Establishment and maintenance of regulating ecosystem services in a dryland area of Central Asia: The Kökyar Protection Forest, Aksu, NW China, as an example

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Abstract

The city of Aksu, situated at the northern fringe of the Taklimakan Desert in northwest China, is exposed to periodic severe dust and sand storms. In 1986, local authorities decided to establish a peri-urban shelterbelt plantation, the so-called Kökyar Protection Forest, with the aim to reduce dust and sand storm impacts on Aksu City by the regulating ecosystem services provided by the plantation. It was realised as a patchwork of poplar shelterbelts and orchards. The total area of the plantation reached 3800 ha in 2005. The Kökyar Protection Forest is exemplarily analysed to answer the following question: Under which institutional frameworks and to which financial conditions can peri-urban shelterbelts be established and maintained? The endeavour of planting the shelterbelt was made possible by the annual mass mobilisation of Aksu citizens, based on the Chinese regulation of the "National Compulsory Afforestation Campaigns". Establishment costs amounted to ca. 60 000 CNY ha^{-1} (ca. 10 000 USD ha^{-1}). Permanent maintenance of the plantation is facilitated by leasing orchard plots to private fruit farmers. From the perspective of the local economy, annual farming net benefits generated by Kökyar fruit farmers more than compensate annual government grants for maintenance, resulting in an overall monetary net benefit of at least 10 500 CNY ha^{-1} (ca. 1600 USD ha^{-1}) on the long-term average. For a more complete understanding of Kökyar Protection Forest, future research should be directed towards quantifying the effect of its regulating ecosystem services, and on investigating the negative downstream consequences of its water consumption.

1. Introduction

1.1 Shelterbelts in China

More than 40% of China's total territory is characterised by arid and semi-arid climates. These drylands are predominantly located in the north and especially in the northwest of the country (Li et al., 2012). Shelterbelts have been seen as an effective instrument to fight negative influences from deserts and semi-deserts ever since the beginning of the People's Republic of China (Chokkalingam et al., 2006). The objectives of shelterbelts usually comprise environmental security (alleviating soil erosion, droughts, dust and sand storms, dry hot winds etc.) and economic development (increasing crop production, stockbreeding production, timber production and other forest products etc.). Structures and species compositions of the plantations alter according to site-specific conditions and purposes (Li et al., 2012, Chokkalingam et al., 2006). The biggest and globally best-known shelterbelt, the so-called Three-North Shelterbelt, is an overarching project that aims at increasing forest cover from 5% to 15% in an area of 4 069 000 km² that stretches over 13 province level administrative units all from the northwest to the northeast. Its establishment began in 1987 and is expected to last until 2050. 244 690 km² have been afforested so far (Li et al., 2012).

A special shelterbelt type has developed in the Tarim Basin in northwest China. The Tarim Basin is framed by the Tian Shan Mountains in the north and the Kunlun and Karakorum Mountains in the south and southwest, the Taklamakan Desert lying in the middle. Continental position, precipitation shadow of the mountain ranges, and intense solar radiation form a hyper-arid climate. Oasis cities are located along the periphery of Taklamakan Desert, wherever rivers, running down from the surrounding mountains, provide sufficient water (cf. Fig. 1). Most of these cities, such as Korla, Bügür, Aksu, Kashgar or Hotan, have experienced a rapid growth over the last decades, in the course of which natural greenbelts formed by native tree and shrub species have been eliminated by urban sprawl and agriculture. In order to protect the citizens from the

influences of the surrounding desert lands, authorities of all these cities try to establish a special type of shelterbelt which could be labeled as peri-urban protection forest: broad greenbelts that optimally should surround the cities from all sides (Halik, 2003). The Kökyar Protection Forest in Aksu was one of the first of these.

1.2 Geographic conditions of Aksu City

Aksu is a city of about 580 000 inhabitants of which 314 500 live in the urban core (Akesu Shi Renmin Zhengfu, 2012). It is the capital of Aksu Prefecture, lying in the west of China's northwestern Xinjiang Uyghur Autonomous Region, close to the border of Kyrgyzstan. At a geographical position of 41°10' north and 80°15' ea st and at an altitude of 1100 m above sea level, it is situated on a long, slightly inclined slope between the Tian Shan Mountains in the north and the Taklimakan Desert in the south (cf. Fig. 1). The slope is traversed from northwest to southeast by the Aksu River, which is fed by snow and glacier melt water as well as rainfall from the nearby Tian Shan Mountains as introduced in Rumbaur et al. (submitted to this issue). The Aksu River formed a flat 10 km wide river valley with a steep cut bank of about 20 m height at its northeastern shore. The core of Aksu City lies exactly under the cut bank within the river valley, while today's suburbs spread deeper into the valley and on the bank.

An annual evaporation rate of 1868 mm and annual precipitation of merely 75 mm indicate an extremely arid climate (Kökyar Annals Compilation Committee, 2006). Due to its location at the Aksu River, Aksu receives sufficient water to ensure agriculture, which places the city in a huge river oasis (ca. 1000 km², including Awat and Onsu County; Halik, 2003). However, the arid environment becomes very tangible whenever the regular hot and dry north winds blow down from the Tian Shan Mountains (Föhn effect). Maximum wind speeds are reached in springtime with 15 m s^{-1} (Yoshino, 1992). Raising dust and sand from the barren areas north of the oasis, the north winds cause an annual average of 11.5 sand storm days (visibility less than 1 km) in Aksu City (Kökyar Annals Compilation Committee, 1996; also cf. chapter 3.2 Site conditions). The severe dust and sand storms of Aksu are blackening the sky, making respiration difficult,

covering everything outside and inside houses with brown dust, inhibiting traffic, and disrupting public life (Aksu Prefectural Forestry Department and Kuqa Television Station, 2006; Aksu Prefectural Greening Committee, 2006; Aksu citizen interviews 2011).

During the 1980s, the dust and sand storms were increasingly perceived as a major problem to the city. There are two probable factors for this change: Firstly, in the previous decades, Aksu City had undergone fast socio-economic changes: The composition of the population shifted from a nearly 100% autochthonous Uyghur society to a majority of foreign Han-Chinese settlers, and the city was transforming from a small rural oasis town into a regional industrial and service centre (Halik, 2003; Intercontinental Pan-Chinese Network Information Co. Ltd., 2008). A different environmental and cultural background of the settlers and shifted ideas of the living standards in cities may have fostered the new problem perception. Secondly, the immigration-based growth and the economic development of oasis cities in the Tarim Basin usually was accompanied by degradation of the natural vegetation at the fringes of the oases, thus compromising their regulating ecosystem services and contributing to a factual aggravation of dust and sand problems (Halik, 2003). However, there is no literature on the specific situation around Aksu City.

