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Preface

This book considers and contains research results on aeolian processes as dust and sand storms in the deserts of Central Asian and Kazakhstan. Dust and sand storms are a common natural phenomenon in the arid and semi-arid regions of Central Asia and Kazakhstan, especially in its southern parts where the land is covered by a great variety of deserts, which are a powerful source of mineral and salt aerosols.

Aeolian processes as storms are important in arid environment such as deserts. Desert covers >40% of the territory of Central Asia. These deserts are characterized by large areas and empty expanses of sand. The sandy deserts of Central Asia are bordered by the green plains of the Central Asian steppe in the north and abutted by soaring mountain ranges that border with Iran, Afghanistan, and China in the south and east.

Deserts occupy much of Kazakhstan and almost all of Uzbekistan and Turkmenistan. The deserts of Kazakhstan mostly cover lowlands and extend from the eastern coast of the Caspian Sea to the piedmonts of the Tien-Shan Mountain.

Central Asian deserts—particularly the sandy northern desert in central Kazakhstan and the southern desert, which covers Turkmenistan, Uzbekistan, and southern Kazakhstan—have a great diversity of natural conditions.

Desert areas are major source areas of dust- and sand-storm activities. Storms are particularly dangerous for the environment because they have a great impact on soil conditions. Thus, the study of aeolian processes as dust and sand storms in the sandy deserts of Central Asia and Kazakhstan has great importance toward aiding in the prediction and monitoring of storms and their movement patterns.

The aim of the study is the detection of dust, sand, and salt storm sources and determining their causes based on the consideration and analysis of numerous cartographic materials, data from weather stations, and satellite-monitoring materials, thereby providing an accurate picture of the distribution and frequency of storms over the deserts of the Central Asia and Kazakhstan. In addition, we also aimed to conduct a quantitative assessment of sand and dust transport during the process of deflation and thus determine the mobile-sand process in the deserts of Central Asia and Kazakhstan.

Consideration of the interesting topic of dust- and sand-storm distribution in the deserts of Central Asia and Kazakhstan, as well as the identification of powerful sources of dust- and sand-storm origin, is important and required to determine their role in soil deflation and desertification. Information and published scientific materials on dust and sand storms in Central Asia are quite limited, and especially rarely do such publications appear in English-language peer-reviewed journals. Therefore, this publication will fill a gap in our knowledge of aeolian processes as dust and sand storms in arid or desert areas of Central Asia and Kazakhstan.

The book is mainly addressed to scientists and researchers whose research has been focused on storm and land-degradation and -desertification studies as well as students and planners. It is intended to be a source of information and inspiration for all readers who feel responsible for initiating the sustainable development and sustainable use of natural resources in Central Asian countries. We are hopeful that readers will gain some useful information and inspiration from this book for their own work. We believe that this publication provides a great contribution to our knowledge about the nature of dust and sand storms, the causes of their origin, and the environmental issues they create.

Almaty, Kazakhstan/Urumqi, China Gulnura Issanova
Urumqi, China Jilili Abuduwaili

Content and Structure of the Book

This book summarises the outcomes of research results and recent studies related to dust and sand storms occurring in Central Asia and Kazakhstan. The book has seven individual chapters as follows. Chapter 1, “Introduction and Status of Storms in Central Asia and their Environmental Problems,” provides an overview of issues related to dust and sand storms, land degradation and desertification, shrinking lakes in Central Asia and their environmental changes, the relationship between dust storms and desertification process, as well as data sources on storms and research methods. The chapter contains six sections that analyze the current status of environmental issues brought by dust and sand storms. Chapter 2, “Natural Conditions of Central Asia and Land-Cover Changes”, provides information about climate conditions and weather processes in Central Asia, the natural geographical division of deserts in Central Asia and Kazakhstan, as well as land and soil resources and changes in soil and vegetation cover. Chapter 3—“Spatial and Temporal Distribution of Storms in Central Asia and Kazakhstan,” contains six sections providing information on the spatial and temporal distribution of storms and the variance of dust deposition in Central Asia, temporal changes in the frequency and intensity of storms in Kazakhstan, and atmospheric parameters influencing dust transport. Chapter 4, “Relationship Between Storms and Land Degradation,” contains three sections considering and analyzing the relationship between storms and land degradation. It provides information about natural and geographical conditions (topography, soils, vegetation) serving as sources of sand storms, the land-degradation process produced by wind erosion created by storms, and a comparative analysis of storm sources using temporal remote-sensing data along with ground-monitoring data. Chapter 5, “Dust Storms in Central Asia and Kazakhstan: Regional Division, Frequency and Seasonal Distribution,” contains eight sections that consider and describe the main sources of dust storms in Kazakhstan and Central Asia as well as their seasonal distribution, duration, and frequency. It provides information about main dust-storm sources in the Aral Sea basin including the Pre-Aral Karakum, Kyzylkum, and Aralkum deserts, other sources such as the Southern Pre-Balkhash and Naryn deserts, the seasonal distribution, duration, and frequency of storms, the relationship between storm origin and soil texture with favorable plant community, and visual identification of dust-storm sources based on satellite images. Chapter 6, “Aeolian Transport of Dust and Sand in the Deserts of Kazakhstan,” contains five sections that give a quantitative assessment of dust and sand transport during deflation and thus determines the mobile-sand process in the deserts of Kazakhstan. It offers quantitative information on the transport of dust and sand in the deserts of Kazakhstan (the Aralkum, Southern Pre-Balkhash, and Naryn deserts) as well as the direction of dust transport, the size of sand particles, and physical–statistical modelling of dust- and sand-transport processes. Chapter 7, “Conclusions”.

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Contents

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Gulnura Issanova has published many papers in international peer-reviewed journals with high level and wrote a handbook, "How to Write Scientific Papers for International Peer-Reviewed Journals."

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Jilili Abuduwaili has built international cooperation in research between Russia and Central Asian countries. He has published more than 200 papers in international and domestic journals and 7 books: *Lakes and Salt Dust Storms in Arid Lands* (in Chinese), *Overview of Central Asian Environments* (in Chinese), *Climate Change Effects to the Ecological System in TianShan Mountains* (in Russian), *Natural Geography of Kyrgyzstan* (in Russian), *Water Resources and Utilization in Uzbekistan* (in Russian), *Arid Soil in Kazakhstan: Current States and Utilization* (in Russian), *Salt Dust Storms: Special Disaster in Arid Lands* (in Uyghur).

Chapter 1
Introduction and Status of Storms in Central Asia and their Environmental Problems

1.1 Background of Research on Storms in Central Asia and Kazakhstan

Dust and sand storms are common events in the arid and semi-arid regions of Central Asia and Kazakhstan. In the Central Asian countries the main scientific observations on dust and sand storms were performed mainly before 1980 during the former Soviet Union. Regular monitoring of dust and sand storms began 1930s at a large number of observation sites located over the entire territory of Central Asia. The first studies and results of research regarding the analysis of dust and sand storm in terms of observations were published during the 1960s. The first classification and analyze the frequency and duration of dust and sand storms for the period 1951–1955 at 40 weather stations located all over Central Asian countries was performed by Romanov (1960). Seventeen synoptic processes, which are significant for formation of dust and sand storms, were identified. In addition, a classification of synoptic pre-conditions of the onset of dust and sand storms and recommendation for their forecasting were developed. According to studies, the northern, northeastern, and north-western winds cause the dust and sand storms in the major part of Central Asia, whereas eastern and southeastern winds favor the formation of dust and sand storms in the south of Turkmenistan. Orlovsky (1962) analyzed the frequency, duration, and spatial and temporal distribution of dust and sand storms in Turkmenistan at 42 weather stations during the period 1936–1960. At the same time, several papers about dust and sand storm characteristics for different regions of Kazakhstan were published. An analysis of the number of days with dust and sand storms in northern Kazakhstan was performed by Uteshev and Semenov (1967) whereas a data on dust and sand storms for southeastern Kazakhstan were presented by Fedyushina (1972a, b). Agarkova (1972) described a spatial distribution and duration of dust and sand storms in 5 administrative districts of Western and

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Southern Kazakhstan. A number of researchers—such as Chirkov (1970) and Sapojnikova (1970)—concluded that dust-storm activities over the arid territories of Central Asia are unevenly distributed due to the large variety of soil surfaces, and their frequency is increased from the north to the south. Based on data for 1936–1964, Central Asia and adjacent areas were divided into regions by dust-storm frequency. Semenov and Tulina (1978) published a refined map of dust and sand storms with average annual numbers for Kazakhstan.

Despite the relatively long history of systematic observations on dust storms in Central Asia (although most weather stations have been established in 1936), there is no comprehensive study of dust and salt storms. In addition, there are significant gaps of information and knowledge concerning the dust and sand storm activities before the 1980s in Central Asian countries in the international literature due to the fact that most of the information and research results on dust- and sand-storm observations have been published in Russian language. During the 1980s, by Goudie (1983) and Middleton et al. (1986) reviewed a number of articles in English about the frequencies, dust sources, and meteorological conditions associated with dust storms in the Central Asian countries. Later, Micklin (1988, 2007, 2010) studied the Aral Sea crisis.

Starting in the 1960s, the Central Asian region has experienced major changes in land use and land cover. Since the beginning of dust- and sand-storm monitoring in the Karakum and Kyzylkum deserts, it has been shown the these areas are the main source areas generating dust and sand storms, which in turn affect the entire region (Orlovsky et al. 2005). Zolotokrylin (1996) made an attempt to geographically distribute the dust- and sand-storm frequencies over the Turanian Lowland. He made an analysis based on ground observations at 65 weather stations during 1936–1985. The main geographic borders of dust and sand storm distributions were shown and identified in two maps, which was built based on the averages numbers of dust and sand storms for the periods of 1936–1965 and 1966–1985. According to the comparative analysis of the two maps, the geographic distribution of dust- and sand-storm zones with stable and unstable conditions over the territory of Central Asia were shown. In addition, Zolotokrylin specified that the consistent location of large source areas of dust storms in Turkmenistan and eastern Aral Sea region is one of the main characteristics in the spatial distribution of dust storms.

In the 1980s, methods of forecasting dust-storm development by Agarkova (1981), Polkovnikova and Skakov (1987), Skakov and Dmitrieva (1985), Skakov et al. (1987) were published. In 1985, Skakov and Dmitrieva developed three schemes of long-term forecasting of anomalies of dust storms. They proposed the background forecast with a lead-time of $\leq$4 months to give a typical field of dust storms on the territory of Kazakhstan. The other two methods are based on statistical two-level analysis with 15-factor linear models, thus allowing long-term forecasts of dust-storm anomalies.

Further progress has been made in the study of aeolian processes associated with conducting field and laboratory investigations on the nature of dust and sand storms. Since 1969–1998, 14 expeditions to the exposed bottom of the Aral Sea and 5 expeditions (field works) to the southern Pre-Balkhash deserts (Semenov 2011) have been conducted. In later years, the efforts of Kazakhstan meteorologists on the experimental study of storms have focused on areas of Kazakhstan that have been subject to intensive land-degradation and desertification processes.

1.2 Sand and Dust Storms in Central Asia and Kazakhstan

Dust and sand storms are common phenomena that occur in the arid and semi-arid regions of Central Asia and Kazakhstan (O'Hara et al. 2000). The term "Middle Asia" in the Soviet and Russian literature consists of the former USSR (e.g., Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan, and the southern part of Kazakhstan), whereas the term "Central Asia" includes as well the western parts of China and Mongolia (Cowan 2007). This vast region covered by a great variety of desert types and they represents a significant source areas of mineral and salt aerosols on the Asian continent along with the Gobi and Taklamakan Deserts (Orlovsky et al. 2009; Breckle 2009).

Dust storms are most dangerous in the desert, especially in the mobile sand massifs, which are a consequence of human activity including immoderate grazing and anthropogenic impacts (Babaev 1999; Orlovsky and Orlovsky 2001; Indoitu et al. 2012). Central Asia and the Southern Kazakhstan comprises a region with a high frequency of dust, sand, and salt storms. Storms are common events in arid and semi-arid regions of Kazakhstan, especially in its southern parts, where areas are covered by a great variety of deserts and are a powerful source of mineral and salt aerosols. The deserts are characterized by a scarcity of vegetation cover, frequent repetition of soil, and atmospheric droughts, strong winds, and a continental climate with long and dry summers (Faizov 1983; Faizov et al. 2006; Medeu 2010). In addition, many Kazakhstan drylands are represented by sandy and solonchak deserts of natural and anthropogenic origin, which are a source of mineral and salt aerosols (Orlova 1983; Orlova and Seifullina 2006). Sandy deserts and other types of deserts have been identified as active source areas of dust and sand storms. Ecosystems of the sandy deserts are unstable due to changes of natural and anthropogenic factors.

In Kazakhstan, apart from natural environmental factors, anthropogenic activities have exacerbated dust and sand storms during the last 50 years. The development of dust and sand/salt storms are associated with the crisis of the Aral Sea. The Aral Sea crisis was deteriorated by enhanced human activity in the basin. As a result of long-lasting anthropogenic factors in the use of water resources of the basin, issues related to the reduction of water surface and volume of the sea have formed. The driest part of the Aral Sea is considered to be a source for the development of salt and dust storms. Salt and dust particles from the dried bottom of the sea started to be transported over a significant part of the basin. The salt and dust thus removed affects not only climate and landscapes but also the health, living condition, and economic activity of the local population (Micklin 2007; Prospero et al. 2002; Gills 1996). In addition, the intensive salt and dust transfers and deposits affect the quality of the environment as well as the local biodiversity and biological productivity. At present, the removal, transportation, and deposition of dust, sand, and salt—all of which arise due to human activity and natural factors—are some the most negative phenomena experienced in the Aral Sea region and southern Pre-Balkhash deserts. The problem of the Aral Sea is part of the general desertification process occurring in many areas of the world.

The processes of desertification and soil degradation have occurred due to anthropogenic activity and level change of the Aral Sea and Balkhash Lake in Kazakhstan (Medoev 1981; Kudekov 2002; Faizov and Tapalova 2003; Spivak et al. 2012; Issanova et al. 2014, 2015a, b). Regulation of the flow level of the Syrdarya and Ili rivers led to a reduction of the groundwater level, thus increasing their mineralization, soil salinization, and drying of pond, which lead to the promotion of deflation processes. All of these actions seriously destroyed the environmental processes and led to serious forms of rapid soil and land degradation.

A deflation process due to sand and dust storms dominates the vast territory of desert pastures, located in southern Kazakhstan, with brown, gray-brown, takyr, and sandy soils (Faizov 1983; Dzhanpeisov 1977; Faizov et al. 2006). Deflation processes are important in arid environments such as deserts. Desert areas are also major source areas of dust- and-sand storm activities. The deserts of Kazakhstan mostly cover lowlands and extend from the eastern coast of the Caspian Sea to the piedmonts of the Tien-Shan Mountain.

The study and assessment of the dynamics of deflation processes due to dust and sand storms in sandy deserts is one the main crucial issues for arid areas in Kazakhstan. From this review, it is clear that investigations of soil deflation, desertification, and land and soil degradation are important and required. Therefore, the study of deflation process due to dust and sand storms in the desert zone of Kazakhstan has great importance and significance for the ecosystem ecology of the arid land.

In addition, studies on the detection of dust- and sand/salt-storm sources are required to find the causes of this phenomenon based on consideration and analysis of numerous cartographic materials, data from weather stations, and satellite-monitoring materials to provide accurate picture of the distribution and frequency of dust and sand storms over Kazakhstan.

1.3 Land-Degradation and Desertification Processes in Central Asian Countries

Land degradation is the gradual deterioration of the biological, chemical, and physical properties of the soil, thus reducing soil fertility (Almaganbetov and Grigoruk 2008). In addition, there is loss of biological productivity, and hence a decrease in the economic value of agricultural land caused by changing soil conditions as a result of natural causes or the irrational use of land (water and wind erosion, soil salinity, flooding, overgrazing, fires, cutting bushes, deforestation, etc.). Land degradation and desertification in arid, semi-arid, and dry subhumid regions is an global environmental issue. To develop global actions and measures to prevent and eradicate the problem, an accurate assessment of the status and trend of desertification process is needed. These are worldwide problems in drylands and moist lands; the term "desertification process" refers to the degradation of drylands (Breckle 2009; Belgibayev 2001; Kovda 2008). Drylands are territories where water income (precipitation) is less than the potential water expenditure (consumption and evapotranspiration by plant growth) during part of a year or during an entire year. This shortfall is the measure of aridity (Kassas 1995). In addition, land degradation occurs everywhere, but it is defined as desertification when it occurs in drylands; however, degradation in the tropics (savannahs, rain forest) may have even more severe consequences and may lead to unproductive, disastrous landscapes by definition (this process is not included in the term "desertification"). Some 70% of the 52 million km^2 of drylands around the world used for agriculture are already degraded. Thus, the desertification process has now damaged practically one quarter of the total land surface area of the world (Breckle 2009; Kovda 2008).

Desertification is a process that changes an entire landscape or ecosystem from an optimal and dynamic ecological equilibrium through various processes of degradation toward an area with less productivity, less biodiversity, and less sustainable land-use options (Breckle 2009; Kovda 2008). Combinations of several factors cause the desertification process. Desertification is the consequence of a set of important processes that are active in arid and semi-arid environments, where water is the main limiting factor of land use in ecosystems, as well as several factors such as climate change and human activities. Human activities are a major degradation factor in drylands. Livestock is one of the human activities. Overgrazing is caused by several indirect factors such as growing numbers of livestock to meet market demand and the concentration of livestock due to sedentarization policies (Schlesinger et al. 1990; Laycock 1991; Fleischner 1994; Archer et al. 1995; Daily 1995; van Auken 2000; Okuro 2010). Another important anthropogenic factor is agricultural activities. Inappropriate agriculture includes shortening of the fallow period/crop interval, reclamation of less-favored areas, insufficient use of fertilizers, improper use of irrigation water, poor drainage, and the absence of anti-erosion measures (Okuro 2010). In addition, over-exploitation of vegetation is also regarded as a major factor in desertification. Deforestation leads to the depletion of wood resources as well as the onset of desertification. Cultivated land and pastoral rangeland leads to synergistic interaction and enhances the land-degradation process.

Changes in climate, human-induced stress, herbivore, and fire regime are also mechanisms in desertification. The desertification process is deeply associated with biodiversity loss, and it contributes and affects to global climate change. Soil and vegetation losses may cause the release of a major fraction of their carbon stores to the atmosphere with significant feedback consequences to the climate

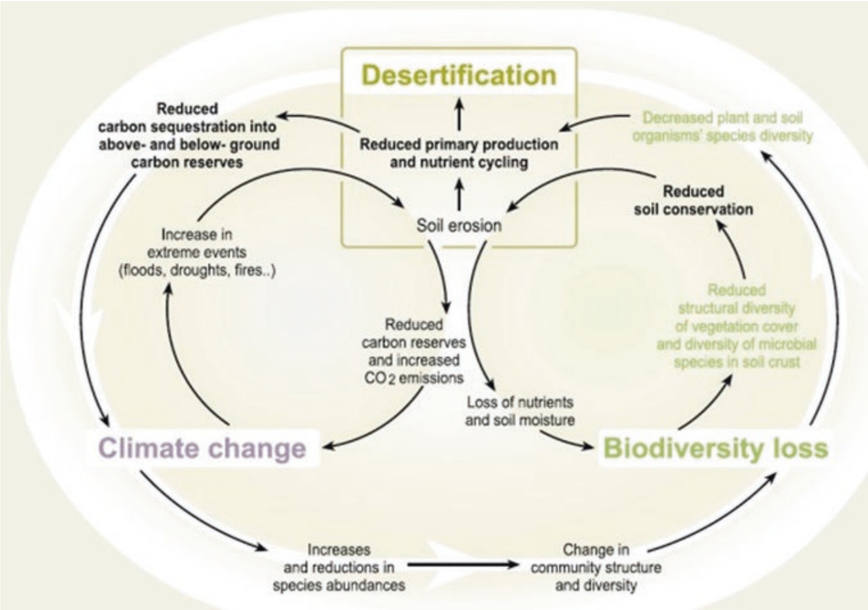

Fig. 1.1 Relationship among desertification, global climate change, and biodiversity loss. The major components of biodiversity loss (*in green*) directly affect major dryland services (*in bold*) (MA 2005)

system at a global scale (Fig. 1.1). Global-climate warming may also adversely affect biodiversity and community structures due to increased evapotranspiration (Okuro 2010).

The UNCCD is one of the three main international ecological conventions. The UNCCD states that "Desertification is the degradation of land in arid, semi-arid and dry sub-humid areas that caused primarily by human activities and climatic variations." It is the result of complex interactions among various factors including climate change and human activities (Thomas 1997; UNCCD 1994). The process contributes to environmental instability of natural landscapes and anthropogenic pressures. Land degradation is also defined as the reduction or loss of the biological and economic productivity and complexity of irrigated croplands and rainfed lands, pasture, forest, or woodlands resulting from land uses and processes arising from human activities and habitation patterns.

Desertification occurs in dryland ecosystems. Dryland ecosystems cover more than one third or even half of the land area in the world. The ecosystems in drylands are inappropriate for land use and extremely vulnerable to overexploitation. Deforestation, overgrazing, unsustainable irrigation practices, as well poverty and political instability, all undermine the productivity of the land (Breckle 2009). The manifold aspects of desertification are listed in Table 1.1.

Table 1.1 Main characteristics, effects and aspects of desertification according to Breckle (2009)

Causes/reasons	Ecological aspects	Economical aspects	Social/Human aspects
Deforestation, forest fires Overgrazing Over-exploitation by collecting plants Over-exploitation by hunting, fishing Irrigation with improper water Sol erosion and soil compaction Salinization Plowing at wrong places and wrong time: wind erosion Pollution by various sources (industrial poisoning, pesticides) Mining Dumping	Loss of biodiversity of plants, animals, and ecosystems Loss of upper soil horizons (less humus and the wrong clay minerals, less N, P, and K storage) Loss of freshwater lakes Decreased seapage but increased water logging and salinity More frequent sand and dust storms More erosion by wind and water; accumulation of particles elsewhere: sand/dust deposition	Decreasing yields from cultivated plants Loss of agricultural and farm areas Loss of suitable grazing grounds Decreased capacity for grazing cattle, etc. Abandonment of agricultural and farming grounds Abandonment of grazing grounds, more bush encroachment and bush fires Drifting sand and blowing dust block roads and railway tracks Increasing sediment loads of rivers causing increased danger for inundations of farmland, settlements, cities, etc. Loss of property and income sources for cash	Sand and dust storms causing damage and danger for human and animal health Health problems, famines Migration of people from rural areas to cities Increased poverty of rural populations Increased number of (economic) refugees in urban centers and across countries Increased economic problems for supplying infrastructure in growing urban centers Increased chaos, anarchy, terrorism, and crime

The most significant climatic factors of desertification are drought, strong winds, and dust storms. Climatic parameters (temperature, humidity, precipitation, wind, etc.) determine the intensity of the physical evaporation, the degree of soil moisture, and consequently the processes of soil erosion and deflation due to dust and sand/salt storms.

The problem of desertification is an issue of global importance. Approximately 70% of drylands in the world (approximately 3.6 billion ha) have been degraded (Eric 2003). In 1994, the Central Asian countries signed and ratified the United Nations Convention to Combat Desertification. The Central Asian countries were among the first states in the world to combat desertification. Desertification and related forms of land degradation in Central Asian countries have greater consensus than the remaining environmental issues. Diverse factors cause and exacerbate desertification and land-degradation processes within the Central Asian countries. Diverse factors—such as loss of vegetation cover from over-grazing, expanding human populations, pollution of natural resources, wind and water erosion, water logging of soils and salinization from substandard irrigation practices, depletion of soil resources from the non-rotation of crops, and the desiccation of the Aral Sea—may cause desertification and land degradation in general (Breckle 2009; Kovda 2008). Consequently, land degradation in Central Asia is a concern in deserts and semi-deserts in Turkmenistan, in agricultural valleys in Uzbekistan, and at high altitudes where areas in the populated areas of Tienshan and Pamir mountains of Tajikistan and Kyrgyzstan.

The total area affected by desertification amounts to >1073 thousand km^2 in Central Asia. This is due to extensive land use, which leads to their degradation (Eric 2003). Causes of land degradation and desertification are mainly due to climatic variations and human activities.

Kazakhstan is the largest country of Central Asia with largely cover desert. Approximately 60% of the territory of Kazakhstan is deserts and semi-deserts compared with Turkmenistan and Uzbekistan where desert covers 80% of the territory (Breckle 2009; Faizov et al. 2006). The remaining Central Asian countries (Tajikistan and Kyrgyzstan) are more mountainous, although they also contain arid and desert areas. Despite the sensitivity of these arid lands and the expense of reclamation, deserts and semi-deserts within Central Asian countries are extensively used for cattle grazing and agriculture.

Arable lands are heavily degraded in Central Asia. For instance, 95% of irrigated lands in Turkmenistan suffer from soil salinization and 40% from extensive land degradation; only 17% are acceptable to use. Approximately 30% of agricultural lands in Kazakhstan are salinated, waterlogged, or at-risk. Sixteen percent of irrigated lands in Tajikistan are subject in some degree to soil salinization; another 8% are otherwise degraded; and the majority of areas of the country are affected by soil erosion and can not be used directly for agriculture (Breckle 2009). Regarding the adverse impacts of these factors on Central Asia, desertification and land-degradation processes reach levels similar to those of Africa. These trends are exacerbated by the transition period. During this period, total numbers of livestock have decreased, which allowed the natural restoration of areas where livestock graze and as well as the control and regulation degrading activities. However, livestock-grazing areas are over-grazed and oversight has become lax, consequently contributing and leading to the degradation of the local land capacity (Almaganbetov and Grigoruk 2008; Alibekov and Alibekov 2008; Breckle 2009).

The root causes of land degradation and desertification in Central Asia are not actively being discussed yet, and consequently corresponding efforts and activities have not yet been made to address these them. In addition, there is little political will to do so. In Central Asia, the extensive cultivation of cotton is a prime reason for degradation.

The main factors of soil degradation and desertification is soil salinization, soil erosion (wind and water erosion), dehumification processes, soil deflation, and decreased productivity of arable lands (Asanbayev and Faizov 2007; Faizov et al. 2006).

In Central Asian states, including Kazakhstan, degradation generally occurs as a result of secondary soil salinization; irrigation and wind erosion, reducing the amount of humus and organic matter; soil contamination with agrochemicals; water logging, etc. (Mueller et al. 2014; Issanova et al. 2014, 2015a, b).

In Kazakhstan, land degradation began in the 1950–1960s due to the development of virgin lands, increasing livestock numbers, and changing grazing practices (Robinson et al. 2003; Almaganbetov and Grigoruk 2008). In Kazakhstan, land degradation and desertification are observed in almost all soil-climatic zones, especially in areas with a predominance of extensive agriculture (Mueller et al. 2014; Almaganbetov and Grigoruk 2008). Soil degradation and desertification is a common process in arid and semi-arid regions of Kazakhstan, especially in its southern parts, where areas are covered by a great variety of desert types, which are the most arid regions of Kazakhstan. In deserts, soil-forming processes take place under conditions of severe water shortage as well as a high level of soil degradation and desertification (Muller et al. 2014). Currently desertification processes occur in all regions of Kazakhstan. Moreover, there is a tendency for them to accelerate. A large area in Kazakhstan—120 million ha of deserts is subject to desertification due to anthropogenic factors (Iskakov and Medeu 2006; Almaganbetov and Grigoruk 2008). Analysis of the current status of the soil cover has shown intensive land-degradation and -desertification processes. Seventy-five percent of the territory of Kazakhstan has been subjected to degradation and desertification, and >14% of pastures have reached an extreme degree of degradation or are completely degraded (Almaganbetov and Grigoruk 2008; Orlova and Saparov 2009; Mueller et al. 2014). The desertification of huge territories is accompanied by soil contamination, water logging by surface water and groundwater, soil salinization, erosion (water, wind), degradation of vegetation cover, dehumidification, and decreased general regional biological capacity (Kovda 2008; Medeu 2010). Wind erosion has affected the plains and exposed >20 million ha of arable land and 25 million ha of pasture. Water erosion hit 19.2 million ha of land and continues to progress (Iskakov and Medeu 2006). In addition, anthropogenic desertification caused by industrial activities, loss of humus in soils, and salinization of irrigated lands appears to be quite a serious issue. During the past 40 years, the humus content in the soil has decreased by 20–30% (Akhanov 2008).

The influence of anthropogenic factors is seen almost in all natural landscapes, especially in the Aral Sea region, where degradation and desertification processes are becoming more widespread. In addition, the northern Caspian Sea and southern Balkhash deserts are subject to a significant degree of land degradation under due to grazing (Medeu 2010; Issanova et al. 2014).

The irrigated agriculture expansion programs were the major reason for and factor of land degradation in Uzbekistan and Turkmenistan. The irrigated agriculture expansions lead to vast areas of natural desert pastures being transformed into cotton fields (Saiko and Zonn 2000; Wiggs et al. 2003). One of the major consequences of the landscapes transformation were the increase of dust- and sandstorm frequencies for significant territories of Central Asian countries including Kazakhstan.

Conditions for the development of land degradation are in violation of the seasonal features of soil formation under the influence of drought. Another prerequisite to desertification is a weakly formed land cover and its dynamics. These natural land features of Kazakhstan result in poor resistance of the environment to human impact (Asanbayev and Faizov 2007; Faizov et al. 2006).

The main natural factors for these processes are flat terrain, high degree of arid climate, salinity, carbonate content, lack of structure, and low natural soil fertility. However, the anthropogenic factors of desertification and soil degradation have become dominant in the last decades. Desertification is caused mainly by anthropogenic factors such as the active development of irrigation networks, the excessive use of water for cotton production, inadequate drainage, and the degradation of ecosystems.

The Aral Sea region, Northern Caspian Sea, and Southern Balkhash deserts can be observed as areas of intensive soil-desertification, -salinization, and -deflation processes. In addition, the desertification process are progressing in the irrigated soils of the deltas of the Syrdarya, Shu, Ile, and Karatal rivers. In the most fertile delta–alluvial plain of the Syrdarya River, the area of desertified land is 1.1 million ha, and in the dried-up bottom of Aral Sea it is 1.5 million ha, of which saline marsh soils occupy 0.8 million ha (Mueller et al. 2014; Issanova et al. 2014). The most fertile delta–alluvial plain of Syrdarya River is the primary rice granary of the country. In addition, the Balkhash–Alakol region is widely noted as being subject to the processes of secondary soil salinization of irrigated lands and destruction; land erosion and digression is now occurring in foothill and mountain areas (Issanova et al. 2014). In addition, a strong degree of desertification has been observed in the valley and delta of the Syrdarya River. The vegetation cover has changed and has been replaced by desert plants. Noted that reeds, forb-grass plants, and liquorice meadows have almost completely disappeared. Desertification in the Syrdarya River delta and floodplain is more concerned with the economics, or rather, the mismanagement of human activities.

On the vast territories of Kazakhstan exist a number of regions where the combination of various forms of environmentally damaged soils has resulted in a crisis situation. The ecological crisis in the Aral Sea region remains the main problem in Southern Kazakhstan. The area is subjected to irreversible processes of desertification, intensive soil desertification, salinization, and deflation (Faizov and Tapalova 2003; Pankova et al. 1996; Issanova et al. 2014; Abuduwaili et al. 2015). A decreases area of the Aral Sea has led to desertification of vast territory in the delta–alluvial plain. The salted sea bottom was exposed over an area of 3 million ha, of which 2 million ha lies in the region. There Desert landscapes have formed, resulting in the removal of salt and dust toxic mixture to other territories, thus consequently changing the environment (Abuduwaili et al. 2012, 2015).

For a better understanding of soil- and land-degradation and -deflation processes, it is necessary to reveal the regional divisions of deserts in Central Asia and Kazakhstan, which are the most prone to the dust and sand storms.

1.4 Shrinking Lakes in Central Asia Plus Dry Regional Environmental Changes

Central Asia is rich in many continental and foothill lakes. The largest of the lakes is the Caspian and Aral seas, Balkhash, Alakol, Ebinur, Lobnur, which are included in the list of the largest inland water reservoirs on the Earth. The lakes are like a “crown of diamonds” surrounded by mountains in the steppes and deserts. They comprise linked and interacting system that softens the arid or dry conditions of surrounding areas.

The Aral Sea belongs to the category of large water reservoirs on the Earth. The sea is located amid the Central Asian great deserts (Fig. 1.2). Its drainage basin covers 1.8 million km^2 within Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, Afghanistan, and Iran. Only Kazakhstan and Uzbekistan are riparian on the sea proper and possess an approximately equal length of shoreline. The entire Aral Sea coastline lies within Karakalpakstan in Usbekistan (Micklin 2007). The terminal lake has a surface inflow but no surface outflow. Therefore, given the balance between inflows from the Amudarya and Syrdarya rivers, net evaporation (evaporation from the sea surface minus precipitation on it) fundamentally determines the level of the sea. Net groundwater inflow has been estimated at from 1.3 to 3.4 km^3 year^{-1} and has been considered an inconsequential part of the water balance (Bortnik and Chistyaevaya 1990). However, in the past several decades, this part of the water balance has become a more important factor due to the diminution of surface inflow.

Due to the unscientific and uncontrolled extraction of water for irrigation in Central Asia and Kazakhstan, which began in the 1950s to 1960s of the last century, the water flow has decreased in the Aral Sea and since the 1980s has ceased. As a result, anthropogenic impacts on the basin ecosystem have led to several negative consequences such as soil salinization, desertification, and environmental changes.

Fig. 1.2 Aral Sea basin (Micklin 2007)

The sea level variations were <4.5 m from the mid-eighteenth century until the 1960s (Bortnik 1996). From 1911, when instrumental observation began, and until the early 1960s the water balance of the Aral Sea was remarkably stable in terms of annual inflow and net evaporation. During this period, the water balance of its each components was nearly 56 km^3 on average with net evaporation consisting of evaporation of 66 km^3 from the surface of the sea (estimated by theoretical and empirical formulae) minus 9 km^3 of precipitation on the surface of the sea (calculated from measurements taken at shore and island stations) (Fig. 1.3) (Bortnik and Chistyaevaya 1990; Micklin 2007). Hence, the maximum variation of the lake level was <1 m, and the water balance was in long-term equilibrium.

The Aral Sea, according to its area with slightly >67,000 km^2, was the world's fourth largest inland water body in 1960 (Micklin 1991). The salinity of the lake was approximately 10 g/l on average, which is one third less compared with the ocean's salinity. Freshwater fish species mainly inhabited the sea (Micklin 2007). A major fishery was supported by the sea. The sea functioned as a key regional transportation route. A diversity of flora and fauna are sustained in the extensive deltas of the Syrdarya and Amudarya rivers. The deltas of these rivers also supported irrigated agriculture, cattle grazing, fishing, hunting and trapping, and harvesting of reeds, which is used as building materials, as well as fodder for livestock.

Since the early 1960s, the water balance, morphology, and ecology of the Aral Sea have changed dramatically. Consequently, the sea has steadily shrunk and

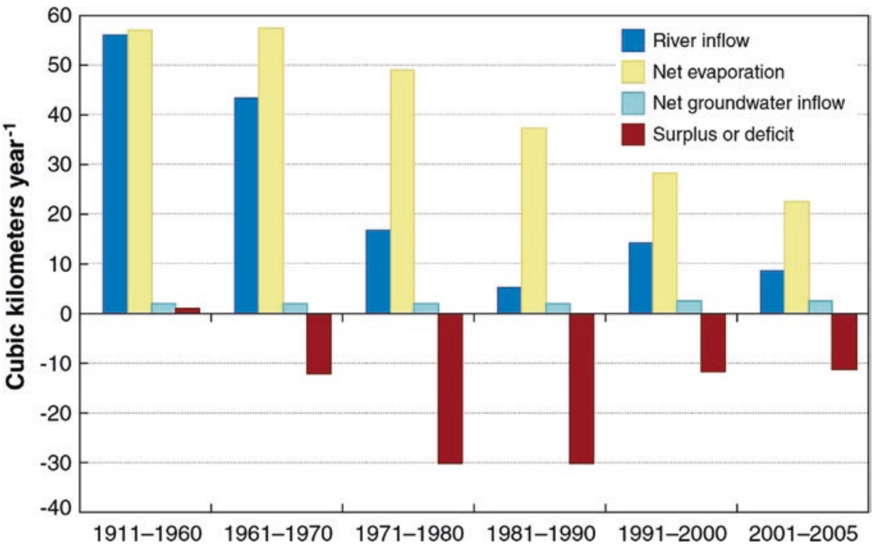

Fig. 1.3 Average annual water balance for the Aral Sea (1911–2005). *River inflow* = flow of Syrdarya and Amudarya to Aral Sea; *net evaporation* = evaporation from the sea surface minus the precipitation on it; *net groundwater inflow* = groundwater flow to sea minus flow from sea; *surplus or deficit* = (inflow to sea + net groundwater inflow) minus net evaporation. From Bortnik and Chistyaevaya (1990); Uzglavgidromet (1994–2003), Micklin (1990–2006), Annual Data (1987), Shivareva et al. (1998) and Micklin (2007)

been salinized (Table 1.1) (Micklin 2007). The river inflow decreased dramatically for the period after 1960 (Fig. 1.3). For the 1960s, the discharge to the sea was 43 km^3 $year^{-1}$ on average; net groundwater inflow was 2.5 km^3 $year^{-1}$; and net evaporation was 57 km^3 $year^{-1}$ yielding a water deficit of 12 km^3 $year^{-1}$. During the 1970s and 1980s, the water-balance deficits for both periods were >30 km^3 $year^{-1}$; therefore, the difference between the river inflow and net evaporation was particularly pronounced. Consequently, during these two decades the sea level decreased especially rapidly. From 1974 to 1986, the Syrdarya River provided no flow to the Aral Sea, and the Amudarya River provided minimal or no flow in 1982–1983, 1985–1986, and 1989 (Izrayel and Anokhin 1991; Micklin 2007). The water flow from the Amudarya and Syrdarya rivers, which represent the major input for the Aral Sea, was approximately 55–60 km^3 in 1960 (Orlovsky and Orlovsky 2001). The water volume discharged has almost ceased and was only 4.1 km^3 five decades later during 2006–2010 (Micklin 2010). However, during the 1990s the water balance for the Aral Sea has substantially improved. This is due to more precipitation in the flow, which is generated from the mountains of the Aral Sea basin as well as some reduction in water withdrawals for irrigation (12% reduction between 1980 and 1995). A significant reduction in net evaporation decreased the water-balance deficit to approximately 12 km^3 $year^{-1}$. River discharge to the sea was approximately 14 km^3 $year^{-1}$ on average (Micklin

2007). For 1999 through 2001, average annual inflow to the Aral Sea was nearly 5 km^3 with nearly 90% provided by the Syrdarya River. Inflow to the Aral Sea was approximately 9 km^3 at average for the period 2001–2005, and net groundwater inflow was approximately 2.5 km^3 with a net evaporation of approximately 22 km^3, which gives a deficit approximately 11 km^3 (Micklin 2007).

Since 1960, the surface area and water volume of the Aral Sea has diminished. The sea level declined substantially with a 53% decrease in surface area and a 70% decrease in volume (Wiggs et al. 2003). The water volume of the Aral Sea was 1093.0 km^3 in 1960; it decreased to more than half (448.00 km^3) in 1986; and further decreased to 105 km^3 in 2009 (CAWater Info). The surface area of the Aral Sea was 67,500 km^2 in 1960 (Micklin 2010), whereas the water surface occupied the area 13,500 km^2 in 2009 (CAWater Info). The fourth largest inland water reservoir on the Earth in 1987 was divided into two parts: northern Small Aral, and southern Big Aral. In 2009, Big Aral was separated into the deep Western and shallow Eastern parts. The Syrdarya River flows into the former sea (Small Aral), and the Amudarya River flows into the Big Aral. Between 1960 and January 2006, the level of the Small Aral decreased by 13 m and in the Big Aral by 23 m (Table 1.2).

