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Novel Measurement and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia

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Preface

Origin of the Book

In 2009, during the 18th International Soil Tillage Research Organization (ISTRO) conference in Izmir, Mekhlis Suleimenov from Kazakhstan and Lothar Mueller from Germany came into contact and had their first few talks about soil and water conservation and the situation of agriculture in their countries. They found some common areas of interest, and it seemed to be worthwhile and challenging to explore opportunities for a more intensive exchange of ideas. Abdulla Saparov, Director of the Uspanov Institute for Soil Science in Almaty, and Gunnar Lischeid, Head of the Institute of Landscape Hydrology at the Leibniz Centre for Agricultural Landscape Research in Muencheberg, were very responsive to the suggestion of starting to cooperate and encouraged, inspired and headed this project. A research funding initiative by the German Federal Ministry of Education and Research (BMBF) provided the framework, and our submission was confirmed. In September 2010, the project KAZ 10/001 "Novel Measurement and Assessment Tools for the Monitoring and Management of Water and Soil Resources in Agricultural Landscapes of Central Asia" got started. The International Bureau of the BMBF escorted and administered the project. Over a period of two years, funding has been provided to support short visits by experts, exchanges by young scientists, a workshop in Almaty and the publication of this book. The duration of the project was not enough for extended joint experiments but was sufficient to gain an impression and basic understanding of the status and achievements of research, and of the great potential benefits that longer lasting cooperation would have.

Purpose of the Book

This book is intended to be a source of information for all those dealing with its subject: methods for the characterisation and wise utilisation of water and land resources in Central Asia. There are indications that existing methodologies do not

meet international standards and current resource use is not sustainable. The book is to help improve this situation and initiate sustainable developments in Central Asia.

We advocate the role of science and technology in improving our understanding of ecosystem processes and creating monitoring and controlling mechanisms. Reliable data based on advanced, internationally proven and acknowledged methods are required. This implies the exchange of knowledge and the transfer and joint advancement of methods in the scientific community.

The main intended innovation of the book is its focus on methodologies, not on results and facts. Scientific tools will be proposed for measuring, evaluating, modelling and controlling processes in agricultural landscapes. Their application will create a knowledge shift and synergetic effects leading to practical results and conclusions. The book shall act both as a milestone by offering novel tools and ideas, and as a cornerstone by creating lasting research cooperation between scientists and institutes of Eurasia.

Our addressees are people dealing with the development and conservation of land and water in a vast region, where these valuable resources have often been handled wastefully in the recent past. The book mainly addresses scientists, planners, teachers, students and decision makers. It is intended to be a source of information and inspiration for all readers who feel responsible for initiating the sustainable use of resources in Central Asia. This shall help to prepare a secure and better future for the young generation growing up, by preserving the capacities of terrestrial and aquatic ecosystems.

Content and Structure of the Book

The book offers a broad array of methods to measure, assess, forecast, utilise and control land and water resources: laboratory and field measurement methods, methods of resource evaluation, functional mapping and risk assessment and remote sensing methods for monitoring and modelling large areas. It contains methods for data analysis and ecosystem modelling, methods for the bioremediation of soil and water and the field monitoring of soils and methods and technologies for optimising land use systems.

The book has 43 individual chapters in three sections and eight thematic clusters. In order to focus on the scientific value of individual chapters and the expertise of their authors, the editors have decided to keep the structure on a flat level of hierarchy and to allocate the chapters to three parts only. Part I, *Environmental and Societal Framework for the Monitoring and Management of Land and Water Resources*, shall provide an overview of issues related to land and water in Central Asia and prepare the reader for an understanding of the methodological chapters presented in the subsequent two sections. Part I contains 6 chapters analysing the current status and trends. Part II, entitled *Novel Methodologies for the Measurement of Processes and Assessment of Resources* and

Part III, *Applications and Case Studies*, shall provide information about novel methods and give examples of their practical use. Methods that are not yet well known in Central Asia but may have a particular novelty and potential importance are presented in Part II, whilst other new methods and solutions are given in part III. A fourth section, *Executive Summary and Conclusions*, allocates all individual chapters to thematic clusters, reviews them and makes proposals for how they can be applied.

