-1, Naryn-2, and Naryn-3 hydropower stations, with a total capacity of 191 MW and an annual output of 1,055 billion kWh. Construction of the Akbulun hydropower station was started in May 2013.

The confirmed effects of climate change on water resources are of paramount importance because of the high dependency on fluvial water originating from mountains. Monitoring water resources and planning water use and the balance between water use and water resources are most important issues in this region because the majority of the water supplied from Central Asian mountains is used within the irrigation zones of the arid flat plains. This demand will increase in the future due to food- and energy-security concerns in the region, and this might even lead to water wars among nation states.

8.2 Geocryological conclusions

Studies of ground ice and cryogenic phenomena are of great practical significance. We would like to emphasize works in mountains, for which the knowledge of permafrost conditions is especially important. Most often road builders (Figure 12) builders have to come across areas with permafrost. They need information not only on the depth of ground ice occurrence and ice content, but also on solifluction, heaving and fracture phenomena.

Figure 12: Roads and electricity lines in the mountain valleys, Arabelsuu catchment; Destroyed roads and falling electricity poles to different directions (A) are often encountered. One of building of the Global Change Observatory – Central Asia Station "Gottfried Merzbacher" on the permafrost, Central Tian Shan (B).



(20 Aug., 2011; M. Duishonakunov)

Construction of buildings for different purposes (cultural centers and bases for cattle-breeders, meteorological and other scientific stations, alpinist camps) and especially their heating systems requires most careful selection for construction. We know cases of unfortunate buildings' construction on permafrost where better locations without icy grounds could have been chosen.

In many parts of the Alps, hazardous bedrock instabilities occur more often during the past 30 years (King et al., 2013). In many cases, permafrost degradation played a central role for instability (e.g. in 1987 the Val Pola rockslide, Italy), at other events, the role of permafrost degradation is more complex or unpredictable (e.g. in 1991 the Randa rock fall, Wallis, Swiss Alps). Problems encountered with the construction of touristic infrastructure in the Alps are exemplarily described by King et al. (2013).

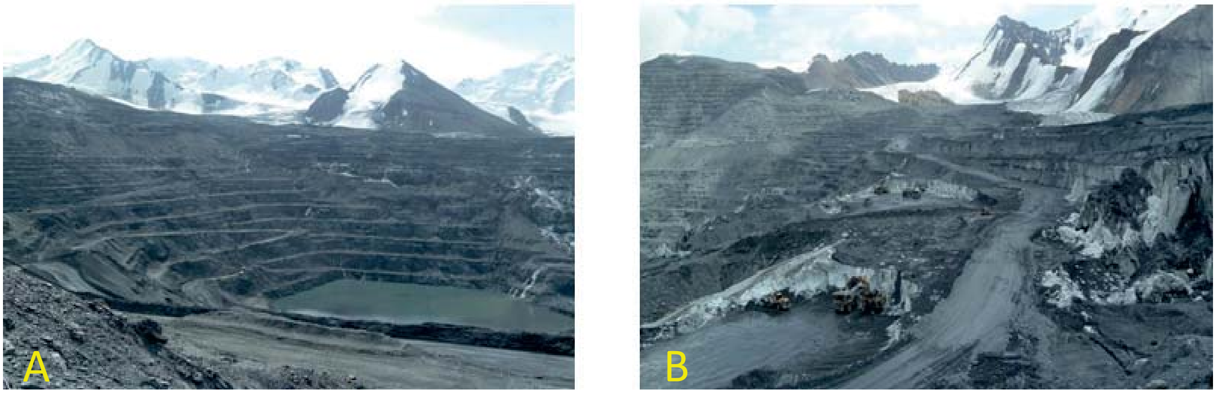
Kyrgyzstan wants to be a tourist state, and as our political leaders like say this has the second highest priority. The upper Naryn catchments are also part of the touristic locations of Kyrgyzstan. But before the building of touristic infrastructure, the permafrost conditions need to be investigated in the field. It could be a possibility to benefit from the experiences of the tourism industry in the Swiss Alps where tourist places are built under nearly similar conditions (mountain permafrost). Here, the infrastructure erected on permafrost consist of hotels, restaurants and mountain huts, station buildings of railways, funiculars, ski lifts and installations for artificial snowing the ski-runs. Some problems with these constructions due to permafrost degradation are shown in (King, L., 2013). At the Kleinmatterhorn mountain station at an altitude of 3820 meters, today's MAAT ranges between -6 °C and -8 °C. During the construction of a tunnel in 1981 bedrock temperatures were at -12 °C. Over the past 30 years, these bedrock temperatures have risen to about -2.5 °C, due to the heat brought into the tunnel by heating of the facilities and by the more than 490 000 visitors per year walking through the permafrost tunnel. In an elevator shaft, the temperature even rose above freezing point close to the surface causing melt-water, and refreezing in the shaft, thus blocking the elevator movement (King, L., 2013).

The running of underground connections needs also investigations on ground temperatures. This then will allow selecting the optimal location of pipes, e.g. water pipes for artificial snowing of ski runs. Construction of communication lines and power transmission lines requires identification of dangerous areas, susceptible to solifluction, thermokarst and heaving. Many examples could be listed here.

Data on thickness and temperature of ground ice are especially important for the drilling of water wells. Sinking of wells, not taking into account their frozen ground conditions can result in large, useless financial costs. Several cases of wells freezing and failure are known in Tian-Shan.

At the implementation of mining works it is also necessary to pay attention to the frozen condition of not only soft sediments but also solid rock. Frozen rocks can complicate mining works when rock blasting is required for mining. But competent utilization of such properties requires knowledge of permafrost conditions in each special case. For instance, the team of Kumtor Gold Mine Company faced several engineering design challenges including weather, permafrost and a drop-cut within a glacial moraine with ice lenses (Figure 13). Kumtor Gold Mine is an open-pit gold mining site in the Upper part of Chon Naryn catchment at an altitude of 4000 meters in permafrost. It is the second-highest gold mining operation in the world after Yanacocha gold mine in Peru. The mine started operation in 1997 and produced more than 180 000 kg of gold up to the end of 2006 (The Gazette of Central Asia (29 June, 2012).

Figure 13. Kumtor Gold Mine area, 4000 m a.s.l.; anthropogenic direct impact to the Davydov glacier (B) and to the permafrost at the same time (A)



(July, 2011, Duishonakunov)

Detailed mapping of frozen soft rocks and the study of their physical condition is very important for identification of probable mudflow origination sites. And this, in its turn, will allow to planning most effective measures for the protection of populated settlements against probable catastrophic phenomena. In summary, the formation of surface and underground waters, the water general balance and the origin of extreme runoff events in the Kyrgyz high-mountain areas cannot be understood without taking into account also the hydrological role of ground ice and permafrost.

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AEOLIAN DUST DEPOSITION IN THE SOUTHERN ARAL SEA REGION – SPATIAL AND TEMPORAL ANALYSES OF AN ECOLOGICAL CRISIS

I. ASLANOV, M. GROLL, CH. OPP, N. VERESHAGINA and T. LOTZ

0 ABSTRACT

Aeolian transport of sand and dust is a common natural process in arid regions worldwide. In Central Asia, this process is superimposed by anthropogenic desertification which leads to an increase of the overall dust transport and the frequency of severe dust storm events. The formation of the Aral Kum as a result of the Aral Sea syndrome has caused a great variety of desertification processes, adding a harmful cocktail of salts, pesticides and heavy metals to the airborne dust deposition which can lead to ecological and economic problems and is therefore an important issue in Central Asia. Data about the spatial and temporal distribution of the dust deposition however is scarce and derived mostly through remote sensing. Little is known about the actual dust deposition, the composition of the deposited material and its potential impacts on the arable land and the human health. Between 2006 and 2009 the CALTER project (funded by the 6th framework program of the EU) established a monitoring network in Kazakhstan, Uzbekistan and Turkmenistan and identified the main transport routes and the spatial and temporal hot spots of the dust deposition in the Aral Sea basin. The study presented here continues this important dust monitoring using seven meteorological stations in the Southern Aral Sea region. The results show that while the average dust deposition is highly dynamic from year to year, the percentage of harmful dust events increased during the last decade which reflects the impact of the newly formed Aral Kum desert. Two main seasons for the aeolian dust transfer were identified – summer (with severe dust storm events and high average deposition rates) and winter (with the highest percentages of samples exceeding the health threshold of 10.5 $g/m^2*month$). On top of this temporal dynamic the dust sampling stations also revealed a strong spatial dynamic as stations which were close to the dust sources were characterized by much higher deposition rates than stations in a larger distance to the source regions. The results furthermore showed that while the stations close to the Aral Kum were strongly affected by aeolian dust, both the Kyzyl Kum and the Kara Kum have a much bigger influence in terms of the quantity of dust transported in Central Asia. The dust at all stations contained high percentages of clay sized minerals (PM10 and smaller) which indicates the long-range aspect of the aeolian transport and is the most harmful fraction of the dust. The chemical analyses revealed that the dust in the Southern Aral Sea region consists almost exclusively of salt compounds which will, due to the amount of deposited material, negatively influence the soil salinity in this region and

accelerate the salinization processes. Furthermore, the heavy metal concentrations in the dust samples were higher than in the soil samples so that a negative impact pf the dust on the soil toxicity can be expected as well.

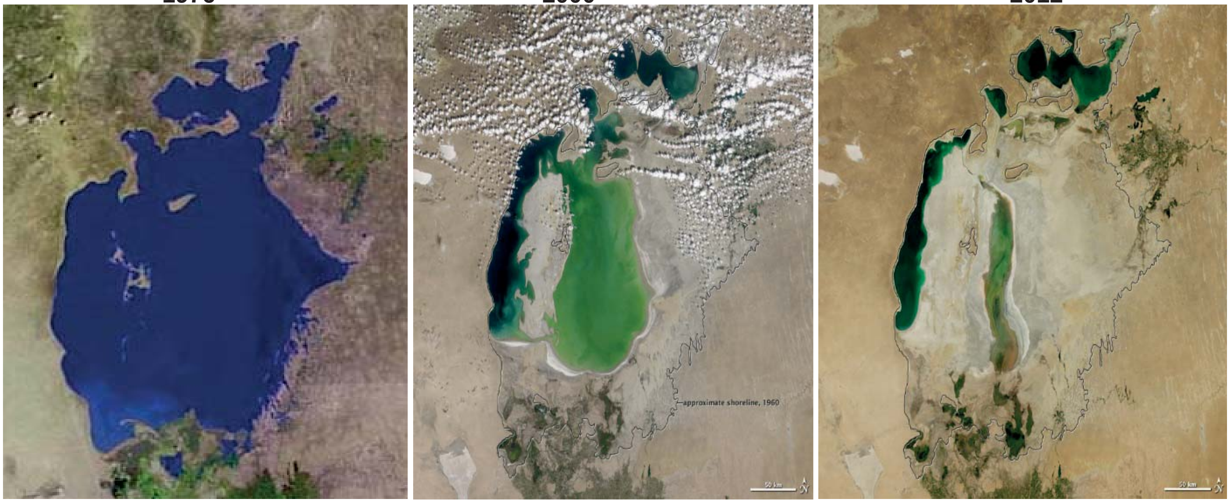
1 INTRODUCTION AND PROBLEM SETTING

The mobilization, transport and deposition of small particles caused by aeolian processes are natural phenomena which occur worldwide. In arid regions these processes are of particular importance as they can cause severe dust storm events and manifold problems (Gomes and Gillette, 1993; Goossens et al. 2001; Sun and Zhao, 2008).

Deposited dust can increase the soil salinity (Popov, 1998) and reduce the photosynthetic efficiency of plants (Razakov and Kosnazarov, 1996; Usmanov, 1998), while dust entrained in the air can impair the health of humans and lifestock (Gao and Washington, 2010; Ochmann and Nowak, 2009; Orlovsky et al. 2004; Taylor, 2002). The impact of dust is even greater if the aeolian processes are amplified by anthropogenic activities (D'Odorico et al. 2013; Ginoux et al. 2012; Sivakumar, 2007). Large scale desertification and man-made soil erosion increase the amount of mobilized dust while the pollution of the source regions (e.g. with agrochemicals) can lead to additional problems (e.g. toxic or saline dust) (Field et al. 2010; Phillips, 1999; Youlin et al. (Eds.) 2001). One of the most impressive examples for the dimensions of this kind of anthropogenic impairment has become known as the Aral Sea syndrome (Opp, 2004, 2007; Opp and Groll (Eds.) 2009), the largest manmade ecological disaster (Saiko and Zonn, 2000). The Aral Sea basin has been cultivated for oasis agriculture since ancient times, but during the 20th century the irrigation farming expanded greatly (+40.6% between 1918 and 1960; +216.9% between 1918 and 2008). The main crop cultivated during this period became cotton (16.9% of the irrigated area in 1918; 48.9% in 1960) and the high water demand of the cotton plants in the arid climate of the basin led to a large increase of the water consumption for irrigation purposes (+41.2% between 1918 and 1960; +106% between 1918 and 2008). Combined with a strong population growth (+128.7% between 1918 and 1960; +660% between 1918 and 2008) this development resulted in the overexploitation of the available water resources provided by the two large streams Amu-Darya and Syr-Darya (Dukhovny and de Schutter (Eds.) 2011; Gaybullaev et al. 2009). As the inflow into the Aral Sea decreased, almost 90% of the lakes water volume and 74.3% of its surface area were lost until 2008 (Dukhovny (Ed.) 2008; www.cawater-info.net 2011). The once fourth-largest inland lake of the world desiccated into three fragments of which only the northern part (the "Small Aral") is considered to be savable (Figure 1). The southern part of the Aral Sea is now a desert covering almost 54.000 km², called the Aral Kum (Figure 2), and the former salt sink became a salt source (Opp 2008, 2012).

Figure 1: Development of the Aral Sea between 1976 and 2012

1976 2000 2012



www.visibleearth.nasa.gov 2012

The desiccation of the Aral Sea is in its dimensions a spectacular manifest of human ambitions and the unsustainable exploitation of natural resources, but it might have repercussions which reach much further than just the loss of the water body. The irrigation farming did not only consume vast amounts of water, it also created highly polluted drainage water, which was returned to the large streams and finally dumped into the Aral Sea. As a result fertilizers (e.g., the organophosphate phosalone) and pesticides (e.g., organochlorines, DDT, toxaphene and lindane) accumulated in the Aral Sea as well as salts which were leached from the irrigated fields where soil salinization is a widespread problem (Micklin, 1988; O'Hara et al. 2000; Whish-Wilson, 2002; Zetterström, 1999, Opp 2005, 2007). An additional pollution with heavy metals (especially nickel, lead, mercury and zinc, but also vanadium, copper, cadmium and chromium), radioactive matter and oil products is caused by the ore processing industries in the upper catchments and by industrial and urban waste waters (Groll et al. 2013b; Kulmatov and Hojamberdiev, 2010; Kulmatov and Soliev, 2009; Wiggs et al. 2003a). These pollutants accumulated in the Aral Sea over the last decades and the desiccation led to an accelerated increase of the water salinity (10.2 g/l in 1947; 90 g/l in 2002). After the saturation point was reached the pollutants started to accumulate in the lake sediments (Létolle et al. 2005). Today a salt layer of at least 0.5 m thickness covers a huge area of the Aral Sea bed and as the water recessed those salty deposits got exposed to aeolian processes – namely wind erosion (Micklin, 1988; Orlovsky and Orlovsky, 2001).

Figure 2 Dry bottom of the southern Aral Sea with the ship cemetery of Muynak

Photo Ch. Opp 2013

Today the Aral Kum is covered by salty crusts (75%), sand dunes and with saxaul communities (Haloxylon aphyllum) which are the climax vegetation type for the saline environment of the new desert. Furthermore the loss of water led to a change of the local climate towards a more continental state. The amplitude of the annual average temperature of the surrounding meteorological stations increased by 1.5 to 2.0 °C and the amplitude between the hot summers and the cold winters grew. This also increased the number of days with dust storm characteristics in that region (Opp 2007). The flat eastern and southern shores of the Aral Sea are for the most parts free of vegetation and are the main source areas for these dust storms. Estimates put the amount of salty (and potentially polluted) dust blown out of the dry sea bed between 15 and 75 mln tons per year (with an average of 43 mln t) (Micklin, 1988, Saiko and Zonn, 2000) which characterizes the Aral Kum as one of the most important dust sources worldwide (Shi and Zhao, 2003). This dust is distributed to an area of more than 150,000-200,000 km2. The highest dust deposition rates (1.3 to 2.5 t/ha and month) were detected within a 100 km circle around the Aral Sea and the amount of salt within this dust was in average 520 kg/ha (Orlovsky and Orlovsky 2001, Opp and Groll (Eds.) 2009). Based on sporadically conducted remote sensing analyses the amount of dust originating in the Aral Kum and the main directions of its transport are known on a regional scale. But there is still much uncertainty about the when and where of the dust deposition and about the chemical properties of the dust and its effects on the arable land and on the human health (Dukhovny, 2008; Orlovsky et al. 2004). That is why a dust monitoring program in the Aral Sea basin was established by the CALTER project (Long Term Ecological Research Program for Monitoring Aeolian Soil Erosion in Central Asia; 2006-2010) which was continued in the Southern Aral Sea region within the LUCA project (2010-2013).

The objectives of the study conducted within the LUCA project were:

- Analysis of the spatial and temporal characteristics of the dust and sand deposition in the southern Aral Sea region;
- Analysis of the connections between the dust deposition dynamic and meteorological parameters;
- Analysis of the mineralogical and chemical characteristics of the deposited material;
- Comparison of the dust characteristics with local soil characteristics and an estimation of the effect of deposited dust on the arable land.

2 RESEARCH AREA

The climate of Central Asia is sharply continental with cold winters and hot summers. It can be characterized by large annual and daily temperature amplitudes and high degrees of solar radiation which results in many hours of sunshine, high evaporation rates and little effective precipitation. The study presented here was conducted in the southern Aral Sea region (Figure 3). It covers the three Uzbek provinces/autonomous regions Khorezm, Karakalpakstan and Navoiy, which are characterized by an arid climate with long and particular dry summers, annual precipitation rates of less than 150 mm, an average air temperature of more than 12°C and strong winds (Indoitu et al. 2012).

The research area is located in the Turan lowlands and stretches for approximately 500 km from West to East and for 400 km from North to South. It borders to four major source areas for aeolian dust – the Kyzyl Kum (“red sand”) to the North-East, the Kara Kum (“black sand”) to the Southwest, the Ustyurt Plateau to the West and the newly formed Aral Kum to the North.

In this research area seven meteorological stations were selected for the detailed dust monitoring – Muynak, Jaslyk and Takhiatash in Karakalpakstan, Beruniy, Urgench and Yangibazar in Khorezm, and Buzubay in Navoiy (Figure 3). The regional focus on the southern Aral Sea region was based on the results from the CALTER project and other studies, which identified northern winds as the prevailing wind direction and thus a mostly southern vector of the dust transport from the Aral Kum (Bennion et al. 2007; Galayeva and Idrissova, 2009; Groll et al. 2013a; Kovalevskaya et al. 2009; Micklin, 2010; Orlovsky and Orlovsky, 2001; Orlovsky et al. 2005; Romanov, 1961; Wang et al. 2010). This allowed the detailed analysis of the impact of the Aral Kum on floodplains and river delta areas in the lower Amu-Darya catchment which are densely populated and intensively used for agricultural purposes.

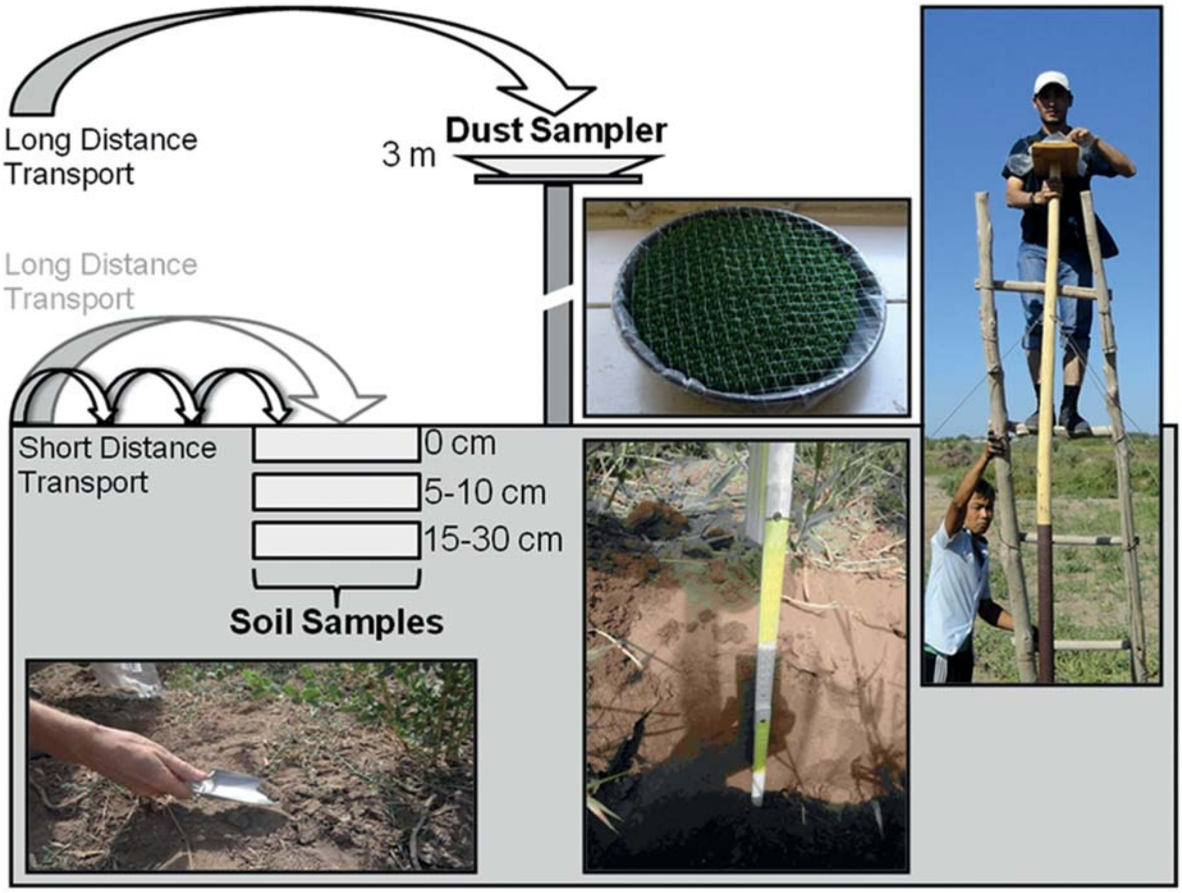
Figure 3: The research area with the seven dust sampling stations

(Base map: United Nations (Ed.) 2004)

Methods

The spatial and temporal distribution of the dust deposition was analyzed using passive deposition samplers installed in the seven stations in the region. The dust from each sampler was collected monthly between 2010 and 2012. The samplers were designed to endure the extended field measurement campaign and so that they were easy to maintain and operate by the local staff. Each sampler consists of a plastic tray (diameter 23 cm) as the dust and sand sink, filled with artificial grass and mounted in 3 m height in the open field (Figure 4, Opp et al. 2011). The same dust sampler design had previously been used in other Central Asian studies with great success (O'Hara et al. 2000; Orlovsky et al. 2004; Tolkacheva, 2000; Wiggs et al. 2003a,b). In addition to the collected dust soil samples in three different depths were collected in 2011 at six of the seven stations.

Figure 4: Dust and soil sample setup



Meteorological data was collected at all seven stations including the average monthly air temperature, monthly precipitation sums, daily wind speed and direction data as well as information about the occurrence and duration of dust storms.

The collected dust and soil samples were analyzed in laboratories in Tashkent (Uzbekistan) and Marburg (Germany) for the following parameters:

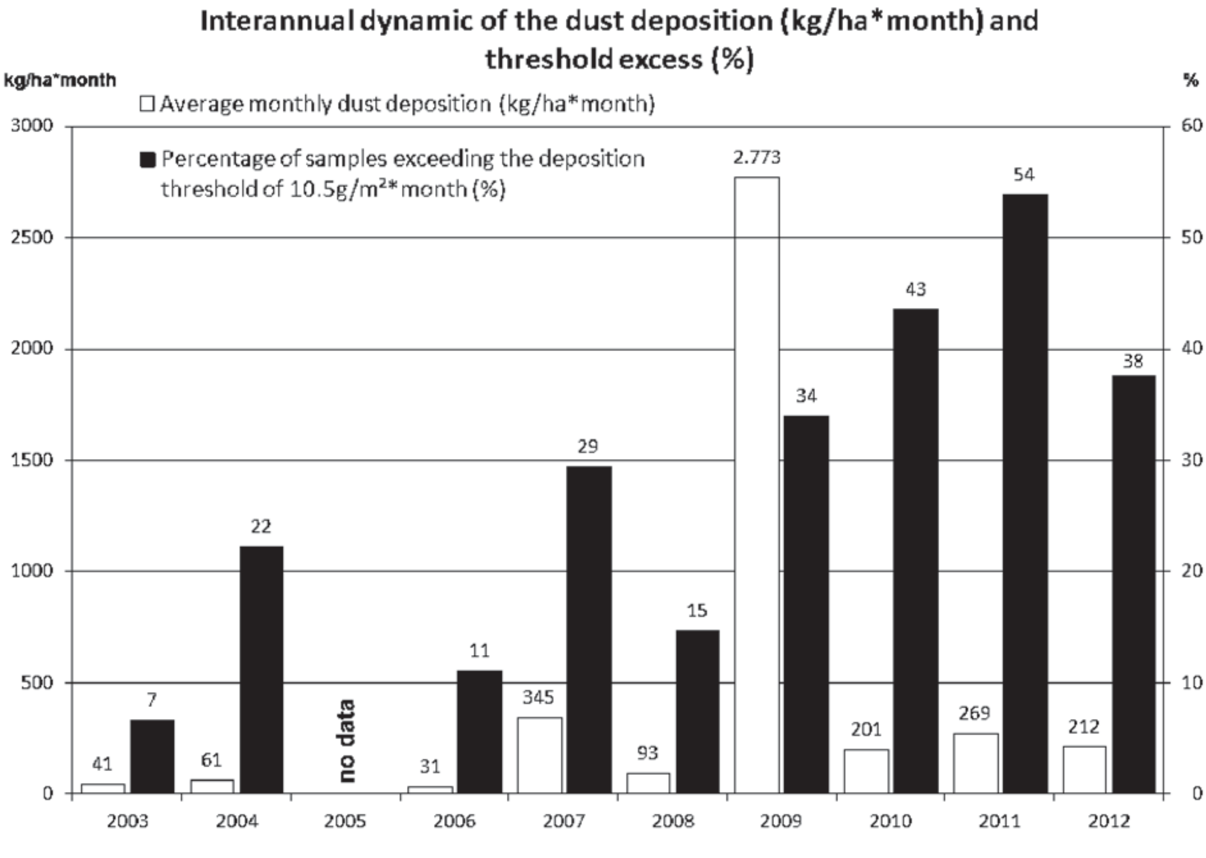
- Sample weight (dust samples only) using a precision scale with an accuracy of 0.0001 g;
- Grain size distribution (dust and soil samples) by means of microscopic grain size counting in four representative subsamples per sample;
- Mineralogical composition (dust and soil samples) using X-ray diffraction (Debye and Scherrer, 1916);
- Elemental composition (dust and soil samples) using the wavelength dispersive X-ray fluorescence (WDXRF; Glocker and Schreiber, 1928) and flame atomic absorption spectrometry (Beaty and Kerber, 1993; Walsh, 1955).

The laboratory and meteorological data were statistically analyzed and interpreted under special consideration of additional (literature and database) data.

3 RESULTS AND DISCUSSION

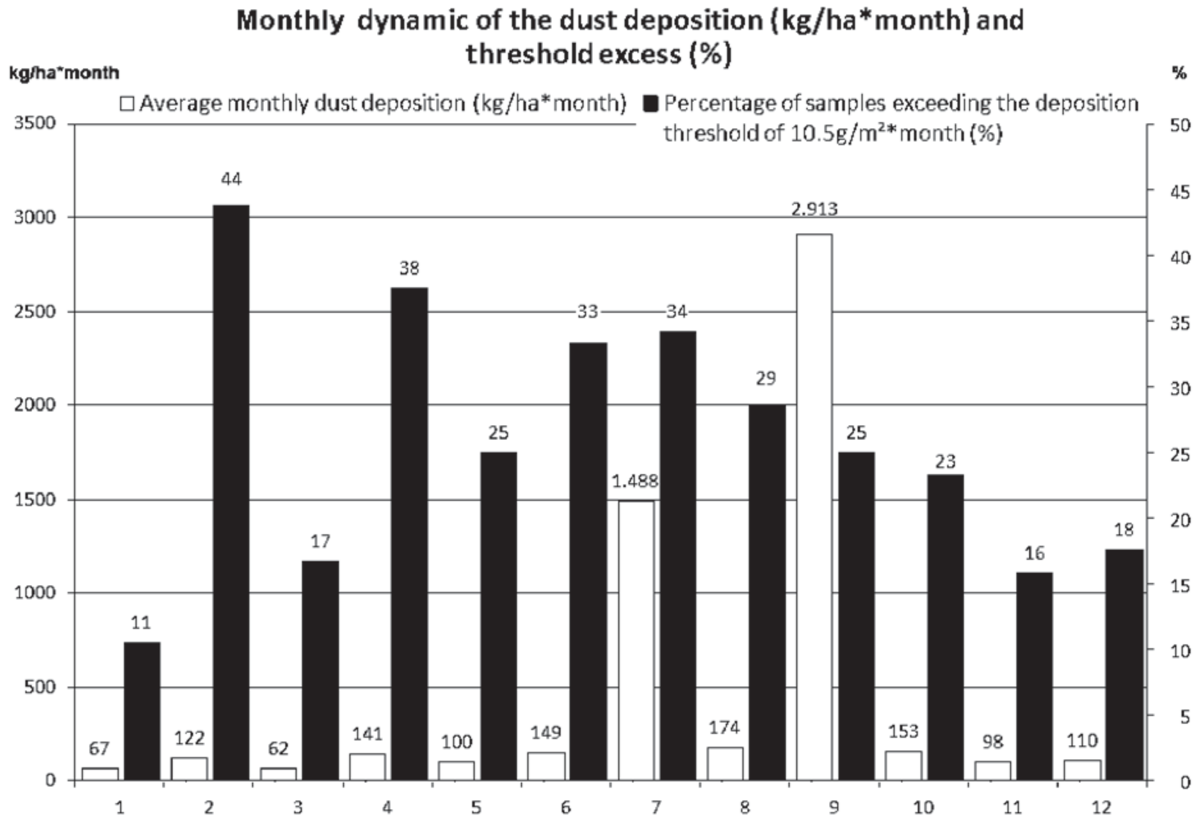
A total of 321 dust samples were collected in the Uzbek parts of the Southern Aral Sea region and the average amount of dust deposited in those samples was 598.4 kg per hectare and month. 141 additional samples had been collected during the CALTER project and those samples were used to compare the results from the southern Aral Sea region with other parts of Central Asia. The annual averages of the dust deposition show a high variability (Figure 5) over the course of ten years covered by both projects. The maximum dust deposition (2,773 kg/ha*month) was detected in 2009, a year characterized by many severe dust storm events. The analysis of satellite image scenes confirms the importance of this year as the Eastern part of the Aral Sea completely dried out during the summer months of 2009 (Aslanov et al. 2013). As 2009 was also a year with low precipitation, the importance of local dust sources in Karakalpakstan and Khorezm (areas affected by desertification) was probably higher than normal in this year.

Figure 5: Interannual dust deposition rates and percentage of samples exceeding the health related threshold of 10.5 g/m²*month between 2003 and 2012



The deposition rates during the duration of the LUCA project (2010-2012) remained with values between 201 and 269 kg/ha*month well below this extreme year. But those last three years showed a relatively consistent dust deposition activity which was higher than that at the start of the analyzed decade. This becomes even more obvious when the percentage of samples with deposition rates of more than 10.5 g/m²*month is considered (Figure 6). This threshold is based on medical analyses of the effects of deposited dust on the human health (BMU (Eds.) 2002) which means that samples, which exceed this threshold, might be harmful for the local population and the livestock at that station. The three last years (2010-2012) were characterized by the highest percentages of samples exceeding this deposition rate threshold and the maximum (detected in 2011) percentage was 54%. This means that even though the overall dust deposition in 2011 was with 269 kg/ha*month much smaller than in the stormy year 2009, the year 2011 might have been more harmful than 2009, where “only” 34% of all samples exceeded the threshold.

Figure 6: Monthly dust deposition rates and percentage of samples exceeding the health related threshold of 10.5 g/m²*month between 2003 and 2012



The analyzed time frame of ten years is still too short to evaluate the temporal dynamic in terms of a possible trend. It could be expected that with the ongoing shrinking of the Aral Sea and the effects of the climate change (increasing air temperatures and less available water resources) the aeolian dust transport will become even more important in the future, but without a continuation of this dust monitoring this hypothesis cannot be verified.

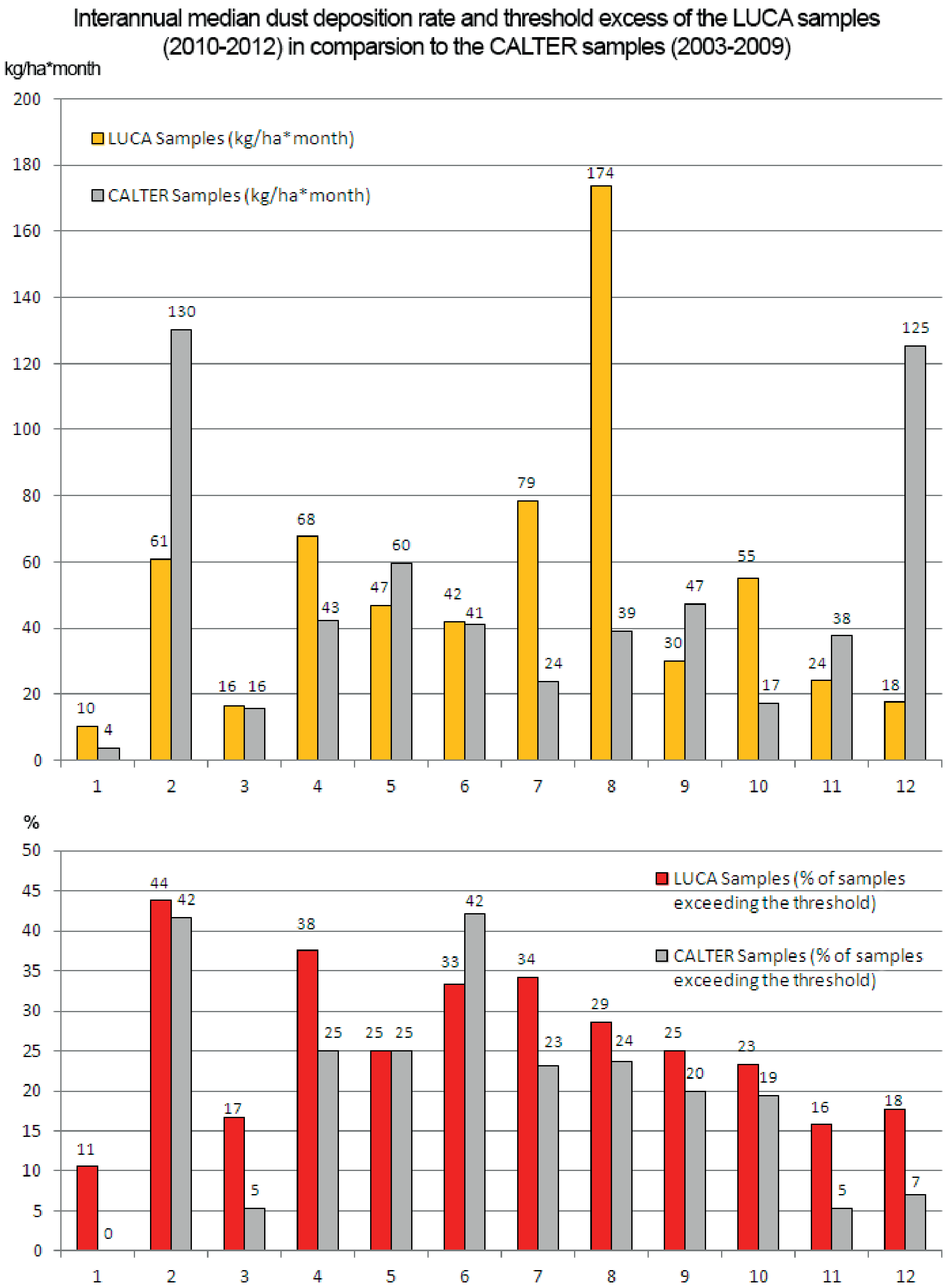
Next to the annual variability the interannual dynamic of the dust deposition is important for identifying the relevant processes involved in the Aeolian dust transfer. Figure 6 shows that the month with the highest average dust deposition rate within the duration of the LUCA project was September (2,913 kg/ha*month), followed by July (1,488 kg/ha*month). Besides those two months, the rest of the year was characterized by much smaller mean dust deposition rates (between 62 and 174 kg/ha*month).

But interestingly, the months with a below average dust deposition rate showed relatively high percentages of samples which exceed the threshold. In February the highest percentage throughout the year was detected (44%) while the average dust deposition rate was unremarkable (122 kg/ha*month). This means that the summer and early fall months in the Southern Aral Sea region are the time of year when the majority of dust storms occur. These dust storms lead to very high average deposition rates but the overall impacts of deposited dust might not be higher in summer than during the winter months. Therefore it is also interesting to analyze not the mean but the median deposition rates as shown in Figure 7. Winter in this part of Central Asia is the main rainfall period and the potential snow cover reduces the aeolian dust transport, but the results presented here show that the reduced vegetation cover on the arable land during the winter months still leads to significant dust transfer rates which make it the second most important season for the dust deposition.

The results obtained within the LUCA project show a number of similarities and differences compared to the data gathered within the CALTER project, which also contained samples from Kazakhstan, Turkmenistan and Eastern Uzbekistan. Both data sets show a high significance of the summer and winter months for the dust deposition in Central Asia. The peaks for the threshold excess can be found in February and June/July and the maximum percentage of samples exceeding the threshold are very comparable, regardless of the spatial origin of the samples (Figure 7). The amount of dust deposited during each month however differs between both data sets. The samples collected in the southern Aral Sea region (LUCA samples) showed the highest median deposition rates during August, while the samples from the CALTER project were characterized by the highest median deposition rates during the winter months (December and February). The reason for the higher importance of the summer months for the dust deposition in the Southern Aral Sea region could be found in the very high evaporation rates over the Aral Sea during the summer which leads to an additional shrinking of the water body and an increased exposure of the dry bottom for aeolian processes. This evaporation is amplified by the change of the local climate caused by the desiccation of the Aral Sea – leading to a positive feedback loop between the increasing summer air temperatures, evaporation rates and an accelerated shrinkage of the Aral Sea. Furthermore the water diversion for irrigation purposes is highest during the summer months which additionally reduces the inflow of water from the Amu-Darya into the Aral Sea.

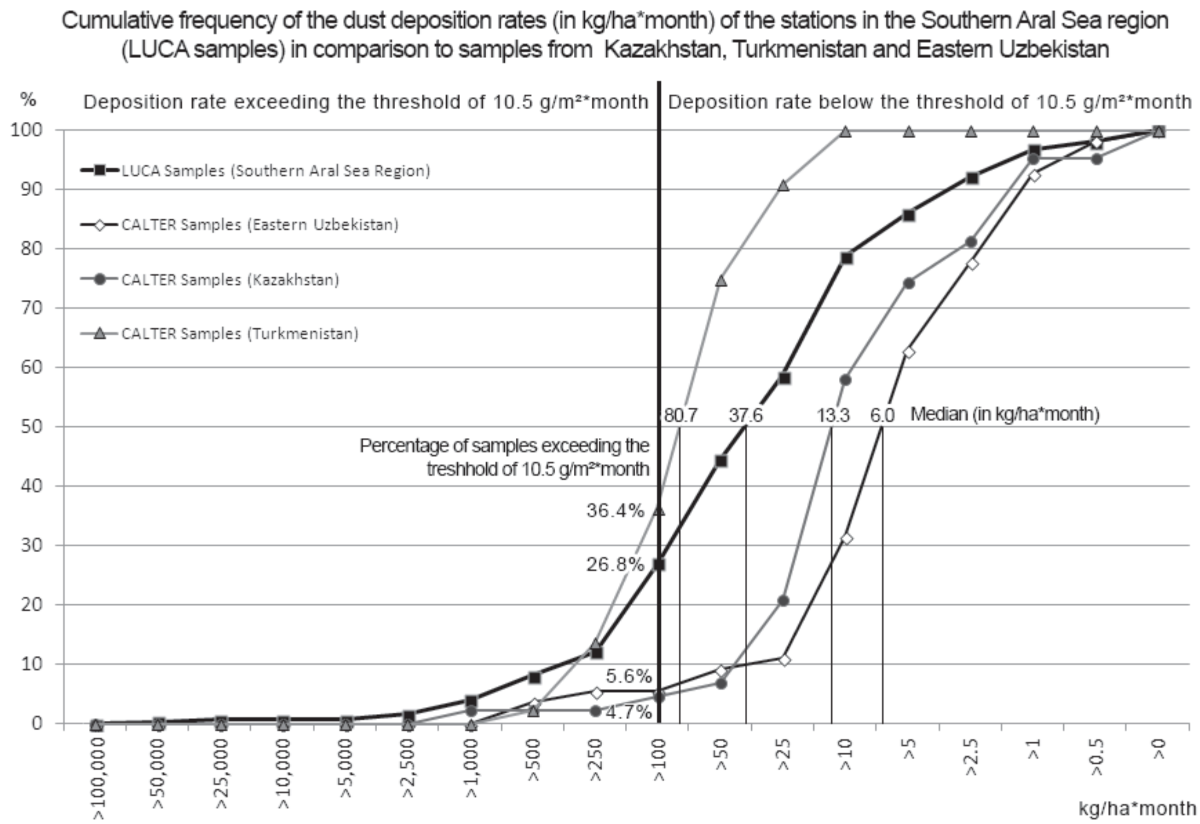
In order to discuss the characteristics of samples from different regions within Central Asia the cumulative frequencies of the dust samples from the Southern Aral Sea region, Eastern Uzbekistan (Bukhara, Ferghana, Nurata, Tashkent, Termez), Kazakhstan (Aralskoe, Dzhusali, Kazalinsk, Kyzyl-Orda) and Turkmenistan (Bokurdak, Darvaza, Kekir, Kunja-Urgench, Repetek, Schasenem) were analyzed (Figure 8).

Figure 7: Differences of the median monthly dust deposition rates and percentage of samples exceeding the health related threshold of 10.5 g/m²*month between the LUCA (2010-2012) and the CALTER (2003-2009) samples



The samples from Turkmenistan were overall characterized by the highest median deposition rate (80.7 kg/ha*month) and the highest percentage of samples exceeding the threshold of 10.5 g/m²*month (36.4%). As all Turkmen stations are located within or close to the Kara Kum desert, this shows the high importance of this local dust source for the dust deposition, which was also discussed by Groll et al. (2013a). The samples from the Southern Aral Sea region were characterized by the second highest median deposition rate (37.6 kg/ha*month) and the second highest percentage of samples exceeding the threshold (26.8%). The samples from the northern and eastern parts of Central Asia on the other hand were characterized by low median dust deposition rates (13.3 kg/ha*month in Kazakhstan and only 6.0 kg/ha*month in Eastern Uzbekistan) and very low percentages of samples exceeding the threshold (4.7% in Kazakhstan and 5.6% in Eastern Uzbekistan).

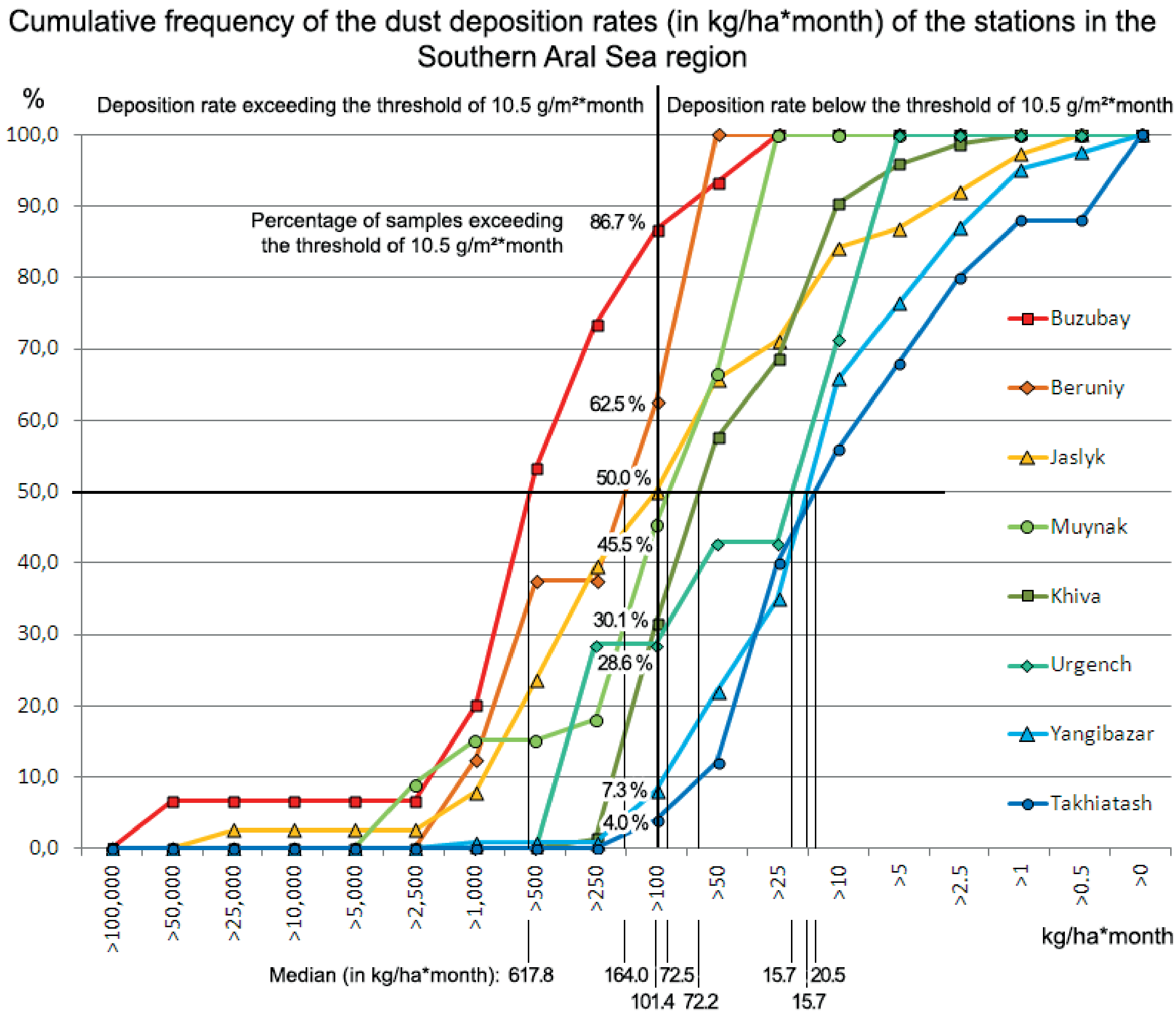
Figure 8: Regional differences of the cumulative frequency of the average monthly dust deposition rate



These results mirror the general climatologic properties of Central Asia where the western parts of the Turan lowland are extremely arid (resulting in more available source material for an aeolian transport) and the main wind directions are to the South (resulting in higher deposition rates at stations to the South of the Kyzyl Kum, Kara Kum and the Aral Kum deserts). The results thus show that the Southern Aral Sea region is most important for analyzing the effects of dust coming from the Aral Kum.

But even within the Southern Aral Sea region as one of the four datasets analyzed in Figure 8 the seven LUCA stations (plus Khiva as another station in that region which was only part of the CALTER project) showed a wide range of dust deposition patterns.

Fig 9: **Differences of the cumulative frequency of the average monthly dust deposition rate between the Southern Aral Sea stations**



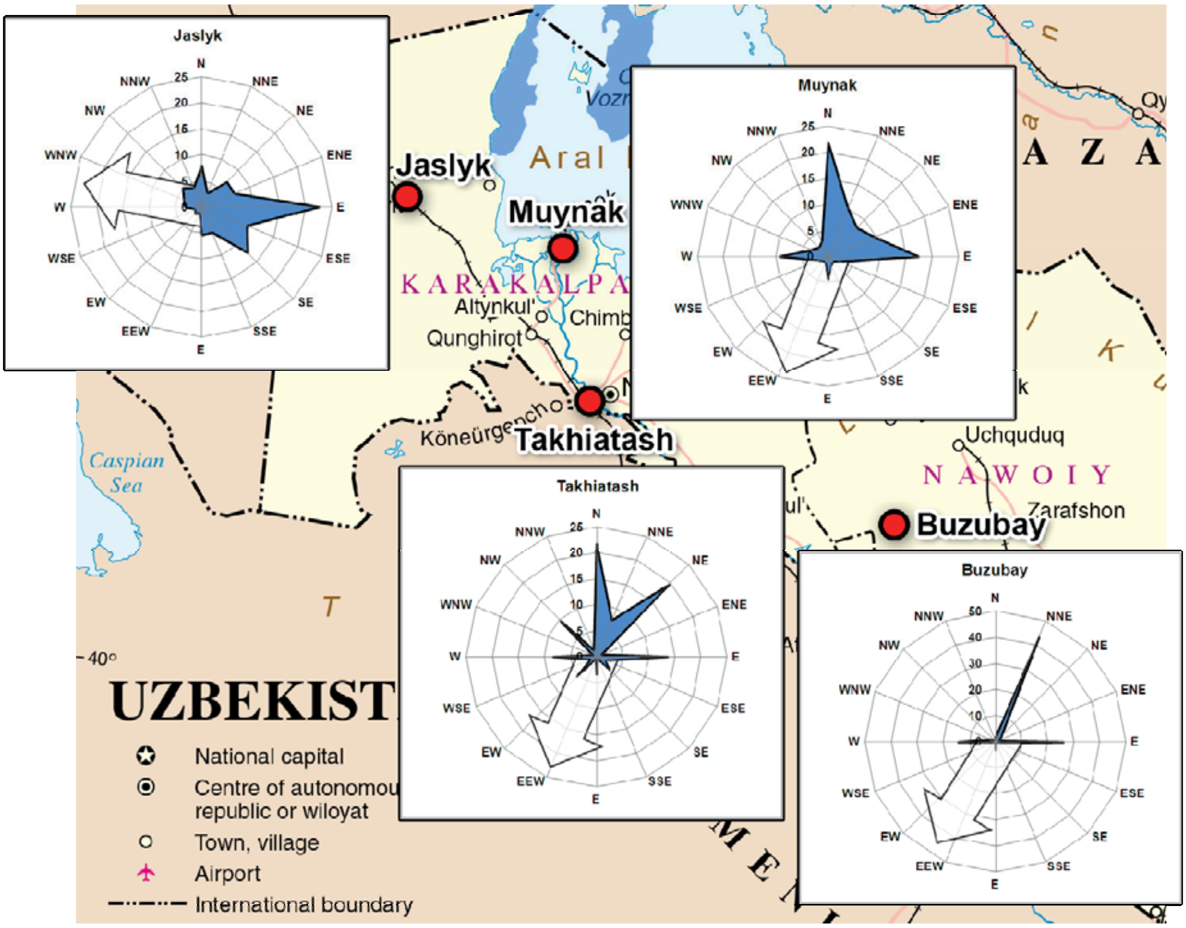
Buzubay stands out among those stations as it is characterized by the highest median dust deposition rate (617.8 kg/ha*month; and an average of 6970.8 kg/ha*month) as well as an extremely high percentage of samples which exceeded the threshold of 10.5 g/m²*month (86.7%) (Figure 9). As Buzubay is far away from the Aral Kum, the dust deposited here is coming from the Kyzyl Kum instead. This is further supported by the prevalent wind directions, which clearly indicates the Kyzyl Kum as the main source of dust at the Buzubay meteorological station (Figure 10). The stations closer to the Aral Sea, especially Jaslyk and Muynak, were characterized by relatively high dust deposition rates (with medians of 101.4 kg/ha*month for Jaslyk and 72.5 kg/ha*month for Muynak) and percentages of threshold excess (50.0% in Jaslyk and 45.5% in Muynak) as well, but those values were much smaller than the ones detected in Buzubay. The prevalent wind directions for those stations is very distinct from Buzubay so that the deposited dust is in truly originating in the Aral Kum (Figure 10). This means that both natural deserts (the Kara Kum for the Turkmen stations – see Figure 8 – and the Kyzyl Kum for Buzubay) are characterized by much higher dust transfer processes than the newly formed Aral Kum. The reason for this could be that the salty sediments on the bottom of the dry sea bed tend to form crusts which can be puffy (Orlovsky and Orlovsky, 2001) but still are resilient to aeolian entrainment (Genis et al. 2013; Langston and McKenna Neuman, 2005).

The stations Urgench, Yangibazar and Takhiatash, which are all located along the Amu-Darya river were characterized by very small dust deposition rates (with median deposition rates between 15.7 and 20.5 kg/ha*month and threshold excess percentages between 4.0% and 28.6%). Beruniy on the other hand, which is located very close to Urgench and Yangibazar, showed the second highest dust activity with a median deposition rate of 164 kg/ha*month and an excess of the threshold for 62.5% of all samples. These drastic differences between nearby stations illustrate that the dust deposition is not only determined by the long range transport from one of the three major dust sources but that it is also – and maybe even to a larger degree – influenced by the local conditions (land use in the surrounding of the station or the location of the station in relation to settlements). It can be speculated that the stations in Khorezm (Beruniy, Urgench, Khiva and Yangibazar) are influenced by both – the Aral Kum and the Kyzyl Kum as they are located halfway between those two deserts and that, in dependence of the major wind direction, the importance of both dust sources might vary over time.

Besides the pure dust deposition rates, the composition of that dust is important for analyzing its possible impact on the arable land and the human health.

The grain size analysis of the soil and dust samples in the Southern Aral Sea region showed a considerable variation from station to station. In general the soil surfaces were characterized by finer grains (clay and silt) than the deeper layers (Figure 11). Especially clay sized particles (= PM10 and smaller) are of the highest importance in terms of impacts on the human health but also on the vegetation as those smallest grains can easily infiltrate the respiratory system and clog the stomata of plants (BAuA (Ed.) 2001; Ochmann and Nowak, 2009; Razakov and Kosnazarov, 1996; Usmanov, 1998). On average the amount of clay (grains smaller than 0.002 mm in diameter) on the soil surface was 1.68 times higher than in 25-30 cm depth with Takhiatash (3.18x) and Beruniy (0.45x) being at the two ends of the spectrum.

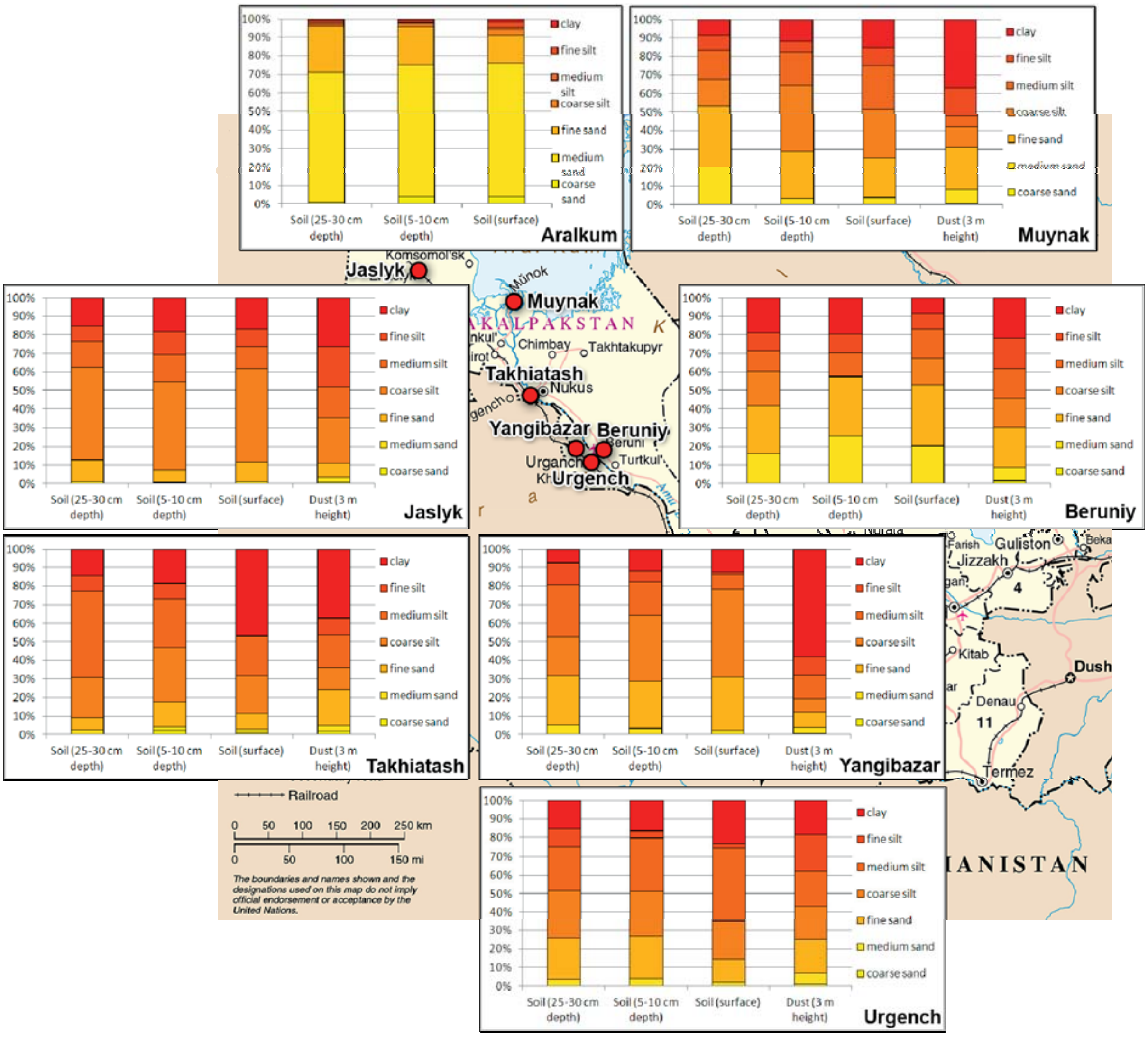
Figure 10: Wind directions in the Southern Aral Sea region (in averaged % of wind events detected at each station during the duration of the LUCA project)



(Data source: Uzhydromet; Base map: United Nations (Ed.) 2004)

The percentage of clay sized particles in the dust samples was even higher. On average one third (33.2%) of the dust particles were smaller than 0.002mm and the averages for individual stations ranged from 18.5% (in Urgench) to 58.2% (in Yangibazar). As those two stations are very close to each other, the differences in the dust composition cannot be explained by the long range dust transfer from the Aral Kum or the Kyzyl Kum deserts. Instead local factors are much more likely to have an impact on the dust deposition. A part of the samples from Yangibazar for instance were collected within a plantation and it can be speculated that the tree foliage was acting as a dust filter and that larger grains were retained before they could reach the dust sampler. Analyzing this aspect would be worthwhile but would require a more specialized research setup than the one used within this project.