A channel (river) was connected the two water bodies through the flow from the Small Aral to the Big Aral Sea. This flow mainly occurs during the spring and early summer period because the water discharge from the Syrdarya River to the Small Aral is greatest during this period. However, the flow is much less and often entirely ceases during most of the year. The area of both water bodies combined decreased by 74% and by 90%, respectively, in volume (Micklin 2007). According to MODIS real-time satellite imagery in the late 2005, the Big Aral Sea became three distinct water bodies: a “deep” western lake, a “shallow” eastern lake with a connecting narrow channel, and a cut-off Gulf of Tshche-Bas. For the last several years, including 2006, the cut-off Gulf of Tshche-Bas was reconnected for a short period to the Big Aral Sea during the spring and early summer period of heavier runoff (MODIS Rapid Response System 2006).

Efforts to partially restore and preserve the Small Aral Sea are underway: In 2005, a dike 13-km long was constructed to block the water inflow of the Syrdarya River into the Big Aral Sea to preserve at least the Small Aral Sea. The discharge gates of the dike have now been opened and water flow is again allowed to flow to the Big Aral Sea. The Small Aral Sea’s level will be maintained at 42 m. Consequently, the ecological condition of the sea will be improved: The water body of the sea will be fresh and fishery prospects will be developed (Micklin 2007).

A desiccation of the Aral Sea, caused mainly by human activities and waterflow reduction, soil salinization, and pollution of influent rivers (Syrdarya and Amudarya rivers) has had severe negative effects for the environment (Micklin 2000, 2004). In addition, the consequences of these negative effects affected the area surrounding the sea including a population of several million (Khvorog 1992). The regions that suffered the most include some parts of the Kyzylorda

Table 1.2 Hydrological and salinity characteristics of the Aral Sea for 1960 to 2011 (Micklin 2007)

Year	Level (m asl)	Area (km^2)	% (1960)	Volume km^3	% (1960)	Average salinity (g/l)	% (1960)
1960 (whole Aral Sea)[a]	53.4	67,499	100	1089	100	10	100
Large Aral Sea	53.4	61,381	100	1007	100	10	100
Small Aral Sea	53.4	6118	100	82	100	10	100
1971 (whole Aral Sea)[a]	51.1	60,200	89	925	85	12	120
1976 (whole Aral Sea)[a]	48.3	55,700	83	763	70	14	140
1989 (whole Aral Sea)[b]		39,734	59	364	33		
Large Aral Sea	39.1	36,930	60	341	34	30	300
Small Aral Sea	40.2	2804	46	23	28	30	300
2006 (whole Aral Sea)[b]		17,382	26	108	10		
Large Aral Sea	30.0	14,325	23	81	8	East Sea >100 West Sea 70–80	100 700–800
Small Aral Sea[d]	40.5	3057	50	21	26	12	120
2011 (whole Aral Sea)		12,130	18	90	8		
Large Aral Sea[c]	28.3	8550	14	62	6	>100	>1000
Small Aral Sea[d]	42.0	3258	53	27	33	~10	100

Notice [a]Annual average
[b]On January 1
[c]The sea was divided into western and eastern parts
[d]After implementation of the North Aral project in 2005
Data for 1960, 1971, and 1976 from Annual Data (1987) and Bortnik and Chistyaevaya (1990); data for 1989, 2006, and 2011 from Uzglavgidromet (1994–2003); Micklin (1990–2006, 2005); Ptichnikov (2000, 2002, 2002–2003)

region in Kazakhstan and Karakalpakstan in Uzbekistan. Dashauz is the one oblast (or region) in Turkmenistan that has been substantially affected although the region is not abutted on the sea (Micklin 2007).

In addition, the extensive Amudarya River delta, which has a rich and diverse ecosystem primarily located in Karakalpakstan (Uzbekistan), has suffered considerable harm (Micklin 1991, 2004).

In Kazakhstan, the Syrdarya River delta has endured relatively less but still substantial damage. The river flows through the deltas have been greatly reduced by the virtual elimination of spring floods and construction of upstream storage reservoirs. As a result, the level of the Aral Sea has decreased and, consequently, groundwater levels have declined. All of these realities have led to a spreading and intensified desertification process in the Aral Sea basin. The vegetation community of the region has replaced by other types of vegetation. For instance, halophytes and xerophytes are rapidly replacing endemic vegetation communities (Novikova 1996, 1997). Moreover, salts have accumulated on the soil surface, which form solonchak (saline soils) in some places, and therefore these places have become worthless (non-fertile) land for growing. Vast areas with unique tugay vegetation communities, which are distributed along the main rivers and distributary channels, have been particularly d damaged. For instance, in 1950 tugay communities covered 100,000 ha in the Amudarya River delta (Novikova 1996), but by 1999 they decreased to only 20,000–30,000 ha (Severskiy et al. 2005).

Lakes and wetlands, as well ad their associated reed communities, have significantly diminished due to the desiccation of the river deltas. The area of lakes in the Amudarya River delta decreased from 49,000 to 8000 km^2 between 1960 and 1980 (Chub 2002). Reed communities in the delta covered as much as 500,000 ha in 1965, but by the mid-1980s the area had declined dramatically (Palvaniyazov 1989). This destruction of natural resources (water, soil, vegetation, etc.) has resulted in serious ecological consequences and changes of the environment. The ecological consequences of these negative effects have affected even waterfowl (permanent and migratory) in these dessicated zones. A number of permanent and migratory waterfowl are currently endangered (Micklin 1991). In addition, the aggregate water surface area decreased, and the water bodies have been increasingly polluted primarily by irrigation runoff containing salts, pesticides, fertilizers, herbicides, and cotton defoliants, which adversely affect aquatic bird populations. However, since the late 1980s measures for improvement have been taken, and significant efforts have been made to restore wetlands, decrease environmental pollution, and improve habitat conditions (Chub 2002).

Irresponsible water use of the Amudarya and Syrdarya rivers affected the irrigated agriculture in the deltas. Consequently, the irrigated agriculture has suffered from an inadequacy of water, that is, water inflow to the deltas has decreased because of heavy upstream consumptive use for irrigation. In addition, the leaching of salts, which is caused by repeated use in the middle and upper courses of the rivers, has elevated the salinity of the water reaching the river deltas (World Bank 1998; Micklin 2007). At times >2 g/l, these saline flows have decreased crop yields and, in association with poor drainage of irrigated fields, have promoted soil salinization. In addition to the reduction of pasture area and their declining productivity resulting from replacement of natural vegetation suitable for grazing by inedible species, decreasing groundwater levels and desertification process in general have led to damage to animal husbandry in the deltas and desert regions adjacent to the Aral Sea (Micklin 2007).

As a result of the intensive development of irrigation, irresponsible use of water resources has led to serious soil- and land-degradation process. Significant areas of secondary saline soils and anthropogenic solonchaks have appeared in the Aral Sea basin. These areas have become a source of salt, dust, and sand transfer. Dust, sand, and salt from the dried bottom of the Aral Sea are transported by strong and very strong winds. Large portions of blown material is transported onto surrounding areas that are now a barren desert.

Observation from space reveals the main sources of salt- and dust-cloud formation, their size, and the main directions of salt and dust transportation. Since the mid-1970s, satellite images have shown major salt and dust clouds or plumes extending as far as 500 km downwind that transfer and drop dust and salt over a considerable adjacent area to the Aral Sea in Uzbekistan and Kazakhstan as well as Turkmenistan albeit to a lesser degree (Micklin 1991, 2004; Glazovskiy 1990; Ptichnikov 2002). Although dust and salt storms affect the entire surrounding zone of the Aral Sea, major storms mostly occur with north and northeast winds. Storms most seriously impact the Usturt Plateau in the west part of the sea and the Amudarya River delta in the south end of the sea (Bortnik and Chistyaevaya 1990). The Amudarya River delta is the most densely settled as well as economically and ecologically important region around the sea. According to analysis and estimates by Glazovskiy (1990) made in the 1980s, the total deflated material was from 40 to 150 million tons. Salts in different (dry and aerosol) forms are the most harmful. They include sodium chloride, sodium sulfate, and sodium bicarbonate, and they settle on natural vegetation and crops particularly in the Amudarya River delta (Belgibayev 1984; Yongxiao et al. 2016). Consequently, in some cases, plants are killed outright, but more commonly their growth and yield is substantially reduced. In addition, salt and dust storms have negative effects on wild and domestic animals (Palvaniyazov 1989). Salt and dust that blow from the dried bottom of the sea and from irrigated farmland in areas adjacent to the Aral Sea are contaminated with heavy metals and pesticides, which would exacerbate the negative impacts on humans and other animals (O'Hara et al. 2000).

The desiccation of the seafloor affected the ecology as a whole including climate condition in the region. Due to shrinkage of the sea volume, microclimate condition has changed 100 km–wide along the former shoreline in Uzbekistan and Kazakhstan (Micklin 1991, 2007; Glazovskiy 1990; Abuduwaili et al. 2010). Maritime conditions of the sea have been replaced by more continental and desertic regimes. Summers have become warm and winters cool; the air humidity is lower; the growing (vegetation) season has become shorter; and the autumn frosts come earlier and the spring frosts later. According to expert climate researchers from Uzbekistan, the surface radiation depends on atmospheric content, that is, the increasing level of salt and dust in the atmosphere reduce the surface radiation and thereby photosynthetic activity, as well as increase the acidity of precipitation (Chub 1998).

The salt and dust storms can also affect the health and living conditions of the local population around the sea. The population living in the ecological disaster zone suffers acute health problems. Environmental pollution associated with the use of toxic chemicals as pesticides and defoliants for cotton in irrigated agriculture cause serious health-related problems (Micklin 1992; Medicine sans Frontieres 2000). According to the health expert's opinion, airborne salt and dust is a main factor that contributes to high levels of respiratory illnesses and impairments, eye problems, and throat and esophageal cancer in the Aral Sea region (Abdirov et al. 1993; Tursunov 1989). Nevertheless, the most serious health issues are directly related to hygienic conditions and practices, health, and nutrition. Contamination of drinking water by bacteria is pervasive. It has led to very high rates of dysentery, viral hepatitis, paratyphoid, and typhoid. Liver and kidney ailments are widespread because of the excessively high content of salt in the drinking water (Anokhin et al. 1991).

1.5 Sand and Dust Storms and Desertification in Central Asia

Sand and dust storms are both a symptom and cause of desertification. In Central Asia, including Kazakhstan, sand and dust storms are common due to the vast areas of sandy, solonchak, and clayey deserts with a scarcity of vegetation cover and strong winds (Fig. 1.4).

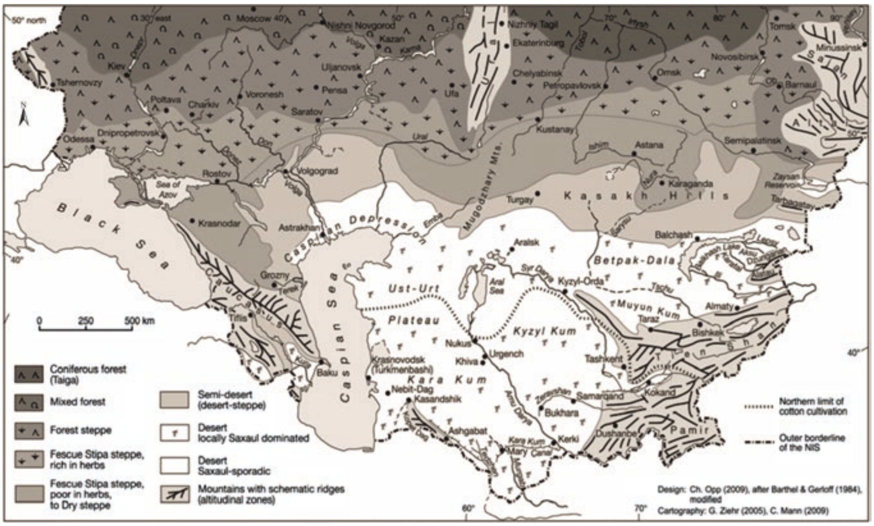

Fig. 1.4 Vegetation zones of Central Asia (Orlovsky et al. 2009)

Dust and sand storms can be a cause of serious anthropogenic land degradation and desertification process with dire consequences. Storms affect the climate at a global scale by forming clouds that affect rainfall patterns as well as the global carbon cycle and oceanic ecosystems. Dust storms are the main factor of air pollution in Central Asia, which affect the ecological and environmental situation of the region as well as the living conditions and health of the local population. Storms damage not only the environment and living conditions in the source area, they also has adverse impacts on non-drylands through the transport of anthropogenic atmospheric pollutants, which cause respiratory diseases in eastern Asian countries.

Dust storms are among the most serious wind-erosion events in arid environments. Storms are natural phenomena in which the wind carries dust, sand, and salt from dried playas (desiccated seafloor) and deserts. Anthropogenic desertification processes have resulted in wind erosion and the deposition of sediments in saline lake basins in Central Asia including Kazakhstan. Desertification and shrinking of terminal lakes are producing aeolian dust and salt sediments, which

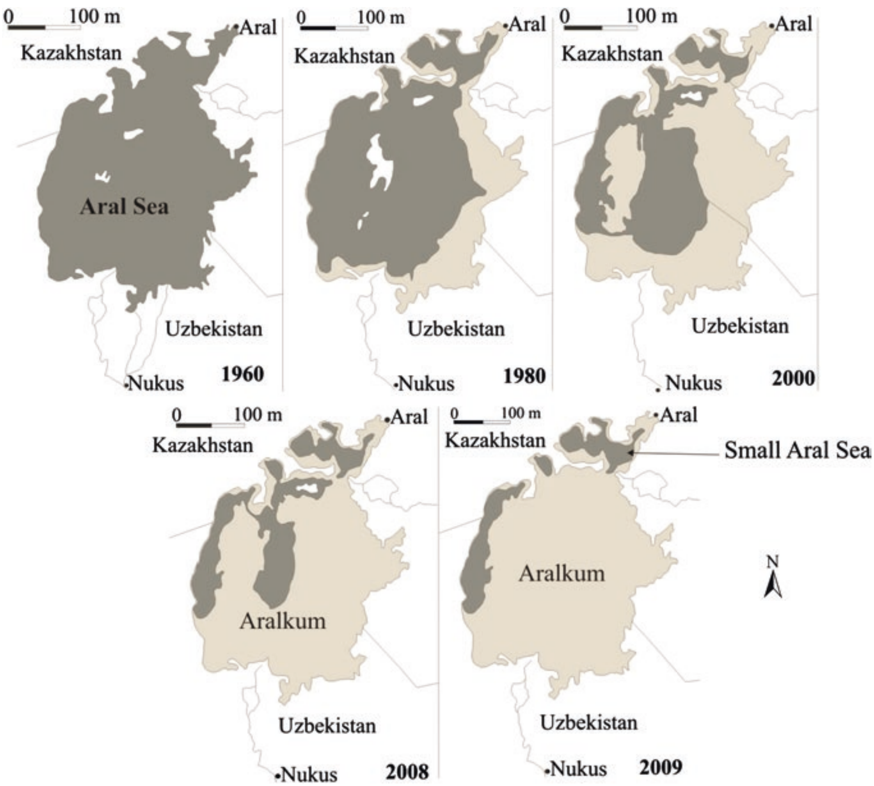

Fig. 1.5 Changing the Aral Sea profile and formation of the Aralkum Desert (1960–2009). *Dark grey* = water-covered area. *Light grey* = dry sea bottom (modified after Groll et al. 2012)

have negative impact on the environment (degradation of air/soil quality and sensitive ecosystems) and human health (respiratory health effects) as well as potential geomorphological effects such as changes in playa and dune surfaces and the development of aeolian horizons in soil profiles (Gills 1996). The playas formed by human factors as a result of desiccation of the Aral Sea are the largest main sources of fugitive dust, sand, and salt in Central Asia and Kazakhstan. Large-scale anthropogenic changes, such as the drying of the Aral Sea, have lead to the formation of new salt- and dust-emitting sources (Fig. 1.5) (Mainguet 1991; Giese 1997; Breckle 2001; Opp 2007).

1.6 Data Sources on Storms and Research Methods

In this study, we used traditional geographic methods as well as modern methods of mathematical modeling and remote sensing.

1. Comparative and geographical method and GIS technology. GIS technologies rely on the use of spatial information as a basis for modeling various processes of environment including erosion processes. GIS technology for monitoring and modeling of dust storms using satellite imagery makes it possible not only to describe the process of dust storms but also to fulfill their complex analysis in order to assess the extent of the process; it is extremely urgent to develop concrete solutions in case of emergencies. In addition, as it should be used by the Hydrometeorological Services of Kazakhstan in forecasting and analyzing strong dust storms.
2. Remote-sensing satellite imagery. Using satellite imagery makes it possible to identify new sources of powerful dust extensive take-out and study the dynamics of dust and salt storms in space and time. This is new information about this phenomenon of nature that could never be obtained ground-based measurements. In addition, having photographs of storms from space on a meso-meteorological scale allows for a more precise description of the geometric dimensions of the dust cloud and to accurately detect the location of dust sources. Remote sensing is a useful method of aeolian soil–erosion monitoring.
3. Using methods of mathematical, physical, and statistical modeling and remote sensing allow us to estimate such critical factors as the amount of removed aerosol as well as the distance to which it is imposed during dust and salt storms.

Mapping- and space-observation techniques extend our ability to estimate the scale of dust storms. The prospects of these methods to obtain information about the content of mineral aerosols in the Earth's atmosphere are evident. Only these methods allow to quickly assess the weight of the aerosol, its optical characteristics, and its life span in the atmosphere, which are required for solving many applied and environmental challenges.

The first part of the research was performed to reveal the regional divisions of Kazakhstan that are mostly prone to the dust storms. In this part, the aim of

Fig. 1.6 Distribution of weather stations located in particular areas of interest in Kazakhstan

this study was the detection of dust-, sand- and salt-storm sources as well as finding the causes of this phenomenon—based on consideration and analysis of numerous cartographic materials and data from weather stations and satellite-monitoring materials—in order to provide an accurate picture of the distribution and frequency of dust, sand, and salt storms over the territory of Kazakhstan and Central Asia.

The second part of the research includes the active sources of dust, sand and salt storms within Kazakhstan and Central Asia. This part focuses on the analysis of dust- and sand-storm dynamics, seasonal distribution, amount of sand and dust transport, and the role of dominant wind direction.

Dust-storm observations were made at meteorological stations located in particular areas of interest in Kazakhstan including Central Asian countries (Fig. 1.6).

For the analyses, we used data from the Dust Storm Climatology for Kazakhstan databases. This database comprises the archive data collections contained in the Reference Books of Kazakhstan Climate (2003). This database contains the monthly 39-years average number of days with dust storm for each weather station (30 weather stations) as well as their frequencies. Additionally, some necessary data provided by Grol et al. Indoitu et al. also used in this study.

In this study, for the analyses of dust and sand storms and to show their dynamics, we used the long-term observation data of dust and sand storms in the region from meteorological stations located in Kazakhstan for the period between 1971 and 2010. We also analyzed the seasonal frequency of dust and sand storms in the desert zone of Kazakhstan according to the average number of days with dust and sand storms in different months for the period of 1966–2003 from 7 weather stations.

For the purpose of analyses and the calculation of sand and dust transport in the southern Pre-Balkhash deserts region, we used data on wind speed, wind direction, and average size of sand particles during the period of 1966–1986 from 7 weather stations (Matay, Naimansuiek, Auyl 4, Kuigan, Shyganak, Bakanas, and Kapshagai) to conduct quantitative assessment and determine the dominant direction of sand movement during deflation processes. The sand and dust transport in southeastern Pre-Balkhash deserts between the Karatal, Aksu, and Lepsi rivers were investigated according to the data from Matay and Naimansuiek weather stations. Parameters of the amount of sand transported from the left bank of the Ili River (Taukum and Moiynkum deserts) were performed using the data from Shyganak, Kurty, Kapshagai, and Bakanas weather stations. The western part of the Saryesikatyrau desert was characterized according to data from the Auyl 4 station and the eastern part of this desert using data from the Naimansuiek weather station.

Observations of storms and wind for the period 1986–2008 from the following six weather stations—Atyrau, Ganyushkino, Karabau, Makhambet, New Ushtogan, and Sagyz—were used to assess the development of deflation processes in sands of the Northern Caspian Sea plains (Naryn or Ryn desert). Scalar evaluation of transported sand masses have been received for each station for each month and year. The sand mass carried by the wind was counted for 1 year.

The transported sand masses at the surface, the probability and direction of sand movements, and amount of dust-particle transport were calculated using the model created by Semenov (1988). This model allowed calculation of sand and dust transport by the wind in various Kazakhstan regions as well as the objective estimation of the possible intensity of sand deflation. The Semenov model allows to calculate the amount of sand and dust is transported through a distinct migration plain of 1-km length by sand drift (between 10 and 30 m) and dust transport (between 150 and 200 m). The model was applied to calculate the amount of sand carried by wind in the ground layer during sand deflation. This study represents the first quantitative assessment of intensive of deflation process in the southern Pre-Balkhash desert region and the Aral Sea region. The wind roses display which masses of dust and sand are transported in the lower atmosphere by wind in which direction. The length of the vector arrow represents the amount of sand and dust transported. This is known from changes in the shape of the newly formed barchans and other aeolian relief forms, which can change their direction of movement several times according to the prevailing strong wind vectors. However, the resultant (vector addition) gives an idea of the overall long-term sand and dust movement and transport integrated over time. The resultant vector shows the final direction of the sand and dust transport. On the basis of map schemes (Fedyushina 1972a, b; Semenov and Tulina 1978), we constructed the map of the direction of sand and dust movement in the Southern Pre-Balkhash desert region.

In addition, in this study we used numerous cartographic materials (Dedova et al. 2006; Lobova 1946; Semenov and Tulina 1978; Rachkovskaya et al. 2003), weather-station data, and data from satellite monitoring for the detection of strong dust-, sand-, and salt-storm centers (sources) and their causes. The data of space monitoring in Kazakhstan were analyzed with a NOAA, TERRA, and AQUA Landsat satellite to visually identify powerful dust storms. For the identification of potential sources of dust and sand storms in Kazakhstan, all information about soil texture on the map of dust-storm frequency was studied. Arc Map software was used as a main tool to analyze the regional distribution of dust-storm events as well as for sketching the map of dust-storm frequency. Using this map, we may identify the sources of dust, sand, and salt storms, estimate their area, and define the relationship between dust-storm origin and soil texture with plant communities.

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Chapter 2
Natural Conditions of Central Asia and Land-Cover Changes

2.1 Natural Geographical Division of Deserts in Central Asia and Kazakhstan

More than 40% (or more than three quarters) of the territory of Central Asia is desert lowland, which varies greatly in configuration as sandy, stony, salt, and clay deserts (Lewis 2003). The deserts of Central Asia expand from the shores of the Caspian Sea in the west up to the foothills of Alatau Mountain (Tianshan) and Pamir-Alay to the east and southeast. This wide territory is represented by a great variety of desert types.

Specific features of general lithological–edaphic conditions in the formation of Central Asian and Kazakhstan deserts are classified into six groups: sandy, sandy–gravel and gravel, crushed stone–gypsum, loess, clay, and solonchak (Fig. 2.1).

Sandy deserts are a widespread type of landscape in the territory of Central Asia. Deserts occupy much of Kazakhstan and almost all of Uzbekistan and Turkmenistan. They cover the Karakum, Kyzylkum, Pre-Aral Karakum, Moiynkum, Saryesikatyrau, and sandy deserts in the Ferghana Depression, etc. The total area of sandy deserts is approximately 618,000 km^2 (17%) of the territory of Central Asia and 246,000 km^2 (9%) of the territory of Kazakhstan (Table 2.1) (Babaev 1999).

The greatest of these deserts is the Karakum Desert, which stretches >350,000 km^2 and lies between the mountains and the Amudarya River. The desert borders with the northern Caspian lowland and the Usturt Plateau on the west, and on the east it lies on the foothills of the Pamir-Alay mountains. The primarily alluvial rocks are the origins of this desert, and aeolian erosion contributes as well (Lewis 2003).

The Kyzylkum Desert is a part of the Northern Desert. It is located southeast of the Aral Sea between the Amudarya and Syrdarya rivers. The cover area is approximately 300,000 km^2 and stretches across Kazakhstan, Uzbekistan,

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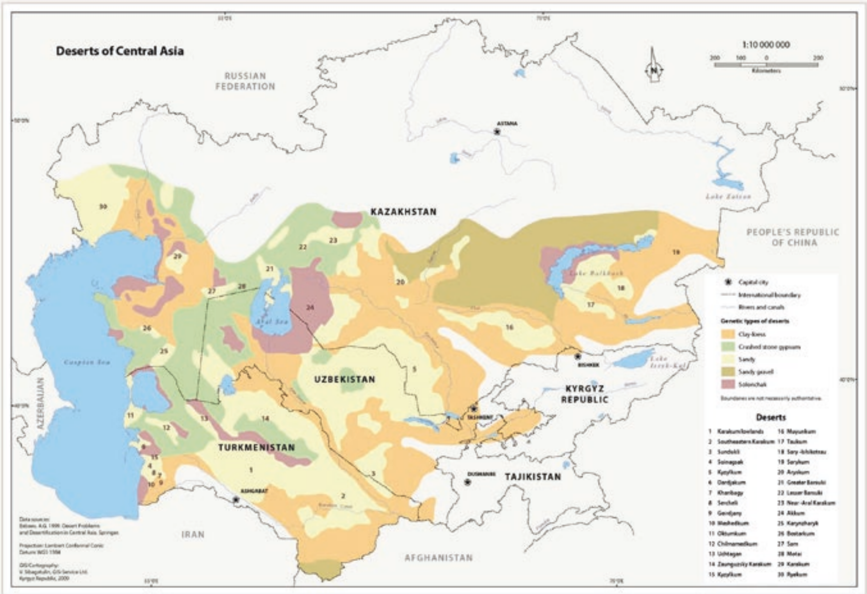

Fig. 2.1 Distribution of deserts in Central Asia and Kazakhstan [see Amid Deserts, Steppes and, Mountains (available at: http://www.carecprogram.org/ru/index.php?page=central-asia-atlas-natural-resources)]

Table 2.1 Area covered with deserts in Central Asia (Zakirov 1980)

Country	Total area	Area covered with desert		
		All types	Sandy desert	%
Kazakhstan	2,715,000	747,000 km^2	246,000	32.9
Turkmenistan	488,000	387,000	260,000	67.2
Uzbekistan	449,000	250,000	107,000	42.8
Tajikistan	143,000	25,000	5000	20
Kyrgyzstan	198,000	70,000		0
Total	3,993,000	1,479,000	618,000	41.8

and Turkmenistan. The desert presents a diversity of landforms and wealth of resources for Central Asia. Sandy, sandy-gravel, gravel desert, crushed stone gypsum, loess, and takyr soils are distributed in the desert. The desert consists of a massive plain with an altitude of $\leq$300 m that slopes down toward the northwest with a few small basins and mountains that rise to 900 m (Babaev 1999).

The arid Usturt plateau lies in northwestern Central Asia between the Caspian and Aral seas. It is a flat plain with occasional small hills containing salt lakes, salt marshes, and sand. Rain and running water are practically nonexistent on the plateau.

These sandy deserts have a different genesis, but they have developed largely over thick, loose, sandy sediments, mostly of a riverine and marine origin. In terms of sediment origin, they are subdivided into the following subtypes:

- Sands of ancient alluvial plains: Karakum lowlands, Chilmamedkumy, Sundukli, Kumcebshen, Kattakum, sands of the Central Ferghana, Pre-Aral Karakum, Moiynkum, and others.
- Sands of marine lowlands: Incorporate sands formed as a result of the deflation of ancient and recent marine deposits. They are locally developed mostly on the eastern coast of the Caspian Sea (Western Turkmenistan).
- Sands of piedmont plains: These spread mainly as separate, large, sand massifs on the piedmont plains of Kopetdag, Nuratau, Karatau, and others. In their geological structure the proluvial deposits (sands, loamy sands, loams) dominate.
- Sands of ancient structural plains composed of Paleogene, Neogene, and Cretaceous sandstones occurring mainly in Zaunguzsky Karakum, Uchtagan, and Kyzylkum.

Closer to the surface these plains are composed of mostly Neogene sandstones striking horizontally. More seldom outcrops of Paleogene and Upper Cretaceous sandstones and limestones are observed on large areas. Sands of this subtype are widespread.

Concerning sand mobility and thickness of a vegetation cover, the sandy deserts are subdivided into three groups:

- *Bare sands* are represented by single and group barkhans, complexes of barkhans, barkhan chains, and barkhan-ridge sands. They expand over an area of >3 million ha or approximately 7% of the area of sandy deserts. Such sands occur largely in Western Turkmenistan, Djillikume, along the Amudarya, in the eastern part of the Aral region, and in the Ferghana valley, etc. Barkhan sands also surround settlements, pits, or develop along point and linear objects. Sand formation is connected with a number of physiographical and anthropogenic factors. Affected by intensive winds, they can move, which can impede the operation of some economic units.
- *Semi-overgrown sands.* On the territory of Central Asia, semi-overgrown sands comprise many varieties: ridge, barkhan-mound, ridge-mound, cellular, ridge basin, and ridge-honeycomb sands. In general, they do not move. Barkhan-like mobile forms are found only on tops of ridges with very thin vegetation cover. Some mobile forms appear among overgrown sands as a result of an anthropogenic impact. After the end of that impact, the vegetation continues growing. Barkhan sands are overgrown with *Carex physodes*, *Stipagrostis karelinii*, and other pioneer grasses, then shrubs and grasses–ephemerals, and still later semishrubs. However, natural vegetative regeneration of barkhan sands is a very slow process that is connected with high sand mobility.
- *Overgrown sands.* This group incorporates stable, often unmovable, forms of sand relief-mounds, vegetated sand dunes, honeycomb, and slightly rolling

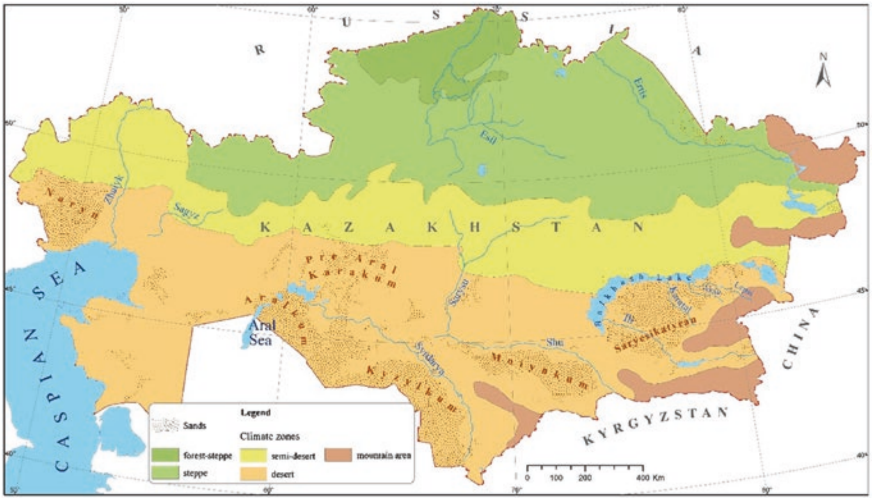

Fig. 2.2 Distribution of sandy deserts and climate zones within Kazakhstan

sands well fixed with vegetation. After destruction of a vegetation cover, they turn within a short time period into drifting, barkhan forms.

Sandy deserts are a widespread type of landscape in the territory of Kazakhstan. Kazakhstan lies between the Siberian Taiga in the north and the Central Asia deserts in the south, the Caspian Sea in the west, and the mountain range of the Tien-Shan and Altay in the east (UNDP 2002). Approximately 60% of Kazakhstan is flat lands. Deserts and semi-deserts occupy approximately 50% of the territory, most of them situated in the Turan plain. Arid territories spread from Caspian Sea to foothill plains of the Zhetysu (Dzhungar) Alatau, and Tien-Shan mountains. These vast territories have various geological structures and landscape features such as sandy deserts of Naryn, Kyzylkum, Pre-Aral Karakum, Moiynkum, and Southern Pre-Balkhash deserts (Saryesikatyrau, Taukum, etc.) (Fig. 2.2). The northern parts of Kazakhstan are steppes and forest-steppes (Danayev 2008). Desert areas are more often the principal source of dust- and sand-storm development (Squires 2001).

The southern Pre-Balkhash deserts (Saryesikatyrau) belong to the category of sandy deserts. The sandy deserts are located in southeast Kazakhstan, within the vast (size approximately 70,000 km^2) and shallow southern Balkhash Depression. The depression was formed in the Neogene period. The Paleogene rocky deposits are found mainly in the periphery (Abdullin 1994). The territory of Balkhash Lake basin is characterized by great diversity and complexity of geological structure. This depression is bordered by the Shu-Ili Mountains in the west, by Balkhash Lake in the north, and by the Arganty, Arharly, and Saikan mountains and north-eastern spurs of Zhetysu (Dzhungar) Alatau in the east (Dzhanalieva et al. 1998;

Skotselias 1995). The southern Pre-Balkhash deserts consist of the Taukum and Moiynkum deserts, which stretch along the left bank of the Ili River. The Saryesikatyrau, Bestas, Irizhar, and Zhamankum deserts are located between the Ili and Karatal rivers. Zhalkum sands are situated between Karatal and Aksu rivers.

The southern Pre-Balkhash sandy deserts are formed on quaternary sedimentary depositions. Among them maritime–alluvial, alluvial–delluvial, and sandy–clay deposits are widely distributed. Most of the territory is covered by aeolian sand deposits (Faizov 1983).

Arid climate, frequent strong winds, scarcity of vegetation, and dominance of friable (loose) sandy–clay rocks in the overburden contribute to the active development of aeolian processes. As a result of aeolian transportation and redeposition, the following huge sand massifs and deserts have formed: Kyzylkum, Naryn, northern Caspian Sea and Pre-Aral Karakums, Big and Small Barsuk, Saryesikatyrau, and Taukum (Fig. 2.2). The sand massifs and deserts have various relief forms such as alveolate, hilly, hilly–ridge, barchans–ridge, and barchans–alveolate, etc. Sandy and sand–loam deposition of various origins—as well as marine sediments, sediments of alluvial and alluvial–deltaic plains, sandy marine and river beach barriers, soil of light texture, and plump solonchaks—are subject to the aeolian process.

Aeolian processes are most intensive in piedmont areas composed mainly of poorly cemented sandstones, loess loams, and similar ground that is subject to easy scouring and weathering. After the demise of the ancient river system, the alluvial plains were gradually subject to deflation and aeolian dissection. Therefore, in Central Asia, most widespread are sandy deserts that were largely formed in areas of development of ancient or modern alluvial or lacustrine–marine, loose deposits (Babaev 1999).

Based on a variety of synoptic process, rainfall patterns, and annual and inter-annual temperature regimes, the Central Asian deserts are divided into two climatic provinces: northern and southern (Rachkovskaya 2003). The northern province includes the Northern Caspian Sea deserts (Naryn desert), Mangyshlak, Northern Usturt, Moiynkum, Southern Pre-Balkhash deserts, and Dzhungaria. The Southern province occupies the southern regions of the Aral–Caspian lowland–south part of Usturt Plateau, Karakum desert, and the Central and Southern Kyzylkum deserts.

These two major Northern and Southern deserts are characterized by temperature extremes, seasonal drought, snowy winters, and strong winds that move dunes, stir up blinding dust and sand storms, and erode agricultural land.

The climate of desert is characterized by dry and long summers with high temperatures. Deserts exhibit temperature extremes from winter to summer and from day to night. They receive little rain, and the rain received evaporates quickly. Deserts contain uncommon biodiversity where animals and plants have learned to make the most with less.

The Northern province is characterized by a cold and dry continental Central Asian type of climate, whereas the southern one is distinguished by a hot and dry Mediterranean climate. The Northern Desert during cold season is under the activity of the winter Siberian anticyclone, and severe, long winter with frosts and lasting snow cover is typical for the area. In the Southern Desert, precipitation is ≤70 mm with a maximum at spring with the remainder in the late autumn and winter seasons. This creates two seasons: a mid-May through mid-October, which is the dry season, whereas the rest of the year is the humid season. Winters are generally mild with unstable snow cover. January temperatures between −1 and 5 °C, and most plant growth stops for a short period only. Climate conditions are more severe in the equally large Northern Desert where January temperatures are −10 to −15 °C and increase to 24–26 °C in July. Precipitation may fall any time of year on average ≤150 mm annually. The precipitation amount varies between 80 and 200 mm within the provinces. Less than 100 mm of precipitation has been registered in the Karakum and Kyzylkum deserts, Betpakdala, and the western Balkhash shore (Indoitu et al. 2012).

Among the Eurasian deserts, the Central Asian deserts—particularly the sandy Northern Desert in central Kazakhstan and the Southern Desert, which distributes in Turkmenistan, Uzbekistan, and southern Kazakhstan—present the greatest species of desert diversity. Black and white saxauls are the most common tree shrub vegetation in the deserts. The deserts are also home to Asian wild asses and Bactrian camels, which belong to rare and endangered animals with small numbers (Babaev 1999).

2.2 Climate Conditions and Weather Process in Central Asian Deserts

Central Asia is a land-locked region of the Eurasian continent with multiple climatic regimes that range from heavy precipitation in the mountains to arid deserts. Climate conditions in Central Asian deserts are multiple and complex. Annual precipitation patterns explain the arid environments in the region generally. Annual precipitation in the deserts of Central Asia is <100 mm/y, which indicates a dearth of precipitation across the great deserts of Turkmenistan, Uzbekistan, and Kazakhstan. Precipitation gradually increases to the north, south, and east around the deserts on the steppes and plateaus. The majority of precipitation received by the eastern and southeastern mountains of the Central Asia amounts to ≥1000 mm on average. The mighty rivers that flow from these mountains provide power (electricity) to Kyrgyzstan and Tajikistan and irrigation to southern Kazakhstan, Uzbekistan, and Turkmenistan (Fig. 2.3).

Temperatures across most of the steppes and deserts in the region vary from north to south. The temperature is as low as −20 °C in January. Winters are severe in northern Kazakhstan, and crops and pasturelands are covered by snow for much of the winter (Fig. 2.4). Climate conditions in the south become milder, but average mid-winter temperatures do not exceed zero except in southern Turkmenistan and Uzbekistan.