Authors, Readers and their Responsibilities

The authors are inventors and activists behind novel methods, as well as being innovative and experienced scientists. Most of them come from Kazakhstan, Germany, Uzbekistan and Russia, others from different regions of the globe. Not all the authors took part in the project. Many of them were invited to contribute an article afterwards because of the relevance and novelty of their approaches.

Possible divergences between the findings, conclusions and statements of some individual authors are natural. They do not necessarily need to coincide with the particular opinion of the editors. The authors are free to highlight and point out aspects of their study from their typical, individual perspective. The transliteration of local names for rivers, cities or other geographical items or units may also differ from chapter to chapter. All statistical data given in the various chapters of this book may include slight uncertainties, biases and inconsistencies. The editors have made no attempt to harmonize them because this is natural and reflects the different sources and local and temporal scales of the data.

The editors are hopeful that readers will gain sufficient information and inspiration for their own work from this book. However, it is not a cookbook with clear recipes. Readers will become aware of the inconsistencies and deficiencies of some approaches when it comes to measuring and assessing processes in complex ecosystems. They are encouraged to find their individual optimum when drawing conclusions and acting imaginatively.

In some chapters, trade names are used to provide specific information. Mentioning a trade name does not constitute a guarantee of the product by the authors or editors. Neither does it imply an endorsement by the authors or editors of comparable products that are not named.

One brief remark on the book's language. Our aim of providing standard scientific English throughout the book could not be ensured for some chapters. Some constraints restricted this. Despite those deficits we decided to include these chapters because of their relevance and novelty. Though the English is imperfect, in our opinion the content is a valuable contribution to the book. We believe it is preferential and more useful to reach out to some important potential readers in the region by also providing the titles, summaries, figure captions and table headers in

Painting Teris-Asjibulak

Teris-Asjibulak is a small village and correspondent water reservoir (Терс-Ашибулакское водохранилище) about 50 km SW of Taras, Kazakhstan. It was built mainly for irrigation purposes in 1962. The view is from the outlet of the reservoir in south direction towards the Alatau mountain range in Kyrgyzstan where the water comes from. The painting shows a midsummer scene in a typical medium-term dry period. Water shortage occurs since some years. Dry agricultural lands and semi-aquatic vegetation which grew up in the former aquatic area form red–brown belts. Painter: Ute Moritz, 2012. She dedicated the painting to this book edition. Material is oil on canvas. Original size 70*50 cm.

Russian. This information will be available as extra material. Readers feel free to contact the chapter authors or the editors.

Müncheberg and Almaty, May 2013

Lothar Mueller
Abdulla Saparov
Gunnar Lischeid

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Dipl. Ing. (FH) Ute Moritz dedicated her painting "Teris Asjibulak" to this book edition.

Prof. Dr. Jutta Zeitz (Berlin), Dipl. Ing. Igor Klein (Oberpfaffenhofen), Dr. Rolf Sommer (Nairobi), Dr. Eddy de Pauw (formerly in Aleppo), Dr. Konstantin Pachikin (Almaty), Dr. Azimbay Otarov (Almaty), Prof. Dr. Tobias Meinel (Astana) and Dmitry Chistoprudov (Moscow) provided additional photos and graphics.

The Springer publishing house ensured that the editoral and printing process was smoothly managed and completed.

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Part I
Environmental and Societal Framework for Monitoring and Management of Land and Water Resources

Land and Water Resources of Central Asia, Their Utilisation and Ecological Status

Lothar Mueller, Mekhlis Suleimenov, Akmal Karimov, Manzoor Qadir, Abdulla Saparov, Nurlan Balgabayev, Katharina Helming and Gunnar Lischeid

Abstract Central Asia is the global hotspot of a nexus of resources. Land, water and food are key issues in this nexus. We analysed the status of land and water resources and their potential and limitations for agriculture in the five Central Asian Transition States. Agricultural productivity and its impacts on land and water quality were also studied. The ecological status of open waters and soils as dependent on the kind of water and land use was shown. The main sources were information and data from the scientific literature, recent research reports, the statistical databases of the FAO and UNECE, and the results of our own field