Figure 11: Grain size composition of soil and dust samples in the Southern Aral Sea region

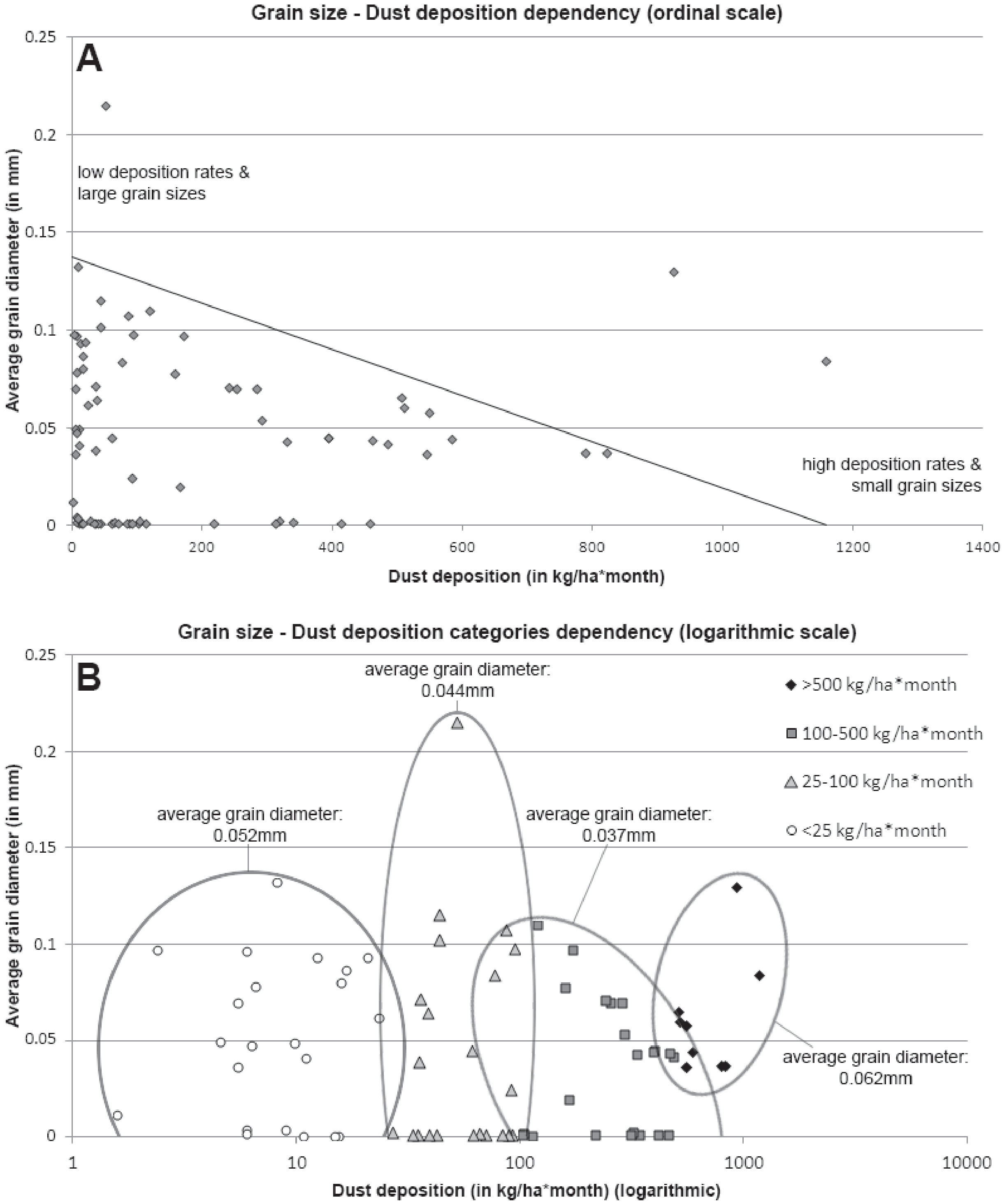


(Base map: United Nations (Ed.) 2004)

Another interesting aspect of the grain size composition is how it is related to the dust deposition rate. The expected relation would be that high deposition rates go together with larger average grain diameters. The reason for this is that high deposition rates usually occur at times with higher wind speeds (mostly dust storm events) and higher wind speeds mean that heavier (=larger) grains can be entrained and transported much easier than during smaller wind speeds (Goudie and Middleton, 2006). The results of this project however do not reflect this relation. On the contrary, low deposition rates seem to be related to larger average grain sizes than high deposition rates (Figure 12A). After grouping the deposition rates into 4 suitable categories and displaying the same results on a logarithmic scale this inverted trend could not be verified (Figure 12B) but all four deposition rate categories showed very similar average grain sizes so that, at best, the results of this study indicate that the grain size distribution of the dust is independent from the dust deposition rate and thus the intensity of the aeolian processes. Analyzing this in more detail could deepen the understanding of the dust deposition processes, but again, would require a more specialized research approach.

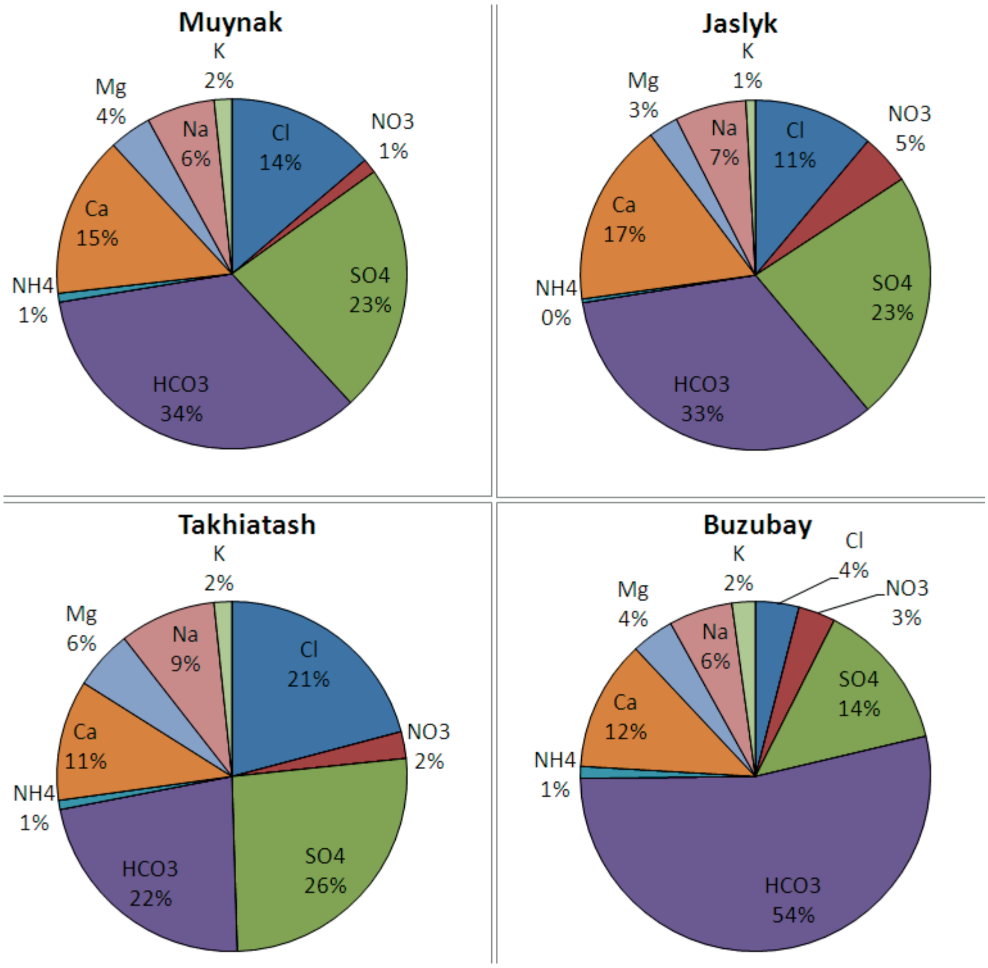
While the grain size of the dust determines how easily the dust can enter the respiratory system and the plants stomata, its chemical composition determines its potential for affecting the arable land in the location of its deposition. Figure 13 shows the concentrations of the most common elements found in the dust samples from four stations in the Southern Aral Sea region. The stations Muynak and Jaslyk, which are closest to the Aral Kum are characterized by a very similar elemental composition. In both stations bicarbonate (HCO_3^-) is the most common compound with concentrations of 34 and 33%. Bicarbonate forms salts with many elements also detected in the dust samples (especially with Na^+ and Ca^{2+}) and is the most common salt compound in water based systems. Calcium, which constituted 15 and 17% of the dust samples from Muynak and Jaslyk, can furthermore and in combination with SO_4^{2-} (23% in both stations) form gypsum ($CaSO_4 \cdot 2H_2O$) which is a common mineral in the Aral Sea basin and a mineral that precipitated early in the desiccation process of the Aral Sea (Létolle et al. 2005). Another salt detected in the dust samples was sodium chloride (NaCl) and this is also closely related to water based processes. Together, those salty compounds (Na^+, Ca^{2+}, SO_4^{2-} and Cl^-) clearly show that the origin of the dust is the dry sea bed of the Aral Kum. The exact effects of this dust on the arable soils in the Southern Aral region can however not be quantified exactly, as the compounds are also geogenic to this region. For such an evaluation a reference soil profile (or an artificial sediment) would need to be analyzed in detail and the changes caused by the deposition would have to be monitored. But as the dust samples analyzed within this project consist almost completely of salty compounds it can be assumed that they will have a major impact on the soil salinity and on the salinization process in the Southern Aral Sea region. With an average dust deposition rate for the two stations Muynak and Jaslyk of 1,018 kg/ha*month and salt concentrations of almost 100% it is safe to assume that several metric tons of salt will be deposited per hectare each year in the immediate surroundings of the Aral Sea.

Figure 12: Dependencies between dust deposition rate (ordinal (A) and logarithmic (B)) and average grain diameter



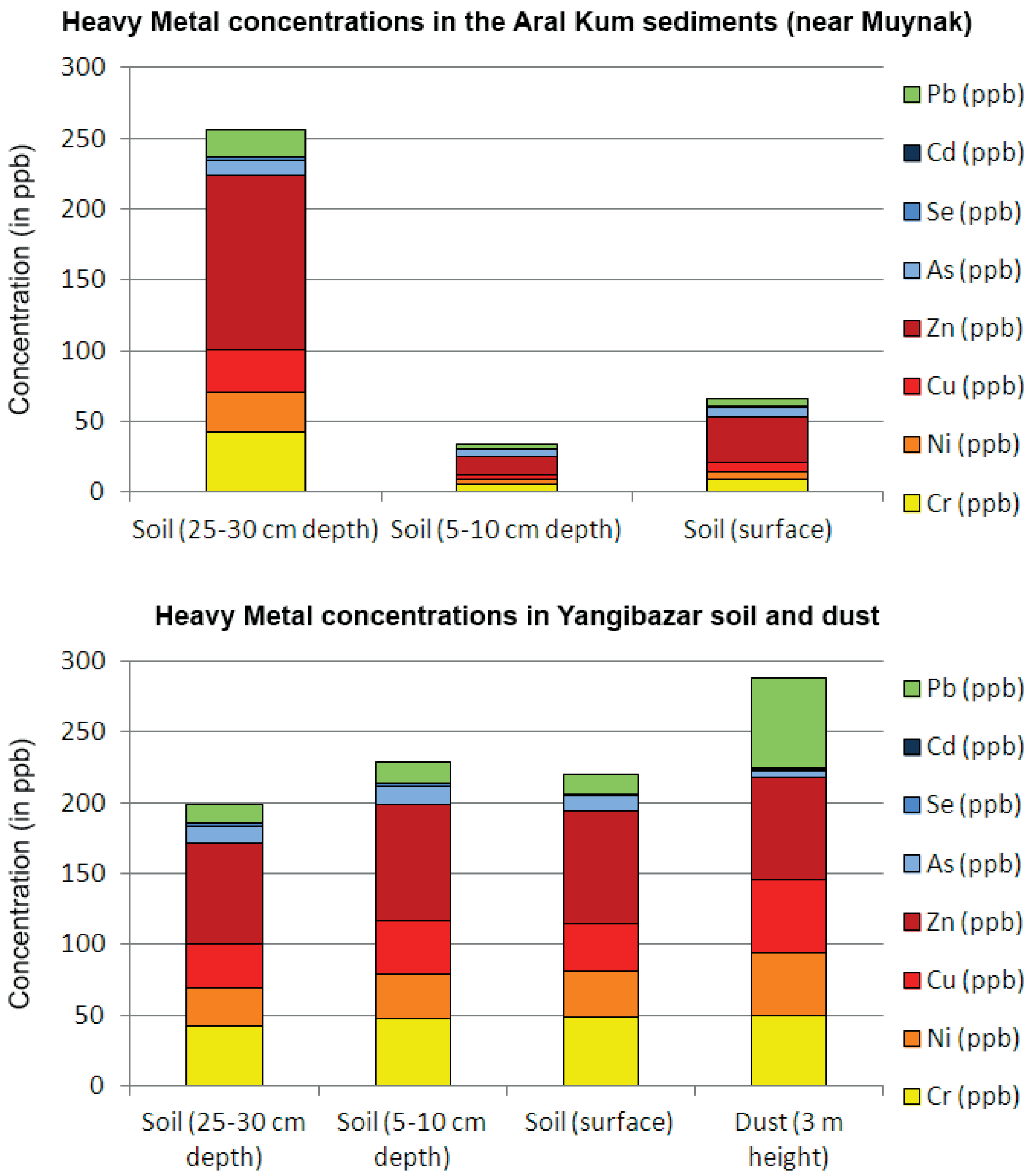
The station Takhiatash is farther away from the Aral Kum and the chemical composition of the dust deposited there is significantly different from the characteristics of the stations closer to the Aral Kum. The lower concentration of bicarbonate and the higher concentration of chloride are the most important differences. But if these differences are indicators for different deposition processes or dust source regions cannot be determined as the overall dust deposition rate in Takhiatash was much smaller than in all other stations – even in nearby stations. The differences could therefore be also the result of a selective deposition caused by local factors influencing the Takhiatash meteorological station. If the surroundings of the station would act as a dust filter (which then leads to a reduced deposition at the dust sampler), certain compounds could be retained easier than others (e.g. based on their preferences to form conglomerates), which then would alter the results of the chemical analysis. This again shows the importance of the local parameters on the results of such a large scale (=regional) monitoring program.

Figure 13: Chemical composition of the dust deposited in the Southern Aral Sea region



Buzubay, as the fourth station displayed in Figure 13, shows a unique chemical composition as the concentration of bicarbonate is much higher there (54%) than in the samples from all other stations. Furthermore, the amount of chloride is much lower in the dust deposited in Buzubay (4%) than in all other stations. This supports the results of the wind direction analysis which indicate the Kyzyl Kum as the main dust source for this station.

Figure 14: Heavy metal concentrations in soil samples from the Aral Kum (near Muynak) and in soil and dust samples from Yangibazar (in ppb)



In a final step the heavy metal concentrations in the soils at the meteorological stations were analyzed for three different depth levels (0cm (soil surface), 5-10cm depth and 25-30cm depth) and compared to the heavy metal concentrations in the dust samples. Exemplarily the results for the dust source Aral Kum and the station Yangibazar are displayed in Figure 14. Even though the Aral Sea had been the main sink for all pollutants transported with the water of the two large streams Amu-Darya and Syr-Darya, the heavy metal concentrations in the Aral Kum sediments were not significantly higher than in the soils of the meteorological stations in the Southern Aral Sea region. Furthermore, the top layer and the surface of the Aral Kum were characterized by very low heavy metal concentrations while the deeper layer showed much higher concentrations. This could mean that most of the heavy metals from the top layer have already been deflated during the last years. But it could also mean that the heavy metals contained in the Aral Sea already precipitated at a very early stage of the desiccation process and are now amassed in sediments below the 30cm depths analyzed here or that the desiccation process included a vertical relocation of the heavy metals into deeper sediment layers. With the data available within this project this question cannot be answered, but they would be very interesting for future research endeavors.

The dust deposited at the Yangibazar station on the other hand was characterized by very high heavy metal concentrations with Zinc (72 ppb), Lead (63.8 ppb), Copper (52.2 ppb) and Chrome (50 ppb) being the most prominent. As these concentrations are much higher than in the Aral Kum sediments it remains unclear if the Aral Kum is indeed the main source of those chemicals. Local pollution sources (industrial and municipal) could superimpose those results as well as the procedures applied for the sample extraction, preparation and analysis.

The soil surface and the top layer of the soil are both characterized by a higher heavy metal concentration than the deeper layer. All heavy metals expect for Selenium showed a concentrations in the top layer which were 5 and 23% higher than in the deeper layer. The soil surface still showed an increased heavy metal concentration in comparison to the deeper layer, but the values were lower than in the top layer. This could mean that the heavy metals, which are deposited with the dust, are then relocated into the top soils over time.

Overall, the dust deposited in the Southern Aral Sea region is rich in salts and heavy metals and due to the large amounts deposited each year will have a definite and lasting effect on the arable land and on the human health.

4 CONCLUSIONS

The results presented here covered a wide range of aspects related to the aeolian dust transfer and the dust deposition in the Southern Aral Sea region. The collected ground data complement and validate the results gathered by other projects by the means of remote sensing and. The region south of the Aral Sea is directly affected by the dust deflated from the Aral Kum which was shown by both meteorological as well as chemical analyses. The deposition rates throughout the region vary from year to year as well as from month to month, but the available data showed that the dust activity is highest in summer and winter and that the harmfulness of the dust deposition increased over the last years. On top of this temporal dynamic the dust sampling stations also revealed a strong spatial dynamic. As expected, station which are close to the source regions of dust (the Kyzyl Kum and the Aral Kum) were characterized by much higher deposition rates than stations in a larger distance to the source regions. As stations which were located close to each other showed a large variance in their dust deposition rates, local factors (like the land use in the surroundings of a station) play a major role in the results as well. The results also showed that while the stations close to the Aral Kum were strongly affected by aeolian dust, both the Kyzyl Kum and the Kara Kum have a much bigger influence in terms of the quantity of dust transported in Central Asia.

The dust at all stations contained high percentages of clay sized minerals (PM10 and smaller) which indicates the long-range aspect of the aeolian transport and is the most harmful fraction of the dust, but the stations also showed a significant spatial variance in this regard. Further analyses showed that the grain sizes of the dust samples were not clearly related to the dust deposition rates and thereby to the wind speed, a surprising finding that could not be explained within the framework of this study. The chemical analyses revealed that the dust in the Southern Aral Sea region consists almost exclusively of salt compounds which will, due to the amount of deposited material, negatively influence the soil salinity in this region and accelerate the salinization processes. Furthermore, the heavy metal concentrations in the dust samples were higher than in the soil samples so that a negative impact pf the dust on the soil toxicity can be expected as well.

However, not all questions could be answered and several new questions arose which would be intersting topics for a future research project.

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RADAR REMOTE SENSING FOR ANALYZING OF MASS MOVEMENTS AND EARTHQUAKES IN SOUTHERN KYRGYZSTAN

K. TESHEBAEVA, S. ROESSNER, H.-U. WETZEL, H. SUDHAUS, H. ECHTLER, B. MOLDOBEKOV and A. ZUBOVICH

0 ABSTRACT

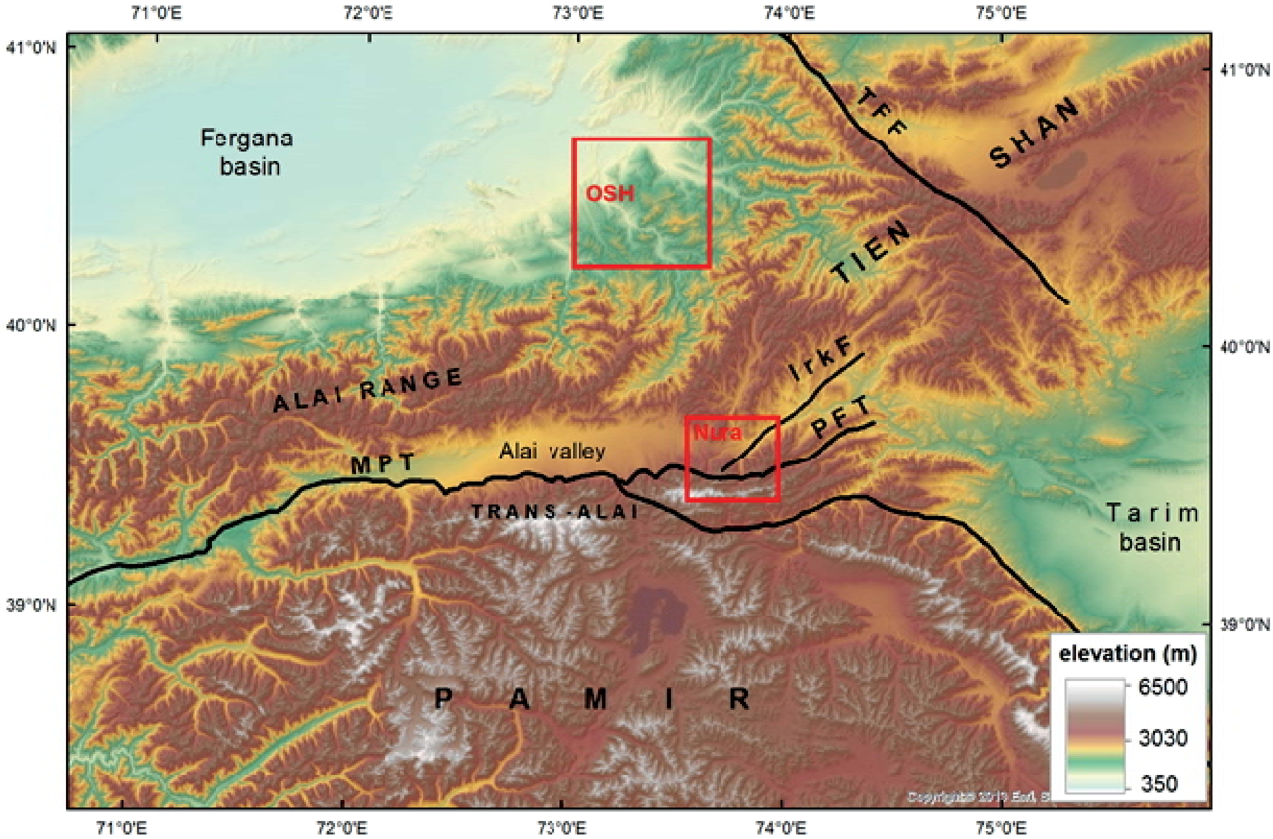
Southern Kyrgyzstan is a mountainous region affected by ongoing high tectonic activity leading to frequent occurrence of destructive earthquakes and mass movements. Since large areas are affected, there is a big need for efficient analysis and monitoring of these hazardous processes. In this study we use radar satellite remote sensing, in particular L-band ALOS/PALSAR and C-band ENVISAT imagery to analyze surface deformation related to earthquakes and mass movements by applying SAR interferometry (InSAR) and pixel offset techniques. We present two case studies: (1) The Nura earthquake which occurred on 5th October 2008 with magnitude 6.6 at the eastern termination of the intramontane Alai valley between the southern Tien Shan and the northern Pamir. Our SAR data analysis has revealed a spatially differentiated signal of the surface deformation related to the earthquake showing clear gradients in the vertical and horizontal directions along a complex pattern of surface ruptures and active faults. For interpretation of these results, we complement them with seismological data and geological field observations. (2) Monitoring of landslide prone slopes at the southern rim of the Fergana basin. We performed multi-temporal advanced InSAR time-series analysis and validated the results by optical remote sensing data and field observations. Our results show that InSAR techniques are capable to detect mobilizations of mass movements in a quantitative way and thus indicate areas which are especially prone to experiencing landslide failures in the near future. The results of both case studies show the high potential of radar remote sensing for efficient spatiotemporal process analysis in mountainous areas of Southern Kyrgyzstan.

1 INTRODUCTION

Kyrgyzstan is landlocked mountainous country of around five million people, which borders China, Kazakhstan, Tajikistan and Uzbekistan. The total area of high mountainous terrain, alpine meadows and pastures exceeds 70% of the Republic’s territory, whereas the greater part of the Kyrgyz Republic is occupied by the Tien-Shan Mountains. Kyrgyzstan is a highly active seismic region and has been shaken by numerous significant earthquakes as a consequence of the ongoing collision between the Indian and Eurasian tectonic plates. In the result, the mountainous country is faced with a large variety of natural hazards (mainly earthquakes, large landslides and floods) which frequently lead to the occurrence of natural disaster (e.g., 1994: about 1,000 landslides failed and caused 115 human fatalities; 2008: Nura earthquake M=6.6 led to74 human fatalities and 150 injured people, 90 glacial lakes endangered for regularly occurring outburst floods). Under these conditions, there is high demand for efficient and spatially differentiated hazard assessment requiring an improved understanding of natural processes with high hazardous potential. Since large areas with often limited accessibility are affected, satellite remote sensing plays an important role in contributing to improved process knowledge in this region (Roessner et al., 2005). In the presented work the potential of advanced remote sensing techniques based on Synthetic Aperture Radar (SAR) satellite data is investigated for characterizing spatio-temporal surface changes related to mass movement and earthquakes. Our study focuses on one study site of high landslide activity in the Osh province and on another study site which has been affected the most by the destructive Nura earthquake in 2008 (Fig.1).

Case study 1 – earthquakes: On 5th October of 2008, the 6.6 magnitude Nura earthquake struck Alai region, killing about 74 people, injuring many and destroying dozens of buildings in the southern province of Osh. The area most affected was the village of Nura situated in a mountainous region close to the border with China. Seismic shaking of this earthquake affected large parts of Southern Kyrgyzstan as well as the border region with Uzbekistan, Tajikistan and China. The Nura earthquake was recorded by a temporary seismic network deployed by the Tien Shan-Pamir Geodynamic Program (TIPAGE) (Sippl et al., 2013; Mechie et al., 2012; Krumbiegel et al., 2011) and the Earthquake Task Force group of GFZ Potsdam (German Research Centre for Geoscience). Using these data, Kalmetieva et al. (2009) located the main shock and some aftershocks along the NE-SW striking Irkeshtam fault, which was thought to have ruptured during this earthquake. The fault is exposed close to Nura village (Figure 1). In contrast to Kalmetieva et al. (2009), Krumbiegel et al. (2011) and Sippl et al. (2013) located the Nura main shock at a shallow centroid depth of 4 km along the east-west striking Pamir Frontal thrust (Figure 5, 8). Their main-shock location suggests that the Nura earthquake ruptured part of the Pamir Frontal thrust, instead of the Irkeshtam fault. This assessment is further supported by their moment-tensor solution pointing to a clear east-west oriented fault plane related to a thrust earthquake. Because of the described discrepancies in locating the Nura earthquake and the complex structural setting of this region, our remote sensing and field-based study investigates the locus of the faulting and the corresponding surface expression of this earthquake.

Figure 1: Tectonic map of the Pamir – Tien-Shan region showing the active faults overlaid on the colour-shaded topographic relief based on SRTM data. The red boxes indicate the study areas: Osh and Nura regions. Main structures are: Main Pamir thrust (MPT), Irkeshtam fault (IrkF), Pamir Frontal thrust (PFT), Talas-Fergana fault (TFF).



The area near to the town of Gulcha is especially affected by landslides. On 26th April of 2004 a large landslide occurred in the vicinity of the village of Kainama. This combined rotational slide/flow-type mass movement reached a high speed and the displaced masses crossed the Budalyk river and covered parts of the village of Kainama resulting in 33 victims. Danneels et al. (2008) have carried out more detailed post-event investigations of this landslide in order to better understand its failure mechanism. They found that most likely a combination of the effects of seismic shaking together with changes in the groundwater level has triggered this destructive mass movement. They also reported that during the last 10 years prior to their investigations about 15 big landslides each covering between 20.000 and 950.000 m2 had developed in the area near the town of Gulcha (Danneels et al., 2008). Field investigations which have been carried out by the GFZ Potsdam since 1998 confirm these findings and show that landslide activity has been continuing to date in this area. Under these conditions, there is high demand for efficient and spatially differentiated assessment of the development of slope failures. Therefore, this area represents an ideal study site in order to investigate the potential of multi-temporal satellite remote sensing for detailed spatio-temporal analysis of landslide activity.

2 METHODOLOGY AND REMOTE SENSING DATA

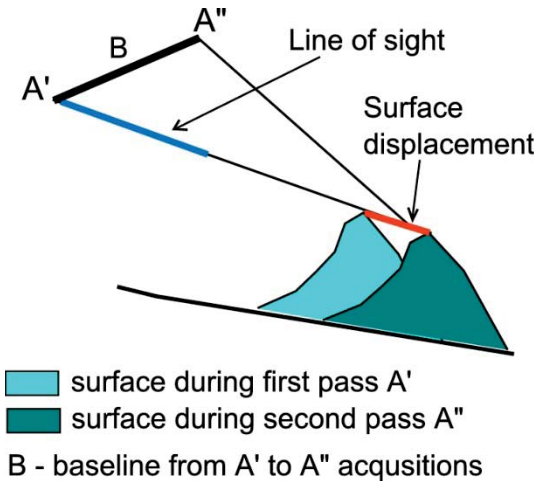
Methodological focus has been put on using Synthetic Aperture Radar (SAR) data acquired by different satellites for detecting surface displacements as a consequence of earthquakes and slope instabilities in Southern Kyrgyzstan. Radar remote sensing as a so-called active remote sensing technique is based on microwave radiation. The radar system (antenna) emits non-optical microwave wavelengths ranging from a few centimeters to more than one meter. The same antenna records the returned signals after they have been backscattered from the Earth’s surface. In comparison to optical remote sensing, radar has the advantage of being independent from clouds and daylight. The first civilian satellite-based radar remote sensing systems have become wider available at the beginning of the 1990-ies (e.g., ERS-1, JERS-1) whereas their number and quality have steadily increased since then. Based on these data various analysis techniques have been developed. One group of methods focuses on multi-temporal analysis of SAR data for quantitative assessment of surface displacements comprising Differential SAR Interferometry (D-InSAR) and pixel offset techniques. In this study we use both methods for analyzing surface displacements which are related to earthquakes and landslides in Southern Kyrgyzstan. We complement our remote sensing analysis by field investigations in order to validate and interpret our SAR-based results.

2.1 Differential SAR Interferometry

The InSAR (Interferometric Synthetic Aperture Radar) is a powerful image analysis technique which has successfully been used for geophysical monitoring of a wide range of processes representing potential natural hazards. They include earthquake-caused surface rupturing and deformation as well as mass movements resulting from landslides (e.g. Wright et al., 2001; Fialko et al., 2005; Notti et al., 2010; Zhao et al., 2012; Strozzi et al., 2013). In the result InSAR has emerged as a widely used method for spatially continuous detection and mapping of surface deformation. InSAR allows quantification of deformation causing topographical changes in the range of centimeters by analyzing differences in the phase component of the radar signal recorded by the remote sensing sensor.

The geometric principle of SAR interferometry is illustrated in Figure 2. This technique requires repeated data acquisition from slightly differing data recording positions (A’ and A’’). In case a topographic change has occurred between consecutive data acquisitions, the related surface displacement can be quantitatively derived in the direction of the line of sight of the sensor (Figure 2). This way, the obtained displacement indicates whether the amount of movement has occurred towards or away from the satellite. SAR satellites move along ascending (from south to north) and descending (from north to south) orbits. In case of an ascending orbit, SAR observations are made from the west, whereas in case of a descending orbit, they are made from the east. In areas of topographically pronounced relief, images from both look-directions covering the same terrain are used in order to minimize no-data areas resulting from radar shadows.

Figure 2: SAR interferometry imaging geometry and surface displacement in the plane normal to the flight direction. The surface has moved between the first A' and second A" observations

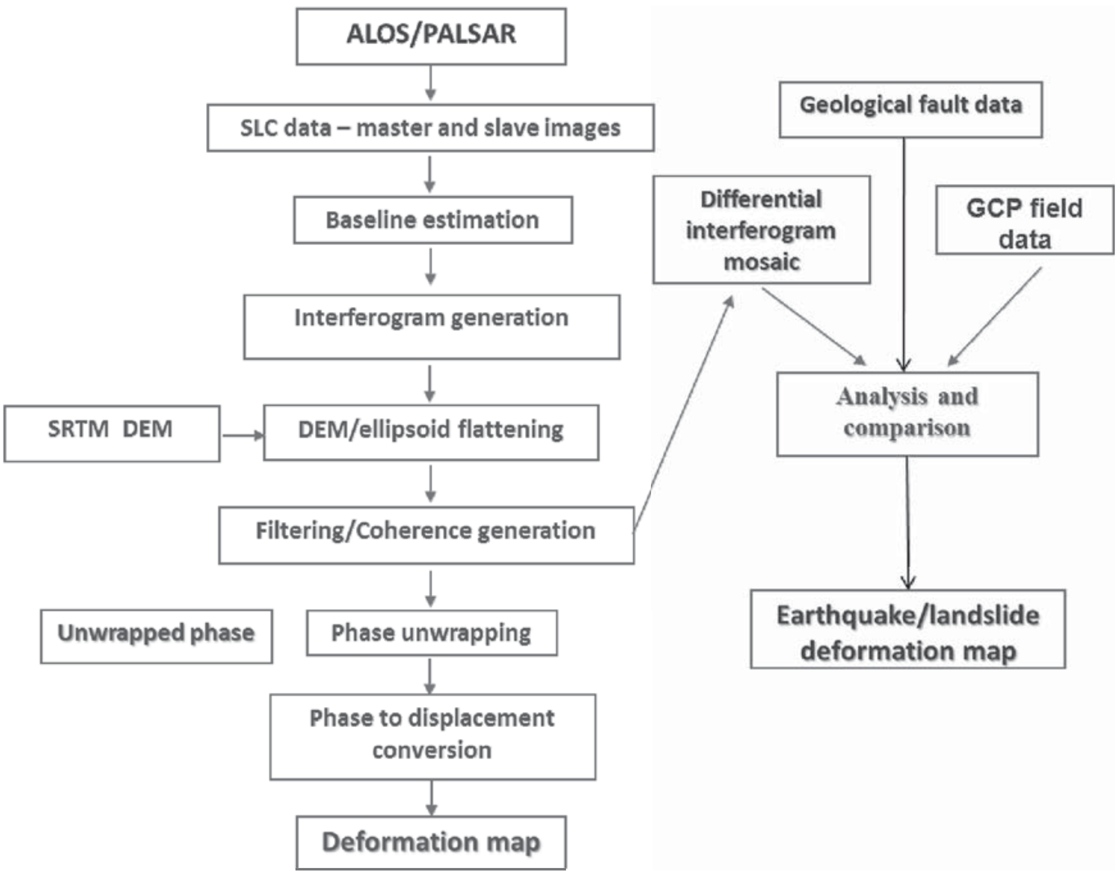


(Rosen et al. 2000)

The InSAR image analysis is based on calculation of the interferometric phase (Massonnet and Feigl 1998; Rosen et al. 2000) and comprises a multi-step procedure which is shown in a principle way in Figure 4.

Depending on the temporal repeat interval of InSAR data acquisition, deformation rates can be derived for time spans ranging between days and years by performing time series analysis in order to determine slow and temporal uniform deformation. The quality of the radar interferometry results is influenced by the size of the observing radar wavelength (Michel and Rignot, 1999). Shorter wavelengths are more irregularly backscattered from the surface increasing the noise part of the signal, whereas longer wavelength can penetrate not completely covered surfaces, such as vegetation leading to less noise in the returned signal. Another influencing factor is the overall similarity between the images of the different data acquisitions. Both of these factors are described by the interferometric coherence as mainly determining the quality of the interferometric measurement. Coherence is sensitive to microscopic object properties and to short-term scatter changes. The thematic information content decreases with increasing acquisition interval, mainly due to phenological or manmade changes of the object or weather conditions (e.g. Rosen et al. 2000). In case of a high dynamics of surface changes coherence can be reduced to the point of its complete loss making it impossible to apply InSAR techniques. In such cases the pixel offset method represents an alternative.

Figure 3: The flow of the interferometric processing of SAR images and surface deformation map



2.2 Pixel offset

Surface displacement may also be derived from the correlation peak of the amplitudes of the intensity images using the pixel offset method. The resulting pixel offsets represent two-dimensional vector displacements and are more robust against temporal decorrelation of the radar signal because they are based on the image intensity information. In order to obtain reliable estimates of the surface displacement, these image offsets need to be determined with sub-pixel precision (Michel and Rignot, 1999). Overall accuracy of this method is mainly determined by the size of the image pixels (spatial resolution of the sensor).

2.3 Used SAR data

In Nura earthquake study InSAR and pixel offsets processing has been performed using ALOS-PALSAR and ENVISAT radar data. PALSAR is an L-band sensor onboard the Japanese ALOS Satellite with a wavelength of 23.6 cm and the C-band sensor of the European ENVISAT satellite has a wavelength of 5.6 cm (Table 1). Thus, PALSAR uses a longer microwave wavelength which is known for achieving good coherence even in densely vegetated areas (Rosen et al. 1996). The ALOS data used in this study were provided by the JAXA ALOS Research Program (Proposal P610).

Different satellite mission hold various capabilities to monitor Earth surface depend on their properties. Table 1 shows TerraSAR-X and ALOS/PALSAR mission characteristics. The TerraSAR-X mission has high ground resolution due to its shorter wavelength and repeat cycle and thus more sensitive due to surface roughness. TerraSAR-X InSAR is capable to capture landslide process phenomena in more detail (Motagh et al 2013). In contrast to TerraSAR-X, the ALOS/PALSAR sensor emits a longer wavelength and thus is less sensitive to surface roughness and provides information on landslides process over longer period of time.

In landslide study InSAR analysis has been performed using ALOS/PALSAR radar data. A total of 26 ascending ALOS/PALSAR raw SAR data were received from JAXA covering the study area during the time period between 2007 and 2010.

Table 1. Satellite missions characteristics of the analyzed SAR data

Characteristics	TerraSAR-X DLR/Astrium	ENVISAT /ASAR ESA	ALOS/PALSAR Jaxa
Launch date	June 15, 2007	March 1, 2002	Jan. 24, 2006
Wavelength	X-band (31mm)	C-band(56mm)	L-band (236 mm)
Repeat cycle	11 days	35 days	46 days
Resolution	up to 3m (StripMap)	20m (ASAR)	7m to 44m (FBS Mode) 14 to 88m (FBD Mode)
One frame	30 x 50km		70 x 60 km

2.4 Case 1 – Nura earthquake analysis

SAR data for the Nura epicentral region have been available from the ALOS and ENVISAT satellites. We processed 16 ascending ALOS and 7 descending ENVISAT images spanning from 8 May 2008 until 20 August 2009, and we formed differential interferograms and pixel offset maps. Ideally, by combining ascending and descending sets of observations and pixel offsets, three-dimensional displacements can be measured in the affected area (Wright et al. 2004; Fialko et al. 2005). To provide ground truthing to the SAR-based surface displacement maps, we complement our remote sensing investigations by structural field observations guided by our SAR results.

We processed ALOS images and ENVISAT images, with perpendicular baselines of less than 300 m and temporal baselines of less than 14 months using the SARscape and the ROIPAC (Rosen et al. 2004) software packages. We then selected one interferogram from each look direction for further analysis. The chosen interferogram pairs provided optimal coherence and had short perpendicular baselines, which are 91 m for the ALOS and 131 m for the ENVISAT image pairs (Table 2).

In addition to SAR interferometry, we used pixel offset estimates between amplitude images of the coseismic data pairs in the azimuth and range directions to measure ground displacements. These pixel offsets were determined through a cross correlation of small subsets in the image, which provided measures of pixel shifts between the two images at a sub-pixel resolution. Pixel offset measurements in the range direction complement the interferometric displacement measurements because they give the component of displacement in slant range direction (Michel et al. 1998), the same projection as the ALOS interferogram, but they do not suffer from phase ambiguity (Fig.8). Pixel offset measurements in the azimuth direction, however, add a new displacement component that is purely horizontal in the satellite's flight direction. We estimated the offsets with window sizes of 64 and 128 pixels in the range direction and the azimuth direction, respectively.

Table 2. SAR scene acquisition information of the analyzed interferograms.

Pass	Track	Frame	Master	Slave	Perpendicular baseline between the orbits [m]	Incidence angle [degree]
ALOS/PALSAR						
Asc	527	780	2008/07/02	2009/08/20	90.01	34.3
ENVISAT/ASAR						
Desc	234	2817	2008/05/08	2009/05/28	131.494	23

2.5 Case 2 – landslide analysis

The InSAR method has already been successfully applied for landslide monitoring in a variety of environments (e.g., Squarzoni et al., 2003; Catani et al., 2005; Colesanti & Wasowski, 2006). In Southern Kyrgyzstan landslides have already been investigated by the InSAR method using the German X-band TerraSAR-X satellite (Motagh et al., 2013).

For this study InSAR processing has been performed using the SarScape software. For InSAR processing selected data pairs are with less than 300 m perpendicular baseline and a temporal baseline of less than 14 month. In total, 38 InSAR ALOS/PALSAR pairs from the ascending mode with an off-nadir angle of 34.3 degrees were processed and interferograms were calculated. In the ascending mode observations are made from the west. Applying the InSAR method, only one-dimensional displacements in the satellite's line of sight can be observed (e.g. Rosen et al., 2000). Therefore, the resulting SAR interferograms only show such displacements where the surface moves towards or away from the satellite along this line of sight. The obtained InSAR results have been checked during subsequent field investigations. The obtained result has been compared with the findings of the TerraSAR-X based study (Motagh et al., 2013). The results from TerraSAR-X complement ALOS/PALSAR results adding new information for the 2009 on slope development history during 2007-2010. The TerraSAR-X InSAR analyses have been performed using images between May and November 2009 (Motagh et al., 2013).

3 RESULTS AND DISCUSSIONS

Our results from the InSAR and pixel offset analyses show capability of the techniques to map surface deformation of the two different natural hazards as earthquakes and landslides. In case of earthquake we measure co-seismic surface displacement and capable of mapping total affected area in not easily accessible areas as Pamir-Alai Mountains. In case of landslide phenomena the differential interferometry and time-series InSAR analyses provides slow and temporal deformation on slope mobilization.

3.1 Case 1 – Nura earthquake

For this study we selected suitable InSAR ALOS PALSAR datasets with less than 250 m perpendicular baseline and a temporal baseline with less than 30 month. In total, seven InSAR pairs were processed and interferograms were calculated. Additionally, suitable ENVISAT datasets were selected applying the same baseline constraints. In the result 10 descending ENVISAT images were processed.

Measuring the coseismic surface displacement using InSAR is challenging in this region of high topographic relief because of abundant areas of layover and all-season snow coverage. In this case, the ALOS data perform better than the ENVISAT data (Figure 4). The larger average radar-beam incidence angle of 39 degrees for the ALOS SAR sensor reduces layover in the interferograms compared to the 23 degrees incidence angle of the ENVISAT SAR sensor.

Furthermore, the L-band data are less sensitive to small changes on Earth's surface and corresponding changes in the backscatter characteristics compared to the C-band SAR data. Therefore, the L-band data preserve the coherence of the interferometric phase and backscatter characteristics over longer time spans. Although the ENVISAT data seem to be less suitable for measuring the surface displacement in this environment, information on the different look angle of the descending orbit is important and complements the ascending track data from ALOS (Wright et al., 2004).

In the ascending ALOS interferograms, we observe a clear coseismic surface displacement north of the footwall of the Pamir Frontal thrust and at the hanging wall of the Irkeshtam fault. We observe widespread motion away from the ascending sensor and a strong signal of movement towards the ascending sensor north of Irkeshtam fault. At these locations, we measure large and sudden changes of negative and positive line-of-sight displacements that amount to approximately -24 cm and 48 cm, respectively. In the corresponding descending ENVISAT interferogram, we observe widespread motion towards the satellite north of the Irkeshtam fault, with up to 6 cm of line-of-sight displacement (Figure 4, 5). Such large differences in the measured line-of-sight displacements between the ascending and descending images are to be expected only for a considerable amount of E-W horizontal surface displacement. In both interferograms the phase gradients increase from north to south towards the Irkeshtam fault. At the fault the gradients are discontinuous and the phase coherence is lost abruply towards the south and the high mountains. These observations point to surface rupture. Far-field surface displacements of the surface can be observed in the south. The ENVISAT data show a positive to negative phase shift, whereas these movements seem to be not prominent enough to be captured with L-band data from ALOS (Figure 4).

The pixel offsets add new information at and south of the Irkeshtam fault, where no InSAR data are available (Fig.5, 6). In addition to strong atmospheric disturbances, our offset measurements using the ALOS data show a sharp displacement discontinuity across which the surface movement is in the opposite direction. The boundary length of this feature extends continuously for approximately 25 km in a northeast-southwest direction, and this is identical with the strike of the Irkeshtam fault. The purely horizontal azimuth pixel offsets show, similar to the range pixel offsets, a clear discontinuity parallel to the Irkeshtam fault (Figure 4, 6). They show that south side of the Irkeshtam fault is displaced northward with across-fault displacement of up to 2 m. The boundary length of this feature extends continuously for approximately 25 km in a northeast-southwest orientation and with high accuracy in the strike direction of the Irkeshtam fault, as mapped on the regional geological maps (Figure 8).

Figure 4: ALOS (top) and ENVISAT (bottom) interferograms over a shaded relief show the line-of-sight (LOS) surface displacement close to the Nura earthquake epicenter (white star). The white dashed lines outline the Pamir Frontal thrust (PFT) and the Irkeshtam fault (IrkF). The inset in the top panel shows an enlarged image of the in white outlined area, where steps in the interferometric phase values point to surface rupture (Fig.7).

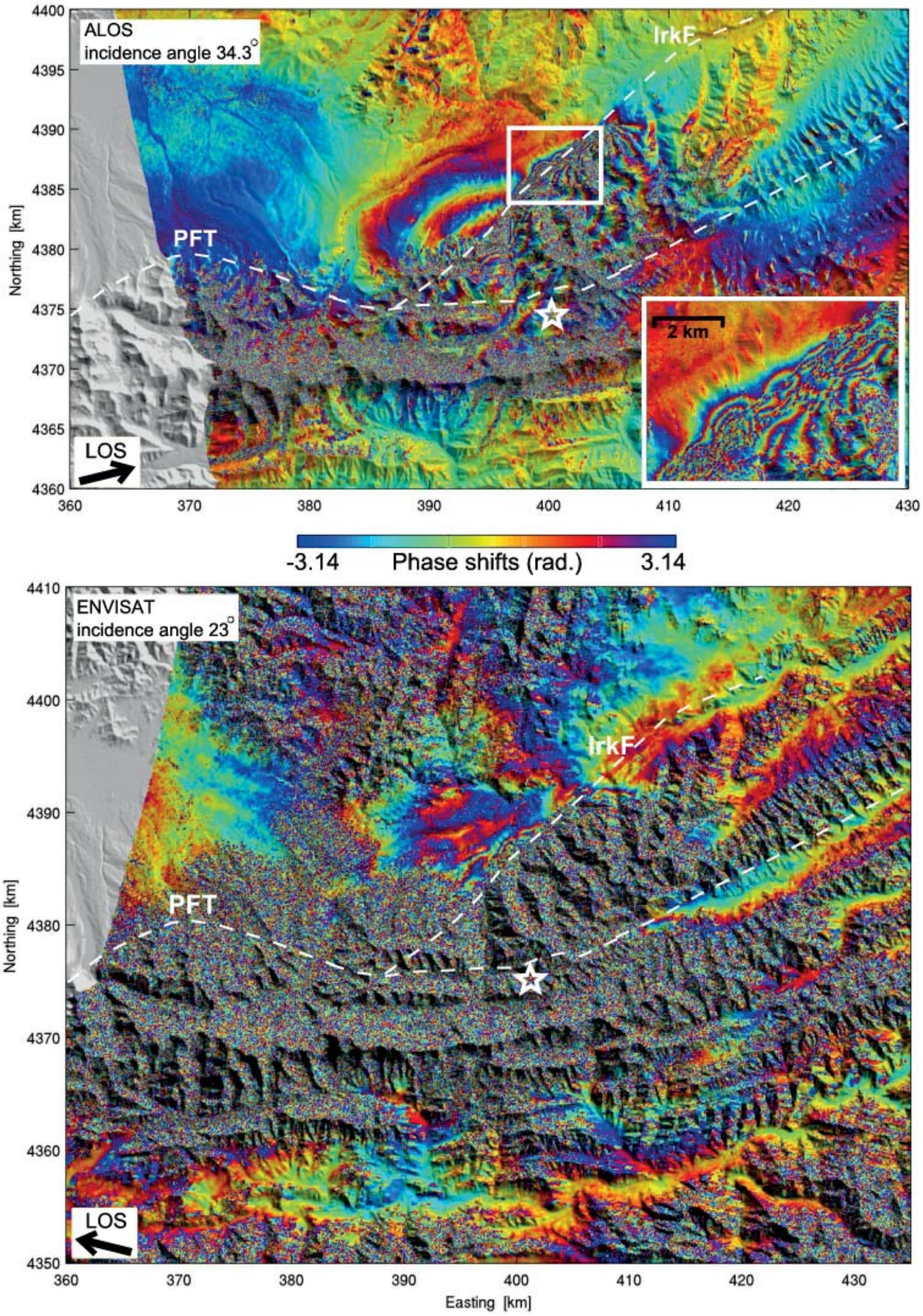


Figure 5: **ALOS interferogram close look for the deformed area verified from the field observations. Black arrows show location of the surface ruptures obtained during field investigations in 2012. Thick black arrow shows line of sight direction of the image acquisition.**

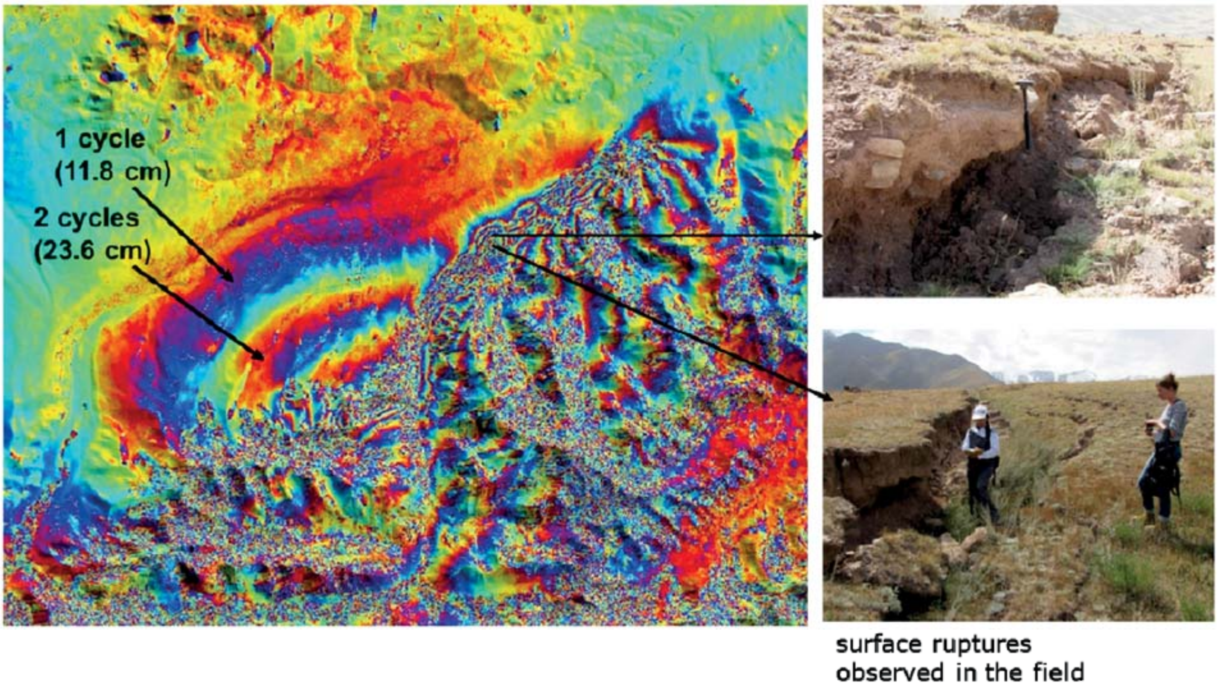
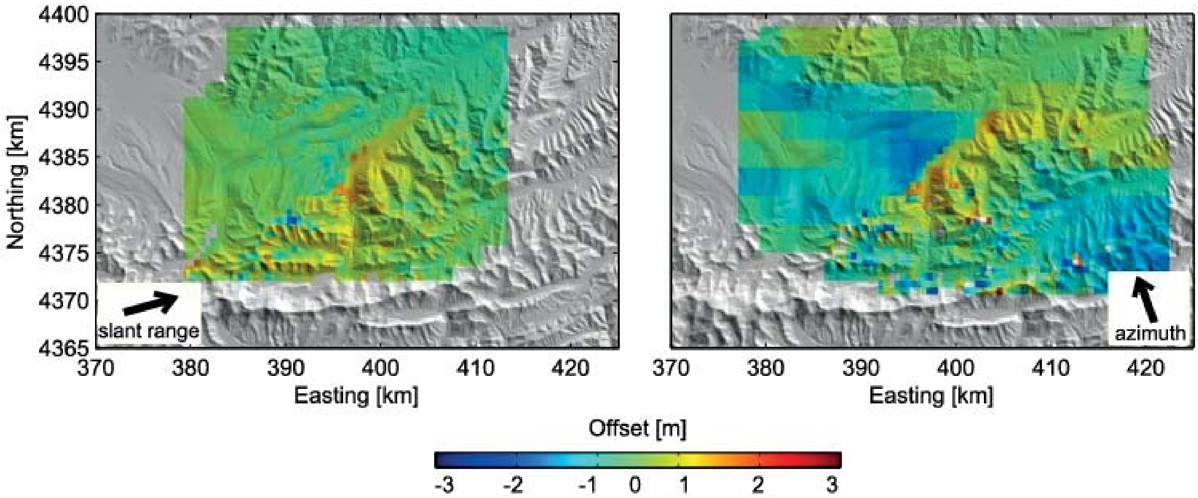
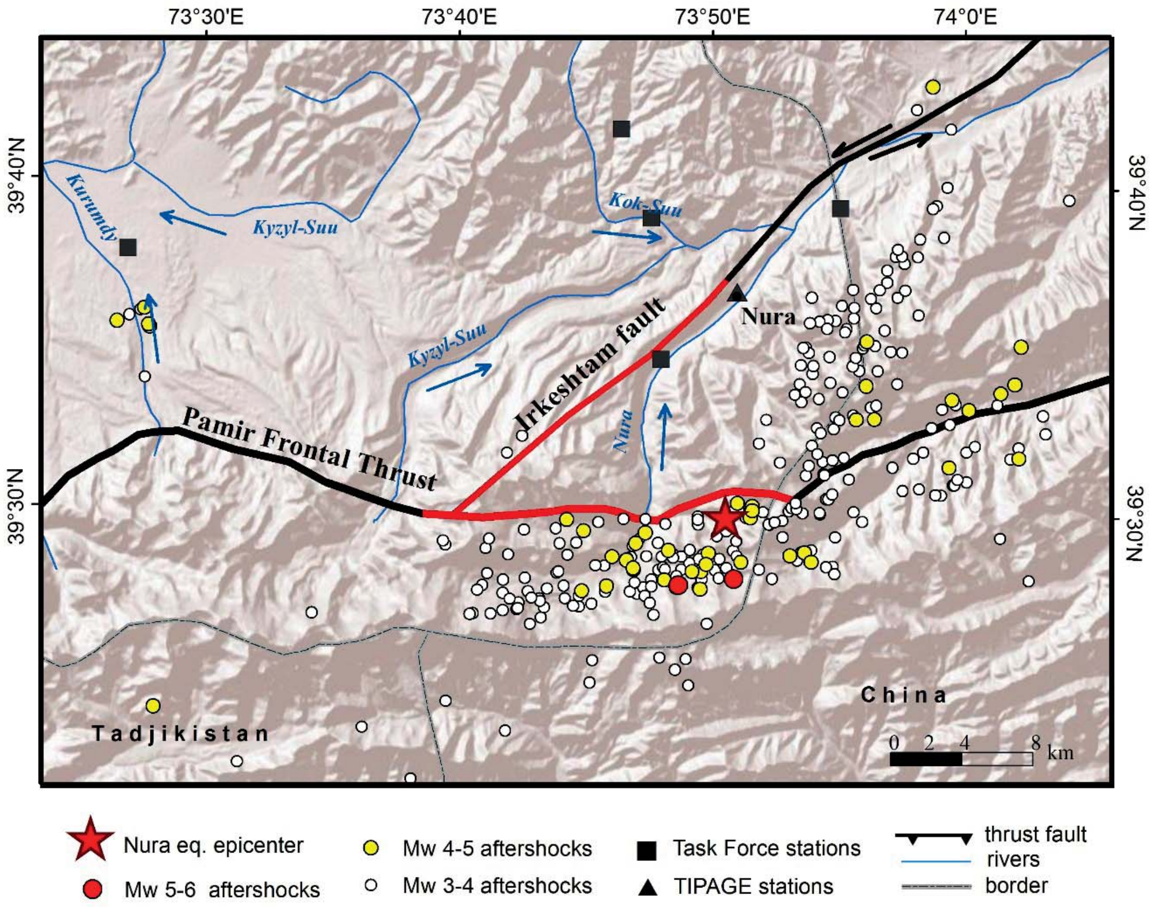


Figure 6: **ALOS range (left panel) and azimuth (right panel) pixel offset measurements. The range offsets are in the slant range direction (left panel, black arrow). Azimuth offsets give purely horizontal surface displacements in the direction parallel to the satellite flight direction (right panel, black arrow).**



Recent studies of Strecker et al. (2003), Burtman (2000), Arrowsmith and Strecker (1999), Burtman and Molnar (1993), Nikonov et el. (1983), Davidzon et al. (1982) reveal the active closure of the Alai Valley for late Pleistocene up to recent times which is concurrent with GPS data analysis carried out by Zubovich et al. (2010), Mohadjer et al. (2010), Reigber et al. (2001). Thus, these investigations underline the definition of the most active segment of the Pamir-Alay collisional structure.

Figure 7: Main and aftershock location map of the Nura region with the activated Pamir frontal thrust (PFT) and the Irkeshtam fault (red color). The main shock (red star) moment tensor and aftershock locations are after Krumbiegel et al. 2011.



3.2 Case 2 – landslides

The processed ALOS/PALSAR interferograms cover a time period of three years. They show very good coherence over longer periods of time (up to one year) and thus they can provide longer-term information on landslide process phenomena. The results of ascending interferograms are sensitive to mass movements occurring on eastward facing slopes.

Detailed visual analysis of these interferograms has shown that they mainly contain information on reactivation and mobilization of mass movements in areas which have already been affected by landslide in the past. Figure 7 shows thespatial distribution of surface displacement related to mass movements which were outlined based on the results of the InSAR analysis. The different colors of the polygons indicate different time periods of occurrence. So far, within the analyzed study area (Figure 7) 18 areas could be identified which are likely to have experienced slope mobilizations. Among those areas we have chosen the two test sites of Uzgen and Kainama (Osh province) to look more closely at our results from InSAR analysis (Fig.8).

Results from ALOS/PALSAR show longer-term mobilization between July 2008 and August 2009 of entire slope (blue to violet color) for the Uzgen test site (Figure 9). Figure 9 shows slow moving slope (blue to violet color) and indicate a large-area slope mobilization which has occurred during a longer period of time. These results demonstrate that ALOS/PALSAR data maintain very good coherence even during a longer period of time of more than one year in this mountainous and vegetated area. Thus, the data are suitable for mapping mobilization of slopes related to landslides. In order to better understand the InSAR results for the Uzgen slope, we compared them with results which were obtained by analyzing optical remote sensing data (Rapid-Eye and ASTER). They comprise visual mapping of the main scarps (outlined in cyan) as well as the displaced masses (outlined in yellow) of already existing landslides. All of these results as well as a true color visualization of RapidEye data have been overlaid on a perspective visualization of a DEM (Digital Elevation Model) derived from stereoscopic ASTER data (Figure 9). Comparison of these results with results obtained by TerraSAR-X data analysis (Figure 9) shows that spatially limited mobilization could be detected in the same area for an 11-day time period falling within the longer time period which has been analyzed based on the ALOS/PALSAR data. These results indicate that the ALOS/PALSAR interferogram represents the cumulative surface displacement for the whole analyzed time period showing a reactivation of the entire slope. In contrast, the TerraSAR-X based results show the mobilization of a small part of the slope during a short period of time. However, also this area is part of a reactivated slope. Thus, it can be concluded that the results obtained by the two independent systems are consistent and can be used complementary in order to assess short- and longer-term landslide activity in this area.