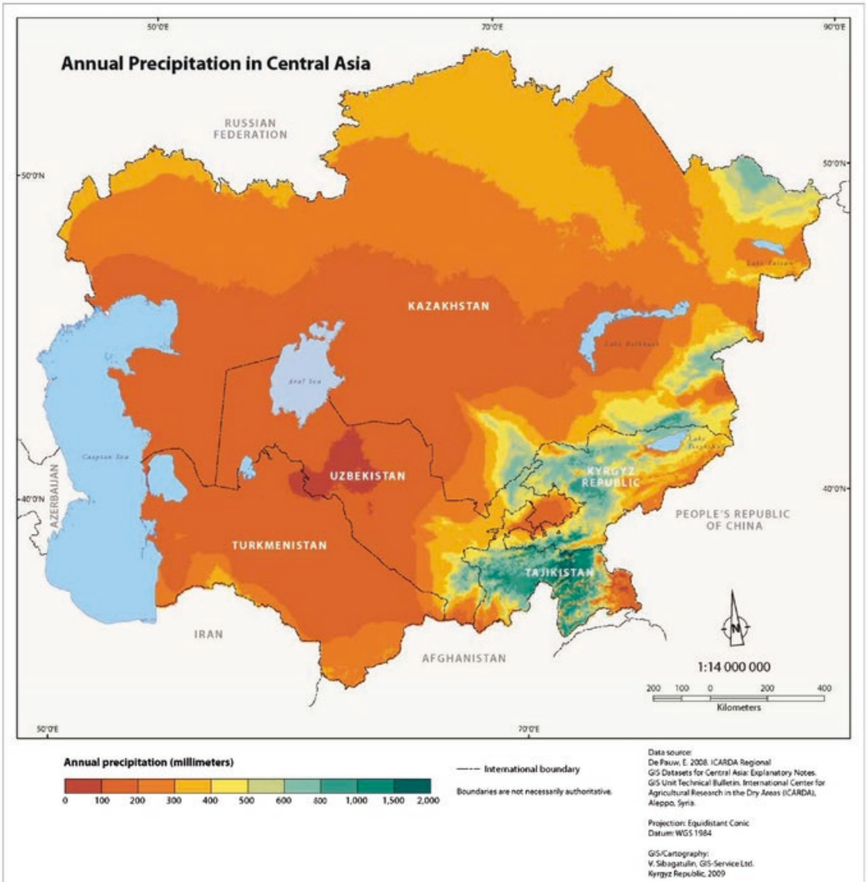

Fig. 2.3 Annual precipitation in Central Asia [see Amid Deserts, Steppes and, Mountains (available at: http://www.carecprogram.org/ru/index.php?page=central-asia-atlas-natural-resources)]

Throughout the steppes and deserts, the temperature is above zero in the summer season. In northern Kazakhstan, temperatures are on average ≤25 °C in midsummer and >30 °C in southern Turkmenistan (Fig. 2.5). However, temperatures decrease quickly with altitude in the mountains in the east and southeast. Winters are bitter, and the temperature is lower than −25 °C on average in the highest plateaus, which remain snow-covered year round. Even temperature in the lower slopes of the mountainous areas average ≤10 °C or less in middle summer.

The following climatic regions/zones exist in the territory of Central Asia and Central Kazakhstan: (1) temperate zone/belt: continental steppe region, continental North Turan region, and Tianshan mountain region; (2) subtropical zone: continental South Turan region and Pamir-Alai mountain region (Alisov 1969).

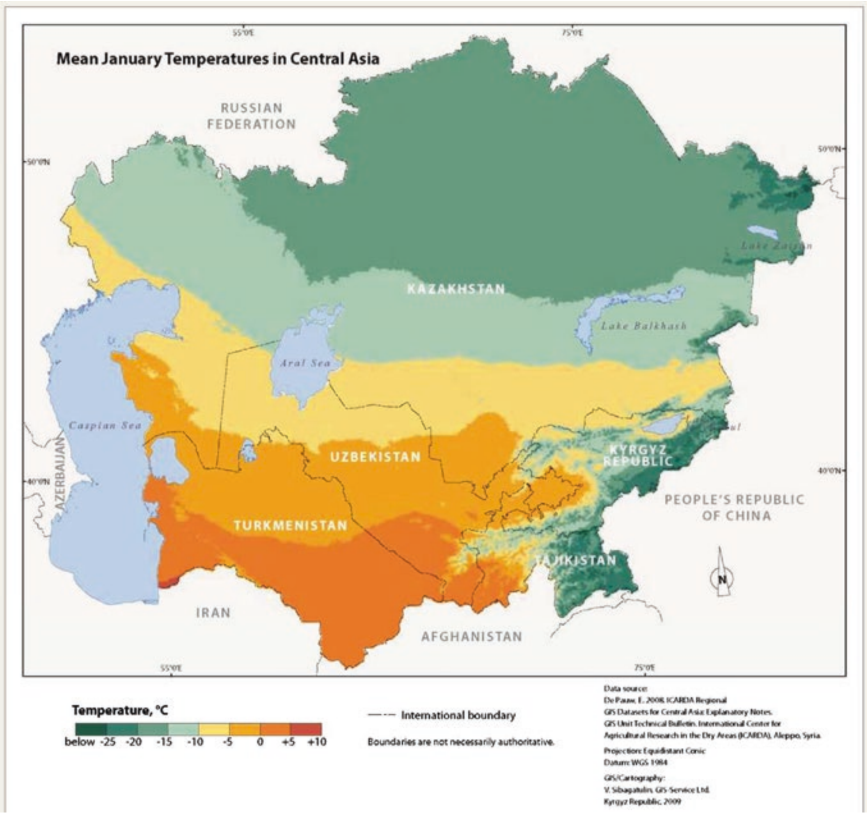

Fig. 2.4 Mean January temperatures in Central Asia (see Amid Deserts, Steppes, and Mountains: http://www.carecprogram.org/ru/index.php?page=central-asia-atlas-natural-resources)

(1) *Temperate zone/belt.* The climate of the continental steppe region comprises a significant exposure to radiation factors characterized by rapidly increasing aridity to the south. The southern border of the region coincides with the northern boundary of the desert zone. January temperature ranges from −18 to −15 °C and in July from 22 to 25 °C. The annual precipitation is 200–300 mm. The snow cover is low.

The continental North Turan region occupies the central and northern part of the Turan lowland and Balkhash Lake. Radiation factors have a decisive influence on the formation of the climate, especially in the summer. In winter, the prevailing northeasterly winds bring continental Siberian air. In the summer, the northern and northwesterly winds bring continental air from Western Siberia and the southeastern regions of the European part of the USSR. These air mass within the region undergo the second phase of transformation and become closer to tropical air masses. The temperature difference between the air and the transformed tropical

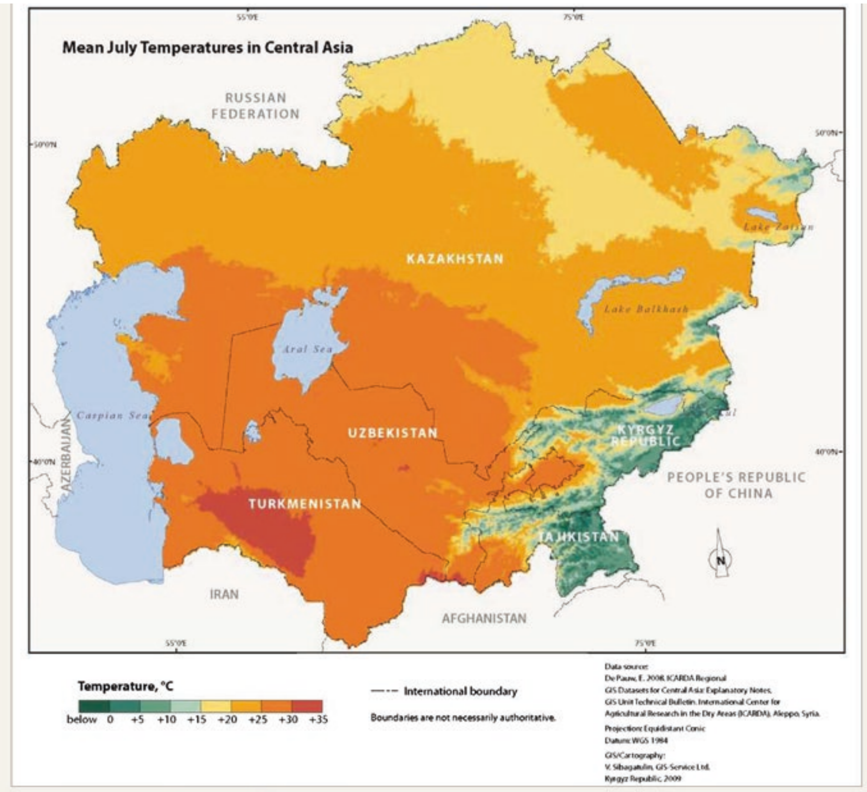

Fig. 2.5 Mean January and July temperatures in Central Asia [see Amid Deserts, Steppes, and Mountains (available at: http://www.carecprogram.org/ru/index.php?page=central-asia-atlas-natural-resources)]

air of southern origin are smoothed out, and the cyclonic activity is weakened. January temperatures range from −15 °C in the north to −3 °C to the south and in July from 25 to 30 °C. The annual precipitation is ≤10–200 mm.

The Tienshan Mountain region occupies the main part of the mountain range. The climate is formed by the action of circulation processes, which develop over Kazakhstan and Western Siberia, and under the influence of altitudinal zonation. The mountainous terrain increases the cyclonic activity and rainfall. The temperature decreases with height in January to 0.5 °C and in July to 0.7 °C/100 m. On the western slopes, the rainfall averages approximately 800 mm average for the year (in some places it is >1600 mm).

(2) *Subtropical zone.* The continental South Turan region occupies the southern part of the Turan lowland corresponding to the southern subtropical desert zone. Major climatic factors are radiation and cyclonic activity of the Iranian branch of the temperate-latitudes front. January temperature ranges from

−3 °C in the north to 2 °C in the south (between the western extremity of the Kopetdag and Caspian is 4 °C) and in July range from 30 to 32 °C. The annual precipitation is 150–200 mm. The zone is characterized by spring rainfall and sudden changes in weather conditions in the winter.

In the Pamir-Alai mountain region the major climatic factors are radiation, cyclonic activity of the Iranian branch of the temperate-latitudes front, and altitudinal zonation. The average January temperature in the foothills ranges from −5 °C in the north up to 2 °C in the south; on the high plateau (approximately 4000 m) it averages −20 °C. In the foothills, the average July temperature is 25–30 °C, and on the high plateau (approximately 4000 m) is averages 8 °C. In the high-altitude area with forests, precipitation >1000 mm/year, sometimes >1600 mm, falls on the Fedchenko Glacier; in the Western Pamirs precipitation is 2236 mm/year; and on the plateau of the Eastern Pamirs precipitation averages approximately 100 mm/year.

The atmospheric circulation is primarily affected by the continental position and the division of Central Asia and Kazakhstan into a terrain of deserts and mountains (Borisov 1965).

The mountain system located in the surrounding areas of Central Asia have a great influence on the climate of the region. It involves not only the barriers protecting Central Asia from the south (from the South Asian monsoon penetration), it also involves the mountains located to the west and southwest (Greater and Lesser Caucasus and the Armenian Highland, Zagros, etc.). They form a barrier in excess of 3000-km length and have a distorting effect on the high-altitude frontal zones, which significantly affects the development of cyclonic activity in Central Asia. Due to this mountain barrier, atmospheric waves cause the development of strong foehn that eliminate precipitation. The effect of these processes is observed almost over all of the territory of Turkmenistan. The mountain barrier greatly reduces the amount of rainfall brought by the West, in particular the Southwestern (Mediterranean) cyclones to Central Asia.

Altitudinal climatic zonation appears in the mountain regions of Central Asia. The lower zone of the mountain is exposed to the same air masses and circulation processes as the neighboring deserts. The frontal process is aggravation of the slopes. The western air transport in the middle layers of the troposphere strengthen in the upper zones. The windward slopes produce a significant amount of rainfall (in some places >1600 mm), and in the “shadow of the barrier” it falls sharply. In the Eastern Pamirs, annual rainfall is as low as in the most arid regions of the Turan lowland.

Atmospheric circulation, solar radiation, and landscape shape are the three main factors that determine a climate. Solar radiation to the surface depends on cloudiness, fog, haze, and dust and sand storms, etc. The process of global atmospheric circulation is mainly a planetary factor and determined the input of solar radiation. In Central Asia, the atmospheric circulation are diverse with several types such as cyclonic, anti-cyclonic, frontal, and local (breeze, highland–valley, etc.). Each type of the atmospheric circulation has its own features. For instance, the cyclonic circulation occurs in the zones with low pressure and is characterized by constant turbulent air movement. The airflow trajectory inclines toward the minimal pressure, namely, to the storm center. According to the law of conservation of mass, and due to a convergence of airflows, the air is displaced upward. The mass of air expands while moving upward moves into upper strata with lower pressure. It cools down adiabatically (1 °C/100 m of altitude) and becomes saturated with moisture. Thus, vast cloud systems are formed in the cyclones and rain falls constantly. Anti-cyclonic circulation occurs in areas with high pressure. Any area with high pressure is characterized by the clockwise turbulent movement of air. With that, the airflow trajectory inclines from the center of maximum pressure toward the periphery. This leads to a divergence of airflow that give rise to a vertical movement of the air from the top downward. This factor moves air masses into the strata with higher pressure downward and warms up adiabatically (1 °C/100 m of altitude). Warming of the air leads to an abrupt decrease of the relative humidity and leads to a dissipation of cloud systems, which favors fair weather without rainfall.

The synoptic processes can be divided according to the type of weather. For instance, the synoptic processes in Central Asia are classified into four main categories: cyclonic circulation, cold-wave intrusions, the group of synoptic processes conditioning fair weather, and the group of synoptic processes causing unstable weather.

Cyclonic circulation is one of the main categories of synoptic processes in Central Asia. The South-Caspian, the Upper-Amudarya, and the Murgab are three basic types of cyclones (Fig. 2.6).

Cold-wave intrusions are subdivided into three types—western, northwestern, and northern—according to areas of their origin and direction of movement. The most abrupt deterioration of weather occurs when intrusions move in the rear of cyclones. Northwestern cold intrusions form sandstorms and haze in the dry season (Fig. 2.6).

Three types of processes—such as confining cyclones, wave activities, and the southwestern and southern peripheries of anti-cyclones—belong to group of synoptic processes causing unstable weather. The wave activities are typical for highland areas, and they take place in cold frontal partitions. Such a process can continue with significant rainfall from several days to 1 week. The process is accompanied by widespread rainfall in the winter and springtime when an influx of arctic air masses occurs along the southeastern periphery of the anti-cyclones with intrusions of western and northwestern humid air.

The following processes—thermal depressions, southwestern peripheries of the Siberian anti-cyclone, and small-gradient fields of decreased or increased air pressure—belong to the group of synoptic processes conditioning fair weather. The thermal depression is characterized by very hot, hazy weather and is typical only in the summer season. The thermal depression played a major role in creating a long drought in Central Asian countries in 2000.

The climatic features of Central Asia and Central Kazakhstan are determined by: (1) their inland position and remoteness from the oceans, which are the main

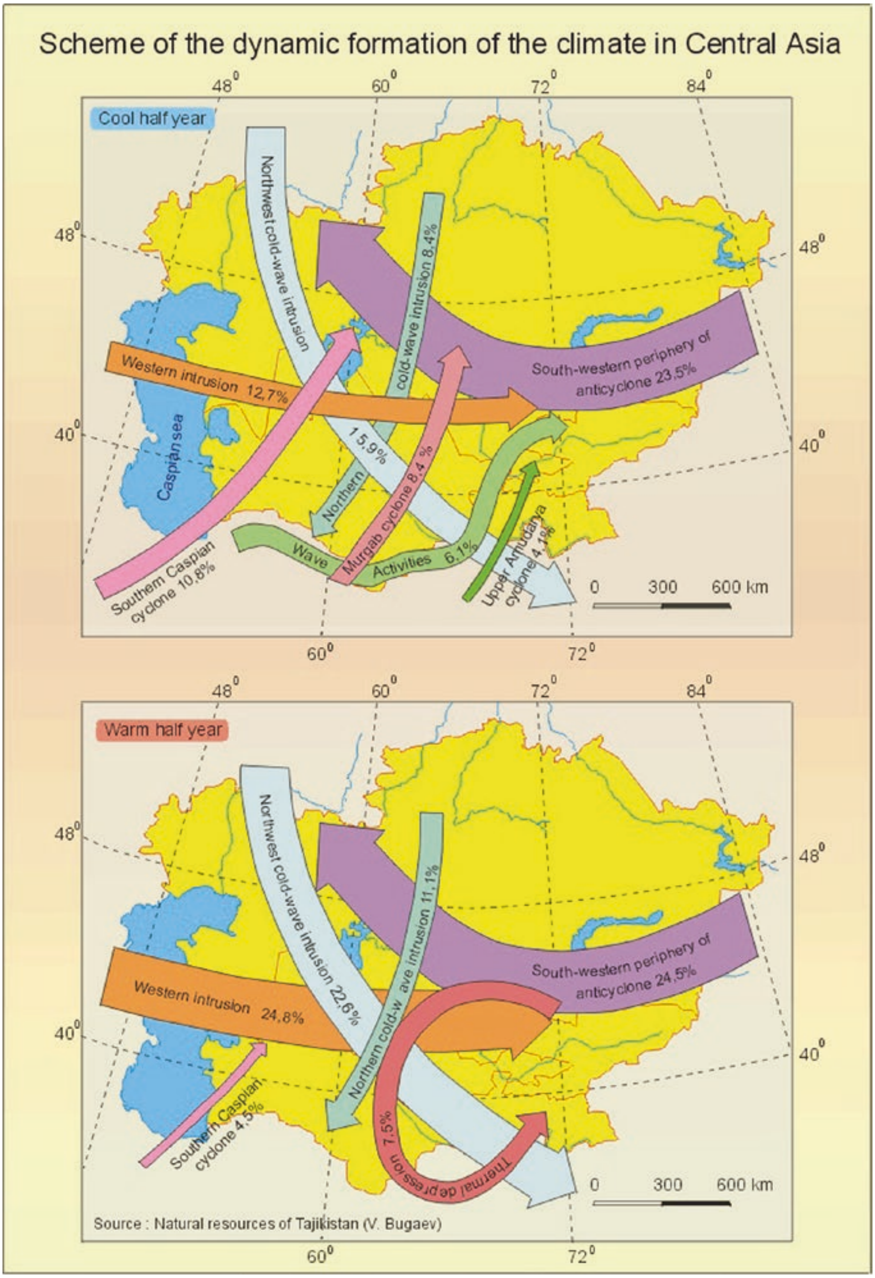

Fig. 2.6 Formation of climate in Central Asia (see http://enrin.grida.no/htmls/tadjik/vitalgraphics/eng/html/c9add.htm)

sources of atmospheric moisture; (2) location at a relatively low latitudes caused by the relatively high value of the radiation balance; (3) their surface, which largely depend on the characteristics of atmospheric processes.

The location of the region in the interior part of Eurasia, at a great distance from the oceans, causes a pronounced continental condition and is associated with intense radiation in the southern part, which yields the continental climate of the low plains of the main parts of the territory that has an arid character; desert landscapes develop under these circumstances.

The value of total radiation (direct plus diffuse) is approximately 100 kcal/cm^2 in the north of the region and >160 kcal/cm^2 in the south. Radiation balance is approximately 22 kcal/cm^2 in the north and in the south is >40 kcal/cm^2/year.

The air of temperate latitudes is dominated in the region, and during the summer it is vigorously transformed into a tropical (i.e., rain) climate in the most part. In the south, the seasonal change of the prevailing air of temperate latitudes in the winter rain, which dominates in the summer, is due to the characteristic of the subtropical zone of seasonal movements of the temperate-latitudes fronts.

The temperature conditions are an indicator of continental climate in Central Asia. Central Asian deserts are hotter than the tropics in the summer season. The average July temperature is 26–32 °C, whereas in the tropics it is equal to 24–28 °C. The absolute maximum temperature reaches 50 °C (Southeast Karakum desert, Termez on the Amudarya River), and the surface of the sand in the desert heats up to 79 °C (Repetek in the Karakum Desert). However, the plains of Central Asia do not have a cold winter, and the average annual air temperature amplitude reaches very high values (−32 to 40 °C). The region is characterized by large temperature variations from year to year: sharp daily fluctuations in temperature, sharpness of the transition from season to season (especially from winter to summer), a small amount of precipitation (<200 mm/year; in vast territory it can be <100 mm and sometimes even <75 mm), little cloudiness, many hours in sunshine, and dry air (average relative humidity of 20–25% in the summer; however it significantly decreases below).

Central Asia and Kazakhstan lie at the periphery of two important pressure systems, which explains the continental climate. In the winter season, the Asiatic High, which originates over northwestern Mongolia, is dominated by the pressure systems of Central Asia (Lewis 2003). The pattern of pressure divergence that forms over northern Kazakhstan results in a high pressure ridge where winds diverge north toward Siberia and the Arctic and south toward Central Asia (Lydolph 1977). In winter season, this brings a northeasterly flow air into Central Asia and a decrease in barometric pressure from north to south with isobars trending east–west. The prevailing northeastern winds are very cold because they transfer the air from a more northerly part of the continent to a more southerly part (Lewis 2003).

An eastern extension of the Azores High is the other major pressure system. In summer season, the Azores High brings moisture to southern Europe but loses almost all moisture while crossing the Caucasus Mountains and reaching Central Asia. This tropical air mass brings a northwesterly airflow to Central Asia. Air from the north reaches the region as well. Ninety percent of the air mass in Central Asia consists of continental temperate and continental tropical air (Borisov 1965).

The climate of deserts in Central Asia, Kazakhstan, and elsewhere in the world are characterized by high air temperatures and a long dry period during the summer. The Aralkum Desert is located within the Asiatic Desert belt. The northern part of the desert belongs to the Kazakh–Dzungarian Desert and the southern part to Turanian deserts (Breckle and Wuchere 2012). The climatic conditions and weather process of the Aralkum (Aral Sea region) are mainly governed by relatively low elevation of the Aral Sea Basin within the center of the Asian continent (Budyko 1956, 1974; Grigoriev and Budyko 1959). In general, the Aralkum region is characterized by hot and dry summers and cold winters with strong continentality. The continentality is a reason for the very intensive radiation. The temperature amplitude varies from 40 to 85 K during the year. The relevant monthly means may reach almost 40 K, and the absolute temperature extremes can reach >85 K. Rare cloudiness and low precipitation is typical for the region. The number of days without clouds amounts to approximately 260. Low precipitation, rare cloudiness, and high radiation result in hot and very dry summer months.

High mountains do not influence the atmospheric circulation of the region. Most of the year, the surrounding region of Aralkum is under the influence of northwesterly and northerly air intrusions and a southwestern margin of a huge Asiatic (Siberian) anti-cyclone system (Bugaev 1957). The region geographically is located opposite to the Turanian or Turgai gate, i.e., in the main axis, which plays an important role in invasion of cold air masses from the north along the Ural mountains. The basin, which lies at low altitude within Middle Asia, favors the development of stable cold air masses and relatively considerably low temperatures in winter. The normal synoptic processes in the Region—such as the stable southwestern peripheral part of the Siberian anti-cyclone in autumn, winter, and early spring—cause clear and dry weather and drastic temperature minima (Myachkova 1983). This is a consequence of the advection of low-humidity air masses from continental Siberia and the Arctic.

During the winter season, moist Atlantic air masses from the west normally do not reach the Aralkum region; they reach this region only in spring and rarely in summer. Consequently, strong winds and storms can occur due to the drastic differences in temperature between air masses. Those air masses from the west and south are driven by cyclones followed high humidity and rains. During the summer, a clear to cloudless sky and very high temperature are typical weather conditions in the region. Air masses play a major role in temperature and precipitation variations. For instance, the northerly and northwesterly air masses can occur from time to time and lead to slight a decrease in temperature and often to some precipitation.

The climate of the Southern Pre-Balkhash Desert is arid and continental. The desert is characterized by high level of solar radiation and experiences large daily and annual variations of air temperature. In the northern part of the desert, the average air temperature in January is −16 °C and in the southern part of the plain territory it is −5 °C. The average air temperature in July is approximately

20–25 °C. The distribution of precipitation over the region is very variable. In the north, northwest (coast of Balkhash Lake) precipitation is approximately 150 mm and 200–300 mm in the southeast in the foothill (submountainous) areas. Precipitation on the plain during the warm seasons almost completely disappears through the process of evaporation. The greatest amount of precipitation falls during the spring months (April through May) and the least amount falls in February and August through September (Akhmedsafin et al. 1980). Strong winds are very common in the region, especially in the Zhungar Gates region, with a wind speed of 70 m/s.

2.3 Land Resources (Soil Cover) and Changes in Vegetation Cover and Climate

Soils in deserts are very thin, and humus content in them is meager (Faizov et al. 2006). The main characteristics the soils in deserts are low contents of humus, significant presence of carbonates and gypsum and also phenomena of solonetz and solonchaks. A special structure of the soils in deserts is marked: there is no soil-forming horizon in the upper part of the soil profile, which is typical of the steppe pedogenesis. Desert crust changing by sub-crust is presented. The main soil types in the desert are sandy desert, brown, grey-brown, serozems, takyr-like, takyrs, solonchaks, and solonetz (Fig. 2.7). Zonal types of soils are brown desert and grey-brown desert. Sandy and piedmont serozems are formed in automorphic conditions, takyr like soils and takyrs at additional watering conditions on alluvial plains as well as different types of solonchaks. The soil cover of the desert zone has great diversity. Soil cover and its composition in the desert zone are different.

Brown desert soils haven’t a grass sod; upper humus horizon is low consolidated. It belongs to desert soil type (Uspanov and Faizov, 1971). Humus is about 1.5 % and it is evenly distributed within the soil profile. Fulvic acids

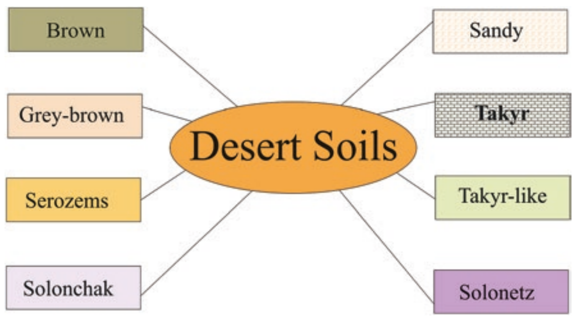

Fig. 2.7 Desert Soils

dominate in humus composition. It can be observed the accumulation of silty particles in soil horizon B. Effervescence begins from 15 cm or from the surface. Carbonates accumulated on the depth 25–35 cm, gypsum and light soluble salts on 60 cm (Rachkovskaya, 2003).

Grey-brown desert soils are distributed on the Usturt Plateau, in the Betpakdala (Central Kazakh Hillocky area), the Mangyshlak and Krasnovodsk Peninsula. They are formed on rocks of various petrographic composition. There are some soil horizons in the soil profile of grey-brown soil: desert porous crust, undercrusting scaly horizon, condensed soil horizon B, and horizon with gypsum accumulation. Soil profile can be overfill with gypsum. All grey-brown soils are carbonate from the surface and usually carbonates in maximum amounts are found in the upper-most soil horizons (Rachkovskaya, 2003).

Serozem is an original soil type on piedmont territories. They occupy inclined piedmont plains and hilly piedmonts that are a lower step in vertical zonation of mountains. Soil profile of serozem has the following soil horizons: humus light grey horizon soded in upper part; transitional with low content of humus and some carbonates; condensed carbonate-illuvial soil horizon with white soft carbonate spots. In upper soil horizon quantity of humus varies from 1 up to 3.5 %. Such significant varieties determine the dividing on soil subtypes such as light, typical and dark serozem (Rachkovskaya, 2003).

Solonchaks belong to saline soils and they occupy the large territories in desert zone. They are formed under influence of saline rocks or owing to high-mineralised ground waters. Solonchaks are divided into automorphic and hydromorphic. The automorphic type is formed on the outcrops of ancient saline rocks, mainly clays. Water regime is not ablutional. The superficial soil horizon contains not less than 1 % of light soluble salts. The hydromorphic solonchaks is developed in conditions of close ground waters. They have a specific character of surface. which is covered by salt efflorescence and may be puffy, crust-puffy or even wet in dry season. The content of salts in upper soil horizon is 2 % up to 6–8 %; and it may be 20–30 % in the most superficial soil horizon. There are typical, meadow and sor solonchaks (Rachkovskaya, 2003).

Sandy desert soils differ depending on a degree of consolidation, which is caused by presence of oozy particles. Humus horizon is weak-developed and often has small thickness, consequently humus content is very low. Low accumulation of silty and clayey particles is fixed in the middle part of soil profile. Sandy desert soils have a light texture and therefore they are severely prone to the deflation process (Rachkovskaya, 2003).

Takyr is a specific soil formation having a polygonal-fissuring surface with stagnant atmospheric water on it. The same genetic soil horizons as in takyr-like soil but with another physical properties. Crust horizon is rather solid and it becomes compact and viscous under influence of watering. Horizon under crust is enough firm also. The lower unstructured soil horizon is not distinguished essentially from soil forming rock. All takyrs are carbonate from surface only and carbonate in new formations are absent. The majority of takyrs have solonchak's properties. Gypsum accumulations are absent and it is typical for takyrs. Mostly takyrs have a heavy mechanical composition or soil texture (Rachkovskaya, 2003).

Takyr-like desert soils are rather young. They are distributed on dried alluvial and proluvial-alluvial plains without ground watering. Differentiation of the soil profile of takyr-like soils is fixed in its uppermost part only. Crust is not solid; both scaly horizon and the condensed unstructured soil horizon, turning into weakly changing mother rock, and they are marked insufficiently. Soils are carbonate on soil surface only. Illuvial carbonate horizon is absent. A total content of gypsum is insignificant (Rachkovskaya, 2003).

Solonetz have the heightened content of sodium (Na) in humus horizon that results in the presence of such specific properties as alkaline reaction and formation of soda, which are regarded as solonetz. They belong to saline soils and mainly distributed in northern and central parts of Kazakhstan. Usually the solonetzes occur in conjunction with zonal and intrazonal soils, rarely whole massif. Solonetz is characterized by small water penetration and low physiological availability of water. According to the character of water regime, solonetz is divided into three types such as automorphic, semihydromorphic and hydromorphic. The lower soil horizons of the solonetz soil profile contain the toxic salts for plants (Rachkovskaya, 2003).

The natural conditions in the region promote the formation of a huge area of saline soils, solonchaks, and sand massifs. The total area of the desert zone is 119.2 mln.ha (43.7%) of the whole territory of Kazakhstan (Faizov 1983). The soil cover is 113.7 mln.ha, including 55.7 mln.ha with brown soil in the northern desert, and 58.0 mln.ha with gray-brown soils in the central desert zone. Automorphic soils are dominant in the soil composition, i.e., approximately 45–53%. The ratio of hydromorphic and semi-hydromorphic soils is approximately 15% from the whole soil cover of the desert zone. Saline soils (solonchaks, solonetz) cover >20 mln.ha (18%) in the zone (Fig. 2.8). Most of them are distributed in Atyrau, Mangystau, Kyzylorda regions, and the Zhambyl and Almaty regions. Takyr-like soils and takyrs cover 9.0 mln.ha (8%) from soil cover of the zone (Fig. 2.8). They are mostly distributed in ancient alluvial undrained plains such as Balkhash–Alakol, Shu Moiynkum, and Syrdaria. These types of soils are inclined toward the salinization process during irrigation (Faizov 1983).

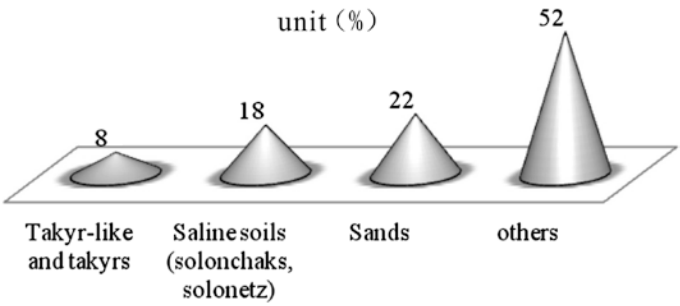

Fig. 2.8 Portion of soil types in the desert zone of Kazakhstan

The huge territory of desert zone is covered by sand massifs with both ancient and modern accumulation of sands. The total area of them is >25 mln.ha including 8.3 mnl.ha in the brown soil subzone; in the gray-brown soil subzone the area is 17.4 mln.ha (20%) of the entire territory of the zone (Fig. 2.8). The large sand massifs are distributed in the Balkhash–Alakol, Shu–Moiynkum, Kyzylkum–Shardara, Northern Caspian, and Aral Seas regions.

Sandy desert soils dominate in the southern Pre-Balkhash deserts. They stretch latitudinally from the western bank of the Balkhash Lake to Alakol Lake in the east (Faizov 1983). The foothill plains of Arganty Mountain are covered by gray-brown soils, whereas the foothill plains of the Shu-Ili Mountains have predominantly light sierozems with fine structure. Floodplain meadow soils are typical for major near-river plains and deltas such as the Ili River. Modern floodplain terraces of rivers in the southern Pre-Balkhash deserts have alluvial–meadow soils and shallow groundwater. The takyr-like soils are distributed in most areas of the Bakanas and Akdala ancient dry delta plains, along the left bank of Karatal river, and in the northeast outskirts of Zhusandala. The takyr-like soils have mostly fine structure (Asanbayev and Faizov 2007). Takyrs are very common in the southern Pre-Balkhash deserts, but they cover a small area and are often buried under sands (Faizov et al. 2006). Solonchaks are common along the coastal stripe of the Balkhash Lake. The largest solonchaks are found along the western and eastern coast of the Balkhash Lake, as well as in the delta of the Ili River, where all types of solonchaks are observed. The desert solonchaks are the main source for salt atmospheric aerosols (Orlova and Seifullina 2006). The surface layer of solonchaks is covered by soluble salts (Borovsky 1978, 1982). The sparse vegetation of the region is characterized by Ephedra, sagebrushes, and various shrubs (Kudekov 2002; Ivashenko 2005).

Sandy desert soils are widely distributed in the Aral Sea region. Sands and soils of light texture dominates most parts of the Aral Sea region. There is a predominance of soil with light texture favoring the development of wind-erosion processes in the region and the formation of aeolian land forms. The average size of sand particles in the region varies from 90–100 to 170–270 μm: 90–160 μm on the desiccated seafloor and 170–270 μm in adjacent desert areas (former coastal dunes, former islands, and sandy deserts). These particles are most easily involved in wind transportation (Semenov 2011). In terms of chemical composition, the soil is sulfate–chloride and chloride–sulfate (Orlovsky and Orlovsky 2001) and is formed on sandy or sandy–loam maritime soils (Semenov 2011).

Since the 1960s, the Aral Sea surface area has started to decrease, and this has caused a significant decrease in precipitation. Saline dust blows from the dried bottom of the sea, and the exposed lake bed has been implicated in rapid climate and vegetation changes. The sea desiccation has caused significant climate and vegetation changes not only in the coastal area but also he entire system of atmospheric circulation in the basin. Air temperatures in the summer and winter months at weather stations near the sea shore have increased by 1.5–2.5 °C, and diurnal temperatures increased by 0.5–3.3 °C (Glazovsky 1995; Chub 2000; Lioubimtseva et al. 2005). The mean annual relative humidity near the coast has decreased by

23%, and the occurrence of days with drought has increased by 300% (Glazovsky 1995). In addition, there has been a change in annual cycle of temperature and precipitation. A seven-fold rise in the albedo of the area previously occupied by the Aral Sea caused a three-fold increase in reflected solar radiation and increased the overall continentality of the climate (Chichasov 1990; Glazovsky 1995). Regional modelling scenarios suggest that the increased air temperature in Central Asia should cause a further increase of evaporation by 8–15%, whereas further aridization of the climate in the Aral Sea area may result in an evaporation increase to 20% in this region (Chub 2000). Additionally, the exposed former lake-bed areas, especially on the eastern side of the Aral Sea, represent by enormous source of highly saline wind-blown material and salt that contain ≤1.5% of the total mass of hard particles transported by the wind. Dust, sand, and salts from the dried bottom of the Aral Sea are deposited at a long distance from the source and, the aeolian deposition of salts has adversely affected the vegetation cover of vast adjacent areas and environment as well. According to an estimation by Semenov (1990), the amount of aeolian deposition from the former Aral Sea bed exceeds 7.3 to 10^6 ton/year, which includes 5 to 710^4 tons of salt/year. Currently, the dried bed (i.e., the bottom of the Aral Sea) has become one of the most powerful and active sources of dust, sand, and salt aerosols and storms in the world. Salt storms or dust containing salty aerosols are blown from the dried playa into the atmosphere, and they play a major role in climate conditions and climate changes at the global and regional scales. This is another important factor that must to be considered in the modelling of climate simulations at different levels. Dust reflects the sunlight back into space and cools the Earth. As a result, this decreases rainfall by suppressing atmospheric convection. Consequently, there are changes in climate and vegetation cover as well. After increasing the rainfall in arid regions, the dust flux decreases, which is explained by increased stabilizing vegetation cover and soil moisture. The dust flux decrease causes a further increase of rainfall. However, according to the generally forecast, the global climate becomes moist due to increasing greenhouse gas levels; this effect is patchy, and some desert areas may become drier according to certain climate-simulation models. In this case, the increased dust flux may increase aridity and also suppress rainfall outside of the desert areas themselves.

In addition to climate changes, there are changes in the vegetation cover in Central Asian countries. The grazing impact on vegetation cover in Central Asia has been constantly increasing during the past decade, especially in the Aral Sea region (Neronov 1997; Kharin et al. 1998; FAO 2004). Over-grazing is the main reason for environmental changes in many parts of the Karakum and Kyzylkum deserts. As a result of significant anthropogenic activity, over-grazing with different types of livestock degrades rangelands and causes a desertification process (Manzano and Narvar 2000). Approximately 75 mln.ha of land on the Earth are severely degraded by overgrazing, i.e., the original biotic functions of the soil are largely destroyed (Sinha 1998). In addition, soil and vegetation degradation in arid and semi-arid environments is particularly related to surrounding areas with water (natural or artificial) such as wells or boreholes (Lange 1969).

The natural ungulate fauna in the area are almost extinct. The grazing impact on vegetation cover has significantly increased: Annual grasses or mosses have gradually replaced the sparser natural perennial vegetation, and the surface has become more compacted. During the last decades, unprecedented growth of kara-harsangs from microphytic communities occurs only in the undergrazed areas perhaps this is associated with increasing of CO_2 fertilization (Lioubimtseva et al. 2005).

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Chapter 3
Spatial and Temporal Distribution of Storms in Central Asia and Kazakhstan

3.1 Spatial and Temporal Distribution of Storms in Central Asia and Kazakhstan

Due to the vast and diverse desert types across Central Asia and Kazakhstan, dust storms vary by frequency, duration, and intensity. The spatial distribution of dust storms in Central Asia and Kazakhstan is varied during the periods 1936–1960, 1936–1980, 1980–2000, and since 2000 (Fig. 3.1). During the period 1936–1960, the number of dust storms in Central Asia was high (great) compared with the following decades with the average number of dust-storm events being 10–20 days/year. Based on measurements, 24% of weather stations (WS) registered dust storms of vary high frequency with >40 days of dust storms/year (Fig. 3.1a).

The Karakum Desert is the largest source of dust storms in the area. The desert is an enlarged source of frequent outbreaks of dust storms with >30 days of dust storms/year, which appear as a "dust belt" stretched from west to east over the southern deserts, Northern Caspian sands, deserts around the Aral Sea basin, and Southern Pre-Balkhash deserts. The "dust belt" of high frequency of dust storms extended from the Northern Caspian sands in the west, with the maximum number of days at Kurguzul WS being 81/year. Furthermore, the source persisted throughout the Central Karakum Desert [according to the Erbent (56 days/year), Repetek (62 days/year), Cheshme and Uch-Adzhi (50 days/year), and Bokhordok (48 days/year)] WS up to the Amudarya River valley in the east (Indoitu et al. 2012). The situation in the northern deserts was slightly different due to the variety of lithological cover types of the deserts. The Naryn and Voljsko-Uralsk sands in the North Lowland of the Caspian Sea and the sandy–clayey Kyzylkum Desert in the eastern region of the Aral Sea were two large sources with high frequencies of dust storms. On the solonchak deserts of the northeastern shore of the Caspian Sea, the Komsomoletz WS registered the maximum number of days (38 days/year) with dust storms. The northern areas of the Aral Sea are one of the hot spots of

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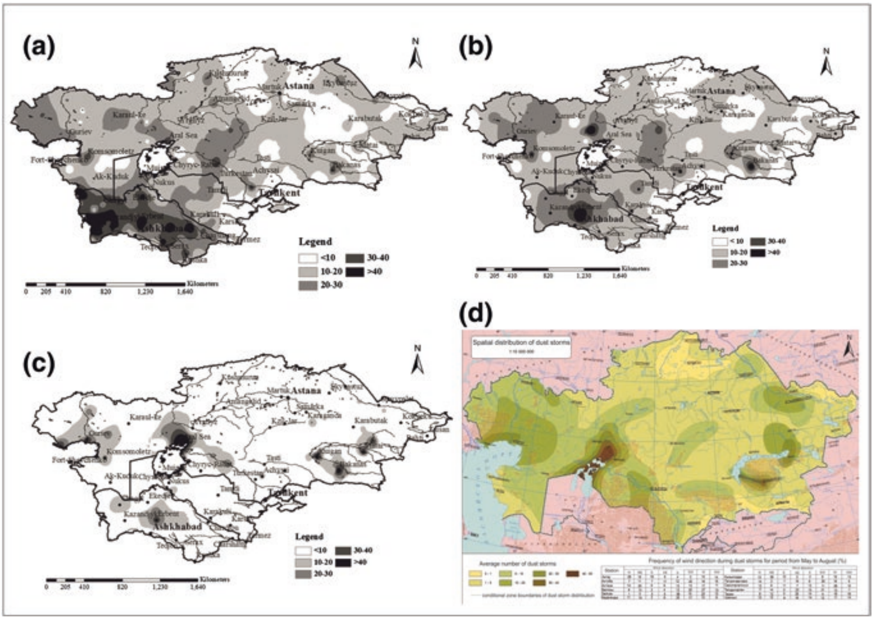

Fig. 3.1 Spatial distribution of dust storms over Central Asia and Kazakhstan **a** during 1936–1960; **b** during 1936–1980; **c** during 1980–2000; and **d** since 2000 (modified after Indoitu et al. 2012; National Atlas of Kazakhstan 2010)

frequent dust storms: The Aral Sea WS recorded 35 days/year, and the Kyzylorda WS registered 33 days/year (Indoitu et al. 2012) (Fig. 3.1a).