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work. Agriculture is crucial for the economy of all Central Asian countries and responsible for about 90 % of their water use. We found that land and water resources may provide their function of food supply, but the agricultural productivity of grassland and cropland is relatively low. Irrigation agriculture is sometimes inefficient and may cause serious detrimental side effects involving soil and water salinisation. Dryland farming, as currently practiced, includes a high risk of wind and water erosion. Water bodies and aquatic, arable and grassland ecosystems are in a critical state with tendencies to accelerated degradation and landscape desertification. Despite all these limitations, agricultural landscapes in Central Asia have great potential for multi-functional use as a source of income for the rural population, tourism and eco-tourism included. The precondition for this is a peaceful environment in which they can be developed. All major rivers and their reservoirs cross borders and involve potential conflict between upstream and downstream riparians. The nexus of resources requires more detailed research, both in the extent of individual elements and processes, and their interactions and cycles. Processes in nature and societies are autocorrelated and intercorrelated, but external disturbances or inputs may also trigger future developments. We emphasise the role of knowledge and technology transfer in recognising and controlling processes. There has been a lot of progress in science and technology over the past ten years, but agri-environmental research and education in Central Asia are still in a crisis. Overcoming this crisis and applying advanced methods in science and technology are key issues for further development. Science and technology may provide an overall knowledge shift when it comes to recognising processes and initiating sustainable development. The following chapters introduce the results of further, more detailed and regional analyses of the status of soil and water. Novel measurement and assessment tools for researching into, monitoring and managing land and water resources will be presented. We will inform future elites, scientists and decision makers on how to deal with them and encourage them to take action.

Keywords Central Asia · Soil · Water · Sustainable development

1 Introduction

The 21st century is characterised by accelerating demands for most natural resource commodities. Natural resource governance faces increasing complexity, especially when the linkages and interdependencies between different resources are considered (Andrews-Speed et al. 2012). This has implications for all global regions including Central Asia. Public documents have stated that there is a "Water and Energy Nexus in Central Asia" (World Bank 2004). Based on the situation that all available water resources in the region are trans-boundary, the key questions in the region are "Who has the right to consume all the water?" and

"Water for food or water for energy?". However, this is only part of the problem; the situation is much more complex. Central Asia is the global hotspot of a struggle for all main resources: food, land, water, energy and minerals. These resource categories are closely interrelated in different spatial and temporal scales and dimensions of cognition. Typical segments and key questions differ.

What is Central Asia? The region of Central Asia can be characterised and defined by terms from different scientific disciplines and perspectives. As a geographic category, it is the centre of the Eurasian continent, consisting of striking landscapes such as the high mountains of Tien Shan and Pamir, deserts such as Kara Kum, Kyzyl Kum, or Taklamakan, the second largest desert of the world, large steppe lowlands (Fig. 1), great internal basins, water bodies such as the Aral Sea, Issyk Kul and Lake Balkhash, the Silk Road, the most famous trade route of the world, and more. As a socio-economic or political category, it includes a number of countries in whole or in part. The term "Central Asia" is frequently used for the territory of five land-locked Transition States of the former USSR: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. This coincides with the FAO's area classification (FAO 2012b).

When dealing with topics related to natural resources such as land and water, their implications for human society, and scientific/technological approaches to resolving problems, a mixed consideration of both natural/geographical and political/territorial aspects can be useful. Here, we refer primarily to the territory of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan (calling them Central Asia) with some focus on Kazakhstan. The latter country is much larger than the others, contains very diverse landscapes and, in some geographical and agricultural regions, faces typical problems of land and water monitoring and management. Most of these issues are typical for the other countries, too. They may be also true for a much larger area, based on a broader definition of Central Asia. The regions of Siberia, Mongolia, North-Western China and of other neighbour regions surrounding the territory of the five Post-Soviet Transition

Fig. 1 Grazing sheep on semi-natural pastures in the vicinity of Almaty, Alatau mountains in the background. Photo: Courtesy of Volker Hennings

States face similar problems with natural resources and their management. We believe that Kazakhstan holds as a typical example for most scientific problems related to land and water with implications for agriculture and the environment.