1.3 The Kökyar Protection Forest

As a response to the dust problems, in the 1980s the local authorities decided to lay out a peri-urban shelterbelt plantation, called Kökyar Protection Forest. Work began in 1986 and was completed in 1990, the plantation then covering an area of 1308 ha (Kökyar Annals Compilation Committee, 1996). From 1990 onward, the project was enlarged by three more project periods, each of which converted more patches of desert land into forest plantations (cf. Fig. 2). The four project periods and their corresponding areas were then chronologically labeled from Kökyar I to IV, while the complete title, Kökyar Protection Forest, usually refers to the sum of the four project areas. According to local authorities, the total area covered 3842 ha by 2005 (Kökyar Annals Compilation Committee, 2006; Aksu Prefectural Greening Committee, 2006).

The Kökyar Protection Forest is not unique, but rather forms part of a series of such greening projects in different cities of the Tarim Basin, e.g. in Korla, Kashgar, and Hotan (Halik, 2003). However, among them all, Kökyar is regarded as a kind of lighthouse project, due to its vast dimensions, and because it was realised without the aid of the central government. An accompanying propaganda effort, including the publication of books and documentaries as well as the erection of a large exhibition hall, further boosted its prominence. In 1996, it was included in the "Global 500 Role of Honour for Environmental Achievement" of the United Nations Environmental Programme (Kökyar Annals Compilation Committee, 1996). It is a showcase project in China and could be a model for other drylands. This paper undertakes an exemplary analysis of the Kökyar Protection Forest under the following research question: Under which institutional frameworks and to which financial conditions can peri-urban shelterbelts be established and maintained? This analysis can turn out to be helpful for the planning or running of other similar projects, especially in geographically similar areas.

2. Methods

The data for this paper is drawn from existing literature on the Kökyar Protection Forest, a socio-economic household survey on Kökyar farmers conducted by the authors in 2012, and some additional interviews conducted by the authors in 2011 and 2012.

Literature on Kökyar is scarce and until today available exclusively in Chinese. The main sources of information on the project are: firstly, the "Annals of the Kökyar Greening Project" in two volumes, provided by the Kökyar Annals Compilation Committee, a committee constituted by the project managers; secondly, a picture book called "Green Kökyar" produced by the Aksu Prefectural Greening Committee; and thirdly: a documentary with the title of "The Green Feat: Commemorating 20 Years Construction of Kökyar" by the Aksu Prefectural Forestry Department and the Kuqa Television Station. This paper draws heavily on the "Kökyar Annals", especially for the description of the establishment process of Kökyar, and, to a minor extent, on the other two sources. Since all these sources were written or produced under the aegis of persons and

organisations involved in the establishment process of the Kökyar Protection Forest, there is a certain danger of biases in favour of the project.

The existing sources of information on Kökyar neglect to give any figures for the running costs of the project or the actual economic situation of the farmers within its area. To close this knowledge gap, a socio-economic household survey was conducted in 2012. A raster of 19 evenly distributed sample points was projected on the whole area of Kökyar I, and subsequently the closest available household to each ideal sample point was identified. All the sample households lie within a radius of 200 m from the ideal sample points. The heads of the 19 identified households were interviewed in Chinese (except for one that was interviewed in Uyghur) according to a fixed questionnaire.

For information on the institutional processes and economic conditions of the state-owned organisations running the project, a semi-structured interview with the former head of the Forest Management Station was conducted. Other important information on the general circumstances all around the Kökyar Protection Forest were gathered by interviews with random Aksu citizens, a private farming consultant in Aksu, and a seasonal worker in the plantation. All these interviews were conducted between 2011 and 2012 (cf. Appendix A).

In order to make costs and incomes of Kökyar Protection Forest comparable between all different time periods between 1986 and today, monetary values will be presented adjusted for inflation, in their actual monetary value of the year 2014. The Chinese yuan, abbreviated as CNY, is traded at about 0.16 USD.

The economic situation of the main actors of the Kökyar Protection Forest (i.e. private fruit farmers within the plantation and state-owned managing organisations) is estimated by cash based accounting. The effect of the Kökyar Protection Forest on the local welfare is summarised from the perspective of cost-benefit analysis. Cost-benefit analysis is an assessment method that “quantifies in monetary terms the value of all consequences of a policy to all members of society” (Boardman et al., 2011). In contrast to normal accounting practices applied by profit-

oriented corporations to identify the most profitable investment opportunities, cost-benefit analysis is not limited to the monetary costs and benefits of the decision maker himself, but accounts for all marketable and non-marketable costs and benefits experienced by all individuals residing within the area of interest (Mishan and Quah, 2007). In a nutshell: a “benefit” is an increase in human wellbeing, and a “cost” is a reduction in human wellbeing (OECD, 2006). The term “net benefit” (i.e. subtraction of costs from benefits) therefore represents the overall societal welfare gain of a country or region. For the analysis conducted in this paper, the scope will be narrowed down to the local level, which means that downstream ecological costs caused by the Kökyar water consumption, although undoubtedly existent, will not be included. The focus will be set on marketable costs and benefits, while non-marketable effects will be verbally described (for more general information on cost-benefit analysis cf. Boardman et al., 2011).

3. The establishment of Kökyar Protection Forest

3.1. Emergence

The first scheme of the later Kökyar Protection Forest came up in 1985, when water was needed for planned road side greening along National Highway 314 north of the urban core of Aksu. The Aksu Prefectural Party Committee decided to build a new fork canal from the existent northern Great Revolution Canal (*geming daqu*) leading southward to the planned greening site (cf. Fig. 2). The terrain to be crossed by the canal was the area of the later Kökyar Protection Forest. Because of its unfavourable environment (cf. following chapter), it was decided to protect the canal with poplar shelterbelts on each side. A year later, in 1986, the original plan was enlarged to cover the whole area with a protection forest, and the evocative title “Kökyar Greening Project” was suggested (Kökyar Annals Compilation Committee, 1996). “Kökyar” means “green cliff” in Uyghur language.

3.2 Site conditions

The plantation site of the Kökyar Protection Forest lies in the north of Aksu City. It is a long stretch with an area of 1308 ha that extends 15.8 km from the Great Revolution Canal in the north to the suburbs of Aksu City in the south (cf. Fig. 2). It lies above Aksu City on an old fluvial terrace which slightly slopes from 1230 m above sea level in the north to 1125 m above sea level in the south. Most of its western boundary is defined by a steep cut bank of 20 m down to the Aksu River valley. The cut bank was canyoned by erosion gullies which extended deep into the area of later Kökyar, thus posing great problems for the levelling of the planting ground and construction of canals (Kökyar Annals Compilation Committee, 1996).

The fluvial terrace itself is composed of brown desert soil lying upon a gravel bed. The grain size at the surface changes from sandy gravel in the north to sandy silt and clay in the south. A high groundwater table and the regional extreme evaporation rate result in an average soil salinity of 2.87% and pH-values of 7.1 to 9.0. Before the afforestation, the soil was predominantly devoid of vegetation, with some areas being sparsely covered by *Alhagi spec.* and other herbaceous plants. The barren soil of the Kökyar plateau was regarded as a major source of wind erosion, thus contributing to the regular northerly dust and sand storms in Aksu City (cf. Fig. 2; Kökyar Annals Compilation Committee, 1996; Aksu Prefectural Forestry Department and Kuqa Television Station, 2006).