The spatial distribution of dust storms for the period 1936–1980 showed a decreasing trend of dust-storm activity (Fig. 3.1b). Similar to previous decades, the average number of days with dust storms was 10–20 days in the region, whereas the number of storms in the major source areas decreased significantly to <30 days/year on average. Dust storms were registered with a frequency >40 days/year only at three storm sources in the Central Karakum Desert (Erbent WS), the Southern Pre-Balkhash deserts (Saryesikatyrau Desert), and the northern part of the Aral Sea (Fig. 3.1b). Protective activities and measures improved the vegetation cover as well helped to considerably reduce the areas of major dust-storm sources (Fig. 3.1b). As a result, dust-storm events showed a slight shifting to the east in the dust-storm source of the northern Caspian Sea. Thus, in the source area, dust-storm activities decreased to 10–20 days after 1960, whereas before 1960 there were 20–30 dust-storm outbreaks/year. The years after 1980, compared with previous decades, showed the most visible evidence of considerably decreased dust-storm frequency during the last century (Fig. 3.1c). The frequency of dust storms in the entire region was reduced to <10 days/year, i.e., the major source areas of dust storms diminished considerably. The northern part of the Aral Sea was the only significant area to generate dust storms. The number of dust-storm events at Aral Sea WS almost doubled. In previous decades it was <40 days, whereas during 1980–2000 the average number of dust events increased to 64 days/year. This active source area of frequent dust storms was associated with the desiccation of the Aral Sea, and the source area extended to the south due to the dried bottom of the sea.

3.2 Spatial and Temporal Variance of Dust Deposition in Central Asia

Research results show a large spatial and temporal variance of dust storms. The spatial distribution of the average monthly dust deposition shows the highest values in the Uzbek part of the Aral Sea basin, at the Southern fringes of the Kyzylkum, and the Aralkum deserts ($\leq$9616 g m^{-2}) compared with the average for Uzbekistan (of 56.2 g m^{-2}). Turkmenistan stations close to the Karakum Desert were characterized by relatively high dust-deposition rates (50.4 g m^{-2} compared with 12.4 g m^{-2} for Turkmenistan), whereas stations in the North of the Aralkum and Kyzylkum deserts (Kazakhstan) showed the smallest average monthly dust-deposition rates (4.9 g m^{-2}) (Groll et al. 2012).

The average and maximum dust-deposition rates show the physical characteristics of the dust transport in different regions of Central Asia. The results of the analysis show a different pattern than the median dust deposition because they reflect not only the deposition averaged over a longer period but also include the frequency with which severe events occur. Although most dust was deposited close to the Aralkum and Kyzylkum deserts, only during 21.4% of all months was this threshold exceeded, whereas close to the Karakum an excess was registered during 36.4% of all months. The dust in the central lowlands of the Aral Sea basin was deposited mostly in few but intense storm events. Close to the Karakum desert, in contrast, potentially harmful conditions were registered more often, but the intensity of the dust storm events was less severe. North of the Aralkum and Kyzylkum deserts, the percentage of months exceeding the threshold was almost negligible at 4.7%. This scheme is further supported by the categorized dust-deposition intensity (Fig. 3.2), which clearly shows that the samples from Kazakhstan (North of the Aralkum and Kyzylkum deserts) mostly show monthly deposition rates <2.5 g m^{-2}, whereas samples from Uzbekistan—especially at the Southern fringes of the Aralkum and Kyzylkum deserts—showed the highest percentages within an intensity range between 1.0 and 25.0 g m^{-2}. The samples from Turkmenistan, which reflect the impact of the Karakum Desert, were characterized by the smallest variance with a maximum of approximately 5.0–10.0 g m^{-2} (Groll et al. 2012). These findings support meteorological data suggesting that dust transport from the Aralkum Desert occurs in a mostly southern direction. An analysis by sampling station reveals much more differentiated results than a comparison

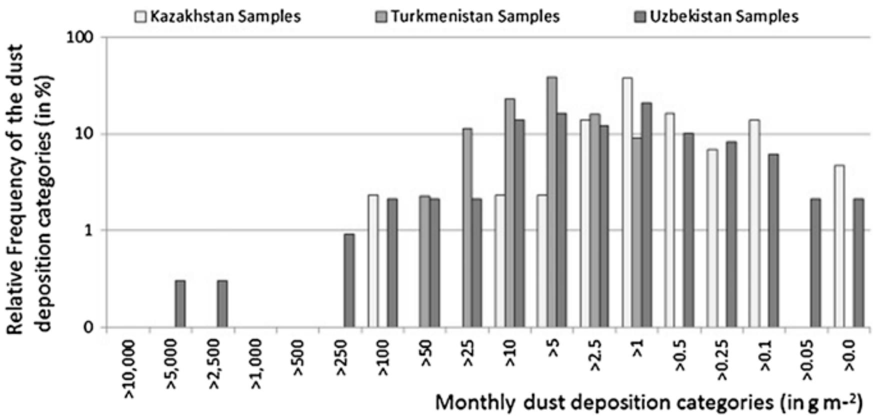

Fig. 3.2 Relative frequency (%) of the dust-deposition intensity categories (in g m^{-2}/month) in the three countries (Groll et al. 2012)

of the three Central Asian countries. The spatial distribution of the median dust-deposition rates/month shows three regions of especially high intensity.

These regions are closely related to three separate source areas within the Aral Sea basin (Fig. 3.3). The weather stations of Mynak, Jasliq, and Kunya-Urgench form the first area of high deposition activity, and they are located close to the southern shore of the former Aral Sea in Karakalpakstan and Khorezm. This region is clearly influenced by the dust and sand material blown out of the Aralkum Desert. The maximum deposition rate in this region was 4660 g m^{-2} (recorded in July 2009), and the highest average monthly deposition rate was 8.45 g m^{-2} (both values were recorded in Jasliq).

Comparable dust-deposition measurements taken in Karakalpakstan between June 2001 and May 2002 showed a similar average monthly dust-deposition rate of 11.6 g m^{-2} (Bennion et al. 2007). The highest deposition rates were registered close to the shoreline of the former Aral Sea. The weather station Bozaubay lies in the second region of very high deposition intensity, and it is close to the main source area of the Kyzylkum Desert. The highest maximum deposition intensity [9616 g m^{-2} (in September 2009)] of all stations was detected at this one, and the average monthly deposition rate was also much higher there than at the stations close to the Aralkum Desert (61.78 g m^{-2}).

The weather stations of Bokurdak and Repetek in Turkmenistan form the third region of high dust-deposition intensity, and they are directly influenced by the Karakum Desert. These two stations show a much smaller maximum deposition intensity (34.0 g m^{-2} in May 2007) at the Bokurdak station; however, the average monthly deposition rate is higher than in the Aralkum region (14.46 g m^{-2}). The weather stations near the Karakum and Kyzylkum deserts also registered the highest amount of months exceeding the threshold of 10.5 g m^{-2} (75% in Bokurdak, 50% in Repetek, and 87% in Bozaubay). The stations close to the Aralkum Desert,

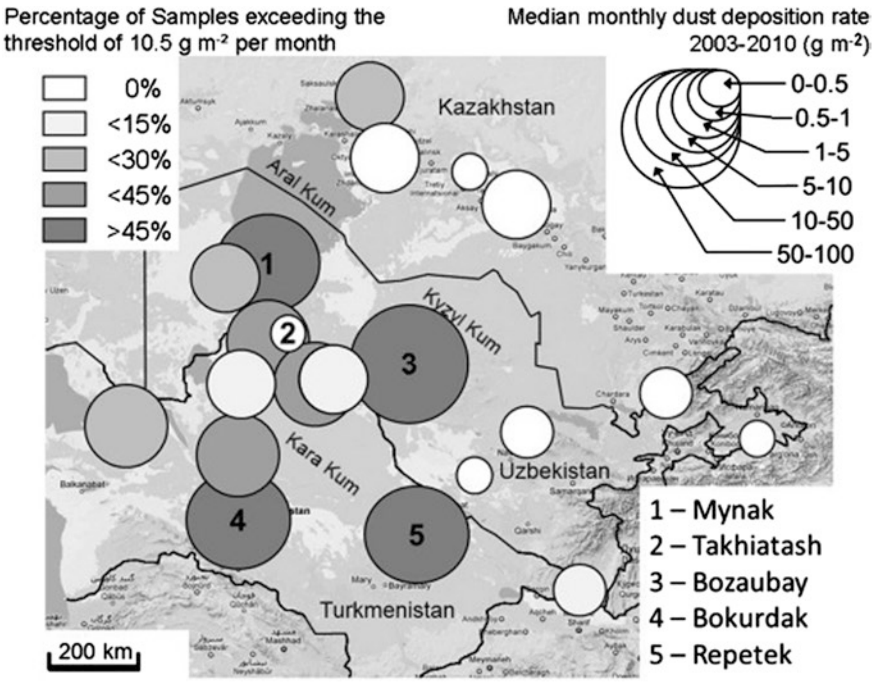

Fig. 3.3 Spatial distribution of the dust-deposition based on ground measurements at 21 meteorological stations (2003–2010) (Groll et al. 2012)

in contrast, showed much smaller deposition rates (28% in Jasliq, 33.3% in Kunya-Urgench, and 45.5% in Muynak) (Groll et al. 2012). The weather stations in Kazakhstan, in contrast, showed neither high deposition intensities nor high percentages of threshold excess. In the Aral Sea station, at the shore of the Small Aral Sea, the deposition rates were the highest (maximum: 134.9 g m^{-2} in June 2007; the average monthly deposition is 1.61 g m^{-2}), but they were still one order of magnitude smaller than those at the southern shore of the Aral Sea (Groll et al. 2012).

The spatial distribution of dust deposition is clearly related to the three main source areas of dust in the Aral Sea basin. The Muynak, Bozaubay, Bokurdak, and Repetek stations are all located at the southern fringes of the Aralkum, the Kyzylkum, or the Karakum deserts (Fig. 3.3), and they are characterized by the highest dust-deposition intensities, respectively. The large desert areas not only provide the source material for aeolian transport, they also act as generators of heated air up to average monthly air temperatures of 32.9 °C in Bozaubay as well as strong winds up to average monthly wind speeds of 20 m s^{-1} in Bozaubay, which increase the dust-deposition fluxes considerably ($R^2 = 0.53$ for the correlation between the average monthly air temperature and the monthly dust deposition and $R^2 = 0.85$ for the correlation between the average monthly wind speed and the monthly dust deposition in Bozaubay) (Groll et al. 2012). Stations further away from the dust source areas are characterized by lower deposition intensities and weaker correlations between the air temperature ($R^2 = 0.42$ in Takhiatash) and the wind speed ($R^2 = 0.34$ in Takhiatash) with dust deposition (Groll et al. 2012).

Differences can also be found between results of chemical analysis of storms. A clear distinction can be made between samples taken from stations close to the Aralkum and those taken near the Kyzylkum. The dust from the Kyzylkum Desert is dominated by hydrogen carbonate (56%) with only smaller contributions of calcium (13%) and sulfate (12%) (Groll et al. 2012). The dust from the Aralkum Desert is characterized by a more balanced distribution of hydrogen carbonate (35%), sulfate (22%), and calcium (15%) and a high concentration of chloride (12–21%). Analysis of the mineral composition showed that all of the dust samples were dominated by quartz, plagioclase, and calcite, dolomite, and orthoclase were also very common but showed slight differences among the three countries with the former being more common in Turkmenistan and Uzbekistan and the latter being more common in Kazakhstan. Even the trace minerals found only in small quantities (muscovite, clinochlore, clinoferrosilite, illite) are very similar in all of the samples (Groll et al. 2012).

In addition to spatial analysis, temporal distribution is the second and equally important component of the dust-deposition dynamic. In the light of manmade global changes and the growing economic and ecological pressure on the Aral Sea basin, the question of the future development of the aridity of Central Asia is very important for the provision of drinking water, for the agricultural sector, and for the exposure of the population to harmful dust. Over a given year, the median monthly dust-deposition flux over all 21 stations ranged between 1.01 g m^{-2} in 2008 and 9.22 g m^{-2} in 2010 (Fig. 3.4), thus showing the high temporal dynamic of the dust emission and deposition in the Aral Sea basin (Groll et al. 2012).

A similar dynamic was found for the percentage of samples that exceed the monthly threshold of 10.5 g m^{-2}. The temporal pattern seems to be undulating with a tendency for a slight increase during the 7-year period (Fig. 3.4). This conclusion requires support from further studies, however, because of the relatively short timescale. Because the atmospheric dynamics follow decadal trends, a sampling series over a period >10 years would allow a more reliable assessment of the long-term development of this trend (Groll et al. 2012).

A second temporal trend is visible in the results. During the last several years, the percentage of high-intensity dust-deposition samples increased, whereas the number of low dust-–deposit events decreased considerably (Fig. 3.5). The reason for this is partly due to a higher frequency of dust-storm events with deposition rates of >1000 g m^{-2}/month (as in 2009) and partly due to a significantly increased percentage of months with a very high average deposition activity but less extreme dust-storm events (as in 2010).

In addition to changes in deposition activity from year to year, there are also large differences in deposition intensity from month to month (Fig. 3.6). The results show that the most dust is deposited during the summer months (June in particular)

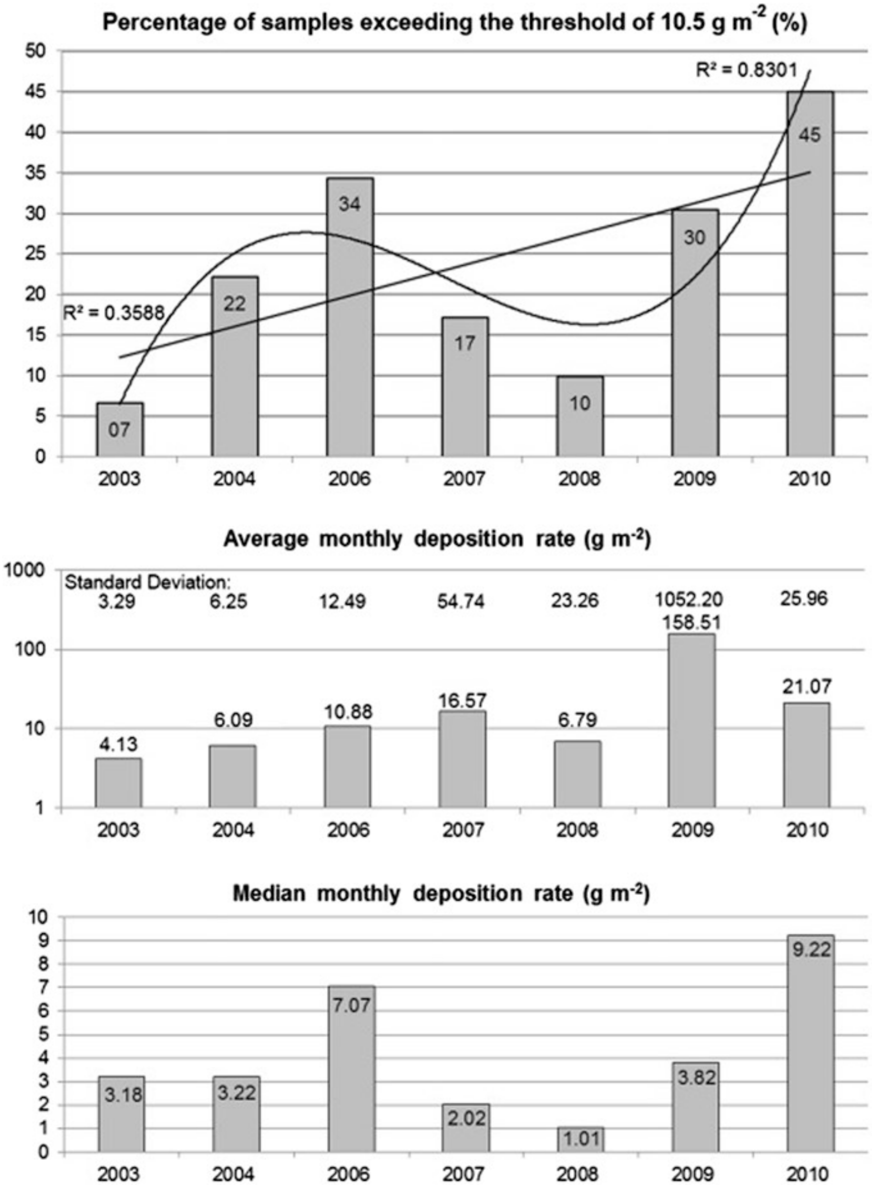

Fig. 3.4 Temporal dynamics of dust deposition in Central Asia (Groll et al. 2012)

(Bennion et al. 2007; Indoitu et al. 2009, 2012). This month is characterized by an extremely high deposition rate that is >25 times the average of all samples. September and July are other months with high deposition intensities; however, during these 2 months only 3 times the average amount of dust is deposited.

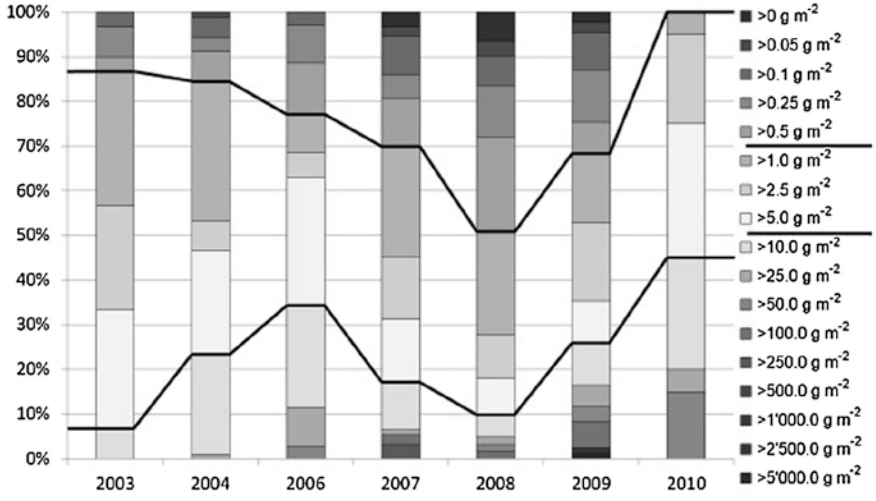

Fig. 3.5 Temporal distribution of monthly dust-deposition intensity categories (in g m^{-2}) (Groll et al. 2012)

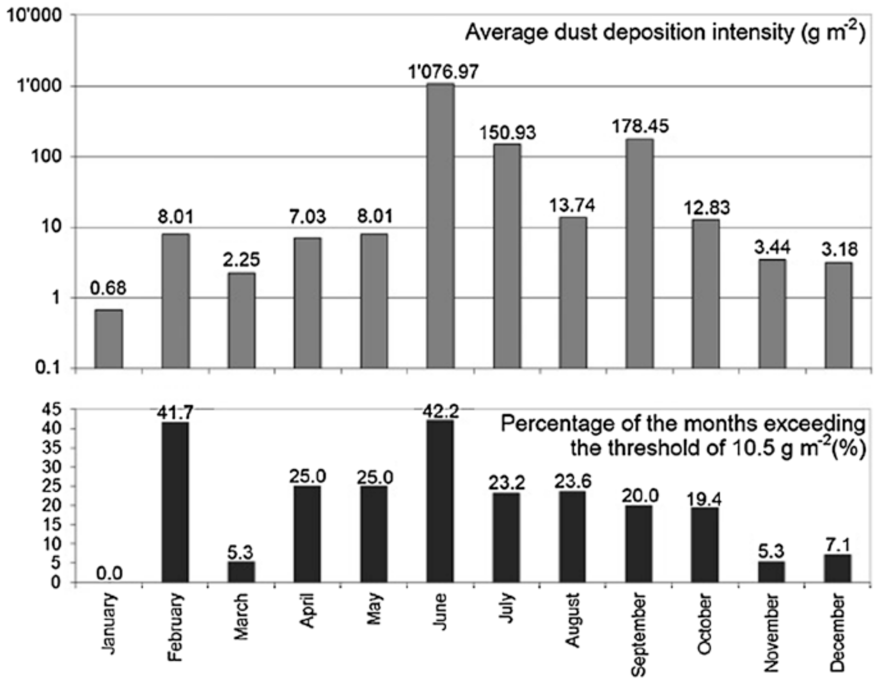

Fig. 3.6 Monthly distribution of the average dust-deposition rate and the percentage of samples exceeding the deposition threshold of 10.5 g m^{-2} (2003–2010) (Groll et al. 2012)

The lowest deposition rates were registered during the winter months (November through January) and in March. Winter in the Aral Sea basin is especially characterized by more frequent rainfall in the southern part and snowfall in the northern part. These precipitation events decrease the amount of dust emission from soil surfaces. Analysis of the threshold excess/month, however, showed that despite a less intense dust deposition during the Northern Hemisphere winter, almost 42% of all samples collected in February showed deposition rates that are potentially harmful to human health (Fig. 3.6). A slightly higher percentage was detected only in June, a month characterized by frequent dust-storm events (Groll et al. 2012).

A similar annual pattern was reported with two maxima for the frequency of dust storms in the former Soviet Union, and this was attributed to agricultural activities in combination with strong winds (Goudie 1983). Dust storms are defined as meteorological events characterized by high wind speeds and a visibility of <1000 m due to a high load of dust and sand (Goudie 1983). In the research area, they were registered between May and November with most events occurring in July. The highest monthly dust-deposition rate during these events was recorded in September (4980 g m^{-2} averaged over all September dust storm samples) followed by July (2100 g m^{-2}). In spring and autumn, only minor dust-storm events (<1000 g m^{-2}) were detected. The summer months are also the season with the highest frequency of dust storms in the Aral Sea basin (Indoitu et al. 2009). The shortest dust-storm event lasted for only 20 min and deposited a monthly equivalent of >4600 g m^{-2}. The most severe dust storm was registered in September 2009 in Bozaubay (Uzbekistan). Over the course of 14 h, a monthly equivalent of >9600 g m^{-2} was deposited, thus highlighting the paramount importance of these short events in the context of total dust deposition. This dust-deposition intensity is >500 times greater than what Goudie (1983) presented for the Negev desert. The main factors leading to these major dust storm events are surface wind velocities of >15 m s^{-1}, a negative annual rainfall anomaly, and high temperatures (Indoitu et al. 2009).

The seasonal distribution of dust deposition with two maxima confirms the results from other studies (Indoitu et al. 2009). The high intensity of dust deposition during the late winter months seems to be connected to the Siberian High (Orlovsky et al. 2005). The extremely high deposition intensity during the late spring and early summer, in contrast, is related to the warming of the Tibetan Plateau, which leads to dry and hot conditions in the western part of Central Asia (Duan and Wu 2005; Indoitu et al. 2012). The dark surface of the Kyzylkum desert contributes to the heating of the Aral Sea basin during the summer and thus to the generation of a more intense aeolian transport of sand and dust (Orlovsky et al. 2005) as well as the more energetic cyclone activity and cold-wave intrusions during the warm season (Létolle et al. 1993).

3.3 Temporal Changes of Storms Regarding Frequency and Intensity in Kazakhstan

Dust and sand storms are especially intense in areas of the Aral and Caspian Seas, man-made Aralkum and Southern Pre-Balkhash deserts, as well Karakum and Kyzylkum deserts in Central Asia. The vast Central Asian deserts are a source of dust and sand storms with different intensities, durations and frequencies. These source areas are characterized by the great variety of desert types and abundance of loose material available for transportation. The frequency of dust and sand events varies in a wide range of 5–146 days of dust and sand storms/year (Orlovsky et al. 2005; Dedova et al. 2006; Galaeva and Idrysova 2007). Desert areas are the principal source of dust-storm development (Squires 2001; Yang and Scuderi 2010; Moutaz et al. 2012).

A look into the research history proves that dust storms already were a widespread phenomenon in the Central Asian republics. A map published by Goudie (1983), after Klimenko and Moskaleva (1979), shows close connections between the frequency of dust storms/year (measured as visibility <1000 m) and the mean annual rainfall. The other map covering the same area was published by Orlovsky and Orlovsky (2001) showing classes of dust storm frequencies on the basis of meteorological observations from 1941 to 1991. This map shows two main intensity areas, a northern and a southern one, whereas the southern area of Central Asia is often subject to dust storms. Littmann (2006) performed a broader-section analysis of annual dust-storm frequency in Asia. The corresponding map showed that the highest frequency (>20 dust storms/year) occurred east, south, and southwest of the Aral Sea. Only for Turkmenistan Orlovsky et al. (2005) were areas mentioned with dust-storm frequencies ranging from 30 to 40 and >40 days/year.

In the northern sub-zone of Central Asia, an average of 20–30 days of dust storms have been observed between April and October 1990–2000. Along the Syrdarya and Ili River valleys, a yearly average of 28 dust storms was monitored, and the number of dust storms to the south of Lake Balkhash for the same period was 30 events. In this northern sub-zone, the maximum number of dust and sand storms is 67–108. In the southern sub-zone, dust storms occur year-round. In the central Karakum Desert, the annual mean frequency of dust storms is 60 events, and in the eastern Karakum Desert this figure is even higher—62 dust storms—and in the western Karakum Desert an average of 67 storms has been observed. During some years, the number of days with dust storms in the southern sub-zone can reach 106–146 days (Orlovsky and Orlovsky 2001). Most of the dust-storm events last from several minutes to several hours. Dust storms occur during the day time between 5 a.m. and 9 p.m. with most of them occurring between 11 a.m. and 6 p.m. with a peak time between 11 a.m. and 3 p.m. In the northern sub-zone, as observed in 1961–1991, the average duration of a dust-storm event is <1.5 h, but some dust storms can last 5.5–10.4 h; 3% last >12 h. The average yearly sum of dust storms in the northern subzone is 116 h (Orlovsky and Orlovsky 2001).

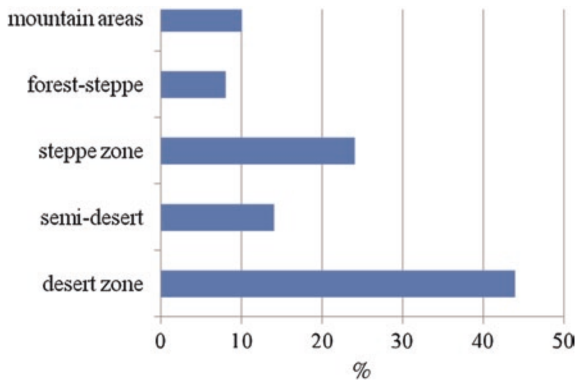

Fig. 3.7 Area ratio of climate zones

In the southern sub-zone, as observed in 1961–1991, the average duration of a dust-storm event is 6 h, whereas the duration of dust storms can varies from 0.5 to 23 h. The average yearly sum of dust storms in the southern sub-zone is 500 h. At Repetek meteorological station, the yearly maximum sum of dust storms was measured as 721 h. A single dust-storm event measured in Chargyl lasted for 39 h, in Kyzyl-Atrek for 57 h, and in Nebit-Dag for 60 h (all stations are located in Turkmenistan) (Orlovsky and Orlovsky 2001). In general, it can be summarized that the higher the frequency of dust storms, and the longer the events. A special problem of many dust storms in Central Asia is the "white salt dust," storm. This problem became especially large as a consequence of the Aral Sea disaster (Opp 2007) because a great amount of dust blown from the dry Aral Sea bottom is loaded with salts. However, salt dust is a wide-spread phenomenon in Central Asia because 14% of the land area there is covered by solochak pans, salt depressions, and salty sediments. Salty surfaces cover 110,000 km^2 in Kazakhstan, 24,000 km^2 in Turkmenistan, and 15,000 km^2 in Uzbekistan. The average composition of salt dust consists of 47% soluble salts and 53 insoluble particles, 90% sulfates, 7% chlorides, and 2% bicarbonates (Orlovsky et al. 2009).

3.4 Typical Regional Climate and Weather Process (Wind Regime) in Kazakhstan

The territory of Kazakhstan has four climate zones: (1) forest–steppe (8% of the entire territory of the country), (2) steppe (26%), (3) semi-desert (14%), and (4) desert (44%) (Fig. 3.7). Lowland regions (plains) in the northern part of Kazakhstan, which are supplied with moisture, belong to the forest–steppe climate zone. The steppe climate zone comprises a vast territory to the south. The semi-desert climate zone comprises the central part of Kazakhstan.

The desert zone is distributed on most of the plain are (Fig. 3.7) in the southern part of country and the sloping piedmont plains of Zhetysu (Dzhungar) Alatau and Tien Shan (Dzhanalieva et al. 1998). The desert zone of Kazakhstan can be divided into two subzones: the northern zone, which comprises the northern part of Usturt plateau, the northern part of Aral Sea (up to the Syrdarya River), the Betpakdala Desert along the Shu River, and northern part of Balkhash Lake up to Tarbagatai Mountain. In the territory of Kazakhstan, the north border of the desert varies between 48° and 46° nl. Moiynkum and the southern Pre-Balkhash sandy deserts belong to the northern subzone according to the vegetation cover (Breckle 2009). The southern subzone includes most of the Kyzylkum desert. Southern clay deserts cover the southern part of Usturt Plateau, part of the Syrdarya River valley, and the ridges of West Tien Shan. The subzone soil is light desert serozem (Breckle 2009).

The temperature for the vegetation period is 4204–3141 °C in the northern subzone, whereas in the southern subzone it is between 4686 and 4139 °C. The second factor, which directly determines the border of the desert zone, is the distribution and amount of precipitation (Grigoryev and Kondratyev (1981, 1950). Usually the precipitation does not exceed 200 mm/year in the southern subzone. Half of this amount falls during the vegetation period in early spring (March to April).

The third factor is air humidity, which is related to temperature and precipitation. Dry surface air masses in the second half of the summer are well illustrated by "dry precipitation" The sandy deserts with extreme heat cause the rain to evaporate before it hits the ground. The lack of humidity also contributes to the dryness with summer low-humidity averages of 50% for Kazaly station (Suslov 1961).

The wind speed is high in the desert zone of Kazakhstan, and it dries the soil surface and increases plant transpiration. The weathering process (deflation) of surface sand, soil, or salt can occur only above some critical wind speed. Therefore, determining the values of the critical wind speed is one of the important scientific and practical significance.

The forth factor is duration of the snow-free period and snow cover. The snow-free period is long. The snow cover is almost absent in the southern part of desert zone in Kazakhstan; it is inconstant in the northern part of desert zone; and only in some places is it stable in January and February.

Kazakhstan is far from oceans and receives winds from the north. Kazakhstan's climate is a sharp continental one with uneven distribution of precipitations within the territory. Plain areas are generally dry and receive precipitation from 100 mm in the southwest to 400 mm annually in the north. In the mountainous regions, the precipitation ranges between 400 and 1600 mm (ADB 2003; Almaganbetov and Grigoruk 2008). The average temperature is −18 °C in January in the north and −3 °C in the south. The average temperature in July increases gradually from 19 °C in the north to 28–30 °C in the south. The Republic of Kazakhstan has vast wind resources. According to the geographic location, Kazakhstan is situated in the wind zone of the Northern Hemisphere, and quite strong air currents occur in vast territories mainly in the northeast and southwest directions. Almost the whole territory is known to be windy. The wind-speed regime is variable throughout Kazakhstan. The average annual wind speed reaches 4–5 m/s for almost 50% of Kazakhstan territory (Fig. 3.8). However, the average annual wind speed can reach

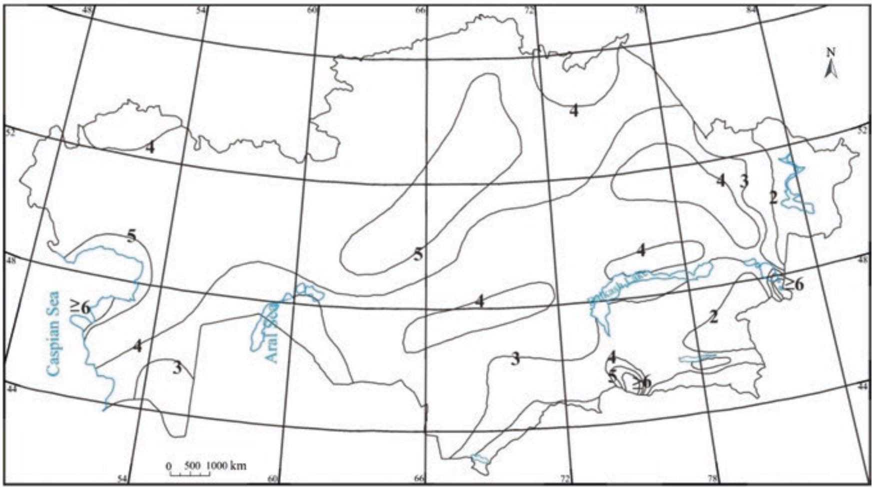

Fig. 3.8 Distribution of average annual wind speeds (m/s) within Kazakhstan

6 m/s and even more in some regions of the central parts of Kazakhstan, coastal areas of Caspian and Aral Seas, as well as some areas in the south, southeast, and southwest of Kazakhstan (Uteshev 1959). An average annual wind speed generally increases from south to north in the plain. The flat areas of Kazakhstan have a maximum wind speed in the spring and autumn seasons and a minimum in summer (Danayev 2008).

In addition, in the vast denuded plains, as a result of the unsystematic movement of transport mechanisms, the soil–vegetation cover is destroyed, and sources of dust storms are formed during average wind speeds. The average annual wind speed ranges from 4.0 to 4.5 m/s in the steppe zone; in Central Kazakhstan it decreases to 4.0–4.5 m/s; and in the desert zone it is 3–4 m/s. But the average annual wind speed reaches ≥6 m/s in some regions of Kazakhstan. Such areas are located in the central part of Kazakhstan, coastal areas of the Caspian Sea, and also in some areas in the south, southeast, and southwest of Kazakhstan. In the foothill (sub-mountainous) areas of the south and southeast of Kazakhstan, winds are observed that have small speeds (1–2 m/s). Conditions such as complex of topography features can affect wind regimes, and they are very unsteady under such conditions. For instance, places sheltered from wind by relief such as hollows, lee, and low parts of slopes usually experience low wind speeds (≤1 m/s); however, the wind speeds of mountain passes, corridors, and peaks can exceed 5 m/s (Danayev 2008).

As a result of the strong winds (>15 m/s) huge areas have become subject to the deflation process. The upper layer of loose soils from 70% of the whole territory of Kazakhstan consists of particles <0.5 mm (Medeu and Iskakov 2006). Therefore, any disturbance of the soil–vegetation cover causes an increase in deflation of the surface. The dynamics of the deflation processes during the past two decades in most cases show the anthropogenic factor and the risk of development of negative manifestations of this process, which deteriorates the ecological conditions of the region (Danayev 2008).

The wind regime in Kazakhstan mostly has a continental character. The wind regime is determined mainly by local barik-circulation conditions. The effects of topography, orographic features, and sun exposure cause much variety in the local circulation systems (breezes, mountain–valley winds, Ebi, etc.) (Medeu 2010).

The wind regime, in particular the western spur in the winter (cold weather) is mainly influenced by the Siberian anti-cyclone. Western, northern, and northwestern cold intrusions are responsible for development of 40% of dust storms. In 22% of cases, dust storms occur in the periphery of the anti-cyclone and 14% cases at the exits of the southern cyclones (Romanov 1960).

Wind of southwest direction dominants in the forest–steppe and steppe zones of Kazakhstan from Altai to Mugalzhar in the winter. Opposite directions of wind are much less. The predominance of winds of the northeastern quarter, in combination with a low frequency of the opposite western rumba, is typical for desert and partially in the foothill zone of the southern part of the country.

The wind regime in Kazakhstan, as in most parts of Eurasia, rapidly changes in the summer. This time of year, there is pronounced dominant removal of air masses from extreme northern latitudes of the continent to central regions. In general, the high air temperature of the summer in the continent leads to a major conversion of the pressure field in Eurasia (Uteshov 1959).

3.5 Atmospheric Parameters Influencing Dust Transport in Central Asia

The endurance and intensity of dust and sand storms mainly depends on the general atmospheric circulation and macrorelief. The range, intensity, and duration of aeolian transport of the dust, sand and salt from the Aral Sea region are determined by the atmospheric characteristics and their dynamics. The following are the main three factors—(1) Arctic and North Atlantic Oscillation (AO/NAO), (2) the Siberian High (SH), and the Tibetan Plateau (TP)—with the strongest influence on the climate of Central Asia and thus the aeolian dust and salt transport (Groll et al. 2012). Although the NAO exists throughout the year, it is strongest during the northern winter months and can have a great influence on the weather of Europe and Asia during the cold season (Ogi et al. 2003). The Arctic Oscillation and the NAO actually are almost identical, especially during the winter (Deser 2000; Dickson et al. 2000). The winter AO/NAO directly influences the atmospheric conditions in Central Asia (Aizen et al. 1997; Chen et al. 2008; Li et al. 2008; Small et al. 1999).

The teleconnections between the AO/NAO and the weather and climate in Central Asia—as well as the importance of the SH and the TP additional factors such as the East Asian winter monsoon—are not yet fully understood (Bingyi and Jia 2002), but it is commonly agreed that the combination of parameters is responsible for the arid and windy conditions that lead to the aeolian transport of dust in large quantities (Aizen et al. 2001; Chen et al. 2008; Zavialov 2005; Sorrel 2006). The AO/NAO indirectly impacts the climate of Central Asia by regulating the winter SH. If the AO/NAO is in its positive (negative) phase, the SH is weaker (stronger) than normal (Bingyi and Jia 2002; Duan and Wu 2005; Li et al. 2008).