Figure 8: **Overview of landslide area in Osh province with selected Uzgen and Kainama test sites. InSAR results from ALOS/PALSAR overlaid on shaded relief from ASTER DEM. The outlined polygons in different colors show results from InSAR time series analysis during 2007-2010 period of time (Figure 10).**

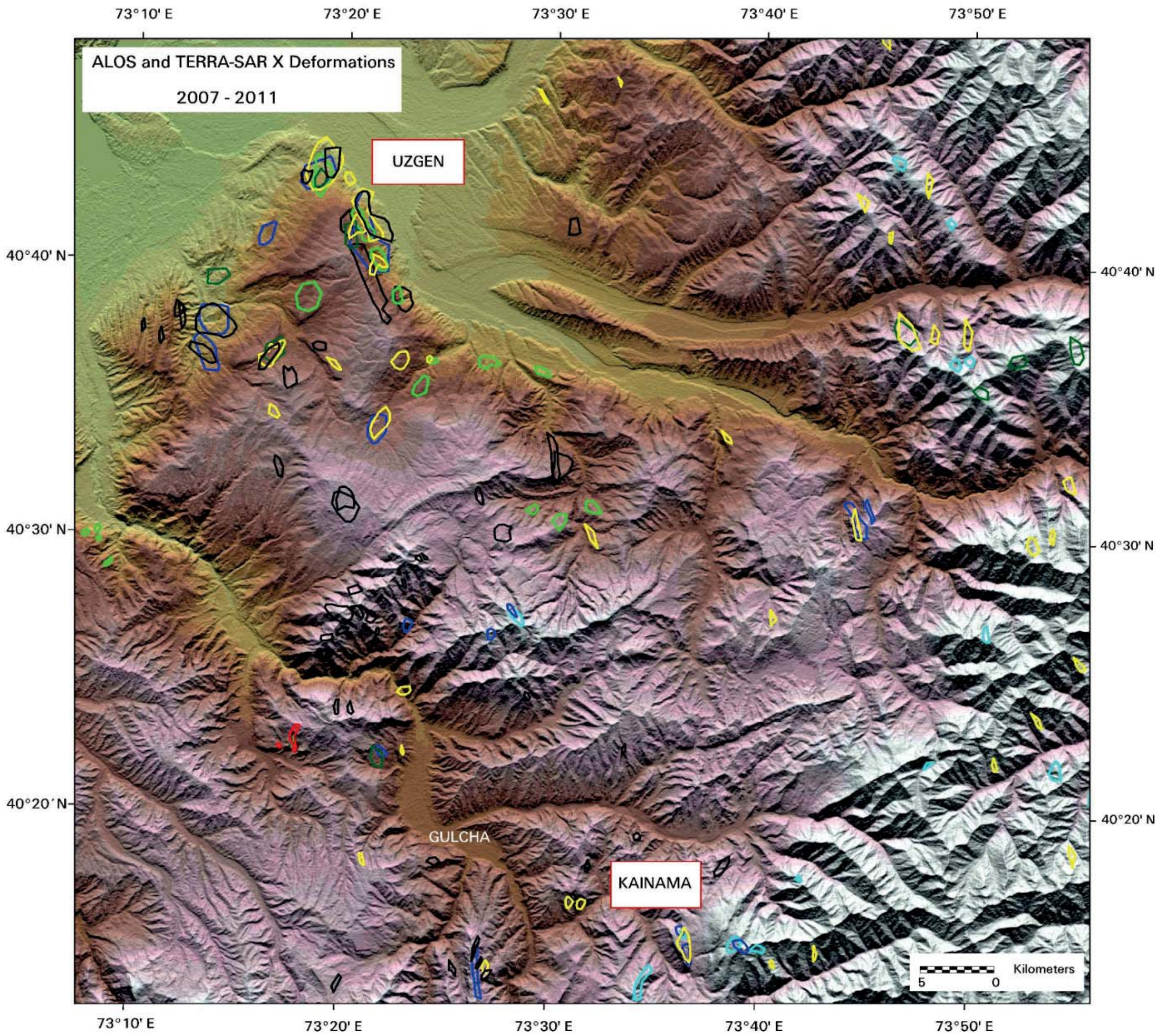
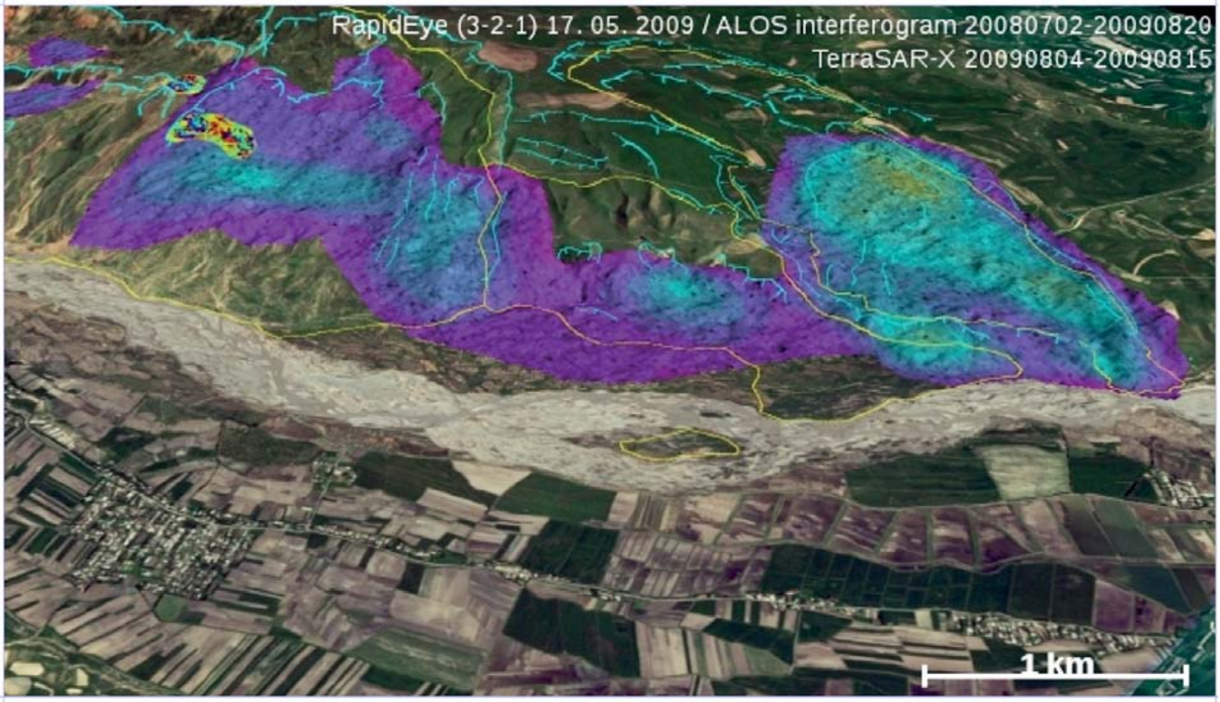


Figure 9: View of landslide prone slope near Uzgen, Osh province. Results from ALOS/PALSAR show longer-term mobilization between July 2008 and August 2009 of entire slope (blue to violet color) in comparison with TerraSAR-X results showing a local short-term slope mobilization during a 11-day period in August 2009 (upper left corner color changes from green to red).



The area of the Kainama landslide system has experienced the highest landslide activity during the analysed time period between 2007 and 2010 (Figure 8, 10). The obtained results have been verified for the surroundings as well as for the Kainama landslide system itself during field investigations carried out in September of 2011 and 2012 (Figure 10, 11). These findings have shown that the results obtained by the L-band ALOS/PALSAR satellite can also be used in this area in order to assess longer-term landslide activity. They still need to be investigated in more detail also using results obtained from interpretation of optical satellite remote sensing data. However, the obtained results are in accordance with results from earlier studies (Danneels et al., 2008) indicating a continuous landslide activity in the area of the Kainama landslide system. They emphasize the need for regular monitoring of slope mobilization as part of hazards assessment in this region.

Figure 10: Osh province, Kainama landslide system and surroundings. The highlighted green to red colour patches indicate areas of surface deformation related to mass movements which have been obtained from ALOS/PALSAR interferometry for different time periods between 2007 and 2010. The yellow and red circles indicate the sites of field checks performed in 2011 and 2012.

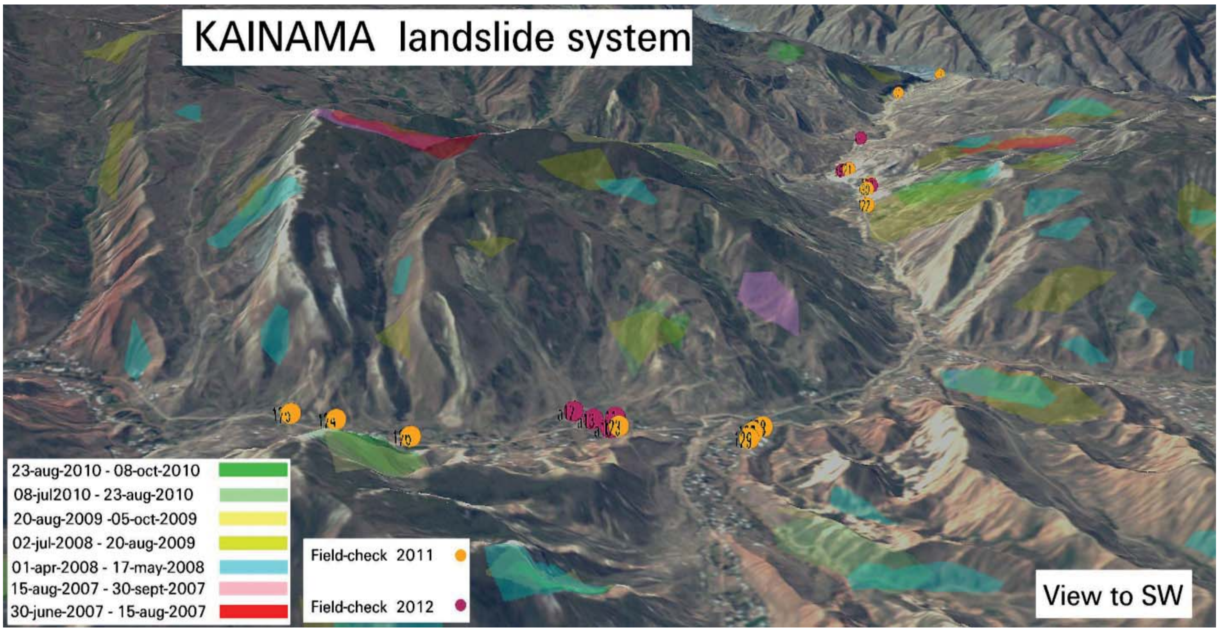
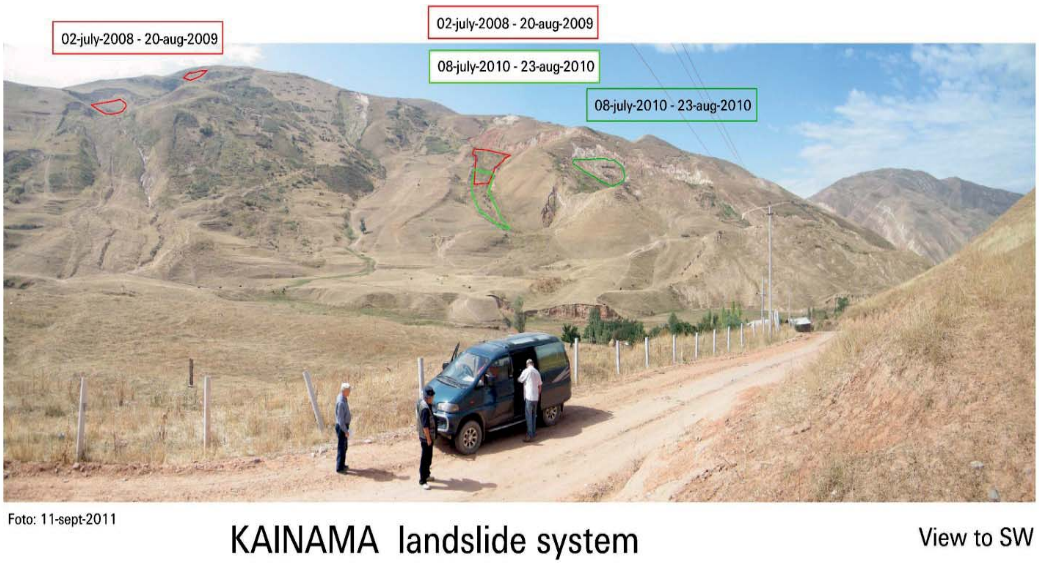


Figure 11: Field photograph of the Kainama landslide system taken during September 2011 field-check of InSAR results. The areas outlined in green and red colours indicate the areas where slope mobilization has been detected by InSAR analysis.



4 CONCLUSIONS AND RECOMMENDATIONS

In our study, we have demonstrated the usefulness of advanced remote sensing InSAR and pixel offset techniques for analyzing surface displacements which are related to earthquakes and landslides in Southern Kyrgyzstan. Both process types have a high hazardous potential and thus, they need to be better understood in their spatio-temporal consequences. The obtained results have been further analyzed in combination with geological information, seismological data, field observations and the results of visual analysis of optical remote sensing data in order to enhance the understanding of the analyzed processes related to active tectonics in a structurally complex continental collision zone.

Case 1 – Nura earthquake

We found that the 2008 Nura earthquake Mw 6.6 ruptured an imbricated thrust system. This thrust system is part of the Pamir Frontal thrust in the eastern convex transition of the Trans Alai range, where it collides with the Tien Shan to the north. The Irkeshtam fault was coseismically activated by the Nura earthquake, as documented by prominent surface ruptures and fractured boulders along the trace of the rupture; meanwhile, the earthquake nucleated at the back-range Pamir Frontal thrust. The Nura earthquake thus caused dip-slip thrusting and sinistrally-oblique thrusting on the kinematically connected Pamir Frontal thrust and the Irkeshtam fault. This event presents an example of coseismic strain partitioning in a tectonically active collision zone, which is characterized by northward orogenic wedge migration toward the Tien Shan Mountains.

Case 2 – Landslides

We demonstrated the principle capability of InSAR analysis based on ALOS imagery for quantitative monitoring and mapping of surface displacements related to landslides for larger areas. InSAR time-series analysis has resulted in information on slow and temporally uniform slope mobilizations which have occurred during a time period of three years (2007-2010). Further analysis of these results in combination with already existing information about landslide activity in this area has shown that most of the obtained deformation represents reactivation of already existing landslides. The results have demonstrated the potential of InSAR for continuous landslide monitoring at a regional scale.

The obtained earthquake and landslide results show that the used advanced radar remote sensing techniques allow quantitative characterization of surface displacements over large areas and during longer periods of time. Thus, they have a big potential for supporting regular process monitoring as part of quantitative hazard and risk assessment as well as early warning in Kyrgyzstan and Central Asia. Since Southern Kyrgyzstan is seismically active region with frequently occurring earthquake and landslide that are endangering important human living spaces, remote sensing techniques are of special importance for the development of efficient strategies for dynamic and up-to-date hazard assessment. They greatly depend on the availability of suitable radar remote sensing data which in the past has been fairly limited for Central Asia. However, upcoming new satellite-based missions, such as Sentinel-1 (launch in April 2014) of the European Space Agency (ESA) and ALOS-2 (launch in May 2014) of the Japanese Space Agency (JAXA) will greatly improve data availability and open up new opportunities for the implementation of SAR-based monitoring systems in Central Asia.

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ECOHYDROLOGY IN A CHANGING ENVIRONMENT: FIELD TESTING OF DRAINMOD 5.1 IN SIMULATION OF GROUNDWATER LEVEL AND DRAIN OUTFLOW UNDER IRRIGATION MANAGEMENT IN FERGANA PROVINCE, UZBEKISTAN

SH.M. KENJABAEV, V.A. DUKHOVNY and H.-G. FREDE

0 ABSTRACT

This paper is part of the work given in the Dissertation titled “Ecohydrology in a changing environment”. To fulfill the part of objective (2) of the work: modelling relative impacts of different land use on water and matter fluxes, this study is aimed to analyze groundwater level fluctuation and drainage discharge affected by field level water and crop management in Fergana province of Uzbekistan. For that, hydrological performance of DRAINMOD 5.1 was field tested. The model was separately run to predict and compare groundwater level (GWL) for six fields with 14 crop growth periods as well as drainage flow for the three drainage parameters over 2009-2011. Once irrigation input was modified, the model was accurately simulated GWL response on irrigation rate. Predicted GWL were in good agreement with observed values for all crop years (mean absolute error, MAE= 8.8-25.2 cm; Nash-Sutcliffe coefficient, EF = 0.5 to 0.8 and the index of agreement, d= 0.79 to 0.93). The estimated drainage flow was shown to vary widely from measured values among individual drain fields depending on crop type, irrigation management and the distance from the outlet. Hence, high difference in flow rate between predicted and measured values resulted poor statistics. High heterogeneity of irrigation water supply for the crops grown in the fields limits the model application in arid/semi-arid conditions. The results of the study show that for the wider application of the model, it could be better to modify the irrigation module of the model.

1 INTRODUCTION

Agriculture in Uzbekistan, due to arid climate, relies heavily on irrigation, where about 90% of the water supply is used by agricultural sector for irrigation on roughly 4.2 Mha of land (CAWaterInfo, 2013; Aquastat, 2013). However, the sustainability of irrigated agriculture in the country is threatened by waterlogging and soil salinization. In addition, there is also increasing pressure on agriculture to cede a portion of its supply to meet the demands of an increasing population for domestic as well as industrial uses.

Rapid expansion of irrigated lands during 1960-1980 in Uzbekistan is followed by installation of drainage systems in response to water logging and salinity problems. Currently artificially drained area in Uzbekistan covers about 2.9 Mha, of which 19% (about 13% of country's irrigated land) constitutes subsurface drainage systems (Dukhovny et al, 2007). Depending on hydrological and economic conditions, the depth of subsurface drainage installation is usually 0.3-1.0 m deeper from the depth of active groundwater level (GWL) and space is not less than 50 m (Dukhovny et al., 2005; 2007). Most of these drainage systems were typically designed to discharge water continuously, without regard for the environmental consequences.

Environmental quality issues are significant in relation to irrigated agriculture. Subsurface drainage water quality reflects the ground water quality and soil water constituents of the soil being drained. Because of the soil salinization, inefficient irrigation and inadequate drainage, large amounts of waters are annually withdrawn from the rivers for land washing (so called salt leaching). This activity implies considerable volumes of return waters containing salts, agro-chemicals and trace elements to rivers and streams associated with the discharge of collector-drainage water (CDW) (Qadir et al., 2009; Ollson et al., 2013; Toryanikova & Kenshimov, 1999).

With a total cultivated land area of 476.000 ha and a population of 3.28 million people in 2011, Fergana province has the second highest population density of 485 inhabitant per km2 among other provinces of Fergana valley (CAWATERinfo, 2012). Such a high population density makes agriculture as main source of income in rural population (74% of total population). Hence, agriculture in the province is contributing 26% to Gross Regional Product (GRP) (average for 2001-2010) (OblStat, 2012).

Irrigation system in the province contributes 93% to the total water supply (in average for 1993-2011), whereas contribution of the pumped water from the vertical drainage wells and collector drainage network makes up 4.0% and 3.0%, respectively (OblGGME, 2012). However, low efficiencies of irrigation conveyance (0.55) as well as irrigation techniques (0.73) in the province (Ikramov, 2007) increase return water flow into the Syrdarya River. Water conveyance and field losses contribute to the formation of the CDW that ranged from 44 to 66% of total water withdrawal for agriculture during 1980-2011 (CAWATERinfo, 2012; OblGGME, 2012). Therefore, improved management of irrigation and drainage systems is very important to minimize water loss and return flow. Improved field water use efficiency enables to reduce canal water withdrawal; whereas conserved additional water then could be supplied for downstream users or environmental purposes. In addition, reduced drainage flows will result in less transport of salt and other pollutants to surface water, thereby improve overall water quality in the river ecosystem.

Modeling of the hydrology in artificially drained area can provide guidance to evaluate the potential role of irrigation water management in altering hydrologic fluxes through the irrigation-groundwater level-drainage relationships. Among the few models available for evaluation of drainage water management systems, DRAINMOD (Skaggs, 1980) is one of the most widely used. In the last two decades, many researchers have extensively been tested the model for different climatic conditions, soil types and farming practices. In these evaluations, the model was calibrated and validated against field measured GWL data (Gupta et al., 1993; He et al., 2002; Sinai & Jain, 2006; Yang, 2008), subsurface drainage flow data (Bechtold et al., 2007; Dayani et al., 2009; El-Sadek & Vazquez, 2012; Fernandez et al., 2007; Luo et al., 2010; Salazar et al., 2008; Singh et al., 2006; Wang et al., 2006), or combination of these both (Helwig et al., 2002; Skaggs et al., 2012; Tian et al., 2012). Although the model has been extensively used in different parts of the world to evaluate the hydrology of artificially drained lands, less is known in the arid regions, where irrigation is main pathway altering sub-surface hydrology. The overarching goal of this study is to understand how irrigation practice impacts sub-surface drainage flow in Fergana province of Uzbekistan. The specific objective of the study is to test the DRAINMOD 5.1 in simulation of GWL as well as drainage flow in irrigated agricultural fields on a daily basis. The analysis was based on two years (2009-2010 and 2010-2011) field work conducted at the fields cultivated with cotton, wheat and maize.

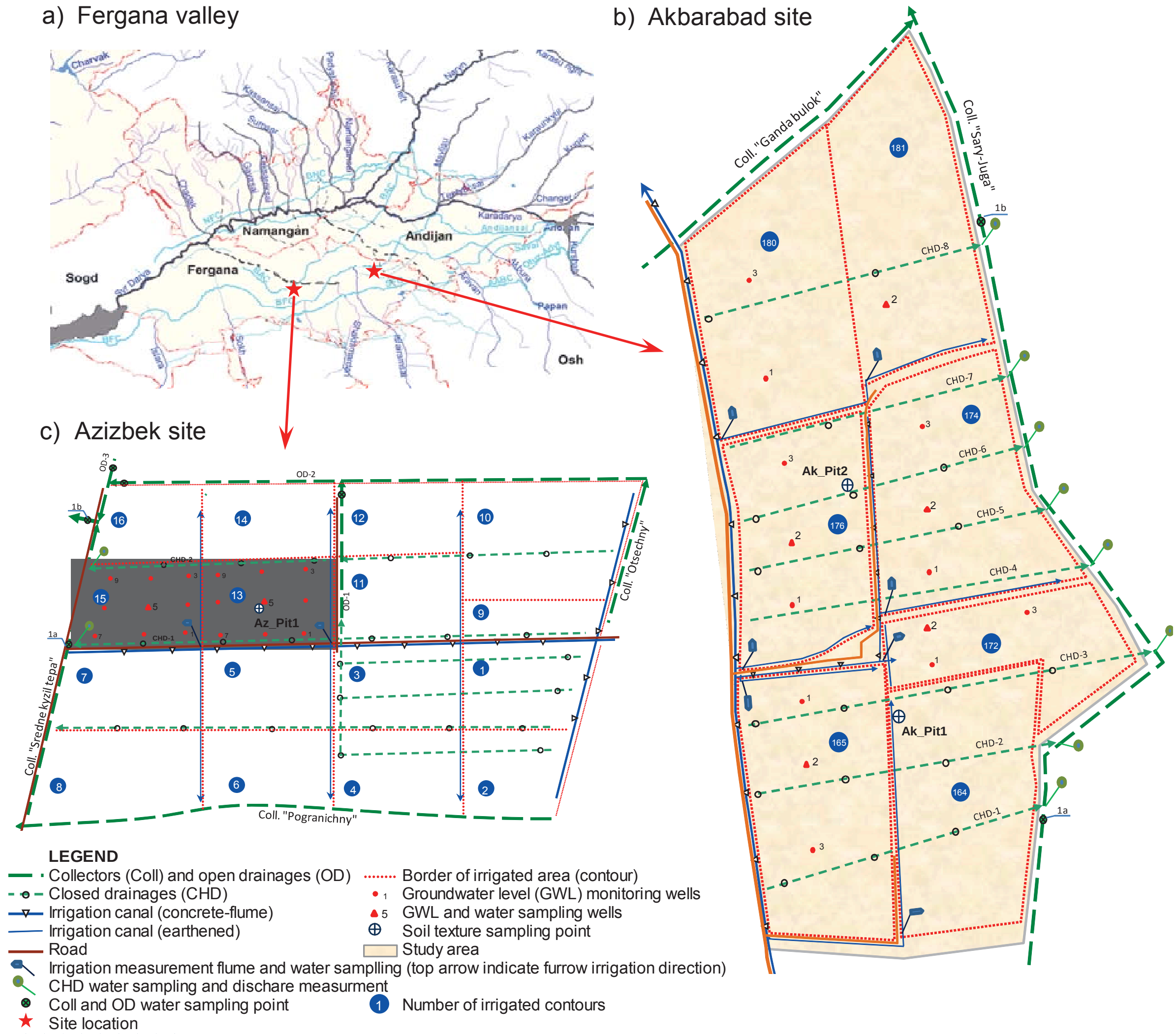
2 MATERIALS AND METHODS

2.1 Description of study sites

Two study sites, namely Akbarabad (40032’-40033’ N; 71056’ E) and Azizbek (40o28’N; 71o32’E) in Fergana province were selected (Figure 1). These sites vary with drainage design parameters and irrigation management practices. Eight closed horizontal drainages (CHD) with installation depth and drainage modulus of 2.2-2.3 m and 0.55-0.5 l s-1 ha-1 respectively are operating for seven agricultural fields in Akbarabad site (Figure 1b). Whereas two CHD with installation depth of 3.2 m and drainage modulus of 0.17 l s-1 ha-1 are serving for four fields in Azizbek site (Figure 1c). Average salinity (electromagnetic conductivity, EC) of the irrigation water sampled during 2010-2011 irrigation period in Akbarabad and Azizbek sites was 1.1 and 0.7 dS m-1, respectively. Return collector-drainage water and canal water is supplied for irrigation of the fields in Akbarabad and Azizbek, respectively.

The lands in the study fields are mainly flat and have a slope of 0.003-0.005. Groundwater level (GWL) and salinity (total dissolved salts) fluctuates within 1.0-3.0 m and 1.0-4.6 g l-1, respectively (Dukhovny et al., 2005; Nerozin & Babajanov, 2010; Stulina et al., 2005; Yakubov et al., 2006). Type of soil salinity in both sites are dominated by sulphate where the ratio of Cl:SO4 ranges within 0.1-0.2.

Figure 1: Fergana valley (a) and location of the study sites: Akbarabad (b) and Azizbek (c)



Source: Wegerich et al., 2012 (a); Own presentation (b) and (c)

2.2 Irrigation method and crops grown in the fields

The main crop rotation in the sites comprises cotton and wheat as well as secondary crop – maize following wheat harvest. Irrigation of cotton, winter wheat and maize was performed by alternate furrow (except charging irrigation), furrow-wise and mixed, respectively. Irrigation water, supplied for each field and surface runoff from the fields were measured by weir WCH-50. During 2009-2011, three to four irrigations with the total irrigation ranging from 280 to 500 mm, five to seven irrigations from 380 to 960 mm and two to four irrigations from 46 to 110 mm were applied during the growing period of cotton, wheat and maize, respectively.

For detailed description of on-site agronomic practices, climate and soil data refer to Kenjabaev et al. (2013).

2.3 Groundwater level and drainage discharge measurements

Three and nine shallow GWL monitoring piezometer-wells were installed in five fields (C-165, C-172, C-174, C-176 and C-180&181) and two fields (C-13 and C-15) in Akbarabad and Azizbek, respectively. GWL was measured with the frequency of 5 days interval and more frequent after irrigation. Besides of that, GWL with hourly measurement interval was also carried out by CAWa Project team in 2011 using data-logger-Odyssey (Dataflow systems Pty LTD, New Zealand), in order to assess irrigation impact on GWL.

Subsurface drainage (CHD) water depth was measured using the WCH-50 from the effluent point into the collector. Volumetric method using bucket (15 l volume plastic bucket with volume graduations) and stopwatch were also applied in Akbarabad site.

2.4 Description of the model

DRAINMOD model was developed to analyze the performance of drainage, sub-irrigation and controlled drainage systems based on the soil water balance. It estimates water table depth, soil water conditions, and drainage rates on a daily basis (Skaggs, 1980). Version 5.1 of the model was used in this study, considering the hydrological component only.1 In general, the hydrologic module, as main routine of the model, simulates the water balance on a unit of cross-sectional area extending upward from an impermeable layer to the surface, whilst the modeling point is located midway (L/2) between adjacent drains (Figure 2). The water balance for a time increment (Δt) may be written as (Skaggs, 1980):

$$\Delta Va = D_r + ET + DP - F \qquad (1)$$

where, ΔVa: change in the water-free pore space or air volume in the soil (cm); Dr: lateral drainage from or sub-irrigation into the section (cm); ET: evapotranspiration (cm); DP: deep percolation (cm); F: infiltration entering the soil profile (cm).

Subsurface drainage (Dr) can be calculated using Hooghoudt's and Kirkham's equations, which are applicable for both non-ponded and ponded surface conditions, respectively

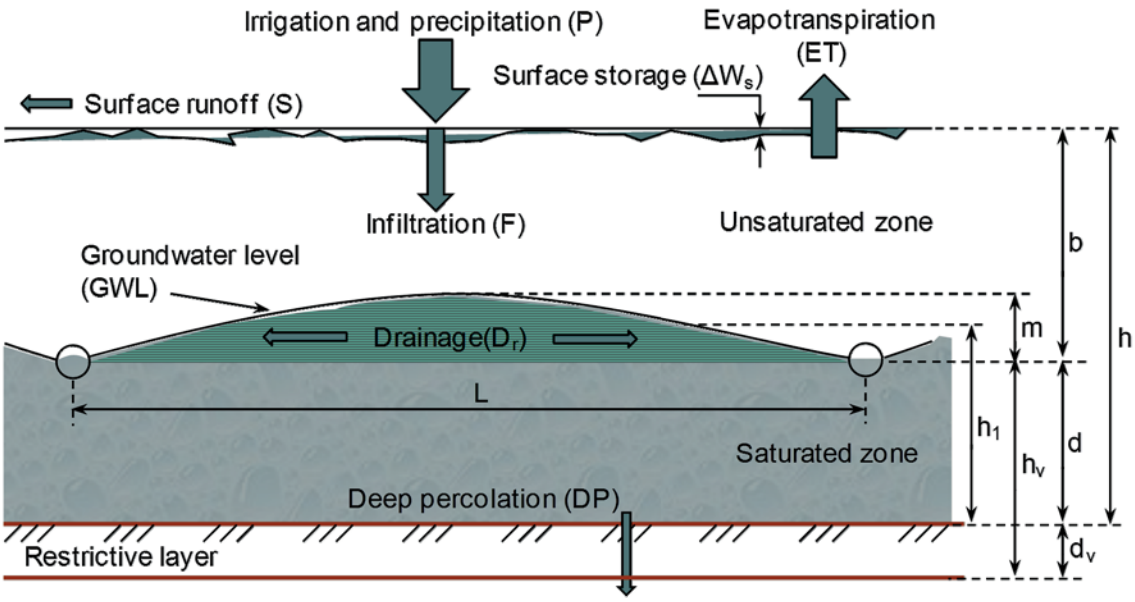
1 Other components are DRAINMOD-S (salt) and DRAINMOD-N (nitrogen) which simulate soil salinity affected by irrigation management and drainage system design as well as crop yields affected by stresses due to soil salinity (Kandil et al., 1995) as well as the movement and fate of nitrate-nitrogen (Breve et al., 1998). However, both sub-models are based on water balance calculations included in the hydrologic module of the model.

(Skaggs, 1980). When the depth of water on the surface is less than the surface storage (ΔWs), the Hooghoudt's steady-state equation may be written as:

$$q = \frac{8K_e d_e m + 4K_e m^2}{L^2} \qquad (2)$$

where, q: drainage outflow (cm hr-1); Ke: the effective lateral saturated hydraulic conductivity (cm hr-1); de: equivalent depth from the drain to the restrictive layer (cm), m: midpoint water table height above the drain (cm); L: drain spacing (cm).

Figure 2: Diagram of main hydrologic processes simulated in DRAINMOD



Note: shaded area (horizontal lines within the GWL and m curve) indicates water flow area into the drains considered in the model

Source: modified from Skaggs (1980) and Skaggs et al. (2012)

In calculation of drainage rate using the Equation 2, an assumption is made that lateral water movement occurs mainly in the saturated zone of the soil layer (the shaded area in Figure 2). Whereas underground water inflow and outflow as well as artesian water up-flux is not included in current version of the model, which could be calculated using the Ernst equation (Ritzema, 1994). Therefore, in the studies of Helwig et al. (2002), Ale et al. (2009) and Skaggs et al. (2012), the predicted drainage rate using the DRAINMOD became zero when the GWL fluctuated below the drainage depth (or midpoint water table height above the drain: m = 0 cm).

The potential evapotranspiration (PET) is estimated by temperature-based Thornthwaite method (ETT) using the latitude and heat index for the location along with daily maximum and minimum air temperature data. The estimated ETT can be adjusted on a daily or monthly basis by using daily or monthly ET factors2 in DRAINMOD. In addition, PET can also be entered into the model calculated by different methods (e.g., Penman-Monteith, ETPM). As a default, the daily PET is distributed over 12 hours between 6:00 a.m. and 6:00 p.m., and set equal to zero in case of rainfall (Brown et al., 2013).

Referring to the Figure 3, the rate of deep percolation (DP) through the restrictive layer is calculated using the Darcy's law (Skaggs, 1980):

$$DP = K_{satV} \frac{h_1 + d_v - h_v}{d_v} \quad (3)$$

where, DP: deep vertical percolation (cm hr-1), KsatV: effective vertical hydraulic conductivity of the restrictive layer (cm hr-1); h1: the average distance from the bottom of the restrictive layer to water table (cm); dv: thickness of the restrictive layer (cm); h2: the hydraulic head in the groundwater aquifer referenced to the bottom of the restrictive layer (cm).

Infiltration (F) is calculated using modified Green-Ampt equation (Skaggs, 1980):

$$f = \frac{A}{F} + B \quad (4)$$

where, f : infiltration rate (cm h-1); A (cm2 hr-1) and B (cm hr-1): parameters that depend on soil and plant properties, and rainfall (Yang, 2008).

Detailed description and examples of hydrology using DRAINMOD can be found in its Reference Report (Skaggs, 1980) and other literatures (Brown et al., 2013; He et al., 2002; Singh et al., 2006; Skaggs et al., 2012; Wang et al., 2006).

2.5 Model input parameters

The input data required to run the DRAINMOD hydrologic model are weather data, soil properties, drainage design parameters, crop parameters, irrigation and land trafficability parameters. Below brief information is provided for each parameter.

2.5.1 Weather data

The climatic input parameters such as daily precipitation, daily maximum and minimum air temperatures (including latitude, longitude and altitude) from "Fergana" weather station were used as model climate input data. Daily observed precipitation was evenly distributed over 5 hours starting from 6 AM using the utility program provided in the model (Skaggs et al.,

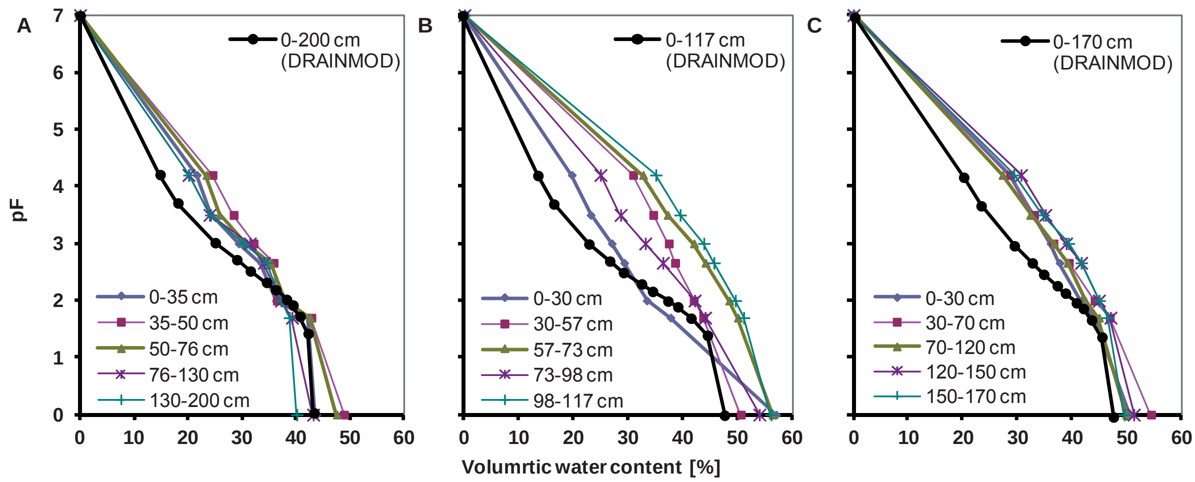
2 The monthly correction factors can be determined as a ratio of ETPM /ETT with minor adjustments (< 15%) to these factors (Skaggs et al., 2012).

2012). The PET was calculated using ETo Calculator (Raes, 2009) based on the FAO Penman-Monteith equation (Allen et al., 1998) and considered as model input.

2.5.2 Soil data

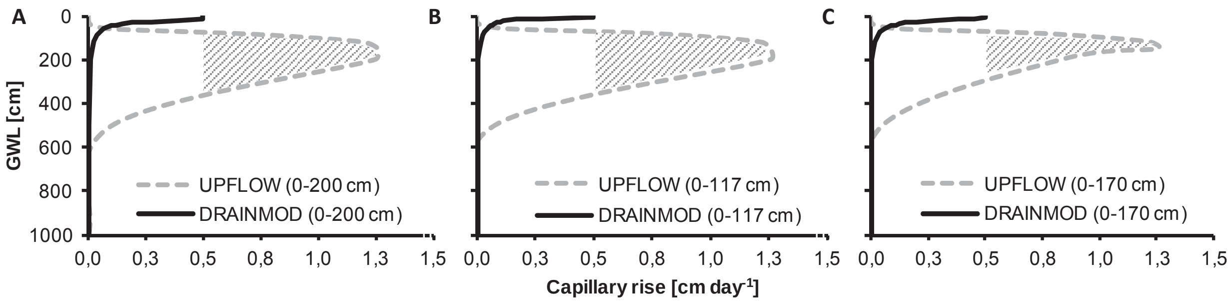
The soil profile having up to five distinct horizons, each with unique soil water content versus pressure head (pF curve) relationship, hydraulic conductivity and relationships between the GWL versus volume drained/upward flux/Green and Ampt infiltration parameters with a specific format (.SIN) are required to run the hydrology module of the model (Kale, 2011; Thorp et al., 2009). The SOILPREP program, provided in the model, was used to define these relationships through Rosetta estimated soil water retention parameters (WRPs1-5): θr, θs, α, n, L, Ko, and Ks (Salazar et al., 2008), which included all 5 WRP results from 3 soil data from Az_Pit1, Ak_Pit1&2 (see Figure 1 for pits location). The results of the SOILPREP program were compared with available and estimated data, e.g., pF curve with the laboratory results (Figure 3), GWL vs. upward flux from UPFLOW model (Figure 4) and GWL vs. field measured infiltration parameters. It is necessary to note, that capillary rise from the GWL of 0 cm was maximum (0.5 cm hr-1) for all WRP combinations using the SOILPREP program. The same estimations were reported by Bechtold et al. (2007) and Yang (2008). However, studies of Yang et al. (2007) showed that capillary rise was reducing after its peak and becoming zero at the GWL close to the soil surface due to wetness of the root zone, reduction of the crop evapotranspiration by an aeration deficit and mainly by downward movement of water (Raes & Deproost, 2003). Therefore soil hydraulic parameters were further calibrated due to uncertainty influenced by measurement errors and spatial variability within the field (Wang et al., 2006).

Figure 3: pF curve (averaged for whole horizon) estimated by SOILPREP (DRAINMOD) and weighed average for 5 layers from the laboratory measurements



Note: Az_Pit1 (A), Ak_Pit1 (B) and Ak_Pit2 (C)

Figure 4: The GWL versus upward flux estimations using UPFLOW and SOILPREP (DRAINMOD)



Note: Estimations are averaged for 0-200 cm, Az_Pit1 (A); 0-117 cm, Ak_Pit1, (B) and 0-170 cm, Ak_Pit2 (C). The shaded area in the curves is an extension of upward flux considering PET varying from 0.5 to 1.26 cm day-1 in UPFLOW model.

2.5.3 Drainage design parameters

Important drainage system design parameters include drain spacing (L) and depth (b), effective drain radius (re), depth to the impermeable layer (h), and weir settings for water table management. Additional inputs are also required to characterize down slope, deep and lateral seepages and surface storage (ΔWs). Hydraulic head of aquifer was taken 20-100 cm higher than GWL (Dukhovny et al., 2005). As Skaggs et al. (2012) proposed, most of these input data were directly measured in the field or obtained from drainage design reports and calibrated during the simulation run (Table 1). One subsurface drainage parameters in Azizbek site (CHD-2) and three in Akbarabad site (CHD-3, CHD-6 and CHD-8) were considered as model input owing to their location relative to the adjacent fields (see Figures 1b&c). The effective drain radius (re) was taken from Skaggs (1980) depending on actual radius of drains. The depth to impermeable layer (h) was assumed to equal collector’s bottom depth. A maximum drainage rate was taken as drainage coefficient that was observed during the study period (Skaggs et al., 2012). Soil surface storage capacity (ΔWs) was taken high (Skaggs, 1980) that considers frequent soil tillage practices in the lands. Hence, there is no groundwater control structure (applicable for sub-irrigation mode); the weir settings were equaled to drain depth (free drainage).

Table 1: Drainage design parameters

Drainage Parameters	Azizbek	Akbarabad	
	CHD-2	CHD-3	CHD-6
Drain depth,1 b (cm)	320	220	220
Drain spacing,1 L (cm)	25000	13000	12500
Effective drain radius,2 re (cm)	10	10	10
Depth to impermeable layer,3 h (cm)	400	400	400
Drainage coefficient1 (cm day-1)	9.8	13.8	10.4
Initial depth of GWL1 (cm)	170	200	220

Surface storage2, ΔWs (cm)	3	3	3
Kirkham's depth for flow to drains,3 SI (cm)	1	1	1
Bottom width of the ditch1 (cm)	300	300	400
Ditch side slope1 (-)	0.66	0.40	0.40
Weir settings1 (cm)	320	220	220

Note: 1 directly measured in the field or obtained from literature; 2 according to Skaggs (1980); 3 assumed values.

2.5.4 Crop and irrigation data and trafficability parameters

DRAINMOD requires maximum effective rooting depth and time versus distribution of crop roots. The effective rooting depths of cotton, wheat and maize during the growing season were assumed to increase from a minimum 3 cm on the preferable planting date to a maximum 72, 60 and 45 cm at the harvest, respectively (Table 2). A value of 3 cm was applied for the fallow periods to reflect the soil depth, where soil evaporation would occur in the absence of a crop (Skaggs, 1980). Field observed irrigation data was used as model input. Hence, irrigation routine of the model does not allow entering actual irrigation date, the rainfall file was modified to include the irrigation amounts (personal communication with Dr. Skaggs, 2013) and surface wastewater irrigation mode was switched off. Desired cropping period and trafficability parameters that are practiced commonly are listed in Table 3. Crop yield simulation was not considered in this study using DRAINMOD model, thus yield decline factors were set as a default crop parameter.

Table 2: Distribution of effective rooting depth of cotton, wheat and maize

Cotton1		Wheat2		Maize1	
Date	Root depth (cm)	Date	Root depth (cm)	Date	Root depth (cm)
1-Jan	3.0	10-Oct	3.0	1-Jan	3.0
28-Apr	3.0	15-Nov	8.3	20-Jun	3.0
10-May	20.4	30-Dec	15.0	30-Jul	6.2
24-May	41.6	15-Apr	21.2	8-Aug	8.6
8-Jun	51.5	30-Apr	34.6	31-Aug	40.4
28-Jun	61.0	10-May	45.4	10-Sep	42.5
9-Jul	65.0	1-Jun	60.0	26-Sep	45.0
28-Jul	71.0	20-Jun	60.0	5-Oct	45.0
28-Aug	72.0	20-Jul	3.0	30-Oct	45.0
8-Sep	72.0			20-Nov	3.0
28-Sep	72.0			31-Dec	3.0
10-Oct	3.0				
31-Dec	3.0				

Note: 1 actual values for cotton and 60% for maize from SANIIRI Report (2002); 2 assumed values

Table 3: Trafficability and crop parameters

Parameter description	Cotton	Wheat	Maize
Minimum water-free pore space needed to work the soil (cm)	3.5	2.5	2.5
Minimum daily rainfall to stop field operations (cm)	0.6	0.6	0.6
Minimum time after rainfall before work can restart (day)	1	1	1
Starting /ending hours for working			8 a.m. / 8 p.m.
Start counting work days 1st period / 2nd period	15.03 /15.08	20.09 / 10.06	20.06 / 15.10
End counting work days 1st period / 2nd period	20.04 / 31.10	31.10 / 1.07	20.07 / 15.11
Lower limit of water content in the root zone (cm^3 cm^{-3})	0.173	0.173	0.173
Limiting water table depth for no crop damage (cm)	40	30	30
Period to count wet / dry days	15.03 / 31.08	15.10 / 20.06	15.06 / 15.09
Length of growing season (day)	175-185	245-260	105-125
Last day of year to plant without yield loss (Julian day)	120-125	300-320	175-180
Days required to prepare seedbed and plant (day)	10	5	2

2.5.5 Model calibration

The GWL data for 2011, measured from the piezometers located in the middle of the monitored fields (piezometer # 2 in Akbarabad site and # 5 in Azizbek site are highlighted in Figure 1b & c, respectively), were used for model calibration and validated for 2009-2010. The following sensitivity input parameters were considered as model calibration: monthly PET factors, soil water characteristics (pF curve), GWL versus upward flux, GWL versus infiltration parameters, depth to impermeable layer, drainage coefficient and as well as hydraulic head of an aquifer (He et al., 2002; Skaggs et al., 2012). The agreement between the observed and predicted GWL during calibration and evaluation of the model were visually compared and quantified using objective functions described below.

2.5.6 Model performance evaluation

The performance of the model was evaluated: 1st – by comparison of model simulated GWL and q with observed values through a graphical representation and 2nd – by four statistical estimators:

the root mean square error (RMSE):

$$RMSE = \sqrt{\frac{1}{n} * \sum_{i=1}^{n} (Pi - Oi)^2} \qquad (5)$$

Nash-Sutcliffe efficiency (EF, Nash & Sutcliffe, 1970):

$$EF = 1 - \frac{\sum_{i=1}^{n} (Oi - Pi)^2}{\sum_{i=1}^{n} (Oi - \overline{O})^2} \qquad (6)$$

Mean absolute error (MAE):

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |Pi - Oi| \qquad (7)$$

the index of agreement (d, Willmot et al., 1981):

$$d = 1 - \frac{\sum_{i=1}^{n} (Oi - Pi)^2}{\sum_{i=1}^{n} (|Pi - \overline{O}| + |Oi - \overline{O}|)^2} \qquad (8)$$

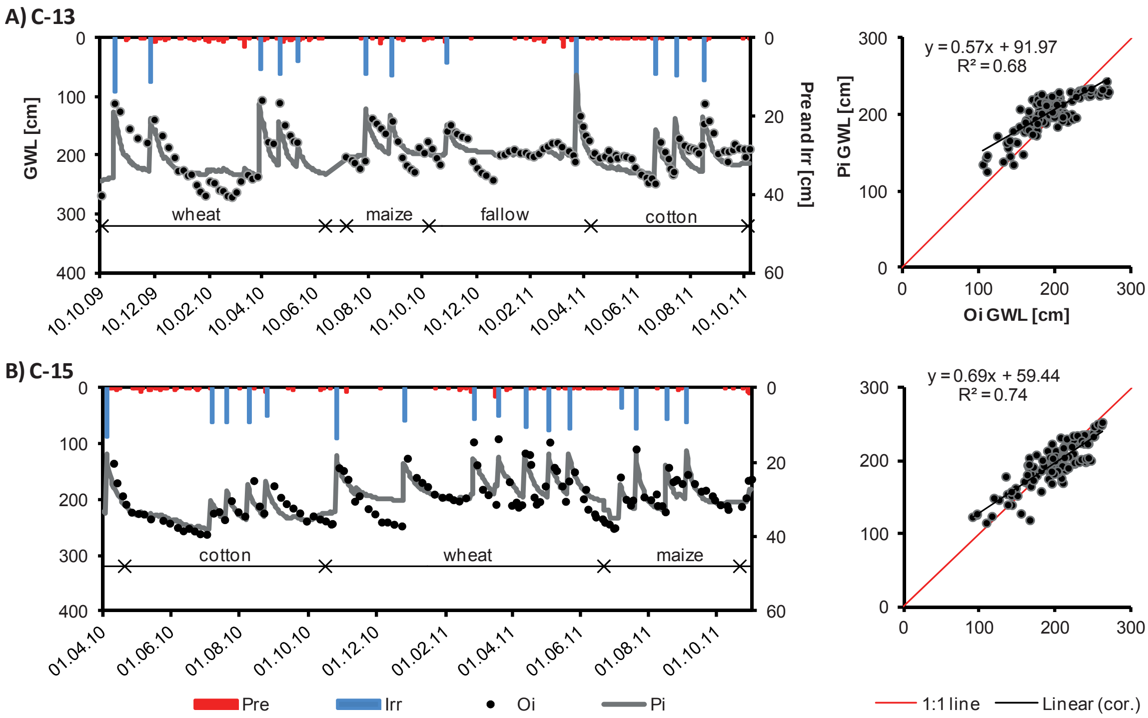
where $\overline{O}$ and $\overline{P}$: mean observed (Oi) and predicted (Pi) variables; i=1, 2, …, n: number of paired variables.

3 RESULTS AND DISCUSSIONS

3.1 Simulation of groundwater level (GWL)

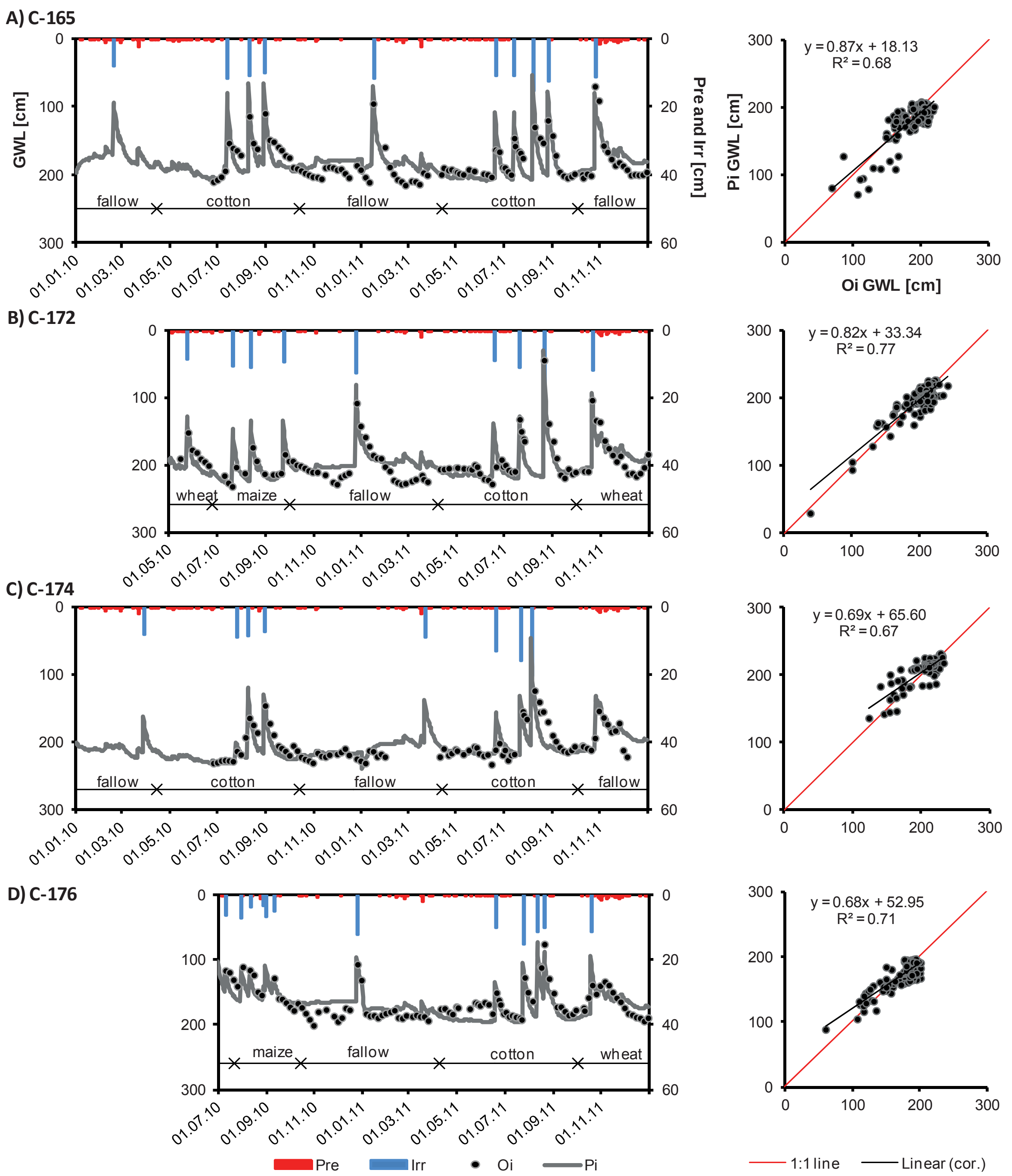
The measured (Oi) and simulated (Pi) GWL for Azizbek and Akbarabad sites are presented in Figures 5 and 6, respectively. Simulations of the GWL were performed separately for each crop type. Here, Figures 5and 6 (including correlation coefficient) show combined values for the considered period. Generally, DRAINMOD 5.1 simulations of water table fluctuations were accurate for both sites. Observed and predicted water tables often rise rapidly in response to irrigation, causing rapid fluctuations of the GWL.

Figure 5: Comparison of the observed and predicted GWL (left) and their correlations (right) in 2009-2011 in Azizbek site



Note: wheat-maize-cotton crop rotation at C-13 in 2009-2011 (A) and cotton-wheat-maize crop rotation at C-13 in 2010-2011 (B). Pre – precipitation, Irr – irrigation, Oi – observed GWL (averaged data from piezometer ## 2, 5 and 8, refer to Figure 1c) and Pi – predicted GWL

Figure 6: Comparison of the observed and predicted GWL (cm) (left) and their correlations (right) in 2010-2011 in Akbarabad site



Note: cotton-cotton crop rotation at C-165 (A), wheat-maize-cotton crop rotation at C-172 (B), cotton-cotton crop rotation at C-174 (C) and maize-cotton-wheat crop rotation at C-176 (B). Pre – precipitation, Irr – irrigation, Oi – observed GWL (averaged data from piezometer # 2, refer to Figure 1b) and Pi – predicted GWL

Over the simulated period, the root mean square error (RMSE) ranged from 12.3 cm (C-174) to 29.5 cm (C-13) (Table 4). The mean absolute error (MAE) fluctuated from 8.8 cm (excellent, according to criteria by Skaggs et al., 2012) for plot C-174 to 25.2 cm (acceptable) for plot C-13 (Table 4). On average on a field basis, the MAE values were 9.9 cm for plot C-174, 11.8 cm for C-172, 12.0 cm for C-176, 14.5 cm for C-165, 15.5 cm for C-13 and 18.0 cm for C-13 (Table 4). The Nash-Sutcliffe efficiency (EF) values were in the range of 0.45 to 0.78, and 14%, 57% and 29% of case studies (n=14) classified as “acceptable,” “good” and “excellent,” respectively (Table 4) based on the criteria developed by Youssef et al. (2006). In general, these EF values, according to Youssef et al. (2006), are considered good for daily water table predictions, because of the rapid fluctuations that can occur after irrigation and the effect of time lag.

Table 4: Statistical comparison between observed and simulated daily groundwater level for plots C-13 and C-15 (Azizbek site) as well as C-165, C-172, C-174 and C-176 (Akbarabad site) during 2009-2011

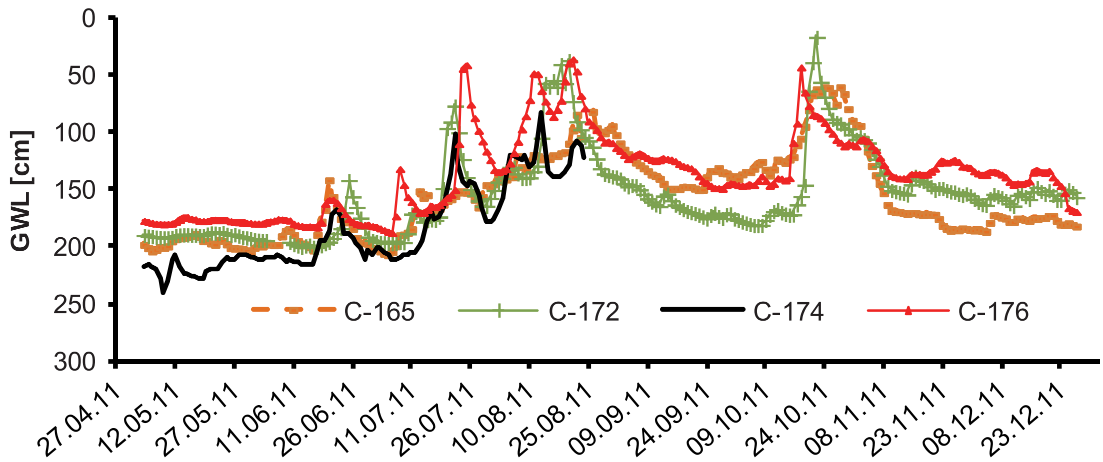
Year	Field	Crop	n	RMSE (cm)	MAE (cm)	MAE criter.ξ	EF (-)	EF criter.ξ	d (-)
2009-10	C-13	Wheat	36	29.53	25.24	a	0.66	g	0.86
2010		Maize	28	19.20	16.64	a	0.52	g	0.79
2011		Cotton	67	18.16	14.72	g	0.45	a	0.85
C-13 all combined			131	22.07	18.02	a	0.61	g	0.86
2010	C-15	Cotton	40	15.30	11.25	g	0.78	e	0.92
2010-11		Wheat	57	24.00	19.81	g	0.67	g	0.88
2011		Maize	33	14.73	12.10	g	0.78	e	0.93
C-15 all combined			130	19.78	15.48	g	0.73	g	0.91
2010	C-165	Cotton	35	16.80	14.45	g	0.53	a	0.88
2011		Cotton	69	18.48	14.52	g	0.61	g	0.90
C-165 all combined			104	17.93	14.50	g	0.59	a	0.90
2010	C-172	Maize	35	12.67	9.86	e	0.75	e	0.93
2011		Cotton	68	15.51	12.83	g	0.77	e	0.93
C-172 all combined			103	14.61	11.82	g	0.77	e	0.93
2010	C-174	Cotton	35	11.25	8.79	e	0.70	g	0.92
2011		Cotton	55	15.46	10.75	g	0.62	g	0.87
C-174 all combined			90	13.97	9.99	e	0.66	g	0.89
2010	C-176	Maize	29	16.08	12.98	g	0.67	g	0.87
2011		Cotton	72	14.08	11.61	g	0.68	g	0.90
C-176 all combined			101	14.68	12.00	g	0.71	g	0.90

Note: n – the number of paired variables; RMSE – the root mean square error; MAE – the mean absolute error; EF – Nash-Sutcliffe modelling efficiency; d – index of agreement. ξ criteria for the MAE and EF is according to Skaggs et al., 2012 (a: acceptable, g: good and e: excellent).

Figures 5 and 6 reveal numerous examples of the water table rising 34 to 135 cm (C-13), 50 to 105 cm (C-15), 100 to 150 cm (C-165), 75 to 170 cm (C-172), 30 to 150 cm (C-174) and 20 to 115 cm (C-176) in a day depending on the method, depth and frequency of irrigation.

Although, manual measurement of the GWL was carried out at the above stated plots with 5 to 10 days interval, it does not imply the full range of GWL fluctuations (in most cases the GWL was measured 1-3 days after irrigation, thus maximum rise may not be observed). Moreover, the DRAINMOD was not able to simulate GWL rise caused by lateral (sub-surface) water movement (Sinai & Jain, 2006) owing to the irrigation of upper part of the field (e.g., multi-tier irrigation, Horst et al., 2005; Reddy et al., 2013). Therefore, water levels increased immediately after irrigation for all case studies (see Figures 5 and 6). Hence, GWL data-logger -Odyssey (Dataflow systems Pty LTD, New Zealand) with hourly measurement interval, installed at C-165, C-172, C-174 and C-176 in 2011 was used to capture the daily GWL fluctuations (Figure 7). It can be seen from the Figure 7 that water levels fluctuated throughout the year. However, water levels tend to increase gradually, indicating delayed response to field irrigation water supply. In fact, the maximum rise of the GWL (even though irrigation was started 1-3 days before) due to point measurement, was concomitant with irrigation of the part of the field where the piezometer-wells are located.