3.3 Design

The plantation was established as a raster of shelterbelt strips consisting mainly of white poplar (*Populus alba* 'Pyramidalis') with fruit plantations between. In the five years between 1986 and 1990, 686 ha of poplar shelterbelts and 623 ha of orchards were planted, totalling 1308 ha and 1 085 000 trees (Kökyar Annals Compilation Committee, 1996).

The infrastructure backbone of the plantation is formed by a vertical main canal and a parallel main asphalt road which interlink the Great Revolution Canal in the north with the city of Aksu in the south, providing the area with water and making it accessible. This main axis has a length of

15.8 km and is protected by a shelterbelt strip of 100 m width at each side. The areas east and west of it are criss-crossed by a regular grid of in total about 125 km earth roads and a hierarchical system of subordinate irrigation canals. Shelterbelts, planted in single or double rows, protect the earth roads and subordinate canals, forming a checkered pattern over the area (cf. Fig. 3). The rectangular fields in between are filled with orchards (for details of the orchard management cf. chapter 4.3 The perspective of the farmers). Hundreds of small farm houses are scattered all over the orchards. Furthermore, the area is equipped with all necessary technical infrastructure, such as water gates, waterlocks, overflows, bridges, drainage canals, water tabs, power lines, telephone lines and administrative buildings.

Today, the shelterbelts of Kökyar I consist mainly of white poplar (*Populus alba* 'Pyramidalis') in dense rows, partly mixed with Euphrates poplar (*Populus euphratica*), and some oleaster (*Elaeagnus angustifolia*), tamarisks (*Tamarix*) and willows (*Salix*) in the understory. Most white poplars have reached breast diameters of 20-30 cm, with some reaching up to 60 cm (field observations 2012).

The later project periods of Kökyar II, III and IV are not located in the direct vicinity of Kökyar I. They are scattered over the most problematic dust fields to the north and east of Aksu City (cf. Fig. 2). Their lay-out follows the basic design of Kökyar I, but they tend to have smaller shelterbelt areas compared to total area (cf. Table 1; Aksu Prefectural Greening Committee, 2006). For the latest scheduled project period, Kökyar IV, data have yet to be published.

3.4 Key actors

In 1986, the Prefectural Party Committee authorised two important governmental organisations, the Aksu River Drainage Area Management Department (*akesu heliuyu guanlichu*) and the Prefectural Forestry Department (*diqu linyechu*) to run the project jointly. Each of them founded an on-the-ground working station especially for the purpose of establishing and managing the plantation: the Kökyar Greening Project Water Management Station (*kekeya lühua gongcheng shui guanzhan*; from here on referred to as Water Management Station) and the Kökyar

Greening Project Protection Forest Management Station (*kekeya lühua gongcheng fanghulin guanzhan*; from here on referred to as Forest Management Station) with a staff of about 50 persons each (Kökyar Annals Compilation Committee, 1996; interview 1). The main task of the River Management Department and its local Water Management Station lay in preparing the planting ground through spatial planning, bulldozing the terrain, establishing a road network, building irrigation canals and other hydraulic engineering for provision of irrigation water, and drainage canals to depress the saline ground water level (Kökyar Annals Compilation Committee, 1996; interview 1), while the main task of the Forestry Department and its local Forest Management Station lay in forest design planning, provision of cuttings and saplings and afforestation management (Kökyar Annals Compilation Committee, 1996).

Many other governmental organisations or government owned enterprises, e.g. the Prefectural Traffic Department, the Prefectural Road Construction Group, the state-owned Experimental Forest Site, or the equally state-owned Red Flag Slope Farm contributed to the establishment of Kökyar Protection Forest with expertise, labour, resources or money, however, the main promoters were the River Management Department and the Forestry Department with their corresponding on-the-ground stations (Kökyar Annals Compilation Committee, 1996; interview 1). Due to lack of funds, none of these institutions were given additional funds by the local government. Therefore, they had to restructure their regular annual budgets in order to mobilise funds for the project (Kökyar Annals Compilation Committee, 1996; interview 1).

Kökyar II (1991-1998) was organised and implemented by the same governmental institutions, and in the same manner, as Kökyar I.

For Kökyar III, in contrast, a market economy approach was chosen: The land was given to private entrepreneurs who were freed from rent payments and water fees for the first couple of years but had to make all other necessary investments themselves. In return, they can keep all revenues generated on the land for themselves, according to the principle “who invests earns” (Aksu Prefectural Greening Committee, 2006).

3.5 Compulsory labour

In order to meet the challenge of establishing huge forest areas in a poor financial situation, a legal regulation adopted in 1981 obliging all Chinese citizens to participate in "National Compulsory Afforestation Campaigns" (*quanmin yiwu zhishu yundong*) played a key role (Halik, 2003; interview 1). Based on this regulation, beginning from 1986 the Aksu Prefectural Party Committee called "all citizens, no matter which ethnicity, military or civilian" to participate in compulsory labour (*yiwu laodong*) on the fields, levelling the terrain, preparing the ground and planting trees with hard physical labour (Kökyar Annals Compilation Committee, 1996; interview 1). In reality, it seems that mainly prefectural governmental organisations and prefectural government owned enterprises under direct order of the Aksu Prefectural Party Committee were convinced or forced to take part, e.g. prefectural administration, police, and prefectural schools (interview 1). Even so, the mobilisation of manpower reached very high levels: About 70 different organisations and enterprises sent thousands of workmen twice a year, for periods of 8, 12 or even 30 days at a time (cf. Fig. 4). On one top day in 1988, 8459 people were working on the desert plateau simultaneously (Kökyar Annals Compilation Committee, 1996). Although the areas of Kökyar III were to be developed and exploited by private investors, the system of calling ordinary citizens to compulsory labour was maintained, thus massively supporting newly evolving large landholders with gratis manpower (Aksu Prefectural Greening Committee, 2006).

3.6 Initial investment costs

The establishment costs of Kökyar I are more or less systematically listed in the Kökyar Annals (Kökyar Annals Compilation Committee, 1996), comprising the costs of bulldozing and other heavy earthworks, all types of water engineering, the construction of asphalt and earth roads, telephone and power lines, and the costs of afforestation proper, as they were borne by the major contributing organisations (cf. Table 2; Kökyar Annals Compilation Committee, 1996). However, some matters of expense are omitted by the Annals: Firstly, the costs of surveying, planning, organising etc.; secondly, the costs of establishing drinking water facilities; and thirdly,

the costs of compulsory labour. While we cannot, in retrospect, ascertain the costs of the first and second point, there is a way to approximate the costs of the third point, compulsory labour. The Kökyar Annals exactly list the physical extent of compulsory labour performed for the establishment of Kökyar Protection forest but fail to treat it as a matter of cost, probably because it appeared as cost-free to the project makers. However, compulsory labour did, of course, involve costs, but the costs were passed along as opportunity costs to those institutions, organisations and enterprises which had to provide the workers, and to the workers themselves who had to pay for shovels and picks as well as for transportation (interview 1). The opportunity cost of one man-day can be calculated by the fee of 30 CNY people had to pay in case they were unable to attend to compulsory labour (interview 1; value not adjusted for inflation. Multiplying the value of this fee by 346 000 performed man-days, and further adding tool and transportation costs, reveals that compulsory labour, in fact, was the largest single expense of Kökyar I (interview 1; Kökyar Annals Compilation Committee, 1996). Adjusted for inflation and calculated per area, the overall establishment costs of Kökyar I amount to 61 245 CNY ha^{-1} or, if compulsory labour is excluded from the calculation, 38 700 CNY ha^{-1} (cf. Table 2).