In this book, we focus on novel scientific methodologies for measuring and assessing some crucial properties of land and water resources. This is intended to help monitor and manage processes in agricultural landscapes of Central Asia better. A sustainable use of the resources of land and water must be initiated. First, an analysis is required of the extent and current status of the resources of land and water and of some development trends. This will take place in this and some following chapters.

This chapter will provide an overview of quantities, qualities and productivity of land and water, and agriculture based on them in Central Asia. We have analysed available sources on the status of water and land, trends in their use and developments. The information and data came from the scientific literature, recent research reports, statistical databases and commission reports of United Nations Organizations such as the FAO and UNECE, international research and development projects, and the results of our own field work.

2 Key Elements of a Nexus of Resources: Food Security and Water Consumption

2.1 Food Security

Within a resource nexus, food is a special and fundamental category. Having enough food is a basic human right, and food security is crucial for the stabilization and survival of civilisations. The FAO's definition states, "Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that needs their dietary needs and food preferences for an active and healthy life" (FAO 2002).

Other resources such as land, water, energy and minerals directly or indirectly impact on food security (Fig. 2).

The availability and good condition of land and water are natural preconditions for agriculture, the main basis of food production. The situation of human society and governance regarding the utilisation of all resources determines the framework for agricultural production and food security. Some basic data on the five Central Asian countries are given in Table 1.

Kazakhstan has extensive land and water resources and its national economy is in an acceptable condition, mainly due to oil, gas and mineral resources. The country is sparsely populated. In terms of its gross domestic product (GDP) and the human development index (HDI) it ranks above the world average. Related to the land area, water resources are relatively low and unequally distributed. The dependency ratio of 40.1 means that about forty percent of total available water

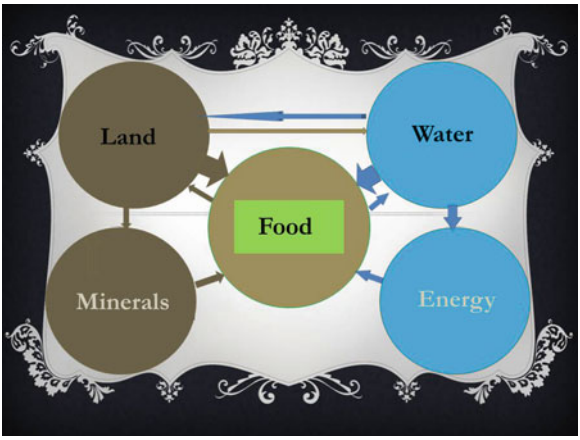

Fig. 2 The resource nexus on the carpet of prosperity and welfare for the countries of Central Asia (simplified, with emphasis on land, water and food)

Table 1 Basic data on land, water and economy in the five Central Asian states

Country	Total land, (M ha)[1]	Water resources (TRWR, km^3/year) and dependency ratio[2]	Population in millions[1]	Economy, GDP $ per capita (rank)[3]	HDI, value (rank)[4]
Kazakhstan	272.490	107.50 (40.1)	16.207	13,000 (95)	0.74 (68)
Kyrgyzstan	19.995	23.62 (1.1)	5.393	2,400 (183)	0.61 (126)
Tajikistan	14.255	21.91 (17.3)	6.977	2,100 (189)	0.60 (127)
Turkmenistan	48.810	24.77 (97.0)	5.105	7,800 (128)	0.67 (102)
Uzbekistan	44.740	48.87 (80.1)	27.760	3,300 (168)	0.62 (115)

[1] Data from FAOSTAT (FAO 2012b), M ha = million hectares, 1ha = 0.01 square kilometres
[2] Data from FAOSTAT (FAO 2012b), *TRWC* Total Renewable Water Resource, dependency ratio = percent of external water resources to TRWC
[3] Data from the CIA World Factbook 2011 (CIA 2011), *GDP* Gross Domestic Product, the rank in parentheses refers to the countries of the world
[4] Data from the Human Development Report (UNDP 2011), *HDI* Human Development Index, mainly based on indexes of income, health and education

resources come from neighbouring countries, in this case mainly from Kyrgyzstan and China.

Kyrgyzstan and Tajikistan are relatively small countries characterised by a poorly developed economy. They have an extremely low GDP and rank well below the world average in terms both of GDP and of HDI. Related to their land area, they have extensive water resources and are largely independent of other countries. Their potential for hydropower is very good.