Figure 7: Hydrograph of average daily GWL in wells for the fields in Akbarabad site in 2011

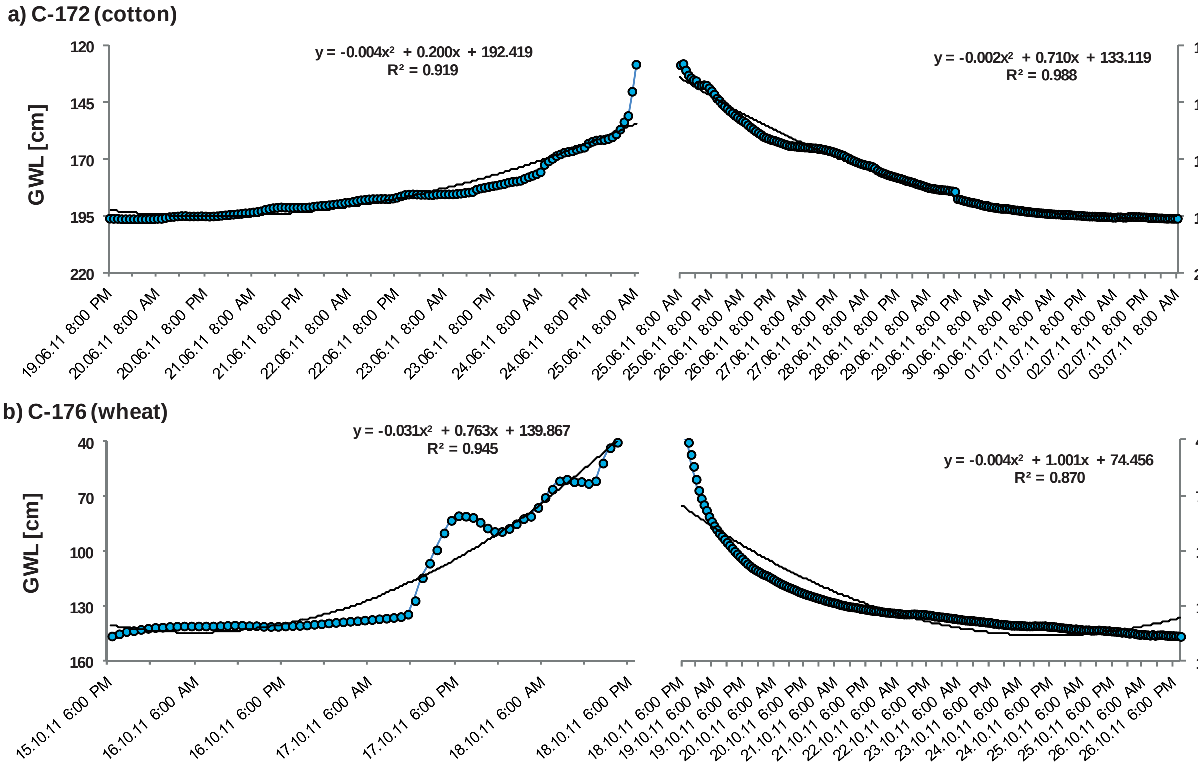


Note: daily GWL data is based on hourly measurements by data-logger, installed at piezometer # 2 in four fields (for the location of the wells refer to Figure 1b)

Source: CAWa Project data

To understand the irrigation-groundwater level relationship, the 1st irrigation of cotton at C-172 and charging irrigation of wheat at C-176 out of five major groundwater recharge events in 2011 (see Figure 7) were selected for further analysis. Between 2nd and 4th irrigations of cotton, the hydrographs were complicated by frequent irrigations that led to intermittent groundwater recharge and variable water table rise (see Figure 7). During the first irrigation of cotton in plot C-172 located close to the collector “Sary-Juga,” the duration to rise GWL from 196 cm up to 130 cm was 5 days (including irrigation duration – 3 days), while it took 9 days to drop down to the initial level (196 cm) (Figure 8a). Whereas, the first (charging) irrigation of wheat in plot C-176, located relatively far from the collector, took 4 days (including irrigation duration – 3 days) to rise the GWL from 140 cm up to 40 cm and 10 days to drop down till 140 cm, i.e. the rate of drop is half of that of rise (Figure 8b).

Figure 8: Accession (left) and recession (right) of the GWL during the first irrigation of cotton in C-172 (a) and charging irrigation of wheat in C-176 (b) in 2011



Source: CAWa Project data

Moreover, in the part of the fields located at the drain mid-spacing, the lagging of GWL lowering is higher, i.e. this process is slower (data is not given). Such a trend of the GWL fluctuation after irrigation was consistent with previous studies in Azizbek site (Dukhovny et al., 2005). In their studies, duration of the groundwater rise and drop down to the initial level was 2-5 days and 5-11 days, respectively.

In addition, the amplitude of the GWL change was the highest in the 1st irrigation of wheat, ranging from 80 cm to 130 cm, while the amplitude was less in the 1st irrigation of cotton, varying from 50 cm to 70 cm. This could be associated with border (every furrow) irrigation of wheat compared to alternate furrow irrigation of cotton and the GWL prior to irrigation (see Figures 5-6). The attenuation of the seasonal fluctuation in water tables in the cotton fields is an indication that water saving due to alternate furrow irrigation, may affect the regime of the shallow groundwater level.

Although different approximations (PTF derived soil hydraulic parameters, merging irrigation and rainfall data into one input file, hydraulic head of aquifer, depth of impermeable layer, etc.) were used in this study, the predicted GWL deviations from the observed one are quite comparable to the values obtained by other researchers (Gupta et al., 1993; Sinai & Jain, 2006; Skagss et al., 2012; Yang, 2008). Hence, the model prediction of GWL seems to be satisfactory under Fergana condition.

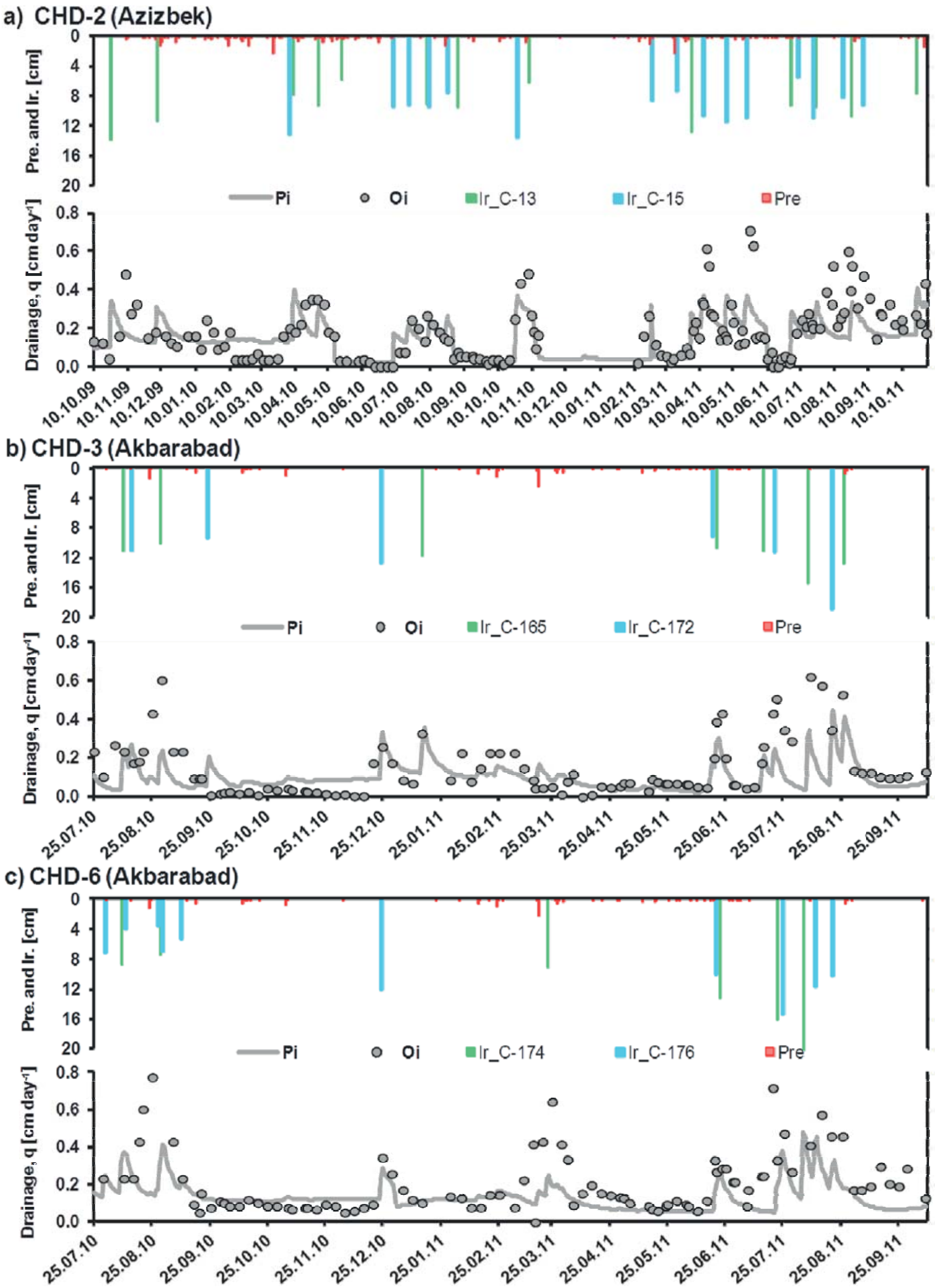
3.2 Simulation of drainage discharge

Figure 9 presents graphical comparisons of simulated and observed daily subsurface drainage flow for Azizbek site (CHD-2) and Akbarabad site (CHD-3 and CHD-6). Based on this figure, it can be seen that drain flow prediction is highly deviated from the observed values for all the drains considered. Drain flow peaks were poorly predicted, i.e., there are discrepancies in the magnitude of some events, especially during the irrigation of an area at one field or both fields at the same time relative to the drain outflow point.

It is apparent that drainage rate (q) in DRAINMOD is a function of midpoint water table height above the drains (m, refer to Equation 2) that satisfies q=f(m) relationship (Skaggs et al., 2008; 2012). However, multi-tier irrigation within a field and irrigation effect of two adjacent fields have complicated the q=f(m) relationship. In fact, periodical irrigation in 15-20 days creates uneven drainage loads and causes the dispersion of a groundwater mound (m) to a non-irrigated area within a field (Dukhovny et al., 2007). This produces relatively important differences in the infiltration opportunity time between upstream and downstream and thus accession and recession deviations in the model prediction of q.

Field observations reveal that there was a case when maximum drainage rate has not occurred and even though GWL between the drains was shallow (piezometer # 2 in Akbarabad and ## 2, 5 and 8 in Azizbek). This leads to misestimation of the accession of drainage flow. In addition, recessions were usually underpredicted, meaning that the model did not respond as quickly as the fields actually did under drain flow recession conditions. Moreover, GWL recession (see Figure 8, right), due to evapotranspiration (Yin et al., 2013), is gradually reducing groundwater flow into the drains (Kellogg et al., 2008). Therefore, both the visual (Figure 9) as well as the statistical (Table 5) comparisons indicate that predicted daily drainage rates were in poor agreement with measured values. Overall, the model did not show signs of consistent range (zero and peak discharges) of drain flow under irrigation conditions. Separate run of the model for each crop year at different field and sum of the q within one drain area could be some reason for such poor statistics.

Figure 9: **Comparison of the observed and predicted drainage rate (cm day-1) affected by irrigation practices conducted at (a) C-13 & C-15, (b)C-165 & C-172 and (c) C-174 & C-176**



Note: Pi – predicted drainage (summed from all crop years from two adjacent fields, e.g., drain serving area); Oi – observed drainage; Irr – irrigation of respective fields; Pre – precipitation

Manual measurement of the q with 5 to 10 days interval may also be another reason. Moreover, one drainage in both sites crosses two adjacent fields (see Figure 1b and c), which vary by crop type and irrigation scheduling. Hence, irrigation in two adjacent fields, due to upslope effect and depending on groundwater (hydraulic) gradient, creates various drain water interception (e.g., interception is increasing as the hydraulic gradient increases, Khan et al., 2003). These all might have influenced on the DRAINMOD predicted drainage rate. In general, the sum of model predicted drainage volume at CHD-2 in Azizbek site was 225 and 370 mm, respectively during vegetation period (April-September) in 2010 and 2011, respectively. This corresponds to 4% and 19% less than total observed (measured) subsurface drainage volume during that period, respectively. Predicted drainage volume at CHD-3 and CHD-6 in Akbarabad site was 168 and 218 mm, respectively during vegetation period in 2011. These values were almost twice (48%) less than observed drainage volume during that period.

Table 5: Statistical comparison between observed and simulated daily drainage rate (cm day-1) for CHD-2 (plots C-13 and C-15) in Azizbek site as well as CHD-3 (C-165 and C-172) and CHD-6 (C-174 and C-176) in Akbarabad site during 2009-2011

Period	Drainage ђ	Fields Ω	n	r2 (-) ¥	RMSE (cm)	MAE (cm)	EF (-)	d (-)
10.2009-10.2011	CHD-2	C-13, C-15	150	0.43	0.112	0.076	0.403	0.762
07.2010-10.2011	CHD-3	C-165, C-172	97	0.41	0.118	0.079	0.333	0.707
07.2010-10.2011	CHD-6	C-174, C-176	94	0.33	0.172	0.108	0.075	0.584

Note: ђ closed horizontal drainage (CHD); Ω field contours above a drain; ¥ the determination coefficient (r2) from the linear regression analysis. Other abbreviations are same as described in Table 4.

Based on the observations, simultaneous irrigation in two adjacent fields increased the designed drainage discharge (drainage modulus, refer to Section 2.1) by 2.3-fold in CHD-2 and 2.0-fold CHD-6. The maximum drainage discharge (7.2 l s-1) in CHD-3 has corresponded to the designed drainage module (0.6 l s-1ha-1). Hence, drainage peak has occurred when ~80% of a field (relatively near to drain outlet into the collector) or ≥50% of the above drain area (both fields) was irrigated simultaneously in a day. Similar results were observed by Dukhovny et al. (2007) in Azizbek site. In their studies, simultaneous irrigation on more than 50% of the area between drain spacing has increased the drainage modulus twice. Ayars et al. (2006b) reviewed that the majority of sub-surface drainage systems across Australia were over-drained and drainage rates exceeded the designed drainage modulus.

It is also important to note that Skaggs et al. (2008; 2012) and other researchers (Wang et al., 2006; Dayani et al., 2009) simulated hydrology in DRAINMOD was different based on the conditions they have considered (e.g., humid climate; daily rainfall is uniformly distributed over the entire field). Whereas in arid climate, particularly in Fergana region, irrigation, due to uneven distribution over the field and prolonged duration within one event, has complicated the environment that needs to be considered in any model (including DRAINMOD). In addition, the length and depth of the subsurface drainage, constructed in the study area, is quite long (L=500-1670 m) and deep (b=2.3-3.2 m) compared to those constructed in humid region (for detailed description on drainage design parameters in humid region refer to Ale et al., 2009; Ayars et al., 2006b; Breve et al., 1998; Dayani et al., 2009; El-Sadek et al., 2003; Skaggs et al., 2012). Thus, deep drainage results in deeper water flow paths into the soil profile and deeper GWL that allows increased percolation from irrigation and continuous drainage flow (van Beers, 1976; Huo et al., 2011).

Due to drain slope, there might be also significant differences in the crop irrigation requirement across as well as between fields (Ayars et al., 2006a; 2006b). Dukhovny et al. (2005) observed that the head above drainage pipe along the drains ranged from 0.5 to 1.4 m with maximum head at drain outlets. Hence, capillary rise could be high at midpoint between the drains as well as near to drain outflow point. The latter, however is controlled by the water level at receiving collector.

At first glance, the DRAINMOD simulated hydrology seemed to be acceptable, however, literature about comprehensive analysis of DRAINMOD predicted hydrology (comparative analysis of GWL and drainage discharge, together) were scant (Helwig et al., 2002; Skaggs et al., 2012; Tian et al., 2012). Based on the results (including extensive literature review), it can be concluded that better performance of the model simulating GWL (see Table 4) does not imply that best result in drainage discharge (Table 5) can be achieved under the same environment, particularly in irrigation conditions. It was found that altering the model input data (especially, hydraulic head of an aquifer that performed better water table simulations) resulted in different soil water volume to be drained into drains (data is not shown). Moreover, drainage intensity (cm day-1) in irrigated fields vary depending on daily rate of irrigation area covered with each day irrigation (IAC, Dukhovny et al., 2005) above the drain. Analysis of Dukhovny et al. (2005) showed that formation of groundwater mound (m), as a result of changes in the flow pattern associated with IAC, has small effect on drainage flow (q).

4 CONCLUSIONS

DRAINMOD was separately run to predict and compare groundwater level (GWL) for the six fields with 14 crop growth periods as well as drainage flow for the three drainage parameters over 2009-2011. For wider application of the model, especially in arid regions, it could be better to adjust the irrigation module of the model considering the share of sub-surface drainage area covered by surface irrigation and dynamics of groundwater (artesian water) inflow into the field area. In this study, irrigation input was modified so that the daily precipitation was combined with irrigation amount. Hence, lack of entering actual date and amount of irrigation, it was the only solution to adapt the current version of the model for irrigation conditions. This modification has yielded an acceptable result in terms of the GWL simulations. It was found, that drainage discharge prediction is influenced due to high heterogeneity of irrigation water supply for the crops within the fields.

In general, DRAINMOD 5.1 can be used to predict GWL as well as drainage discharge in arid regions considering the following pre-conditions:

- The drain, under consideration should serve only one field (relatively small field area) with a single crop per field;
- Irrigation in a field ought to be applied at the same rate within a day, whereas prolonged irrigation (e.g., irrigation duration >1 days) results in different water load into a drain, thus Hooghoudt equation (refer to Eq. 2) does not describe the q=f(m) relationship for the entire drainage period (Skaggs et al., 2008; 2012);
- Lateral flow has to be in a steady-state condition (Hooghoudt equation), i.e., the cross-section of water flow area into the drains (see shaded area in Figure 2) is constant for the entire drainage line over the period. However, it seldom occurs in real practice (van Beers, 1976).

Further research is needed to understand the behavior of groundwater flow into sub-surface drains under the irrigation conditions (including precipitation and underground water recharge). Field investigations with installation of automated devices may increase the frequency of monitoring of the GWL and soil moisture content. Combined use of the tipping bucket device (Tait et al., 1995) for irrigation inflow (including IAC) and drainage outflow measurements could increase the research findings.

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Part II:
Socio-economic and institutional framework

THE IMPACT OF POPULATION GROWTH AND INCREASING CONSUMER INCOME ON THE AGRICULTURAL SECTOR OF TAJIKISTAN

P. KHAKIMOV, P. M. SCHMITZ, I. PAWLOWSKI & KH. UMAROV

0 ABSTRACT

Tajikistan shows constant economic growth for more than a decade. This growth is mostly fed by ever increasing labour migrant remittances. The agricultural sector serves as an important safety net for the population due to its important subsistence production, but it also produces the cash crop cotton for export. There is substantial population growth in the country. The present contribution focuses on the effects of worldwide and domestic population growth as well as economic (income) growth on production, trade, and welfare of the agricultural sector of the country analysed by using a partial equilibrium model.

Results of the study reveal that worldwide (including domestic) population growth has a substantial effect leading to an increase in prices, production, and import of agricultural commodities in Tajikistan. Domestic income growth impacts additionally on the demand and import of livestock products. Most farmers in Tajikistan are subsistence farmers who do not much produce for the market and thus do not respond much to higher price incentives. However, they gain from higher prices. The increasing demand needs to be satistfied by imports, thus further deepening the negative trade balance for nearly all agricultural products. The cash crop cotton that is produced for the international market does not much respond to domestic income growth. The state budget will gain through taxes and other levies at the border. The consumers gain by the immense transfer of income through remittances.

1 INTRODUCTION

Tajikistan is an agrarian country with its vast majority of population living in rural areas. Therefore, agriculture is crucial for the development of the country, and the interrelation between natural resources, land use, and human welfare is manifold. The present study represents one part of a comprehensive analysis of the impact of macroeconomic and sectoral framework condition changes on Tajik agriculture. The focus here is on the effects of population and income growth on agricultural production, trade, and producer and consumer welfare.

Tajikistan went on a bumpy road to independence, stability, and development. However, since the year 2000 the country has experienced prominent growth. The average annual rate of economic growth (GDP) was 8 percent for the period 2000-2013 (Agency on Statistics, Republic of Tajikistan [AS], Tajikistan in Figures, 2005, 2009 & 2013). The economic growth has brought about substantial increase in consumer income and food consumption. On the other hand, the constant population growth leads to an increasing food demand, too. Tajikistan's population has been growing by 2 percent on average over the last twenty years (AS, Demography in Tajikistan, 2010).

The agricultural sector is essential for Tajikistan by feeding its population mainly through subsistence but also by providing revenues through cotton export. About three-quarter of the population live in the countryside and depend on agricultural production. Between 1985 and 2000 the agricultural sector has constituted more than 30 percent of the country's GDP, and even in 2001-2011 the figure was still close to 25 percent (AS, Agricultural Sector in Tajikistan, 2000 & 2013). The agricultural sector has undergone substantial changes after independence, caused, inter alia, by a land reform resulting in transferable land-use rights to private farmers as well as a quite liberal agricultural and trade policy for all commodities except cotton. The agricultural sector absorbs half of the total employment and produces 30 percent of total export revenues and, therefore, has become a backbone of the economy (AS, Tajikistan in Figures, 2013).

But the main factor of growth in Tajikistan is the surge of remittances of labour migrants into the national economy. Since 2007 Tajikistan has been on top of the list of the remittances-to-GDP-ratio with an average of 40 percent in 2005-2012 (World Bank, 2013). Nearly 30 percent of the labour force of Tajikistan works as temporarily labour migrants abroad (AS, Labour Market in Tajikistan, 2013). Remittances have exceeded the Official Development Assistance (ODA) and the Foreign Direct Investments (FDI) by five and seven times respectively in 2004-2011 (World Bank, 2013). Remittances have become a significant source of income for Tajikistan. They have to be considered as a source of foreign exchange inflow with a great influence on the macroeconomic level. Imports exceeded the exports on average by 2.3 times in Tajikistan in 2002-2012 and showed a sharp increase in 2005 due to the sudden increase of remittances (AS, Foreign Economic Activity, 2013). In general, remittances play an ambiguous role in the development of an economy on macro and micro level. On the one hand, they can become a driver for growth while on the other hand they might serve as an obstacle to development, e.g. by causing an appreciation of the domestic currency.[1]

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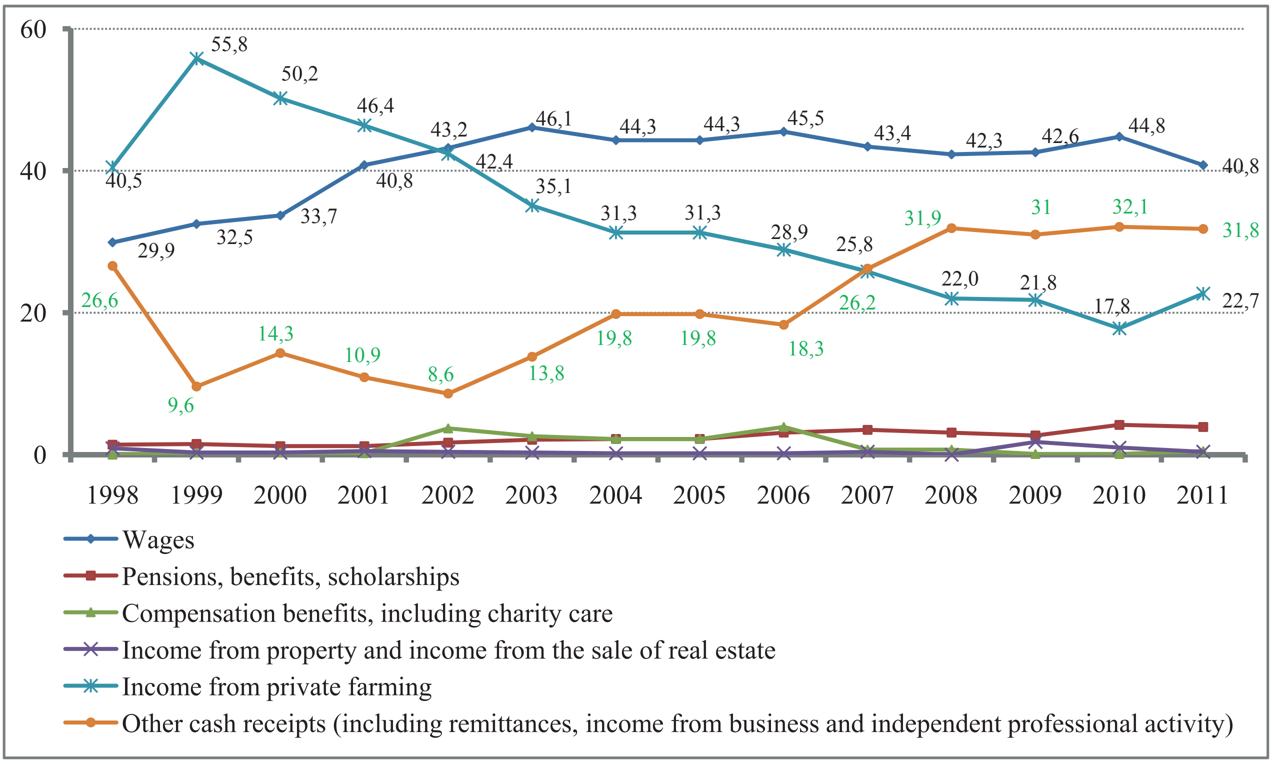
[1] Among the positive effects of labour migration and inflow of remittances are e.g. income growth, and hence an increase in demand and spending power of the population, alongside with poverty reduction, growth of the real economy like transport and construction sector, growth of the trade sector, and a

Looking closer to the development of income and its sources of the Tajik population makes it obvious (figure 1): There has been constant increase in income. The GNI per capita in 2013 amounts to 2500 USD and increased by 2.8 times compared to 2000 (PPP, current international USD) (World Bank, 2013). Remittances and the income from private farming (i.e. mainly subsidiary plots) together constitute more than half of the aggregate income of the population, hence underlining their importance for the country's economic growth (AS, Household Budget Survey, 2007, 2009, 2011 & 2013).

Figure 1: Income sources of the population of Tajikistan (in percent of total income, 1998-2012)



Source: Own compilation based on quarterly Household Budget Survey conducted by Agency on Statistics under the President of the Republic of Tajikistan (AS).

The increase of population as well as of consumer income has an effect on consumption levels and patterns. The study analyses the effect of population and income growth on the agricultural sector of Tajikistan. Main research questions are: (a) How do demand and supply

relaxation on the domestic labour market. The negative effects of labour migration and remittances are e.g. the effect of foreign purchases (the excess of imports over exports), high inflation level, stagnation of some sectors of economy and appearance of Dutch Disease symptoms, the strengthening of the national currency, increasing consumer price indices, and interest rate growth during economic boom (Khakimov, Schmitz & Pawlowski, 2014b).

of agricultural commodities respond to the growth of population and consumer income? (b) How are producers and consumers of agricultural commodities affected? (c) How does the trade balance, the state budget and the welfare change in response to these effects?

2 METHODOLOGY

The methodological approach of the study is based on the principle of welfare economics that analyses on how the allocation of resources affects economic well-being. The applied research tool is a partial equilibrium net trade model, called AGRISIM. It is a non-linear, partial equilibrium, multi-market and multi-region trade model. The model builds on a GAMS interface and uses GAMS/CONOPT2 solver - a non-linear optimization package.

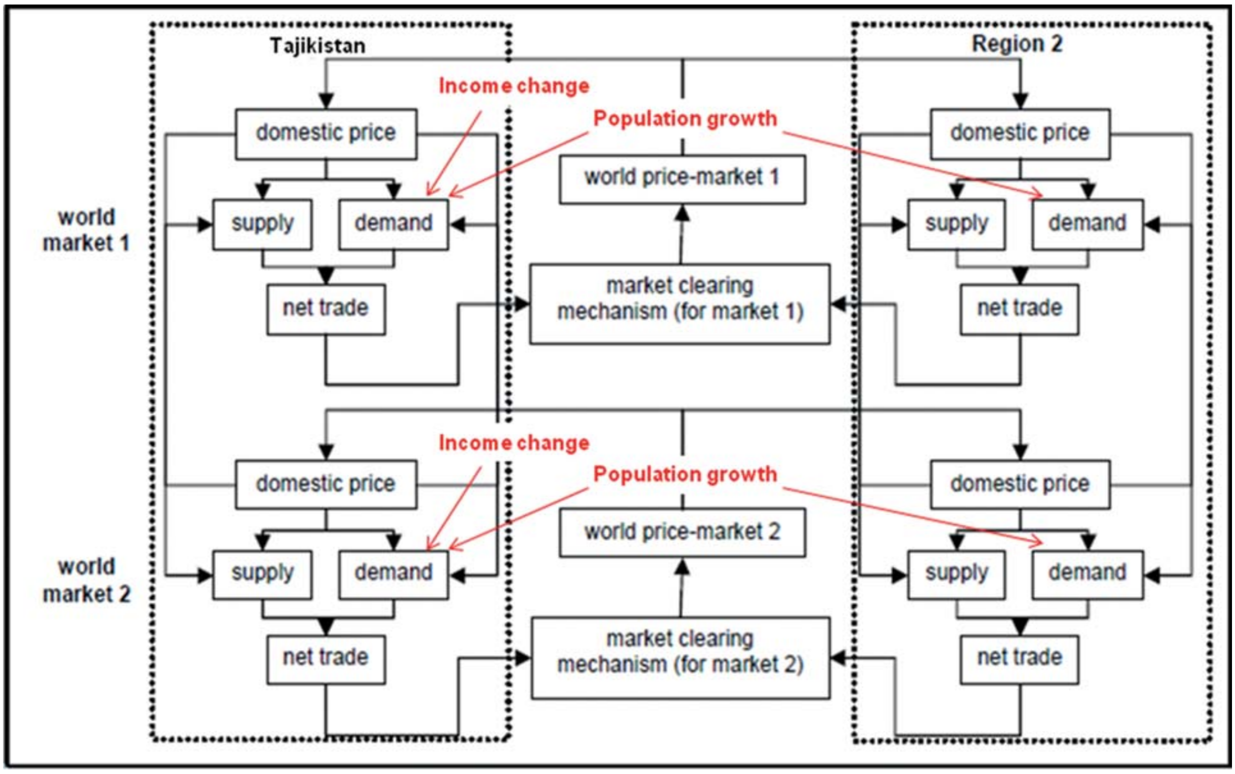
The AGRISIM model uses a multi-market approach that is widely used in general equilibrium modeling (CGE) but deals with just one sector of the economy (agriculture), while CGE models seek equilibrium for a number of sectors. As a dynamic component, the AGRISIM model allows the simulation of population and income growth with projections of agricultural production and subsequent agricultural trade changes, *ceteris paribus*. While free trade is in place, this model allows identifying the gap between production and consumption and allocation of land under different crops, thus, serves as a basis for policy implication in order to minimize the gaps.

The AGRISIM model includes 18 countries/regions and the rest of the world (ROW). The 27 countries of the European Union are considered as one region (EU). The difference between the world and the 17 specific countries (including Tajikistan) plus 1 region (EU) is represented by ROW. The model includes 24 agricultural commodities partly aggregated into commodity groups[2]. A simplified structure of the model is presented in the following figure.[3]

[2] Commodities included into the model are poultry (chickens, ducks, geese, turkey and other poulry), coarse grains (rye, barley & oats), oilseeds (rapeseed, soybean, sunflower and cottonseed), mutton and goats, as well as the single commodities of wheat, maize, milk, beef and veal, pigmeat (pork), eggs, soybean, cotton, sugar and rice.

[3] Details on the model structure and the related model equations can be found at Khakimov (2013) and (2014). Further two simulations conducted for Tajikistan by the author are: 1) diminishing water availability and growing land degradation both affecting the supply side; and 2) liberalization efforts (membership of Tajikistan of WTO and CES -Common Economic Space with Russia, Belarus, and Kazakhstan) affecting tariffs and thus domestic prices.

Figure 2: Simplied structure of AGRISIM model (2 markets/commodities, 2 regions)



Source: Own illustration based on Roningen (1997).

The base year (BY) of the model represents the status quo situation as the average of the years 2004-2006. Then the model simulates a base assumption (BA) as a forecast of 2016 against the BY where it adjusts production, consumption, and trade over time by considering population growth worldwide including Tajikistan. In the BA a future moderate population growth of annually 1.4 percent was applied for Tajikistan, and respective figures were applied for the other countries. For the Rest of the World (ROW) a weighted average annual growth figure was used considering the share of population of each country on ROW population.

The scenario of economic and remittances driven income growth (SC-I) in Tajikistan is simulated against the BA as a forecast of 2016 throug a shift in the demand function. The average annual rate of income growth in Tajikistan has been 8 percent during 2000-2013 (measured as as GNI per capita growth (World Bank, 2013)) an that was the shift factor applied for the simulation.

The data for the model originate from official international and national statistics. Population growth figures were derived from the United Nations Population Division (UN, 2012); the agricultural and trade data were taken from databases of FAOSTAT and OECD.

The net producer protection figures for each commodity for Tajikistan have been calculated applying the PSE-approach of the OECD.[4] Initial elasticities for supply, demand, and income are taken from the SWOPSIM database and are calibrated for all countries and regions.[5]

3 RESULTS AND DISCUSSION

Both population growth and increase of income impact on national demand and lead to changes in agricultural production, balance of trade, producer and consumer welfare, and state budget.

3.1 Consumption response

Rising incomes and their influence on production and consumption of agricultural products have been examined by many studies. For instance, Abler (2010) evaluates the effects of economic growth and rising incomes on the composition of agricultural product demand across product categories, within product categories, and on the evolution of price and income elasticities of demand for agricultural products. Shifts of the income spent on staple foods to non-staple foods due to income growth are e.g. accentuated in the studies of Zhou et al. (2012), Westcott & Trostle (2012), and Thiele & Weiss (2003).

Aggregate demand and demand patterns shift in response to income change. The propensity to consume and the income elasticity of demand are two concepts that reveal the relationship between income and consumption. The propensity to consume is the proportion of consumer's total income spent on food, non-food, and services. Significant parts of household income in Tajikistan are spent on food products. While due to income growth the total expenditures on food continued to raise over time, the share of food in total spending declined, e.g. from 87.6 in 2000 to 57.8 percent in 2012. At the same time food consumption pattern changed: the per capita consumption of livestock products significantly increased while per capita wheat consumption remained more or less the same (AS, Household Budget Survey, 1998-2013).[6]

The scenario of income growth in the applied model is in line with these developments (see table 1).

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[4] For details on the calculation of the protection measures see Khakimov, Pawlowski & Schmitz (2014a).

[5] For details on the calculation of the elasticities see Khakimov (2014).

[6] Developments in food consumption in Tajikistan therefore confirm the Engel's law.

Table 1: Demand changes (in thousand ton)

	BY (status quo)	BA (population growth)	SC-I (income increase)	Change in % BA against BY	SC-I against BA
Beef & veal	36	41	50	12.4	22.9
Coarse grain	52	60	59	16.7	-2.7
Cotton, fiber	24	27	34	13.4	24.7
Eggs	11	13	17	11.9	35.7
Maize	86	100	98	16.4	-2.5
Milk	389	444	528	13.9	19.0
Mutton & goat	26	29	35	13.6	21.8
Oilseeds	78	93	97	19.2	3.9
Pork	5	6	8	13.2	25.8
Poultry	7	7	10	12.6	37.5
Rice, refined	44	49	59	12.4	19.6
Sugar, refined	206	237	262	15.3	10.5
Wheat	1089	1238	1198	13.7	-3.2

Source: Own compilation based on AGRISIM simulation results

While population growth (BA) leads to a consistent increase in demand throughout all commodity categories, the income increase (SC-I) shows a differentiated picture. Compared to the BA, in SC-I the demand for livestock commodities further increased to a large extent (19 to 37 percent), while the staple food products of wheat, coarse, and maize showed even a small reduction in demand (-2 to -3 percent). The demand for cotton by domestic processors has also increased.

The question whether this additional demand will be met by domestic production or in form of imports is answered in the following sub-chapters.

3.2 Price effects

The base assumption (BA) of global population growth leads to an increase in demand and consequently to an increase in world market prices. It is assumed in the model that the producer prices in Tajikistan increase to the same degree like the world market prices (assumption of a price transmission elasticity = 1.00). The scenario of income increase (SC-I) does not show any additional price effects, because Tajikistan has only a minor market share in the world context.

The difference between border and producer prices represents tariff and non-tariff trade barriers. Most commodities show higher producer prices than border prices. Although this is beneficial to producers of such commodities, consumers pay unnecessarily more especially since the products are net-imported. The opposite holds true for the cash crop cotton: several taxes of together 43-45 percent suppress the domestic producer price and thus discriminate cotton producers (Khakimov, Pawlowski & Schmitz, 2014a).

Table 2: Producer and border price changes (in USD)

	Producer Price			Border Price			Difference Producer and Border Price (in BA)
	BY (status quo)	BA (population growth)	SC-I (income increase)	BY (status quo)	BA (population growth)	SC-I (income increase)	
Beef & veal	2343	2627	2628	1839	1839	1839	788
Coarse grain	167	180	180	194	194	194	-14
Cotton, fiber	506	537	537	1193	1193	1193	-656
Eggs	1585	1703	1703	812	812	812	891
Maize	181	195	195	195	195	195	0
Milk	222	235	235	298	298	298	-63
Mutton & goat	2659	2837	2839	2806	2807	2808	30
Oilseeds	554	573	573	573	573	573	0
Pork	1395	1494	1494	1493	1494	1494	0
Poultry	2981	3151	3151	1611	1611	1611	1540
Rice, refined	979	1045	1045	580	580	580	465
Sugar, refined	294	300	300	300	300	300	0
Wheat	194	245	245	111	111	111	134

Source: Own compilation based on AGRISIM simulation results

3.3 Production response

Price increases in response to demand growth incentivize production. By theory, income and demand growth are not the only determinants of changing production pattern. Another one is the existence of tariff and non-tariff trade barriers leading to price gaps between world market and domestic market and thus hampering the flow of price signals. Furthermore, also the limitation of natural resources, like arable land and water, are frontiers to production growth.

The assumption of worldwide population growth (BA) reveals only a marginal increase in production in Tajikistan (table 3). The simulation shows the lowest increase of production for rice (0.3 percent) while somewhat higher production response can be observed for wheat (4.7 percent).[7] The production increase of the various commodities is related to the price increase: those commodities showing a relatively higher price increase than others (such as wheat, beef, and veal) also show a relatively higher production increase and consequently result in higher output values. However, the increase in prices is considerably higher than the increase in production. The additional income growth in Tajikistan (SC-I) does not show any production effects.

Table 3: Production changes (in thousand tons)

	BY (status quo)	BA (population growth)	SC-I (income increase)	Change in %	
				BA against BY	SC-I against BA
Beef & veal	25.8	26.4	26.4	2.3	0.0
Coarse grain	65.3	65.8	65.8	0.8	0.0
Cotton, fiber	154.4	155.8	155.8	0.9	0.0
Eggs	5.3	5.3	5.3	0.8	0.0
Maize	135.9	135.2	136.0	-0.5	0.0
Milk	522.6	528.5	528.5	1.1	0.0
Mutton & goat	25.5	26.0	26.0	1.8	0.0
Oilseeds	271.1	272.5	272.5	0.5	0.0
Pork	1.0	1.0	1.0	0.7	0.0
Poultry	0.4	0.4	0.4	1.0	0.0
Rice, refined	54.1	54.3	54.3	0.3	0.0
Sugar, refined	0.0	0.0	0.0	0.0	0.0
Wheat	630.0	659.6	659.6	4.7	0.0

Source: Own compilation based on AGRISIM simulation results

An explanation for this rather meagre production increase lays in the small scale production structure and the low responsiveness of self-sufficient producers to domestic demand and price changes in Tajikistan. Most food products in Tajikistan are primarily produced on

[7] Sugar is not produced in Tajikistan (value of 0.0).

subsidiary plots and are thus less dependent on market price changes. Official statistics on agricultural production in Tajikistan indicate that the share of household subsidiary plots in the total production of agricultural commodities (except cotton) was 63 percent in the year 2009 although their share in land use is rather small. Only 6 percent of total agricultural land (or 20 percent of arable land) was cultivated by household subsidiary plots. The share of household subsidiary plots in total production by type of commodities is e.g.: crop production 51.4 percent, grain 35.1, meat 92.5, milk 93.5, and eggs 44.6 percent (AS, Agriculture in Tajikistan, 2010). Those figures clearly indicate that the holders of subsidiary plots (i.e. households) play an important role for the supply of agricultural commodities.
But at the same time they are the main consumers of their produced commodities, too, and do not produce much for the market.

3.4 Balance of trade effects

Tajikistan shows a negative trade balance (net-importer) for its agricultural sector in total. Most staple food such as wheat, coarse grain, and animal products as well as processed food is imported. An export surplus is gained only for some vegetables and fruits as well as the cash crop cotton. How would the trade balance change if population growth and income growth occurs in the country?
Assuming that agricultural and factor productivity will remain constant it is expected that the trade deficit will deepen because domestic production cannot meet the rising domestic demand as the simulation has already shown above. This is proved by the simulation: The assumption of worldwide population growth (BA) and the scenario of income growth (SC-I) show principally a further extension of the trade balance in Tajikistan resulting in a net-import situation for all commodities, except cotton (table 4). However, the income growth (SC-I) shows a slightly differentiated effect: while most products are even more imported (especially milk and sugar), wheat, maize, and grain reduce their import gap due to the lower demand. Cotton farmers who produce for the international market are not very sensitive to domestic income growth. Therefore, cotton production does not change and subsequently also the trade balance is only marginally affected.

Table 4: Net trade effects (in thousand t)

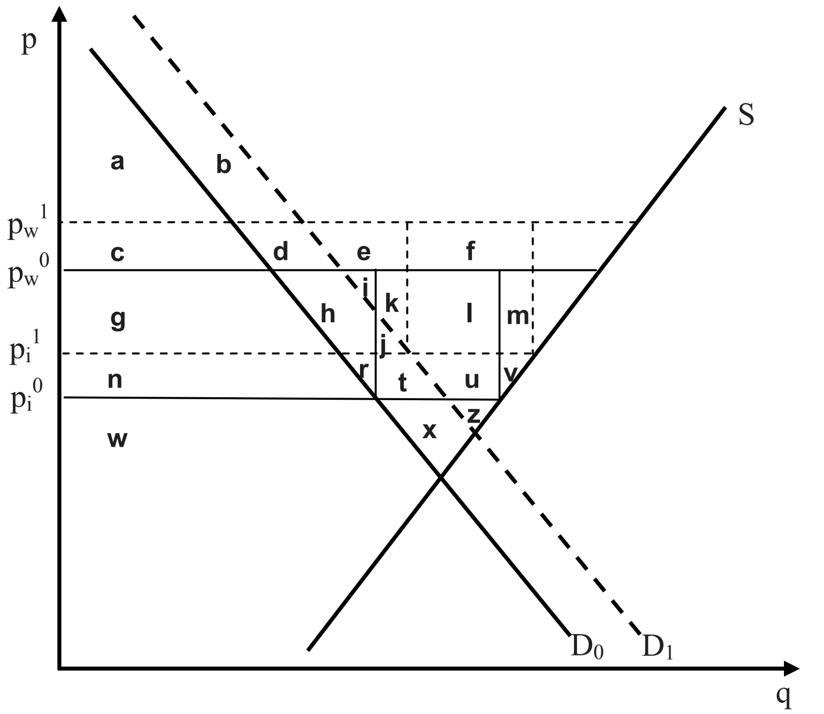
	BY (status quo)	BA (population growth)	SC-I (income increase)	Change of net trade situation (in 1000 t)	
				BA against BY	SC-I against BA
Beef & veal	-10.5	-14.4	-23.7	-3.9	-9.4
Coarse grain	-6.0	-14.4	-12.8	-8.4	1.6
Cotton, fiber	130.4	128.5	121.8	-1.9	-6.7
Eggs	-6.2	-7.5	-12.0	-1.3	-4.6
Maize	-0.1	-15.7	-13.2	-15.6	2.5
Milk	-3.7	-51.8	-136.3	-48.1	-84.5
Mutton & goat	0.0	-3.0	-9.3	-3.0	-6.3
Oilseeds	-50.6	-68.5	-72.2	-17.9	-3.7
Pork	-4.3	-5.0	-6.6	-0.7	-1.6
Poultry	-6.2	-7.1	-9.8	-0.8	-2.8
Rice, refined	1.7	-3.6	-13.2	-5.3	-9.7
Sugar, refined	-205.7	-237.3	-262.1	-31.6	-24.9
Wheat	-688.5	-810.7	-770.5	-122.2	40.2

Source: Own calculation and compilation based on AGRISIM simulation results

3.5 Welfare effects of population growth and income increase

Welfare changes can be explained in theory with the help of the surplus concept. The geometric expression of the effects of population growth (BA) and income increase (SC-I) is presented below. Two cases are illustrated exemplarily: figure 3 presents the effects for a net export commodity with a negative protection (e.g. cotton in case of Tajikistan); figure 4 shows the effects for a net import commodity with a positive protection (e.g. beef or wheat in case of Tajikistan). The welfare effects are caused by two changes: first, the increase of the world market price p_w^0 to p_w^1 and the producer price p_i^0 to p_i^1 (assumption of increase to same extent) due to the worldwide and Tajik population growth (BA), and second, the shift of the demand function D_0 to D_1 due to both the population growth and the income increase in Tajikistan (SC-I). The volume of change of consumer surplus, producer surplus, and budget depends on the degree of the single effects: if the quantity effect caused by the demand shift is higher than the expansion of supply due to the price effect, the consumer surplus and the budget rise in comparison to status quo. If the quantity effect is lower than the price effect, the opposite holds true. The producer surplus always rises due to the price effect.

Figure 3: Welfare effects of worldwide population growth and income growth in Tajikistan (net export situation and negative protection)

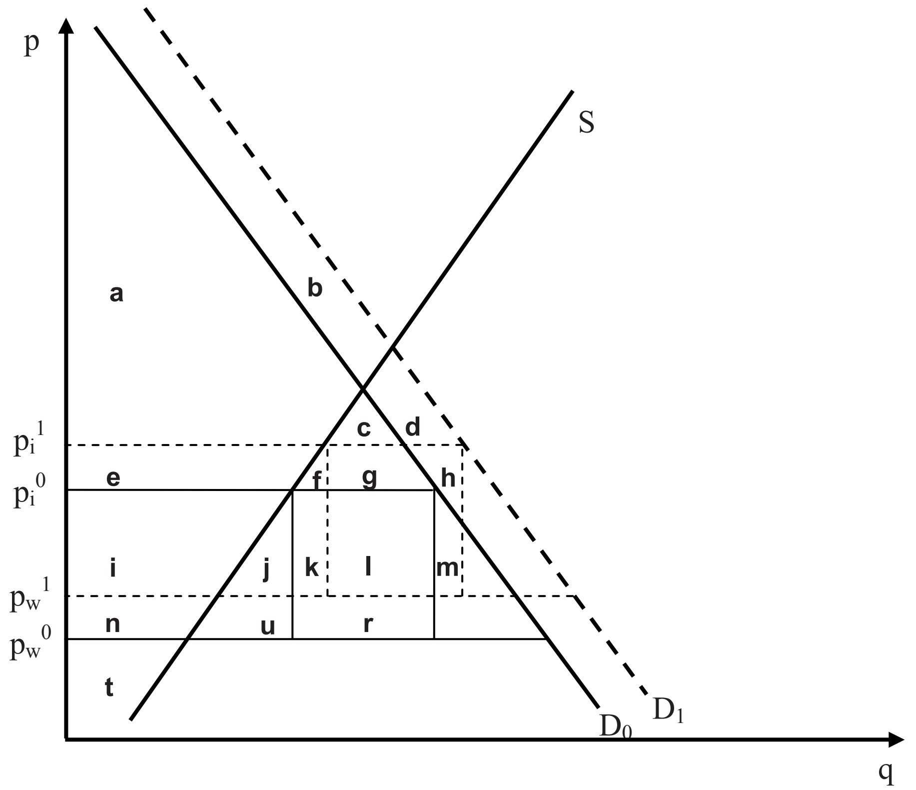


	BY (status quo: p_i^0 ; D^0)	BA and SC-I (population growth and income increase: p_i^1 ; D^1)	Δ (change)
Consumer surplus	a c g n	a b c d g h j	+b +d +h +j -n
Producer surplus	w x z	w x z n r t u v	+n +r +t +u +v
Budget	k j l t u	f l m	+f +m -k -j -t -u
Total welfare			+b +d +h +r +v +f +m -k

Note: (SC-I) compared to status quo (BY); case of net export situation and negative protection (example of cotton in Tajikistan)

Source: Own illustration

Figure 4: Welfare effects of worldwide population growth and income growth in Tajikistan (net export situation and negative protection)



	BY (status quo: p_i^0 ; D^0)	BA and SC-I (population growth and income increase: p_i^1 ; D^1)	Δ (change)
Consumer surplus	a c e f g	a b c d	+b +d -e -f -g
Producer surplus	i n t	e i n t	+e
Budget	k l r	g h l m	-k -r +g +h +m
Total welfare			+b +d +h +m -f -k -r

Note: (SC-I) compared to status quo (BY); case of net import situation and positive protection (example of beef or wheat in Tajikistan)

Source: Own illustration

Concluding from the theoretical explanation to the empirical model brings following results for the agricultural sector of Tajikistan (as an aggregation across all commodities) (table 5):

Table 5: Welfare changes in the scenario of worldwide population growth and income growth in Tajikistan (in million USD)

	BY (status quo)	BA (population growth)	SC-I (income increase)	Change SC-I against BA (in mill. USD)
Producer surplus	0.000	66.92	67.05	0.13
Consumer surplus (sequentially measured)	0.000	-86.49	-86.59	-0.10
Remittances as transfer for consumers*			2665.00	
Budget	0.000	46.15	51.48	5.33
Total	0.000	26.58	2696.94	5.36

Source: Own compilation based on AGRISIM simulation results and *further calculations

The producers will benefit due to the higher prices. Also the state budget will gain due to tax retention. The results for the consumers consist of two effects: a loss due to consumer price increases and an immense gain due to the transfer of remittances from abroad. The model calculates the consumer effect based on the price change only (which equals the area -n in figure 3 and the area -e-f-g in figure 4). However, the change of income by remittances transfer has to be added as well (which equals the area +b+d+h+j in figure 3 and the area +b+d in figure 4).[8] The calculation of the transfer for consumers in this empirical case has been guestimated as follows: The GNI per capita in Tajikistan in 2013 was 2500 USD (PPP, current international USD) (World Bank, 2013). Assuming a future annual income growth of 8 percent until the end of the forecast period of the model in 2016 (the shift factor of the demand function applied in the model) would result in a total income growth of 649 USD per capita. With an estimated population of 8.2 million the income growth in 2016 would amount to 5330 million USD. Assuming that expenses for food represent approx. 50 percent of the total income leads to a transfer for consumers of approx. 2665 million USD by 2016. Looking at the cash transfer of labour migrants of totally more than 4 billion USD in 2013 (World Bank, 2013),

[8] See more explanations to the measurement of consumer surplus in a price-income change at Just, Hueth, & Schmitz (2004), pp 151.

this guestimate seems to be plausible. The total welfare effect identified by the model calculation is therefore positive.

3.6 Summary and model limitations

The scenario of worldwide population growth and domestic income growth has an effect on the agricultural sector of Tajikistan. It would translate into a substantial growth of aggregate demand for agricultural products with livestock products being the most demanded. While the worldwide population growth causes an increase in world market prices and producer prices, the domestic income increase does not result in any additional price or production effects. The reason can be found in the small scale subsistence agriculture of Tajikistan where the lion̂s share of produce comes from household plots. Thus, agricultural producers are at the same time the main consumers of their products and produce only little for the market. The increase in demand will be satisfied by imports that further extent the negative trade balance in agriculture particularly for livestock products and oilseeds. The cash crop cotton that is produced for the international market does not much respond to domestic income growth. The sectoral welfare analysis shows that agricultural producers and the state budget will gain. The impact on the consumer estimated by the model is immense due to the direct income transfer. Without this direct transfer the consumer surplus would be negative due to higher consumer prices.
The present empirical analysis using the partial equilibrium model AGRISIM indicates possible future developments for the agricultural sector of Tajikistan. Like every model application also these results have to be carefully interpretated taking into account methodological and data limitations. First, the model covers many but not all commodities. Certain commodities in which Tajikistan has a comparative advantage (e.g. table grapes and raisin, apricot and dried apricot, tomatoes, potatoes, onions and apples) were not included due to the unavailability of elasticity figures (supply, income and demand). Also, it was not possible to reveal the effects of production increase for those commodities that are traded but not produced in the country like sugar. Second, the calculation of the consumer surplus in the model considers only the price effect. The income transfer from the economically external source of remittances has to be added manually. A third issue that was not considered in this study but would need to be further elaborated is the effect of labour migrant remittances on the exchange rate and the trade. The inflow of remittances of such a large extent as in Tajikistan likely leads to an appreciation of the domestic currency, and subsequently exports could diminish and imports rise which would mean a disincentive for the

agricultural sector of Tajikistan.[9] Fourthly, the reliability of official data used in the model is worth discussing. For example, for all commodities, except cotton and wheat, the official border price did not indicate the actual observable price but was underestimated and had, therefore, to be adjusted. Finally, the scenario simulation has been done *ceteris paribus*. A simultaneous influence of other factors determining consumption, production, and trade of agricultural products, e.g. changes of agricultural productivity or trade policy aspects, was blinded out. Those factors were analysed separately by further scenarios.

4 CONCLUSION

Tajikistan shows constant economic growth for more than a decade caused by ever increasing labour migrant remittances. With about 50 percent of the national GDP, remittances have become crucial for the country's development. The agricultural sector is also important for Tajikistan because it is the main source of livelihood (subsistence) but also the provider of revenues (mainly to the state) through cotton export. As part of a broader analysis the present study focuses on the effect of population growth, economic (income) growth, and subsequently consumption (demand) growth on production, trade, and welfare of the agricultural sector of of Tajikistan. Results reveal that the worldwide population growth has a dominating effect on production, trade, and welfare. Income growth in Tajikistan impacts additionally on it, particularly with regard to livestock products. However, the increase in demand is mainly satisfied by increasing imports because most farmers in Tajikistan are subsistence farmers who do not much produce for the market and thus do not respond to higher price incentives. Therefore, the negative trade balance in agriculture will further deepen. The state budget will gain through taxes and other levies at the border. Consumers will win through the direct income transfer although they have to pay higher prices for food. The study has demonstrated that the agricultural sector of Tajikistan is far behind its potential. An investment of the remittances for the development of the agricultural sector could be a starting point: Better rural infrastructure and access to markets would increase farmers' responsiveness to higher prices and stimulate production. This, but also an increase in agricultural productivity, would strengthen domestic supply response to income and demand growth, increase the competitiveness of Tajikistan's agricultural sector, and improve the trade balance.

[9] Macroeconomic effects of remittances in Tajikistan, including remittances-induced currency appreciation are addressed in Khakimov (2013) and Khakimov, Schmitz & Pawlowski (2014b). For a similar discussion on Kyrgyzstan see the contribution of Zhunusova & Herrmann in this book.

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LAND USE, FOOD AND NUTRITION SECURITY – CASE STUDY IN RURAL UZBEKISTAN

B. GOJENKO, A. MÖSER and I.-U. LEONHÄUSER

0 ABSTRACT

Guaranteeing food security is of critical importance for the Central Asian region due to its landlocked nature, the large number of rural population with low incomes, and the transition from planned centralized economy to market economy. Uzbekistan has adopted a rigid approach to food security that prioritises self-sufficiency but lacks an emphasis on balanced nutrition and affordable food. This case study examines the current food and nutrition status of farmers' households in Uzbekistan collecting primary data through 220 quantitative interviews (2011-2012) and analyses the income, food, and nutrition situation of households according to producing cash and food crops on farm land, and/or on homestead plots. The study points out that food secure households are characterised by larger acreage cultivated in homestead plots and higher diversity of crops produced than food insecure households. Diversification of agricultural production will lead to a diversified food supply and a more varied diet of the population. Hence, it is recommended to support the production of food crops on homestead plots by the local authorities. Further, household size as well as the education of the head of the household affects the food security situation of the households. Therefore, bringing forward economic and physical accessibility of food at the household level, also the knowledge of farmers has to be improved. This might include trainings in crop production on homestead plots, direct marketing by farmers as well as on preservation strategies. These achievements might help households with lower education level to make the most out of their land.

1 INTRODUCTION

According to a currently accepted definition, "Food Security (FS)" is achieved when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996 cited by FAO, 2008). This definition includes four dimensions. First, physical availability of food addresses the aspect of food supply at the national or international level by food production, stocks and net trade. Second, economic and physical access to food ensures the food availability at the household level. Third, food utilization describes the ability of the human body to ingest and metabolise food. This determines the nutritional status of a person. And finally, stability ensures that the three dimensions are adequate over time without risking a deterioration of the nutritional status. In this context, food is defined as any substance that people eat and drink to maintain life and growth (FAO, 2008). Gross (2002) points out that food also has an important social role in keeping families and communities together, which is discussed within the third dimension of food security. As a result, “food security can accomplish its social role only when sufficient culturally adapted food is available within households and communities to meet their biological and social needs” (Gross, 2002, p. 343).

“Halving hunger by 2015” has been declared as part of the First Millennium Development Goal to eradicate extreme poverty and hunger. However, despite the fact that the proportion of undernourished people in developing countries decreased from 23.2 % in 1990–1992 to 14.9 % 2010–2012, one in eight people in the world today still remains chronically undernourished (UN, 2013). According to the Food and Agricultural Organisation (FAO), the World Food Programme (WFP) and the International Fund for Agricultural Development (IFAD) (FAO, WFP & IFAD, 2012), people living in the Caucasus and Central Asia face a slightly different situation. Whereas in 1990-92 12.8% of the people were undernourished, this share increased up to 15.8% in 1999-2001. Then, improvement was achieved in the first decade of the 21th century and the prevalence of undernourishment decreased in 2004-2006 to 9.9%. Since then, global progress in reducing hunger has slowed and levelled off: 7.4 % of the people living in the Caucasus and Central Asia are still undernourished in 2010-12.

Therefore, guaranteeing food security is of critical importance for the Central Asian region due to its landlocked nature, the large number of rural population with low incomes, and the transition from planned centralized economy to the market economy. As a result, the population is severely impacted by worldwide fluctuations in food prices. The primary concern surrounding food security in the region is the relatively high level of poverty faced by Tajikistan and Kyrgyzstan, and to a lesser extent Uzbekistan (Sedik et al., 2011). During the transition from planned to market economy, the Central Asian Republics (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) experienced rising poverty, food insecurity and malnutrition as well as serious degradation of natural resources, in particular of water and land. This transition process has not been adequately supported by an institutional development which resulted in a decline in living standards of the population and which is reflected in high levels of food insecurity and malnutrition (Babu and Tashmatov, 2000).

Among the Central Asian Republics, since declaring independence in September 1991 Uzbekistan has adopted a rigid approach to food security that prioritises self-sufficiency but lacks an emphasis on balanced nutrition and affordable food. According to UNDP (2010), although Uzbekistan produces adequate calories to feed its population, almost 30 percent of its people live below the food poverty line, and large nutritional disparities exist among income groups. Land use strategies in Uzbekistan determine the level of self-sufficiency.

While the area of rangelands is vast, the livestock farming and production of grains, fruits and vegetables play a major role in food security and they also are the basic source of rural population income. During the years of independence Uzbekistan has undertaken a number of measures in order to reach food security which primarily meant the self-sufficiency in foodstuff. It is basically grain, but does not consider the availability of balanced food for the population. From 2000 to 2007, agricultural production rose steadily by at least 6 percent per year, significantly outpacing the population growth rate. Owing to a successful wheat self-sufficiency policy, the wheat harvest expanded almost nine-fold between 1991 and 2006. At the same time, import restrictions and a policy to produce import substitutes reduced food imports by one-third (UNDP, 2010). However, food security also encompasses affordable food and a diverse diet that includes essential nutrients. The poorest population spends an average of 60 percent of their income on food and consumes a diet dominated by cereals. Wheat and cotton together account for almost 80 percent of the country's cultivated land, reducing the area devoted to other crops and livestock fodder, and narrowing the selection of available nutrients. Yet average wheat yields remain quite low and, in some provinces are close to pre-Green Revolution levels (UNDP, 2010).