The validity of this cost calculation for Kökyar I, as it is given in the Kökyar Annals, can be cross-checked by comparison to the costs given for Kökyar III in another publication: A 2006 publication of the title “Green Kökyar” indicates the establishment costs of Kökyar III based on the examples of one single investor commanding over 333 ha and a group of 13 investors commanding over 1200 ha (Aksu Prefectural Greening Committee, 2006). Adjusting their costs from inflation and calculating them per area allows a comparison between the establishment costs of Kökyar I and Kökyar III (cf. Table 3).

The comparison shows that installation costs of both project periods are, roughly speaking, of the same magnitude. The coherence between those numbers can be taken as evidence that the cost calculation of Kökyar I is realistic, and that the costs of the past are transferrable to the present.

4. The present functioning of the Kökyar Protection Forest

4.1 The leasing system

In 1981, the State Council of the PR China had started promoting private forestry on a leasing basis by its “Resolution on Issues Concerning Forest Protection and Development” (*guanyu baohu senlin, fazhan linye ruogan wenti de jueding*; for backgrounds cf. Delang and Yuan, 2015). In 1987, when the Kökyar afforestation work was still in the early stages, the Forest Management Station and Water Management Station reacted to this resolution and to the dire financial situation of their afforestation project, with the introduction of a leasing system that is fundamentally still in force today: Plots of already planted orchards, and plots which were ready for planting were leased to private fruit farmers (Kökyar Annals Compilation Committee, 1996). Leasing contracts guarantee them, for a period of about 10 to 15 years, a small section of orchard land (mostly between 0.5 and 1 ha, which may include single or double row poplar shelterbelts on one or two edges of the plots), regular irrigation water supply and some technical advice in fruit production (socio-economic household survey 2012). The leasers, in return, have to pay a substantial lease and an irrigation water fee. Additionally, they have certain duties and prohibitions. The main duty is to annually attend 7 to 50 days of compulsory labour, which is mostly maintenance work on the shelterbelt plantations and the irrigation canals. The main prohibition is not to damage the poplar plantations by cutting of trees or branches (even if they overshadow fruit trees) or by grazing. The leasers have to compensate any loss of poplar trees on their area. Some contracts further contain prohibitions to change the cultivation from fruit trees to field crops, although it is anyhow economically the most promising to cultivate fruit trees (socio-economic household survey 2012).

This system of economic incentives and regulative norms, as it is fixed in the lease contracts, guarantees the cultivation and persistence of vigorous orchards amongst undamaged poplar shelterbelts, it provides free labour for the maintenance of infrastructure and poplar shelterbelts, and it ensures an income to the lessor organisations that they can reinvest into the plantation.

The project leaders soon recognised the leasing system as an instrument to successively transform Kökyar from a purely government-sponsored protection forest into a self-supporting protection forest (Aksu Prefectural Greening Committee, 2006). Consequently, they try to set the lease as high as possible, without the leasers backing out (interview 1; socio-economic household survey 2012).

Kökyar II is organised in parallel to Kökyar I.

Kökyar III also features an orchard leasing system, with the main difference being that the local government withdraws and private large-scale investors step into the role of the governmental lessor organisations: They act as main tenants who first make the necessary infrastructure investments and then sublease their large estates in small patches to hundreds of leasing households, compensating their initial investment costs with income from the subleases (for exemplary area sizes of main tenants comp. Table 3). The exact conditions under which the main tenants obtain land from the government have not been researched. However, it seems that privatisation of the protection forest business has advanced the idea of converting Kökyar into a self-supporting system, as government grants have been reduced substantially ever since (Aksu Prefectural Forestry Department and Kuqa Television Station, 2006).

4.2 The perspective of Aksu citizens

Shelterbelts in drylands are generally assumed to provide vital regulating ecosystem services, such as air humidification and cooling, wind speed reduction, air filtration and soil fixation (Yimit et al., 2006; Halik, 2003; Chokkalingam et al., 2006). Among these, air filtration and soil fixation are of the greatest relevance for Aksu City, since these ecosystem services have the effect of dust and sand storm mitigation, the primary reason for which Kökyar Protection Forest was initiated. An improvement of the dust and sand storm situation of Aksu City after the establishment of Kökyar Protection Forest is claimed by the Kökyar Annals (Kökyar Annals Compilation Committee, 1996; for details cf. next paragraph) and has been perceived and described by Kökyar farmers (socio-economic household survey 2012) and Aksu citizens (Aksu

citizens interviews 2011; also cf. Halik, 2003). However, the precise contribution of Kökyar to this positive development is hard to determine, since there are more contributing factors in addition to Kökyar, such as the extension of the irrigated agricultural area around Aksu, the protection of the natural vegetation in the surrounding deserts and semi-deserts by a programme which reduces livestock densities, and fluctuations in precipitation patterns (interview 2; Yimit et al., 2006; Yang and Cui, 2006).

The first volume of the Kökyar Annals illustrates the Kökyar effect by presenting figures for reduced "wind-borne sand events" (*fengshaci*) in three periods between 1954 and 1990 (cf. Table 4; Kökyar Annals Compilation Committee, 1996). The figures demonstrate, first of all, that the situation in Aksu City and Onsu County Town, which are directly adjacent to Kökyar Protection Forest, improved considerably over this period, whilst at the Fifth Corps of the First Agricultural Brigade, which is 60 km away from Kökyar (Kökyar Annals Compilation Committee, 1996), wind-borne sand events remained frequent – thus indicating that *local* measures have caused this improvement. Furthermore, the table demonstrates that the situation at Aksu and Onsu was relatively stable between the first two periods, but suddenly grew massively better in the third period – thus indicating that a *new* measure starting from 1987 must have caused the improvement. Spatial and temporal coincidences combine to provide strong evidence for Kökyar being the main factor effecting the reduction of sand storm events.

This data set, however, does not clarify the physical properties of the alleged reduction, whereby the term "wind-borne sand events" obscures the duration of each "event" as well as the concentration of airborne particles. The second volume of the Kökyar Annals does present dust quantities by annual averaged densities of "total suspended particles" (TSP), but only for the years from 1996 till 2006, thus not allowing a comparison with the previous years (Kökyar Annals Compilation Committee, 2006). For clarification of the exact dust and sand storm mitigation effect of Kökyar Protection Forest, more research is necessary.