The Siberian High (SH) is a semi-permanent, stationary, strong anti-cyclone circulation system centered over Siberia and Mongolia (Gong and Ho 2002; Panagiotopoulos et al. 2005). It is purely a regional feature that influences Central Asia, but it has no effect on the North Atlantic sector (Bingyi and Jia 2002). It is the most important atmospheric center of action in Eurasia during the Northern Hemisphere in winter (Gong and Ho 2002). The SH itself deflects the Westerly cyclones over the Aral Sea by changing their trajectories to southern directions (Lioubimtseva et al. 2005; Orlovsky et al. 2005). The northern parts of Central Asia are thus strongly and directly influenced by the SH, whereas the western parts (including the Aralkum) are mainly characterized by the deflected western cyclonic circulation associated with the NAO (Aizen et al. 1997; Orlovsky et al. 2005). When the SH is especially strong, the humid air masses from the Mediterranean cannot reach Central Asia, thus leading to reduced precipitation during those years (Small et al. 1999). In addition to these atmospheric processes, the uplift of the TP increases the aridity of Central Asia as well. The high mountain ranges of the plateau separate Central Asia from the humid air masses coming from Southern Asia (Guo et al. 2002). Furthermore, the highlands heat up intensively during the summer months, creating a local “elevated heat pump” that attracts dry air masses from the inner continent in the southern direction (Kang et al. 2003; Lau et al. 2006). This process is reinforced by the deposition of dust from Central Asia on the slopes of the Tibetan Plateau.

The Tibetan Plateau (TP) is a highland with an average elevation of >4000 m covering 2.5×10^6 km^2 (Zhu et al. 2011). It has a strong orographic influence on the circulation patterns in South and Central Asia because it diverts the mid-latitude Westerlies (Kang et al. 2003; Schiemann 2007). In addition, strong insolation over the highlands enhances the Asian summer monsoon on the Southern flanks and the subsidence of dry air on the Central Asian slide of the plateau (Chen et al. 2008). The effect of the Tibetan Plateau on the Central Asian climate is related to the monsoons (Chen et al. 2008). The warm and humid air masses drawn to the TP from the south by the heat pump subside on the Northern slopes of the plateau as dry air, thus contributing to the aridity in the Central Asian lowlands.

The increase of the Eurasian mean air temperature influences dust-transport intensity (D’Arrigo et al. 2005; Druyan and Rind 1993; Huang et al. 2011). The SH was in a pronounced weak state during the last 30 years of the 20th century whereas it was strong during the 1960s. The NAO has been in its positive phase since the 1970s (Hurrell 1995). This shift in dominance has a direct effect on the aeolian transport of dust in Central Asia (Han et al. 2008; Huang et al. 2011).

Western, northern, and northwestern cold intrusions are responsible for development of 40% of dust storms in Central Asia. In 22% of cases, dust storms occur in the periphery of anti-cyclone and in 14% cases at the exits of the southern cyclones (Romanov 1960).

3.6 Analysis of Dust-Storm Trends in Central Asia

Analysis of data from weather stations showed a decreasing trend in the last six decades (at global scale); however, increasing trends of dust storms have been noticed in some areas of Sahel, whereas Mongolia, China, and Australia, etc., have shown declining trends (Goudie and Middleton 1992; Indoitu et al. 2012). In the second half of the 20th century, in particular the middle 1970s, inter-annual dust storm occurrences at a global level showed significant decreasing trends (Ekström et al. 2004; Goudie and Middleton 2006). The decreasing trend in the frequency of dust storms continued until the end of the last century. According to the long-term data on dust-storm frequency variations from weather stations in different areas over Central Asia, dust storms showed a considerable decreasing trend, namely after the 1970s (Fig. 3.9). There were cycles of maxima and minima of dust-storm activities at the Aral Sea WS during 1936–2005 (Fig. 3.9f) based on data available only for 1951–1955 and 1966–2006. Each area has a particular characteristic. At the beginning of the 20th century, statistical analysis shows that dust-storm outbreaks in the region as a whole was not as great. However, in the 1940s to 1950s, a large number of stations registered upward trends of dust-storm frequencies (Indoitu et al. 2012). The middle of 1960s was the first period of a significant decreasing trend in dust storms in the central and southern parts of the Kyzylkum Desert (Uzbekistan) (Fig. 3.9b, e).

Large number of observation sites, prominently more so in the northern deserts, registered a downward trend of dust-storm events. However, at the end of the 1960s to the beginning of the 1970s, northern deserts showed a slight increase in the frequency of dust storms; there was a more considerable increase for the southern deserts. At the end of 1970s and the beginning of the 1980s, Central Asian dust-storm outbreaks, concomitant with the global dust-storm pattern, showed significant decrease in dust-storm frequency. Most of the weather stations observed this discernible pattern. The 1970s trend of decreasing dust-storm frequencies continued until late 1990s. During this period, the number of dust-storm events was reduced by 2–3 times, and all of the stations monitored a reduction. However, the southwestern, eastern, and northeastern areas of the Aral Sea region were the exception. In the Aral Sea region, the frequency of dust storms has increased since 1980 (Fig. 3.9f) (Indoitu et al. 2012). At the end of the 1990s and the beginning of the 2000s, few records show a slight increasing trend of dust-storm frequency.

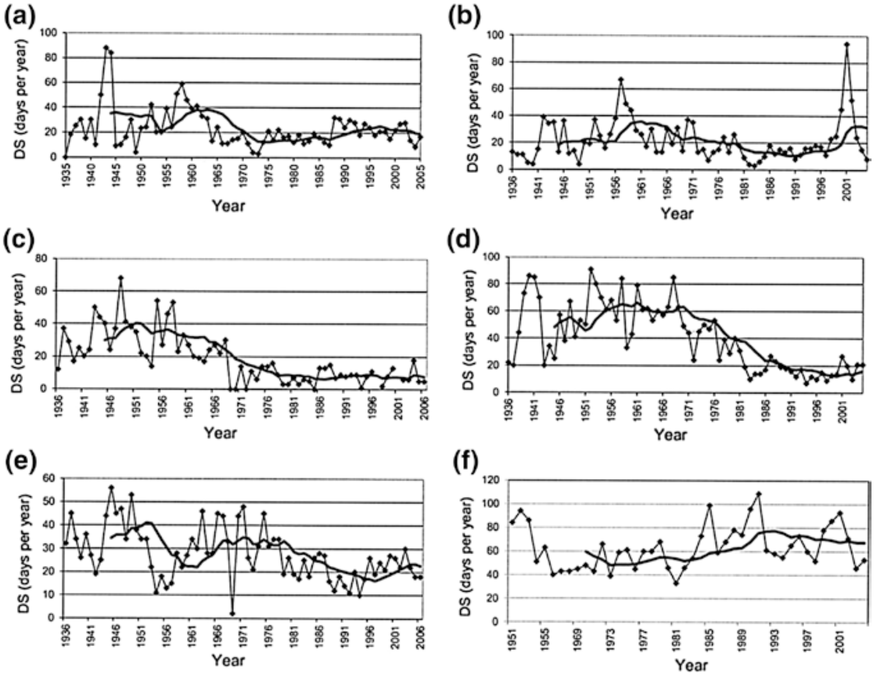

Fig. 3.9 Dust-storm dynamics in different regions of Central Asia during 1936–2005 (line with marker = total annual days with DS, *solid line* = 10-year moving average). **a** Kyzylorda (Kazakhstan), **b** Zhusaly (Kazakhstan), **c** Tamdy (Uzbekistan), **d** Erbent (Turkmenistan), **e** Termez (Uzbekistan), and **f** Aral Sea (Kazakhstan) (Indoitu et al. 2012)

Since 2000, almost all weather stations in the region showed the increase in dust-storm activities. The alteration in the regional and global atmospheric circulation can explain such changes. Northern, western, and northwestern cold intrusions are responsible for development of 40% of dust storms. In 22% of cases, dust storms occur at the periphery of anti-cyclones and in 14% of cases at the exits of southern cyclones (Romanov 1960; Indoitu et al. 2012). According to Zolotokrylin (1996), the recurrence of these three synoptic processes in 1966–1985 decreased by 26–29% compared with the period of 1936–1965. This may explain the decrease in dust-storm frequencies during that time. In addition, the average annual wind speeds recorded at several stations in the northwestern section of Kyzylkum Desert (Kazakhstan) show at the same time a decreasing trend starting in the mid-1960s and continuing until the early 2000s (Weidel et al. 2004).

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Chapter 4
Relationship Between Storms and Land Degradation

4.1 Sources of Natural and Geographical (Topography, Soils, Vegetation) Storm Conditions

Almost all major sources of dust and sand storms are located over topographical lows or on lands adjacent to strong topographical highs where fluvial action is evident by the presence of ephemeral rivers and streams, alluvial fans, playas, and saline lakes (Prospero et al. 2002). Kazakhstan and Central Asia together comprise a vast region with varied geography and climates; thus, dust- and sand-storm activities are highly variable at annual and inter-annual scales. In general, dust- and sand-storm outbreaks in Central Asia and Kazakhstan are common for the spring and summer seasons, although they can also occur in the autumn and winter months (Indoitu et al. 2012). Central Asian and Kazakhstan deserts are characterized by continental and Mediterranean climate with long dry summers, relatively low air moisture, scarcity of vegetation cover, strong winds, lack of soil moisture, and frequent repletion of soil and atmospheric droughts (Indoitu et al. 2012). Deserts are dry, fragile areas with scarce or no vegetation. Therefore, winds can remove sand-, silt-, and clay-sized particles from the surface and transport them over long distances by way of dust and sand storms (Al-Dousari et al. 2012). The main persistent sources of dust and sand storms of Central Asia and Kazakhstan are located in the large "dust belt" that extends from west to east over the southern deserts, north of the Caspian Sea deserts, Aral Sea region (Kyzylkum, Aralkum deserts), and Southern Pre-Balkhash deserts (Fig. 4.1). The high frequency of dust and sand storms occurs mainly in sandy deserts and other types of deserts where sensitive ecosystems have suffered substantially from human impact (Orlovsky and Orlovsky 2001; O'Hara et al. 2000; Indoitu et al. 2012).

The origin and intensity of dust and sand storms is controlled by unstable atmospheric conditions, strong winds, and surface material susceptible to wind erosion and transport. At a wind speed of 60 cm/s, particles come loose from the

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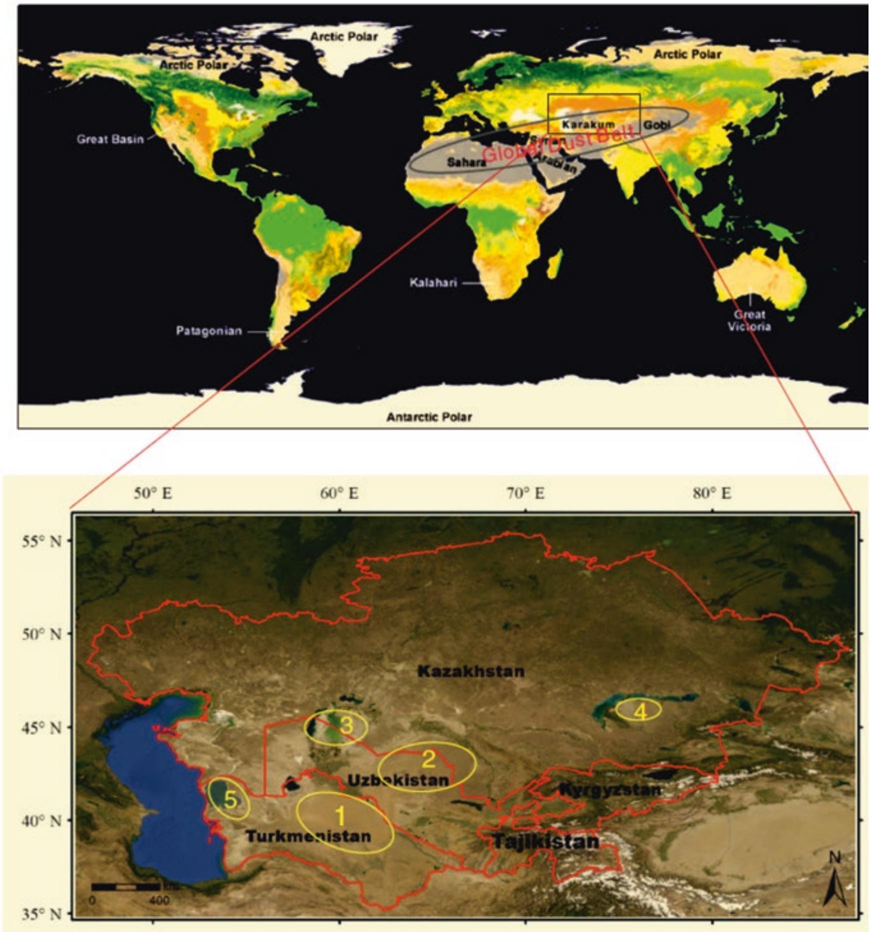

Fig. 4.1 Distribution of major dust-storm sources in the deserts of Central Asia: (*1*) Karakum Desert, (*2*) Kyzylkum Desert, (*3*) Aralkum Desert, (*4*) Southern Pre-Balkhash Desert, and (*5*) Kara-Bogaz-Gol (Shen et al. 2016)

ground. After coming into movement, winds of only 16–24 km/h (8.7–13 knots) can sustain particle movement (Orlovsky et al. 2009).

The amount and size of blown particles depends mainly on the soil surface structure and wind regime. The wind is one the main of exogenous factors, which influences relief and forms specific depositions. The relief-creating function of the wind consists of deflation (blowing and winnowing), corrasion (grinding, scraping), transportation, and accumulation.

Sand, silt, and clay can all generally be transported by wind. Another precondition for aeolian particle transport is the dryness of the upper soil layer. Another factor influencing the detachment of particles from the ground is the presence of biogenic soil crusts on the soil surface. Soil surfaces without biogenic crusts are prone to dust and sand transport (Orlovsky et al. 2009). The vegetation cover is the other crucial factor influencing the dust-emission potential. Less vegetated areas, i.e., sites with a low percentage of vegetation cover, function as dust sources and thus are sinks for aeolian particle transport.

Approximately 90% of dust in the atmosphere is of natural origin caused by wind erosion from dry surfaces such as dry soil surfaces, dried lakes and river beds, glacial and periglacial sediments from volcanic-ash transport, aerosol transport from forests, and grassland fires and sea spray. Ten percent of dust in the atmosphere is caused by human activity such as burning of fossil fuel, alteration of surface cover, industrial emissions, slash-and burn agricultural regions, overgrazed grassland, and open cast mining (Orlovsky et al. 2009).

In Kazakhstan, dust storms appear under the conditions of some critical thresholds of wind speed depending on topography and soil structure when unrelated particles are <250 μm, high soil dryness, and scarcity of the vegetation cover; thus, these thresholds vary from region to region (Uteshev and Semenov 1967; Romanov 1960; Semenov 2011).

Meteorological features (temperature and dryness) of southern deserts in Kazakhstan and its landscape with sparse vegetation are prone to dust and sand storms because winds blow soil particles from the ground surface very easily. Dust, sand, and salt storms often occur simultaneously with hot, dry winds in the region (Semenov 2011; Fedyushina 1972a, b). They play an important role in the removal of salt from solonchaks (Orlova 1983; Abuduwaili et al. 2008; 2010).

Lack of precipitation and surface water and groundwater, intensive weathering, poorly developed soil–vegetation cover, and wind regime are the main factors for the intensive development of deflation, deflation–aeolian, and accumulation processes consequently leading to degradation.

4.2 Storm-Produced Wind Erosion and Land-Degradation Processes

Destruction of soil surfaces as a result of wind impact is most commonly referred to as the “deflation process” or “wind erosion.” This process includes the removal, transport, and re-deposition of soil mass.

In Central Asia, wind erosion (deflation) is probably the greatest issue in the arid and semi-arid steppes and pastureland. In Kazakhstan, as much as 45 million ha of plowed land and rangeland have been affected and degraded by wind erosion. Wind erosion affects almost one quarter of all agricultural land in Tajikistan. Vast deserts in Turkmenistan and Uzbekistan are especially susceptible to wind erosion once the land is disturbed.

Desertification due to the deflation process (wind erosion) has affected the steppe, dry steppe, semi-desert, and desert landscapes of Kazakhstan (Parakshina et al. 2010). Kazakhstan has differing soil and climatic conditions, topography, and geology, and deflation processes are very common (Dzhanpeisov 1977; Uteshev and Semenov 1967; Gael and Smirnova 1963; Belgibayev 1993).

Deflation processes in deserts and dust deposits occur due to the physical–geographical and climatic conditions of the region (Yang and Scuderi 2010; Uteshev and Semenov 1967). The process is especially intensive in the areas of the Aral and Caspian seas, the man-made Aralkum and southern Pre-Balkhash deserts, as well as the Karakum and Kyzylkum deserts in Central Asia, which are the main source areas of deflation process in terms of dust and sand storms, which affect the entire region (Orlovsky et al. 2004, 2005).

Storms are both the symptom and cause of the desertification process. They contribute to the spread of desertification and the development of intensive deflation. The effects of dust and sand storms on the Earth's surface are diverse: In source areas dust storms result in the wind erosion of surface layers, the loss of organic soil matter, and the exposure of subsoil layers. In deposition areas dust storms result in natural vegetation and crop damage, changes in the geochemistry of the soil, the damping up of rivers, the contamination of drinking water, etc. From the trans-Atlantic atmospheric transport of Saharan dust, it is known that in years of pronounced dust transport, there is a substantial decline of the coral reef (i.e., coral bleaching) in the Caribbean Sea. In contrast, great amounts of dust in the atmosphere over the Atlantic Ocean cause cooling of the ocean water and as a consequence prevent the formation of hurricanes (e.g., in 2006), whereas low amounts of dust in the atmosphere over the Atlantic Ocean promote the development of hurricanes (e.g., 2005 and 2008) (NASA 2008). In addition, smaller particles such as silt and clay have influence as aerosols in the higher atmosphere and on the climate as well. It is known that after eruptions volcanic dust becomes a part of the regional and global atmospheric circulation and even affects the stratospheric ozone layer. Atmospheric aerosols have a profound affect on the global and regional climate by absorbing and reflecting the incoming solar radiation, which is called the "direct radioactive effect." They can increase cloud albedo and increase or decrease precipitation by modifying cloud microphysical properties (Washington et al. 2003).

Desertification occurs as a form of land degradation as a result of various factors including climatic variations and human activities in arid, semiarid, and dry sub-humid areas (UNEP 1992; Elsayed 2012). The development of desert land resources in Kazakhstan has intensified during the last 10 years. Unsustainable land practices and the irresponsible use of natural resources as well as environmental pollution have lead to land degradation and desertification in almost every region of Kazakhstan. Sandy deserts of the Southern Pre-Balkhash region undergo intensive human activity. In the 1970s, creation of the Kapshagai water reservoir and intensive use of water from the Ili, Karatal and Lepsi rivers (for irrigation and electric-energy production) led to the water level decreasing in Balkhash Lake where the mirror pond decreased by $\leq$4700 km^2. As a result, a considerable part of lands in the coastal area of Balkhash Lake have undergone soil salinization and degradation. Reducing and regulating the flow level of the Ili and Karatal rivers, respectively, led to the drying of many lakes including salty lakes in the deltas of these rivers (Skotselias 1995; Belgibayev 2001; Kudekov 2002). As a consequence, new sources of soil deflation and sources of dust, sand, and salt storms have appeared in the Southern Pre-Balkhash deserts, which have lead to high concentration of aerosols in the atmospheric flows. These aerosols provoke the deterioration of pastures, reduction of biodiversity, salinization, and desertification of soils. In addition, critical changes in the hydro-meteorological regime of the Aral Sea have lead to soil degradation and the desertification of huge areas of land. A new phenomenon of salt–dust storms from the dry sea bottom has caused a catastrophic degradation of the Aral Sea region. The dried bottom of the sea is rich in salt and is subjected to wind erosion under conditions of strong wind. Consequently, during storms the salts from the dried sea bottom are transported and thus affect the environment. In addition, the exposed part of the seabed is composed of saline soils and represents an enormous saline surface. The wind regime of high wind speeds combined with light-textured soils and sands contributes to the development of deflation processes (wind erosion) on the dry seabed as well as the transport of sand and salt aerosols to the surrounding territories. The likelihood of dust storms on the dry sea bottom is 10 times greater compared with that of the surrounding areas because the dried surface structure is unstable and easily subject to wind erosion.

Dust storms produced by wind erosion occurring in natural and anthropogenic deserts of Central Asia transport huge amount of deflated material over great distances and significantly affect human health and agricultural activities. The large amount of deflated material transported by wind erosion reduces agricultural yields and leads to irreparable land damage. Agricultural activities mainly suffer from intensification of the soil-salinization process, degradation of pastoral vegetation, decreasing agricultural crops, and increasing salinity level of surface waters and groundwaters (Shardakova and Usmanova 2006; Kuzmina and Treshkin 2009). This is a prominent problem in the Aralkum region (Breckle et al. 2001a, b).

Dust storms are characterized by the transport of a huge amount of dust particles by strong winds. The dust particles are variable in terms of their chemistry. Salty deserts often have various salts (NaCl, sulphates, carbonate, and chlorides) in high percentages (8–10%) (Orlovsky and Orlovsky 2001). Those salt and dust storms are particularly dangerous in terms of human health, decrease productivity of agricultural fields by enhancing soil salinization and land degradation, and increased salt desertification in general.

4.3 Sand-Storm Outbreaks (Sources) Based on Temporal Remote-Sensing Data Combined with Ground-Monitoring Data

Storms occur in tens or hundreds of kilometers, and they belong to the category of local mesometeorological weather events. Only in very rare cases may catastrophic dust storms have a scale with thousands of kilometers. Such a scale of the phenomenon require a comprehensive approach to the study of storms; along with ground-based measurements is necessary to obtain information about them from spacecraft. Space exploration has opened up broad prospects for future monitoring of the development of powerful dust storms on the Earth. It has become possible to make a quantitative interpretation of satellite images because the image of each element can have data on the absolute brightness of the earth's surface and atmosphere. Space-observation techniques allow estimates of dust-plume mass in the removal of strong storms (Grigoriev and Kondratyev 1981; Kondratyev 1979).

In Kazakhstan and Central Asia storm-recognition methods on satellite images have been developed and described by Zakarin et al. (2007), Grigoriev and Lipatov (1982), and Dedova et al. (2006). The prospects of these methods to obtain information about the content of mineral aerosols in the Earth's atmosphere are evident. Only these methods allow to quickly assess the weight of the aerosol as well as its optical characteristics and life span in the atmosphere, which are required for many applied and environmental challenges. Systematic organization of space monitoring is important for the prediction of global and regional climate changes.

Satellite images of storms, in conjunction with ground-based measurements of the aerosol-concentration profile, can more accurately determine the source coordinates of soil weathering and, describe the geometric dimensions of dust clouds, or determine transparency of the atmosphere as well more accurately determine the mass of the removed particles. In addition, observation from space can detect sources and areas of occurrence of dust and sand flows to obtain necessary data on the underlying surface and movement of dust formation. These atmospheric parameters are needed for the climate and for the solution of many applied problems of ecology and the environment.

Dust storms are dangerous meteorological phenomena and are a powerful source of atmospheric pollution. Aerosols can be transported to transboundary territories, and these phenomena have posed harmful effects to large areas. The problem is exacerbated by the continuous formation of new sources of removed aerosols due to land degradation. The African and Asian continents were the most powerful sources of aerosols in the atmosphere (Grigoriev and Kondratyev 1981; Grigoriev and Lipatov 1979; Zakarin et al. 2001, 2007; Lipatov 1974; Arao and Ishizaka 1986; Dulas et al. 1992; Liu and Linsheng 1999).

Information from space allows detection of the presence of powerful sources of aerosol flow over the territory of Kazakhstan. One of the most dangerous sources of sand and salt storms in Central Asia remains the dried bottom of the Aral Sea (Fig. 4.2). The intense aerosol source from the dry part of the bottom of the Aral Sea is well known in ground-based as well as space observations. The first analysis of satellite images of dust storms and evaluation of the amount of dust material transported during dust storms in the Aral Sea were made by Grigoriev and Lipatov (1974) and Lipatov (1974).

In 1991 began a joint study of sand and salt storms in the Aral Sea between different research institutes in Kazakhstan. During the study, the institutes performed research on the composition of soils from the removal source and analyzed the

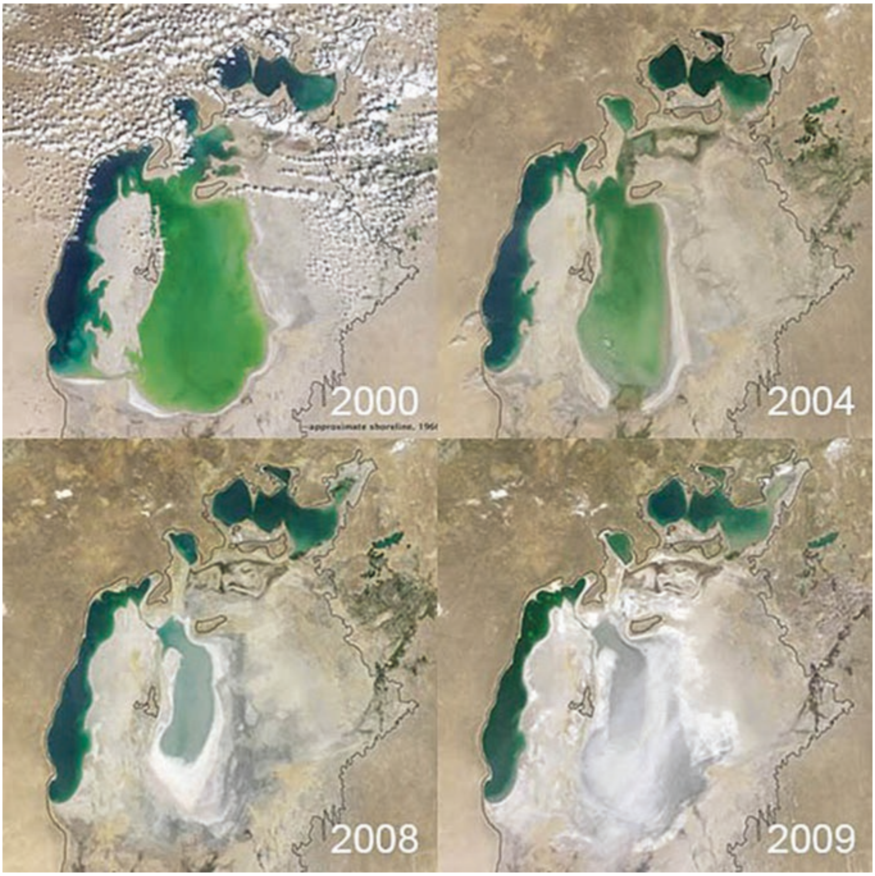

Fig. 4.2 Dried bottom of the Aral Sea (*source* https://www.google.kz)

data of meteorological observations and space monitoring. Due to anthropogenic factors, mainly the overexploitation of water resources for irrigation, the Aral Sea has rapidly shrunk, and the region has become an ecological disaster zone. The exposed sea floor is estimated to be almost 60,000 km^2 (Indoitu et al. 2012). The exposed sea floor is now an active and powerful source of storms, which contain salt and fine dust with impurities of various chemicals that adversely affect the environment. The Aral Sea is located within a powerful air stream from west to east, which transfers these aerosols in the upper layers of the atmosphere; thus, air contamination is enhanced. To mitigate the problem, the observation from space should be combined with ground investigations. The observation and regular monitoring of dust storms was started in 1936. However, due to funding and other factors, the number of weather stations and ground investigations of the Aral Sea region have been sharply reduced in recent years. In this regard, there is an increasing need for satellite monitoring (Zakarin et al. 1999).

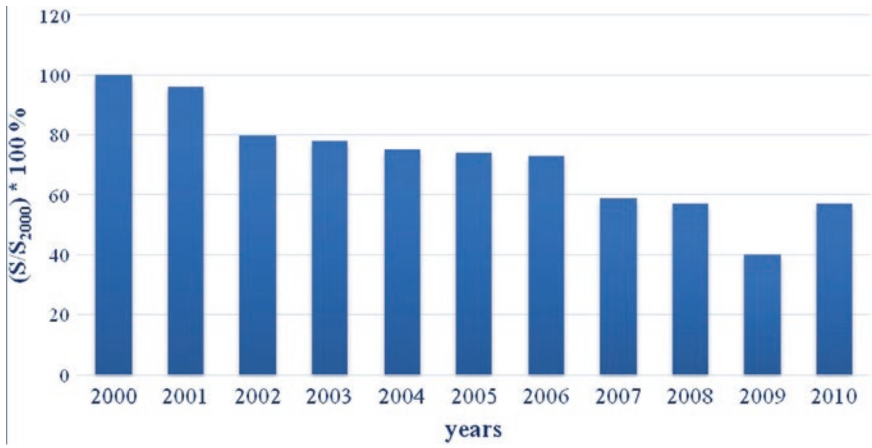

Fig. 4.3 Dynamics of the water-surface area of the Aral Sea in the period 2000–2010 (2000 = 100%) (according to Spivak et al. 2012)

For the analyses and space monitoring of storm events occurring in the Aral Sea region, daily images from the National Oceanic and Atmospheric Administration (NOAA)/Advanced Very High Resolution Radiometer with a resolution of 1100 m in the visible and near-infrared spectrum (1.2 channel) for the period 2000–2010 were used.

Satellite data show the dynamics of the water surface of the Aral Sea for the period 2000–2009 (Figs. 4.3 and 4.4). Within this short time, the water surface decreased by 60%. The eastern part of the Aral Sea practically no longer receives water from rivers. In this regard, the decrease was significant. The eastern coastline has receded by tens of kilometers due to annual fluctuations of the surface area. According to the results from satellite images, the water surface in the eastern part of the Aral Sea from May until October 2009 decreased tremendously (Fig. 4.5).

Satellite images allow one to well recognize dust plumes above the water surface (Fig. 4.5). Dust storms are most typical in the spring season. In the spring, the soil surface is getting rid of accumulated winter moisture and dries, and vegetation cover will also be minimal, thereby forming conditions favorable to the formation of dust storms. Space monitoring of the Aral Sea region provides the observation of dust storm events each year and as well the direction of storm plumes (Table 4.1).

In 2002, the maximum number of dust storms was observed. An analysis of NOAA satellite images from 2002 to 2004 A confirms the increased frequency and occurrence of dust plumes from the area of the Aral Sea (Semenov 2011). The transport distance of fine particles (aerosols) from removal plumes in the Aral Sea region during sand and salt storms based on satellite images during 80–90 years is estimated at 250–400 km. In the early 21st century, after weathering of sand

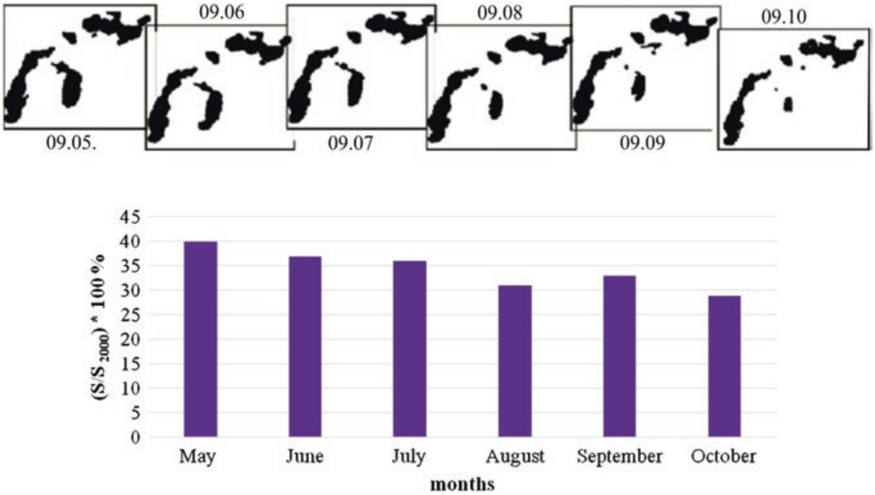

Fig. 4.4 Changes of the water surface of the Aral Sea during the period May to October 2009 (According to Spivak et al. 2012)

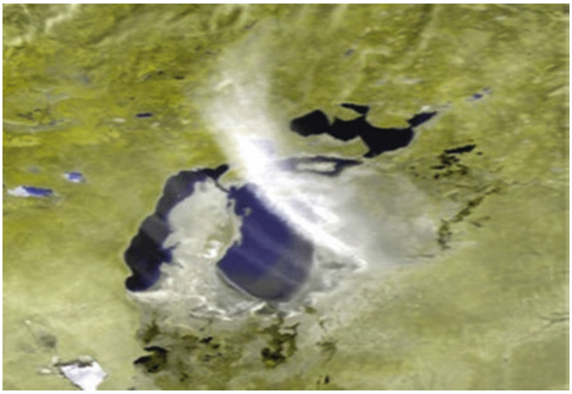

Fig. 4.5 Dust-storm episode from the dried bottom of the Aral Sea (NOAA/AVHRR) satellite data (9 May 2007) (Spivak et al. 2012)

and silt sediments, the number of dust-storm removal plumes increased, which is clearly visible on satellite images. NOAA satellite images from 2002 to 2004 show that the maximum distance that storm plumes spread in 2002 with 620–700 km and 540–660 km in 2004. The distance of aerosol spread has increased 1.5–2 times compared with their transfer at the end of the 20th century (Semenov 2011; Dedova et al. 2006).

Interpretation of expert for a set of vertices defines the zone of dust removal and dust-storm intensity. The contours of aerosol zones were constructed for the period 2000–2008. A complex median filter was used for mapping the intensity of wind erosion. For instance, the dust-storm episodes occurring in 2008 were

Table 4.1 The number of dust storms recorded on NOAA satellite images for the period 2000–2009 and broken down according to the direction of aerosol transfer (Spivak et al. 2012)

Years	Number of episodes							
	N	NE	E	SE	S	SW	W	NW
2000	6	1	4				1	
2001	13 1		5			1	4	2
2002	22 2	1	6	2	3	5	3	
2003	19		16			2	1	
2004	7		5			1	1	
2005	11	2	2			2	4	1
2006	11					5	4	2
2007	13	1	3	2		2	3	
2008	15					6	9	
2009	17 2	1	8	1	1	2	2	

analyzed, and the results of processing are shown in Fig. 4.6. The water surface in the eastern part of the Aral Sea was drastic reduced; consequently, the sites with an unstable surface, which is subject to wind erosion, tremendously increased (Spivak et al. 2012).

The dried bottom of the Aral Sea is an active and powerful source of dust-storm generation. The territories with enough moisture are exceptions due to seepage and the presence of groundwater. These territories include sites adjacent to the water mirror of the Large and Small Aral Sea and the Syrdarya and Amudarya river deltas. The main reason for changing the zone of storms is reduced filtration at the bottom of the eastern part of the Aral Sea. The eastern part of the Aral Sea is the most powerful and dynamic source for dust, sand, and salt removal (Fig. 4.7). Because there is no water in this part of the sea, it has almost completely disappeared since late summer 2009. Hence, there is an expectation that the zone of dust removal at the eastern part of the Aral Sea will increase conspicuously in coming years (Fig. 4.8e). This depends on the future low-level hydrological equilibrium from year to year (Spivak et al. 2012).

Significant differences in the frequency and magnitude of dust storms with time can be noticed based on the results of satellite information. In addition, the annual activity of dust-transport processes is increasing monotonically. Two independent phenomena—such as progressive drying seabed and the formation of unstable surface without vegetation—variable and unstable wind conditions are the base for the process of removal of salt-dust aerosols from the dried sea playa.