Turkmenistan and Uzbekistan are extremely dependent on water resources coming from other countries, mainly from Kyrgyzstan and Tajikistan. Though they have some fossil fuel resources, their economy is still weakly developed. Uzbekistan is the most densely populated country in the region. In some oases, the population density is particular high.

The different overall economic situation in these countries is underpinned by their trade balance. In 2011, Kazakhstan, Turkmenistan and Uzbekistan had a positive overall trade balance (merchandize exports higher than imports), whilst the balance of Kyrgyzstan and Tajikistan was negative (WTO 2012). The combination of a low gross domestic product with a negative trade balance is a burden for the development of a prospering economy taking ecology into consideration. These different figures may have implications for the status and utilisation of water and land resources in the various countries.

Overall, the territory of the five Central Asian Transition States Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan covers about 399 million hectares (M ha). This is almost in the order of the geographic magnitude of the European Union (EU), whilst the population is only about 12 % of that in the EU.

Regional food security is a key issue for human development and social and political stability everywhere. It cannot yet be considered to be ensured in Central Asia. Over the past twenty years, all five countries witnessed an initial decline in agricultural productivity, and currently they have an increase in productivity. The situation is not stable, and there are big differences between countries (Swinnen and Vranken 2010). Food quality is another issue related to food security. Awareness of good food quality has to be based on reliable procedures and data regarding monitoring and control (Tultabaieva 2012).

Sustainable food security in the region does not only depend on food production: there are other, decisive factors influencing the long-term balance between food demand and food availability (Dukhovny and Stulina 2011). Factors controlling food demand include demographic structure, population growth, preferred kinds of food and consumer incomes. Some main factors in food availability are the status of natural resources such as land and water, and policies promoting their utilisation through initiatives, skills and investment.

Currently, there are gaps between the production and consumption of some kinds of basic food products. For grain products, Tajikistan shows a clear gap, whilst Kazakhstan has an over-production. Oils are in deficit in all five countries. In case of vegetables, production and demand coincide. With meat, Tajikistan and Kazakhstan indicate deficits (Fig. 3).

Overall, Tajikistan shows deficits in food security from these data (Dukhovny and Stulina 2011). The factors affecting this are the population's insufficient purchasing power, limited production and very high population growth rates. Food prices increased due to inflation by 10–120 % for many agricultural products in 2010. A law "On Food Security" of 29 Dec. 2010 was one measure used to improve the situation (Bobodzhanova 2012). In Kyrgyzstan, too, the situation has worsened over the past 25 years. In the 1980s the country was self-sufficient and exported food. Now, food security issues are based on the 2008 law "About food safety in the Kyrgyz Republic" (Mansurova 2012). More than half of food commodities need to be imported, amongst them basic products such as bakery products, meat, sugar and oils. In 2009, about one third of the population, the vast majority of them in rural areas, lived below the poverty line (Kulmyrzaev 2012).

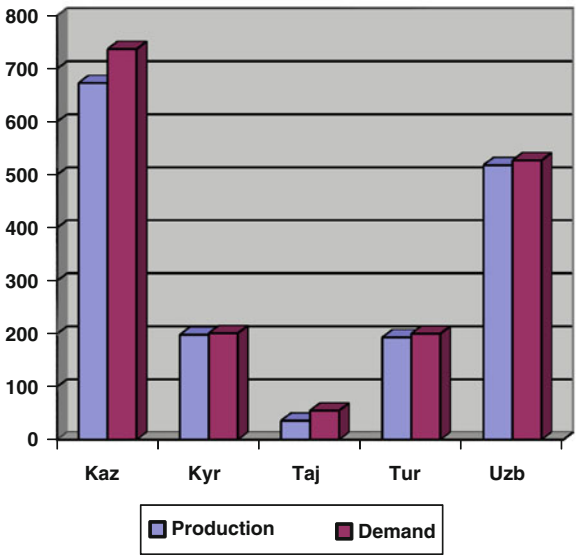

Fig. 3 Production and demand of meat (in millions of tonnes), data from Dukhovny and Stulina 2011

Uzbekistan is self-sufficient but supplying food for the balanced, safe nutrition of a growing population remains a challenge (Payziyeva and Paiziev 2012).