Methods for the economic valuation of ecosystem services could theoretically attach annual monetary values to dust and sand storm mitigation effects. The Kökyar Annals indeed present a precise figure for the Kökyar Protection Forest, attaching a value of 285 CNY ha^{-1} to the joint effect of airborne sand reduction and soil fixation (Kökyar Annals Compilation Committee, 1996; value adjusted for inflation). However, this figure is cited from a publication which is not focused on peri-urban protection forests in drylands, but rather aims at estimating an average Chinese forest value (Qi, 2007; Lang and Li, 2000). Since Kökyar Protection Forest is established precisely on the largest dust fields in the region where it has the maximal impact on a large urban population in immediate vicinity, it is expected to have a far above-average value, and the presented figure is likely to understate the true monetary value of Kökyar's regulating ecosystem services.

Because of uncertainties in respect to the physical properties as well as the monetary value of the dust and sand storm mitigation effect exerted by the Kökyar Protection Forest, this paper refrains from expressing the benefits of its regulating ecosystem services in monetary terms. Yet, the principal fact that Kökyar reduces dust and sand storms appears to be beyond doubt.

4.3 The perspective of the farmers

The following description of the socio-economic situation of the Kökyar farmers is based on a household survey conducted in 2012 on the area of Kökyar I. The transferability of the survey to Kökyar II and III is uncertain. Their leasing conditions may differ, while the market and environmental conditions are very similar.

The Kökyar I leasers recruit mostly from the huge pool of Han-Chinese migrant workers who jump at the chance to get settled there with their families (Kökyar Annals Compilation Committee, 1996; socio-economic household survey 2012). Families mostly have 2 to 5 members and both husband and wife are involved in farm work. During harvest time they may hire additional seasonal workers, while in winter some use their spare time to make extra money on Aksu City construction sites. Their main agricultural income is generated by the cultivation of fruit trees and

the resulting harvests, with apple and pear being the major crops and jujube, walnut and others being minor crops. As long as fruit trees are still small and do not shade the soil surface, some leasers cultivate maize or cotton between the trees. In addition, many leasers can create indirect incomes from their land: Dead wood is used as fencing material or as fuel substituting coal; small scale horticulture and husbandry beneath the fruit trees contribute to subsistence; animal dung provides some quantities of fertilizer. However, only the fruit production is economically significant, and these indirect income items, although doubtlessly contributing to the living conditions of the farmers, are presently not quantifiable and cannot be incorporated into the subsequent income calculations.

The leasing contracts usually assign areas between 0.5 and 1 ha to the households, with some outliers at 2 ha or 3 ha, thus fostering small-scale farming. The lease is tailored to the age of the fruit trees and expected yield, shifting between 0 and 15 000 CNY ha^{-1}. Irrigation water fees usually fall between 1125 CNY ha^{-1} and 1275 CNY ha^{-1}. (These prices probably represent the costs of the irrigation infrastructure and operation; they do not reflect externalities.) A high share of leasers additionally have to perform compulsory labour of up to 50 man-days per year, its value being assessable by the fees they have to pay in case they are prevented. Besides the fixed costs for the lease, irrigation water and compulsory labour, the leasers need to make annual farming investments in fertilisers, pesticides, machinery, diesel, and harvest hands. While annual costs are rather steady, annual incomes vary from year to year, since the yields depend on weather conditions, pests, and natural fructification alternations (cf. Table 5). The net income shifts between 55 166 CNY ha^{-1} in a year of good harvest (2010) and 11 465 CNY ha^{-1} in a year of bad harvest (2011), with the long-term average being 47 376 CNY ha^{-1}.

Based on the household survey conducted in 2012, it can be estimated that the household members on average have to spend 180 man-days per leased hectare per year (socio-economic household survey 2012). Net farming incomes per working day can be calculated by dividing per-hectare net farming incomes by per-hectare work load (cf. Table 6).

While years of good harvests appear to provide satisfying incomes, years of bad harvest result in marginal incomes, with the income per man-day lying below the wage level of migrant workers and seasonal workers (socio-economic household survey 2012; interview 3). With such strong year-to-year variability, it is hard to evaluate their long-term income situation. However, from the perspective of the farmers themselves, the actual conditions seem to be promising on the long run, since during the household survey conducted in 2012 nearly all of them were optimistic for the future and declared themselves willing to sign up for the next leasing period (socio-economic household survey 2012).

4.4 The perspective of the governmental organisations

The state-owned Water Management Station and Forest Management Station as subsidiary bodies of the Aksu River Drainage Area Management Department and the Aksu Prefectural Forestry Department are the organisational backbone of the system. They are responsible for tending the shelterbelts, maintaining roads and canals, operating the irrigation system, managing and enforcing the leasing system, and educating leasers in the cultivation of fruit trees. To fulfil these indispensable tasks, they are equipped with all necessary resources and staff, involving substantial costs (Kökyar Annals Compilation Committee, 1996; Kökyar Annals Compilation Committee, 2006; interview 1). A part of the costs can be covered by lease payments and irrigation water fees derived from the leasing households, yet from the perspective of the government budget, the system is far from economic self-sufficiency (interview 1). As it was not possible to conduct interviews with the persons responsible for the Kökyar project, no exact data on permanent government grants could be gathered. However, an interview with the former head of the Forest Management Station revealed that the Water Management Station and the Forest Management Station can only cover 30% of their expenses with the income generated from the lease and irrigation water fees. The remaining 70% of their budget is being covered by government grants (interview 1). Lease payments and irrigation water fees can be assessed at an amount of 5.765 million CNY (8979 CNY ha^{-1} lease and 1324

CNY ha^{-1} water fees, multiplied by 560 ha extant orchard area within Kökyar I; socio-economic household survey 2012; Kökyar Annals Compilation Committee, 1996). This being their self-generated income share of 30%, the other 70% covered by governmental grants must amount to 13.451 million CNY, and the total budget must add up to 19.215 million CNY. Unfortunately, it is unknown how the budget is divided between the orchards and the shelterbelts.

In the very near future, the poplar shelterbelts will provide an additional income to the Water and Forest Management Station. Besides their protective value to the orchards, they also have a direct economic value in their timber, which needs to be harvested before becoming over-mature. The earliest planted poplars are already almost fit for cutting. As soon as a systematic harvest begins, an annual wood increment of 21.5 m^3 ha^{-1} at a value of 8545 CNY ha^{-1} can be logged in the shelterbelt areas (Kökyar Annals Compilation Committee, 1996; monetary value adjusted for inflation). As investment costs for the shelterbelts are unknown, there is no way to determine the net income they provide. However, a comparison between the expected gross timber income of 8545 CNY ha^{-1} and both the gross and net income of the orchards (78 704 CNY ha^{-1}, 47 376 CNY ha^{-1}; see above) already shows that the shelterbelts are being by far less profitable than the orchards.

A timber income of 8545 CNY ha^{-1} translates into an overall timber income of 4 785 144 CNY for the area of Kökyar I (8545 CNY ha^{-1}, multiplied by 560 ha extant shelterbelts). This additional income reduces necessary annual government grants from 70% to 45% and, in absolute numbers, from 13.451 million CNY to 8.666 million CNY (values adjusted for inflation). Although a systematic harvest has not yet begun, timber is integrated into the income calculation, since it has regular annual increments which the governmental organisations could convert into income at any time. Incomes and costs of the two Stations are summarised in Table 7.