According to FAO, WFP and IFAD (2012), poor consumers in many countries have to compromise the quality and diversity of the food they consume by reverting to cheaper and less nutritious foods if they face income losses and/or higher food prices. However, such impacts are difficult to quantify with currently secondary data available in most countries. As a result, the presented case study examines the current food and nutrition status of farmers' households in Uzbekistan collecting primary data through 220 quantitative interviews. The case study aims at one hand to analyse the income, food and nutrition situation of households according to producing cash and food crops on farm land, and/or on homestead plots[1]. On the other hand, the impact of production on homestead plots on household's food security is assessed. The remainder of the paper is organized as follows. In the next section, literature on household food security is reviewed. Chapter 3 describes shortly the methodological approach of the study. Main results are presented in Chapter 4, and the next section is focused on the discussions of the results in comparison with other studies. The final section offers recommendations to improve food security (FS) in Uzbekistan, and suggestions for future work in this area.

1 Uzbekistan has undertaken several steps of land reform after independence. Land is still property of the state; farmers are able to use land by land use rights only. Homestead plots (also called *dehkan* farms) are small agricultural units of a maximal allowed size of 0.35 ha of irrigated or 0.5 ha of non-irrigated area. Farm land refers to agricultural enterprises (also called private farms) which originate from former state or cooperative farms. Farm land is subject to the state order of cotton and wheat production, while homestead plots can be freely used for any agricultural production. Homestead plots produce more than 60% of the total agricultural output of Uzbekistan (vgl. Herman, 2005 and Herrfahrdt, 2004).

2 LITERATURE REVIEW

There are some studies in developing countries which investigate the food security status of households. However, only few studies are available on Central Asia, and especially on Uzbekistan. Table 1 presents an overview.

Additionally, there are two studies in Uzbekistan which are not exclusively focussed on food security, but on food consumption and poverty. UNDP (2010) indicates that the poorest population of Uzbekistan spends more than 60 % of their income on food, whereas households with highest level of income spend around one-third of the income on food. Further, they assert that almost 30 % of Uzbek people live below the food poverty line. The authors investigated factors influencing poverty in Uzbekistan using household level consumption data from World Bank's Uzbekistan Regional Panel Survey (URPS) of 2006 (3,000 interviews). They found that number of children, age of household members, number of adult female members as well as the region affect the probability of being poor. Additionally, they indicate that the head of Uzbek poor households has an average of 10.1 year of education in comparison to non-poor households. Those heads have an average of 11.7 years of education. Further on, they specify that the poorest households consume a diet dominated by cereals, so large nutritional disparities exist among income groups.

Finally, a WFP (2008b) analysis of poverty and food security in Uzbekistan shows that despite the small size of household homestead plots they play a major role in terms of agricultural production and, more importantly, in household food security and food consumption. Homestead plots are vital for the survival of farm households as they provide more than a quarter of the food consumption of rural households (WFP, 2008b).

Table 1: Studies on food security

Author(s)	Country	Sample size	Factors influencing food security
Abdalla (2012)	Sudan	200 farm households	Household size (due to the higher number of dependent members), education of the household head, household income.
Khatri-Chhetri & Maharjan (2006)	Nepal	128 farm households	Large land and livestock holders, business and service jobholders, households with high-income level (proxy of household's expenses).
Sharafkhani et al. (2011)	Iran	2,500 households	Distance from the city, number of centers that provides food, residential infrastructure, family size, presence of both parents in comparison to the presence of single parent at home.
WFP (2008a)	Kyrgyzstan	5,000 households	Family size, lack of adequate education, gender of head of household (with male-headed households are more likely to be food insecure than female-headed households), household size (especially those above 4 members), age of head of household.
WFP (2013)	Kyrgyzstan	2,000 households	Poverty, livelihood group (e.g., unskilled workers with irregular incomes as well as persons relying on pensions and small allowances), average acreage cultivated per capita.
WFP, FAO, UNICEF & Government of Tajikistan (2008)	Tajikistan	798 rural households	Household size and composition (large families including one or two income-earning members and/or receiving remittances regularly and in large amounts may be better-off than small families with an under-employed adult member), income level, amount of acreage planted with potatoes and wheat, ownership of animals (and higher diversity of animals)
Yeudall et al. (2007)	Uganda	296 urban farmers	Assets, primary caregiver's education, area of land farmed.

Source: Own compilation.

3 METHODOLOGICAL APPROACH

The principal instrument of the present study was a primary data collection through field visits where 220 farm households were interviewed. The field study was conducted using different questionnaires, taking place in two regions of Uzbekistan: Markhamat region of Andijan province and Denau region of Surkhandatya province. First of all, a structured household questionnaire was used in order to collect socio-economic data, and dwelling unit data. Additionally, a modified Household food security survey module (HFSSM) following (USDA, 2000), a Food list recall and a Food consumption score questionnaire (FCS) following IFPRI (2009) were applied to clarify the food security and food consumption status of the investigated households.

Descriptive statistics were used in order to classify study households into groups, taking into account their food security and food consumption status. This tool permitted to identify the threshold between food secure and food insecure household, as well as the households with a high food consumption and low food consumption status. Bivariate analysis based on U-tests and t-tests helped to assess the dependency of food security and food consumption on socio-demographic characteristics of the households, crop production and production on homestead plots. Finally, logistic regressions were used in order to understand the factors which influence food security and food consumption status of the households.

4 MAIN RESULTS

4.1 Food security status

The food security status was calculated using the primary data obtained by the Household Food Security Survey Module (HFSSM). The HFSSM is a household measure which assesses the food security situation of adults as a group and children as a group within a household. The HFSSM does not determine the food security status of each individual member residing in the household (USDA, 2000). Table 2 provides the scale and results of descriptive statistics with regard to food security. First of all, the scale for the food security status was developed. Secondly, investigated households were divided into groups by their food security status.

The first group of households was decided as being “high food secure” because they are based on 0 HFSSM score. That means that these households never face a problem with food supply. There are 39% of such households in Markhamat region and 36% in Denau region.

Table 2: Food security status of investigated households

HFSSM status	HFSSM score	Both regions (n=220)	Markhamat (n=110)	Denau (n=110)
High FS	0	0.37	0.39	0.36
Marginal FS	from 1 to 3	0.24	0.18	0.29
Low FS	from 4 to 9	0.34	0.37	0.30
Very low FS	more than 9	0.06	0.06	0.06

Source: Own computation with data of the questionnaire.

Note: U-Test for statistical significance of HFSSM status between regions is p=0.65.

The second group constituted the "marginal food secure" households, which have a HFSSM score between 1 and 3. These household rarely have problems of food security. The number of such households in Markhamat region is much lower than in Denau region and indicate 18% and 29% respectively. The third group consists of "low food secure" households, which are represented by 37% of investigated households in Markhamat region and by 30% in Denau region. This group has a HFSSM score between 4 and 9. The last group according HFSSM represents the households with "very low food security". Consequently, this group contains the households with the maximum of HFSSM score, i.e. more than 9. These are households which often have difficulties with food supply. The number of "very low food secure" households is the same in both regions (6% of investigated households).

For further analyses investigated households were regrouped from these four groups into two groups. The first group combines those households which have "high" and "marginal" food security and gets the name of "food secure households". This group is represented by 134 of households in both regions. The second group combines "low" and "very low" food secure households and is characterised as "food insecure households". There were found 86 of "food insecure" households in both regions.

4.2 Food consumption status

The food consumption score analysis is based on the frequency of consumption of one or more items from eight different food groups. Households are grouped according to their overall consumption score: "poor food consumption", "borderline food consumption" and "adequate food consumption". In the context of the present study, households with "poor food consumption" have not been found. Consequently all investigated households were joined in two groups.

Thresholds for separating these groups are generated by using a weighted food consumption score. Each food group is given a weight based on its nutrient content and then multiplied by the number of days a household consumed one or more items from that group within a seven-day period. Table 3 provides the number of households with different food consumption status divided by groups due to food consumption scores (FCS).

Table 3: Food consumption status of investigated households

Food consumption status	FCS	Both regions (n=220)	Markhamat (n=110)	Denau (n=110)
Borderline	from 21.5 to 35	0.04	0.01	0.07
Adequate	more than 35.5	0.96	0.99	0.93

Source: Own computation with data of the questionnaire.

Note: U-Test for statistical significance of food consumption status between regions is p=0.21.

Thus, households with “borderline food consumption” have a FCS from 21.5 to 35. Only 4% of all investigated households in both regions represented this group. In turn, only one household was found in Markhamat region and eight in Denau region, which represent 1% in Markhamat region and 7% in Denau region.

The main part of investigated households in both regions can be assigned to the group with a high FCS or “adequate food consumption”. Thus, on the average 96% of all investigated households have the “adequate food consumption”, whereas 99% are situated in Markhamat region and 93% are in Denau region.

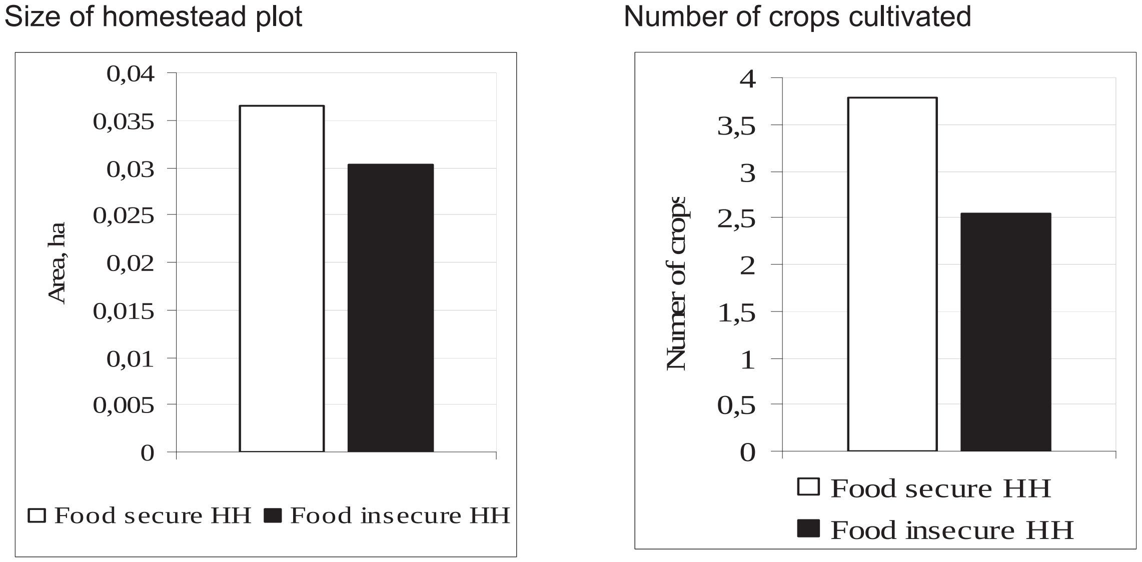
4.3 Factors influencing food security and income

The literature review (see chapter 2) indicates that several factors might influence food security. In the following subchapters the different aspects are investigated.

4.3.1 Homestead plots

Figure 1 indicates that food secure households (HH) have a homestead plot with the average size of 0.0366 ha. The average size of homestead plot of food insecure households is 0.0302 ha only. This difference is statistically significant (U-test, $p<0.0001$). The bigger size of a homestead plot permits the household to produce more food crops and consequently to be more food secure.

Figure 1: Influence of homestead plots on food security



HH: Household

Source: Own computation with data of the questionnaire.

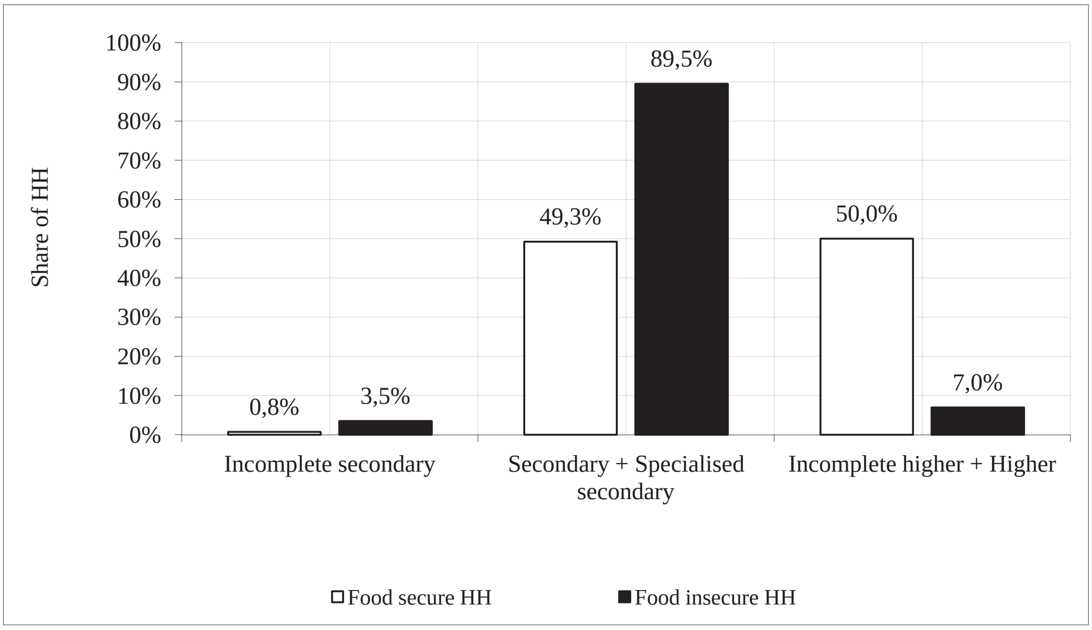
Further on, Figure 1 indicates not only the influence of the size of the homestead plot on FS, but also the variety of their cultivated crops. The average number of crops cultivated on the homestead plot of food secure households is 3.79. In turn, the average number of crops produced by food insecure households is quite smaller (2.55).

4.3.2 Education of the household head

The level of education of the household head might influence the food security status of the whole household. In Uzbekistan eleven years of education are compulsory and free. The education begins with four years at primary school, and is continued by two phases of secondary education taking five and two years respectively. Primary school begins at the age of seven (or incomplete seven) and there is no specific leaving examination after the four years are complete (UNESCO, 2011). The next five years are spent at general secondary school from ages ten to 15. After that, there is a choice of between two to three years of upper education at either general or technical vocational schools. The former provides a certificate of completed secondary education and the opportunity to enter university, the latter can be completed with a diploma of specialised secondary education, through a network of secondary vocational institutions (UNESCO, 2011). All further stages of education i.e. “Bachelor”, “Master”, “PhD” are considered as a higher education. This classification was used in the context of the present study due to its clarification for all interviewees.

Figure 2 combines the data on household head’s education level with regard to the food security status of his/her household. Thus, incomplete secondary education prevails between heads of food insecure households. Statistic crosstabs show that only 0.7% of food secure households are headed by persons with incomplete secondary education versus 3.5% of food insecure household heads. Household heads of the second group of education i.e. 'secondary' and 'specialized secondary' are represented by 49.3% of food secure households and by 89.5% of food insecure households.

Figure 2: Level of education of household head



Source: Own computation with data of the questionnaire. Note: HH: Household.

The most noteworthy difference was observed between the obtained results on the third group of education combined 'incomplete higher' and 'higher' levels of education. Thus, 50% of food secure households have heads with such a level of education. In the same time, only 7% of food insecure households are headed by persons with 'incomplete higher' and 'higher' education. This gap could be explained by the fact that more educated heads of household have more knowledge on agriculture, crop growing, food intake, and other aspects influencing the food security status of their household.

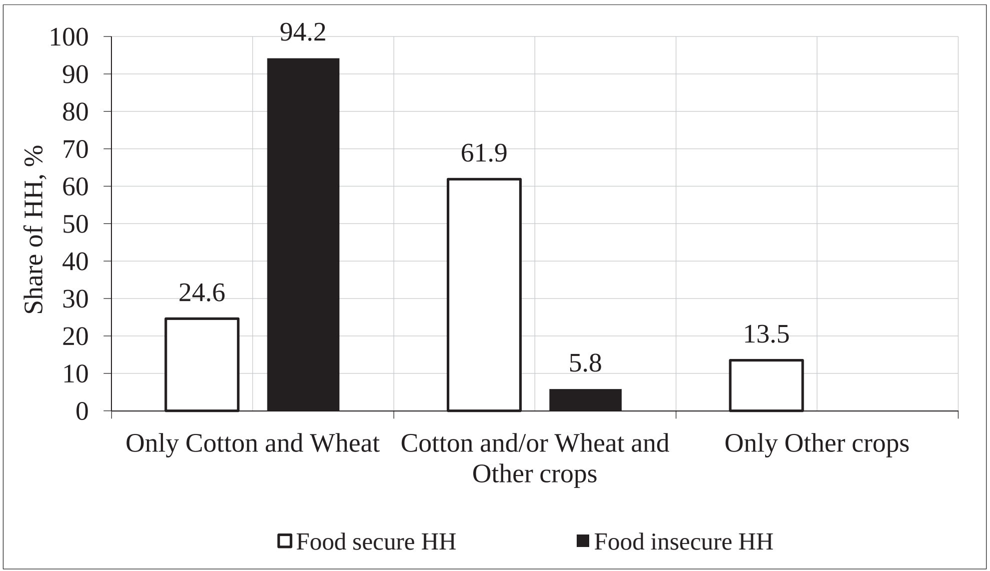
4.3.3 Production strategies

"Production strategy" is a term developed during the present study in order to designate the combination of crops cultivated by farmers on their farm land. Usually, all Uzbek farms can be divided into three groups taking into account the kind of crops produced by them. Thus, the first group or production strategy includes farms producing **only cotton and wheat** (so-called "strategic crops") on their farm land. For example, cotton is produced in irrigated areas throughout the country, accounts for about 40 % of cultivated land and makes up about 40 % of export earnings (WFP, 2008b). It makes Uzbekistan the fifth largest cotton producer and the second largest cotton exporter in the World. Since declaring independence, and as a result of the self-sufficiency food policy adopted by the Uzbek government, wheat was admitted as the second "strategic crop". It accounts for about 30 % of the cultivated area. The rest of the cultivated area is used for growing fruits and vegetables. Uzbekistan continues to be one of the major suppliers of fresh and processed fruits and vegetables in Central Asian region (WFP, 2008b). The state maintains tight control over the production of cotton and wheat, while state planning control on all other crops has been removed, allowing farmers' individual choice regarding production. State order means for cotton to market the whole production (100 %), while for wheat it is 50 % (i.e. another 50 % of production can be sold on the open market). The production amount of the state order for cotton and wheat is fixed by the government annually and refers not only to the quantity of each crop to be produced in each region but also to the crop areas to be assigned to these two crops. At the regional and local levels, these overall quotas are broken down into specific quantities and areas for each farm (SDC, 2011). In addition to setting quotas for the production of cotton and wheat, the state also controls inputs through annual credits (state loans) for production costs. These are tied to specific quantities of the various inputs and the disbursement of the funds is controlled by the bank where the farmer's account is located. The whole system is detrimental to improving productivity because the farmer has little flexibility to vary inputs according to the particular needs of his land or to adjust methods to improve outputs (SDC, 2011). The second production strategy group includes farmers who produce **cotton and/or wheat together with other (more profitable) crops** such as fruits, vegetables or melons.

Farmers who follow the third production strategy produce **only other crops**. The production of all other crops is not controlled by the state, but since the state order specifies land use as well as output, many farmers do not have available land (or only small areas) for other, often more profitable crops. Some farmers are able cultivating second crops on some parts of the wheat area after the wheat has been harvested. A second planting period and crop rotation are possible if irrigation systems are available.

Figure 3 demonstrates how the production strategy determines the food security status of investigated households. Thus, 'cotton and wheat' are produced by 94.2 % of food insecure households. This production strategy does not enable farm households to earn additional income by growing other food crops for own consumption or for selling on the market. 5.8 % of food insecure households produce 'cotton and/or wheat with a small plot of other crops'. Moreover none of investigated food insecure household produces 'only other crops'.

Figure 3: Production strategies and food security status



Source: Own computation with data of the questionnaire. Note: HH: Household.

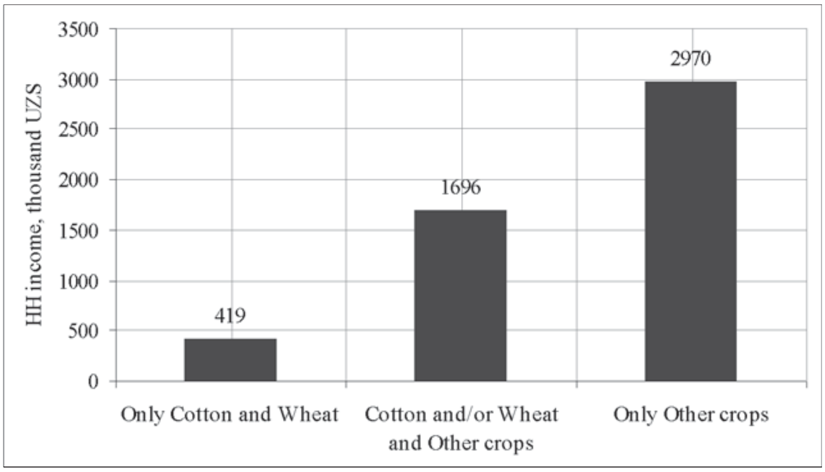
In the same time, only 24.6 % of food secure households produce 'only cotton and wheat'. The majority of households having the status of food secure use the 'cotton and/or wheat and other crops' production strategy. Finally, 13.5 % of food secure households produce 'only other crops'.

4.3.4 Income influencing factors

The level of income is clearly affected by the chosen production strategies. Thus, those households which produce 'only cotton and wheat' have the average income of 419000 UZS (175 €[2]) per month (see Figure 4). Households practiced 'cotton and/or wheat and other crops' production strategy have an average monthly income of 1696000 UZS (707 €). Households which produced 'only other crops' have the highest level of income represented by the amount of 2970000 UZS (1238 €) per month. In summary, the income of households which produced 'only cotton and wheat' is four times less than the income of households which produced 'cotton and/or wheat and other crop', and seven times less than the income of households which produced 'only other crops'.

[2] According to the web-site www.oanda.de the average yearly currency rate for 2011 was 1 € = 2400 UZS

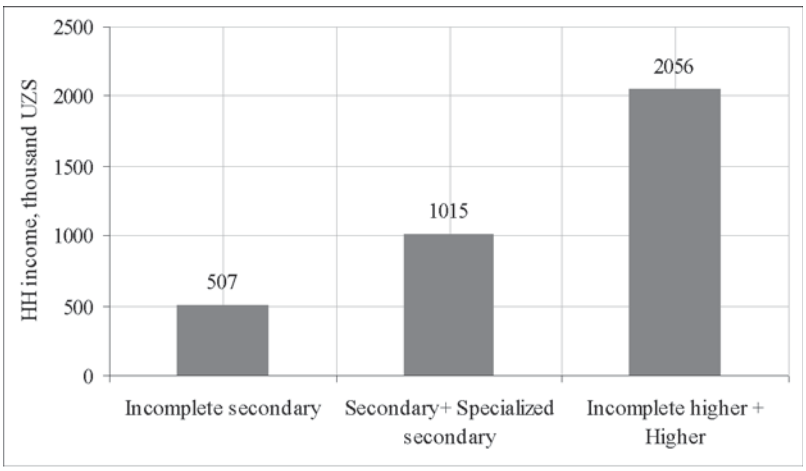
Figure 4: The effect of production strategies on households' level of income



Source: Own computation with data of the questionnaire.

Further on, the education of the head of household clearly affects the average amount of income (Figure 5). Thus, households headed by persons with 'incomplete secondary' education have on average 507000 UZS (211 €) per month. Households with a head belonging to the group of the 'secondary + specialized secondary' monthly earn on average 1015000 UZS (423 €). The highest monthly income of 2056000 UZS (857 €) households have are headed by persons with 'incomplete higher and higher' level of education. It can be concluded that households which are headed by persons with 'incomplete higher and higher' education have an income two times more than those which are headed by a 'secondary and specialized secondary' educated person, and four times more than those which have a head with the 'incomplete secondary' education.

Figure 5: The effect of the household head's education on the level of income

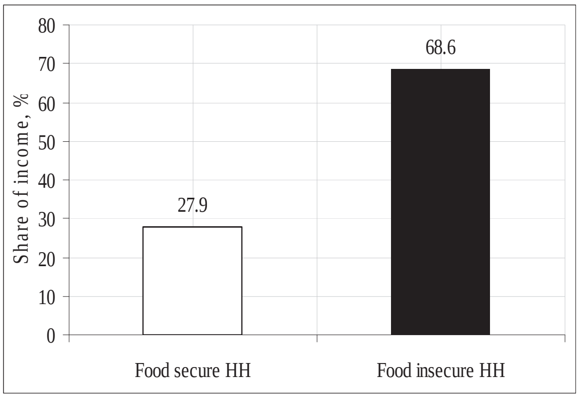


Source: Own computation with data of the questionnaire.

4.4 Income spent on food

The share of income spent on food is the most important indicator of the country's population well-being (UNDP, 2010). Figure 6 indicates that food insecure households spend 68.6 % of their total income on food. At the same time, food secure households spend only 27.9 % of their total income on food. It is noteworthy that one third of investigated food secure households have a high level of income.

Figure 6: Income spent on food



Source: Own computation with data of the questionnaire. Note: HH: Household.

4.5 Food security and food consumption modelling

Regression methods have become an integral component of any data analysis concerning the relationship between a response variable and one or more explanatory variables. The goal of analysis using this method is the same as that of any model-building technique used in statistics, i.e. to find the best fitting and most parsimonious model to describe the relationship between an outcome variable and a set of independent variables (Hosmer & Lemeshow, 2000). In the context of the present study two logistic regression models were developed. The first model was developed for food security. In this case food security plays the role of the dependent variable and the relationship with the set of independent variables (e.g. socio-demographic characteristics, production on homestead plots and production strategy) was analysed. The second logistic analysis has been run for households' food consumption. Here food consumption acted as the outcome variable. Table 4 describes the dependent and independent variables used in the two regression models and summarises the expected influence on food security (food consumption).

Table 4: Definition of variables

Variables	Description	Definition	Exp. Sign
Dependent variable			
Food security	Food security according HFSSM scale	Food secure = 1, food insecure = 0	
Food consumption	Food consumption according FCS	Adequate food consumption = 1, borderline food consumption = 0	
Explanatory variables			
HH_Education_group	Education of head of household	Incomplete secondary (1)	-
		Secondary & Specialised secondary (2)	-
		Incomplete higher & Higher (ref. cat.)	
Number_HHmembers	Number of household members	Number of members	-
No_Children_under_fourteen	Number of children under the age of 14	Number of children under 14	-
Crops_Homestead	Number of kind of crops produced on the homestead plot	Number of different kind of crops	+
Level_income	Household income level (per month/person)	< 189 000 UZS (1)	-
		189 000 UZS - 2 410 000 UZS (2)	-
		> 2 410 000 UZS (ref. cat.)	
Production_strategy	Production strategy	Only cotton and wheat (1)	-
		Cotton and/or wheat and other crop (2)	-
		Only other crop (ref. cat.)	

Source: Own computation with data of the questionnaire.

Modelling food security

Initially, several independent variables were included in the model. In line with figure 3, the production strategy clearly affects household's food security status. Hence, in comparison to a household which produced 'only other crop' (reference category), being a household which produced 'cotton and/or wheat and other crop' decreases the probability that the household is food secure. Further on, in comparison to a household which produced 'only other crop', being a household following the 'only cotton and wheat'-strategy decreases the probability that the household is food secure. Thus, the more household produces 'other crops' on farm land, the higher the household's probability to be food secure. Almost all other variables were statistically not significant.

In order to assess the impact of other factors which might influence food security status and which are discussed in the previous chapters, it was decided to delete the variables regarding production strategies from the model. The deletion of 'production strategy' as independent variables led to the second, reduced model, which is displayed in Table 5.

Table 5 shows that in comparison to households headed by a person with a high level of education, being a household headed by a person with middle (secondary & specialised secondary) or low level of education (incomplete secondary) decreases the probability that the household is food secure. Both coefficients are statistically significant at 95% or higher. This means that the more the household head is educated, or the higher the level of education of the head of household is, the higher the probability that the household is food secure. A more educated head of household seems to have more knowledge, more experience and more ideas how to manage his/her farm, how to earn more money, and how to efficiently use the available resources.

Table 5: Logistic regression model for food security

Variables	Coefficient
HH_Education_group (1)	- 1.883**
HH_Education_group (2)	- 1.548*
Number_HHmembers	- 0.346*
No_of_children_under_fourteen	- 0.204
Crops_homestead	+ 0.421**
Level_income (1)	- 2.218[a)]
Level_income (2)	- 1.750

Source: Own computation with data of the questionnaire.
Note: Number of observations=220; Nagelkerke's R-Square= 0.485; Significance level: ***-99.9%, **-99%, *-95%, [a)] -90%

The next indicator which has an impact on household food security is the number of crops produced on the homestead plot. This indicator has a positive sign and is highly statistically significant at the 99% level. Evidently, the more kinds of crops the household produced on the homestead plot, the higher the probability that household is food secure. The household size or the number of household members plays an important role in food security of the household, too. The coefficient of household members has a negative sign with statistical significance on the 95% level. Thus, with the rising number of household members, the probability that household is food secure decreases. The number of children under 14 years also has an impact on food security in the household. This factor has a negative sign, but is not statistically significant. Another significant factor which influences household food security is the level of income. Hence, in comparison to households with high income, being a household with low income decreases the probability that the household is food secure. This variable is statistically significant on 90% level and has a negative sign. In turn, in comparison to households with high income, being a household with middle income decreases the probability that the household is food secure. In this case, the variable is not statistically significant. Certainly, the higher the household income is, the more such a household has the opportunity to buy food for its members, and thus the higher is the probability to be food secure. Moreover, a household which has a high level of income has more opportunities to buy the food exactly needed and thus could have a higher nutrition status.

Food consumption modelling

Analogous to the logistic regression model for food security, initially a wide set of explanatory variables was included in the food consumption model. Hence, in comparison to a household produced ‘only other crop’, being a household which produced ‘cotton and/or wheat and other crop’ decreases the probability that the household has adequate food consumption. The coefficient has a negative sign with a 99.9 % statistical significance level. In turn, in comparison to a household which follows the ‘only other crop’-strategy, being a household which produced ‘only cotton and wheat’ decreases the probability that the household has adequate food consumption. In this case the coefficient also has a negative sign with a statistical significance on 95 % level. All other variables were statistically not significant.

Therefore, it was decided to delete the variable ‘production strategy’ from the model, which led to the second, reduced model (see Table 6). As well as in the case of the logistic regression modelling for food security, the education of the head of household clearly influences food consumption. Table 6 shows that in comparison to households headed by a person with a high level of education, being a household headed by a person with a middle level of education decreases the probability for adequate food consumption. The coefficient has a negative sign with 99 % statistical significance level. In turn, in comparison to a household headed by a person with a high level of education, being a household headed by a person with low level of education decreases the probability of adequate food consumption. In this case the coefficient also has a negative sign with statistical significance on 99 % level. This means that the higher the level of education of the head of household, the higher the probability that the household has adequate food consumption. A more educated head of household seems to have more knowledge on different aspects of food consumption (e.g. what kind of food is necessary for his/her household members and what kind of food crops needed to be cultivated in the household homestead plot).

The number of household members has a negative sign for food consumption with the highest statistical significance on the 99.9% level. Hence, the more members the household has, the lower the probability for adequate food consumption is. The number of children under 14 years also has an impact on food consumption in the household. This factor has a negative sign with the high statistical significance on the level of 99%. Thus, an increasing number of children under the age of 14 in a household decreases the probability for adequate food consumption.

The number of crops produced on the homestead plot also positively influences food consumption. This indicator is highly statistically significant on the level of 99%. That means that the more kind of food crops are produced on household's homestead plots, the higher the probability to have adequate food consumption.

Table 6: Logistic regression model for food consumption

Variables	Coefficient
HH_Education_group (1)	- 2.294**
HH_Education_group (2)	- 2.146**
Number_HHmembers	- 0.754***
No_of_children_under_fourteen	- 0.945**
Crops_homestead	+ 0.578**
Level_income (1)	- 3.816**
Level_income (2)	- 2.508*

Source: Own computation with data of the questionnaire.

Note: Number of observations=220; Nagelkerke's R-Square= 0.485; Significance level: ***-99.9%, **-99%, *-95%, [a)]-90%

Another significant factor which influences household food consumption is the level of income. Table 6 shows, that in comparison to households with high income, being a household with middle income decreases the probability of adequate food consumption in the household. This variable is statistically significant on 95% level. In turn, in comparison to households with high income, being a household with low income decreases the probability of adequate food consumption in household. This variable is statistically significant on 99% level.

5 DISCUSSION

Discussion of results with regard to research in Uzbekistan

UNDP (2010) indicates that the poorest population of Uzbekistan spends more than 60 % of their income on food, whereas households with highest level of income spend around one-third of the income on food. Own results with more recent data found that food insecure households spend 68.6 % of their total income on food. This is explained by the fact that about one third of food insecure households have a low level of income and about two thirds have a middle one. At the same time, food secure households spend only 27.9 % of their total income on food. Further, UNDP (2010) asserts that almost 30 % of Uzbek people live below the food poverty line. The present study confirms this fact as 39 % of investigated households in both regions are food insecure due to low income. Moreover, 6 % out of 39 % have very low food security. The differences of these measures could be explained by the outdated data used by UNDP (2010), obtained from research in 2001-2007, while the data of the present study was obtained during field surveys in 2011-2012.

Another factor which influences food security and food consumption status is the household composition. Both logistic regression models confirm that an increasing size of households reduces the probability of being food secure or obtaining adequate food consumption. UNDP (2010) confirms that the average number of households is higher in households under the poverty line than above (6.4 versus 4.8 members). But not only household size, but the number of children and their age matters, too. The own regression analysis outlined that the number of children under the age of 14 influences the food consumption status. With an increasing number of younger children the probability decreases that the households achieves adequate food consumption. UNDP (2010) found that poor households have more than two children on average, while households above the poverty line have less than two. Further on, an increasing number of children increases the probability of being poor.

The regression model developed in the present study indicates that the level of education of the household head influences both, food security and food consumption. The analysis shows that the probability increases significantly of a household being food secure and showing better food consumption with an increase of household head education level. UNDP (2010) found that the head of a poor household has on average 10 years of education, which comes up to complete secondary education in Uzbekistan. Heads of households above the poverty line have on average 11.7 years of education, indicating that at least one-third of those household heads have attended higher educational institutions.

Discussion of results with regard to research in other Central Asian countries

Research in Tajikistan, conducted by WFP, FAO, UNICEF, and Government of Tajikistan (2008), confirms that the size of the households was slightly associated with food insecurity, and that smaller families tend more likely to be severely food insecure than larger families. This may be explained by the fact that the presence or absence of working-able and income-earning members matters, as these people might contribute by their income to food security/insecurity rather than just the size of the households. As such, large families including one or two income-earning members and/or receiving remittances regularly and in large amounts may be better-off than small families with an under-employed adult member. Further on, the influence of the income level was also discussed. Such kind of explanation could also be valid for Uzbekistan. The Tajik research also indicates that large families and/or families with many young children perceive a heightened vulnerability as food, clothing and schooling expenditures contribute to food and economic insecurity. This research generated an interesting fact: food expenditures in Tajikistan represented 81 % of all basic expenditures for the majority of households. This means that only a low share of the income is left for other essential expenditures including health, education, energy and transportation, and even less for clothing, housing, etc. At the same time the own research in Uzbekistan indicates the share of income spent on food is much smaller (68.6 % among food insecure households, but food secure households spend only 27.9 % of their total income on food). However, this difference might be due to different research periods: the Tajikistan study was conducted in 2008 during high volatile world market prices, whereas the own research was done in 2011-2012.

Research by WFP (2013) assessed the food security situation in Kyrgyzstan and found that irregular and low income, acreage cultivated per capita in homestead plots, and dependency on the purchase of food from markets are the main factors for household food insecurity. Food security assessment in Kyrgyzstan in 2013 also evaluated that households with a larger family size are more likely to be food insecure. Household sizes were larger in rural than in urban areas. The difference was statistically significant. Kyrgyz food insecure households spent 61 % of their budget on food, indicating high dependency on food purchases, leaving them vulnerable to market developments, such as the recent price hikes. In line with own research (see Figure 1), the assessment in Kyrgyzstan confirmed that the size of the homestead plot matters. In food insecure households in Kyrgyz Republic the average area cultivated per capita is 0.26 ha/capita in comparison to food secure households cultivating on average 0.43 ha/capita. This indicates that in Uzbekistan as well as in Kyrgyzstan households with small plot sizes are more likely to be food insecure.

6 CONCLUSIONS

6.1 Recommendations

The following recommendations to improve the food security status in Uzbekistan are oriented at the dimension of food security: physical availability of food at the national or regional level by food production, stocks and net trade; economic and physical accessibility to food at the household level; utilization of food at the personal level. It must be noted that stability of these dimensions over time has to be guaranteed.

Physical availability of food at the national level

Trade policy components geared towards self-sufficiency and protectionism have a profound influence upon agricultural policies in Uzbekistan. As noted above, wheat cultivation is predominant in Uzbekistan’s food production. In combination with cotton, these two ‘strategic crops’ amounted for 79.9 % of sown area in 2005 (UNDP, 2010). The authors conclude that “state control over the area sown in cotton and wheat as well as its procurement price (which are three times lower then on the world and/or on the open market) is not in the interest of farmers” (UNDP, 2010, p. 56). The predominance of wheat and cotton within agricultural production is inconsistent with the goal of providing the population with access to balanced food. Currently the government defines for farmers both, the volume of production for the state order and areas of land under the strategic crops. Changing this regime so far that the production will be defined only by volume either than by land sown will give the opportunity to reach the necessary volume of strategic crops production even from smaller areas. On the liberated areas from cotton and wheat the growing of food crops and fodder crops could be organized (UNDP, 2010). This in turn, could lead to higher availability of fruits, vegetables, meat and meat products. Furthermore, improved knowledge of policy makers and institutions (e.g. universities, multipliers) on land management such as e.g. modern kind of irrigation systems (especially for cotton as drop irrigation), modern fertilizers, and cultivation of new varieties of cotton and wheat as well as crop rotation is necessary.

Further, subsidies and tariffs affect food security in Uzbekistan. UNDP (2010) point out that wheat products (flour and bread) are sold to the population at fixed prices, but these subsidized products are not accessible for the rural poor in sufficient quantity. The authors conclude that as “around 60 % of Uzbekistan’s population lives in rural areas, subsidies for the most part benefit the comparatively small number of urban poor [who consumes the bulk of subsidized flour and bread], to the detriment of rural producer and the relatively numerous rural poor. Such a distorted production and distribution system is neither sustainable nor equitable” (UNDP, 2010, p. 56). The authors investigated further how reduction of import tariffs might affect food availability. Their analysis suggests that a relaxing import tariff policy might result in consumer prices for imported flour to fall by 13 % with a 20 % import tariff rate, 25 % with a 10 % import tariff rate, and 38 percent with a zero import tariff rate. They conclude that such a reduction of import tariffs might “provide greater overall food availability in general and, most importantly, lowering prices in Uzbekistan’s market for flour” (UNDP, 2010: 43).

The present study confirms that not only the agricultural production on fields matters, but also the production on homestead plots. WFP (2008b) concludes that despite the fact that most of the production on homestead plots is managed on the basis of primitive manual labour, there have been rapid and strong productivity gains leading to increases in household incomes. In line with this, own research points out that food secure households are characterised by larger acreage cultivated in homestead plots and higher diversity of crops produced than food insecure households. Diversification of agricultural production inevitably entails a diversified supply of foodstuffs, which leads to a more varied diet of the population. Hence, it is recommended to support the production of food crops on the homestead plots by the local authorities. The support could be in form of increasing of homestead plots from current 0.04 ha to 0.08 ha, and even to 0.1 ha. This approach could increase the food security of the households themselves. Further on, due to higher acreage, some households might be able to sell their food produce at local markets in order to earn additional income. The land from the State Land Reserve could be taken for these purposes. Moreover it is necessary to support households by micro credits in order to use limited land and water resources efficiently or to finance facilities to cultivate higher valuable crops (e.g. tomatoes or cucumber) for example via greenhouse-production. In line with this, FAO, WFP and IFAD (2012) point out that in Asia during the Green Revolution, smallholder farmers adopted new technical innovations, increased productivity, and produced enough food to lower the real prices of staple foods for consumers more efficiently than large-scale farmers.

For Tajikistan, WFP, FAO, UNICEF and the Government of Tajikistan (2008) propose mid-term interventions to encourage planting for the next winter wheat, potato and vegetables seasons. Assistance may include the distribution or vouchers for farmers to procure quality seeds, fertilizer, and agricultural machinery services and fuel, the repair of irrigation systems, possibly using food- and/or cash-for-work modalities and protecting seeds from being consumed by distributing a food ration at the same time. Implementing such actions by the government of Uzbekistan seems to be helpful, too.

Further, UNDP (2010) recommend the growth of production and trade of livestock products as the predominance of wheat and cotton in Uzbekistan has reduced the area cultivated with fodder crops. However, rising prices for livestock products enables farmers who own animals to increase their income, but the price hike might make a sufficient quantity of livestock products inaccessible to the majority of the population.

Economic and physical accessibility to food at the household level and utilization at the personal level

Logistic regression analysis confirms that the educational level of head of household influences food security and food consumption. The higher the level of education of the head of household is, the higher the probability is that the household is food secure or has adequate food consumption. A more educated head of household seems to have more knowledge, more experience and more ideas how to manage his/her farm, how to earn more money, and how to efficiently use the available resources. Figure 6 highlights that the higher the education of the head of household, the higher overall income out of agricultural production and homestead plot production is. Further on, a more educated head of household seems to have more knowledge on different aspects of food consumption (e.g.

what kind of food is necessary for his/her household members and what kind of food crops is needed to be cultivated in the household homestead plot). Therefore, to guarantee economic and physical accessibility of food at the household level, the knowledge of farmers has to be improved. This might include trainings in crop production on homestead plots, direct marketing of food by farmers as well as on preservation strategies. All achievements might help households with lower level of education to make the most out of their land. Further on, WFP, FAO, UNICEF and the Government of Tajikistan (2008) propose to improve access to, and performance of local markets of Tajikistan. In this area, both traders and customers can be targeted directly and indirectly through credit and/or vouchers for fuel and transportation of commodities, and/or support to create associations that can pool the transport and storage of goods (if this does not exist already), repair of infrastructure, possibly using food- or cash-for-work modalities as well as cash and/or vouchers to households to restore the demand and subsequent supply response by traders. These actions seem advisable for Uzbekistan, too.

In contrast to the long-term effects of an improved knowledge and better education, it seems necessary to ensure urgent interventions for vulnerable households and persons. In the study region, 6% of households face a very low food security (see Table 2) and 4 % of households were classified with borderline food consumption (see Table 3). Facing similar problems, other Central Asian Republics like Tajikistan or Kyrgyzstan have discussed several options, including among others cash transfers, school feeding, targeted food rations, or food-for-work programmes (WFP, FAO, UNICEF and Government of Tajikistan, 2008; WFP 2012). It seems necessary that Uzbekistan should discuss such options, too.

6.2 Suggestions for further research and limitations of the study

The present study aims to analyse food (and to a certain extent nutrition) security among rural households in Uzbekistan. As quantitative studies on food security and agricultural issues in Uzbekistan are still generally rare, the present study is a valuable contribution to empirical analysis in this field. However, as every study, also the present one has some limitations. First, the field study was conducted during the winter season, when the food and particularly nutrition status of households were worse than during spring, summer and autumn seasons. Secondly, the analysis of food consumption was based on only a seven days food list recall. That might not give the correct information on usual food consumption by the members of households. Thus, the seasonality of food security and food consumption was not considered in the frame of the present study. It is recommended that future research will be conducted during the whole year period in order to assess the food availability, food access, and food supply during each season.

The HFSSM used in the present study was modified with regard to a number of questions, especially concerning the issue of hunger were aborted. This was decided due to the fact that chronic hunger is not observed in today's Uzbekistan. For further research it is recommended to modify the HFSSM with regard to reasons of lack of food in a household (and not only financial difficulties) in order to understand the reasons of low food security on household level in more detail. Moreover, food items in the FCS questionnaire are not always adapted to Uzbek conditions. There are some food items, which are not produced and/or not consumed in rural Uzbekistan. Thus, for further researches it is necessary to modify the food items in order to get more reliable results of household food consumption status.

Additionally, the present study was conducted in two out of twelve regions of Uzbekistan. Certainly, Uzbekistan has "more poor" and "more rich" regions on which the food and nutrition status of household is lower or higher respectively. Thus, the obtained results and recommendations are not applicable for every Uzbek region. It is necessary to conduct similar research in other regions taking into account the specific conditions of each region and/or even the village.

Finally, Uzbekistan is an agrarian country, and around 60 % of its population resides in rural areas. The well-being of Uzbek population strictly depends on agriculture. At the same time Uzbekistan has only limited land and water resources. Thus, future research of food and nutrition security has even more to be linked to land and water availability, access and use. Furthermore, the limitation of time and finances gave no opportunity for a more comprehensive study with a bigger number of households. A sample size of 220 households cannot per se describe the complete food and nutrition situation among rural households.

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AGRICULTURAL INCENTIVES IN THE KYRGYZ REPUBLIC UNDER THE INFLUENCE OF DOMESTIC POLICIES AND CHANGING MACROECONOMIC CONDITIONS

E. ZHUNUSOVA and R. HERRMANN

0 ABSTRACT

Together with the rest of the economy, the agricultural sector in Kyrgyzstan has undergone crucial reforms during the transition period following the collapse of the Soviet Union. The policies influencing agricultural incentives, i.e. farmgate prices, have also changed substantially. Recent macroeconomic developments, such as the booming gold mining sector and an increasing inflow of workers' remittances on the one hand, and increasing import prices on the other hand, are also likely to have an impact on agricultural incentives through the influence on the exchange rate. This paper aims at investigating the impact of both direct agricultural policies and changing macroeconomic conditions on agricultural incentives for the case of Kyrgyzstan. Nominal Rates of Assistance (NRAs) are estimated in order to quantify direct distortions to agricultural prices resulting from the policies in the agricultural sector. NRA estimates show that domestic prices for major food crops in Kyrgyzstan are raised beyond world market prices due to a general encouragement of food-crop production based on food self-sufficiency goals. Relative to food crops, export crops tend to be penalized by lower and less stable NRAs as well as by poor market integration. In the second step, the True Protection Concept is employed in order to analyse relative incentives between importable, exportable and nontradable sectors in the Kyrgyz economy. The true-protection analysis shows that around half of the burden of the price increase for importables is shifted to the exportables sector, including agricultural exportables. This means that if prices in the importable sector increase in response to exogenous factors or certain trade policies, domestic exporters, both agricultural and non-agricultural, would be taxed implicitly. Since the Kyrgyz government seeks to promote exports, findings from the present study may serve as a background for future trade and agricultural policy development.

1 INTRODUCTION

Taking into account that the livelihoods of around half of the population in Kyrgyzstan depend on agriculture, the significance of the sector for the Kyrgyz economy is evident. Just like the rest of the economy, the agricultural sector has undergone crucial reforms during the transition period following the collapse of the Soviet Union, including land privatization, individualization of large-scale state and collective farms, and an elimination of subsidies to agricultural producers as important reform steps. Agriculture was the first sector with a positive growth rate in 1996, and for the period of 1996 to 2001 served as a driver of economic growth. Starting from 2002, however, the agricultural growth has been slowing down (Light 2007). Low agricultural productivity leading to poor returns from farming and hence, to limited private investments has created a vicious circle. Mechanization remained low (FAO 2009), and land and labour resources have been fully employed implying that further growth depends on improved productivity of labour either through the adoption of better technologies and/or strengthened capital stock (Light 2007). Agricultural productivity being closely linked to rural poverty has largely suffered from the smallness of scale[1], which seemed to be the major drawback that hindered farmers' possibility to invest into own machinery and inputs (Lerman and Sedik 2009).

Agricultural policies have centered on four main pillars: food provision, stability of agricultural markets, achieving competitiveness and improving trade, and environmental preservation and food safety. Although the direct interventions into agricultural markets have been abolished, the government uses a number of indirect instruments in order to support farmers and to achieve its strategic sectoral goals. As far as these policies affect agricultural producer prices and, thus, incentives for farmers to produce, they have straightforward implications for farmers' welfare. If the governmental policies affect agricultural prices, they also alter farmers' earnings and their land-use decisions. It seems of high relevance and interest to evaluate how large these price incentives or disincentives are which are caused by implemented policies. The outcome of such an analysis could serve as a useful basis for designing future policies, as they can shed light on the intended and actual effects of policies on agricultural land use. As Krueger, Schiff, and Valdés (1988) point out in their study on 18 developing countries, agricultural incentives are influenced both by governmental policies directly targeting the agricultural sector and by other economy-wide policies that affect agriculture indirectly. Policy measures such as agricultural import or export taxes, subsidies and quantitative restrictions, domestic input and output taxes and subsidies as well as consumer subsidies, affect farmer incentives directly through the influence on agricultural prices and earnings (Schiff and Valdés 1992; Anderson and Martin 2009). The indirect effects of governmental policies arise from the protection of other industries and macroeconomic interventions that discriminate against agriculture relative to tradable and nontradable sectors outside agriculture (Schiff and Valdés 1992). Thus, in order to receive a

[1] Decollectivization led to the redistribution of agricultural land from roughly 500 state and collective farms with the average area size of 2,500 ha of land to more than 240,000 peasant farms averaging 3.8 ha and to about 750,000 individual households with the plot size of 0.1 ha on average (Lerman and Sedik 2009).

full picture of agricultural price distortions, one would need to quantify effects of both direct and indirect interventions.

There is only one publication by Christensen and Pomfret (2007) that reports the estimates of protection rates for Kyrgyzstan. The Nominal Rate of Assistance (NRA) as the measure of protection rate was calculated for six major agricultural commodities including wheat, cotton, maize, cow milk, poultry meat and wool for the period of 1995-2004. Domestic prices for grains were found to be generally above the border prices indicating positive assistance to grain growers by the government. Large price distortions were reported particularly for wheat during the 1990s and early 2000s. Part of the positive gap between the domestic wheat price and the border price for the crop were attributed to a general encouragement by regional authorities to wheat growers, although it remained unclear which measures have been used to promote growth in wheat production. The cotton sector of the Kyrgyz agriculture was found to be the one being better integrated into world markets compared to other sectors. However, distortion estimates for this crop in period 1995-2004 were found to be unexpectedly volatile in both negative and positive directions, whereas NRAs for cotton were expected to be negligibly negative for an export crop under non-distorted market conditions[2]. The study of Christensen and Pomfret (2007) focuses on the price distortions in agriculture arising from sectoral policies only, whereas the effect of other macroeconomic policies is not considered.

Apart from distortions due to direct agricultural policy, it was elaborated in the literature on agricultural protection that agricultural incentives in developing countries were distorted for many years indirectly by macroeconomic policies (Krueger, Schiff and Valdés 1988; Wiebelt et al. 1992). In particular, import-substitution strategies for the manufacturing sector had strong impacts on the exchange rate and factor prices and led to a further discrimination against the tradable agricultural sector. When the implications of direct and indirect agricultural policies were added up, discrimination against the agricultural export sectors was especially high. The World Bank project led by Anderson revealed then that discrimination against agriculture in developing countries, particularly against exportables, has substantially declined since the late 1980s (Anderson 2010).

2 The same argument is valid for other crops: in a country with fairly liberal market conditions and no trade-restricting policies, one would not expect substantial distortions to agricultural prices (incentives). One potential explanation suggested was that large gaps between domestic and world prices could be associated with poor integration of national markets into world markets (Christensen and Pomfret 2007). It is also very important to keep in mind, that these and other estimates of NRAs should be treated as no more than rough figures as Christensen and Pomfret (2007) point out, too, because of the lack of adequate data on reference prices for some of the commodities (especially those traded in insignificant quantities), as well as due to the impossibility to account for all the domestic trade costs that occur between the farm gate and border point.

We will show in Section 3.2 that macroeconomic policies in the Kyrgyz Republic changed several times and included a number of trade-policy and exchange-rate interventions, but there was no clear systematic distortion of the exchange rate in one particular direction as a consequence of domestic policies. Therefore, we do not compare NRAs due to policy-induced distortions of the exchange rate. However, we will also show in Section 3 that the Kyrgyz Republic is highly dependent of international economic development although being a landlocked country. A strong dependence of international prices such as the gold price on the export and the oil price on the import side are cases in point as well as remittances from its workers abroad. It can be expected that these macroeconomic variables affect agricultural incentives, too. A concept that captures effects of trade policy and macroeconomic shocks on price ratios between different sectors in the economy is the concept of true protection. We will apply the concept of true protection, which is based on the seminal work of Dornbusch (1974) and Sjaastad (1980), to the case of the Kyrgyz Republic.

The goal of this paper is to analyze agricultural price distortions in the Kyrgyz Republic caused both by agricultural and economy-wide policies and macroeconomic conditions. In doing so, first the Nominal Rates of Assistance are estimated for major agricultural crops in order to examine the magnitude and development of agricultural price distortions over the last eleven years for which data are available. In the second step, the true-protection concept is employed in order to evaluate the effect of other economy-wide policies and macroeconomic developments on agricultural incentives.

The remainder of the paper is structured as follows. The next section outlines the analytical framework of this study, including theoretical background and previous work on the application of NRAs and the true-protection concept, estimation techniques employed, and a description of the data. An overview of agricultural and macroeconomic policies implemented in the KR is given in Section 3. Empirical results are presented and discussed in Section 4. Findings are summarized and conclusions are drawn in Section 5.

2 ANALYTICAL FRAMEWORK

2.1 Agricultural Distortions: Estimating Nominal Rates of Assistance

This section is mainly based on the methodology of the recent World Bank study that obtained estimates of agricultural distortions for the case of 75 countries covering 70 different farm products for the period of 1955-2007 thereby establishing the largest global agricultural distortions database[3]. The study of Christensen and Pomfret (2007) mentioned in the previous section is part of this World Bank research project.

For a small, open economy with perfect competition, no externalities, transaction costs and exchange rate distortions, Anderson and Martin (2009) show that the government would maximize national welfare by allowing the domestic and consumer prices of a farm product to be equal to the world market price of that product. Any deviation from this equality arising from a government-imposed measure would be welfare-reducing for such an economy.

In the first step of this study, direct distortions to agricultural incentives are estimated. Direct distortions are those which result from sector-specific policies of the government, in this case from agricultural policies (Krueger, Schiff and Valdés 1988). Price-distorting instruments can be imposed at the country border through the introduction of trade measures, such as an import tariff attempting to protect a domestic sector which competes with imports, or an export subsidy following export promotion goals. If an *ad-valorem* tariff on imports is levied, it would be an equivalent of a production subsidy and a consumption tax, both at the rate t_m. If this is the only distortion present, then the support of the government to the farm product's border price can be measured as the Nominal Rate of Assistance (NRA) (Anderson and Martin 2009):

$$NRA_{BS} = \frac{E \cdot P(1+t_m) - E \cdot P}{E \cdot P} = t_m \qquad (1)$$

where NRA_{BS} indicates Nominal Rate of Assistance to farmers through the border price support, which is then the difference between the distorted price, $P(1 + t_m)$, and the undistorted price, P, times the exchange rate, E, as a share of the undistorted price.

Governments can also provide a direct production subsidy or impose a production tax. If that is the only distortion, then the domestic price support NRA_{DS} can be calculated using the formula above. If price distortions exist both at the domestic and border levels, then the total NRA would be the sum of NRA_{BS} and NRA_{DS}.

Calculation of NRAs also takes into account exchange-rate distortions resulting from governmental actions in the domestic market for a foreign currency. For instance, in the case of a dual exchange rate system, the choice of the exchange rate used for the calculation of NRAs would depend on whether the product is an importable or an exportable, while if the system exhibits multiple exchange rates, it would depend on the specific rate applied to the product in each period (Anderson and Martin 2009).

[3] The outcomes of the research project for individual countries delivered in numerous working papers have been compiled and published in the following books: Anderson (2009), Anderson and Swinnen (2009), Anderson and Valdes (2008), Anderson and Masters (2009), and Anderson and Martin (2009).

The distortion is measured relative to the situation which would have occurred had there been no governmental intervention, that is a free-trade situation (Krueger, Schiff, and Valdés 1988). This means that a domestic price (supposedly distorted by governmental interventions) is compared to the reference price which represents a hypothetical price that should have prevailed in the case of no interventions. For tradable commodities, border prices on a free-on-board (f.o.b.) or cost-insurance-freight (c.i.f.) basis usually serve as reference prices. However, since the two prices to compare are valid in different points of the marketing chain, the border price has to be adjusted for all the marketing margins including transportation costs, storage costs, wholesaler or processing costs that arise between the border and a producer location, as well as quality and variety differences (Anderson and Martin 2009; Krueger, Schiff, and Valdés 1988; Westlake 1987).

NRAs as the indicators of direct distortions to agricultural price incentives in the Kyrgyz Republic were estimated for seven major agricultural commodities for the period of 2001 to 2011 following the methodology described in Anderson (2009, p.575). The formula below is used for calculating NRAs for individual agricultural commodities:

$$NRA = \frac{P_{FG} - (P_W \cdot E - C_T - C_H - C_M)}{P_{FG}} \qquad (2)$$

where P_{FG} is the farmgate price of a commodity in Kyrgyz Soms (KGS); P_w is the world price or the reference prices for the commodity in USD; E is the nominal exchange rate between the KGS and US$; C_T, C_H, and C_M stand for transport, handling/processing and marketing costs respectively, associated with the delivery of a product from the farmgate point to the border or vice versa.

Due to the unavailability of detailed information on all the potential domestic trade costs, as well as quality concerns about the officially reported data on domestic and reference prices, the estimates of NRA are to be treated as rough calculations[4]. Assumptions had to be made on the size of marketing, handling and transportation costs for individual crops based on a literature review. The analysis of NRAs over the studied period attempts to elaborate a general trend and a direction of governmental assistance to or discrimination against the producers of specific crops, rather than looking at precise magnitudes of distortions in particular branches of the agricultural sector.

4 Concerns remain that the official data on trade values and quantities are biased from actual figures because of substantial illegal trade going on at the border. In 2012, the National Bank of the Kyrgyz Republic undertook a survey on border trade and re-export of goods not covered by official statistics at the customs posts and markets (Ibragimova et al. 2012). The mirror statistics of imports of goods to Kyrgyzstan from China in 2007 has revealed a tenfold divergence of figures: official statistics in KR showed US$ 356 mln., whereas Chinese authorities reported US$ 3.67 billion. The major part of the unregistered external trade consists of live animals, fruits and vegetables, cattle meat, and consumer goods.