The use of satellite images based on calculation with the method allow us to compare the annual frequency of dust storms from the dry bottom of the Aral Sea (Fig. 4.9a) and the average intensity of wind erosion in the region (Fig. 4.9b). During the processing of satellite images to determine the contour of the removal zone and estimate the intensity of wind erosion was largely employed subjective information (Spivak et al. 2012). However, both techniques/methods show similar

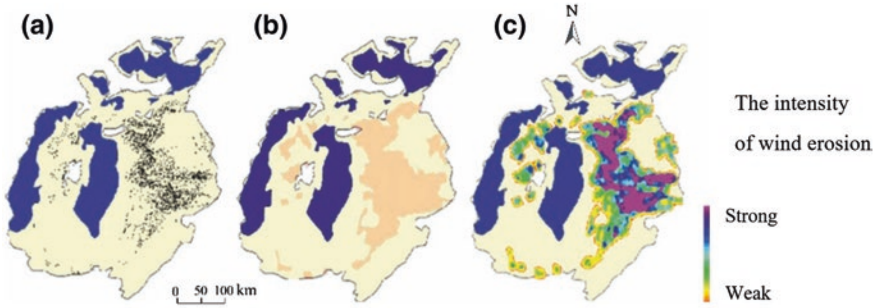

Fig. 4.6 Space monitoring of dust storms from the dried bottom of the Aral Sea in 2008 and stages of mathematical processing. **a** Dust-storm intensity on satellite images for 2008 as estimated by an expert. **b** Outlines of zones of dust removal by calculation of the contour line of dust storms [the state of the water mirror corresponds to the satellite data (May 2008)]. **c** The intensity of dust-removal process (averaged over the yearly data by determination of the density of vertices inside the calculated area of storm removal using a complex median filter) (Spivak et al. 2012)

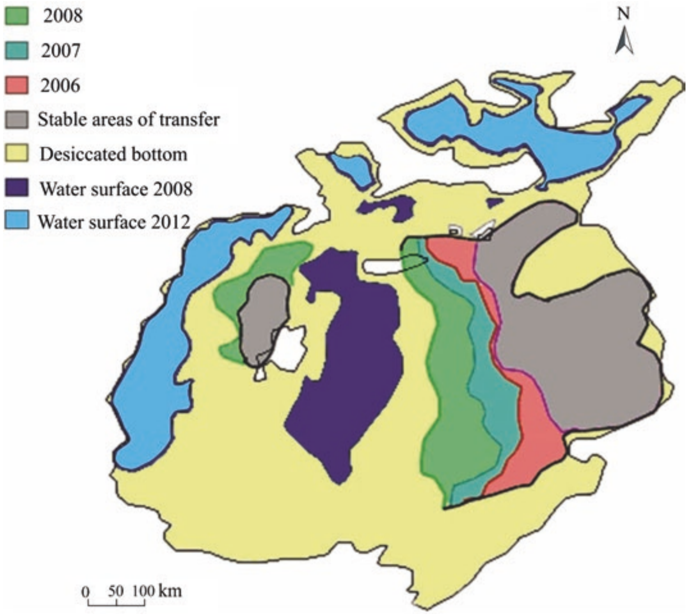

Fig. 4.7 Dynamics of the expansion of the centre of dust removal located on the eastern coastline of the Large Aral Sea (2006–2012) (modified after Spivak et al. 2012)

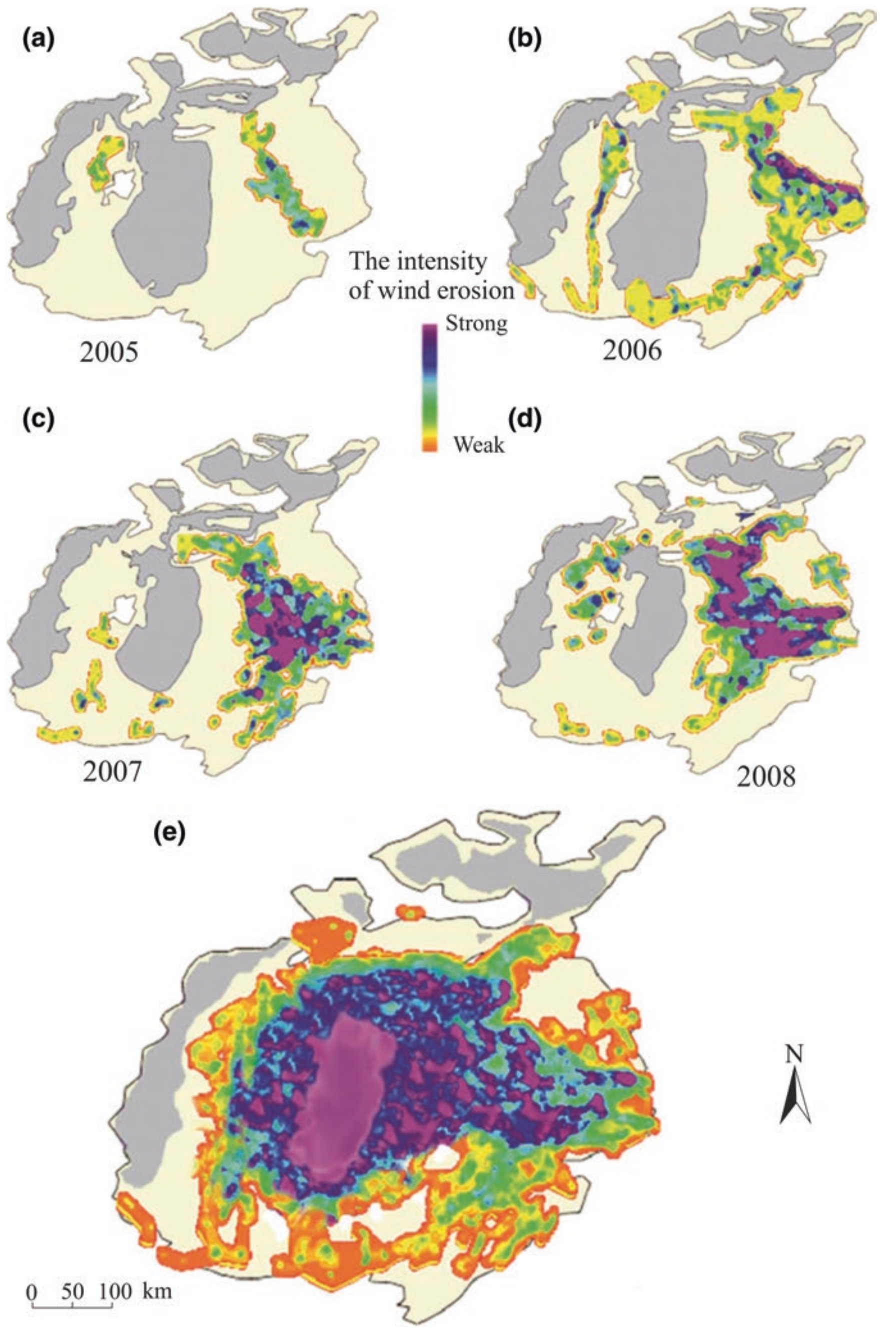

Fig. 4.8 The intensity of dust removal from the dried bottom of the Aral Sea for the period 2005–2008 (**a**–**d**) and the forecast of the state of this site (**e**) in the case of complete drying of the eastern part of the Large Aral Sea. Constructed using NOAA/AVHRR satellite data (Spivak et al. 2012)

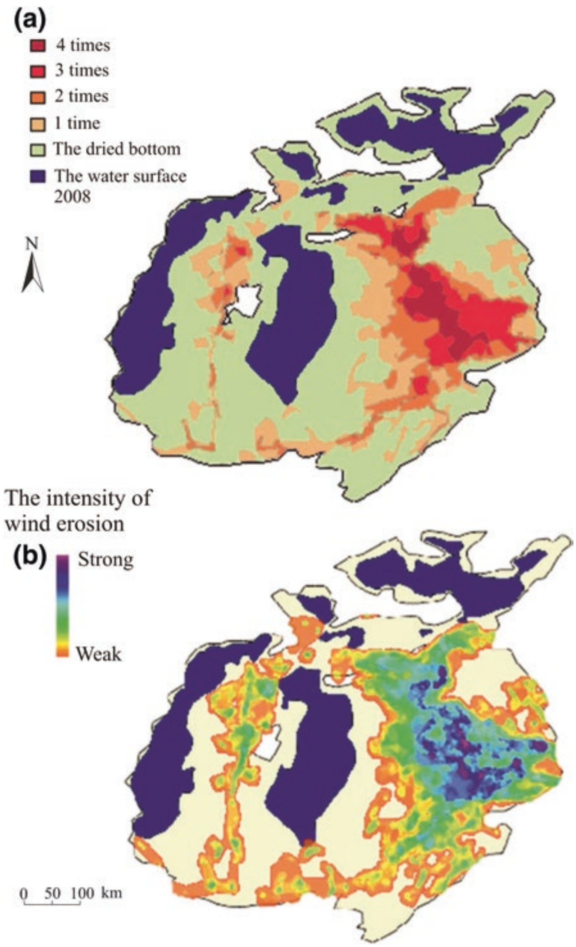

Fig. 4.9 Spatial characteristics of salt–dust storm sources in the dried bottom of the Aral Sea (2005–2008). **a** Frequency of determining territories in the zone of dust removal in the analysis of annual samples for the period 2005–2008. **b** The average intensity of wind erosion for the period 2005–2008 (Spivak et al. 2012)

results and indicate the effectiveness of the methods. The existence of long-lasting dust-storm events according to a Landsat satellite image on 1 September 2006 with 240-m resolution was confirmed by NOAA satellite images for the period from 30 August 2006 (12:24 UTM) to 2 September 2006 (12:50 UTM) (Fig. 4.10). The area of sand is clearly identified on the Landsat satellite image (Fig. 4.10a). The legitimacy of using a system of points to highlight the removal of aerosol is confirmed by the “inkjet” nature of the storm (Fig. 4.10b).

Within the period 2005–2008, increasing drainage of the former seabed inflected the reduction of the water surface in the eastern Aral Sea basin. As a result of this process, the territory with unstable surface was increased because it is prone to wind erosion. According to the analysis and results of satellite images by remote sensing, the following points and issues were observed and investigated: (1) the temporal dynamics of the aerosol-removal zone in the eastern part

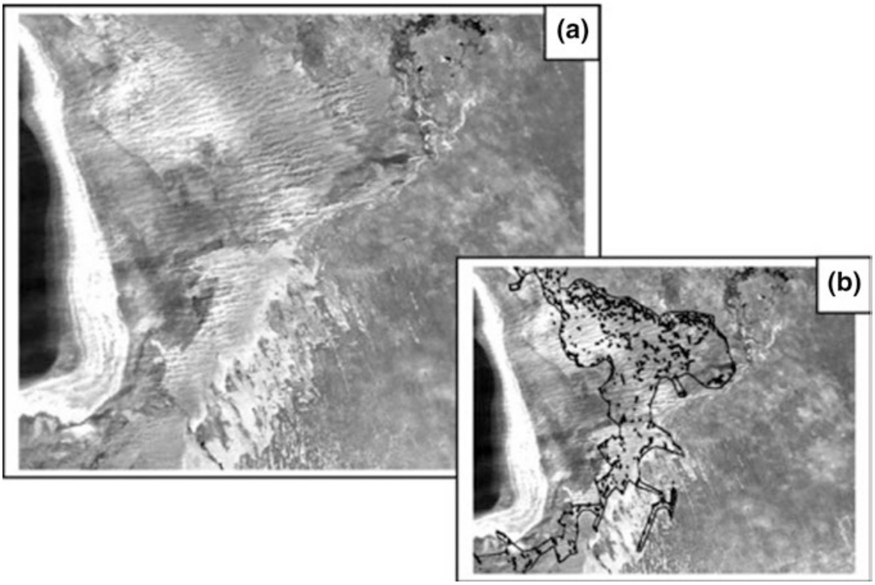

Fig. 4.10 Dust storm from the dried bottom of the Aral Sea using Landsat satellite data (1 September 2006). **a** Landsat satellite image. **b** Selection of the area of dust removal by a system of points (Spivak et al. 2012)

of the Aral Sea; (2) significant differences in the magnitude and frequency of dust storms over time; and (3) annual activity of the dust- and salt-transport processes in terms of monotonically increasing trend. Based on the results of analysis of satellite images for the period 2005 to 2008, the entire territory of the dried bottom of the Aral Sea was a powerful source area of salt and dust removal or transportation. The reduction of infiltration of the eastern part of the Aral Sea led to a change of territories in aerosol-removal zones, namely, there is a relationship between the reduction of the water surface of the Aral Sea and the increase in the area of the salt- and dust-removal zones. The dried parts of the sea bottom were an active source of salt and dust storms in previous years, and it will remain active for years to come.

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Chapter 5
Dust Storms in Central Asia and Kazakhstan: Regional Division, Frequency and Seasonal Distribution

5.1 Main Dust Storm Sources in the Aral Sea Basin: Pre-Aral Karakum, Kyzylkum, and Aralkum Deserts

Dust and sand storms are common events in the arid and semi-arid regions of Central Asia and Kazakhstan (Semenov 2011; Dedova et al. 2006). According to observations by meteorological stations, high wind-speed regime, scarcity of vegetation cover, frequency of soil and atmospheric droughts, and the continental climate of Central Asia and Kazakhstan, all of which promote the development of dust storms, are typical for Central Asia and Kazakhstan almost all over the territory of the republic. However, the distribution and frequency of dust storms in Central Asia and Kazakhstan is heterogeneous and spotty within the territory of Central Asian countries and is characterized by large diversity. Sandy and solonchak deserts—such as Naryn, Pre-Aral Karakum, Kyzylkum, Aralkum, and Southern Pre-Balkhash in the southern part of Kazakhstan—are main sources of dust and sand storms.

Dust-storm dynamics in different Kazakhstan regions are shown in Fig. 5.1. The number of days with dust storms increases from northwest to southeast. In the south part of Kazakhstan, the number of days with dust storms is high in the sandy deserts and river valleys. The average number of days with dust storms along the Syrdarya and Ili rivers is 28 with a maximum of 67; in the southern shore of the Balkhash Lake it is 30 and 103, respectively (Orlovsky and Orlovsky 2001). In general, the annual number of days with dust storms is 20–38 in the steppe zone and 55–60 in the desert zone (near the Aral Sea and Balkhash Lake regions) (NAKZ 2010). The sites with a greater frequency of dust storms (20 days/year) are situated in areas with higher wind speeds and where soils have light texture, which are under intensive use, or in sandy areas with sparse vegetation. On the basis of generalization and analyses of the numerous cartographic materials, meteorological observation, and satellite images of dust storms, we determined the regions with most frequent dust storms.

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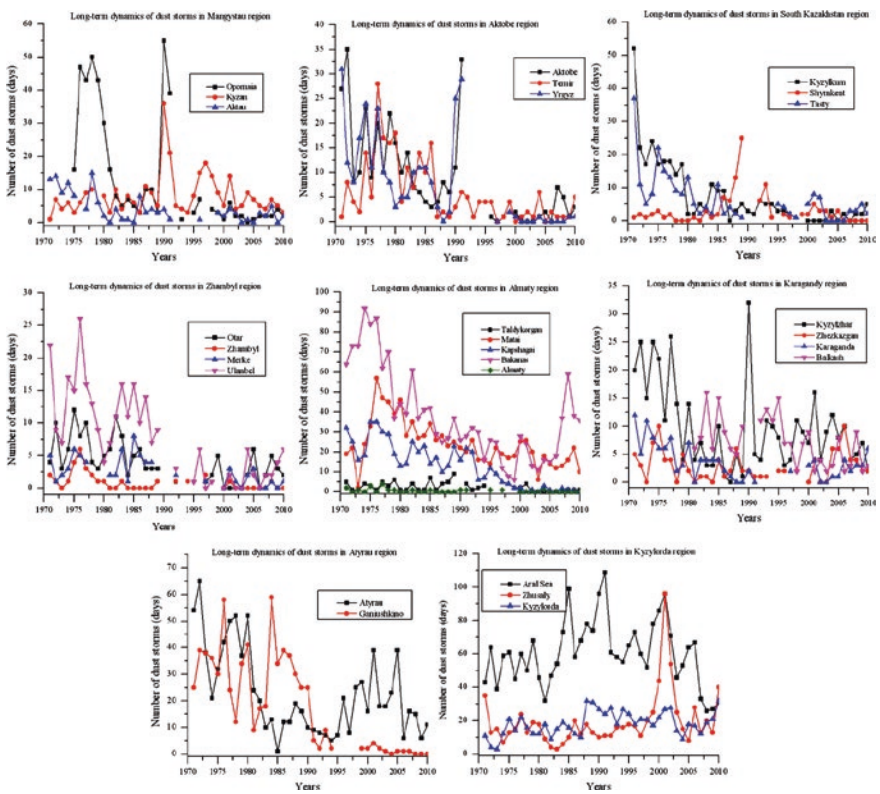

Fig. 5.1 Dust-storm dynamics in different regions of Kazakhstan during 1971–2010

The highest recurrence of dust storms in Kazakhstan was identified as: (1) Pre-Aral Karakum, Kyzylkum, and Aralkum deserts. (2) Southern Pre-Balkhash deserts; and (3) Northern Caspian plain (Naryn sands) (Fig. 5.2).

The high frequency and long duration of dust and sand storms is a feature of arid regions including the Aral Sea and Syrdarya River regions. The arid climatic conditions and open surfaces with fine grain sizes are quite favorable for the development of dust and sand storms in the region. The amount and size of blown particles depends mainly on the soil-surface structure and wind regimes. Strong winds are often recorded in the region with mean wind speeds reaching from 6 to 7 m s^{-1} at weather stations in the region. In the summer, maximum wind speeds can reach 20–25 m s^{-1} (Galayeva et al. 1996; Galayeva and Semenov 2011). These natural factors determine the high vulnerability of the territory to the development of deflation processes as dust and sand storms. The frequency of dust and sand events between 1966 and 1992 at seven Kazakhstan weather stations along the Aral Sea region is shown in Table 5.1. The Aral Sea and Uialy WS are considered as coastal stations for the period; the rest of the stations (Zhusaly, Kyzylorda,

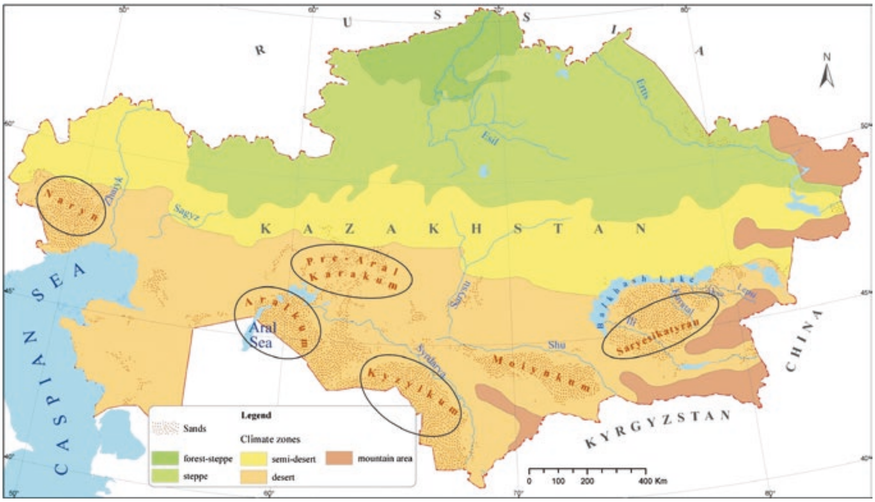

Fig. 5.2 Main dust-storm sources in Kazakhstan

Kazaly, Shirik-Rabat, and Karak) are considered continental stations. Active deflation processes were observed at WS in 1966–1968, 1970–1978, and 1983–1991 (Table 5.1). The most frequent storms were observed in the northern Aral Sea region where the long-term average frequency reached 36–84 days/year compared with 9–23 days/year in the east (Kyzylorda WS, Zhusaly WS); in the southern Aral Sea region (Shirik-Rabat MS, Uialy WS) they vary from 6 to 20 days/year (Table 5.1).

More often they happen in summer, during which the wind speed reaches 10–14 m/s (Babaev 1999). The largest dust storm sources were in the Pre-Aral Karakum (Aral Sea WS) and Kyzylkum deserts where dust storms occur 40–110 days/year (Fig. 5.3).

Several factors play a main role in the origin of dust storms. For instance, the macrorelief (topography) and the general atmospheric circulation (climate) are responsible for the endurance and intensity of dust storms. Changes of annual means in temperature depends on the geographical latitude, namely, they increase from north to south (Fig. 5.4).

In the northern part of the region the annual average temperature is 7.5 °C (Aral Sea WS), and in the southern part it is 9.6–10.4 °C (Uialy and Shirik-Rabat WS). Temperature conditions will also increase due to increasing distances from the Aral Sea toward the east. In Zhusaly and Kyzylorda WS the annual average temperature is 8.8 and 9.4 °C, respectively.

The North and south are differentiated by very clear contrast. The monthly average temperature in January is –12.0 °C in the Aral Sea MS, and in Shirik-Rabat it is –7.9 °C. In July, the temperature is almost the same all around the Aral Sea region, approximately 26.5–28.6 °C (Fig. 5.5).

Table 5.1 Frequency of sand and dust events in the Aral Sea region from 1966 to 1992 (Semenov 2011)

Years	Meteorological station					
	Aral Sea	Uialy	Kazaly	Kyzylorda	Shirik-Rabat	Zhusaly
1966	109	5	55	62	15	30
1967	80	1	46	64	19	19
1968	86	3	36	70	26	31
1969	76	4	25	42	13	19
1970	77	35	30	61	19	37
1971	58	51	23	40	20	35
1972	99	83	10	41	29	13
1973	49	48	10	38	6	15
1974	59	27	22	60	12	8
1975	72	85	17	95	21	13
1976	79	39	14	47	9	16
1977	79	35	14	64	7	25
1978	105	5	3	69	2	13
1979	89	21	11	59	1	22
1980	59	17	5	55	2	18
1981	51	6	1	58	2	9
1982	59	1	0	51	1	4
1983	101	13	0	48	0	3
1984	115	48	4	72	0	6
1985	137	6	2	71	0	10
1986	85	12	1	69	8	18
1987	77	9	0	60	5	13
1988	93	10	0	111	0	55
1989	85	10	2	122	3	13
1990	96	18	0	93	7	9
1991	115	14	0	99	13	4
1992	69	6	0	110	0	0
Average (day)	84	23	12	68	50	9

In arid climates, open surfaces having fine grain sizes are favorable for the development of regular dust, sand, and salt storms in the man-made Aralkum Desert. In the Aralkum region, the frequency of dust storms has increased since the 1980s, and since 2000 almost all meteorological stations in Central Asia have registered an increase in dust-storm activity (Indoitu et al. 2009, 2011; Orlovsky et al. 2004).

However, the frequency of dust storms in the desert regions of Uzbekistan and Kazakhstan, including most of the Aral Sea region in Kazakhstan, decreased at the end of the 20th century. The decrease in the number of dust storms in the region

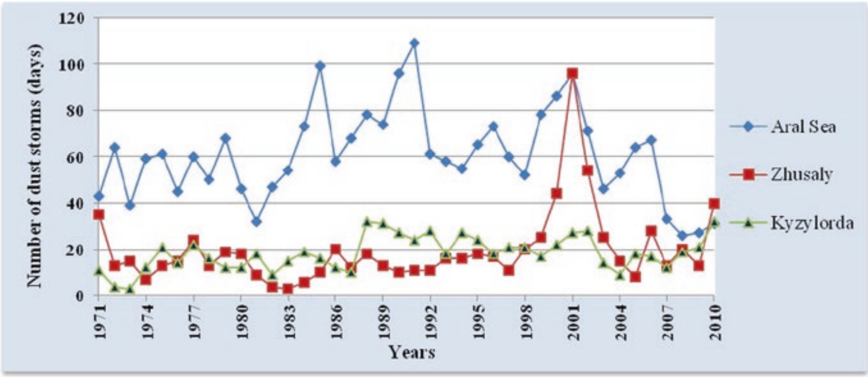

Fig. 5.3 Long-term dynamics of dust and sand events in the largest dust-storm source of Aral Sea region for period of 1971–2010

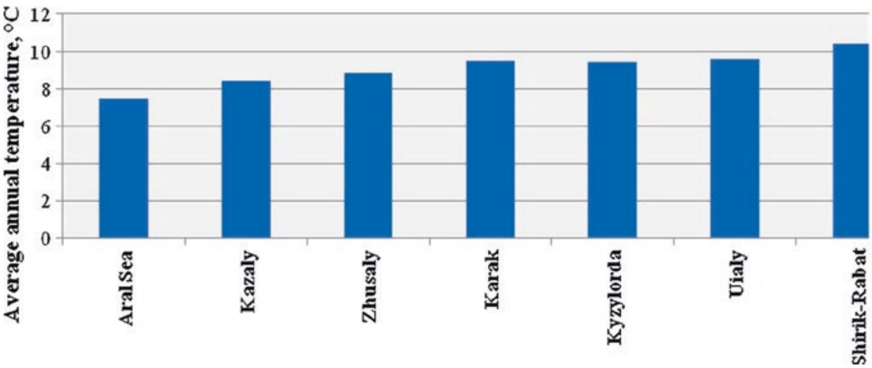

Fig. 5.4 Average annual temperature at meteorological stations in the Aral Sea region for the period 1891–2000

is due to the large-scale reduction of wind speed on the whole of Central Asia in the late 20th century (Muminov and Inogamova 1995; Semenov 2011). However, the number of storms has increased at some continental MS: Karakalpakia (Usturt Plateau), Aral Sea, and Kyzylorda. This might be an effect of increasing anthropogenic load and not a matter of regional climatic conditions. In this region, anthropogenic causes play a major role in the origin of the dust and salt storms. In addition, during last two decades of the 20th century, the Aralkum Desert (man-made desert) became a powerful active source of dust and salt storms and transfer. The desiccated seafloor is a huge open salt surface and consists mainly of salt desert (70%) and sand/sand–loamy deserts (20%) (Micklin 2010). The salt desert is the source of salt and dust storms affecting all of the adjacent regions (Breckle et al. 2012). Salt and dust storms and salt deposits affect the quality of

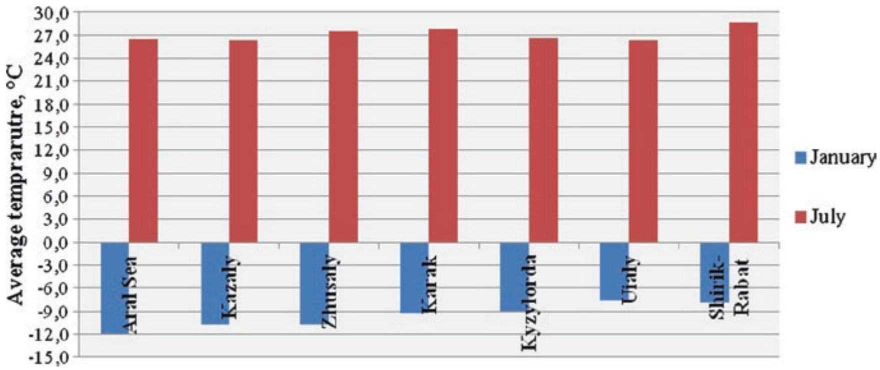

Fig. 5.5 Average January/July temperature at meteorological stations in the Aral Sea region for the period 1891–2000

the environment (climate and landscapes, water and air quality, quality of agriculture and livestock products) and consequently the living conditions, health, and economic activities of the population in the region. According to the type of soil and land degradation (salinization, wind erosion), the anthropogenic genesis is dominant in the region (NAKZ 2010; Medeu 2010).

5.2 Southern Pre-Balkhash Desert Region Is the Source of Dust and Sand Storms

Meteorological features (temperature and dryness) of the Southern Pre-Balkhash deserts and its landscape with sparse vegetation are prone to dust and sand storms because winds blow the soil particles from the ground surface very easily (Fedyushina 1972). Dust and sand storms are common events and often happen simultaneously with hot dry winds in the region (Semenov 1970, 2011; Fedyushina 1972). The number of days with deflation processes (dust and sand storms) in southern Pre-Balkhash deserts reaches 30–40 days (Taukum Desert) in the Ili River deltas and valley and on the southern coast of Balkhash Lake and decreases to 10–20 days in the Saryesikatyrau Desert and the foothills of Zhetysu (Zhungar) Alatau. The dust- and sand-storm dynamics in the region are shown on Fig. 5.6. According to long-term meteorological data we found areas that experience dust storms more frequently. There are large numbers of dust and sand storms in the Bakanas station because the takyr-like soils contain many silty–sand sediment and clay particles (Skotselias 1995). The takyr-like soils are distributed in most areas of Bakanas and the Akdala ancient dry delta plains along the left bank of Karatal River and the northeast outskirts of Zhusandala. The takyr-like soils have a mostly fine structure (Asanbayev and Faizov 2007). The grain size (>100 μm) of the sands in most areas of this region belongs to the category

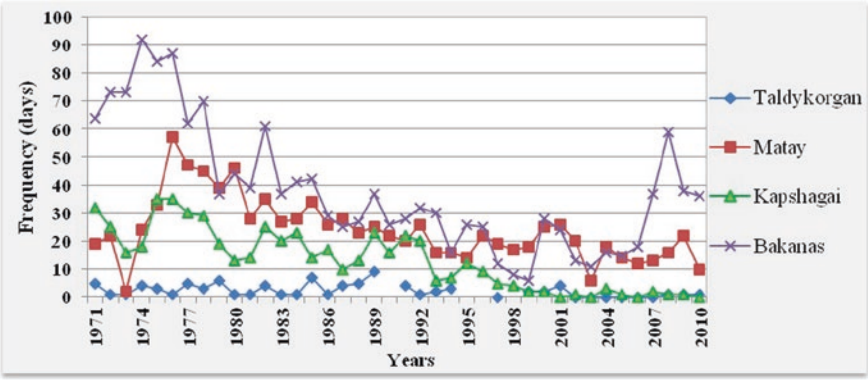

Fig. 5.6 Long-term dynamics of dust and sand storms in the southern Pre-Balkhash desert region for the period 1971–2010

of easily deflated soils (Skotselias 1995). Consequently, in this region the natural landscape has a major role in the origin of dust and sand storms. In addition, the natural genesis of landscape disturbance in the southern Pre-Balkhash deserts is dominant (NAKZ 2010; Medeu 2010). However, the sandy deserts of the southern Pre-Balkhash region undergo intensive human activity. Balkhash Lake is a narrow and shallow large terminal lake in southeastern Kazakhstan. In the 1970s, the creation of the Kapshagai water reservoir and the intensive use of water from the Ili, Karatal, and Lepsi rivers (for irrigation, electric energy production) led to the decreased in water level in Balkhash Lake. Since the 1970, it has been rapidly desiccated because of construction of a dam on the Ili River and water diversion for irrigation from the major tributary and most other streams draining into the lake. As a result, a considerable part of land in the coastal area of Balkhash Lake undergoes soil salinization and degradation. In addition, salinity of the Balkhash Lake has rapidly increased (Aladin and Plotnikov 1993). Respectively, reducing and regulating the flow level of the Ili and Karatal rivers led to the drying of many lakes, including salty lakes, in the deltas of these rivers (Skotselias 1995; Belgibayev 2001; Kudekov 2002). As a consequence, new sources of soil deflation and sources of dust and sand storms have appeared in the southern Pre-Balkhash deserts, which has lead to a high concentration salts in the atmospheric flows. These salts provoke the deterioration of pastures, reduction of biodiversity, salinization, and desertification of soils.

5.3 Sources of Dust and Sand Storm in the Naryn Desert

The Naryn desert is one of the main sources of dust events in Kazakhstan. The Caspian Lowland or the Naryn desert is composed of a thick layer of Quaternary sediments and is gently inclined toward the Caspian Sea. Genetically the Caspian

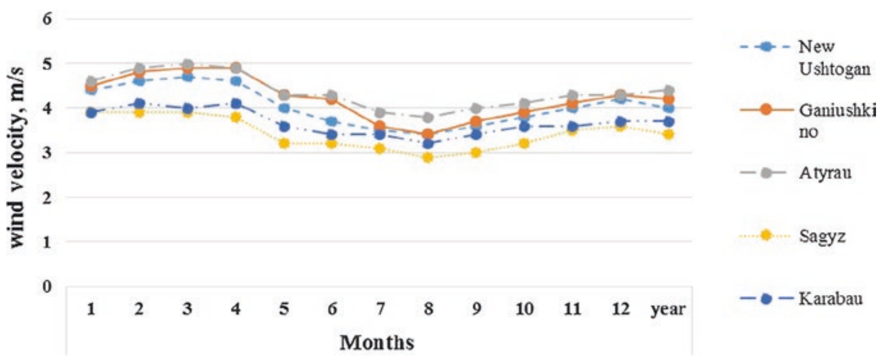

Fig. 5.7 Long-term mean monthly and annual wind speed (in m/s) for period 1986–2008

Lowland comprises accumulative plains with a sea and partially river origin. The absolute height of the surface varies from 50 to 80 m in the periphery and ≤27 m below sea level off the coast of modern Caspian Sea (Sotnikova 1971). Deposits in the Caspian Lowland surface (sand, sandy loam, loam, clay [rarely]) are characterized by low resistance to denudation. However, the weak slopes, arid climate, and negligible surface runoff have resulted in the slow development of modern erosion and denudation processes as well as the relative safety of a primary accumulative plain (Geology of USSR 1970).

Wind conditions are caused by barik-circulation factors and orography, which is somewhat different. The largest annual wind speed is observed from February to April. The second maximum is less significant than that in autumn. They are caused by the aggravation of cyclonic activity during these months (Fig. 5.7).

In cold weather, the wind direction is determined by the influence of the Asian anti-cyclone and its western spur. The axis of the spur runs from Karkaraly to Aktobe. Thus, the high-pressure center in the winter is favorable to the northeast from the Caspian Lowland and in the summer to the north and northwest (Girs 1958; Muminov and Inogamova 1995). Therefore, there is a great repeatability of winds from the northern and eastern part: The direction is northwest in the summer and eastern, southeastern, and northeastern in the winter (Fig. 5.8).

In cold weather, the northeastern regions are influenced by the spur of the Siberian anti-cyclone, which is is dominated by western (20%) as well as northern and southern (10%) wind directions. The territory of the Naryn Desert is subject to the output of cyclones from the Caspian Sea. The effect of the anticylone is then weakened and there is somewhat greater repeatability of eastern (18%) and southeast (21%) wind directions (Bultekov 2013).

The prevalence of these winds is more pronounced (22%) on the north coast of the Caspian Sea associated with the increased transport of colder air masses from the desert to the sea. In the warm season, there is a reorganization of the pressure field, which is why the wind regime in the entire territory changes. In the summer, breezes are observed along the coast.

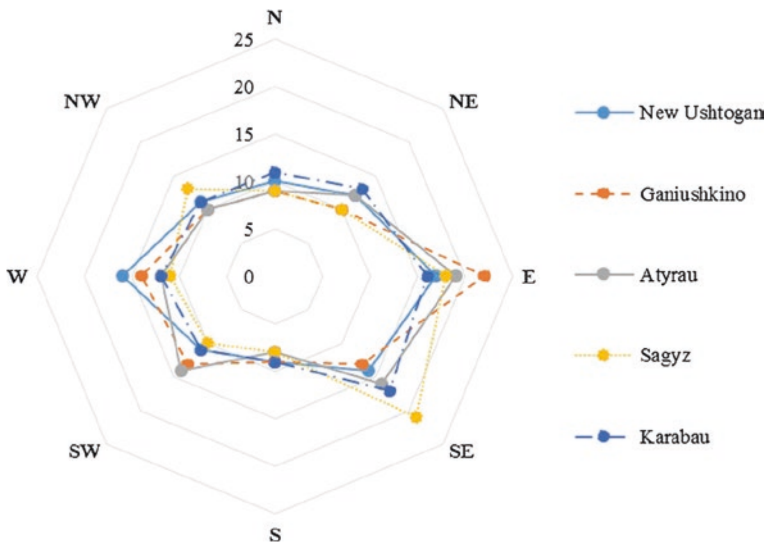

Fig. 5.8 Frequency of wind direction (%) for period 1986–2008

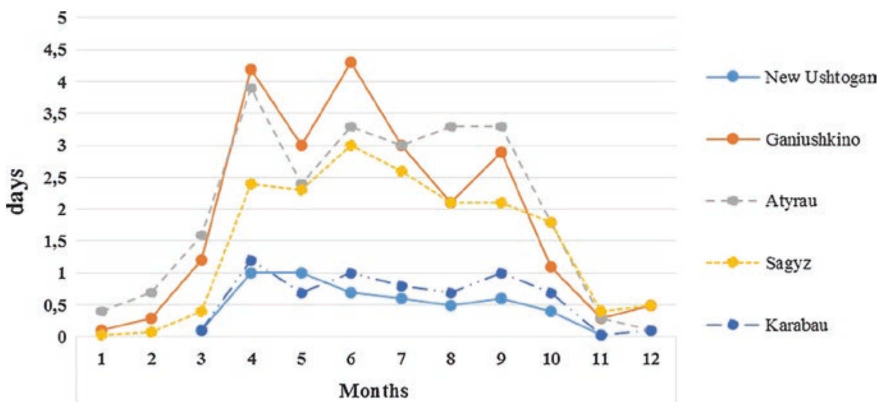

Fig. 5.9 Seasonal dynamics of dust storms in the Naryn Desert for the period 1986–2008

Dust storms in the region are long-lasting. The distribution of dust storms in the Naryn Desert is extremely heterogeneous. The most frequent dust storms in the region are observed at the Atyrau, Ganiushkino, and Sagyz WSs. Dust-storm processes are observed from April to September. A relatively small number of dust storms are observed the Karabau and New Ushtogan WSs (Figs. 5.9 and 5.10).

Dust storms in the Caspian Lowland are long lasting, i.e., generally >1.5 h. Often they last for 5.4–10.4 h. Storm lasting >1 day most often observed at Atyrau WS (Figs. 5.11, 5.12, 5.13, 5.14 through 5.15).

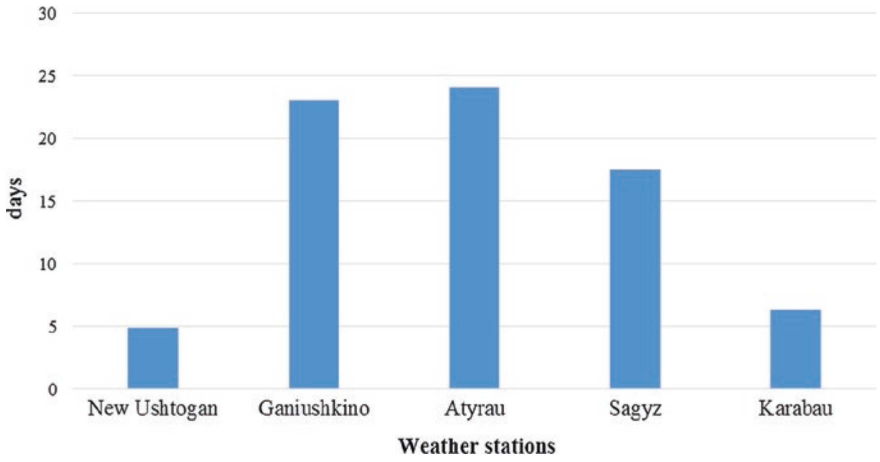

Fig. 5.10 Annual number of dust storms in the Naryn Desert for the period 1986–2008

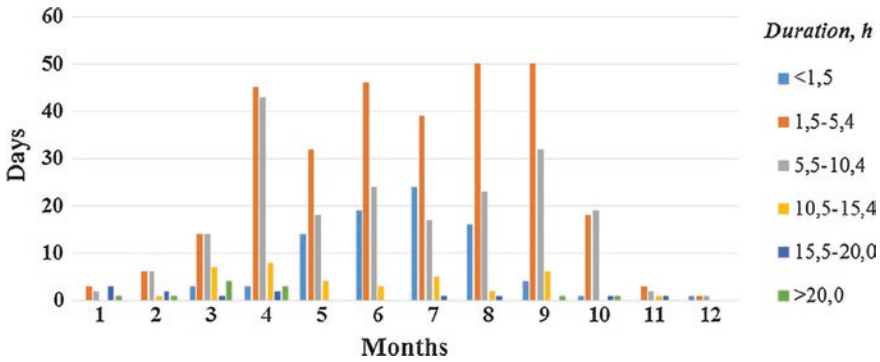

Fig. 5.11 Duration of dust storms recorded at Atyrau WS

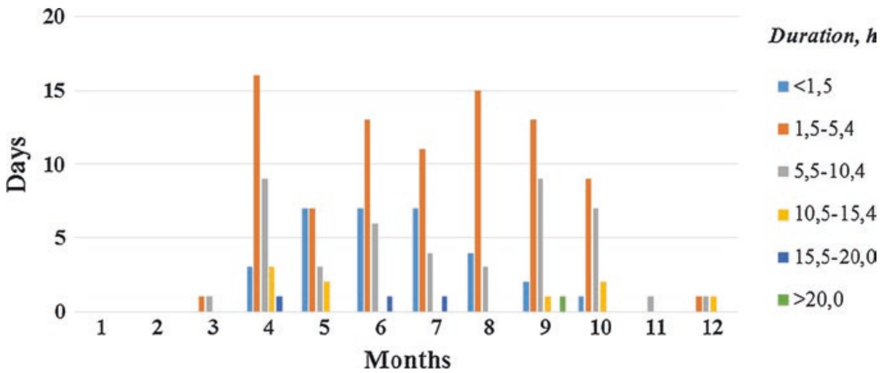

Fig. 5.12 Duration of dust storms at Karabau WS

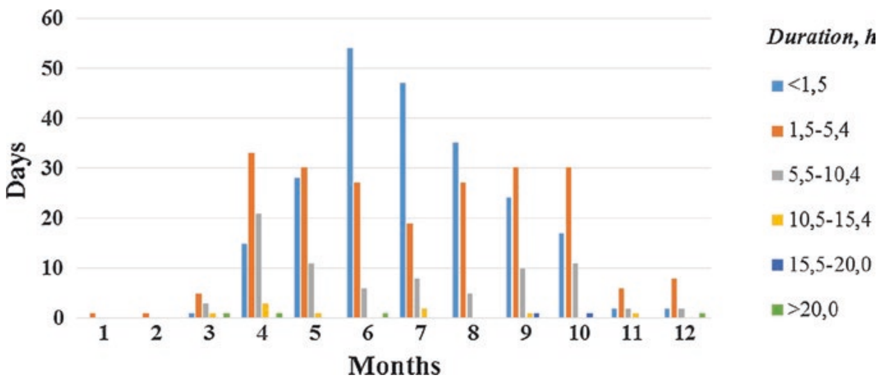

Fig. 5.13 Duration of dust storms at Sagyz WS

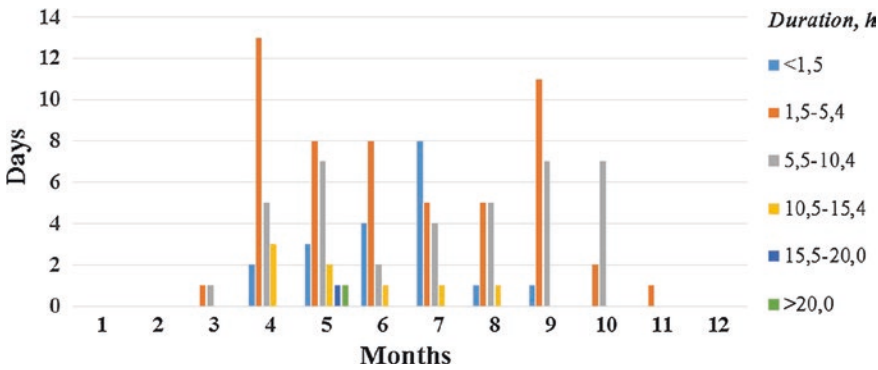

Fig. 5.14 Duration of dust storms at New Ushtogan WS

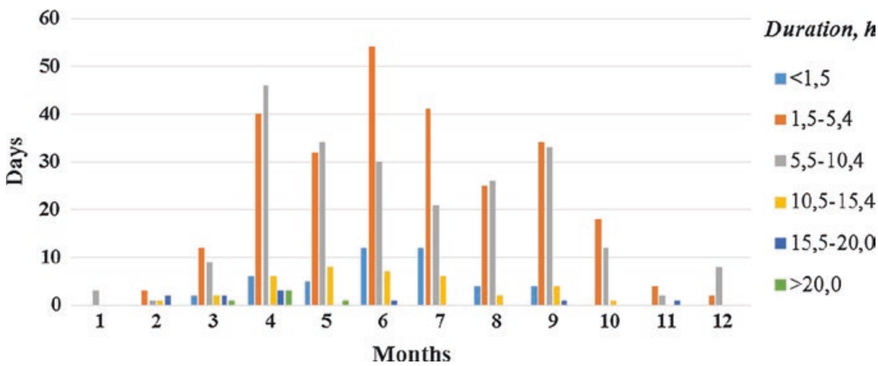

Fig. 5.15 Duration of dust storms at Ganiushkino WS

5.4 Visual Identification of Dust-Storm Sources Based on Satellite Images

Modern methods of geo-information analysis, involving satellite imagery, of natural processes allows us to consider natural dust storms in combination with soil characteristics. Space observations make it possible to show the main sources of salt and dust storms, the formation of dust and salt clouds, and the main directions of salt and dust transportation (Grigoriev and Lipatov 1979; Zakarin et al. 2001).