4.5 The perspective of the local economy

The Kökyar Protection Forest originated from the idea of protecting Aksu City against dust and sand storms. Yet, the invention of the orchard leasing system between the poplar shelterbelts

gradually transformed it into a prospering branch of the local economy. The number of leasing households earning their livelihood in the orchards of Kökyar I can be estimated between 324 (Kökyar Annals Compilation Committee, 1996) and 454 (socio-economic household survey 2012). Extrapolated on the orchard area of Kökyar I, II, and III, these figures would allow an estimation of 1341 to 1880 farming households. In addition to these, a substantial number of jobs in the background organisation and in the poplar forests, and a smaller number of jobs for suppliers and commercial consumers can be assumed.

However, this whole branch is still dependent on annual government grants for the maintenance, regulation, and organisation tasks performed by the Water and Forest Management Station. This section sets out to clarify whether the government grants to Kökyar are justified solely by the protective ecosystem functions it provides, or whether it also benefits the local economy.

This question can be answered from the perspective of cost-benefit analysis by summing up all types of costs and benefits, as they were outlined in the previous sections, and calculating the net benefit. But prior to this, the figures of the previous sections need to be transformed to fit the needs of the net benefit calculation: Firstly, from the perspective of local economy it is necessary to account for the time farmers work in their orchards as an additional farming cost, since without the existence of Kökyar they would contribute to local economy through other activities. These opportunity costs are calculated at the same daily rate as the compulsory labour they have to perform for their lessors, that is 51.52 CNY day^{-1} (socio-economic household survey 2012). Given that Kökyar farmers on average invest 180 working days per hectare of orchards (socio-economic household survey), the opportunity costs of farm work can be set at 9289 CNY ha^{-1} (value adjusted for inflation). Secondly, all costs and incomes of the farming households are in the previous sections given per hectare of orchard land, while costs of the Water and Forest Management Station are only known as a total number without differentiation into forest types and area sizes. In order to calculate in the same units, per-hectare numbers have to be transformed into total numbers. This is done by multiplying all farming incomes and expenses by

560 ha, the total extant orchard area within the borders of Kökyar I (Kökyar Annals Compilation Committee, 1996). After these preparations, all figures are ready for the net benefit calculation (cf. Table 8).

Subtraction of all costs from all benefits shows that Kökyar I in total generates an overall annual net benefit of 11.789 million CNY. Additionally, it provides regulating ecosystem services of a specific value which, however, could not be determined in terms of money. The local economy cycle of Kökyar I is graphically summarised in Figure 5.

The overall net benefit of 11.789 million CNY on the total forest area of Kökyar I expressed per area is 10 530 CNY ha^{-1}. This number, however, applies only to Kökyar I and should not be misunderstood as a general number transferable to Kökyar II, III, and IV. While Kökyar I has an orchard share of 50%, Kökyar II and III have greater orchard shares of 58% and 90%, respectively. As mentioned previously, orchards are by far more profitable than shelterbelts, thus Kökyar II and III can be assumed to create considerably greater net benefits to the local economy than Kökyar I.

Thus, it can be concluded that government grants to the Kökyar Protection Forest do not only provide a return in terms of regulating ecosystem services for the citizens of Aksu, but also in terms of financial benefits. From the perspective of the local economy, the Kökyar Protection Forest is self-supporting, with respect to annual farming net benefits more than compensating necessary annual government grants. The regulating ecosystem services of wind speed reduction, air filtration and soil fixation, with regard to which the Kökyar Protection Forest was initiated, can therefore be provided to the citizens of Aksu without any payments for ecosystem services (PES) or other additional financial burdens on the local economy.

Comparing the initial investment costs of 61 245 CNY ha^{-1} with the overall annual net benefit of 10 530 CNY ha^{-1} shows that net benefits at the current level would offset initial investment costs within merely 6 years. However, this is not the actual payback period, since within the first 10 to 15 years after initialisation, fruit trees had not reached full fructification, and consequently there

were no or only marginal annual net benefits. The actual historic development of the net benefit has not been researched, but under the simplified assumption of a linear net benefit development from 0 CNY ha^{-1} in the first project year to 10,530 CNY ha^{-1} in the 25th project year, the payback period can be roughly approximated at 20 years. In the case of Kökyar II and III, the payback period can be assumed to be shorter, due to their higher orchard share.

5. Discussion and outlook

The paper describes the historic establishment and present functioning of the Kökyar Protection Forest with regard to its institutional frameworks and financial conditions. While the institutional frameworks of Kökyar I and II are described in satisfactory detail, Kökyar III adopts a differing, more market based approach, which has not been systematically documented yet. Further research could clarify the institutional functioning of Kökyar III, especially in comparison to Kökyar I and II. Concerning the description of the financial conditions, the *present* financial conditions of Kökyar have formerly not been subject to any publications, and the results of the respective calculations of this paper, being based on a socio-economic household survey comprising 19 leasing households and one additional expert interview with former leading staff of the state-owned organisations, are deemed to be rather rough estimates. Conducting interviews with actual leaders of the governmental organisations of Kökyar I and II and with large private landholders of Kökyar III would have been extremely desirable, however, under the present political tensions in Xinjiang and the resulting scepticism towards any type of social surveys, this seems hard to achieve.

For a more comprehensive understanding of the costs and benefits of the Kökyar Protection Forest, future research should be directed towards two main fields. Firstly, the exact physical properties of the regulating ecosystem services provided by the Kökyar Protection Forest still need to be determined, especially regarding the amount of dust and sand avoided in the city of Aksu. Secondly, the negative consequences of the Kökyar water consumption for downstream ecosystems need to be investigated. Principally, every drop of water diverted from Aksu River

for the purpose of irrigating the Kökyar Protection Forest is detracted from its lower reaches and its main stem, the Tarim River. The improvement of the quality of life of Han-Chinese settlers in Aksu is thus bought by the resulting desiccation of downstream ecosystems and the consequent loss of downstream ecosystem services, which deprives local Uyghur farmers and herdsmen of their livelihoods. Internalising these downstream effects into the Kökyar water prices may challenge the net-benefit and the positive image of Kökyar Protection Forest.

Appendix A: List of interviews

Interview 1

Interviewee: Ibrahim Yusup, between 1986 and 1995 head of the Kökyar Greening Project Protection Forest Management Station

Interviewers: Siegmund Missall, Abdulla Abliz, Aliya Badrulla

Place and date: Urumqi, 15 October 2012

Interview 2

Interviewee: Zhang Lei, private farming consultant in Aksu

Interviewer: Siegmund Missall

Place and date: Aksu, November 2011

Interview 3

Interviewee: name unknown, seasonal worker in the orchards of Kökyar Protection Forest

Interviewers: Siegmund Missall, Abdulla Abliz, Aliya Badrulla

Place and date: Aksu, January 2012

Aksu citizen interviews

Interviewees: random citizens on the streets of Aksu City

Interviewer: Siegmund Missall

Place and date: Aksu, November and December 2011

(The interview series originally focused on the urban green of Aksu, but many interviewees made spontaneous contributions about Kökyar Protection Forest.)