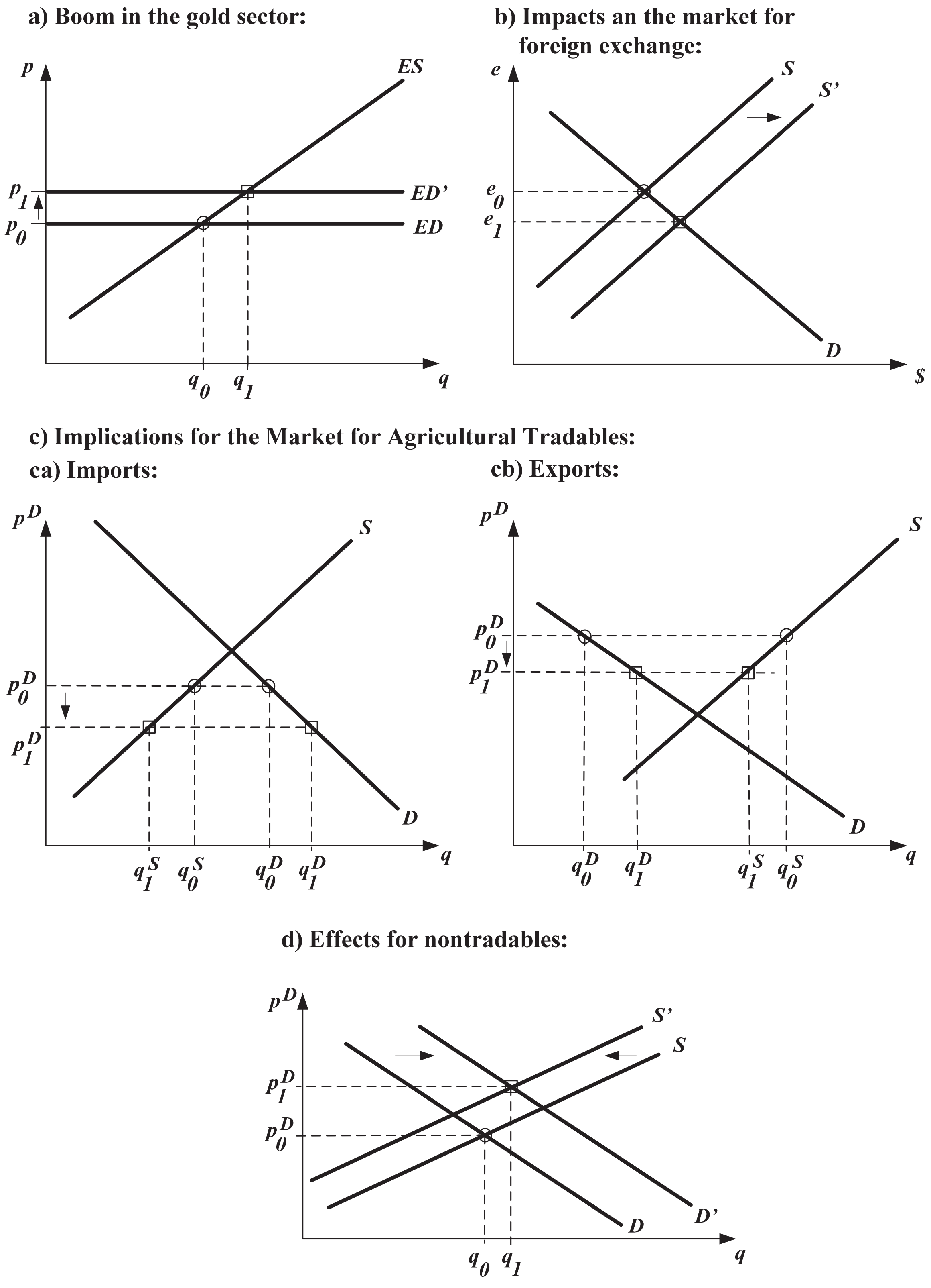
2.2 Agricultural Incentives under the Influence of Changing Macroeconomic Conditions: An Application of the True Protection Concept

It had been observed for many developing countries that a broad range of policy measures existed which included import-substitution strategies on the one and export-promotion policies on the other hand. Given this background, it was often difficult to identify how policies in one sector affected incentives in another sector and which sector carries the major burden arising from a country's trade policy. The true-protection approach can provide answers to such questions. Using the true-protection concept, it is possible to investigate how the burden of protecting one sector is shifted to another sector. Its application to trade policy in developing countries was surveyed by Greenaway and Milner (1987) and by Wiebelt et al. (1992, pp. 36 et seq.), and empirical applications of the concept referred to Cameroon (Milner 1990), Colombia (Garcia 1981), Côte d'Ivoire (Greenaway 1989), Malaysia and Peru (Herrmann, Sulaiman and Wiebelt 1990), Mauritius (Greenaway and Milner 1986), Nigeria (Oyejide 1986), Pakistan (Dorosh and Valdés 1990), the Philippines (Bautista 1987), Saudi Arabia (Milner, Presley and Westaway 1995), Zaire (Tshibaka 1986) and Zimbabwe (Wiebelt 1992). It is possible, too, to apply the concept of true protection to exogenous shocks on the foreign-exchange balance on commodity markets, rather than to changes in trade policy alone. Therefore, Dutch-disease phenomena can also be addressed with the true-protection concept.

The basic theoretical model is a small general-equilibrium model capturing three commodities or sectors: an importable, an exportable and a nontradable (home) good that are produced and consumed domestically. The model is based on the following basic assumptions (Dornbusch 1974). First, the country considered is a small country with an open economy, with given factor endowments and constant real income. Second, trade is initially balanced, and the relative prices of both exportables and importables compared to the nontradable sector are flexible as market clearing occurs in the home-good sector. Third, trade policy interventions are represented by uniform tariffs on imports and/or uniform subsidies on exports. It was shown theoretically by Dornbusch (1974) that an import tariff raises the price ratio between the importable and the exportable sectors relative to the nontradable sector. Apparently, import tariffs tax the nontradable compared to the importable sector, but even more so they tax the exportable sector compared to the importable and the nontradable sector. It is this latter finding that was confirmed in various empirical true-protection studies.

Before we address the measurement of true protection, basic linkages between macroeconomic variables and incentives for agricultural protection shall be explained with Figures 1 and 2. Macroeconomic shocks may arise from changing world prices of major non-agricultural exportables or importables of a country.

Figure 1: Agricultural Incentives and Dutch-disease Effects: A Rising Gold Price



Source: Own illustration.

A major export good of the Kyrgyz Republic is gold. Therefore, Figure 1 illustrates implications of an **increasing world market price of gold** for the price ratios between sectors in the domestic economy. In Figure 1a, we assume that the Kyrgyz Republic is a price-taker on the gold market and that the price-elastic export demand for gold rises due to a booming demand on the world market, i.e. from *ED* to *ED*'.

Gold export supply of the country increases from q_0 at the export price p_0 to q_1 at the new price p_1. Export earnings in the gold sector rise and, thus, the supply of foreign exchange in Figure 1b is raised from *S* to *S*'. The new equilibrium on the currency market yields a lower exchange rate, i.e. e_1 rather than e_0. Apparently, a boom in the major export sector leads to an appreciation of the domestic currency.

The impact on the exchange rate is one element of the so-called Dutch disease. An appreciation of the domestic currency, initiated by a boom in the leading sector, leads to lower prices of other tradable sectors such as agricultural importables and exportables.

The given world price for agricultural tradables, denominated in US-$, has to be multiplied by a lower exchange rate to derive import and export prices in domestic currency (p^D). Thus, p^D declines in Figure 1ca from p_0^D to p_1^D. Imported goods like grains experience a higher consumption and a lower production. The self-sufficiency ratio falls. In Figure 1ca, imports increase from $(q_0^D - q_0^S)$ to $(q_1^D - q_1^S)$. Analogously, price incentives for exporters worsen in domestic currency due to the exchange-rate effect. In Figure 1cb, this is illustrated by a price fall from p_0^D to p_1^D. Domestic production declines from q_0^S to q_1^S, domestic consumption rises from q_0^D to q_1^D, and exports diminish from $(q_0^S - q_0^D)$ to $(q_1^S - q_1^D)$.

Figure 1d shows how the nontradable sector is affected by the boom in the gold sector. The market of the nontradable sector clears – by definition – domestically and the price in the nontradable sector is not determined by a given international price as in the tradable sector. A rising gold price raises income and, to a certain extent, the domestic economy will participate in this income increase. A demand effect occurs by shifting demand for nontradables such as construction and services from *D* to *D'*. As the booming sector raises factor prices, supply of nontradables will shift to the left from S to S'. Apparently, the price in the nontradable sector increases from p_0^D to p_1^D. The price ratio between the nontradable sector and the tradable agricultural sector increases.

Equally important for the Kyrgyz Republic is another possible source of a Dutch-disease effect, i.e. remittances from the country's labor migrants.

Like a rising gold price, an increasing **inflow of migrant remittances** in the Kyrgyz Republic would raise the supply of foreign exchange as illustrated in Figure 1b. The domestic currency would appreciate, and the falling exchange rate would depress the international price in domestic currency for agricultural tradables as well as non-agricultural tradables. As shown in Figures 1ca and 1cb, imports would rise and exports would diminish due to the exchange-rate effect. On the market for nontradables, a demand shift due to rising income transfers would raise the price level. The nontradable sector would gain from improved price incentives relative to the non-agricultural and agricultural tradable sectors.

Another macroeconomic shock on imports of the Kyrgyz Republic could result from **changes on the oil market**. Some likely implications of a booming oil price for the price structure in the Kyrgyz Republic are illustrated in Figure 2. We posit in Figure 2a a rising world demand for oil as a consequence of economic growth in large Asian countries like China or India.

We further assume that the Kyrgyz Republic is a price-taker on the world oil market. The world price increases from p_0 to p_1 and so does the Kyrgyz import price in Figure 2b under full price transmission.

It is very likely that the demand for oil in the Kyrgyz Republic is price-inelastic. Thus, we can expect that a rising oil price will boost import expenditures, too. This leads to a higher demand for foreign exchange, i.e. *D'* rather than *D* in Figure 2c. Initially at $e_{0,}$ the equilibrium exchange rate goes up to e_1. Apparently, a soaring price of a major import good such as oil will lead to a depreciation of the domestic currency.

Again, the change in the exchange rate affects prices in the tradable agricultural sectors. As Figures 2d and 2e illustrate, prices of agricultural importables and exportables in domestic currency increase from p_0^D to p_1^D as the world prices in international currency are now multiplied by a higher exchange rate. Consumers lower demand from q_0^D to q_1^D. Supply will shift upward from *S* to *S*' due to higher marginal costs and we posit that the supply quantity remains constant $(q_0^S = q_1^S)$. Thus, agricultural imports in Figure 2d decline from $(q_0^D - q_0^S)$ to $(q_1^D - q_1^S)$, i.e. by $(q_0^D - q_1^D)$. Agricultural exports in Figure 2e increase from $(q_0^S - q_0^D)$ to $(q_1^S - q_1^D)$, i.e. again by $(q_0^D - q_1^D)$.

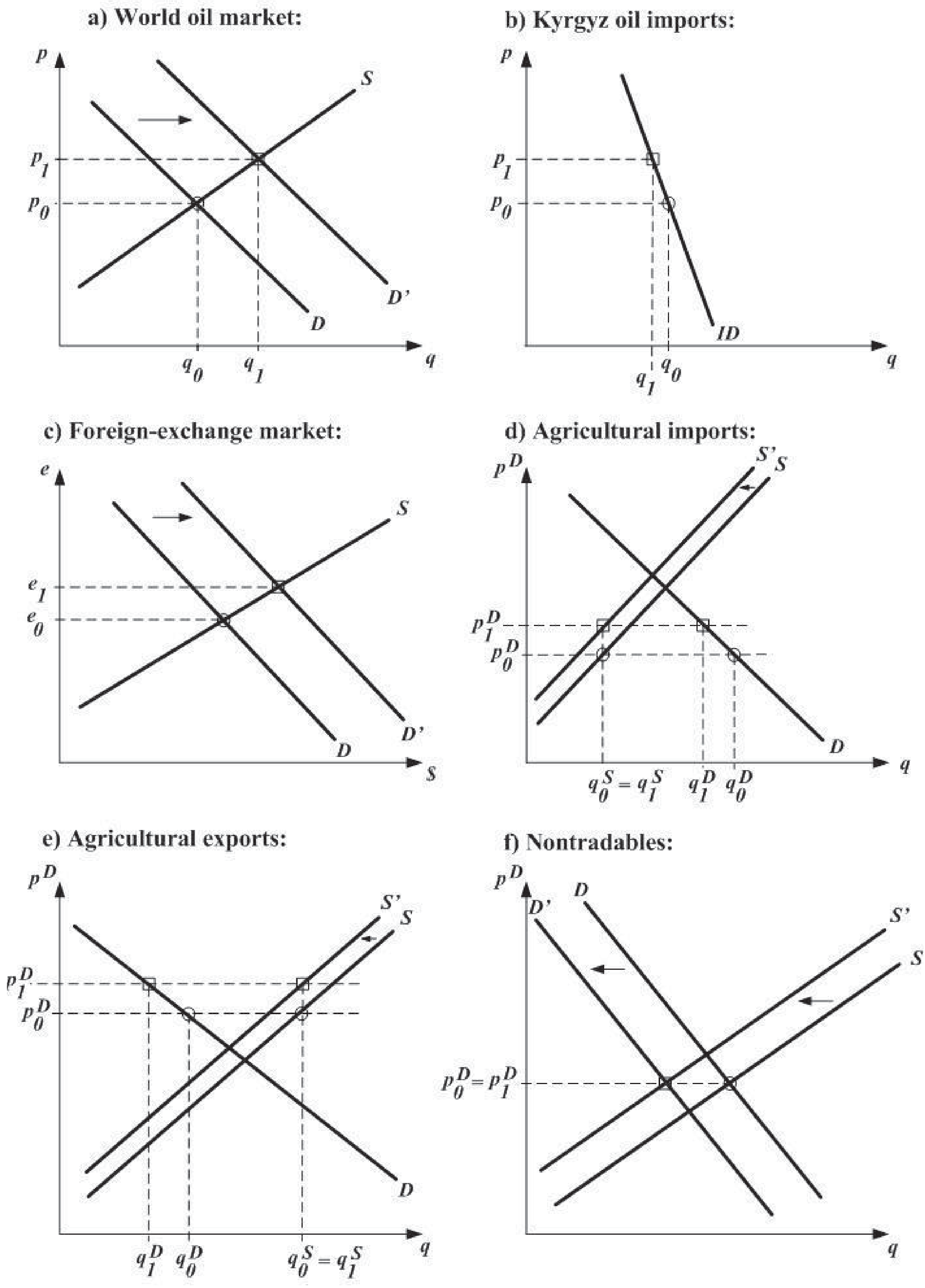
On the market for nontradables, a rising oil price will also lead to higher marginal costs. In Figure 2d, the supply curve of nontradables shifts upward from *S* to *S*'. With given total expenditures and higher expenses for oil and fuels, it can be expected that the demand effect will be negative. The demand curve shifts also to the left – from *D* to *D*'. The price on the market for nontradables may fall or rise or remain constant as a function of the relative shifts of the supply and the demand functions. Figure 2a captures the special case of a constant price for nontradables. We can summarize that a rising oil price may improve the price ratio between agricultural tradables and the nontradable sector.

In the literature on true protection, Sjaastad's incidence parameter ω is often used to measure the incidence of protection across sectors:

$$\omega = \frac{\Delta(P_H/P_X)}{P_H/P_X} / \frac{\Delta(P_M/P_X)}{P_M/P_X} \qquad (3)$$

where P_M *(P_X)* measures the price index in the import (export) sector, P_H is the price index in the nontradable or home-good sector, ω is the percentage change of the price ratio between nontradables and exportables due to a one-percent change in the price ratio between importables and exportables.

Figure 2: Macroeconomic Shocks and Agricultural Incentives: A Rising Oil Price



Source: Own illustration.

ω ranges between 0 and 1 and, the higher the ω, the more is the burden of import protection or an exogenous import price boom shifted to the export sector. Under the extreme case of ω=1, only the export sector would experience unchanged prices, whereas prices in the importable and nontradable sectors would rise by the same rate under either import price protection or an import price boom. With ω=0, the burden of import protection or the import price boom would be placed on the exportable and nontradable sector equally.

The regression model in the three-sector equilibrium model would typically be formulated as:

$$\ln(P_H/P_X) = \alpha_1 + \omega \ln(P_M/P_X) + \alpha_2 Z + \mu_1 \quad (4)$$

where Z is a vector of exogenous shifters and μ_1 is a random error term.

Often, more disaggregation is needed and the exportable sector is divided into the nonagricultural and agricultural export sector. Price indices are P_{XNA} and P_{XA} respectively. Then, the regression model could be changed to:

$$\ln(P_H/P_{XA}) = \alpha_1 + \omega_1 \ln(P_M/P_{XA}) + \omega_2 \ln(P_{XNA}/P_{XA}) + \alpha_2 Z + \mu_2 \quad (5)$$

Z is again a vector of shifters and μ_2 is the random error term. Now, two incidence parameters are included: $\omega_1(\omega_2)$ measures the percentage change of the price ratio between nontradables and agricultural exportables due to a one percent change in the price ratio between the importables (nonagricultural exportables) and agricultural exportables.

2.3 Data

Data for estimating Nominal Rates of Assistance are compiled as follows. Time series of domestic agricultural prices, production quantities and values are obtained from the National Statistical Committee of the KR (NSC) and the Food and Agricultural Organization of the UN (FAO). Data on export and import unit values and quantities are from the United Nations Commodity Trade Statistics Database (UN Comtrade). Exchange rates are from the National Bank of the KR (NBKR).

Products considered in the distortion analysis cover altogether around 50% of total agricultural output in Kyrgyzstan and include wheat, potatoes, maize, cotton, tobacco, milk and wool. Based on the share of exports and imports in domestic production and consumption respectively, agricultural commodities considered in this study are classified into three groups: exportable, import-competing and home goods. Reference prices for traded goods are derived from the value and quantities traded of that good in terms of export and import unit values. For nontradable goods, exported and imported quantities are not sufficient to derive adequate reference prices. Therefore, border prices available for the neighboring Kazakhstan were used as reference prices for nontradable products instead of actual export and import unit values.

Table 1: Summary Statistics of Variables Employed in the Regression Analysis[a]

Variable	Description of the variable	Mean	Std. deviation	Trend
Pm	The price index of importables (IV2002=100) is a weighted average of price indices for machinery and transport equipment, mineral fuels, and manufactured goods	173.07	37.50	2.75*** (0.269)
Px	The price index of exportables (IV2002=100) is a weighted average of price indices for metallurgy, textile and garment, agriculture and power generation.	256.86	155.96	19.48*** (2.366)
Ph	The price index of nontradables (IV2002=100) is an average of price indices for housing services, outpatient services, transport services, catering and hotel services	152.02	51.42	7.58 *** (0.916)
Pxa	The price index of agricultural exports (IV2002=100)	178.19	67.49	6.31*** (0.956)
Pxna	The price index of nonagricultural exports (IV2002=100)	215.19	121.15	14.45*** (1.899)
BT	Balance of trade, mln. USD	-125.96	102.39	-7.85*** (1.382)
GDP	Gross domestic product, mln. USD	993.20	466.14	31.99*** (3.933)
In(Ph/Px)	Natural logarithm of the price ratio Ph/Px	-0.39	0.28	-0.02*** (0.003)
In(Pm/Px)	Natural logarithm of the price ratio Pm/Px	-0.24	0.39	-0.04*** (0.004)
In(Ph/Pxa)	Natural logarithm of the price ratio Ph/Pxa	-0.14	0.12	-0.002 (0.005)
In(Pm/Pxa)	Natural logarithm of the price ratio Pm/Pxa	0.02	0.19	-0.02*** (0.005)
In(Pxna/Pxa)	Natural logarithm of the price ratio Pxna/Pxa	0.11	0.22	0.02** (0.006)
In(BT/GDP)t-1	Natural logarithm of the absolute value of the ratio of BT to GDP with a one period lag	-2.47	0.798	0.05*** (0.011)

[a] Numbers in the last column are the coefficient estimates for the time trend variable in a univariate regression model. Standard errors are in parenthesis. *** and ** indicate p-values at the 0.01% and 0.05% confidence levels respectively. Source: Authors' estimations.

Kazakhstan is chosen for its relatively liberal policies compared to other neighboring countries and due to the fact that is it the major importer of a number of agricultural commodities, such as cow milk and milk products, vegetables and fruits. For instance, 99.9% of milk and dairy products exports went to Kazakhstan in 2012 (NBKR, 2013a).

Data needed for the true-protection analysis are based on the Producer Price Index (PPI) and Consumer Price Index (CPI) obtained from NSC. Weights used for deriving average price indices for each year are calculated on the basis of the Balance of Payments information from NBKR.

Descriptive statistics of the variables used for the true-protection analysis are given in Table 1. The data used are on a quarterly basis from the fourth quarter of 2002 to the first quarter of 2013. Information on price indices was available for this period.

3 AGRICULTURAL AND TRADE POLICIES AND MACROECONOMIC DEVELOPMENT IN KYRGYZSTAN

3.1 Types of Governmental Support to Agriculture

Until the establishment of the Agricultural and Food Corporation (AFC) in 2008, the governmental assistance to farmers in the Kyrgyz Republic was reduced to input-related support. Such input-related assistance consists of subsidies for purchasing agricultural machinery, distribution of seeds, material and technical resources by prices lower than the market prices, providing means for operation and maintenance of water facilities, and other instruments. Information on how much support is provided to individual branches of the agricultural sector is not available. Table A1 presents the compilation of collected records of governmental support to farmers in the Kyrgyz Republic reported in different literature sources.

The government has also attempted to subsidize interest rates in agriculture through providing support to credit unions, often with international donor assistance. However, this approach has been criticized, because financial resources allocated for subsidizing interest rates are likely to be insufficient to cover a target population. The fact that only a limited number of farmers can receive this support could motivate rent-seeking activities, which in the end might shift resources away from competitive “business-worthy” borrowers (FAO, 2009).

A range of incentives for the agricultural sector are also provided by the new Tax Code introduced as of 1 January 2009. First, income received from sales of agricultural produce grown in the KR is exempt from income tax. Profit tax exemptions are received by farms producing berries, fruits and vegetables for industrial processing. A three-year exemption from the profit-tax is also provided to food processing enterprises. The supply of some agricultural chemicals as approved in the special government's list was also identified tax-exempt, whereas supply of domestically produced agricultural equipment was subject to tax exemption for three years period starting from 2009. Agricultural producers including agricultural goods and services cooperatives are all exempt from the sales tax (FAO, 2009).

Food insecurity is still an important issue in Kyrgyzstan. According to the World Food Programme Report in 2011, more than 760 thousand individuals, or around 14% of households in Kyrgyzstan were estimated to be food-insecure at the time of assessment during the lean season[5] (WFP, 2011). Objectives to achieve food security are outlined in the Food Security Concept (2009) and the Food Security Program (2009) of the government. In order to achieve a long-term food security, the Kyrgyz government would have to address the causes of the problem: low agricultural productivity and poverty, especially in rural areas (WFP 2011). In addition, as a country with a small open economy, Kyrgyzstan is vulnerable to external shocks, including food and energy price peaks (The World Bank, 2011). In response to the food price crisis in 2008, approaches implying market interventions have been adopted by the Kyrgyz Government. The 2008 Food Security Law serves as a legal basis for implementing food security monitoring, food distribution, and price and trade interventions. The implementation of these tasks has been assigned to the AFC.

The AFC was established in 2008 with the vision to stabilize domestic food prices and was authorized to fulfil a broad range of functions, starting from food market interventions and developing market infrastructure for food commodities, up to the implementation of investment projects in the agricultural industry (The Governmental Decree as of 31 July 2008 on the Establishment of the Agricultural and Food Corporation (AFC)). However, whether sufficient funds can be provided by the government to finance above-mentioned activities of the AFC remains unclear. Some of its activities cause direct distortions to agricultural commodity prices affecting competitiveness of domestic producers. For instance, it was reported in 2009, that the AFC purchased 20,000 tons of wheat at the price ten KGS per kg, when the market price was about six KGS per kg (The World Bank, 2011).

In summary, the Kyrgyz government does not seem to be following a medium-run strategy in promoting particular branches of agriculture via continuous market price support. However, there are discontinuous agricultural policy measures that shed some light on the implicit preferences of the Kyrgyz government. As Christensen and Pomfret (2007) suggest, a general encouragement for grain producers from local authorities may have existed during the 1990s and early 2000s following food self-sufficiency goals. Second, it is likely that

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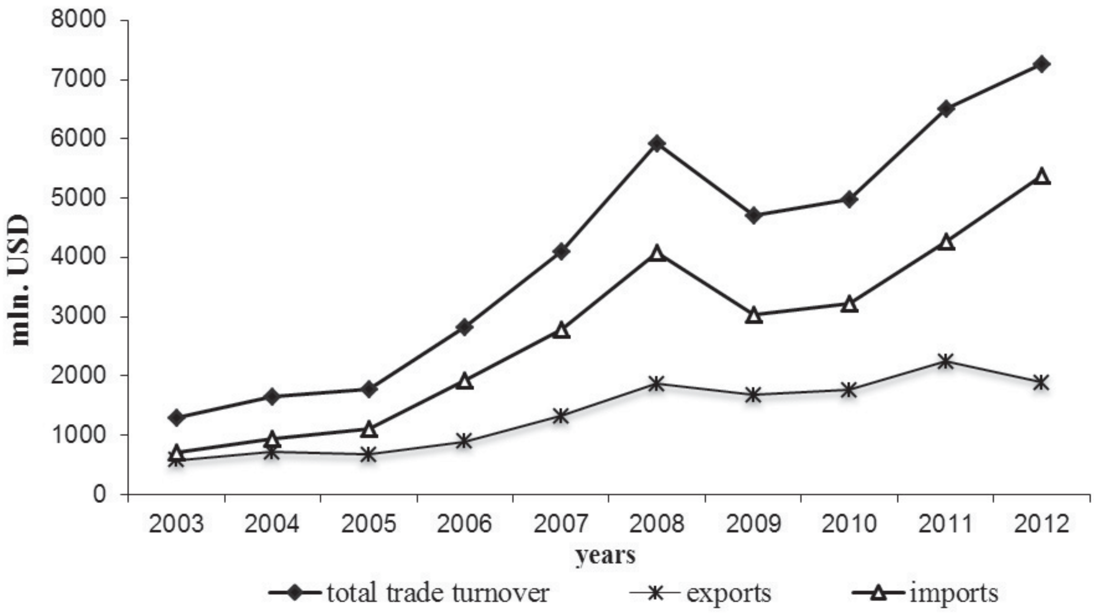
[5] This indicates that those households had inadequate dietary consumption based on cereals and potatoes, and with income available for food consumption below the extreme poverty level. A larger number of households were considered as moderately food-insecure, and some of the food-secure households could potentially be at risk of food insecurity if food crises or price shocks take place (WFP, 2011).

activities of the AFC attempting at food self-sufficiency had price-raising impact on the domestic prices of staple foods considered in the study, such as wheat and potatoes. Since the information on the extent of the interventions is incomplete, it is not possible at this point of time to estimate the magnitude of impact arising from short-run interventions. These considerations have to be kept in mind when analyzing the estimates of NRAs in Section 4.1.

3.2 Macroeconomic Policies and Development in Kyrgyzstan

The Kyrgyz Republic has one of the most liberal policy environments for trade in the Central Asian Region (WTO, 2006a). The openness index or the ratio of total imports and exports to GDP in 2012 constituted 106.5% (NBKR, 2012). Figure 3 shows the development of imports, exports and the total trade turnover in the Kyrgyz Republic over the last 20 years. The main reason for a declining export growth rate was the reduction of gold exports, whereas increased import demand for cars and transportation equipment was attributed to import growth in recent years.

Figure 3: Foreign Trade Dynamics in Kyrgyzstan for 1993-2012



Source: National Statistical Committee of the KR, WTO (2006b).

As of 2012, the major exported good was gold making 33.4% of total exports, followed by energy products (14.9%), agricultural commodities (13.3%) and textile (12.2%). Starting from 1997, gold mining has been brought into operation and gold exports have become a significant part of total exports and one of the major sources of export earnings in the KR. The structure of exports in 2012 is presented in Table A2. The largest share of imports consists of fuel (petroleum, oil and lubricants) and gas imports (22.4%), food products

(14.6%), as well as machines and transportation equipment (25.1%) (Table A3). Cast iron and steel occupy one fourth of imported manufactured goods. More than half of the imported food products consists of coffee, tea, cocoa and their products, cereal products, and meat products (NBKR, 2013a).

Main policy objectives of the Kyrgyz Republic related to trade are a better access to world export markets, export diversification and an improved integration of domestic markets into the world market. The KR is a signatory to a number of multilateral and bilateral trade agreements, most of which have been signed with the CIS member countries. The formal trade regime has been substantially liberalized after the accession of the KR to WTO in 1998. The main trade instrument, a tariff, has been significantly reduced. The average MFN rate was 4.9% in 2006, compared to 8.7% in 1999. There are no domestic taxes (VAT) that discriminate against imports. Import charges and export subsidies for agriculture are set to zero. The WTO reported that KR did not apply any anti-dumping or countervailing measures in the period of 1998 to 2013; and the safeguard duties have been introduced only for wheat flour in the period of November 2009 to November 2010 (WTO, 2006a; 2013a).

In an attempt to prevent critical scarcity of goods in the domestic market that are of significant importance for the country, several temporary export prohibitions and export duties have been introduced in the period of 2008 to 2012. Export of fuel and lubricants was prohibited in 2011-2012, whereas wheat grain and wheat flour were prohibited to export in 2012. Export duties have been applied to selected products, including coal, non-treated animal skins, wool and woolen fabric, wheat flour, wheat grain, sunflower seeds, vegetable oil (in 2008) among others. The listed export duties have been eliminated according to the Country Report of the KR to WTO as of 2013 (WTO, 2013b).

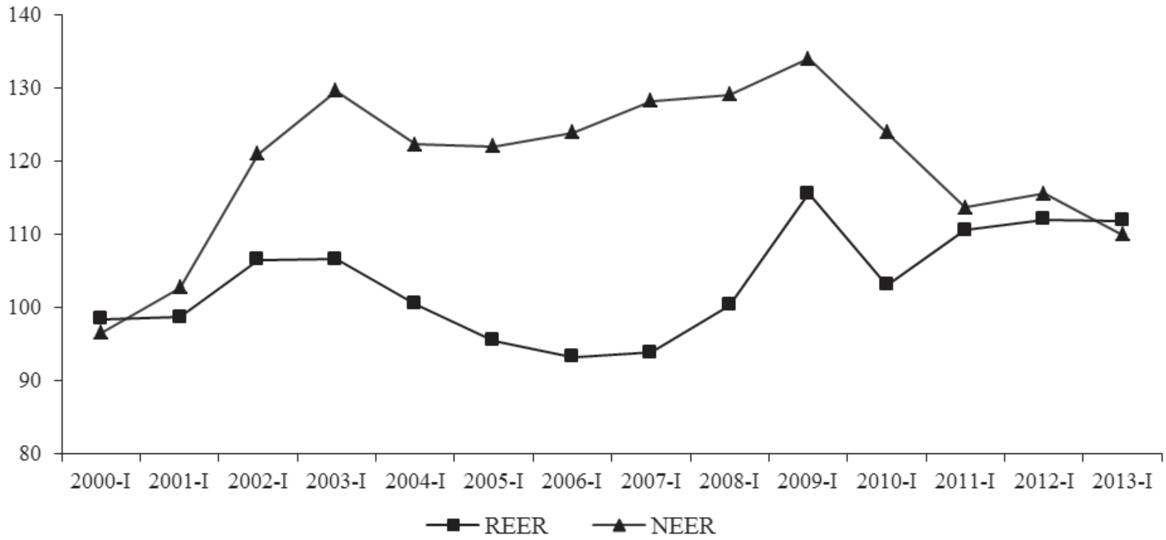
Customs procedures have been improved since the new Customs Code was adopted in 2004. New procedures are based on independent assessment, selectivity and post-customs control. In customs control procedures, i.e. collecting duties and taxes by customs officials, application of information technologies have been advanced (WTO, 2013b).

The framework for operating in Free Economic Zones (FEZ) is part of the customs legislation. Special regimes apply to these zones, the beneficiaries of which receive advantages for external trade and business activities. Companies or entities, which have the right to operate in the zone, enjoy a lower tax burden, and are exempt from non-tariff measures. Wholesale import and export, production and storing of goods, and banking operations comprise the largest part of activities in FEZs (WTO, 2013a; 2013b).

In the case of the Kyrgyz Republic, natural barriers to trade are likely to affect the country's trade performance to a great extent. The fact that 95% of the country is mountainous and its landlockedness require that transport infrastructure is of sufficient quality to ensure the country's access to world markets (The World Bank, 2007). However, this is not the case in reality, and poor transport infrastructure contributes to tremendous trade costs. External impediments are likely to come from trade restrictions of transit countries, for instance Uzbekistan (WTO, 2006a).

The economy is highly "dollarized": in 2005 the share of bank assets in US dollars was 72.6%. The exchange rate system for the Kyrgyz Som (KGS) is managed floating (as of 2006), and no exchange rate paths are pre-announced. Daily exchange rates against the US dollar, which are set in the interbank market, are published by the NBKR. The KGS-US$ exchange rate is determined by interbank quotations. Currently, only those interventions are undertaken by the NBKR which help to smooth down sharp currency fluctuations. According to the Law on Operations in Foreign Exchange (as of 1995), transactions in foreign exchange are unrestricted (WTO, 2013a).

Figure 4: Real and Nominal Effective Exchange Rate Indices for the Kyrgyz Som for 2000-2013



Source: Own illustration based on NBKR (2013b).

According to IMF, the nominal exchange rate flexibility policy with limited interventions has had positive effects on the economy, especially in light of the recent crises of 2007-2008 (fuel price shocks and resulting food crisis) and of political instability in 2010 and related border closures (IMF, 2011). Figure 4 shows that the real effective exchange rate index has been kept broadly stable, that is within the 20% fluctuation band over the period of 2000-2013. Food and fuel price shocks of 2007-2008 have caused a 20% increase in import prices, which quickly passed to domestic prices. In 2010, the prices again rose by 25% responding to international price increases. The higher import bill deteriorated the current account balance. The NBKR allowed the nominal exchange rate to depreciate, which reportedly helped to partly compensate the negative effects of the price shocks and to sustain export competitiveness (IMF, 2011).

Another external shock specific for the country that is likely to influence agricultural incentives through the impact on the exchange rate could be the increasing inflow of migrant remittances. In 2013, the share of remittances in the GDP of the Kyrgyz Republic was 31.4%, which is enormous and makes the country the second largest recipient of workers' remittances after Tajikistan (51.9%) (The World Bank, 2014).

4 RESULTS AND DISCUSSION

4.1 Analysis of Agricultural Price Distortions

The estimates of Nominal Rates of Assistance obtained for seven agricultural commodities for the period of 2001 to 2011 are presented in Table 2.

Table 2: Nominal Rates of Assistance, %

Commodity	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Wheat	56	63	52	34	52	43	31	35	27	8	29
Potatoes	72	63	-8	12	12	52	55	37	52	62	51
Tobacco	-77	-131	-108	-149	-141	-117	-127	-152	-211	-238	-188
Cotton	-17	-10	-4	34	22	38	33	31	29	24	52
Maize	41	16	36	18	21	41	52	18	-13	-5	27
Milk	18	10	4	-39	-63	-34	-14	-15	-45	-69	-71
Wool	35	0	-44	-42	-69	-3	32	21	26	-34	84

Source: Authors' estimations.

As can be seen from Table 2, food crops, such as wheat and potatoes, generally have positive NRAs which indicate that their producers enjoy assistance from the government, apparently targeted at food self-sufficiency goals. This is particularly valid for wheat for which NRAs remained positive over the whole period considered. It was reported that wheat production was particularly encouraged by the government in response to supply disruptions from Kazakhstan in the mid-1990s attempting at less dependence from grain imports. Wheat was favored by farmers as less risky compared to perishable commodities and also because domestic prices for wheat remained relatively stable (Pomfret, 2007). Area sown with wheat has increased dramatically within 1990s: it was only around 194 thousand ha in 1990, but by 2000 it was extended to over 505 thousand ha (National Statistical Committee, 2012). However, starting from 2001, the area devoted to wheat started to decline, possibly indicating that farmers were now turning to the production of more profitable higher-value commodities such as vegetables and fruits whose markets started to develop. NRA estimates for wheat could reflect government's efforts to stabilize wheat prices during the food crisis of 2008 and political crises in 2005 and 2010 that led to temporary border closures with neighboring countries. The gap between domestic and border prices could have been even higher if certain measures such as releases from the State Material Reserve into domestic markets, or subsidized flour imports by the AFC were not implemented.

NRAs estimated for potatoes also show that domestic prices for this crop were generally higher than border prices over the entire period considered in the study. Potatoes are an important staple food in the KR: according to the FAO, Kyrgyzstan was the second-largest consumer of potatoes per capita (143 kg) in the world after Belarus in 2005 (FAO, 2008). A long-term assessment of price instability for potatoes in KR carried out by the World Bank (2011) concluded that price variability between 2003 and 2009 was highest for potatoes compared to wheat, sugar or sunflower. Price gaps for potatoes were substantial and positive in 2001 and 2002 in favor of domestic producers. However, the NRA fell sharply in 2003 and remained negligible over the following years, before starting to increase in 2006. Until 2009, potatoes have been a nontradable product, meaning that trade in potatoes was insignificant relative to production and consumption quantities. It became an exportable in 2010 and 2011, when the share of export in production reached 6-7 %. The fact that it remained nontradable between 2001 and 2009 has implications for identifying adequate reference prices, as mentioned before[6]. The potato sector has rapidly grown during the studied period: production was around 360 thousand tons in 1990, became over one million tons in 2000, and it was 1.38 million tons in 2011.

NRAs for cotton were negative, though not large in relative terms in the early 2000s, whereas the sign of NRAs changed in the other direction in 2004[7]. Apparently, positive NRAs for cotton starting from 2004 could be attributed to improved integration of the Kyrgyz cotton market into the world market (Christensen and Pomfret, 2007). Cotton is a critical sector in Central Asian agriculture. In Kyrgyzstan and Kazakhstan, the cotton sector is basically market-driven compared to the situation in Uzbekistan, Tajikistan and Turkmenistan, where large rents are subtracted from the sector to contribute to public revenues (Pomfret, 2007). A better integration of local markets was facilitated by the growing number of gins: 23 in 2005 compared to only 3 before independence. Prices offered by ginners to cotton producers

6 In the case of potatoes in particular, export unit values for the crop from neighbouring Kazakhstan were used as reference prices, which are significantly different from actual export and import unit values for that small quantity of potatoes traded during 2001 and 2009. This means that if actual border prices were taken as reference prices for this period, NRAs for potatoes would have deviated strongly in both directions. Anderson (2009) suggests the use of alternative reference prices if the trade in the product is very low and trade unit values are not representative.

7 Estimates of Nominal Rates of Assistance for the period 2001-2004 for cotton, maize and wheat are broadly consistent with those reported in Christensen and Pomfret (2007).

seem to become more correlated with world market prices, since local prices have been tied to the Cotlook A cotton world price index recently (Pomfret, 2007).

Distortions to domestic prices of tobacco according to estimated NRAs seem to be very high and negative. The market for this crop is relatively small; there has been a dramatic decrease in the production from about 54 thousand tons in 1990 to 10 thousand tons in 2011. Currently, only two out of four large tobacco-processing plants are still operating, and therewith at 30% of their production capacities. It is very likely that tobacco producers are affected by the so-called “curse of smallness” the most, which is also valid for all individual small-scale farmers in the KR[8]. Large negative NRAs indicate a direct taxation of tobacco producers by the governmental policies. An excise tax is applied for tobacco products; however, it was only introduced in 2011. Hence, it could not have contributed to the estimated price distortions. The potential reason for large distortions in the tobacco sector could be linked to the monopoly for cigarette production (as of 2006) according to the WTO report. Kyrgyztamekisi is a state-owned enterprise, which issues licenses to engage in processing and manufacturing raw tobacco. The enterprise also administers prices for tobacco leaf (WTO, 2006a). Few companies are reportedly engaged in tobacco manufacturing and tobacco exports. They often offer interest-free credits and assistance with seeds and fertilizers for tobacco growers who then have to return the credits at the time of harvest. Preliminary observations show that just in 2011, the domestic price for 1kg of raw tobacco was 65 KGS, whereas the world price was 120 KGS. The major part of the price difference is attributed to wholesaler/processor margins. The large magnitude of transport and marketing costs related to the smallness of scope also contribute to this price gap. So far it seems that farmers who grow tobacco are highly dependent on tobacco-exporting companies, and can only take prices set by them at the farmgate, as marketing costs of delivering own produce for export are too high to make it worthwhile.

Concerning obtained NRA estimates for milk and wool, there does not seem to be a clear pattern of governmental assistance to these sectors. For milk, assistance was positive though not substantial in the beginning of 2000s, but then became negative in 2004 and remained so over the rest of the studied period. The estimates for wool are rather erratic over the entire period, and magnitudes of distortion estimates are generally not large on both directions. It could be explained by the fact that wool is an exportable product and traded in a relatively undistorted environment. There are no direct policies on markets for milk or wool, and general support to the livestock sector is reduced to efforts targeting improvement in epizootic situation in the country. Kyrgyzstan remained the only net exporter of livestock

8 Small output sizes make it difficult for farmers to find buyers for their produce, to transport produced commodities to markets, or to afford inputs to which prices were also too high relative to their income (Lerman and Sedik, 2009). Thus, it is often the intermediaries undertaking the task of marketing agricultural produce from the farmgate to regional markets or to the border.

products in Central Asia (mainly live animals), but most of that trade was claimed to be unregistered (Pomfret, 2007). Distortions to domestic meat prices, the most important sector output, are not considered in this study, because the variety and quality differences between the farm gate and the border point seemed to be extremely high. Vegetables and fruits are not included in the NRA analysis for the same reason.

4.2 Regression Results

Various regression models were estimated to evaluate the incidence of protection in the Kyrgyz Republic and two of those are presented in Table 3. In the first model, aggregate price ratios are used to investigate the effect of the price ratio of importables to exportables on the relative price between the nontradable and the exportable sectors.

Table 3: Regression Estimates of True Protection Models, 2002-2013[a]

Independent variables:	Dep. Variable: ln(Ph/Px)	Dep. Variable: ln(Ph/Pxa)
ln*(Pm/Px)*	0.522*** (0.066)	
ln*(Pm/Pxa)*		0.41*** (0.085)
ln*(Pxna/Pxa)*		0.36*** (0.076)
$\ln(BT/GDP)_{t-1}$	-0.001 (0.012)	-0.002 (0.012)
Constant	-0.321*** (0.054)	-0.212*** (0.048)
F-test	32.23***	25.31***
Durbin-Watson Statistic	1.88	1.61
Adjusted R^2	0.62	0.65
Number of observations	40	40

[a] The Cochrane-Orcutt procedure is applied in both models. *** indicates p-value at the 0.01% confidence level. Standard errors are in parentheses. Source: Authors' estimations.

In the second model, agricultural and non-agricultural sectors are considered separately, where the price ratio of nontradables to agricultural exportables is used as a dependent variable and the effect of import protection and non-agricultural export promotion on agricultural export incentives is evaluated. In both models, a significant share of the variation of the dependent variable can be explained by the regression equation.

All incidence parameters estimated, i.e. the coefficients of ln*(Pm/Px),* ln*(Pm/Pxa),* and ln*(Pxna/Pxa)*, are statistically different from zero. They have positive signs, too, as in almost all earlier studies of true protection in developing countries and as expected by Dornbusch (1974) and Sjaastad (1980) in their theoretical analyses.

According to the first equation in Table 3, a one-percent change in the price ratio between importables and exportables raises the price ratio between nontradables and exportables by 0.52%. A protection of the import-substituting sector induces an implicit tax for the exports sector equal to 52% of the import protection. All other prices would rise more in percentage terms than those of the exportable sector. We can conclude for the Kyrgyz economy that protection in the importable sector or an exogenous upward shift on prices of importables will lead to higher percentage increases of the prices in the nontradable compared to the exportable sector. This implies that an import price boom will place the highest relative burden on the export sector.

It is interesting to look at the second equation additionally in which nonagricultural and agricultural exportables are distinguished. The result reveals that both incidence parameters are significantly positive. A one-percent increase in the price of importables as opposed to agricultural exportables raises the price ratio between nontradables and agricultural exportables by 0.41%. Again, agricultural tradables are implicitly taxed if protection in the manufactured sector or an exogenous import price boom occurs. This holds not only relative to the importable sector, but also to the nontradable sector. A one-percent rise in the price ratio of nonagricultural exports relative to agricultural exports leads to an upward change of the price ratio between nontradables and agricultural exportables by 0.36 %. This means that, e.g., a price boom on the gold market will deteriorate the price of agricultural exportables not only relative to the booming sector but also relative to the nontradable sector. The econometric evidence points to the existence of several intersectoral linkages and to the importance of Dutch-disease phenomena in the Kyrgyz economy.

The coefficient estimate of the combined balance-of-trade and income variable $\ln(BT/GDP)_{t-1}$ was not statistically significant, which means over the years considered in this analysis it did not have a significant impact on the price ratio of nontradables to exportables.

In order to check for the robustness of estimated results, different specifications of regression models have been performed. In all of the models, the estimated incidence parameters were positive and statistically significant, and the magnitude of the coefficient estimates was very similar to those presented in Table 3.

5 CONCLUSION AND POLICY IMPLICATIONS

The goal of this paper was to analyze the impact of agricultural policies and changing macroeconomic conditions on agricultural incentives in the Kyrgyz Republic. Nominal Rates of Assistance were estimated in order to quantify the direct distortions to agricultural prices resulting from the policies in the agricultural sector. In the second step, the True-protection Concept was employed in order to analyze the implications of changing macroeconomic conditions and economy-wide policies on agricultural incentives in Kyrgyzstan.

Summarizing governmental support to agriculture over the years since independence one could conclude that the assistance to farmers has been concentrated mostly to input-related support. Approaches applying output market interventions have been adopted only in 2008. However, their effect on market prices remains under question because of limited resources available for implementing these instruments. The NRA estimates show that deviations of domestic prices from international prices of agricultural commodities exist in both positive and negative directions. NRAs for wheat, potatoes and maize are generally positive pointing at a support or encouragement for food crops from the government following food self-sufficiency goals. Furthermore, according to the NRAs, farmers growing tobacco are prone to the highest price distortions compared to other crops. These distortions are likely to come from the existing system, where only few corporations are entitled by the government to purchase the raw tobacco from farmers and to further market and export this commodity. Lacking detailed information on domestic trade costs, the implications derived from the magnitude of distortion estimates have to be made carefully. But the conclusion seems safe from both the summary of agricultural policies and the estimates of NRAs that the governmental support to farmers in total and to specific branches of the agriculture is not based on a continuous medium-run policy of market price support. There are many individual policy actions for individual years or a few years which were then revised again. Despite this discontinuous policy approach, food crops seem to be favored compared to tradable agricultural products based on the sum of agricultural policy measures and a lack of market integration of the exportables. Political instability in the KR which has caused frequent changes in the government composition (15 times over the last 23 years) was obviously a major obstacle for consistent policy development and implementation not only in the agricultural sector, but also in the rest of the economy.

Regression results demonstrate that a significant part of the increase in the prices in the importable sector is shifted on to the exportable sector as an implicit tax. That is, a one-percent change in the price ratio between importables and exportables raises the price ratio between nontradables and exportables by 0.52 %. Apparently, all other prices would rise more in percentage terms than those of the exportable sector. Thus, for the case of the Kyrgyz economy, protection in the importable sector or an exogenous upward shift on prices of importables will lead to higher percentage increases in the nontradable compared to the exportable sector, i.e. an import price boom will place the highest relative burden on the export sector. When nonagricultural and agricultural exportables are distinguished in the regression model, the results show that agricultural tradables are implicitly taxed with protection in the manufactured sector or if an exogenous import price boom occurs. This means that, e.g., a price boom on the gold market will deteriorate the price of agricultural exportables not only relative to the booming sector but also relative to the nontradable sector.

Strong intersectoral linkages between the prices in the nontradable and tradable sectors have straightforward implications for designing future policies, as they indicate the extent by which each sector would be affected by a certain commercial policy or a general macroeconomic development that affects prices in the importables sector. Since the Kyrgyz government seeks to promote exports, findings from the present study could serve as a useful scientific background for future trade and agricultural policy development.

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7 ANNEXES

Table A1: Records of Agricultural Support Measures in the Kyrgyz Republic in the period of 1992-2000

Years	Type of Support	Description of the support measure	Source of Information
1993	Subsidy	Bread subsidy of 70.6 mln. KGS; other food subsidies 3.9 mln. KGS; 78.8 mln. KGS enterprise support	Christensen and Pomfret, 2007
1994-2002	Indirect subsidies	Low charges for irrigation water or electricity Through the research institutes that deliver new seed varieties to farms Through the distribution of inputs received by the government as aid (fertilizers (1994-1997) and tractors (1995-2001) from Japan) or in barter deals (e.g. tractors from Belarus in 2002)	Christensen and Pomfret, 2007
1995	Budget loans	To oblasts (regions) for bread price support and to Agroprombank amounting 814.1 mln. KGS	Christensen and Pomfret, 2007
1996	Directed credits	Through banks to agricultural enterprises and to the Ministry of Agriculture and Melioration, 240.9 mln. KGS	Christensen and Pomfret, 2007
1997	Directed credits	Through banks to agricultural enterprises and to the Ministry of Agriculture and Melioration, 277.8 mln. KGS	Christensen and Pomfret, 2007
1998	Interest-free credit	Governmental Act as of 18 June 1998 No.367 for strengthening capacities of seed and livestock breeding farms, 30 million KGS for 5 years	Ministry of Agriculture, 2011
1998	Directed credits	Through banks to agricultural enterprises and to the Ministry of Agriculture and Melioration, 83.1 mln. KGS	Christensen and Pomfret, 2007
1999-2000	Export tax	Seasonal export tax on wheat (July-November)	Christensen and Pomfret, 2007

Table A2: Records of Agricultural Support Measures in the Kyrgyz Republic in the period of 2000-2012

2000-2003	Subsidized credits	To agricultural enterprises through the banking system, between 7 -24mln. KGS per year, eliminated in 2004	Christensen and Pomfret, 2007
2003	Subsidy	10.9 mln KGS for cattle breeding farms, Governmental Act as of 7 October 2003 No.628	Ministry of Agriculture and Melioration, 2011
2003	Subsidy	Governmental Act as of 22 May 2003 No.292, 6.7 mln KGS to 3 stud farms	Ministry of Agriculture and Melioration, 2011
2004	Subsidized credit	Governmental Act as of 23 July 2004 No.550, 6.6 mln. KGS	Ministry of Agriculture and Melioration, 2011
2007	Commodity credits	10,000 tons of milling wheat seeds (soft wheat) for 62.0 mln. KGS; 5321,5 tons of wheat and barley seed varieties for 59.9 mln. KGS; 70 combine harvesters “Niva” for 130.6 mln. KGS	Azhibekov, 2009
2007	Subsidy	Distribution of 5000 m³ fuel under the lower than market prices from the State Material Reserve, amounting 75.0 mln. KGS	Azhibekov, 2009
2008	Price stabilization	Establishment of the Agricultural and Food Corporation (AFC)	Governmental Decree as of 31 July 2008, No. 417
2008	Commodity credits	wheat and barley seed varieties, 1885.1 tons amounting 31.5 mln. KGS nitrogen fertilizers, 3585.5 tons amounting 30.0 mln. KGS 306 universal tractors and 102 carriages for tractors, amounting 200.0 mln. KGS	Azhibekov, 2009
2008	Subsidy	Distribution of 15,000 m³ fuel under the lower than market prices from the State Material Reserve, amounting 365.0 mln. KGS	Azhibekov, 2009
2009	Purchase	Through AFC: 20,000 tons of wheat purchased at 10 KGS/ton, whereas the market price was 6 KGS/ton	The World Bank, 2011

Source: Own compilation based on the literature review

Table A3: Structure of Exports in 2012 by the HS sections[a]

Product groups	mln. USD	Share in total exports, %
Total	1683.2	100.0
Precious metals, pearls, precious stones	569.0	33.8
Mineral fuel and oil and energy products	250.9	14.9
Agricultural commodities and food products (live animals, animal products, vegetables and vegetable products, soft drinks and tobacco)	224.4	13.3
Textile and textile products	204.6	12.2
Terrestrial, air, marine transport and their parts	140.2	8.3
Non-precious metals and products of them	74.7	4.4
Machines, equipment and mechanisms	71.0	4.2
Products of chemistry and related industries	57.7	3.4
Other goods	90.6	5.4

[a] Data includes “shuttle traders”. Source: NSC data at c.i.f. prices in NBKR (2013b).

Table A4: Structure of Imports in 2012 by the HS sections[a]

Product groups	mln. USD	Share in total imports, %
Total	5373.9	100.0
Mineral fuel and oil and energy products	1205.0	22.4
Agricultural commodities and food products (live animals, animal products, vegetables and vegetable products, soft drinks and tobacco)	786.0	14.6
Terrestrial, air, marine transport and their parts	713.3	13.3
Machines, equipment and mechanisms	636.8	11.8
Products of chemistry and related industries	482.4	8.9
Non-precious metals and products of them	415.7	7.7
Textile and textile products	374.6	6.9
Plastic and plastic goods, rubber and rubber goods	224.7	4.2
Timber and timber products, charcoal, cork	133.2	2.5
Other goods	402.4	7.5

[a] Data includes “shuttle traders”. Source: NSC data at c.i.f. prices in NBKR (2013b)

IMPLEMENTATION OF THE KYOTO PROTOCOL AND POST-KYOTO COMMITMENTS IN KAZAKHSTAN: LEGAL IMPLICATIONS FOR LAND USE

S. Sabitova, V. Ni and Th. Marauhn

0 ABSTRACT

This article gives a brief overview of the Kyoto Protocol to the United Nations Framework Convention on Climate Change. According to the Kyoto Protocol, greenhouse gas (GHG) emissions can be reduced by several means such as establishing renewable and installing energy-saving technologies, and others of the same nature; however, GHGs can also be reduced through increasing GHG absorbing measures, provided within the Land-use, land-use change and forestry (LULUCF) sector given in the Kyoto Protocol. The paper introduces the history of decisions in Kazakhstan with regard to the Kyoto Protocol and specific reference to the LULUCF sector. In particular, the paper provides with analysis of such research questions as to what extent implementation of the Kyoto Protocol involves legal implication possibilities for the land use sector of Kazakhstan, to what extent the Kazakh emissions trading scheme may be employed for Kazakhstan's quantified emissions limitation and reduction commitment under the Kyoto Protocol, as well as which legal implications for land use in Kazakhstan of the Kazakh emissions trading scheme. The paper analyzes opportunities and challenges of participation of Kazakhstan in the second commitment period of the Kyoto Protocol.

1 BACKGROUND TO THE STUDY

1.1 Negotiations on the Greenhouse Gases Reducing Agreement

Issues related to the Global Warming must be one of the most hotly debated topics nowadays. Climate change is one of the most ambitious undertakings of international governance which is complex in many points. The key accent in climate change is on the greenhouse gases (GHGs), which is a set of such gases as carbon dioxide, methane, nitrous oxide, etc. (Bothe and Rehbinder, 2005). The GHG effect implies that the heat from solar energy is retained in the earth's atmosphere. According to the Intergovernmental Panel on Climate Change, the GHG effect led to an increase of temperature of 0.6 degrees Celsius over the past 50 years which in turn affected the changes in ocean temperatures, in weather behaviour, in precipitation and other important climate changes. The fact is that GHG have the effect to which life on earth owes its existence (Doelle, 2005, p 19).

In Kazakhstan, as in a global format, an average increase of air temperature is being noticed. According to the Kazakhstan Hydrometeorological Organization, for a period between 1894 and 2003 an increase of temperature had an average rate of 0.09 degrees Celsius per ten years in summer and spring and up to 0.23 degrees Celsius per ten years in winter and autumn times. The growth of the average annual temperature in Kazakhstan was 0.15 degrees Celsius per ten years, meaning that in 110 years the air temperature rose by 1.5 degrees Celsius (National Inventory Report, 2012, p 16).

During a semi-political conference held in Toronto in 1988, reductions of CO_2 emissions by 20% in 2005 relative to the 1998 level were discussed. The conference has been known as “Toronto target” and had an arbitrary nature, nevertheless, it strengthened the idea that countries should commit to emission reduction (as opposed to, say, a carbon tax or a technology standard).

By the request of the United Nations General Assembly, the Intergovernmental Panel on Climate Change (IPCC) was formed right after the conference in Toronto. The main mission of the IPCC is to report on what was known and not known about climate change, on the potential impacts of climate change, and on what could be done to forestall and adapt to climate change. The first report of the IPCC was made by 1990, after the release of which a number of OECD countries announced intentions to reduce their CO_2 emissions. For instance, the United Kingdom, Finland, Switzerland set a goal of stabilizing their CO_2 emissions at the 1990 level by 2000, Norway at the 1989 level by 2000, the Netherlands to reduce emissions by 3-5% by 2000, Germany to reduce emissions by 25-30% by 2005 from the level in 1987, while Canada and the United States set a target of stabilizing the emissions of all greenhouse gases.

In October 1990 the European Union (EU) announced its intention to stabilize Union-wide emissions at the 1990 level by 2000. The EU’s announcement was especially important, as it accounted for a large share of global emissions. However, no decision was made at that time as to how it would be met, and a collective policy for meeting the target was needed. This is how the idea of the Framework Convention on Climate Change came to life.

Despite the European Union’s incentives to fix a date for stabilizing CO_2 emissions, the final text of the Framework Convention did not contain any specific targets and timetables (Barrett, 1998, p 25). Details of the Framework Convention on Climate Change were negotiated by the Intergovernmental Negotiating Committee established specifically by the United Nations General Assembly (UN General Assembly, Resolution 45/212, 1990). Having been negotiated and prepared for signing within a relatively short period, the United Nations Framework Convention on Climate Change was signed by over 150 countries at the United Nations Conference on Environment and Development in Rio in 1992 (French, 1998, p 228).

In December 1993 it already entered into force, for the precise reason that it did not oblige signatories to meet any particular target by any particular date. However, Article 4.2 says that returning to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases would be desirable (Barrett, 1998, p 25), implying that this is less a commitment and more of a desideratum (Bodansky, 1993, p 451-558).

Periodic meetings of the Convention Parties, also known as Conference of the Parties (COP), promote and review efforts to combat global warming (Böhringer, 2003, p 457). Article 4.2 (d) states that on the very first COP the Parties should review the adequacy of the individual Parties' commitments in order to ensure that the objective of the Convention is achieved.

The first Conference of the Parties to the Framework Convention was held in Berlin in 1995. There, the Parties agreed to negotiate emission limits within certain time frames that can be developed in a new protocol or another legal instrument. Importantly, emissions limits were not subject to developing countries (Barrett, 1998, p 26). Accordingly, the developed country Parties, as initiators of “the largest share of historical and current global emissions”, should take the lead in combating climate change. Thus, quantified emissions limitation and reduction objectives (QELROs) for the developed country Parties should have been set, along with deadlines for their fulfillment, but no commitments would refer to the developing country Parties (French, 1998, p 229).

The seeds of the Kyoto process can also be found in the Convention. Despite a two-year-period allocation for discussion purposes, no text had been agreed on by the third session of the Conference of the Parties in Kyoto, Japan. Failure of the international consensus in tackling climate change in terms of agreed text gave rise to debates on whether any agreement should be adopted. Unlike the preliminaries of the Framework Convention on Climate Change, negotiations on the Kyoto Protocol were more disagreeable and hot, especially with regard to the first binding limitation and reduction commitment (French, 1998, p 230). From the very beginning the meeting in Kyoto was going to be tough, but historically meaningful. The final text of the Kyoto Protocol was agreed on at the very last possible moment (French, 1998, p 231). Commitment for emissions reduction is perhaps the most important feature of the Kyoto Protocol.

The Protocol is only a first step towards implementing the Convention by achieving stabilization of concentrations. IPCC 1995 assessments conclude that much more radical emission reductions will be necessary. Global average annual emissions would need to be twice less than current levels as per unit of economic activity (IPCC doc, 1995).

1.2 Ratification of the Kyoto Protocol by Kazakhstan

Since the collapse of the Soviet Union in 1991, Kazakhstan's GHG emissions decreased dramatically, accounting for some 360.11 million tons of GHG emissions in 1990 and further decreasing by almost 85.21 million tons by 2011 (accounting for 274.9 m. tons respectively, excluding land use, land-use change and forestry). Please refer to Table 1 for the total emissions of GHGs in Kazakhstan for the period from 1990 to 2011.

Table 1: Total emissions of GHGs in Kazakhstan (m. tons of CO_2-eq.)*

GHG emissions in 1990	360.11
GHG emissions in 2008	241.88
GHG emissions in 2009	261.25
GHG emissions in 2010	262.72
GHG emissions in 2011	274.9

* Author's own compilation from National Inventory Report, 2012 and 2013

An economic crisis in the country caused a sharp decline in production which in turn resulted in fewer emissions of GHGs. As time passed, emissions decreased by 40-45% in 1996-1998 from the level in 1990. A sharp fall in industrial production made "clean" production technically impossible, due to old technology, updating of which was no longer among the prior requirements of local regulators. As a consequence, a relatively inconspicuous reduction of GHG emissions took place. Analysis of the economic state of the country shows that in 1994-1998 Kazakhstan achieved macroeconomic stability and starting from only 1999 the country has been experiencing economic growth. Obviously, the country's economy is heavily dependent on the situation in the world markets and even a slight fluctuation in prices for raw materials affects domestic financial market. The recent fall of emissions was due to the decrease in fossil fuel consumption in the energy sector, the reduction in the livestock population, the use of synthetic fertilizers on agricultural soils as well as reduction of activities in the metal production and mineral products industries.

According to the GHG emissions review, the need to sign and ratify the Kyoto Protocol by Kazakhstan was obvious. The document of the Kyoto Protocol was ready for signing at the Headquarters of the United Nations in New York from 16 March 1998 to 15 March 1999 (UNFCCC doc, the Kyoto Protocol, 1998, Article 24.1). The first step of Kazakhstan in this direction was signing the Kyoto Protocol on 12 March 1999. On 23 March 2000, the Government of Kazakhstan notified the Secretary General about its intention to comply under

Paragraphs 2a), 2b) and 2g) of Article 4 of the UNFCCC (National Inventory Report, 2012, p 15).