Under the climatic conditions of Kazakhstan, dust storms occur mostly during spring and autumn (Figs. 5.16 and 5.17). In Fig. 5.16, based on satellite-monitoring systems we can see some cases of strong dust storms; these Kazakhstan areas are potentially dangerous for the development of deflation. Strong dust storms were shown in the Betpakdala Desert during October 2005 (Fig. 5.16a). The actual boundaries of the strong dust-storm zone are much greater than those shown in the images obtained from the ground-based meteorological observations. The dust storms (Fig. 5.16b) were caused by strong long-lasting winds, extending for 300–350 km, observed in the northern Caspian Sea. The satellite-monitoring system recorded strong salt and dust removal in the eastern (May 16) and western (September 1) directions in the Aral Sea (Fig. 5.16c). In addition, the eastern shore of the Aral Sea and the Amudarya delta region have become powerful sources of salt and dust removal. Analysis of the recent satellite images showed that in August 2011, the area of the Aral Sea dried bottom was 57.529 km^2. The water body area was 2317, 4411, and 3243 km^2 for the Eastern, Western, and Small Aral seas respectively (Kozhoridze 2012). Consequently, the level of the Aral Sea decreased, and new dried areas formed. The new dried areas became active and powerful sources of salt- and dust-storm events and salt and dust aerosols (Wiggs et al. 2003; Galaeva and Idrysova 2007; Indoitu et al. 2012). For million of years, the Aral Sea basin was the recipient of the and for the last several decades have served as an accumulator of pesticides, herbicides, fertilizers, and other chemicals washed from the irrigated massifs of the region. Aeolian erosion has carried white-dust storms from the dried bottom of the Aral Sea, which remains one of the strongest sources of dust, sand, and salt storms in Central Asia. In addition, dust storms recorded in the Balkhash and Balkhash–Alakol regions are shown in Fig. 5.17. All of these images confirm that the determined regions are sources of intensive dust, sand, and salt storms in Kazakhstan.

5.5 Strong and Very Strong Dust Storms Within Kazakhstan

Dust storms appear under the conditions of some critical thresholds of wind speed, topography and soil structure when unrelated particles are <250 μm, high soil dryness, and scarcity of vegetation cover, these thresholds vary from region to region.

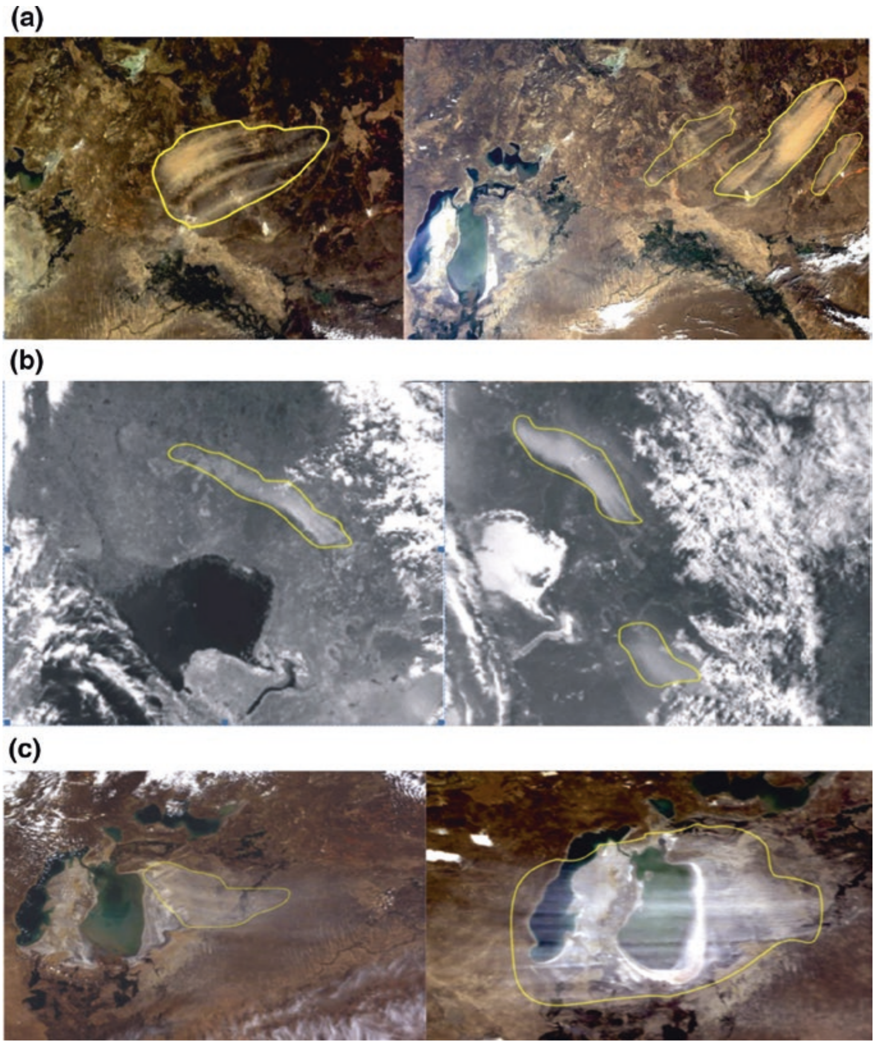

Fig. 5.16 Dust storms, **a** to the west and east from Zhezkazgan city (central Kazakhstan) on 5–6 October 2005, **b** to the north from the Caspian Sea on 9 April 2003, and **c** in the Aral Sea on 16 May and 1 September 2006

Dust-storm observations were made at meteorological stations located in particular areas of interest in Kazakhstan. A dust storm starts with a wind speed >6 m/s. A dust storm is considered "strong" when the wind speed reaches 10–14 m/s with visibility between 500 and 1000 m. Usually such wind lasts from 3 to 12 h. "Very strong" dust storms last $\geq$12 h with wind speeds >15 m/s and decreased visibility $\leq$50 m (Dedova et al. 2006; Romanov 1960).

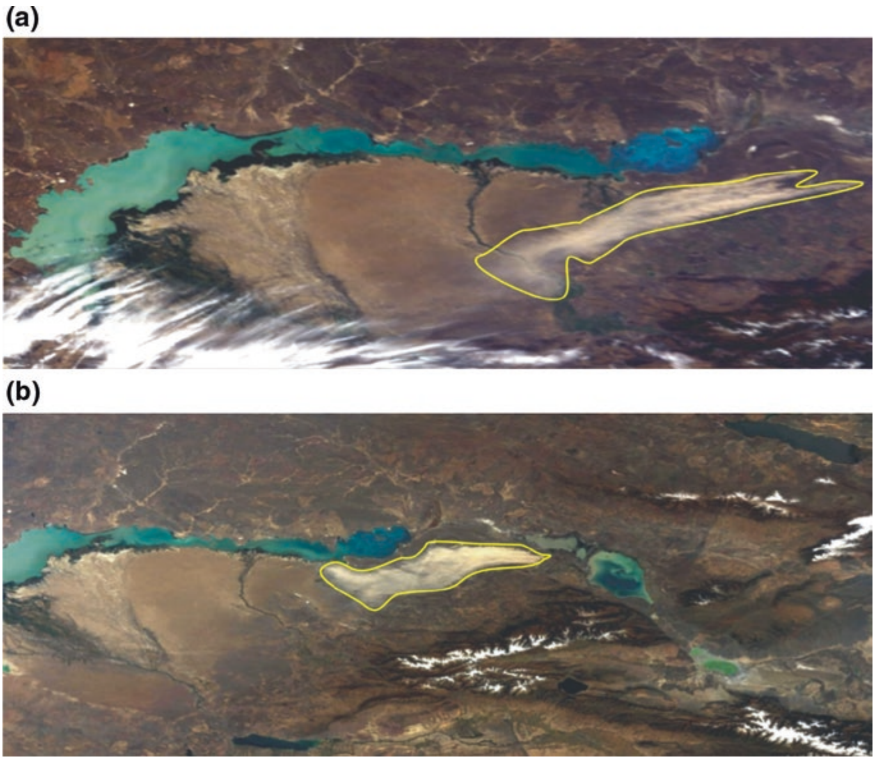

Fig. 5.17 Dust storms, **a** to the south from the Balkash Lake on 4 September 2006 and, **b** in the Balkhash–Alakol region on 1 October 2004

Large areas of strong and very strong dust storms (lasting >4 days) cover mostly the western Kazakhstan and Atyrau oblasts, part of the Aktobe and Karaganda oblasts, the northern half of the right bank of the Ertis River in the Pavlodar oblast, the Ili River valley, Sam sands, Kyzylkum sands in the territory of the Syrdarya River ancient delta, and two sources in the Shu River valley (Fig. 5.18). These areas are used for agricultural or industrial production. In addition, such factors as high wind speed (exceeding 8–10 m/s), light-textured soils (soil particle size <250 μm), dry soils, and sandy deserts with sparse vegetation promote the formation of strong dust storms (Semenov 2011).

The highest number of dust storms takes place during western (26.3%), northwestern, and northern intrusions (24.8%), followed by southwestern, southeastern, and southern cyclones (20.8%) (Orlovsky 2011). Based on a map showing strong and very strong dust storms, we can determine the territory under their influence. Due to their variable frequency, dust storms are further divided into four groups covering areas with the following frequencies: category 1 = >4 days over an area of 518,525 km^2 (19%), category 2 = 3.1–4 days over 141,175 km^2 (5%), category 3 = 1–1.3 days over 144,4561 km^2 (53%), and category 4 = <1 day over

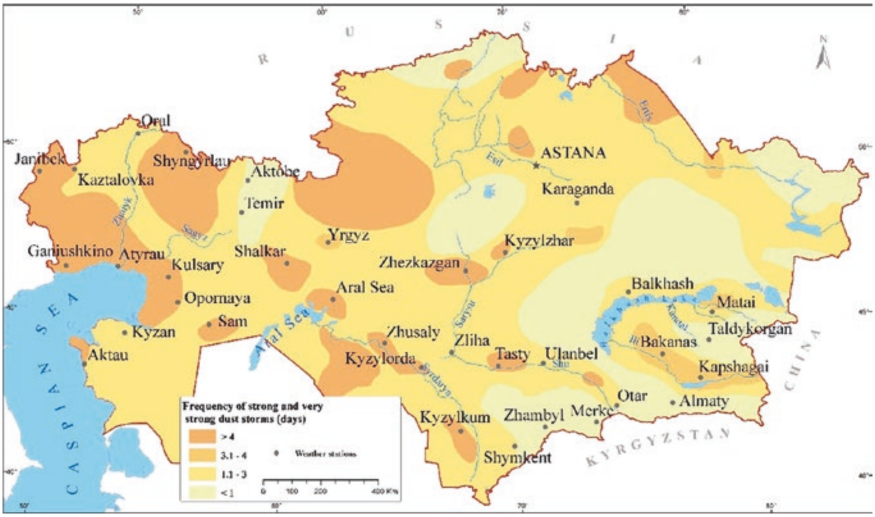

Fig. 5.18 Distribution of strong and very strong dust storms within Kazakhstan

613,445 km^2 ay (23%). The frequency of very strong dust storms (lasting >12 h) is 2.5–4% as observed at the following weather stations: Shyngyrlau, Kyzylkum, Sam, Aral Sea, and Shalkar.

5.6 Seasonal Distribution and Frequency of Dust Storms in Central Asia and Kazakhstan

Central Asia is a vast region with varied geography and climate; consequently, dust-storm activities are highly variable at annual and inter-annual scales. Dust-storm outbreaks in Central Asia are common for the spring and summer seasons. The annual seasonality of dust storms in the northern deserts of Central Asia is similar to that of the southern deserts of Central Asia (Fig. 5.19a, b).

The analysis of long-term data shows an increase in dust-storm activities from May to September (81%) with the maximum during May through June in the northern deserts (Fig. 5.19a). In the southern deserts, the dust-storm frequency is higher than in the northern deserts, and the dust storm occurrence season is longer (Fig. 5.19b) (Indoitu et al. 2012). In the southern deserts, precipitation falls in winter through spring, and stable snow cover is absent. In addition, a lack of rain and high air temperatures are characteristic for summer season. The minimal frequency of dust storms occurs in January and December (Orlovsky and Orlovsky 2001). Dust storms are less active during November to May because the humid season in the southern deserts lasts until that period. In the spring, temperatures will rise dramatically along with high wind speeds, and consequently the surfaces

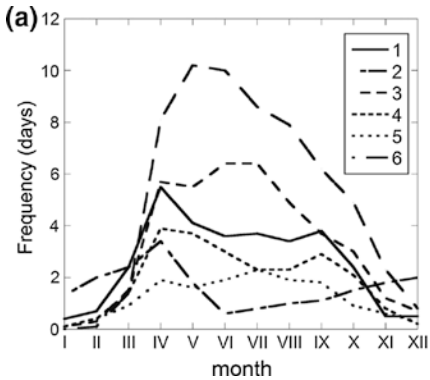

Fig. 5.19 Seasonal dynamics of dust-storm frequency in the deserts of Central Asia for the period 1936–2005. **a** Northern deserts: 1 = Atyrau, 2 = Altau, 3 = Aral Sea, 4 = Kyzylorda, 5 = Shirik-Rabat, 6 = Shalkar. **b** Southern deserts: 1 = Erbent, 2 = Tamdy, 3 = Chagyl, 4 = Bukhara, 5 = Bairam-Ali, 6 = Repetek (Indoitu et al. 2012)

of the southern deserts suffer from rapid evaporation of precipitation, which together with strong winds favors the development of dust storms. Sandy and clayey grounds become very dry in the summer and autumn seasons. Strong winds and dust storms respectively will be active due to synoptic processes during this season (Indoitu et al. 2012). In the southern deserts, almost 82% of the annual dust storm outbreaks were registered during April through October with highest values in April through July.

The central Karakum Desert is one of the main sources of dust storms, which are active during March through October according to the Erbent WS (Fig. 5.19b). Unlike the northern deserts, the dust-storm sources in Turkmenistan are active during the whole year, and they were registered even in December and January (i.e., the winter season). In January 1968 and December 1975 and 1985, the most powerful dust storm events of the last century were observed. During these events, the visibility was zero, and the wind speeds reached 20 m/s (Orlovsky et al. 2005).

Kazakhstan is a large region of variable geographical and climatic features; therefore, dust- and sand-storm activities vary on annual and inter-annual scales. In general, dust- and sand-storm outbreaks are common in the spring and summer seasons. We found two peaks among the average number of days with dust storms in different months for the period 1966–2003: April through June and August though September (Fig. 5.20). Due to the drastic increase in temperatures and high wind speeds in the spring, desert surfaces suffer from rapid evaporation of precipitation, which together with strong winds favors the development of dust and sand events. The Kyzylkum, Pre-Aral Karakum, and Southern Pre-Balkhash deserts are the main regions of Kazakhstan where dust and sand storms are common, especially during the periods April through October and April through August, respectively (according to the Aral Sea and Bakanas weather stations) (Figs. 5.20 and 5.21). This is due to the dryness of the surface of sandy and clayey deserts during

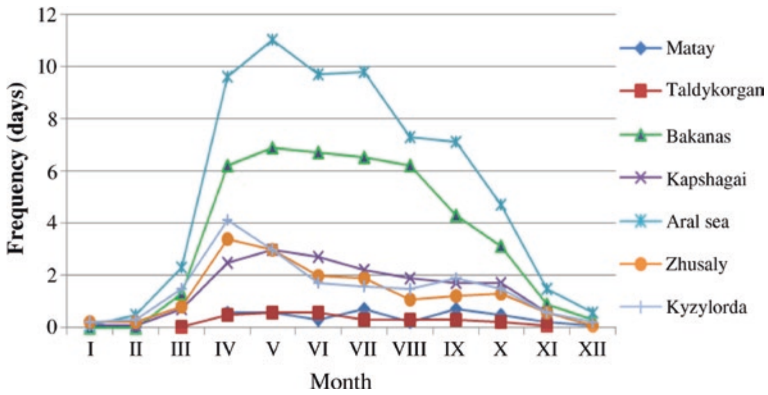

Fig. 5.20 Monthly average frequency of dust and sand storms for the period 1966–2003 in the southern desert zone of Kazakhstan

the summer and autumn seasons along with synoptic processes, which bring strong winds and extremely active dust storms. Almost 80% of the annual dust-storm outbreaks in the southern desert zone of Kazakhstan are registered during April through September with highest values in April through July (Fig. 5.20). In addition, the seasonal distribution, amount, and type of atmospheric precipitation significantly influence the seasonality and frequency of dust storms. In the northern deserts, precipitation falls year-round, and there is stable snow cover. Thus, dust storms occur mainly from April till October and rarely extend from March to November. In the southern deserts, dust storms appear in all seasons of the year.

5.7 Duration and Diurnal Pattern of Dust Storms in Central Asian Deserts

The annual duration and diurnal patterns of dust storms in Central Asia are highly variable. The duration of dust storms varies from 10 min up to >20 h over the Central Asian region. Based on data analysis from most of the independent meteorological stations located in the northern (Fig. 5.22a) or southern deserts of Central Asia (Fig. 5.22b), 40–60% of dust events last an average of 1.5–5.4 h. In the northern desert, dust storms lasting >3 h are rather scarce and change in the range of 20–70%. More prolonged dust storms, which increase sharply in areas with light-textured soils and last between 5.5 and 10 h, represent 30–40% of the total dust events during the year. If the average duration of a dust-storm event is >10 h, then the frequency significantly decreases. The frequency of dust storms lasting ≥12 h is approximately 3%, and it is >3% only in a narrow belt from Central Kazakhstan to the southeast in the Moiynkum and southern Pre-Balkhash deserts (Semenov and Fedyushina 1970; Orlovsky and Orlovsky 2001).

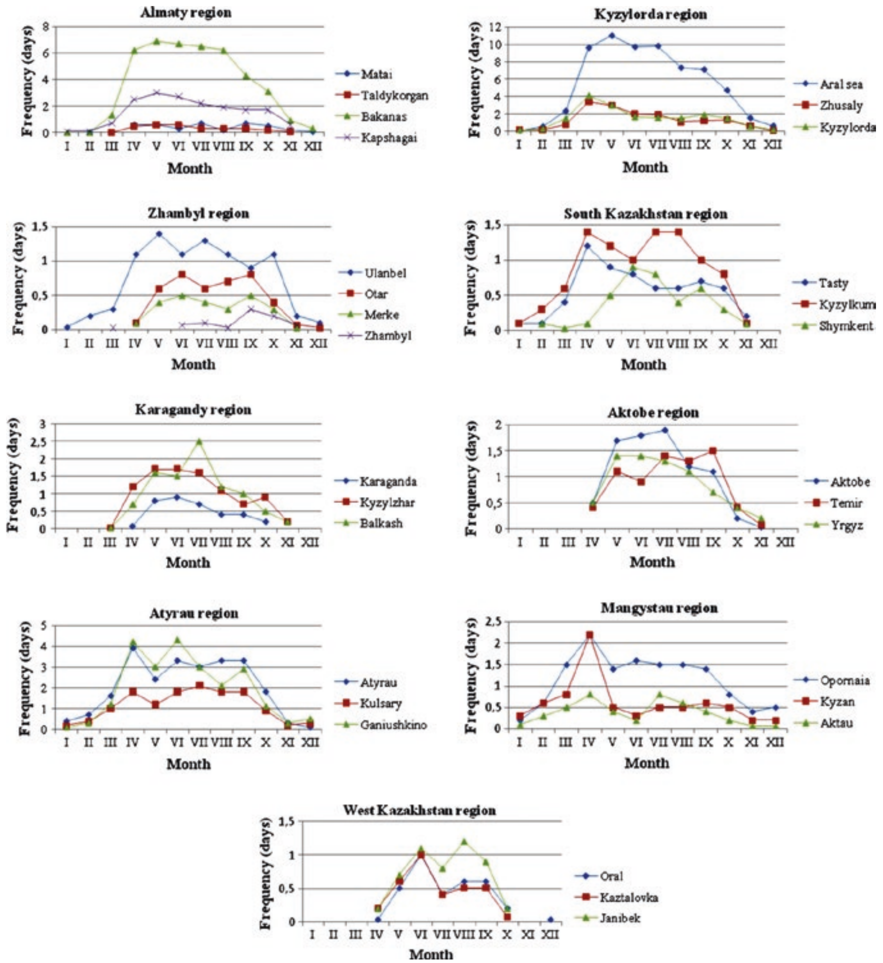

Fig. 5.21 Seasonal frequency of dust storms in different regions of Kazakhstan for the period 1966–2003

Dust storms lasting >20 h are registered very rarely (Indoitu et al. 2012). Usually in the spring or summer seasons, long-lasting dust events occur with maximum frequency. For example, a dust storm at Chagyl WS in northwestern Turkmenistan lasted for 39 h (in March 1949) and at Jaslyk WS in northwestern Uzbekistan lasted for 24 h (in March 1991) (Indoitu et al. 2012). Development of dust-storm outbreaks during the year depends on the many natural factors such as precipitation, temperature, and wind speed, etc. Long-lasting dust storms are also recorded during the autumn or winter seasons.

Long-lasting dust storms usually occur with maximum frequency in Central Asian deserts in the spring or summer seasons. Kazakhstan deserts belong to

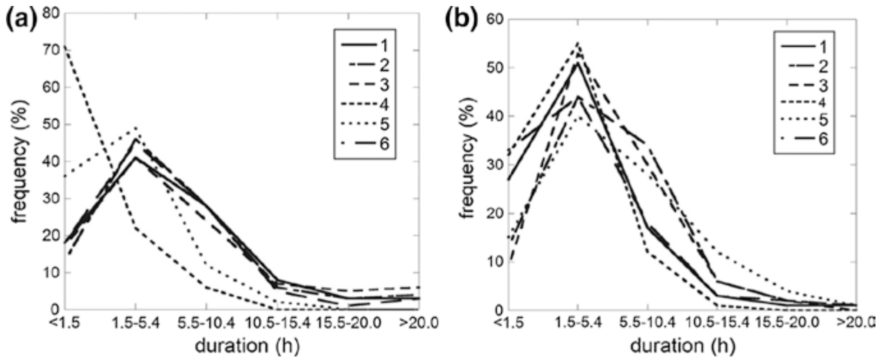

Fig. 5.22 Frequency (%) and time interval (h) of dust storms in the northern (**a**) and southern (**b**) deserts of Central Asia. **a** 1 = Aktau, 2 = Atyrau, 3 = Kyzylorda, 4 = Balkhash, 5 = Bakanas, 6 = Shalkar. **b** 1 = Dashoguz, 2 = Erbent, 3 = Bayram = Ali, 4 = Bukhara, 5 = Termez, 6 = Chardzhou (Indoitu et al. 2012)

the northern deserts. The frequency of dust storms lasting >3 h is rather high at all weather stations (except foothill weather stations) and varies within 12–30% (Table 5.2). More prolonged dust storms, lasting between 1 to 3 and 9 h, represent 10–32% of total dust events during the year. The frequency of dust storms with duration 1–9 h increases in areas with light-textured soils. If the duration of a dust event is >9 h, then its frequency significantly decreases. The duration of a dust storm is normally rather short. The probability of a dust storm lasting >1 day is <5% (Semenov 2012).

Diurnal characteristics of dust storms observed at 27 stations (1991–2005) (Fig. 5.23).

According to the data from observation stations, the start times of dust storms were unevenly spread diurnally. However, the modes appeared at 08:00 and 20:00 h. The number of dust-storms occurrence increased progressively after 05:00 h. The end times of dust storm were even more irregular than the start times. Dust-storm activities in the southern regions tend to decrease more or less after 17:00 h. The southern regions and deserts were identified as the strongest region of dust-storm development (Fig. 5.23) and where dust storms are generates at maximum frequencies between 08:00 and 20:00 h (80%) and at minimum frequencies between 20:00 and 05:00 h. In the southern area of the Aral Sea, dust-storm activities begin around 04:00–05:00 h and end gradually after 15:00 h.

Mainly in summer and winter seasons a diurnal variation or pattern of the wind with maximum speed was observed in the afternoon and the minimum at night and in the morning. The soil surface becomes dry in the daylight hours, and this affects the diurnal variation of dust storms. Dry soil surface is the main factor that stimulates the diurnal variation of dust storms.

The diurnal pattern of the wind speed, and consequently the diurnal variation of dust storms, is deranged during cyclone discharge and cold-front passage during

Table 5.2 Frequency (%) of dust-storm variation (Semenov and Tulina 1978)

Meteorological Station	Duration (h)									
	1	1–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24	>24
Shyngyrlau	18.5	23.7	24.0	19.8	9.1	2.5	1.1	0.6	0.5	0.2
Oral	36.5	27.8	22.4	8.1	3.2	1.4			0.3	0.3
Atyrau	9.8	26.6	29.9	20.5	8.9	1.8	1.1	0.7	0.5	0.2
Aktobe	38.9	25.8	19.8	11.5	3.0	0.8		0.2		
Shalkar	16.7	23.7	23.8	17.8	10.2	3.4	1.4	0.8	0.6	1.6
Yrgyz	37.6	21.4	20.8	12.8	4.2	1.4	0.8	0.2	0.6	0.2
Sam	19.2	25.4	29.1	12.7	7.2	3.0	1.6	1.2	0.3	0.3
Ulanbel	48.1	32.1	15.8	2.5	0.9	0.2	0.2			0.2
Zhambyl	43.0	32.6	16.0	5.6	1.4	0.7	0.7			
Kyzylzhar	30.3	27.2	23.6	10.8	5.4	1.4	0.9	0.2		0.2
Karaganda	55.0	25.3	12.6	5.3	1.7	0.1				
Zhezkazgan	30.0	26.7	23.9	12.7	5.9	0.2	0.2	0.2		0.2
Balkhash	72.4	17.4	3.1	4.1	1.0	2.0				
Aral Sea	20.7	27.8	26.8	12.9	6.0	3.2	0.4	1.1	0.2	0.9
Zhusaly	17.2	27.0	26.0	18.1	7.4	1.7	0.7	0.5	0.4	1.0
Kyzylorda	11.3	23.1	30.4	23.5	8.9	1.5	0.5	0.1	0.2	0.5
Tasty	25.4	31.3	24.0	11.9	6.0	0.6	0.6	0.2		
Kyzylkum	21.2	23.9	24.0	12.9	10.5	3.8	1.4	0.6	0.8	0.9
Shymkent	46.8	31.4	15.0	4.2	0.9	0.4	0.9			0.4
Bakanas	32.3	29.4	21.9	10.1	4.4	1.2	0.4	0.1	0.1	0.1
Matay	29.5	29.0	25.6	11.4	3.6	0.7	0.1		0.1	
Taldykorgan	66.2	27.6	6.2							

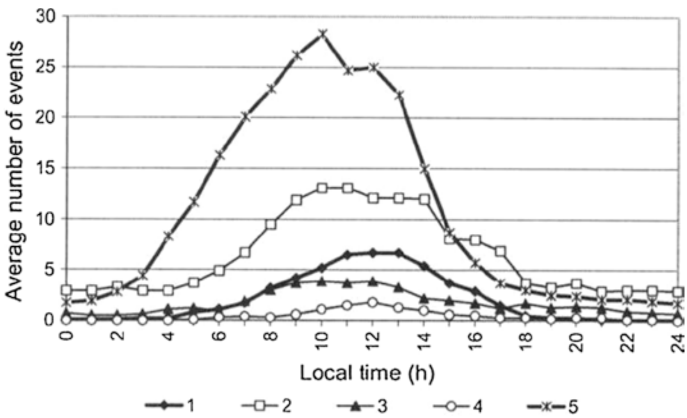

Fig. 5.23 Diurnal pattern of dust storms (1991–2005): 1 = Chagyl (Turikmenistan), 2 = Erbent (Turikmenistan), 3 = Muynak (Uzbekistan), 4 = Takhiatash (Uzbekistan), 5 = Zhusaly (Kazakhstan) (Indoitu et al. 2012)

transition seasons. Thus, in the spring and autumn seasons, a greater frequency of dust storms in the night hours is observed (Orlovsky and Orlovsky 2001). In addition, the southern and southwestern periphery of anti-cyclone and the north-western periphery of the thermal depression prevail over the eastern Turkmenistan, which affects the diurnal variations of dust storms. Dust storms conditioned by thermal depression occur periodically in the afternoon hours and cease toward the night hours according to the diurnal pattern of the air pressure (Bugaev 1957).

5.8 The Relationship Between Dust-Storm Origin and Soil Texture

Soil texture is an important feature that determines soil-surface resistance to wind erosion (i.e., soil deflation). According to the soil map of Kazakhstan, there are following kinds of soil texture: sandy, sandy–loamy, light loamy, loamy, clay, and heavy loamy as well as layered soils of different composition (Fig. 5.24). To determine the potential sources of dust storms, we divided all soils into two classes. The light-textured soils (sandy and sandy–loamy) belong to the first class, and all other soils belong to the second class. The sandy and sandy–loamy soils are more light-textured soils, which are severely prone to deflation processes. The plant community also has a role in the formation of dust and sand storms. Depending on the soil texture and chemistry, certain species of pedogen-rock communities are formed. Communities with similar ecology are grouped in the category of so-called edaphic variants (Rachkovskaya et al. 2003). Edaphic variants of deserts conditioned by soil texture—such as the vast sandy massifs Ryn,

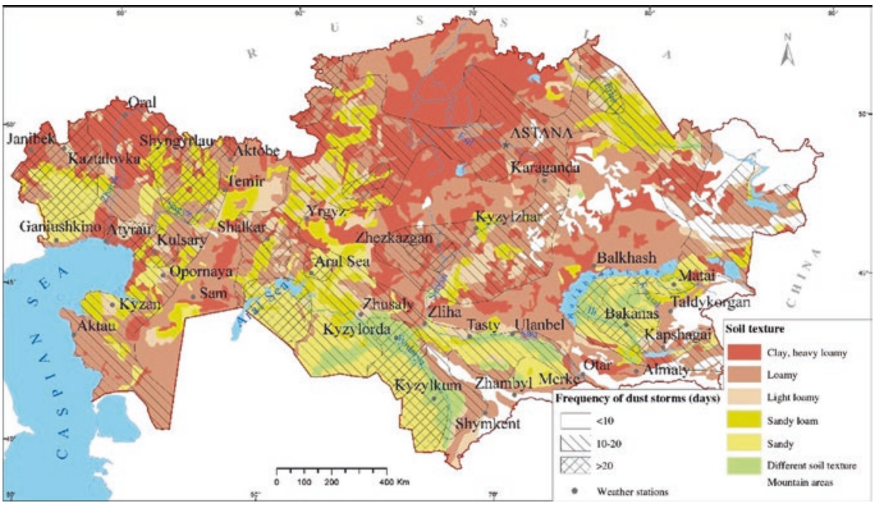

Fig. 5.24 Geographical distribution of soil texture and dust-storm frequency in Kazakhstan

Kyzylkum, Karakum, Moiynkum, and Southern Pre-Balkhash deserts (Taukum, Saryesikatyrau)—belong to psammophytic variants of plant communities. In addition, there are sandy deserts in the Aral and Northern Caspian regions. The communities are formed on the sandy soils and sands. Analysis of the map of edaphic variants of deserts in Middle Asia (Rachkovskaya et al. 2003) show that the psammophytic variants of vegetation are vulnerable for the origin of dust and sand storms. In addition, we analyzed the available data for the location of light-textured soil in areas with strong dust storms. The centers of highly repeatable dust storms (>20 days/year) are situated in areas with light-textured soil and high speed wind (Fig. 5.24). Such areas are also used intensively in agricultural or industrial development or located in regions of sandy deserts with sparse vegetation or sometimes barren dunes. According to Fig. 5.24, the highlighted areas with strong dust storms show easy-to-find regions of light-textured soils or sands. Such kinds of soils with psammophytic plant commuinities are the source of increasing amount of fine aerosol being releases into the atmosphere streams, which are clearly detected by satellite-monitoring systems.

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Chapter 6
Aeolian Transport of Dust and Sand in the Deserts of Kazakhstan

6.1 Physical–Statistical Modelling of Dust- and Sand-Transport Process

Sand and dust storms are complex natural phenomena. During storms, transported sand and dust particles can be observed in a thin sub-surface air layer or even through the whole atmospheric boundary layer (Semenov 2009). Thus, vertical scales of the phenomenon can change from small fractions of 1 m to ≥1 m high.

The high frequency and significant duration of dust, sand storms, and blizzards are typical features of the arid and semi-arid zones including the Aral Sea. For calculation of the sand mass transported by the wind in the surface air during deflation, a physical–statistical model of the sand storm was used (Semenov 1988, 2009). This model allowed a detailed assessment of the intensity of deflation and transport of dust aerosol beyond the dried bottom of the Aral Sea. This was the first time a quantitative assessment of the intensive deflation process in the Aral Sea region has been performed. The model was also used to build the vector rose of the sand transport in this region. Assessments of the scalar and vector volumes of transported sand during dust storms and blizzards were completed for the weather stations in the Aral Sea region. The vectorial roses display which masses of dust and sand were transported in the lower atmosphere by wind and in which direction. The length of the vector arrow represents the amount of sand and dust transported. This was determined from changes in the shape of the newly formed barchans and other aeolian relief forms, which can change direction several times depending on the prevailing strong wind vectors. However, the resultant assessment (vector addition) gives an idea of the overall long-term sand and dust movement and transport integrated over time. The resultant vector shows the final direction of the sand and dust transport.

For the purpose of analysis and calculation of sand and dust transport in the Aral Sea region as input data models, the wind speed and direction and average

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sand-particle sizes from seven meteorological stations (Aral Sea, Kyzylorda, Zhusaly, Kazaly, Karak, Shirik-Rabat, and Uialy) from 1966 to 2005 were used to conduct the assessment and to determine dominant direction of –during the deflation processes of dust storms and sand drifts. It is based on the masts measurements of wind speeds and sand and salt mass transported during storms in the 10 m–high layer.

The weather stations (WS) are located in the northern and eastern parts of the Aral Sea. The sand drifts transported soil particles from the surface to a height of 0.5–2 m, which does not lead to prominent deterioration of visibility. Generally, drifts occurred when the surface was dry and the wind speed was 6–9 m/s. The Semenov model allows calculation of the amount of dust transported through a distinct migration plane 1 km in length by sand drift (between 10 and 30 m) and by dust-storm transport (between 150 and 200 m). The material transported between 0 and 10 m is often rather coarse sand moving by saltation; the material transported between 30 and 150 m is coarse dust and salty particles; and above 200 m only rather small dust particles prevail, which are often transported over very long distances. The following analytical expression approximates the profiles of solid-sand discharge measured during expeditions:

$$q(z) = q_1 \left(\frac{z}{z_1} \right)^{-0.57 \frac{w_g}{u_*}} \tag{6.1}$$

where $q(z)$ is the solid-sand discharge at height z in kg/(м^2 · c); q_1 is the same at height z_1; w_g is the free deposition speed of sand particles of average size (hydrodynamic largeness of particles); and u_* is the friction speed where w_g – 1.6–2.0 m/s and u_* – 0.2–0.3 m/s.

Dependence of the total sand discharge

$$Q_z = \int_0^h q(z)dz \tag{6.2}$$

The Froude constant analogue turned out to be stochastic according to data from the expeditions. The model applies as 50% cumulative probability dependence.

$$\bar{Q}_z = Q_{z50\%} = 2 \cdot 10^{-7} \left[\frac{u_*^2}{(g \cdot x_o)} \right]^2 \tag{6.3}$$

where $g = 9.8\ \text{m/s}^2$ is the acceleration of gravity and the average geometrical size of sand particles on the active surface, which is x0 = 170–270 μm.

Due to the discrete measurement of wind speed at the weather stations, the amount of sand (M) transported during a storm in τ duration should be defined not through the integration of total sand discharge as a continuous function in time; it should be calculated for discrete intervals of time. The duration of a long storm τ can be presented as of the sum of intervals

$$\tau = \Delta\tau_0 + n\Delta t + \Delta\tau_k \tag{6.4}$$

where n is the number of full standard observations at a meteorological station during a sand storm; Δt is the time interval between the standard meteorological observation equal to 3 h or 10,800 s; $\Delta\tau_0$ is the time interval from the moment of the storm beginning to the first next hour of observation; and $\Delta\tau_k$ is the time interval between the last standard hour when the storm was still observed as well as its termination. Then the amount of sand transported during the storm can be calculated with the formula:

$$M = \Delta\tau_0 \cdot Q_{zl} + \sum_{i=1}^{n} Q_{zi} \cdot \Delta t + \Delta\tau_k \cdot \Delta Q_{zn} \tag{6.5}$$

where $\Delta\tau_0$—is the time interval from the moment the storm began to the next and first hour of observation; Q_{zi} is the total amount of sand in a surface layer of the atmosphere in the *i*-th hour of measurement; Q_{zl} is the total amount at an initial interval of time; and Q_{zn} at the final interval of time. Q_{zl} and Q_{zn} are calculated by wind speeds in the first and last standard measurements during a storm. Δt—is the time interval between the standard meteorological observation, which is equal to 3 h or 10,800 s; and $\Delta\tau_k$—is the time interval between the last standard hour when the storm was still observed as well as its termination. In such a manner, sand amounts were calculated for all dust storms and ground sand transport in the observations archive, and two information files were formed. Sand amounts in the first file were considered to be scalar without taking into account a direction of transport. The second file contained vector characteristics of a wind and sand stream, i.e., the amount of sand together with the transport direction.

Dry deposition of sand at various distances from a former initial coast of the Aral Sea was determined by the following dependence:

$$\left(M - M_\varphi\right) = \left(M_0 - M_\varphi\right) exp\left(-\frac{x}{35}\right) \tag{6.6}$$

where M is the dry aerosol deposition on the surface at the distance x from the source of sand escaping, t km^{-2} year^{-1}; M_0 is the dry aerosol deposition at the border of the source of sand escaping; M_φ is the background dry deposition; and x is the distance from the source in km. M_φ was calculated using the radiobalance model of convection formation:

$$M_\varphi = 0.72 \cdot 10^{-3} \exp(\mathrm{B}/\mathrm{B_n}) \tag{6.7}$$

where B = 0.36 mJ; m^{-2} is the minimal value of a positive hour's sum reached at 08:00; and the minimal value is 1.46 mJ m^{-2} in the afternoon. $\mathrm{B_n}$ = 0.35 mJ m^{-2} is the minimal value of an hour's sum of net radiation such that the process of convective raising of dust in the atmosphere began. The received model allowed the calculation of sand and dust transported by the wind in various Kazakhstan regions as well as an estimation of intensity of sand deflation.

For the analyses about dust and sand storms in the southern Pre-Balkhash deserts, the long-term observation data of dust and sand storms in the region from four meteorological stations during period from 1971 to 2010 were used. For the study of sand transport (sand amount transfer) during dust and sand storms, we used the average annual data from the Matay, Naimansuiek, Auyl 4, Kuigan, Shyganak, Bakanas, and Kapshagai weather stations in the Southern Pre-Balkhash region for period 1966–1986 (Skotselias 1995).