The land-locked situation of Central Asia should be a reason to promote regional markets and to reduce imbalances between production and consumption by prosperous trade between countries, embedded in a tension-free and friendly societal and political environment.

Agriculture is a pillar of the economy of all Central Asian countries. For example, in 1999, agriculture made up 11 % of the gross domestic product (GDP) in Kazakhstan, 19 % in Tajikistan, 27 % in Turkmenistan, 33 % in Uzbekistan, and 38 % in Kyrgyzstan (World Bank 2004). More recent figures from 2008 (Kienzler 2009) are 5, 26, 20, 22 and 19 %, showing a downwards trend due to increases in other economic branches such as the energy and mining industries. In Uzbekistan, agriculture is the largest sector of the economy, providing about 25 % of exports and 31 % of employment (Turayeva 2012). Of the Central Asian countries, Uzbekistan has the highest rural population. However, for the economy and to supply food to the population of all five countries in the region, agriculture remains crucial. Agriculture in a dryland region necessarily means irrigated agriculture. Even in Kazakhstan, where only 5–6 % of cropland is irrigated, about one third of the total food production comes from that land (Ismukhanov and Mukhamedzhanov 2003).

FAO statistics (FAO 2012b) show that in 2010 the top five agricultural products by country were:

Kazakhstan: (1) Cow milk, (2) Cattle meat, (3) Wheat, (4) Sheep meat, (5) Potatoes

Kyrgyzstan: (1) Cow milk, (2) Cattle meat, (3) Potatoes, (4) Sheep meat, (5) Tomatoes
Tajikistan: (1) Cotton lint, (2) Tomatoes, (3) Sheep meat, (4) Potatoes, (5) Cow milk
Turkmenistan: (1) Cotton lint, (2) Cattle meat, (3) Sheep meat, (4) Cow milk, (5) Wheat
Uzbekistan: (1) Cattle meat, (2) Cotton lint, (3) Cow milk, (4) Tomatoes, (5) Wheat

Meat and milk from ruminants play a crucial role as food for the population of Central Asia. Figure 4 shows the situation of milk production. The year 1992 represents the start of the transition period, when old structures in agriculture were largely still intact. The year 2000 is typical for the end of the transition period, when the overall production was very low, and the data for 2010 are the most recent available. It can be seen that all countries were keen to increase the per-capita production of milk. This has been successfully achieved in all countries. The data are probably not very reliable, for Tajikistan in particular. Many poor people breed goats for their subsistence, and those data are obviously not available. However, increasing per-capita production despite a fast-growing population indicates increasing pressure on grasslands. Sustainable grassland management is a precondition for securing these traditional commodities on available lands.

For Kazakhstan, Turkmenistan and Uzbekistan, wheat also belongs to the group of the top five agricultural products. Wheat production in Kazakhstan is shown in Fig. 5. The situation has stabilised in comparison with that in the 1990s but prevailing rainfed cropping wheat production still remains largely weather-dependent.

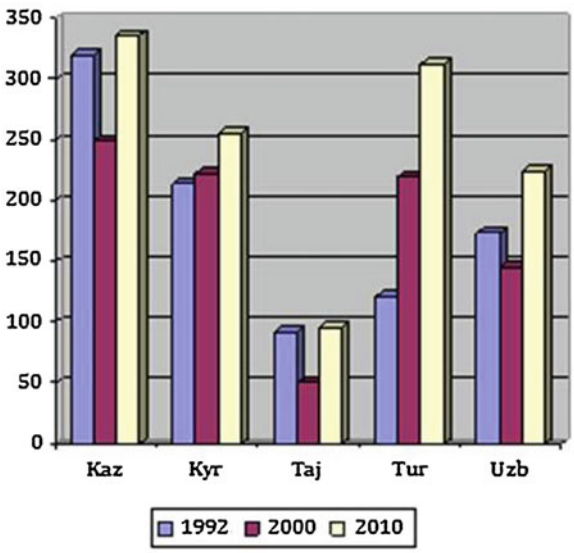

Fig. 4 Production of milk in kg per capita in typical years of three different periods, data from FAOSTAT database (FAO 2012b)