After signing the Kyoto Protocol Kazakhstan has started the process of adapting the national policy to the Kyoto Protocol matters, i.e. preparation of the legislative framework that regulates reduction of GHG emissions. In addition, other regulations are being accepted on the governmental and ministerial levels with the purpose of mitigating climate change. In 2003 Kazakhstan informed the UNFCCC that it was preparing procedures for the Protocol's ratification (IISD doc, 2003, p 15). However, a decision regarding the ratification of the Kyoto Protocol was postponed for a very long period of almost 10 years after singing it in 1999. From the very beginning this process was accompanied by discussions between the legislative and executive branches of the government. In spite of the consistent serious discrepancies in views, the outcome was the need to participate in as well as to ratify the Protocol. From that period on real technical activities towards preparation for ratification of the Protocol have started, including consultations with international experts. As a result the Kyoto Protocol was ratified on 26 March 2009 (Law 144-IV, 2009). Since 17 September 2009, the ninetieth day after submission of the ratification documents to the depositary, Kazakhstan has become a Party to the Kyoto Protocol (National Inventory Report, 2012, p 15), which accounts for a total of 192 Parties as of January 2013 (Status of Ratification, 2013).

2 OBJECTIVES OF THE STUDY

Before ratifying the Kyoto protocol in 2009, Kazakhstan declared its intention to take quantified emissions limitation and reduction commitment, and thus, acquiring a status of Annex I Party to the Protocol, and its proposal was welcomed by the majority of the participating Parties. Since then the government of Kazakhstan has started to oblige domestic companies to reduce greenhouse gas emissions. GHG emissions can be reduced by several means such as establishing renewable and installing energy-saving technologies, and others of the same nature; however, GHGs can also be reduced through increasing GHG absorbing measures, provided within the LULUCF sector of the Kyoto Protocol.

There are six land categories that fall under the LULUCF sector: i) forest land; ii) cropland; iii) grassland; iv) wetlands; v) settlements; and vi) other land (IPCC doc, 2003, p 2.6). Due to the limited understanding of the forest values (descriptive characteristics rather than an assessment of their multiple functions) by the land use planners, forests are often not adequately taken into account by land use planning (Geneletti, 2007, p 220). Forests are beneficial for the country, community or individual in many respects. Forests provide ecosystem services ranging from the sequestration of carbon to the provision of pollinating insects essential to agricultural crop production (Thompson Jr, 2008, p 460). In addition forests provide provisioning, cultural, preserving and supporting ecosystem services (Ruhl, 2008, p 424). Planting new forests to absorb carbon dioxide in the atmosphere is one viable option to employ forests to curb climate change. The idea of planting carbon offsets is now being implemented worldwide under the Kyoto Protocol and beyond it (Schoene and Netto, 2005, p 3). There are three major frameworks for LULUCF projects: first, avoiding emissions by conservation of existing carbon stocks, second, increasing carbon storage by sequestration, and third, substituting carbon for fossil fuel and energy intensive products (García-Oliva and Masera, 2004, p 348). The Joint Implementation mechanism can undertake such LULUCF projects as forest management, crop management, grassland management and revegetation (UNFCCC doc, the Kyoto Protocol, 1998, Article 3.4). The Clean Development Mechanism allows afforestation and reforestation projects within the LULUCF sector (UNFCCC doc, 2005).

By ratifying the Kyoto Protocol, Kazakhstan is automatically obliged to comply with certain obligations that involve, inter alia, the LULUCF sector. For instance, according to Article 2.1 Annex I Parties to the Kyoto Protocol should also promote rational methods of forest management, reforestation, afforestation, and agriculture sustainability while implementing quantified reduction commitments. In addition, Article 3.3, 3.4 and 7 requires Annex I Parties to the Kyoto Protocol to estimate emissions and removals of greenhouse gases as part of a national inventory, including in agriculture and land use, land-use change and forestry sectors. Such rules imply that participating in the Kyoto Protocol requires amending considerable parts of the legislation while complying, including legal framework in the LULUCF sector.

Objective 1: To analyze to what extent implementation of the Kyoto Protocol involves legal implication possibilities for the land use sector of Kazakhstan.

The quality of LULUCF projects depends highly on how measuring, accounting and monitoring systems function in the country. A system of measuring and monitoring requires comprehensive and internationally consistent emission inventories that enable verification of emissions reductions in which uncertainties in measurement are quantified and managed (Eliasch, 2008, p 146).

Objective 2: To analyze how a comprehensive national inventory system enlarges the applicability of GHG reducing projects in the LULUCF sector in Kazakhstan.

As part of measures aimed at implementing the Kyoto Protocol, Kazakhstan prepares itself to launch its first domestic emissions trading scheme. The national cap-and-trade system is expected to be a key climate-policy instrument for reaching general commitments of the country to mitigate climate change. Emitters which are subject to the Kazakh emissions trading scheme are allocated with emission caps, which can be traded within the national cap-and-trade scheme. Such emitters can reduce their own emissions and then sell the excess of cap allowances on the market. If they emit more than allowed, they can buy allowances if any are available, otherwise they are obliged to pay strict fines defined by the government.

Objective 3: a) To analyze to what extent the Kazakh emissions trading scheme is a key instrument for the implementation of the quantified emissions limitation and reduction commitment under the Kyoto Protocol; b) to analyze which legal implications for land use in Kazakhstan the Kazakh emissions trading scheme has.

3 METHODOLOGY AND RESULTS OF THE STUDY

A separate chapter is dedicated to the analysis of each of the objectives. Thus, the aim of one of the chapters is to identify whether the implementation of the Kyoto Protocol, including the UNFCCC provisions, has influenced the legal framework in the LULUCF sector of Kazakhstan and to indicate these amendments. The chapter starts with an analysis of the major implications of the Kyoto Protocol for Kazakhstan, such as Kazakhstan's status under the Protocol and in obtaining quantified emissions limitation and reduction commitment. Unlike an Annex II Party, the status of Kazakhstan as an Annex I Party under the Kyoto Protocol requires taking on a certain quantitative commitment to reduce GHG emissions. However, the process of ratifying the Kyoto Protocol in Kazakhstan took a very long time. Therefore, Kazakhstan faced a tough and long process of submissions of its quantified emission limitation and reduction obligation afterwards. Attempts to submit a proposal on the quantitative reduction indicator were not accepted and passed for discussion in the next sessions, for different reasons discussed in the chapter. In the first commitment period of the Kyoto Protocol (2008-2012) Kazakhstan was not able to obtain its quantified emission limitation and reduction obligation. However, at the 7th session of the Ad Hoc Working Group on Long-term Cooperative Action under the UNFCCC in 2009 Kazakhstan voluntarily committed itself to reduce its GHG emissions by 15% in 2020 and by 25% in 2050 relative to the 1992 level of its emissions.

The chapter then focuses on an analysis of legal implications for the land use sector brought by provisions of the UNFCCC and the Kyoto Protocol. As a result, the chapter shows that a considerable part of the legislation has been amending while complying under the Kyoto Protocol and the UNFCCC. Kazakhstan has been developing and implementing strategically significant amendments, including in the LULUCF sector, with a view to reduce GHG emissions that were described in the chapter. To sum up, Chapter 3 aims at research on the statement of the first objective, which is to indicate that implementation of the Kyoto Protocol involves legal implication possibilities for the land use sector of Kazakhstan.

Another chapter discusses the LULUCF sector of Kazakhstan. It starts with the determination side of the sector, defining such terms as sink, forest, afforestation, reforestation, land and forest relations. It then traces the history of the land use relations in Kazakhstan since the country obtained its state independence on 16 December 1991, showing how land ownership passed from being totally state to private.

Institutional cooperation on land use management divides key functions related to the LULUCF sector between the Ministry of Environment and Water Resources, the Forestry and Hunting Committee and the Land Management Agency of Kazakhstan. In particular, the Ministry of Environment and Water Resources is the state body in charge of the implementation of the Kyoto Protocol, including conduction of the national GHG emissions inventory. The inventory is a very important procedure as it shows which and to what extent different categories affect absolute levels or trends in emissions, their uncertainty or qualitative factors. The inventory in the LULUCF sector ensures that estimates of carbon stock changes, emissions by sources and removals by sinks, and uncertainties to them have been reduced as far as practicable considering national circumstances (IPCC doc, 2003, p 1.6). To be exact, the inventory in the LULUCF sector estimates emissions and removals of greenhouse gases from changes in wood biomass stocks of forests, conversion of forests and grasslands, as well as from land use change and farming methods, etc. In addition, it estimates greenhouse gas emissions from fires. Guidance on how to complement the reporting required under the UNFCCC for the LULUCF sector in order to meet the supplementary requirements under the Kyoto Protocol is provided by the IPCC Good Practice Guidance on the LULUCF sector. It is designed to assist countries in producing inventories for the land use, land-use change and forestry sector, in which uncertainties are reduced as much as possible.

As a result of the GHG inventory in Kazakhstan, total emissions accounted for 274.9 million tons of CO2-eq in 2011, excluding the LULUCF sector. The LULUCF sector can be either emitter or absorber of emissions. Absorption from the LULUCF sector was 3.09 m. tons, thus, the sector offset 1.12% of emissions from other sectors in Kazakhstan in 2011.

Analysis of the LULUCF sector shows that the sector is very complex by its nature. Even definitions in different sources may be controversial. It is crucially important to reduce uncertainties in the sector as much as possible, therefore recommendations regarding national inventory reports of the Parties given by an independent expert review team, appointed by the UNFCCC secretariat, must be taken into account and eliminated. The chapter analyzes a set of recommendations of the review team, which finalized it with regard to the national inventory report submitted in 2012 by the Ministry of Environment and Water Resources of Kazakhstan. The chapter explains the general part of recommendations dedicated to the LULUCF sector. The more accurate the inventory in the LULUCF sector, the more the sector can be employed for the need of the Kyoto Protocol, which is the reduction of GHG emissions. The aim of Chapter 2 is to analyze the statement of the second objective on whether the comprehensive national inventory system enlarges the applicability of GHG reducing projects in the LULUCF sector in Kazakhstan.

Another chapter discusses the Kazakh emissions trading scheme, its role in the GHG reducing policy and its implications for the LULUCF sector. At a time when Kazakhstan is actively investigating other options for reducing emissions to comply with its present voluntary commitments and future commitments under the Kyoto Protocol, the establishment of a domestic emissions trading scheme may be a good option. The essence of the emissions trading scheme is a market-based mechanism that allocates a specific amount of GHG allowances for each GHG emitter in the country. If the emitter lacks allowances it can buy them on the emissions trading market, otherwise it can sell them. The government pays serious attention to the Kazakh ETS with a view to raise the interest of operators to gradually move to energy efficiency and low-carbon policy by their own initiatives. There are several reasons given in the chapter for why the emissions trading scheme is advantageous in and of itself comparing to other GHG reducing methods based on the European Union's experience.

The chapter provides analysis and explanation of the legal framework of the national emissions trading scheme. There are about 30 secondary regulations that regulate the newly established domestic carbon trading scheme. The chapter discusses all of them, indicating their regulating objects and subjects. In case a GHG emitter operating in the ETS wishes to decrease its emissions below the specified allowance, it can achieve that by upgrading its energy efficiency or switching to low-carbon technologies or by investing in GHG absorbing projects. The possibility to employ projects aimed at an increase of removals of GHGs implies an involvement of the LULUCF sector of the country. For instance, development and implementation of domestic projects aimed at reducing emissions and/or increase removals of GHGs are based on the domestic emissions reduction mechanism subject to the procedure and criteria established by the environmental legislation of the Republic of Kazakhstan. In addition, this mechanism generates carbon units that are tradable on the domestic emissions trading scheme. This is the first option of how the LULUCF sector of the country can engage in the Kazakh emissions trading market. The second option is participation in voluntary carbon markets that do not have specific regulations. It is possible for Kazakhstan to participate in voluntary carbon markets by submitting to forest protection, afforestation and reforestation projects that can be offered to domestic or foreign participants willing to reduce their anthropogenic impact on the climate system by investing into these projects.

As any other scheme the Kazakh emissions trading scheme has its limits. Hopefully, a transitional (trial) phase will provide opportunities to tackle some of those challenges. So it is important that the trial period will be used to address these challenges and elaborate appropriate solutions by analysis of lessons to be learnt from experiences of similar schemes. The aim of Chapter 4 is to analyze the statement of the third objective on whether the Kazakh emissions trading scheme is a key instrument for reducing GHG emissions and its implications in the LULUCF sector.

4 FUTURE OF THE KYOTO PROTOCOL

There have been continuous debates on the pros and cons of the Kyoto Protocol, even long before it entered into force. Back in 2002 the rejection of opponents culminated in the statement that the agreement was both economically inefficient and politically impractical (McKibbin and Wilcoxen, 2002, p 107). Antagonists of the Kyoto Protocol point out a number of problems in provisions of this international agreement. Turning into details, the flexible mechanisms raise several questions. The Clean Development Mechanism provides shifting abatement toward the non-Annex I countries. However, non-Annex I Parties do not have their emissions capped, therefore potential reductions may result in emission reductions on "paper" only. Joint Implementation implies negotiations on emissions reduction projects between Annex I countries on an individual basis. However, this entails high transaction costs comprising high calculating, analysis and other costs. The theory of trading suggests that high transaction costs limit incentives for bilateral trading. Emissions trading opportunity in the case of including transition countries into the transactions may result in an unfair trade allowing occurrence of "hot air" trading. "Hot air" trading may occur when, for instance, countries in transition, whose present emissions of greenhouse gases is below its 1990 level, might be able to sell a significant part of their emission allowances to other parties. In general, flexible mechanisms cause a further problem by having an "additional to domestic actions" feature (Barrett, 1998, p 31).

Another major issue for adapting flexible mechanisms lies in their validity period. The first commitment period of the Protocol finished at the end of 2012. Moreover, the future of the flexible mechanisms of this international agreement in terms of new post-Kyoto agreements has not been developed yet. In addition, mechanisms continue to be plagued by design failures that can still be improved through relatively simple adjustments, e.g. provision of a long-term perspective to achieve long-term investment security. Whereas, the stability in long-term is again dependent on the post-Kyoto international situation (Freestone and Streck, 2007, p 55).

Issues mentioned here are not the only cases describing shortcomings of the Protocol, which is still being criticized. Despite inclusion of the obligations to reduce GHGs in the text of the Kyoto Protocol, it can not be seen as successful completion of the international negotiations on the issue. Many issues are still left unresolved and no one can guarantee they will be addressed in the future (French, 1998, p 227).

On the other hand, the Kyoto Protocol is the only agreement nowadays that obliges its signatories to reduce emissions of greenhouse gases. The proponents of the Protocol considered it as a breakthrough in international climate policy for several reasons. Firstly, it promised significant emission reductions for the developed world. Secondly, it broadened international mechanisms for more serious climate protection activities in the future. The Protocol builds on market-based instruments that provide cost-efficient responses for GHG abatement (Böhringer, 2003, p 463).

4.1 Evaluation of the LULUCF Sector

As mentioned above there are five sources of GHG emissions that the UNFCCC deal with. Among them are energy, industrial processes, agriculture, LULUCF and waste. LULUCF is the only sector where removals of GHGs take place due to the growth of biomass. This is what makes the LULUCF sector very significant in mitigating climate change. LULUCF involves at least five approaches to reduce emissions. Firstly, provision of renewable energy. Secondly, it allows substitution for more fossil carbon-intensive products. Thirdly, reduction of emissions of non-CO_2 gases from agriculture. Fourthly, it provides sequestration of carbon through enhancement of terrestrial carbon stocks. Finally, conservation of existing carbon stocks, for instance through reduced deforestation, devegetation, forest degradation, and land degradation (Schlamadinger, Bird, Johns et al., 2007, p 273).

For some countries the future of the Kyoto Protocol is associated with new rules for LULUCF in the second commitment period (Fry, 2011, p 124). Some studies even argue that the failure of COP-6 negotiations in 2000 was due to disagreements between the European Union and the United States on LULUCF rules (Vrolijk, 2001, p 167). It is obvious why many Annex I Parties needed the rules before the numbers before accepting anything. That is why they were reluctant to commit to a further quantified emission limitation or reduction targets for the second commitment period until they clarified what accounting rules for the period would be. For the countries where the LULUCF sector plays a significant role in mitigating climatic changes, knowing the rules is a crucial point (Fry, 2011, p 124). Developed countries should not decide upon their emissions reduction levels until they agree upon the LULUCF rules (The European Union COP-15 Information Sheet, 2012).

There have been continuous suggestions and recommendations on what should be included in the LULUCF chapter of the agreement after the first commitment period was over in 2012.

The Parties agreed upon inclusion of only afforestation and reforestation to the LULUCF activities under the CDM for the first commitment period. Afforestation and reforestation projects have credits with expiration dates, and receive temporary CERs and long-term

CERs. In addition, use of afforestation and reforestation credits by Annex B Parties may not be over 1% of their base year emissions per year. For instance, if emissions were 350 m. tons of CO_2-eq in the base year, the LULUCF projects under the flexible mechanisms' scheme may not absorb more than 1% of total emissions in the base year equaling no more than 35 m. tons of CO_2-eq. In addition, there is insufficient geographical distribution of projects and poor market coverage by afforestation or reforestation CDM projects. Reasons for poor coverage include either the accounting approaches for non-permanence or the restricted access to the EU ETS (World Bank doc, 2010, p 25). That is why future rules of LULUCF should consider the improvement of geographic distribution of CDM projects as well as address better accounting rules that solve non-permanence. Unfortunately, these questions have been given little consideration, thus causing further disagreements (Fry, 2011, p 136).

A post-Kyoto international agreement should address deforestation in non-Annex B countries (or their future equivalent), because now deforestation accounts for about one-quarter of global greenhouse gas emissions in developing countries. Several countries and organizations have been calling for this lately (Schlamadinger, Bird, Johns et al., 2007, p 278). Furthermore, leakage concerns are being heavily discussed. One of the main potentials of reducing emissions from deforestation is that it can yield large benefits within a relatively short time. Obviously, it is associated with certain risks that must be taken into account and addressed when including this activity in a possible future agreement (Schlamadinger, Bird, Johns et al., 2007, p 279). Some examples of projects that were designed and implemented outside of the Kyoto Protocol in order to know whether avoidance of deforestation and carbon leakage is possible show that these activities actually can reduce emissions from deforestation. However, these projects must be properly designed integrating community programmes and landowner involvement (Aukland, Moura Costa and Bown, 2003, p 135). Apart from that, there are many other details that should be properly developed to take into account all impacts on deforestation. For example, the choice of the baseline can have a crucial impact on the generated credits. Despite the fact that project baselines can be more accurate than national or regional baselines, leakage can cause more problems at the project than at the national level (Schlamadinger, Bird, Johns et al., 2007, p 279).

Another factor that limits application of the LULUCF in full capacity is that quantitative targets under the UNFCCC and the Kyoto Protocol are set only for the Parties listed in Annex B of the Kyoto Protocol. As mentioned above, adoption of internal policies and measures as well as "flexible mechanisms" that allow non-domestic emission reductions are tools for achieving these targets. Unfortunately, the absence of quantitative targets in non-Annex I Parties limits LULUCF efforts undertaken in these countries. In order to make a greater use of LULUCF, the approaches for LULUCF with regard to climate change mitigation should be expanded (Schlamadinger, Bird, Johns et al., 2007, p 281).

Recommendations of the EU with regard to the post-Kyoto LULUCF agreement state that the LULUCF accounting rules should create a predictable and stable framework that could provide delivery of the full potential of the LULUCF sector (The European Union COP-15 Information Sheet, 2012, at 1), as another obvious difference of the LULUCF sector is that it deals with issues that change naturally over time, irrespective of human interference. In addition, carbon sequestration does not occur over life time of trees. It differs from a period of high rate sequestration to a period of remission when trees die and decompose. Everything depends on the species of tree and its geographical location. Any outside disturbances such as fires or pest attacks also affect the carbon sequestration potential of trees. The harvesting period of trees may cause fewer carbon removal levels or even lead to a negative value, on the contrary emitting CO_2 (Ward, 2008, p 2). That is why the future accounting system should be based on the environmental integrity and ensures permanence of mitigation actions.

Table 10 illustrates accounting approaches for different categories of the LULUCF sector defined for the first commitment period.

Table 2: LULUCF rules for the first commitment period*

Mandatory accounting for:	Optional accounting for:
Afforestation Reforestation Deforestation by using a “gross/net” approach	Forest management by using a “gross/net” approach Cropland management Land management Revegetation by using a “net/net” approach
The gross/net approach accounts for GHG balance using a country’s total net GHG flow from LULUCF in a given year.	**The net/net** approach accounts for GHG balance using the difference between the total net GHG flow from LULUCF in a given year and in a defined base year.

* Author’s own compilation from World Bank doc, 2010

Thus, countries have an option to account for carbon stock changes resulting from forest management, cropland management, grazing land management or revegetation. These options are applicable under Article 3.4 of the Kyoto Protocol and the Marrakesh Accords. So far, revegetation is not associated with a specific land use category, and can occur in croplands, grazing lands and other lands, except forest land (Schlamadinger, Bird, Johns et al., 2007, p 276). It is also appreciative to define revegetation in a specific category to avoid uncertainties.

In case the country chooses to account for carbon stock changes from any of these activities, it must refer to managed lands, since unmanaged lands are not subject to UNFCCC inventories and Kyoto Protocol accounting (Schlamadinger, Bird, Johns et al., 2007, p 275).

According to the IPCC's Good Practice Guidance countries should report all emissions and removals on managed lands used by human beings regardless of the cause of emissions. Similarly, countries are not required to report on emissions from unmanaged lands (Fry, 2011, p 130). The aspect of "managed and unmanaged lands" caused an issue at the IPCC experts meeting in Brazil in 2009, where some acknowledged several shortcomings of this approach due to different national circumstances. Later this issue was raised again in the AWGKP negotiations in October 2010. To date, the concept of "managed lands" is used only for reporting purposes under the Kyoto Protocol, and not for accounting ones (Fry, 2011, p 132).

Among different accounting approaches proposed, a significant approach was introduced by the EU. A so-called "bar approach" sets an agreed level above which removals would be credited and below which they would be debited. This approach was aimed at eliminating "natural disturbances" in the accounting system (Fry, 2011, p 129). Over time, the "bar approach" was advanced to the "reference level approach" which, at first, met several disagreements, however, being acknowledged later on, mostly because it could be incorporated in the work of REDD+. Key aspects of the reference level approach are being designed now by the working groups (Fry, 2011, p 130).

Another recommendation addressed by the EU is that harvested wood products should be a part of the accounting rules for forests. Harvested wood products are wood-based products that store carbon. However their storage capacities depend on duration, usage and others, which is why harvested wood products have been an issue within the context of forest management accounting for a long time. Among harvested wood products paper, cardboard, short-lived timber products and longer-lived timber products can be mentioned. Some Annex I Parties including New Zealand argue in favor of accounting for harvested wood products in the second commitment period (Montgomery, 2008, p 7). There are three approaches for accounting for harvested wood products which are being discussed. They are stock changes, production and atmosphere flow (IPCC doc, 1998, p 4). Approaches differ depending on different circumstances and incentives of countries that consume or produce harvested wood products. For instance, the atmosphere approach is designed to meet both export and import incentives, whereas the production and the stock change approaches give an incentive to import (Tonosaki, 2009, p 393). Like any other LULUCF accounting, the accounting for harvested wood products is a complicated procedure and requires answering many questions such as, what are the consequences if HWP are burnt, etc. (Fry, 2011, p 134).

Another recommendation of the EU with regard to the accounting system of the LULUCF is that the accounting rules should address extreme events (*force majeure*) in emissions and removals of GHGs and that will reduce the risk of such events. The actual definition of "*force majeure*" is an issue. Some Parties even create new definitions for their own particular situation, while there are already internationally accepted definitions. Generally, a *force majeure* refers to a singular catastrophic event such as a wildfire, or severe pest outbreak, flooding, landslide, volcano eruption, earthquake or severe windstorm. Now, accounting for *force majeure* in forests exists in standard forest contracts in the United Kingdom. Force majeure creates a time-out in accounting of emissions and removals for countries experiencing it until the previous state of carbon stocks is recovered. Due to discrepancies in definitions, the term “force majeure” was slightly embedded into the term “natural disturbance” (Fry, 2011, p 130).

The EU agrees that in any way countries should have more flexibility in choosing accounting methods (The European Union COP-15 Information Sheet, p 2).

To sum up, it is important to include LULUCF in the future agreement, as LULUCF has social and environmental benefits. However, there are a number of aspects that should be taken into account, as the UNFCCC and IPCC have always been developing amendments for the future to address missing issues. The following considerations could significantly improve current rules for the LULUCF activities: 1) providing a stable environment for investment in LULUCF activities; 2) simplification and practicability of monitoring and accounting systems; 3) expanding a geographical coverage; 4) inclusion of all significant sources and sinks; 5) addressing leakage and non-permanence; 6) providing consistency with inventory guidelines, internal methodologies (avoiding double counting, etc.), and the long-term goal of climate-change mitigation; 7) considering differentiation of countries and thus circumstances (Schlamadinger, Bird, Johns et al., 2007, p 279-281).

4.2 Negotiations on the Second Commitment Period

Yet, even before entering into force the Kyoto Protocol raised the question of what would happen when the first commitment period ended in 2012. Article 3.9 provides commitments of Annex I countries for subsequent periods. Neither the certain description nor the duration of such commitments is specified (Boston, 2007). Negotiations on the post-Kyoto period have already started several years ago.

One of the last Conferences of the Parties in the first commitment period, COP-16 was held in Cancun, Mexico between 29 November and 11 December 2010. Negotiations in Cancun resulted in the “Cancun agreements”. Agreements cover such issues as mitigation, adaptation, financing, technology, reducing emissions from deforestation and forest degradation in developing countries, including conservation, sustainable management of forests and enhancement of forest carbon stocks, monitoring, reporting and verification and international consultation and analysis. However, most parties considered this document as a relatively small step in mitigating climate change (IISD doc, 2010, p 144). There are several key decisions, covered by the agreement with regard to the future of the Kyoto Protocol: a) it agrees that, as was true in the first commitment period for emissions trading and project-based mechanisms, the transfer of clean technology investments from industrialized countries into developing countries will be available for the second commitment period as an additional means of meeting emission reduction targets; b) it calls for the submission of reference levels for forest management, which allows for a look at how countries include forest management in their greenhouse gas accounts; assessment of these reference levels is important, as it may become a significant application of LULUCF in the future; c) it establishes a Green Climate Fund that will deal with the provision of long-term financing for developing countries and function under the guidance of the Conference of the Parties. Thus far, industrialized countries committed to provide up to USD 100 billion per year by 2020 to support developing countries in transparent mitigation actions (IISD doc, 2010, p 11).

For the next COP-17 the Parties gathered in Durban, South Africa, to discuss climate change issues between 28 November and 11 December 2011. Further commitments under the Kyoto Protocol were discussed throughout the meeting. The Durban Outcome presents a document with a set of decisions adopted during the COP-17 in Durban. The basis of the document constituted the issue of the future of the Kyoto Protocol. The Outcome of the working group with regard to further commitments for Annex I Parties under the Kyoto Protocol includes, *inter alia:* a) proposals to amend Annex B to the Kyoto Protocol (Annex I); b) proposals to amend the Kyoto Protocol (Annex III); c) objective to ensure whether emission reductions in Annex I Parties can be at least 25-40 percent below 1990 levels by 2020; d) calls for submissions of information by Annex I Parties on their quantified emission reduction objectives for the second commitment period under the Kyoto Protocol by 1 May 2012; e) a discussion of an opportunity to carry over assigned amount units to the second commitment period; f) the Establishment of an Ad Hoc Working Group on the Durban Platform for Enhanced Action, which will work on the post-Kyoto legally binding instrument, which will either be a developed protocol, or another legal instrument or an agreed legally binding force under the Convention applicable to all Parties; it was scheduled to start working in the first half of 2012 and shall complete its work as early as possible, but no later than 2015, so that new legally binding outcomes can be adopted at COP-21 and be implemented from 2020 onwards; g) considerations of further commitments for Annex I Parties under the Kyoto Protocol; h) and others (IISD doc, 2011, p 28).

It was expected that the next negotiations with respect to the post-Kyoto period would be tougher. Neither were developed countries eager to bear alone the costs of mitigating global climate change, nor were developing countries eager to sacrifice their economic interests by taking pledges. On the other hand, developing nations strive not to miss opportunities of additional investments coming from this kind of international agreement, as they can improve the efficiency of their industries. Calls for developing countries and major emitters such as China, Brazil, India, on taking any quantitative obligations face strong resistance in return. The COP-17 held in South Africa stuck on existing contradictions about responsibility concerns of the Parties for pollution of the atmosphere.

So, COP-17 also failed to design and conclude on the future of the Kyoto Protocol. Before the last Conference of the Parties in the first commitment period, the Parties considered two possible outcomes for the post-2012 period: 1) the first is a new protocol, agreement or other legally binding instrument to the UNFCCC that will contain quantitative commitments of the Parties starting from 2020 or an earlier date; 2) the second is, to amend Annex B of the Kyoto Protocol for the second commitment period, which shall commence from 1 January 2013 and might last until 31 December 2017 or until 31 December 2020. The future of the Protocol was subject to acceptance of either of two legally binding decisions.

For the last and 18th Conference of the Parties of the first commitment period of the Kyoto Protocol the Parties gathered in Doha, Qatar, from 26 November to 8 December 2012. It also included the 8th session of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (CMP 8). On its 8th session the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol accepted Decision 1/CMP.8 “Doha Amendment to the Kyoto Protocol to the United Nations Framework Convention on Climate Change (the Doha Amendment)” (UNFCCC doc, 2012). Decision 1/CMP.8 was finalized on the last day of the meeting dated 8 December 2012. Acceptance of this Decision faced a controversial situation, as Belarus, Russia and Ukraine tried to disagree with it. Regardless of attempts expressed by the Russian Federation to discuss this issue, the President of the Conference of the Parties announced acceptance of the amendment to the Kyoto Protocol (IISD doc, 2012, p 27).

Should the issues resulting from the implementation of the Doha Amendment provisions by Kazakhstan be resolved, it seems more reasonable for the Government of Kazakhstan to accept a positive decision with regard to the ratification of the Doha Amendment to the Kyoto Protocol. There is another possible outcome for the post-Kyoto period, i.e. 31 December 2020, in terms of the development of a new legally binding agreement. Questions to be resolved, inter alia, include: What role should carbon markets play in the new agreement? Should developing countries be required to take on commitments? What will positions of such great emitters as USA and China be in the subsequent periods? What is the role of voluntary commitments (Chasek, 2011, p 87-108)? Whether it would be the second commitment period of the Protocol or a new international agreement, both are of importance for the country. However, one might find no logic or consistency in Kazakhstan's participation in either of two negotiation agreements. Bearing in mind the country’s non-participation in the first commitment period, it might be considered as the country’s desire to sell “hot air” by using the surplus of the assigned amount it may have. On the other hand, participation in the negotiation process for a new international agreement seems to be safer for Kazakhstan, taking into account issues resulting from the implementation of the Doha Amendment provisions by Kazakhstan. In addition, the second commitment period is likely to face a rigid position of some countries, due to a substantial increase of the level of reduction commitments in accordance with implementation of Paragraph 7 of Article 3 of the Kyoto Protocol.

In any case, voluntary commitments of the country may serve as the starting point to strive for in order to reduce emissions of GHGs in Kazakhstan. In case Kazakhstan ratifies the emission reduction commitment, by ratification of the Doha Amendment, there are some opportunities to reach this commitment, for instance, the domestic emissions trading scheme, as well as participation in Joint Implementation projects. Taking into account the EU's reluctance to participate in CDM projects for its weak emission reduction features, the JI projects may in turn be more attractive, thus giving Kazakhstan an opportunity to be one of the countries to implement JI projects with.

Thus, the agenda on participation of Kazakhstan in the second commitment period of the Kyoto Protocol framework includes a wide range of issues. Obviously, achieving consensus on ratification of the Doha Amendment will not be easy. At the same time, a post-2012 gap could have a negative effect on many aspects of the country in tackling climate change. The scale of the agenda on climate change mitigation has been changing, reflecting the raise of uncertainty on how to practically implement the objectives of mitigating the negative anthropogenic influence on the environment. Anyway, these days the Kyoto Protocol is the only agreement that obliges its signatories to reduce emissions of greenhouse gases, the existence of which is crucial whether as an amendment to the main text of the Kyoto Protocol or in terms of a new instrument.

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THE AGRO-PASTORAL SYSTEM OF THE ZARAFSHAN VALLEY, TAJIKISTAN, AND MODELLING OF MANAGEMENT OPTIONS FOR IMPROVEMENT

S. AVAZOV, T.M. GIBREEL and E.-A. NUPPENAU

0 ABSTRACT

This paper analyzes livelihood conditions of agro-pastoral communities in the Western part of Tajikistan, the Zarafshan Valley. Data was collected primarily on current fodder management practices in eighteen villages and corresponding farming systems. We looked in pure pastoralist and agro-pastoralists' systems making interviews and visual observation at local pasture areas. The interviews and discussions yielded information on decision-making processes as regards to farmer knowledge and that of dehkans (peasants). Interviews were employed to determine the quantity and composition of feed offered to livestock at particular times of the year. Among decisions we found constraints in grazing and limited knowledge to appropriate lopping regimes for different animal fodder species. Varying degrees of access to off-farm fodder sources and the numbers of livestock kept by different households were also seen as affecting fodder management decisions.

Development activities aimed at improved labor use for fodder collection and the exchange of local knowledge regarding local fodder management may most likely result in improvements in the levels of fodder supply. For the majority of households in the short term, grazing is important but also storing feed for winter. Variations in practices were discussed with site-specific dehkan groups and between group representatives at a series of workshops. According to the results, stable types of practices, number of cattle, size of cultivated land, labor availability per household, existence of small ruminant flock in the village, and the number of small ruminants were found to be most important factors affecting household economic status. This paper used a dynamic programming approach on optimizing forage use and inventories. In another words, to find the optimal seasonal feed use, also to improve grasslands and show the benefits from reduced grazing in the beginning of the season when grass still is growing. The model included labor, stocks, crops, nutrition needs and selling and purchasing.

1 INTRODUCTION

Most of the land in Central Asian countries is devoted to pasture, which is making up an estimated 65% to 82% of the whole region. Today, these pasture areas are mainly used by smallholder farmers. Since most of the larger, state-owned agricultural enterprises were abandoned after the collapse of the Soviet Union, smallholders started operation. The shift to small scale farming caused a decline in livestock numbers in almost all of Central Asian states in the eraly transition. At the same time, pasture management systems also changed. In some cases with devastating consequences, grazing became uncontrolled. Until the beginning of the 1990s, pasture management had been based on the high mobility of livestock herds, similar in some respects to the traditional nomadic system, but then some pastures became overgrazed. The demise of the Soviet Union sharply reduced mobility. Especially in areas close to villages, overgrazing resulted in serious degradation, while more distant pastures remained unused (GIZ, 2014).

Pastures play a significant role in the national economy of the Tajikistan. They account of about 3.9 million ha (83 %) of agriculture land in this country with limited agricultural potential (Rakhimov et al., 2011:16). In general, pastures in Tajikistan are distributed along mountain ranges and according to their seasonality of use we see transhumance. Grazing periods are depending on altitude. Summer pastures are used between June and August and are located from 2,200 to 3,400 m above sea level.; spring and autumn pastures are usually used from March to May and September to November and are located between 900 and 1,500 m above sea level; winter pastures are used between November and March and are located 500 to 1,200 m above sea level. All year-round pastures are located at the same location as winter pastures. Additionally farmers make hay on meadows for winter feed and use crops for feeding in winter. There is short distance transhumance and long distance. For long distance transhumance different districts are used though separated by high mountain ranges; and herds are often isolated during the winter season (Kodirov et al., 2010:12-15). Moreover, large herds are moved from mountain pasture to lowlands in winter.

1.1 Research problem statement

Feed demand in Tajikistan is driven primarily by needs of beef herds and dairy cows. Over 60 percent of total feed demand is by cows, while only 24 percent is attributable to sheep and goats. Potential feed supply, however, is natural grass which is situated largely in alpine pastures. Much feed seems to be inappropriate for cows, but because of lack of alternatives milking cows also dwell on natural pastures. Hence productivity is low. This demand-supply mismatch is the predominant cause of the poor nutrition of livestock inventories and low milk as well as meat yields in Tajikistan (Sedik, 2009).

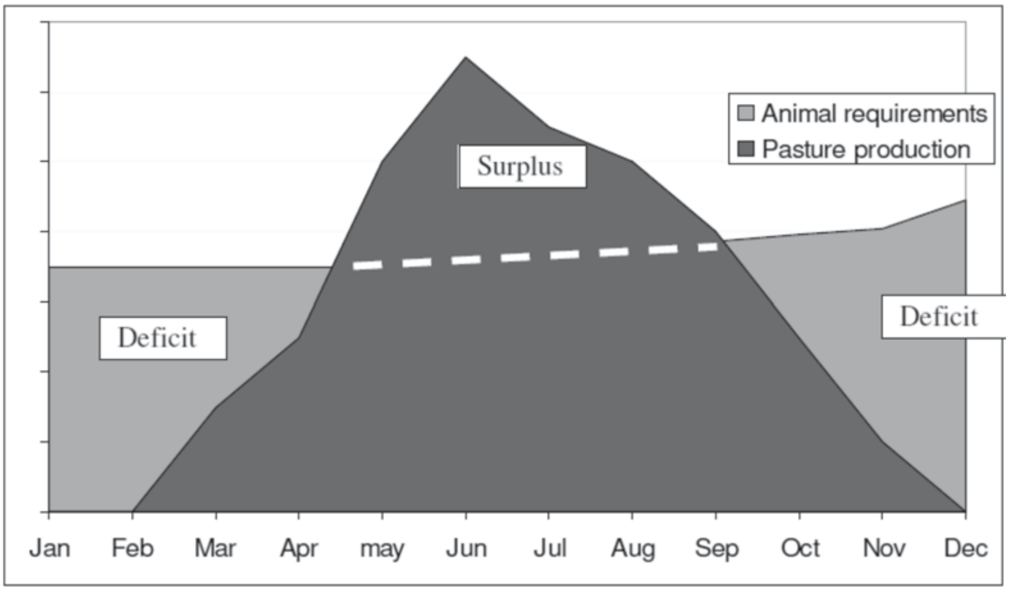
Like in all Commonwealth of Independent States (CIS) countries, at the end of the 1980s and the beginning of the 1990s, economic crises signaled the deterioration of the socialist system of livestock production (Sedik, 2009); in Tajikistan the colchos system and central management of grazing collapsed. Note Central Asia, as a whole including Tajikistan, was a net importer of feed and food grains (Squires, 2012). Mixed feed imports assisted in filling the winter feed gap. This changed in transition. Imports ceased and deficits of feed transpired during those years which transformed the livestock husbandry system in Tajikistan into a resource extraction system and degradation. From a system based on intensive livestock farming, grazing and fodder procurement it transformed to one based on extensive livestock husbandry (Sedik, 2009).

The previous in socialist time designed and intensive livestock husbandry system relied on three main and separate sub-systems for support of livestock rearing (FAO, 2009): First it consisted of livestock inventories in large scale enclosures on state land managed as collective farms, as well as in complexes attached to industrial compounds. The animals in this sub-system were fed on hay, mixed concentrated (as supplement feed) and fresh cut feed all over the year. Second, the system consisted of a subsystem of livestock inventories that spent the winter-spring period in enclosures in the lowlands and the summer-fall period in pastures in mountain regions. This system was predominantly a beef cow, beef cattle, and small-ruminant animal system of certain alpine districts without winter pastures. Animals were in their majority located in northern districts, and this sub-system required 210 days of cultivated forage for feeding. Feeding was in large enclosures. Finally, the third sub-system was entirely pasture-based, with transhumance grazing of livestock in summer in mountains, spring-fall and winter pastures throughout the year in middle altitude areas, and winter grazing in valleys. The system covered mostly sheep, goat and horse inventories. It was typical for the majority of districts in the south (Sedik, 2009). In all three systems herds were large and controlled grazing should assure the fodder basis for the future. Additionally animals were in private hands for subsistence at a scale of not more than 2 to 3 livestock units.

1.2 Situation

The situation has transformed significantly, at least the transformation of the livestock husbandry system in Tajikistan changed from one based on intensive livestock farming to one based on extensive livestock husbandry. For further notice, fodder production at arable land was important. In Tajikistan, intensive livestock farming was established in large dairy and meat complexes where cultivated feed and concentrates were fed to hogs, poultry and, importantly to dairy cows. The needed feed stuffs were raised on corporate farms linked to specialized meat and dairy units, and procured through the state animal feed supply system. This serves to ensure adequate feed. Since these large livestock complexes depended on procured feeds, they liquidated their stock (ceased inventories) when the feed supply system collapsed. As a consequence, the livestock production system, existing today in Tajikistan, relies primarily on grazing of livestock. With limited access to supplementary feeding coming from cultivated feed and concentrates, productivities are low and pressure on pasture in terms of intensified grazing has emerged. As a consequence livestock is confronted with feeding form natural sources which are seasonal uneven distributed.

Figure 1: Outline of pasture feed production and animal feed requirements by month



Source: O'Mara (2006), p. 15. (Found in Sedik 2009)

Regarding the availability of feed, over the course of the year, in all pasture-based feeding systems it is the winter feed requirement that presents the most difficult challenge. From **Figure 1** one can observe that feed availability is a challenge and it seems that Tajik pastoralists are not fully exploring options to smooth use and avoid degradation in productivity of pastures. While animal feed demand is relatively constant throughout the year, gradually it is increasing as animals grow. But though the availability of pasture feed is nearly nil during the winter and limited in the spring and autumn and peaks in the summer months, farmers put animals all over the year on natural grasslands. As shown by figure 1, there is mismatch between pasture feed production and animal feed requirements by month. Winter feeding depends on the availability of cultivated feed (cut hay, silage, feed crops) and concentrates (grain, oilseed meal and wheat feed) during the winter, spring and fall months. The winter should determine the herd size. If not, it implies degradation because of overuse of grass by grazing which reduce the sod to regenerate plants. Despite the fact that animals, fattened from summer feeding in alpine pastures, are able to store food in the form of fat, the winter feeding bottleneck is still the major limiting factor on livestock nutrition in Tajikistan.

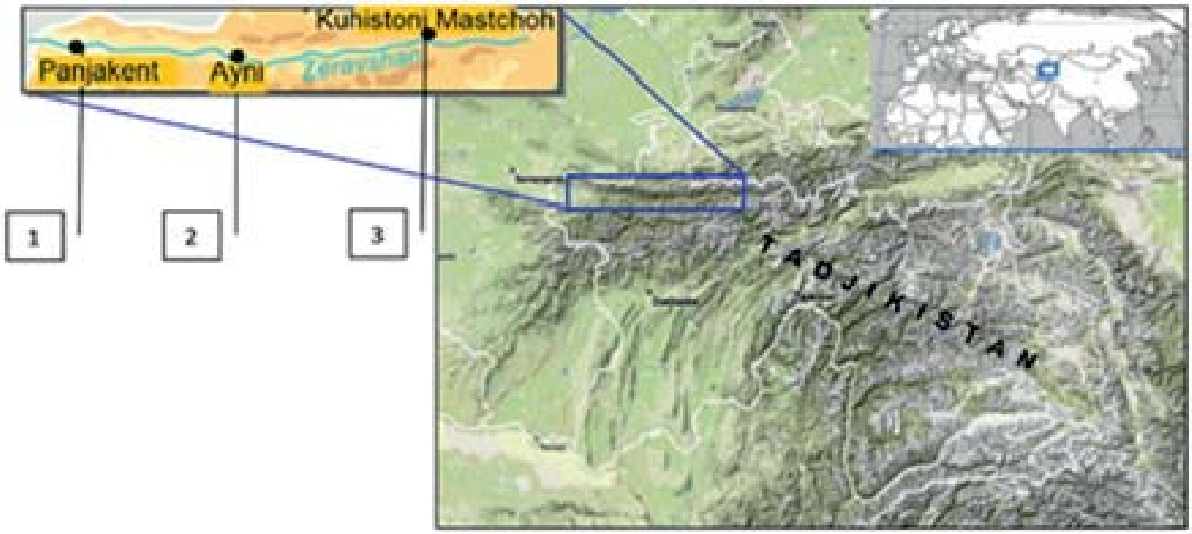
The importance of the winter feeding issue leads to the belief (according to a study of pasture issues in GBAO that "winter fodder, rather than pasture area or quality is important), that the problem is seasonal management. It affects livestock production potential based on natural resources (meadows and pastures) and it is said that livestock numbers are naturally limited by this winter bottleneck (Mountain Societies, 2007, p. 5). This statement from GBAO indicates that the development of the livestock sector in Tajikistan depends vitally on efforts aimed at increasing the production and availability of winter fodder, rather than in increasing the productivity of pasture resources in Tajikistan. Therefore, a major, key challenge of the Tajik livestock policy is that adequate and accessible supplies of feed for livestock are sustained. Accordingly, this paper deals with pasture management as fodder scarcity problem in Tajikistan, which constrains a maximization of livestock and which is formulated as a programming problem to show advantages of improved storage. The overall goal is to determine an optimal pasture management practices that maximize the net present value (NPV) of gross margins for three representative districts, given that the farmers can produce a mix of products, subject to various resource constraints.

2 RESEARCH METHODOLOGY

2.1 Selection and description of the study area

The study was carried out in the Zarafshan Valley, which located in the Sughd province of North Tajikistan between 39˚ 06' and 39˚ 32' east and 66˚ 55' and 70˚ 48' north (Nowak and Nobis, 2010:68) and situated between 850-900 m (Western part of the valley) and 5,489 m (Chimtargha peak) above sea level. The valley is a typical mountainous area, situated between two high mountain ranges, Turkestan and Hissar. Alpine zones of Zarafshan ridge have very steep slopes. It characterized with about seven ecosystems out of a 12 ecosystems found in the country (ADB, 2006:8). Summer pastures are mainly located in the Zarafshan Valley, while, significant areas of winter pastures are located in the south part of the country (Herber sand Nuppenau, 2007:8). The valley administratively consists of three districts: Panjakent, Ayni and Kuhistoni Mastchoh as in **Figure 2**.

Figure 2: Case study of three districts of Zarafshan Valley



Source: Shaumarov (2008:22).

Considering the proportion of the population and numbers in the research area of Zarafshan Valley, six jamoats were selected for the data collection within the three districts: Chinor, Rudaki and Voru (Panjakent); Anzob and Fondaryo (Ayni) and Ivan-Tojik (Kuhistoni Mastchoh) jamoats. The research was conducted in 18 villages within six selected jamoats. The research focused on two types of farming activities: first Cropping – mainly farming with additional livestock activities and second Agro-Pastoralism – mainly livestock keeping with additional farming activities.

2.2 Data collection

Our research is based on primary and secondary data sets. Primary data was collected through constructed farm household questionnaires and interview with experts and stakeholders, and the secondary data was obtained from related sources. The household survey was conducted in the six jamoats of the Zarafshan Valley and covered 18 villages and 90 households (Some results are in Appendix 2: Table 1). While, the primary data focused on the actual study area within Zarafshan Valley, the secondary data provided broader information on regional and national level. The farm household survey covered a wide range of socio-economic data, which included demographic information, production endowment (land, labor and capital), herd sizes, purchased inputs, input and output prices as well as grazing patterns and fodder use at monthly basis. Whereas, the secondary data took account of market prices of inputs, metrological information (precipitation, temperature, humidity); also crops and forage cultivated area, pasture area and yields at monthly basis were retrieved.

3 SURVEY RESULTS AND DISCUSSION

3.1 Survey results for resource endowments of households

3.1.1 Land resource

Pasture land represents the biggest share in the three provinces among different land uses, as it accounts about 4027 hectares, 1598 hectares and 1583 hectares for Ayni, Panjakent and Kuhistoni Mastchoh, respectively. Conversely, crops account for 45.47 hectares, 38.61 hectares, and 17.81 hectares for Panjakent, Ayni and Kuhistoni Mastchoh, respectively. Further, crop land was classified into irrigated, non-irrigated and home garden as illustrated in T**able 1**. Due to population increase, arable land per capita decreases; this represents a threat for future household food security. For this reason, farm household in the study area were categorized into different groups based on land holding size, namely small, medium and large farm households (here with size of less 1 hectare, 1 to <2 hectares and >2, respectively). Shared or rented land for cultivation was not taken into consideration, because many of the farmers (dehkans) rent out/in or share their land for few seasons only; and this land can be withdrawn at any time by primary or secondary land users.

Table 1: Land types and availability in the study area

Land Types	**Panjakent**	**Ayni**	**Kuhistoni Mastchoh**
Pasture Land	1598	4027	1583
Cropland	45.47	38.61	17.81
Irrigated	19.34	10.88	11.87
Non-irrigated	22.36	25.92	4.85
Home garden	3.77	1.81	1.09

Source: own calculation from field survey 2011/12

Table 2 shows that small farms are in the majority in Panjakent and Ayni with55.5 % and 80 %, respectively, whereas 60 % of farms in Kuhistoni Mastchoh are classified as medium class. As result, more than 60 per cent of total selected households are classified as small farm size in the study area. The comparison of the average land holding size among the study area has depicted that the landholders from Ayni own a relatively lower land holding size in two classifications, i.e. small and medium of the land size.

Table 2: Distribution of households by land holding size in the study area

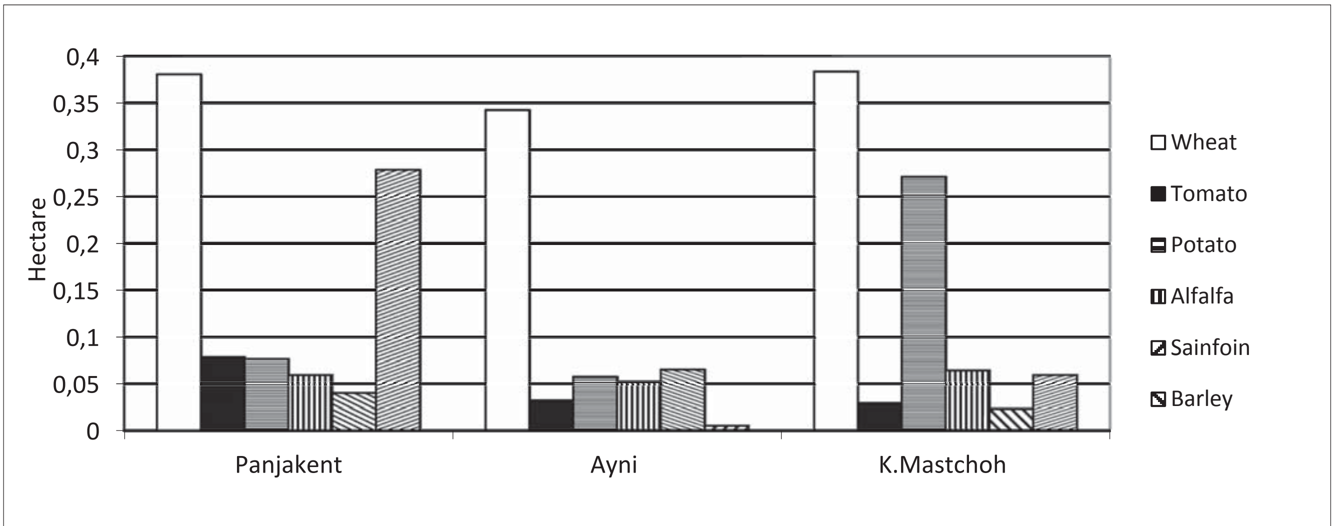
Districts	No. of households	Share of households (%)			Average land holding size (hectare)			
		Small	Medium	large	Small	medium	Large	total
Panjakent	45	55.5	35.6	8.9	0.43	1.27	2.50	0.91
Ayni	30	80.0	13.3	6.7	0.25	1.14	3.06	0.55
Kuhistoni Mastchoh	15	40.0	60.0	-	0.37	1.21	-	0.87
Total	90	61.1	32.2	6.7	0.34	1.23	2.69	0.79

Note: small farms = <1 ha; medium farms = 1 - <2 ha; large farms = >2 ha

Source: Field survey, 2010/11

Thus, with the average of 0.25 ha of the small land holding size, Ayni is relatively lower than Panjakent and Kuhistoni Mastchoh. However, about 7 % of households in Ayni have farm size at the average of about 3 ha. The size of the medium land holding classification is higher in Panjakent with the average indicator of 1.27 ha than that of Ayni (1.14 ha) and Kuhistoni Mastchoh (1.21 ha). The indicated results show that in total, the landholders of Panjakent at the average of 0.91 ha own higher land holding size, which is higher by 39.6 % and 4.4 % as compared to Ayni and Kuhistoni Mastchoh, respectively as shown in **Table 2**. This is because Panjakent and Kuhistoni Mastchoh are less densely populated districts than that Ayni, and most likely it should to have more arable land per household (USAID, 2011:18).

Figure 3: Average crop land allocation by household in the study area

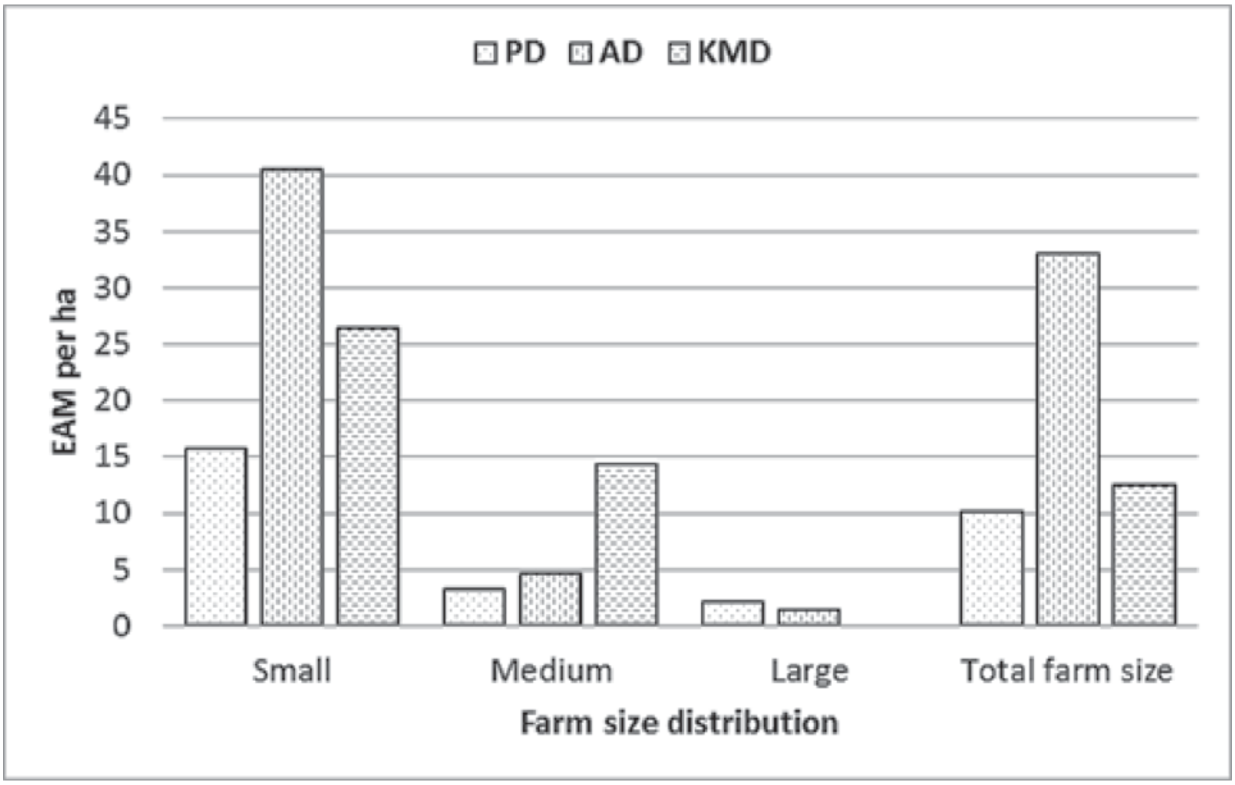


Source: Field survey, 2010/11

The **Figure 3** gives a picture of land crops on different crop activities in the study area. As can be seen from the figure wheat is the dominant crop in the three provinces followed by barley as forage crop in Panjakent and potatoes Kuhistoni Mastchoh; whereas other crops like tomatoes and forage crops (alfalfa and sainfoin) found to be cultivated in small pieces of land, respectively, only.

According to the number of economically active members (EAM: ratio per hectare by farm size categories in the study areas), much pressure falls on small farmers due to size limits in all three research districts with respect to generate food. Even Ayni with an average of 0.25 ha has a low and small land holding size; furthermore, Ayni has the highest rate of EAM per hectare (still in small farm size category). The total farm size is additionally shown in Figure 4. Looking at the household land holding in the study area we see very limited private land for crops. Accordingly, the overall results is that surveyed households have limited farm sizes and are most likely have not the craving for more land use for fodder crops or food crop cultivation must be reduced.

Figure 4: Ratio of economically active members (EAM) per hectare by farm size in the study area.



Note: PD-Panjakent, AD-Ayni, KMD-Kuhistoni Mastchoh EAM – 16-60 years age group, where man and woman equal to 1.0 and 0.8 respectively.

Source: Field survey, 2010/11

3.1.2 Livestock and its composition

Animal husbandry is an integral part of the life and plays a major role in the livelihoods of the households in Zarafshan Valley. Farmers, who do not own any livestock, are considered to be poorest in the region. Hence, livestock is considered as necessary for maintaining farm survivability; every household should have at least 1-2 cows and few small ruminants i.e. sheep and goats (Kurbanova, 2012:145). Nonetheless, better-off households own larger numbers of small ruminants and eventually some cows (5 to 10 cows), whereas poor households have difficulties to keep one cow and some sheep and goats. **Table 3** classifies species of livestock in the study areas by the average number of herd size and average livestock unit. Livestock was estimated in adult units in order to analyzing the grazing pressure on near-village pastures as well as fodder amounts needed. Average livestock units range from 0.24 to 7.73 per household across all types of livestock.

Table 3: Average herd size and livestock unit per household in the study areas.

Livestock species	Average number of herd size and livestock unit (LU)*					
	Panjakent		Ayni		Kuhistoni Mastchoh	
	Head	LU	Head	LU	Head	LU
Cattle						
Cow	1.38	1.38	1.77	1.77	1.80	1.80
Bull	0.29	0.35	0.47	0.56	0.20	0.24
Immature cattle**	1.07	0.60	1.63	0.90	0.80	0.44
Donkey	0.51	0.51	0.70	0.70	0.33	0.33
Sheep	5.64	1.13	6.83	1.37	3.73	0.75
Goat	5.20	1.04	7.73	1.55	4.93	0.99

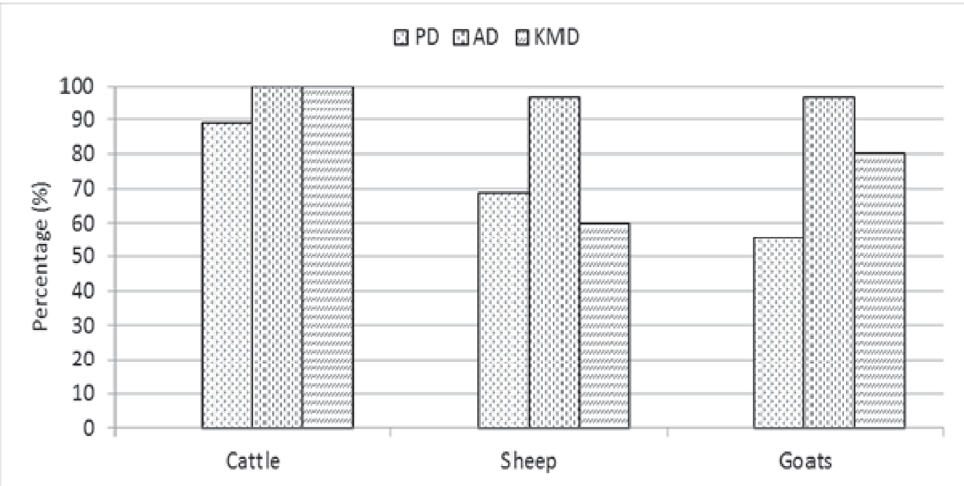
*Livestock unit (LU), calculated as follows: cow and/or donkey = 1 LU; bull = 1.2 LU; immature cattle = 0.55 LU and sheep/goat = 0.2 LU,**Male and female cattle aged up to 4 years, i.e. heifers and calves.

Source: Field survey, 2010/11

More than half of the surveyed households, i.e. 54.4 % own a donkey, which particularly served as transportation of different household's needs (fuel food, timber, etc.) as well as hays from hayfields. Figure 5 demonstrates that almost all households in the study area keep cattle. Families prefer to keep dairy cows because enable the consumption of dairy products in the daily diet. In this regard, during the study survey, attention was given to presence of dairy cows in households. However, productivity is low, as highest livestock numbers per household are observed in Ayni.