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Table 1: Overview of the present four project periods of Kökyar Protection Forest. Bold numbers: sums of single project areas; italic numbers: provisional figures of the planned extent.

Kökyar project period	**Time frame**	**Total area [ha]**	**Shelterbelt area [ha]**	**Orchard area [ha]**	**Shelterbelt area [%]**	**Orchard area [%]**
Kökyar I	1986-1990	1308	686	623	52	48
Kökyar II	1991-1998	1001	423	578	42	58
Kökyar III	1999-2005	1533	153	1380	10	90
Kökyar I-III	**1986-2005**	**3842**	**1262**	**2580**	**33**	**67**
Kökyar IV	*2006-2010*	*10 000*				
Kökyar I-IV	***1996-2010***	***13 842***				

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Table 2: The establishment costs of Kökyar I.

Cost item	Initial investment costs [million CNY]	Adjusted for inflation (2014) [million CNY]	Calculated per area[1] [CNY ha^{-1}]	Share of total [%]
Management (surveying, planning, organising, etc.)	*(unknown)*	*(unknown)*	*(unknown)*	
Bulldozing (and other heavy earthworks)	2.351	7.989	5745	9
Water engineering (including all tasks of the River Management Department)	7.538	21.516	15 480	25
Road construction (asphalt and earth roads)	4.387	12.523	9015	15
Drinking water facilities	*(unknown)*	*(unknown)*	*(unknown)*	
Cable system (power lines and telephone lines)	0.807	2.302	1650	3
Afforestation (including all tasks of the Prefectural Forestry Department)	2.800	9.441	6795	11
Compulsory labour	11.347	31.324	22 545	37
TOTAL	**29.463**	**85.095**	**61 245**	**100**

[1] Calculating with the overall area size of Kökyar I, which slightly exceeds the afforested area of Kökyar I (cf. Kökyar Annals Compilation Committee, 1996).

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Table 3: Comparison of initial investment costs between Kökyar I and partial areas of Kökyar III, excluding costs of compulsory labour.

Area denomination	**Initial investment costs [million CNY]**	**Adjusted for inflation (2014) [million CNY]**	**Area size [ha]**	**Initial investment costs [CNY ha^{-1}]**
Kökyar I	18.116	53.771	1389	38 700
Zhang Lianzhi (part of Kökyar III)	7.000	10.006	333	30 015
13 investors (part of Kökyar III)	30.000	42.734	1200	35 205

675 Table 4: Annual wind-borne sand events in the region of Aksu City 1954 to 1990.

Time frame	Aksu City	Onsu County Town	Fifth Corps
1954 – 1980	11.9	5.6	16.5
1981 – 1986	10.8	5.3	22.2
1987 – 1990	4.3	1.0	20.5

Table 5: Averaged annual incomes and costs of Kökyar I farmers.

Income and cost item	**Adjusted for inflation (2014) [CNY ha^{-1}]**
GROSS INCOME	
a) Good harvest (2010)	86 524
b) Bad harvest (2011)	42 823
c) Long-term average (acc. Kökyar Annals)	78 704
COSTS	
Lease	8 979
Irrigation	1 324
Compulsory labour	1 074
Fertilisers	11 521
Pesticides	5 375
Machines and diesel	1 120
Harvest hands	3 465
NET INCOME	
a) Good harvest (2010)	55 166
b) Bad harvest (2011)	11 465
c) Long-term average (acc. Kökyar Annals)	47 376

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Table 6: Averaged net incomes per working day of Kökyar I farmers.

Income situation	**Adjusted for inflation (2014) [CNY day^{-1}]**
Good harvest (2010)	306
Bad harvest (2011)	64
Long-term average (acc. Kökyar Annals)	263

Tabelle 7: Annual incomes and costs of the Water and Forest Management Station for Kökyar I.

Income and cost item	**Adjusted for inflation (2014) [million CNY]**
GROSS INCOME	
Lease income	5.024
Irrigation water income	0.740
Timber	4.785
COSTS	
Total costs	19.215
NET INCOME	
Loss, covered by regular government grants	-8.665

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Table 8: Annual benefits and costs of Kökyar I from the perspective of local economy.

Benefit and cost item	**Adjusted for inflation (2014) [million CNY]**
GROSS BENEFITS	
Fruit harvests (long-term average)	44.038
Timber	4.785
Lease income	5.024
Irrigation water income	0.741
COSTS	
Lease payments	5.024
Irrigation water fees	0.741
Compulsory labour	0.601
Fertilisers	6.447
Pesticides	3.008
Machines and diesel	0.627
Harvest hands	1.939
Opportunity costs of farm work	5.198
Expenses of the governmental organisations	19.215
NET BENEFIT	
Annual financial net benefit for the local economy	11.789

690 Figure 1: Geographic position of Aksu City in the Tarim Basin, northwest China (adapted from Paproth and Pietsch, 2011).