Almost every household in Ayni also keeps sheep and goats; while the percentage is less in the other two districts. This could be due to the two reasons; first: in the early 1990s, world prices and demand for wool have fallen sharply and this trend continued for nearly ten years. Only in the mid-2000s international prices and demand for wool have increased. Thus, after recovery of international wool prices, sheep herders are now returning to increase wool production (Kerven et al., 2011:26). Tajikistan, along with other Central Asian countries is also trying to establish wool production in the region (FAO, 2012:59-60). Secondly, for the rural population to keep small ruminants requires less cost than cattle. Ayni demonstrates highest share of households breeding cattle and small ruminants.

Figure 5: Distribution of livestock types among households in the study area



Source: Field survey, 2010/11

3.1.3 Labor resources: availability and shortage

Human capital plays an important role in the economic development of the rural society. This is also the case for Zarafshan Valley where labour is mainly provided by households and relatives. There is a tradition of mutual support called "hashar". Labor is expressed as standard man-equivalent in accordance with calculation system used by Lagemann (1977:170). One man-day was considered as an 8 hour working day. The availability of rural labour is often limited as there is a high percentage of temporarily labour migration of Tajik men to Russia and Kazakhstan. In the interviewed households the percentage of labor migrants amounted to 30-35 %. A result of the labour migration is that often women, elder men and children who do farming. Thus it is necessary to look at presence as well as the characteristics of the labour force in the households. All household members, who are able to work in the fields, are considered to be part of household labor force.

Table 4: Labor availability per household by gender and age in the study area

Characteristics	Unit	Panjakent	Ayni	Kuhistoni Mastchoh
Male labour (16-60 yrs)	man-equivalents	2.51	1.97	2.33
Female labour (16-60 yrs)	man-equivalents	1.44	1.60	1.23
Child labour (8-15 yrs)	man-equivalents	0.19	0.45	0.46
Others (>60 yrs)	man-equivalents	0.19	0.03	0.17
Household labour availability	man-equivalents	4.33	4.05	4.19

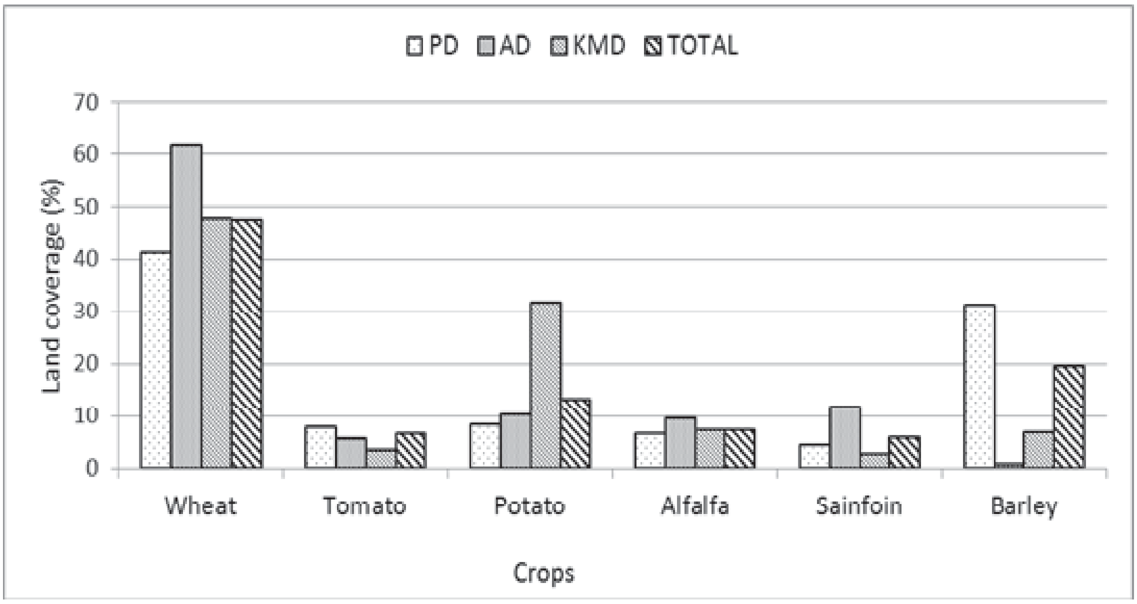
Source: Field survey, 2010/11

Table 4 indicates that the labor force is between 16-60 years including males and females. Besides, child labor (between 8-15 years) all humans were included in the calculation of available household labor. This is because due to the absence of adult males in the households, who are wageworkers, people work. Results show that the availability of labor is almost equal in the study areas.

3.1.4 Crop production and yields

In surveying, special attention was paid to the crops and forage cultivation; data was collected in the cropping season 2010/11. Figure 6 demonstrates the percentage of land coverage by different crops. The food and forage crops are wheat, potato, tomato, and barley. They are the main crops grown in in Tajikistan and in the Zarafshan Valley, mainly for food. In addition fodder crops as alfalfa and sainfoin and also cereal crop residues and partly barley are used for livestock feeding. Compared to other crops grown in the study areas, wheat occupied the highest percentage of land coverage, i.e. 47.4 %. Hay is a fodder not produced on arable land. The following crops are in cultivation: wheat (47.4 %), barley (19.5 %) and potato (13.2 %); but there is a chance for fodder crops.

Figure 6: Percentage land coverage by crops



Source: Field survey, 2010/11

Table 5 Average production, yield and percentage of sold crops by districts.

Crops	Panjakent			Ayni			Kuhistoni Mastchoh		
	Prod. (kg)	Yield (kg/ha)	Sold (%)	Prod. (kg)	Yield (kg/ha)	Sold (%)	Prod. (kg)	Yield (kg/ha)	Sold (%)
Wheat	1583.3	1986.4	6.0	1285.4	2033.1	9.0	1255.6	1829.4	-
Tomato	421.2	4949.0	-	304.1	5029.3	-	194.0	4648.3	-
Potato	2026.3	15786.7	0.8	2181.4	17394.3	-	8710.0	21782.4	49.0
Alfalfa	628.9	6579.9	-	571.3	5677.1	-	727.5	6024.8	-
Sainfoin	180.8	1890.2	-	950.0	1947.2	-	176.3	2046.2	-
Barley	1178.4	1751.2	-	70.0	2041.7	-	386.7	1497.2	-

Source: Field survey, 2010/11

In the case of Panjakent it has a significant percentage of land coverage by barley (31.2 %), compared to Ayni (0.8 %) and Kuhistoni Mastchoh (6.9 %). The reasons behind this is the fact that at first, relatively plainer, rain-fed areas are available in Panjakent, and the second reason is farmers in Panjakent prefer to cultivate barley instead of alfalfa and sainfoin because it is easier to grow. Next, in terms of average production and yield, i.e. concerning the output of the crops divided by land use, results from farmer cultivation are presented in **Table 5**. Crops are for self-consumption.

3.2 Livestock inputs

In case of fodder amount descriptive calculations were made. Livestock fodder balances in case of supply and demand were computed on basis of animal species. To bring the data into a uniform measure for purposes of comparison, calculations were also made on the basis of livestock units.

During the Soviet time, the supply of feed concentrates was carried out continuously and in sufficient quantity. After the collapse of Communist regime and at time civil war, supply of feed concentrates ceased at all. Since then, the system of feeding livestock in the country is faced with a series of difficulties. Nowadays, livestock in rural areas particularly in Zarafshan Valley is fed by crop residues and wastage of households' kitchen. It was discovered that most farmers in the study area are used to prepare concentrates by themselves or buying them from local markets. Supplementary feeding of animals by farmers was mostly done with barley, compounds, cake, etc.

3.2.1 Supplementary feed

Because of the high cost of feed from supplementary or concentrates farmers prefer to supply crop residues and green fodder (natural fodder) as a supplements of fodder for the animals.

3.2.2 Green fodder

Comparing the three research districts, it has been found that Panjakent used the largest amount of feed concentrates. On average, 142 kg of feed concentrates per livestock unit per annum were supplied in Panjakent (89 in Ayni and 76 in Kuhistoni Mastchoh). It is interesting to indicate that in spite of highest priority for livestock, a critically low quantity of feed supplements has been observed in Ayni. A large quantity of feed supplementary was required by the animals (Table 6).

It is difficult to maintain livestock production system without fodder. Green fodder such as lucerne (alfalfa), sainfoin, various mountain grasses as well as leaves are traditional practices of the Tajik farming system. Lucerne and sainfoin are grown by majority of the households in the research areas. Particularly, mountain grasses are cut from hayfields at different altitudes and then fed to livestock in winter. Together with feed concentrates, both green fodder and crop residues were included in the analysis. Farmers in Kuhistoni Mastchoh (despite of lower availability of green fodder 1,596 kg total) show the highest supply of green fodder per livestock unit (395 kg/lu). Panjakent supported the highest amount of crop residues (147 kg/lu) as compared to other districts.

Table 6: Fodder amount per livestock unit per annum in the study area

Districts	Average LU	Supplementary feed		Green fodder		Crop residues	
		mean	kg/LU	Mean	kg/LU	mean	kg/LU
Panjakent	4.23	601.3	142.2	1,604.5	379.3	620.7	146.7
Ayni	5.80	91.0	15.7	1,712.2	295.2	497.9	85.8
Kuhistoni Mastchoh	4.04	138.3	34.2	1,595.7	395.0	405.5	100.4

Source: Field survey, 2010/11

In general, farmers in Panjakent are able to supply the highest quantity of feed concentrates (74 % of needed) and this is from crop residues (44 %). In the case of green fodder, Kuhistoni Mastchoh was found supplying the highest percentage (37 %) as compared to the other two districts. However, results indicate that farmers in Ayni had lower supplies of all three types of feeding.

3.2.3 Other inputs

The average expenses for herding services are indicated in the Table 7. According to the survey, farmers in Panjakent had the highest expenditures on total livestock in the region. Expenses on cattle per household were highest in Ayni. This is because of relatively high amount of cattle holdings in this district. In contrast, in case of small ruminants, farmers in Kuhistoni Mastchoh had less than two times the average (157 TJS per household); namely this wide gap has the reason that farmers in Kuhistoni Mastchoh prefer to graze their livestock mostly by themselves (no shepherds).

Table 7: The average expenses on herding services in the study areas

Districts	Panjakent		Ayni		Kuhistoni Mastchoh	
	TJS/hh	TJS/head	TJS/hh	TJS/head	TJS/hh	TJS/head
Cattle	106.6	10.0	113.0	8.5	94.3	9.7
Goats and sheep	363.4	3.0	372.5	2.6	157.0	3.0
Total	373.5		344.1		151.0	

Note: TJS – Tajik somoni, hh – household

Source: Field survey, 2010/11

3.3 Livestock outputs

Livestock recovery and herd increase as well as milk and meat are the main and most important categories of livestock outputs. Traditionally, Tajik farmers are slaughtering mostly bulls and small ruminants for the meat. It was observed that farm households in Ayni were getting the highest milk collection as compared to the other districts (Table 8 below). Thus, the average milk yield is higher than that of Panjakent and Kuhistoni Mastchoh (by about 10.5 and 2.2 %, respectively). The reason maybe that farmers in Ayni are keeping higher number of livestock holdings per household. In total seasonal milk production (collected per day) is varying from about 5.2 liters (winter-spring) to 7.1 liters (summer-fall). This result explains that households were getting more milk per day in the seasons of summer than winter. However, the amount of milk does not meet the nutrition requirements for households in the region. Therefore, most of the households in the study area used milk only for self-consumption, however they are in deficit.

Table 8: The average milk yield in the study area.

Districts	Liters/dairy cow/ annum	Liters/dairy cow/day		
		All season	Summer-Fall	Winter-Spring
Panjakent	2,136 (1,263)	5.9	6.8	4.9
Ayni	2,386 (433)	6.5	7.5	5.6
Kuhistoni Mastchoh	2,334	6.4	7.4	5.4

Note: The figures in brackets represent data fromTajStat, 2012.

Source: Field survey, 2011

Official Tajik statistics indicate that the average annual milk production in the country has fallen by 1.6 % annually for the last decades. However, in the case of Panjakent, dairy production has increased annually by 4.24 % on average in the last years (Tajstat, 2012:186). A reason might be the low level from which the situation improves. Thus, regarding dairy production in the study areas official data shows opposite indicators. This reflects the potential of Ayni for milk production.

3.4 Income

3.4.1 Farm income

Farm income and off-farm income are used for buying food and other consumption. The status (livelihood) of a household can improve by a surplus from farm products (Adhikary, 2000:97-98). Gibreel (2009:62) and Mungkung (2006:183) claim that farm income is the sum of farm and off-farm income. So we counted both (Table 9). Besides, the fact was taken into account that income is a sensitive issue in interviews. The other thing is that in most cases as usual can be said, due to seasonal prices, income for food purchases can change (Gibreel, 2009:63) and requires smoothing.

Table 9: Average gross income of the surveyed households in the cropping season 2010/11

Items	Panjakent N=45	Ayni N=30	Kuhistoni Mastchoh N=15	Total sample N=90
Farm Income (TJS/hh)	1,092.0	732.57	1,989.4	458.64
Household Income (TJS/hh)	6,354.51	5,104.27	7,349.73	6,103.63
Distribution of Farm Income (%):				
Crop Sales	15.3	9.2	89.8	58.4
Livestock Sales	84.7	90.8	10.2	41.6
Total	100.0	100.0	100.0	100.0
Distribution of HH Income (%):				
Farming activity	4.1	7.5	34.2	10.6
Off-farm	39.1	33.9	36.9	37.2
Remittances	56.8	58.6	28.9	52.2
Total	100.0	100.0	100.0	100.0

Source: Field survey, 2010/11

Table 9 indicates the average total farm income and off-farm income of the sampled households. The results, given in **Table 10**, have been calculated at respective prices for the cropping season of 2010/11. They serve as reference for the modelling. Total farm income and household income were gathered from different sources of households' income statements, as described in the equations above. Here it is empirical observation. According to the results, average farm and household incomes range from 458.6 to 6,103.6 TJS for the total sample. Negative means that expenditures for livestock were higher than monetary returns. However, in comparison with other studies of income from the districts farm income of Kuhistoni Mastchoh farmers were found to be highest, here 1,989.4 TJS per household. This is because of potatoes which they sell and which are heavily cultivated in Kuhistoni Mastchoh. Potato is one of the dominant food crop grown in the region and used for household consumption and sales (USAID, 2011:18). Thus, farm and household incomes are highest for Kuhistoni Mastchoh's households, followed by Ayni (-732.6 TJS) and Panjakent (-1,092.0 TJS) households, which had the lowest and negative incomes. Again negative income means that expenses are higher than financial returns. This shows the high degree of own consumption which is primarily financed by remittances of the labor migrants to Russia.

Also Table 9 illustrates that the two main farm income sources, crop and livestock sales among the sampled farm households, differ. In spite of the fact that more than half of the farmers make losses, farmers on average attained crop sales. But sales are limited. Panjakent and Ayni farmers are preferably going for livestock sales. We can conclude that the higher crop sales in the region are by better off farmers; crop sales were around 58 and 42 % of the farm income for the total sampled households. It comes from field crops. Livestock sales are rare, respectively. The share of income from crops sale was highest for households in Kuhistoni Mastchoh (89.8 %), followed by Panjakent (15.3 %) and Ayni (9.2 %). Among the surveyed households, Kuhistoni Mastchoh seems most benefiting from crops sales and it shows relatively higher income through selling of potato. In case of the livestock sales, conversely, the share of the farm income was highest in Ayni (90.8 %), followed by Panjakent (84.7 %) and Kuhistoni Mastchoh (10.2 %) farm households.

3.4.2 Off-farm income

Apart of farm activities also farmer households earn money from the outside their farms, that is off-farm sources. The off-farm incomes of the surveyed households consisted of salaries as well as wages from non-farming activities and remittances. It was observed that around 11, 37 and 52 % of household income (by district) comes from off-farm and remittance income sources (Table 10). It reduces the share of farm income. Though, income from farming activities was highest, as expected, in Kuhistoni Mastchoh (34.2 %), followed by Ayni (7.5 %) and Panjakent (4.1 %) farming matters. Here farm households having the lowest share; but poverty is also high and income is skewed. However, on average in Panjakent and Kuhistoni Mastchoh farm households received more than half of their household income from the remittances, whereas Kuhistoni Mastchoh farm households received around one third. This depicts that Panjakent and Ayni farm households are less dependent on farming activities than Kuhistoni Mastchoh district. In general, in all cases off-farm activities are used for food purchase showing the livelihood problem and dependency of households on external sources. All sampled farm households attained almost similar indicators as shown in the Table 10. The results indicate that farm households are strictly depending on off-farm sources of income, especially on considerable amounts from remittances. Hence, the gathered analysis informs us regarding alternative sources of income from the outside of farms.

4 MODEL STRUCTURE

As there is a need for a depiction of better, i.e. economically feasible, grazing management strategies that achieve sustainable forage supply, bio-economic models are one method that can be used for evaluating management options. They combine biophysical dynamics with economic behavior to help determining optimal bio-economic strategies. Such models have been developed, for instance, to evaluate ranches by incorporating tree canopy, forage and livestock dynamics. Furthermore to determine the inter-temporal (seasonal) influence of stocking rates on current and future forage and livestock production, seasons are linked in a consecutive way looking a forage growth and reproduction of pastures (Standiford and Howitt, 1992; Pope and McBryde, 1984; and Torell et al. 1991). Mostly models are designed for shortage and abundant periods and storage.

For this paper, a bio-economic, linear programming model has been developed to determine the economic impacts of grazing management strategies in the Zarafshan Valley. The task of the model is to determine the optimal (profit maximizing) net returns of pasture management practices. In that regards it maximizes the net present value (NPV) of gross margins for three representative pastures in three regions under varying crops and annual precipitation levels as well as market prices, given that the farmers can produce a mix of products, subject to various resource constraints.

4.1 Model Design

As it appointed above, the problem handled in this paper is that of determining the optimal mix of pastureland management practices, fodder crops and stockpiling as well as sales of animals over a season which generates maximum net present value of a farm based on gross margins. The bio-economic model consists of a set of relationships depicting objective functions, cow herd equations of motion and forage growth equations. It is solved over 12-months planning horizon.

4.2 Objective Function

The objective function (*equation 1*) of the farm household is to maximize the discounted total gross margin which is revenues minus variable costs over a planning horizon of “m” months. A discount (DF_m) of 12% is used in present value calculations. This is high, but shows credit problems in Tajikistan. The definitions for all variables and subscripts used in the paper are given in table 1.

$$MaxZ = \sum_{REG=1}^{REG} \sum_{m=1}^{M} DF_m * (REVENUE_{reg,m} - VARCOST_{reg,m}) \quad (1)$$

Farm household total revenue (*Revenue* $_{reg,\ m}$), shown in equation 2, is defined as a function of the weight of cow (quantity of meat sold) and the weight of sold crops (wheat, tomato, potatoes, alfalfa, barley and sainfoin, a legume); further the number of cow and the market price received are multiplied. The market prices were 12 months average prices for cow, food and forage crops.

$$REVENUE_{reg,m} = \left(LIVUSEL_{reg,m} * LIVUWT_{reg,m} * PRLIV_{reg,m} + CROPSEL_{reg,m} * CRPWT_{reg,m} * PRCRP_{reg,m}\right) \quad (2)$$

The numbers of cow sold ($LIVUSEL_{reg,m}$) and the amount of crops marketed ($CROPSEL_{reg,m}$) are choice variables within the model and the optimal numbers of animals for sale are determined endogenously. The marketing weights of cow ($LIVUWT_{reg}$) is separate because it depends on fodder intake and crops ($CROPWT_{reg,m}$) were defined according to specific months. Yearling replacement of heifers was not considered in the model due to short periods considered in the analysis. Selling prices ($PRLIV_{reg,m}$ and $PRCRP_{reg,m}$) are prices that farmers receive for their product (survey).

4.3 Variable production cost equation

The annual total variable costs ($VARCOST_{reg,m}$) in the model are given by the livestock rearing and crop production costs, shown in equation 3. In case of livestock it includes labor costs ($LABCST_{reg,m}$)as variable, animal supplements ($LIVSUPC_{reg,m}$) and variable feed costs ($FEDCST_{reg,m}$).

$$VARCOST_{reg,m} = \sum_{month=1}^{MONTH} \left[\left(\mathrm{LABCST}_{\mathrm{reg,\ m}} + SUPCST_{reg,m} + \mathrm{FEDCST}_{\mathrm{reg,\ m}} + OTHCST_{reg,m} \right) + \left(CRPCST_{reg,m} \right) \right] \quad (3)$$

Variable costs per cow in the model are based on an average head household farm budgets for the selected regions (from surveys in Panjakent, Ayni and Kuhistoni Mastchoh). Total livestock feed, as said, costs are dependent upon a number of factors. These are: annual availability of natural fodder, labor costs and purchasing the supplements cost ($FEDCST_{reg,m,}$ $LABCST_{reg,m}$ and $SUPCST_{reg,m}$). They are exogenously given parameters derived from the initial investment costs in animals over the twelve months plus the aggregated other variable costs ($OTHCST_{reg,m}$) associated with the livestock production as improvement system. Moreover, equation 4 denotes the terminal value. It is calculated as the net-present value of an infinite series of net revenue multiplied by the number of animals in the herd in the last year. Further exogenous parameters are value ($NETREV_{reg}$) and (DEATH). They are calculated from the enterprise budget using the low, median and high market prices depending upon the price condition considered. The parameter $HERDSIZE_{reg,m}$ is defined below as the number of mature cows. The purpose of the $TERMVAL_{reg}$ variable is to force the model to consider future production decision as optimization is ruled out in many multi-period models; a tendency, hereby, is to liquidate the herd near the end in order to maximize net revenue. Including the terminal value in the model assumes, the farmers will continue into infinity as the final production level is reached and represents production values of farms beyond month 'm'.

$$TERMVAL_{reg} = \Big(\big(\mathrm{HERDSIZE}_{\mathrm{reg,\,m}} * (1\text{-}\mathrm{DEATH}_{\mathrm{reg,\,m}}) - (SELCAT_{reg,m})\big) * (NETREV_{reg}) * \big(r * (1-1\,(1+r)m)\big) - 1\big) - 1 \Big) \quad (4)$$

4.4 Cow equations of motion

Our livestock production is based on equivalents calculated as adult animal units. There are 6 animal types considered in this analysis which are: cows, bulls, heifers, claves, sheep and goats. Therefore, equations 5 calculate herd sizes ($LIVUGRAZ_{reg,m+1}$), i.e. at the end of the analysis period of twelve months, from initial period herd sizes multiplied by the death rate minus the sold animals. This is relevant since losses are frequent in Tajikistan. Equation 5 represents an equation of change for livestock equivalent units over the twelve months:

$$LIVUGRAZ_{reg;m+1} = (\mathrm{LIVUGRAZ}_{\mathrm{reg,\,m}} * (1\text{-}\mathrm{DEATH}_{\mathrm{reg,\,m}}) - (SELLIVU_{reg,m}) \quad (5)$$

The loss rate (DEATH_{reg}) is assumed to be 2% per month. Equation 6 sets a culling rate of livestock equivalent units as calculated from the available data and from field survey in the three provinces.

$$SELLIVU_{reg,m} \geq \mathrm{LIVUGRAZ}_{\mathrm{reg,m}} * (\mathrm{CULRATE}_{\mathrm{reg,m}}) \quad (6)$$

Other resource constraints are represented by equation 7; they are such as rangeland facilities, which limits the herd ($LIVUGRAZ_{reg,m}$) as defined in livestock animal units (cows, bulls, heifers, claves, sheep and goats) and relate it to total available livestock animal units ($LIVUINITIAL_{reg,m}$)

$$LIVUGRAZ_{reg;m} \leq \mathrm{LIVUINTIAL}_{\mathrm{reg,\,m}} \quad (7)$$

Beside livestock we looked into fodder crops competing with food crops. The production function is considered as the most important elements in determining a producer’s assessment. It is a technological relation of what exists between particular combinations of inputs and the resulting level of outputs (Sadoulet, 1995). The production function used in this study is illustrated in equation 8:

$$CROPO_{o,reg} = \mathrm{CROPYLD}_{\mathrm{o(food,\ forage),\ reg}} * AREA_{o,reg} \qquad (8)$$

Where $CROPO_{o(food,forage),reg}$ represents the food crops (wheat, tomato and potatoes) and the forage crops (alfalfa, sainfoin and barley) in the three provinces. Food crops can be consumed at home or sold in the market and they are important for nutrition in subsistence (below). The parameter of the crop yield ($CROPO_{o(food,forage),reg}$) is exogenously estimated form the surveyed household data. While, the cultivated area ($AREA_{o(food,\ forage),reg}$) is solved endogenously by the model.

4.5 Farm household food demand

Farm households are assumed to consume partially from their production. This will make sure that enough food is available to the household to meet consumptive needs. Cash sales enable purchase of deficit nutrients (food and fodder). Food produced on farm as wheat, tomato, potatoes and meat reduce purchases. Food requirement is set as a conditional constraint (illustrated in equation 9):

$$CROPO_{cb,reg} + PUR_{cb,reg} \geq \mathrm{CROPCON}_{\mathrm{cb,\ reg}} + LIVCON_{cb,reg} \qquad (9)$$

Equation 9 states that the household production of a consumption bundle ($CROPO_{cb,reg}$) plus market purchases gives consumption bundle ($PUR_{cb,reg}$). We used a typical household for reference and multiplied it by the number of households to depict the regional needs (data is from survey). It should be greater than or equal to household consumption bundle measured as needs from own crop production ($CROPCON_{cb,reg}$) and livestock products ($LIVCON_{cb,reg}$). The basis is calories.

4.6 Herbaceous vegetation production

At the pasture ecology level, there are two factors that influence the amount of herbivores available: first the amount of precipitation that falls during the crop season (April through October). Precipitation is considered a key in the biotic determination of forage production (Retzer et. al. 2006 and Sneva, Hyder, 1962). It was found that the response of forage yield to changes in precipitation is consistent on percentage basis even though productivity varies. Second, what determines herbaceous supply is the management decision of the forage utilization at levels of pasturelands.

For the bio-economic part, in our model, i.e. to calculate natural herbaceous production ($HVPRD_{reg,m}$), pasture yields were regressed on technical measures such as grazing resulting in pasture technical coefficient ($PTC_{reg,m}$) and the weather index ($WIND_{reg,m}$). We have coefficients for each province. Also, pasture area parameter ($PAREA_{reg}$) in hectares is incorporated in the equation (10).

$$HVPRD_{reg,m} \leq \sum_{reg=1}^{3}\sum_{m=1}^{12}\left(\left(WIND_{reg,m} * PYIELD_{reg,m} * PAREA_{reg}\right) + PTC_{reg}\right) \quad (10)$$

4.7 Total available fodder

To calculate the total available fodder, the crop residue were assumed to account for 15% of the total crop prodution. As shown in equation (11) the total available fodder ($TAVFOD_{reg,m}$) is calculated as summation of natural herbivores available ($HVPRD_{reg,m}$), produced amount of forage crops ($CROPO_{,forage,reg}$) by the farmer and the residue of the produced food crops.

$$TAVFOD_{reg,m} = \sum_{reg=1}^{3}\sum_{m=1}^{12}\left(\mathrm{HVPRD}_{reg,m} + CROPO_{forage,reg} + 0.15 * CROPO_{food,m}\right) \quad (11)$$

4.8 Monthly forage supply and demand (in AUDs)

The model is specified to ensure that the feed requirements of the herd are met along the 12 months period. As forage from rangeland pastures are available at no additional cost (beyond the in-farm monthly cow cost), it is the first source of feed to be used and exhausted. Keeping a steady herd size consequently demands purchasing increasing quantities of higher cost forage from other sources. As higher cost supplies of forage are utilized, gross margins decline. Other potential supplies of forage are produced forage by the farm household and the residue of food crops output. Thus, the equation 12 shows the sources of forage supply during the period of 12 months to meet the livestock forage requirements.

$$\sum_{reg=1}^{3}\sum_{m=1}^{12}\left(\left(\mathrm{HVPRD}_{reg,m} + CROPO_{forage,reg} + 0.15 * CROPO_{food,m}\right) + SUPUR_{reg,m}\right) \quad (12)$$
$$= \mathrm{LIVUGRAZ}_{reg,m} * FEDREQ_{reg,m}$$

The variable $SUPUR_{reg,m}$ stands for feeding supplementary purchased by the farm household and these are press hay, cake, bran, barley and some nutritional compounds. The parameter $FEDREQ_{reg,m}$ calculated exogenouly from the farm household collected data and it expresses the monthly requirement for a live animal unit.

4.9 Forage inventory equations of motion

The forage inventory provides information for the land manager to know the proper amount of forage to harvest with grazing and/or browsing animals to maintain enough cover to protect the soil and maintain or improve the quality and quantity of desired vegetation. The inventory will record quantity of forage in kg per hectare, quality of forage is not considered in this model. Additional feed available are considered in the inventory of forage and within the forage balance calculations. Additional feed may include, but not limited to: stored or purchased hay, crop residues, and summer annual crops. The inventory accumlation is considered to heppen in two depentding periods, i. e., the use of the forage in the existence time ($FORINV_{reg,m}$) depends on perevious time available forage ($FORINV_{reg,m-1}$). In calculation of forage from clipping hoops, the dry weight taken equals to 45 grams; and the proper use factor of forage is considered to be 50%. Equation 13 demonstrate the formulation of the forage inventory ($FORINV_{reg,m}$) in the first period.

$$FORINV_{reg,m} = \sum_{reg=1}^{3} \sum_{m=1}^{12} 0.15 * \Big(\big(\mathrm{TAVFOD}_{\mathrm{reg,m}} + 0.15 * CROPO_{food,m}\big) - \big(\mathrm{LIVUGRAZ}_{\mathrm{reg,m}} * FEDREQ_{reg,m}\big) + HVPRD_{reg,m}\Big) \quad (13)$$

As long as the decsion concerning the forage utilization in the next period is related to previous period forage inventory management decsison. Thus, anlysis of succeeding period is needed as explaind in equation 14

$$FORINV_{reg,m+1} = \big(\mathrm{FORINV}_{\mathrm{reg,m}} + 0.15 * CROPO_{food,m+1}\big) - \big(\mathrm{DECAY}_{\mathrm{reg,m}} * FORINV_{reg,m}\big) - \big(\mathrm{LIVUGRAZ}_{\mathrm{reg,m}} * FEDREQ_{reg,m}\big) \quad (14)$$

The paramenter $DECAY_{reg,m}$ is considered the loss of forage inventory in the first period to be 25% of the total inventory.

5 MODELING RESULTS

5.1 Scenarios writing for policy simulations

For the detection of management options we used scenarios analysis (on scenario analysis see: Lave and Epple, 1985). Scenarios building and writing, according to Jentsch (1967), is defined as “a technique which attempts to set up a logical sequence of events in order to show how … a future state might evolve step-by step”. In this regards we look at potential future situation which might emerge under conditions of interventions by government to promote better management; i.e. if certain measures are taken, for instance such as rational use of inventories to reduce grazing in winter and early spring, the efficiency of the system can improve. Starting from the present (or any other given) situations, interventions should improve income and food availability as well as livestock rearing based on natural pastures. Particularly, scenario analysis is suited to dealing with such aspects or problems, again more or less simultaneously (Ferris, 2005). In scenarios projections are made to show responses to changes in the system parameters. In our case, if projections could be made which show improved strategic behavior on forage shortages in winter and early spring, options used can reveal improvements of the system. Our work is based on the assumption that farmers would respond positively to increases in the net present value (NPV) of gross margins over a whole season. Especially it is important to increase gross margins and income in offseason. This proposition is including a maximization of incentives to build up inventories, and then it would be possible to explore what would happen to production and input resources allocation under various price scenarios. Given an optimization of seasonal inventories it is the aim of modelling to elaborate on the size and change of inventories. Scenarios are given in **Table 10**. A focus is on feed costs and alternatives to meet forage and food demand from natural pastures over the season.

Note, feed costs represent about 47 percent of the cost of livestock production in Zarafshan Valley as calculated from the farm budget data, which was collected through the farm household survey (see above). Hence, this section focuses on investigating the impacts of feed cost changes (for purchasing concentrates) on output, fodder use and livestock prices. Also we looked into changes of the forage inventories hold in different districts during the 12-month season by linking periods. Results should be interpreted as a test for model calibration. We investigated crop price increase combined with a reduction of the animal feeding cost by 10, 30 and 50 percent. For each scenario we made different model runs of which we only present a selection. Similarly, livestock price increases were taken into consideration. Reductions of the animal feeding cost are 10, 30 and 50 percent, respectively.

Table 10: Scenarios Definition

Scenario-name	Definition
1. Crop Price increase + reducing animal feeding cost Scenario	
SC1_10%CRPR	Increase food price & reduce feeding cost 10%
SC2_30%CRPR	Increase food price & reduce feeding cost 30%
SC3_50%CRPR	Increase food price & reduce feeding cost 50%
2. Livestock Price increase + reducing animal feeding cost Scenario	
SC1_LIV10%	Increase livestock selling price 10%
SC2_LIV30%	Increase livestock selling price 30%
SC3_LIV50%	Increase livestock selling price 50
3. Joint price scenario	
SC4_50%	Increase food price & reduce feeding cost 50% + increase livestock selling price 50%

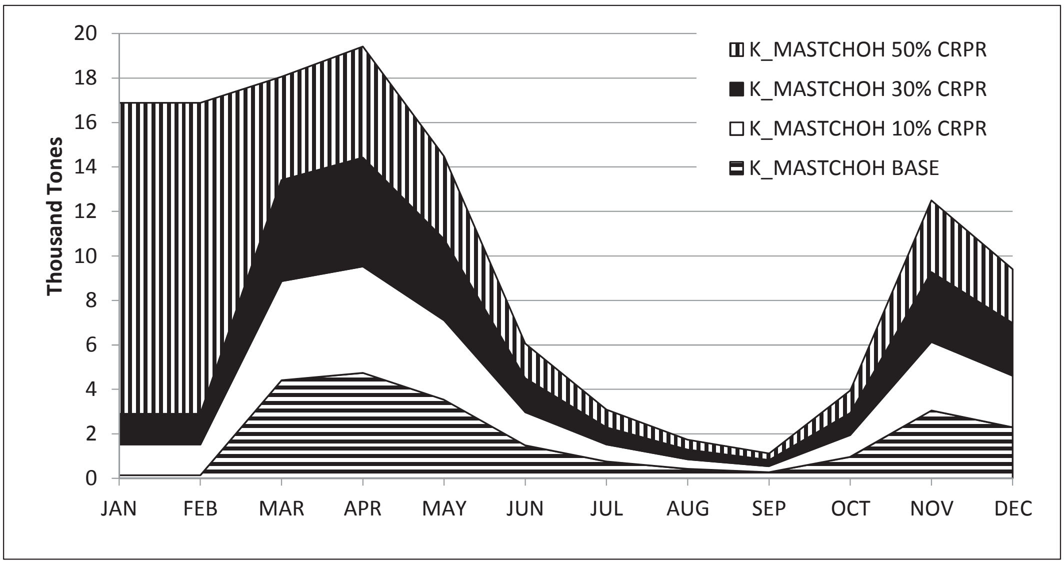
In the different scenarios, simulated, we see them as the trigger to the system evolution. Finally, the impact of combined crop and livestock price increases with animal feeding cost decrease were simulated to find out whether this has an impact on food demand which is the livelihood indicator. Scenarios are mutually exclusive (Table 10, see scenarios).

Finally note, all scenarios are based on a computer model which has been programmed with GAMS. GAMS enables us numerical solutions for dynamic programming using a recursive optimization, here for a season of building up inventories and release of stock in offseason. By different procurement of feed livestock has a different impact on grass growth which was taken into consideration. Inventories are reckoned hay procured in summer, fodder crops and crop residues.

5.2 Forage management analysis

One of the first steps in developing or updating a rangeland management plan is to find out the optimal dynamics for an inventory of the resource. Here we investigated forage production and stockpiling in the growing season as well as stock release in the offseason (USDA, 2005). As illustrated by **Figure 1** the mismatch between pasture feed production and animal feed requirements by months is a crucial point. As can be shown the winter feeding is a bottleneck and it is still the major limiting factor on livestock development in Tajikistan. Due to the deficit in the fodder supply during winter time (December – April), livestock grazing is pertinent in valleys and destroying the vegetation. For a scenario on options a forage inventory is calculated as subtraction of feed from monthly animal feeding requirements and added surplus to the already existing inventor from the past month. This is balanced with total available forage amounts of the next period.

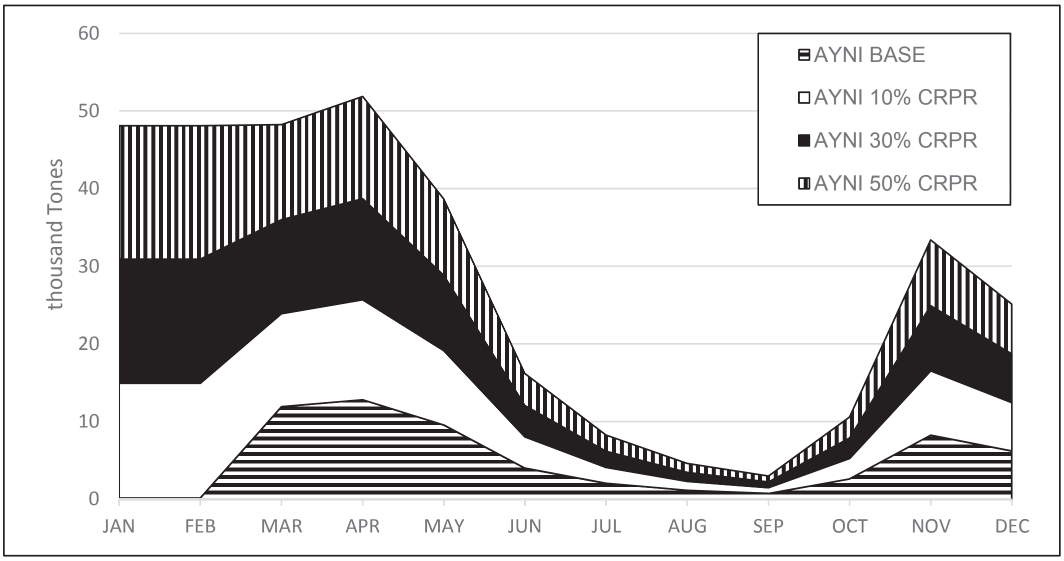
Figure 7: Modelling results for inventories of forage over season in Kuhistoni Mastchoh district of Zarafshan Valley (as compared to a base)



Source: Results from model based on data from the survey, 2010/11

Figure 7 demonstrates how the inventories are filled up and how they should be released in different scenarios. High stocks in early spring indicate that winter fodder should be used to feed animals instead of new grass. Reduced grassing serves to protect the pastures from overuse and degradation. The result is driven by feed and crop prices. The scenario in **Figure 7** demonstrates a situation, which expects to secure forage inventory more than usual during the winter season (January to February). In case of the Kuhistoni Mastchoh districts storage can last until May, and is highest during March to May. From November to December (especially seen from model results for the Ayni district), farmers can already rely on inventories; in other words they should maximize the procurement of winter fodder from natural pastures (hay) and arable land as fodder crops.

Figure 8: Inventory with a moderate increase of fodder costs as well as price for crops (Forage Inventory in Ayni)

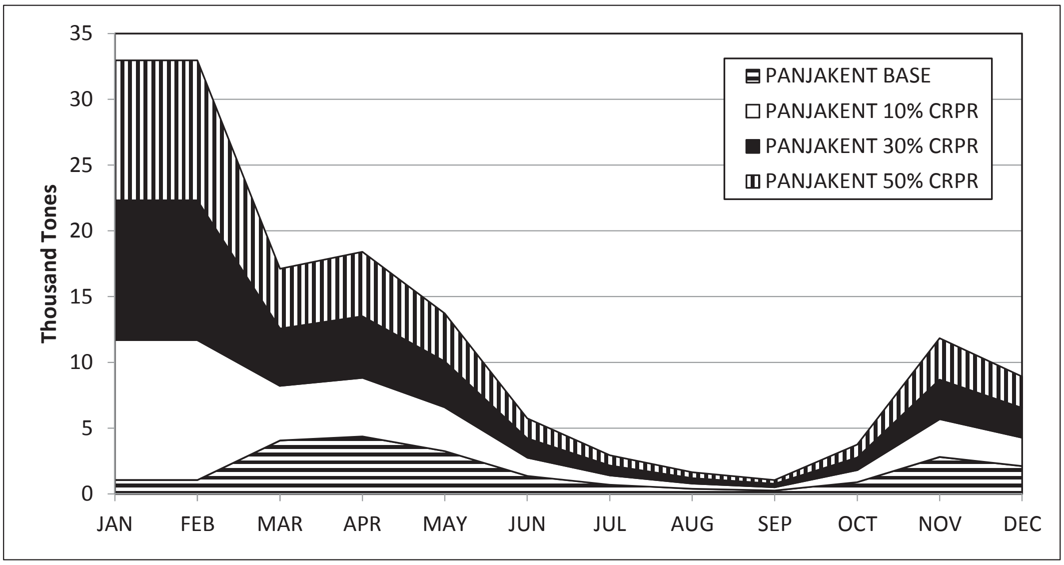


Source: Results from model based on data from the survey, 2010/11

However, the strategy depends on crop prices. Crops are important for food security. As we simulated an increase in crop prices (here the crops for human consumption compete with forage crops like alfalfa), the model results of the impact of crop price increase can be observed in the next Figures (These scenarios were crop price increases which are combined with reduced animal feeding cost scenario). Results which are revealed by **Figure 8**, **Figure 9** and **Figure 10** are that inventories in January become higher. Generally, output price and animal feeding cost simulation show that there is potentiality to manage the critical fodder deficit during winter time in Zarafshan having high inventories on stock in the beginning of the offseason. But, even if prices increase, the impact is still moderate and we see that spring feed demands should be still met by inventories, at least in Ayni. Not reported: in the valley selected districts are buying concentrates. The impact due to price simulation is varying from one district to another. The strongest response to this scenario is given by the model in case of the Ayni district. As forage inventories grow nearly to 20 thousand tones during the period from January to April (compared to base model solution of 10 thousand tones), it can be demonstrated how important haymaking and cropping of legumes (alfalfa) is for high feeding costs scenarios. For early year feeding to maintain livestock inventories are important. These periods have to be considered being the most critical time for livestock feeding.

Then Figure 9 indicates a scenario in which high price in concentrate prices increase inventories only in the most severe periods of food shortages. It demonstrates that inventories (hay, roots crops, etc.) are much earlier released in Panjakent. It implies that animals are to be fed on pastures as early the year as possible which is negative for pasture quality over the rest of the year (late spring and summer). Inventories are used to substitute concentrates because they are expensive.

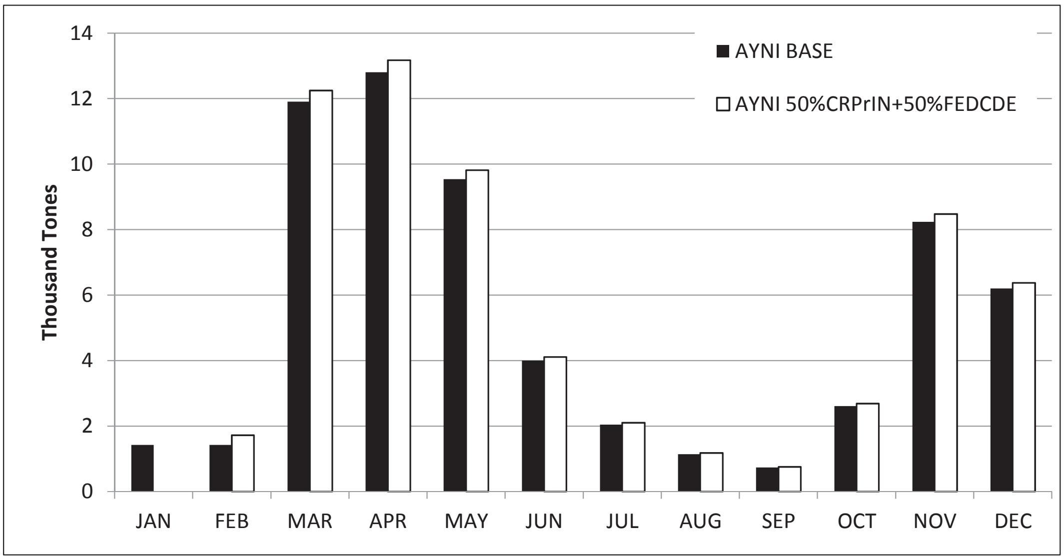
Figure 9: Model results for inventory of forage over season in Panjakent district of Zarafshan Valley (as compared to the base)



Source: Results from model based on data from the survey, 2010/11

To further show the potential of the model we document scenario 4 in which food prices increase and feeding costs from concentrates are reduced. As can be observed from Figure 10 livestock farmers can increase purchase of concentrates and this will release land from fodder crops (alfalfa) for the production of cereals. This scenario demonstrated the situation of Ayni in which it is necessary to buy fodder mainly in March to May to improve pasture quality for the rest of the year.

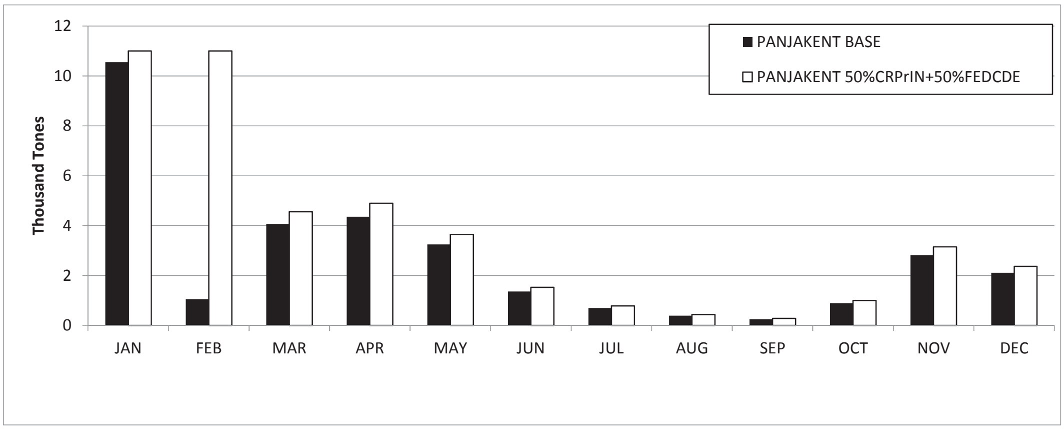
Figure 10: Comparison of inventories by month in the investigated Ayni districts



Source: Results from model based on data from the survey, 2010/11

In Panjakent the situation seems to be different as can be observed in Figure 11. Here inventories are already low in spring and this means pressure on natural pastures. However inventories slightly increase if the price for food increases.

Figure 11: Inventory over season in Panjakent in price scenario 4 (joint of all prices and costs)



Source: Results from model based on data from the survey, 2010/11

The figure 11 presents the impact of the joint price policy scenario (SC4_50%) and livestock price increase combined with reducing animal feeding cost Scenarios (SC1_LIV10%, SC2_LIV30% and SC3_LIV50%). In general, an increase in crop price is associated with an increase of livestock price and this increases animal feeding.

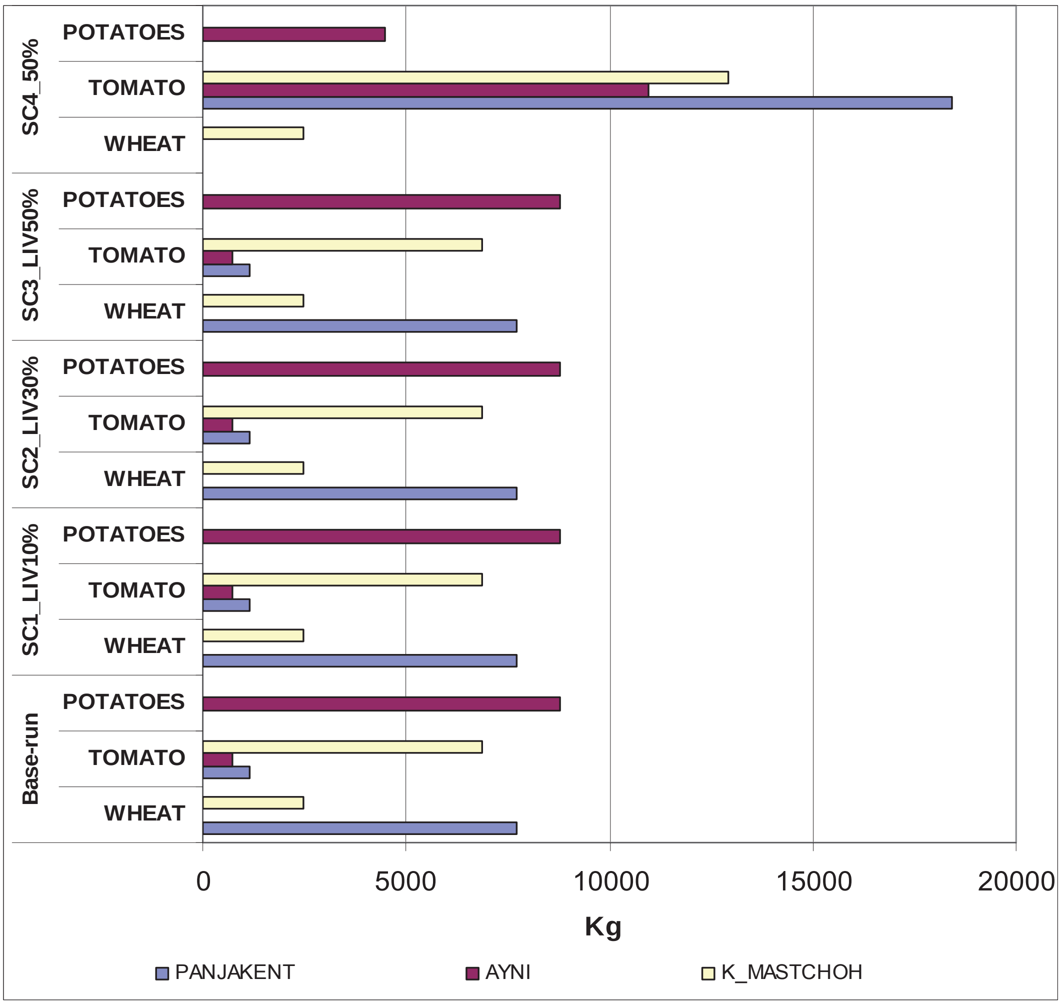
5.3 Impact on food demand

Finally Figure 12 gives an idea on how modelling can be used to detect the food production situation as linked to forage production. It shows that potato production is most important and there will be no land conversion for fodder crops because farmers must secure their livelihood.

The three farm households show no response to increasing livestock price (SC1_LIV10%, SC2_LIV30% and SC3_LIV50%). Whereas, the joint scenario (SC4_50%) has strong impact on tomato demand, as a response to income of the farm households in the three districts. This is attributed to the fact that, tomato is a commercial product which is delivering nutrients based on income, and with increasing crop and livestock prices the farm household's income is enhanced, which enable farmers to increase the demand of tomato.

Costs lead to an increase of the consumption of food items for the household in three districts.

Figure 12: Food demand change dependent on price simulation scenarios in districts



Source: Results from model based on data from the survey, 2010/11

6 SUMMARY AND CONCLUSION

Pastures of Tajikistan, including those of the Zarafshan valley, have gone through many changes during the last century. Especially in Soviet times, fodder was delivered from outside and in terms of property rights the local farmers had access to supplementary feeding. This has changed dramatically with the consequence that pastures are overused and have become degraded. Government policies were the major reasons for changes. After the collapse of Soviet Union the new government faced an impasse to change nomadism to sedentarization, which means the traditional system has been gradually eroded. It contained transhumance at local and regional scale as well as looked for procurement of winter fodder which is today hampered by food security concerns for arable crops instead of fodder crops. Inaccuracy of land reform and absence of laws for pasture management are among the key causes destroying traditional system. Farmers have to be newly informed about the advantages of inventories of hay, fodder crops and crop residues.

To overcome the problem of pasture degradation, there is an urgent need to crystallize the government's role in managing pasturelands and show how the government can play an effective role in achieving a sustainable management plan (Abolhassani, 2011:29). However, the government needs knowledge on and problem statements of options for better management as well as solutions which can be done by surveying the situation and offering options. We modelled scenarios for options based on a new concept how to improve the system by forage production. In the case of the Tajik pasturelands, the role of the government has usually been inappropriate and it is due to the Tajik policy to manage the resource "pasture" more rationally. In the traditional system of pastoralism however, overgrazing was controlled at seasonal level by transhumance and production of hay and fodder crops from arable land such as alfalfa and other local legumes. For finding an answer to the question on how the government can play an effective role in the transition, we showed how concentrate pricing impacts on the system. This requires more studies and research on the relationship between the government and communities in the present day (ibid) in terms of support. The paper made an attempt to inform on gains from improving inventories over the season and promote the production of fodder crops to reduce pressure on pastures by modelling.

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8 ANNEXES

Appendix 1: Names and levels of administration in Tajikistan

- *Hukumat*: Executive power of the country as well as governing authority of cities, *viloyats* (provinces) and *nohiyas* (districts). The heads of cities, provinces and districts state administration (*hukumat*) simultaneously wield executive authority and act as local council chairmen. Nevertheless, these heads are appointed and dismissed by the president;
- *Jamoat*: An institution of self-government in towns and villages. Jamoats (neighbourhood self-governing groups) are former village soviets. Districts subdivided by into jamoats and at the same time, jamoats comprise of *qiahlogs* (villages). Decisions are adopted by open voting in the jamoats. Chairmen of the jamoats are appointed by head of the city or district state administration;
- *Qishloq or Deh (ot*): rural settelements, which are the lowest tier of local government.
- *Mahalla*: Traditional social structure unit i.e. local community within villages level.

Appendix 2: Location of the survey

District	Jamoat	Villages	No of interviewed households
Panjakent	Chinor	Chinor, Toshminor, Yaloqjar	15
	Rudaki	Artuch, Panjrud, Yakkakhona	15
	Voru	Ghaznich, Ghuytan, Voru	15
Ayni	Anzob	Margheb, Pete, Pskon	15
	Fondaryo	Pishanza, Remon, Saratogh	15
Kuhistoni Mastchoh	Ivan-Tojik	Ghuzn, Khudgifioftob, Munjif	15
3	6	18	90

ABOUT THE CONTRIBUTORS

Aslanov, Ilhom: PhD candidate at the Faculty of Geography at Marburg University (Germany); junior researcher in the LUCA project

Avazov, Shakhzod: PhD candidate at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management at Giessen University (Germany); junior researcher in the LUCA project

Duishonakunov, Murataly: PhD candidate at the Faculty of Geography at Giessen University (Germany) (successful PhD defence in June 2014); junior researcher in the LUCA project

Dukhovny, Viktor A., Dr.: Professor, Director of the Scientific-Information Centre of the Interstate Coordination Water Commission (SIC ICWC), Tashkent (Uzbekistan); main investigator and PhD supervisor in the LUCA project

Echtler, Helmut, Dr.: Professor apl. at the Helmholtz-Centre Potsdam GFZ, German Research Centre for Geosciences, Department of Remote Sensing

Frede, Hans-Georg, Dr.: Professor ret. (Resource Management) at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, and former Director at the Center for International Development and Environmental Research (ZEU) at Giessen University (Germany); main investigator and PhD supervisor in the LUCA project

Gibreel, Tarig M., Dr.: Post-doc researcher at the Chair of Project and Regional Planning (Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management) at Giessen University (Germany)

Gojenko, Boris: PhD candidate at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management at Giessen University (Germany); (successful PhD defence in July 2014); junior researcher in the LUCA project; junior researcher at the Scientific-Information Centre of the Interstate Coordination Water Commission (SIC ICWC), Tashkent (Uzbekistan)

Groll, Michael, Dr.: Post-doc researcher (Soil and Hydro-Geography) at the Faculty of Geography at Marburg University (Germany)

Herrmann. Roland, Dr.: Professor (Agricultural and Food Market Analysis) at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, and Director at the Center for International Development and Environmental Research (ZEU) at Giessen University (Germany); main investigator and PhD supervisor in the LUCA project

Kenjabaev, Shavkat M.: PhD candidate at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management at Giessen University (Germany); (successful PhD defence in June 2014); junior researcher in the LUCA project; junior researcher at the Scientific Research Institute of Irrigation and Water Problems (SRIIWP), Tashkent (Uzbekistan)

Khakimov, Parviz: PhD candidate at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management at Giessen University (Germany); (successful PhD defence in July 2014); junior researcher in the LUCA project

King, Lorenz, Dr.: Professor ret. (Climate and Hydro-Geography) at the Faculty of Geography, and former Director at the Center for International Development and Environmental Research (ZEU) at Giessen University (Germany); main investigator and PhD supervisor in the LUCA project

Leonhäuser, Ingrid-Ute, Dr.: Professor ret. (Nutrition Education and Consumer Behaviour) at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, and former Director at the Center for International Development and Environmental Research (ZEU) at Giessen University (Germany); main investigator and PhD supervisor in the LUCA project

Lotz, Thomas: Scientific assistant at Laboratory for Climatology and Remote Sensing (LCRS) and PhD candidate at the Faculty of Geography at Marburg University (Germany)

Marauhn, Thilo, Dr.: Professor (Public International Law) at the Faculty of Law, and Director of the Center for International Development and Environmental Research (ZEU) at Giessen University (Germany); main investigator and PhD supervisor in the LUCA project

Moldobekov, Bolot, Dr.: Co-Director of the Central Asian Institute for Applied Geosciences (CAIAG), Bishkek (Kyrgyzstan)

Möser, Anke, Dr.: ConsumerTrail, Gemünden/Felda (Germany) and Associate Professor at the Institute for Agricultural Policy and Market Research at Giessen University (Germany)

Ni, Vadim: Legal advisor at Almaty Management University (former International Academy of Business); Chairman of Ecoforum of NGOs of Kazakhstan; main investigator and PhD supervisor in the LUCA project

Nuppenau, Ernst-August, Dr.: Professor (Agricultural and Environmental Policy) at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management at Giessen University

Opp, Christian, Dr.: Professor (Soil and Hydro-Geography) at the Faculty of Geography at Marburg University (Germany); main investigator and PhD supervisor in the LUCA project

Pawlowski, Ira, Dr.: Post-doc researcher at the Center for International Development and Environmental Research (ZEU) and at the Chair of Agricultural and Development Policy (Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management) both at Giessen University (Germany); main coordinator of the LUCA project (2010-2014)

Roessner, Sigrid, Dr.: Research fellow at the Helmholtz-Centre Potsdam GFZ, German Research Centre for Geosciences, Department of Remote Sensing; main investigator and PhD supervisor in the LUCA project

Sabitova, Saltanat: PhD candidate at the Faculty of Law at Giessen University (Germany); junior researcher in the LUCA project

Schmitz, P. Michael, Dr.: Professor (Agricultural and Development Policy) at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, and Director at the Center for International Development and Environmental Research (ZEU) at Giessen University (Germany); main investigator and PhD supervisor in the LUCA project

Sudhaus, Henriette, Dr.: Research Fellow at the Institute of Earth and Environmental Science at Potsdam University (Germany)

Teshebaeva, Kanayim: PhD candidate at the Institute of Earth and Environmental Science at Potsdam University (Germany); Research fellow at the Helmholtz-Centre Potsdam GFZ, German Research Centre for Geosciences, Department of Remote Sensing; Research fellow at the Central Asian Institute for Applied Geosciences (CAIAG), Bishkek (Kyrgyzstan); junior researcher in the LUCA project

Umarov, Khojamahmad, Dr.: Professor at the Institute of Economy and Demography, Department of Agroindustry, Dushanbe (Tajikistan); Member of the Academy of Sciences of the Republic of Tajikistan; main investigator and PhD supervisor in the LUCA project

Vereshagina, Nataliya, Dr.: Senior researcher at the Department of Environmental Pollution Investigation and Forecasts at the Hydrometeorological Research Institute (NIGMI), Tashkent (Uzbekistan)

Wetzel, Hans-Ulrich, Dr.: Research Fellow at the Helmholtz-Centre Potsdam GFZ, German Research Centre for Geosciences, Department of Remote Sensing

Zhunusova, Eliza: PhD candidate at the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management at Giessen University (Germany); junior researcher in the LUCA project

Zubovich, Alexander: Research fellow at the Central Asian Institute for Applied Geosciences (CAIAG), Bishkek (Kyrgyzstan); main investigator and PhD supervisor in the LUCA project