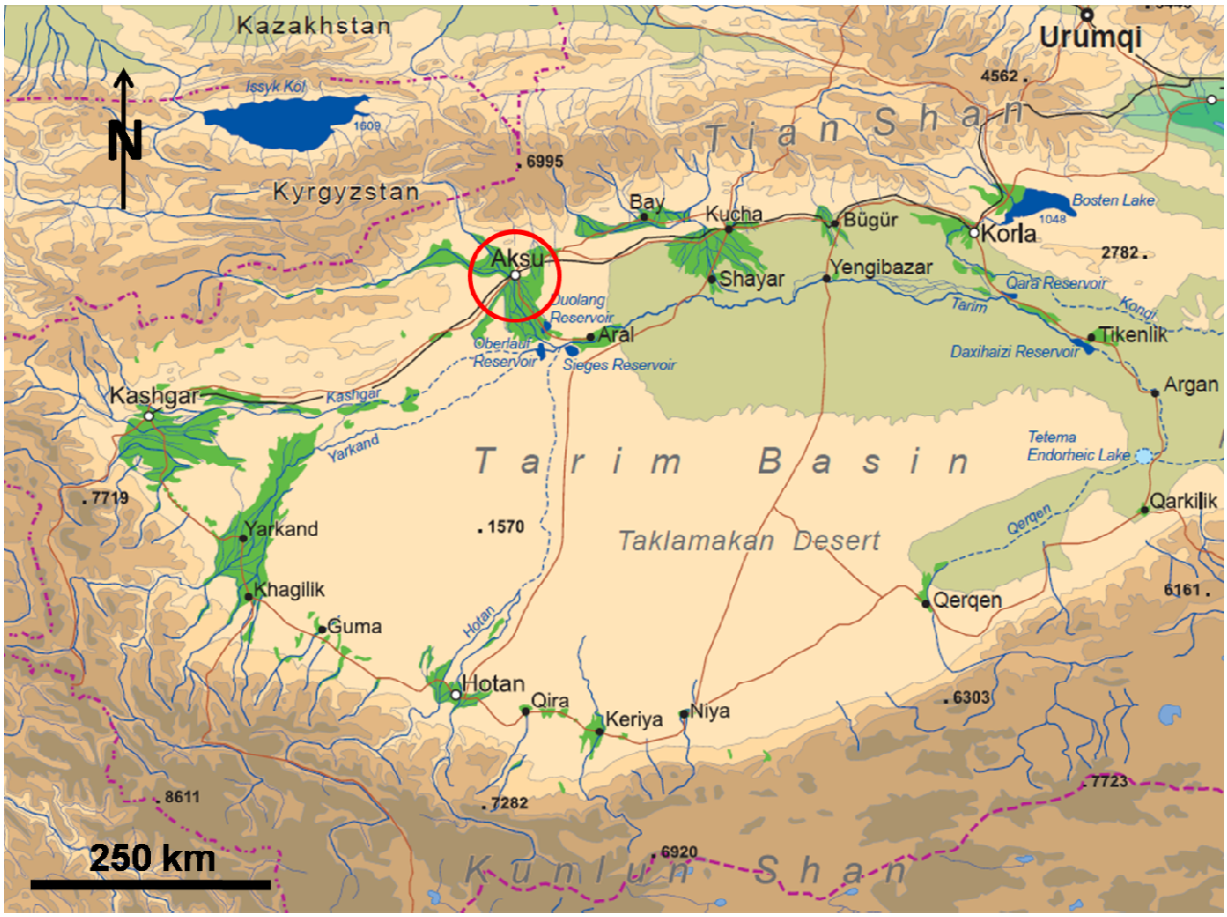

Figure 2: The project areas of Kökyar I, II, III, and IV (partial view; adapted from Kökyar Annals Compilation Committee, 2006).

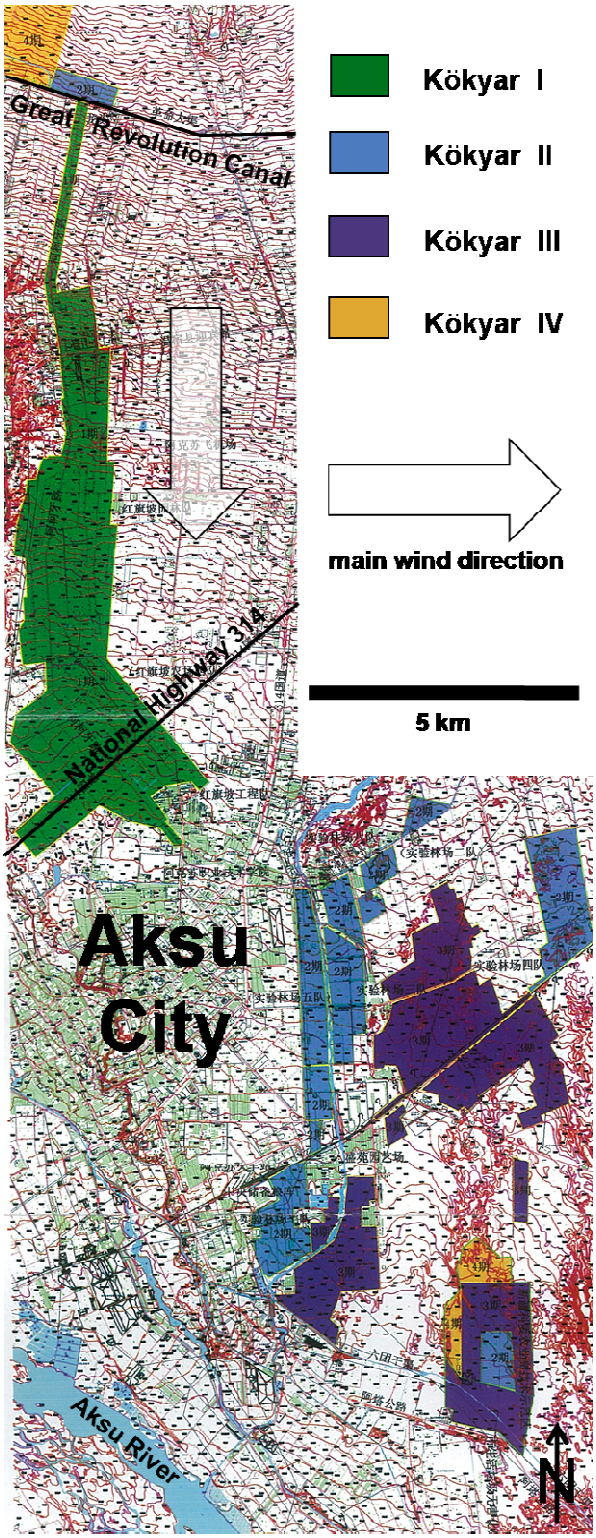

Figure 3: Aerial view of the northern edge of Kökyar I (adapted from Aksu Prefectural Greening Committee, 2006).

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Figure 4: Compulsory labour on the Kökyar fields (adapted from Kökyar Annals Compilation Committee, 1996).

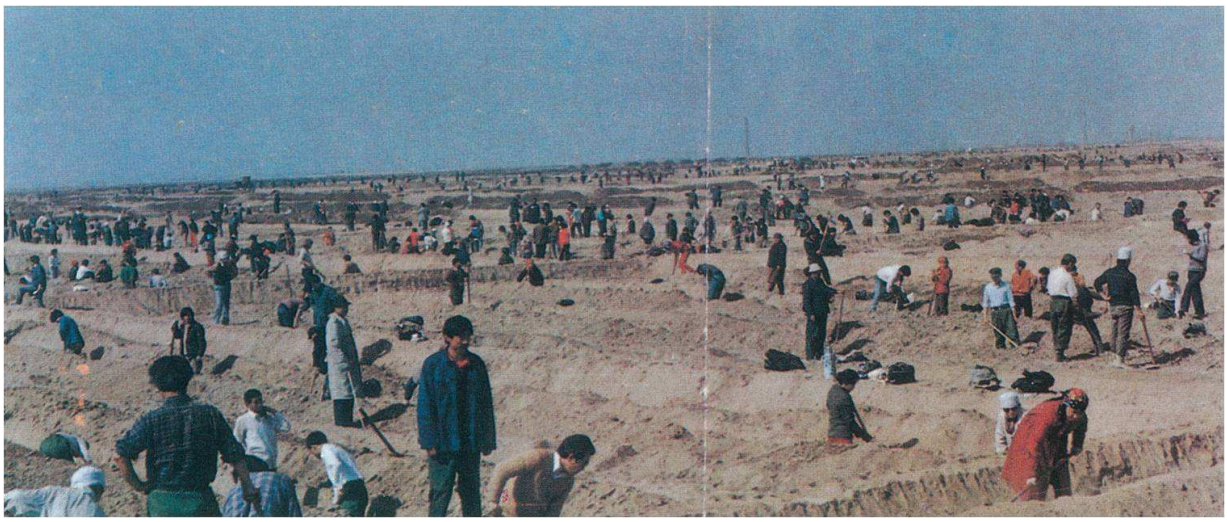

Figure 5: Graphic summary of the cost and benefit flow of Kökyar I (red arrows representing costs, black arrows monetary benefits).