6.2 Aeolian Transport of Dust and Sand in the Aralkum Desert

The aeolian transport of dust is an important process in the deserts of Kazakhstan and Central Asia. Desiccation of the Aral Sea led to anthropogenic desertification in the basin, which has increased the overall dust and salt emission and transport from this region. The frequency of local dust, sand, salt storms also has increased during the last decades (Groll et al. 2012). Aeolian-transported dust, sand, and salt has a great affect on arable land. The agriculturally important loess deposits are the product of an intensive aeolian transport during the Pleistocene (Guo et al. 2002; Groll et al. 2012), and dust from deserts greatly contributes to the productivity of ecosystems. In addition, aeolian dust can also increase the soil salinity (Popov 1988; Orlova 1983), reduce photosynthetic efficiency, and impair human health (Razakov and Kosnazarov 1996; Usmanov 1988; Ochmann and Nowak 2009). Although the aeolian transport of dust, sand, and salt is a natural process, its intensity and effects can be amplified in regions where an anthropogenic factor is added such as in the case in the Aral Sea basin located in the Central Asian countries of Kazakhstan, Uzbekistan, and Turkmenistan. The Aral Sea basin is characterized by natural deserts such as the Kyzylkum, Karakum, and the Usturt Plateau with an annual precipitation <100 mm in the central lowlands near the Aral Sea and in the Kyzylkum and Karakum deserts (Indoitu et al. 2012; Opp 2005; Groll et al. 2012).

Dust storms are characterized by transport of huge amounts of dust and sand particles by strong winds. Transport of salt and dust particles by wind from surfaces is a poorly studied and complex process. The process depends on many factors such as soil humidity, fixation by vegetation, size of soil and salt particles, level and type of soil salinization, percentage of salts and fine earth, density, thickness of the crust and sub-crust horizon, level of destruction under grazing, etc. (Micklin 2007; Orlova 1983; Semenov 2011). For calculation of the sand amount transported by the wind in the ground layer during sand deflation, a physical–statistical model of the sand storm was used (Semenov 1988, 2009). The model allows calculation of the amount of dust transported through a distinct migration plain of 1-km length by sand drift (10–30 m) and by dust-storm transport (150–200 m) (Semenov 2012). The material transported between 0 and 10 m is often

Table 6.1 Statistical characteristics of transported sand and dust masses for some meteorological stations in the Aral Sea region (observation period 1966–2005), M—amount of sand and dust (tons km^{-1} year^{-1}); σ—mean square deviation (tons km^{-1} year^{-1}); C_v—variation coefficient (Galayeva and Semenov 2011)

Meteorological station	Dust storms			Sand drift			Total		
	M	σ	C_v	M	σ	C_v	M	σ	C_v
Aral Sea	6619	2764	0.42	1034	1097	1.06	7653	3486	0.46
Uialy	3256	3630	1.00	2708	3645	1.35	5961	6313	1.06
Kazaly	129	188	1.49	299	409	1.41	428	577	1.35
Kyzylorda	986	703	0.72	959	720	0.75	1940	1238	0.64
Zhusaly	4272	5846	1.37	48	84	1.75	4344	5880	1.35
Shirik-Rabat	722	871	1.21	2	3	1.8	724	873	1.21
Karak	1009	1257	1.25	2	3	1.95	1011	1257	1.24

rather coarse sand moving by saltation; the material transported between 30 and 150 m is coarse dust and salty particles; and above 200 m only rather small dust particles prevail, which are often transported over very long distances (Semenov 2011, 2012).

The average long-term amount of sand and dust transported in the Aral Sea region during storms was variable. Calculated figures from the Semenov model for means of sand and dust masses transported through a cross-section migration plane of 1-km length in the lower atmosphere are listed in Table 6.1. This information is important for the quantification of dust storms, which is necessary for making decisions about protecting from and combating the deflation process. The average long-term amount of sand and dust transported during storms was 7653 tons km^{-1} year^{-1} at the Aral Sea WS. Of that amount, 86% was transported by dust storms and 14% by sand drift. At the Uialy WS, the amount was 3255.6 tons km^{-1} year^{-1}, (55%) was transported by dust storms, and 2708.2 tons km^{-1} year^{-1}, 45% was transported by sand drift. At the Kazaly WS, the average amount of sand and dust was 428 tons km^{-1} year^{-1}, and transport by sand drift was two times more than by dust storms. Total sand transported reached 1940 tons km^{-1} year^{-1}; of that amount, 959 tons km^{-1} year^{-1} by sand drift and 982 tons km^{-1} year^{-1} by dust storms at the Kyzylorda WS. At the Shirik-Rabat WS, transported sand mass was 722 tons km^{-1} year^{-1} most of which occurred during dust storms, a phenomena also mirrored by the Karak WS where the total was 1009 tons km^{-1} year^{-1} and the Zhusaly WS where the total was 4272.5 tons km^{-1} year^{-1}. The Uialy, Zhusaly, and Aral Sea WS showed high amounts of transported sand. The greatest amounts of sand transport are at the Aral Sea WS, and the lowest amounts are registered at Kazaly WS (Syrdarya River delta). The aerosol output for the area from the former coastline is also very variable but in general very high. Sources for dust in the Aralkum are mainly between the former Barsakelmes and Kokaral islands and between Vozrozhdeniya and the former eastern coastline (Semenov 2012). Further desiccation of the eastern basin will increase the salt-dust source area tremendously. It is clear that the arid climate and the structure of the desiccated seafloor with the puffy salt crusts are very favorable for the development of far-reaching salt-dust storms. The environmental cumulative and long-term effects of salt-dust storms may cause negative effects not only on the health of people but also on ecosystems, photosynthesis, productivity and growth of plants, and animals (Semenov 2012; Micklin 2007, 2010; Chub 1998; Abdirov et al. 1993).

6.3 Variability in the Time of Intensive Deflation Processes and Dust-Transport Direction in the Aral Sea Region

The mass of sand and dust transport was found to be highly variable in relation to the climatic fluctuations and varied considerably from time to time (Fig. 6.1a, b). According to Fig. 6.1a, b, the peaks of sand and dust transport were observable during storms. The Aral Sea, Shirik-Rabat, and Zhusaly WSs had three maximums in total (1966–1970, 1984–1986, and 2000–2002, respectively). In general, the amount of sand and dust transport has increased in the Aral Sea WS since 2000, yet transport decreased at the Shirik-Rabat and Zhusaly WSs (Fig. 6.1a).

Since 1966, a consistent trend of reduced sand and dust transport has been observed at the Kazaly and Karak WSs (Fig. 6.1b). Sand storms ceased because of the commissioning of the Kazaly massif of irrigated land. In addition, the Kazaly WS is an enclosed site located on the southern edge of town and surrounded by residential areas. At the Uialy WS in 1984, the maximum sand and dust transport was recorded at 57,472 tons km^{-1} $year^{-1}$, which twice more than at the Aral Sea WS. However, since 1985 the sand and dust transport has been decreasing (Fig. 6.1b). This was possibly due to the fact that since 1994 observations have decreased due to poor funding, and the data were unreliable exclusive of insufficiency (Galayeva and Semenov 2011; Semenov 2012). At the Kyzylorda WS in 1999, a significant increase in sand and dust transport was observed at 7500 tons km^{-1} $year^{-1}$. In general, sand and dust transport in the most of the territory (Shirik-Rabat, Karak, Zhusaly, Kazaly, and Uialy WS) slightly decreased, which may be explained by fixing sand-control measures and other activities that have been performed against deflation processes in the region.

The mean vectorial rose and mean resultant vector of sand and dust transport was one the main parameters of the deflation process (Semenov 2011). According to the result, a vector can determine which direction the sand is moving by analyzing the wind as well as the impact of sand and dust storms in the surrounding territories. The resultant vector also shows the final direction of moving aeolian landforms. The long-term average amount of sand and dust transported during storms in the Aral Sea region is listed in Table 6.2. The differences in sand and dust transport between the northern and southern stations of the Eastern Aral Sea region are clearly visible in the table. Maximum sand transport in the Aral Sea MS was observed heading in east, northeast, and southwest directions with 221, 359 and 232 tons km^{-1} $year^{-1}$, respectively. Minimum sand transport blew at

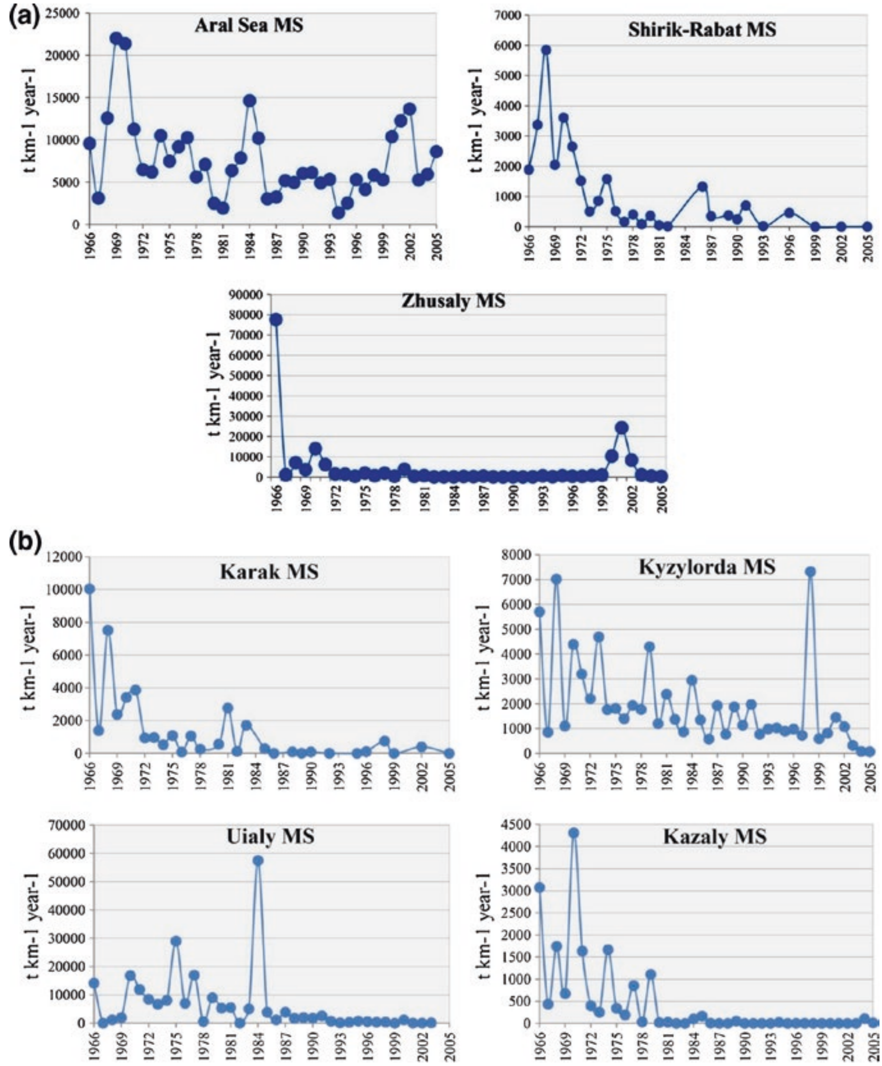

Fig. 6.1 **a** Dynamics of sand and dust transport in the east and on the northern coast of the Aral Sea region. **b** Dynamics of sand and dust transport in the east and on the northern coast of the Aral Sea region

42 tons km^{-1} year^{-1} in a northwest direction. At the other WS, which is located south of the Aral Sea region, transport prevails in the west and southwest directions. However, more intensive transport was observed in a southeasterly direction at Uialy WS.

Sand transport with southwest direction was dominant at the Kazaly, Zhusaly, Kyzylorda, Karak, and Shirik-Rabat WSs. The Karak and Shirik-Rabat WSs are

Table 6.2 Average long-term amount of sand/dust transport during dust storms and sand drifts in the Aral Sea region (t km^{-1} $year^{-1}$) (Galayeva and Semenov 2011)

Meteorological station	Direction, °															
	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
Aral Sea	78	221	359	344	273	152	115	125	206	235	232	184	199	75	42	51
Kazaly	3	5	22	30	45	12	7	3	19	40	46	86	86	22	2	1
Zhusaly	74	7	116	53	226	38	43	31	154	170	274	428	2684	27	7	13
Karak	4	0	12	6	82	44	8	6	26	19	303	359	201	14	7	0
Shirik-Rabat	0	18	71	9	30	21	61	7	10	80	377	171	69	7	2	0
Uialy	146	98	283	154	370	276	1143	289	510	382	967	422	529	216	87	89
Kyzylorda	10	10	11	23	31	10	13	9	36	116	446	629	537	49	8	2

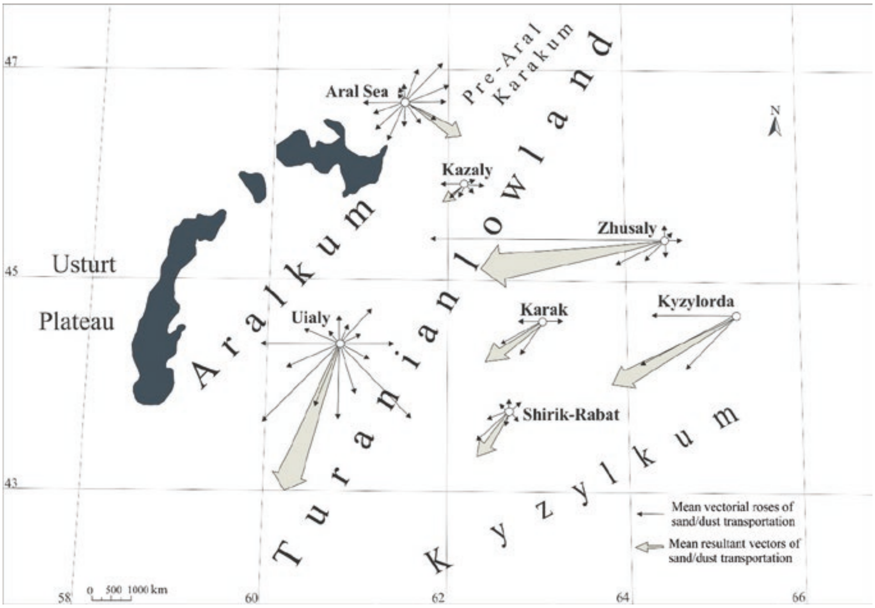

Fig. 6.2 Sand and dust transport in the Aral Sea region

located in a region where the anthropogenic influence on the generation of dust is minimal and there is a little impact of removal from dry areas of the Aral Sea (Galayeva and Semenov 2011). The Kyzylorda WS is analogous to the Karak MS, but the amount of sand transport is somewhat greater and the maximum sand transport in the west and southwest direction was 629 tons km^{-1} year^{-1}, in the western direction was 537 tons km^{-1} year^{-1}, and in the southwest direction wasx446 tons km^{-1} year^{-1}. On the southernmost Shirik-Rabat WS, the sand transport is dominant in a southwesterly direction with 377 tons km^{-1} year^{-1}; and in rest of directions the transfer is very small.

A western direction was dominant for Zhusaly WS in the amount of 2684 tons km^{-1} year^{-1}. Because fixed sands surround the Kazaly WS, it had the lowest maximum at 86 tons km^{-1} year^{-1} in west and southwest directions. The southeast (1143 tons km^{-1} year^{-1}) and southwest (967 tons km^{-1} year^{-1}) directions were dominant at the Uialy WS. A large proportion of the sand transported in the southeast direction was due to a very intense dust storm on 15–17 June 1984 it then was transferred at 29,000 tons km^{-1} year^{-1}, of which 57% is the average long-term transport (Galayeva and Semenov 2011). In general, in the most central and southern parts of the Aral Sea region, the high amount of transport was in the west and southwest directions; only a few weather stations had a maximum amount in the southeast, east and northeast directions (Fig. 6.2). It should be noted at the Aral Sea WS, the direction of the resultant vector does not coincide with the direction of maximum transfer because most vectors are of the northeast and

Table 6.3 Main characteristics of sand amount transport by wind in the Southern Pre-Balkhash deserts (Semenov 2011)

Weather stations	Average size of sand particles (μm)	Amount of sand transported (M) t km^{-1} $year^{-1}$
Matay	100	2634.5
Naimansuiek	100	65.9
Auyl 4	130	246.6
Kuigan	110	2936.1
Bakanas	100	2267.2
Shyganak	110	291.9
Kapshagai	130	2594.5

southwest directions. The long-term resultant vector at five weather stations in the region (Kazaly, Zhusaly, Karak, Shirik-Rabat, and Kyzylorda) has a west-southwest direction. As can be seen, these directions are significantly different from the direction of Aral Sea WS. This may be due to specific synoptic processes in the region.

The highest transport intensity was exhibited at Uialy, Zhusaly, and Kyzylorda WSs. The greatest amount of transported sand was 2684 tons km^{-1} $year^{-1}$ observed at Zhusaly MS at 270° and 1143 tons km^{-1} $year^{-1}$ Uialy WS at 135°. These new, vast, sandy massifs formed after the sea level decreased, thus leaving them exposed and prone to weathering. Consequently, the deflation processes are developed in this region. Thus, the study of dust- and sand-transport directions leads to the conclusion that the process of moving sands in the north of the 46th parallel occurs in east direction; however, in the Eastern Aral Sea region the movement of sand, which is located in the south of the parallel, is observed in the west direction with the exception of Uialy WS where transfer occurs to the south.

6.4 Dust and Sand Transport, Dominant Wind Direction, and Size of Sand Particles in the Southern Pre-Balkhash Deserts

Wind is a relief-forming factor in a sandy desert. It causes the deflation process, transfer, and accumulation of sand. Large quantities of fine particles can erode, transport, and deposit by wind elsewhere on the surface.

The average long-term annual amount of sand transport in the southern Pre-Balkhash desert region reaches 66–2940 t km^{-1} y^{-1} (Table 6.3). The removed particles are transported to another region where they may form sand dunes on a beach or in a desert. A high amount of sand transfer is observed in the east part of the southern Pre-Balkhash deserts (Matay station), western coastal sands of the Lake (Kuigan Station), Moiynkum and Taukum sandy massifs, and a small part

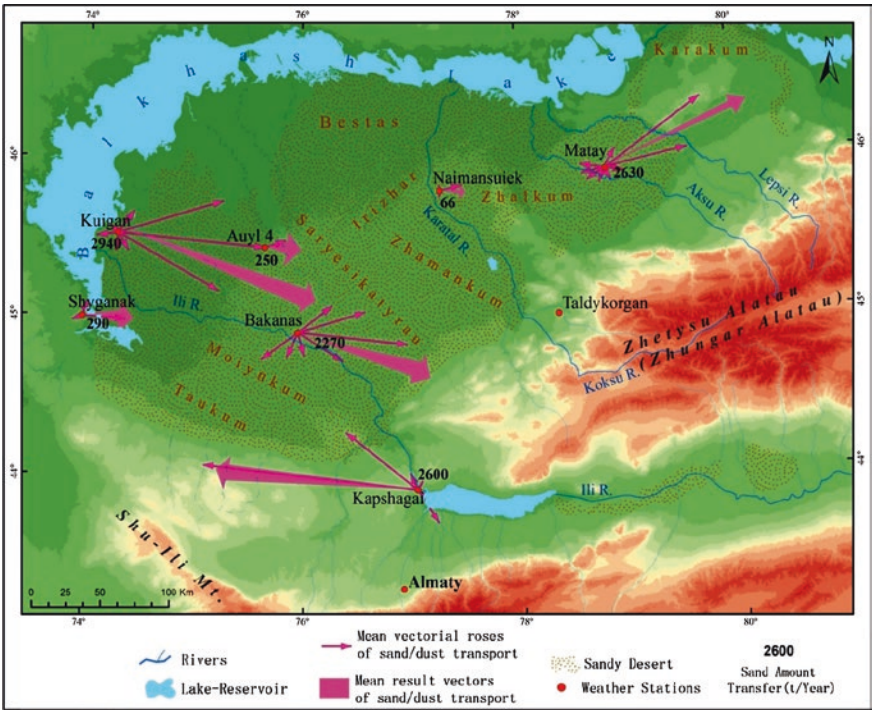

Fig. 6.3 Movement direction of sand and dust on in the Southern Pre-Balkhash deserts

of Saryesikatyrau (right bank of the Ili River [Bakanas and Kapshagai stations]) (Fig. 6.3). A large part of the Saryesikatyrau Desert has a smaller average long-term annual transport of sand (300–450 t km^{-1} y^{-1}). Therefore, the intensity of deflation processes in most parts of the Saryesikatyrau sands is much lower, and the ecological influence to the surrounding areas is low.

Desert winds are a constant phenomenon, and the wind regime is connected with baric relief and synoptic conditions. The direction and rate of transfer are dependent on the wind regime in a particular desert territory (Babaev 1999).

The western winds are dominant in the Southern Pre-Balkhash deserts and are defined by the general circulation of air masses in southeastern Kazakhstan (Skotselias 1995; Semenov 2011). As consequence, the direction of sand movement occurs in the east, southeast, and northeast directions (Auyl 4, Kuigan, Shyganak, and Matay stations). In the southern part of the region, the relief and local orographic conditions provoke the occurrence of strong winds. The underlying relief influences the speed and direction of active dune movement (Yang et al. 2007). Therefore, at the Kapshagay station, a western wind direction is observed; it is a maximum wind vector of the west direction in the Southern Pre-Balkhash desert. This is due to the well-known local easterly Shelek wind.

Apart from the winds caused by general circulation in the atmosphere, local winds exist in various parts of a desert. Local winds, often strong and steadily, are witnessed in the vicinity of mountain spurs and narrows (Babaev 1999). The Shelek wind is a mountain and valley wind formed by the movement of cold air from the area of the glacier (Ile Alatau) at the source of the Shelek River to the Ili River valley. The wind speed during the year is 8–10 m/s (Murzaev 1958). The nature of the manifestation of mountain-valley winds depends on the height of the ridges, slope exposure, and directivity of gorges. Depending on these factors, the wind direction might or might not coincide with the general pattern of winds of the surrounding plains, i.e., intensify or attenuate them. In addition, local air circulation in the region dominates the general circulation in the atmosphere (Sidorov 2006; Uteshev and Semenov 1967). The wind vectors in Bakanas, Kapshagai, and Naimansuiek are directed along the river valleys (Fig. 6.3).

The average size of sand particles in the Southern Pre-Balkhash deserts varies between 100–130 μm. Sand texture is an important feature that determines factors such as sand disposition to wind erosion. The average size of sand grains plays one of the main roles in sand and dust transport. The amount and other characteristics of wind-sand flow depend on the average size of the sand grains. Sand grains in the Southern Pre-Balkhash deserts have different sizes (Table 6.4). Most sands of this region have a hilly-ridge relief, and they undergo deflation of their top and middle parts of the slopes due to the weather (Fedyushina and Semenov 1970; Semenov 2011). Large massifs of moving sands are located in the right bank of the Aksu River near the Matay weather station where these sands occupy an area of approximately 15–20 km^2. Moving sands are found also along the right bank of the Karatal and Ili rivers. The formation of moving sands is the most extreme and most aggressive phase of the desertification process (Kovda 2008).

The average size of sand particles in the weather stations is as follows: Auyl 4, Kapshagai = 30 μm, Kuigan, Shyganak = 110 μm, and Bakanas, Matay = 100 μm (Table 6.3). According to investigations of the grain size, the sands in our study area belong to the easily deflated type because the average size of these type of sands is >100 μm in most areas (Skotselias 1995).

6.5 Aeolian Transport of Dust and Sand in the Naryn Desert (Northern Caspian Plain)

The aeolian transport of dust and sand is a natural and common process in the deserts of Kazakhstan and worldwide as well. The Naryn Desert is one the active sources of dust storms in Kazakhstan. The greatest sand transport observed at the Atyrau WS (3104 t km^{-1} year^{-1}) and the smallest at the Mahambet WS (416.7 t km^{-1} year^{-1}) (Fig. 6.4).

According to an analysis of the results, there are three types of sand transport in terms of annual variation. The first type has two pronounced peaks of transport

Table 6.4 Characteristics of sands in the Southern Pre-Balkhash deserts (according to the data of Semenov 2011)

Coordinates of the selected sites		Characteristics of sampling location	Average size of sand particles (μm)
Latitude	Longitude		
Saryesikatyrau sands			
45°58′	74°50′	Sand ridge in takyr-like soil with haloxylon	123
45°29′	75°12′	Ridge–hilly sands, semi-fixed sands, moving dunes near the Ayul 4 weather station	144
45°44′	75°09′	Ridge–hilly sands, height 10–12 m, dune sands	119
45°43′	75°07′	Ridge–hilly sands with deflated tops	105
45°46′	74°59′	Ridge–hilly sands are covered by bushes and undergo deflation	115
45°46′	74°57′	Deflated front ridge of Saryesikatyrau sands	125
45°20′	76°40′	Ridge fixed sands in the southern part of Irizhar sands	148
45°55′	76°10′	Dune sands in the central part of Saryesikatyrau	128
Moiynkum sands			
44°55′	77° 30′	Hillocky sands	129
Bestas sands			
46°13′	77° 15′	Hillocky–ridge, hillocky with deflation hollows of semi-fixed sands in the northeast Bestas Desert	110
46°20′	77° 14′	Ridge semi-fixed sands by height of 15–20 m	113
46°15′	77° 15′	Ridge–hillocky sands	117
Zhamankum sands			
45°14′	77° 52′	Hilly–ridge–gentle sands	129
45°30′	77° 38′	Ridge–hilly sands by height of 5–6 m	130
45°35′	77°34′	Sand ridges, semi-fixed sands	110
45°48′	77°10′	Moving dune by height of 8–9 m	104
46°03′	77°10′	Sand dunes, moving sands	100
45°34′	77°34′	Moving sands by height of 1.5 m	160
Zhalkum sands			
45°35′	78°34′	Gently undulating fixed sand	81
45°40′	78°37′	Non-fixed sand dunes with surrounded hilly fixed sands with bush	103
45°47′	78°40′	Moving sands along the road	113

(continued)

Table 6.4 (continued)

Coordinates of the selected sites		Characteristics of sampling location	Average size of sand particles (μm)
Latitude	Longitude		
Taukum sands			
44°17′	75°57′	Moving dune at the sand edge	126
44°19′	75°39′	Sand dunes, moving sands	150
44°30′	75°45′	Moving sands	113
44°20′	75°33′	Gently undulating weakly fixed sands at the edge of sand massif	150
44°47′	74°28′	Deflated dune	108
44°50′	74°34′	Moving dune by height of 12 m	123
44°36′	76°24′	Ridge–hilly fixed sands	160

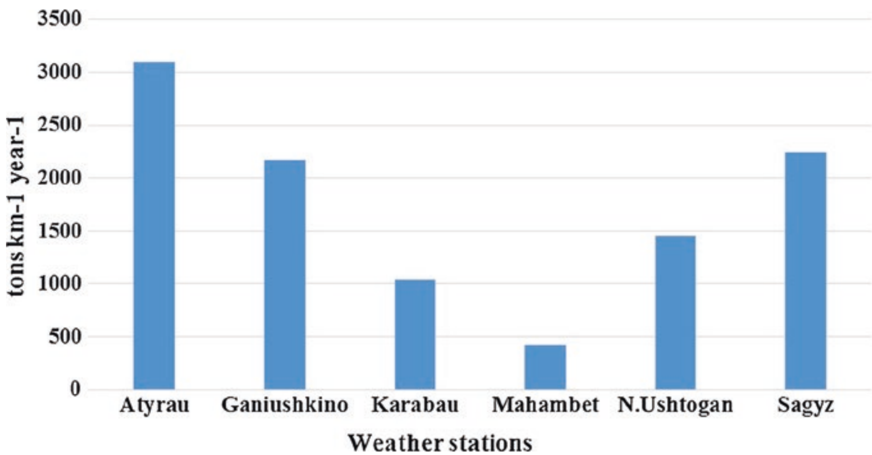

Fig. 6.4 Amount of sand transported in the Naryn desert during the period 1986–2008 (Bultekov et al. 2014)

in March to May and September (N. Ushtogan WS). The second type (Atyrau WS) has three maxima in April, June, and September. The third type (Ganiushkino, Sagyz, and Karabau WSs) is common in the spring, summer, and autumn seasons (Fig. 6.5).

Sand transport was found to be highly variable in relation to the climatic fluctuations and varied considerably from time to time (Fig. 6.6). The peaks of sand transport were observable during storms (Fig. 6.6). All weather stations in the region had main three maxima of sand transport: 1995–1996, 1998–1999, and 2001, respectively.

The average long-term amount of sand transport in the Naryn desert During the storms was variable. The greatest amount of sand transport was found at the Atyrau WS. The lowest amount was registered at Ganiushkino WS (Fig. 6.6).

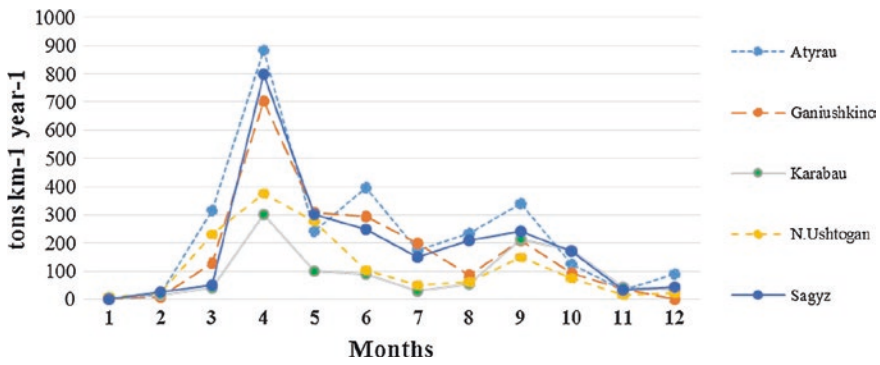

Fig. 6.5 Seasonal dynamics of sand transport in the Naryn Desert during the period 1986–2008 (Bultekov et al. 2014)

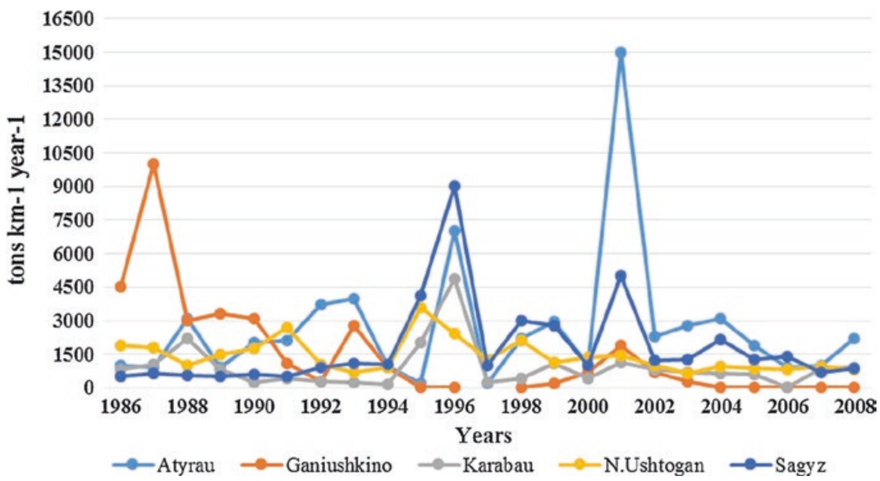

Fig. 6.6 The dynamics of sand transport in the Naryn Desert (Bultekov et al. 2014)

Since 2000, a consistent trend of decreased sand transport has been observed at the New Ushtogan, Karabau, and Ganiushkino WSs (Fig. 6.6).

The amount of sand transport as well as the dust-storm frequency and duration reveals the effect of this dangerous natural phenomenon to the ecological situation of the region. In addition, the average size of sand grains plays one of the main roles in the sand and dust transport. The mean size of sand grains in the Naryn desert is 80–140 µm, which belong to the easily deflated type of sand. Particles of this size are more mobile under the influence of wind and can actively participate in wind transfer on the surface layer and be carried by strong winds around the surface layer of the atmosphere over long distances (Bultekov et al. 2014).

All of this information is important for the quantification of dust storms, which is necessary for making decisions about protecting from and combating the deflation process.

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Chapter 7
Conclusions

Dust and sand storms are common phenomena in the arid and semi-arid regions of Central Asia. Climatic conditions (small amounts of atmospheric precipitation, high temperature, and strong winds), huge areas of sandy, clayey, and solonchak deserts, and scarcity and poorness of vegetation cover all cause dust and sand storms.

Central Asia is one of the regions where dust and sand storms occur at high frequency and intensity. There are vast expanses of sandy and solonchak deserts of natural and anthropogenic origin across Central Asia and Kazakhstan. Central Asian deserts experience dust storms of different intensities, durations, and frequencies. Geographically, the region can be divided into the northern and southern desert provinces. The northern desert province is characterized by shorter and less frequent dust-storm events; a high number of dust storms and more prolonged dust events are common for the southern desert province. According to climatic and soil conditions, the spatial distribution of dust storms differs in the northern and southern deserts. The northern and southern desert provinces are distinguished by seasonal drought, winds that move dunes, temperature extremes, snowy winters, erosion of agricultural land, and great dust-storm intensities.

According to general climate zones, Central Asia is located in the arid and semi-arid climate zones. There are significant differences between climatic conditions in the northern and southern deserts in terms of weather seasons due to latitudinal zonality and peculiarities of the atmospheric-circulation regime. The precipitation regime significantly depends on the peculiarities of atmospheric circulation. In the region, two types of air mass—the air mass of the temperate zone in winter and the continental tropical air in summer—prevail. The air mass changes over the southern part of Central Asian deserts. However, the air of the temperate zone prevails over the northern desert, and there is no pronounced seasonal change of year-round air mass over the northern desert region. Consequently, atmospheric precipitation in the southern desert region gradually

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increases due to the intensification of cyclonic activity from October with the maximum in March to April. The precipitation sharply decreases in May, and the amount is close to zero in July. There are two maxima of precipitation in the northern desert. They occur in late autumn and late spring and are distributed more evenly.

Analysis of the dust storms led to the identification of separate source areas for aeolian dust transport within the Aral Sea basin and the deserts of Central Asia and Kazkahstan. The areas most prone to dust, sand, and salt storms include the Karakum; Pre-Aral Karakum and Aralkum deserts, Kyzylkum and Moiynkum deserts, Ryn (Naryn) sands (Northern Caspian plain), and Southern Pre-Balkhash deserts. The distribution and frequency of dust storms in the southern desert region is characterized by spottiness. The number of days with dust storms increases from northwest to southeast, and the maximum is reached in the central Karakum Desert, where the number of days with dust storms is >60, whereas in the northern desert region the distribution and frequency is heterogeneous and spotty. The sources of dust storms occurring at high frequency (>20 days/year) are situated in areas with soil of light texture and high wind speed. These areas are also used intensively in terms of the agricultural or industrial development or are located in regions of sandy deserts with sparse vegetation or sometimes barren dunes. The number of dust storms is high in the sandy deserts and river valleys, such as those of the Syrdarya and Ile rivers, where the maximum is 28–67 days; on the southern shore of the Balkhash Lake the range is 30–103 days.

The Central Asian deserts suffered changes in surface reduction such as shifting and shrinking of major source areas of dust-storm activities. The newly formed Aralkum Desert became a very active source of dust and salt storms in the last two decades of the 20th century and remains the dominant active source of aeolian sand, dust, and salt aerosols in Central Asia and Kazakhstan. Dust from the Aralkum Desert is mixed with material from the larger source areas of the Kyzylkum and Karakum Deserts. The effects of dust from the Aralkum Desert—in combination with such environmental factors as soil salinization, severe droughts, and low quality of drinking water—are especially strong in Karakalpakstan and Kazakhstan. Dust-, sand-, and salt-storm sources lead to the degradation of pastures and agricultural fields, impoverishment of biodiversity, soil salinization, and general aridization process.

The Karakum Desert plays an important role in the aeolian dust-transport regime of Central Asia as well. However, other source regions are characterized by more severe individual dust-storm events. Research results and analysis of data from weather stations near the Karakum desert show the greatest amount of dust deposition at an intensive rate and thus the highest frequency of local and regional dust storms.

The frequency of dust events varies over a wide range of 5–146 days of dust storms/year. The frequency of dust storms that last >3 h is rather high in all weather stations (except for foothill weather stations) and varies within 12–30%. More prolonged dust storms lasting between 1–3 and 9 h represent 10–32% of total dust events during the year. Dust- and sand-storm frequency in Central

Asian deserts and Kazakhstan showed a clear downward trend for the last century. Over the Karakum desert, the frequency of dust storms significantly decreased from >30 days/year to <20 days/year on average. The significant decreasing trend of dust-storm frequency could be explained by the recovery of desert ecosystems due to decreased anthropogenic activities in the region after 1980s. However, according to the results of a large number of studies, a decreasing trend of dust-storm frequencies was registered worldwide.

In summary, the following points are made:

(a) Dust and sand storms can be classified as extreme weather phenomena that creates powerful sources of atmospheric aerosol pollution. The dust storm is one of the most dangerous weather phenomena, and they occur when wind speed and soil conditions are favorable for their development. In general, the main factors—such as surface material susceptible to wind erosion and transport, strong winds, and unstable atmospheric conditions—are responsible for the formation and intensity of dust and sand storms. Consequently, there is a strong relationship between those conditions and the formation of storms. Therefore, dust and sand storms are distributed unevenly in Kazakhstan depending on the geological structure, soil texture with plant community, wind speed, and meteorological conditions of the region. Based on climate and soil conditions, the southern desert zone of Kazakhstan is more affected by these storms. A dust storm starts when the wind speed is >6 m/s.

(b) Dust-storm intensity depends particularly on soil properties. Light-textured soils (sandy–loamy and sandy) are most affected by deflation processes, and they are main sources of the micro-fine aerosol particles as well as their conversion into atmospheric currents.

Dust and sand storms are common due to the vast areas of sandy and solonchak deserts with a scarcity of vegetation cover and strong winds. Dust and sand storms are typical for sandy deserts in the southern part of Kazakhstan where there is sparse vegetation, favorable climate conditions, and soils with light texture. Sandy and solonchak deserts—such as the Pre-Aral Karakum, Aralkum, Kyzylkum, and southern Pre-Balkhash deserts in the southern part of Kazakhstan—are the main sources of dust, sand, and salt storms. Analysis of the data on dust and sand storms shows that the northern parts of the Aral Sea region experienced dust storms more frequently than the eastern parts. Nevertheless, in this region anthropogenic causes are playing a major role in the origin of such storms. The Aralkum (man-made desert) and Kyzylkum deserts became active and main powerful sources for aeolian dust, sand, and salt storms and transfer in the Aral Sea basin. These powerful sources of aerosols have a great effect on the climate and environmental situation in Central Asia and Kazakhstan. These aerosols can seriously pollute the air and water and thus lead to the soil salinization and vegetation degradation. As a consequence, a desertification process occurs.

The land-degradation process occurs in arid and semi-arid areas as a result of various factors such as climatic variations and human activities. These factors are part of the general processes of desertification. These processes are actively occurring in arid areas that are characterized by extreme climatic conditions. Various factors form climatic variations within different time periods, which ranges from the glacial–interglacial cycle to the solar-activity cycle, atmospheric circulation, and fluctuations of sea-level temperatures. Moreover, high fluctuation in climatic variables, such as precipitation, may be an important bioclimatic factor. This is caused by large inter-annual and seasonal climatic variations and is enhanced by increasing aridity.

Desertification and drought affect all countries of Central Asia: In Kazakhstan they affect 66%, in Tajikistan, 97%, and in Uzbekistan and Turkmenistan, 80% of the territory. In addition, approximately 90% of agricultural land in Kyrgyzstan is degraded and exposed to desertification.

In Central Asian countries, apart from natural environmental factors, anthropogenic pressure has seriously increased the effect of land degradation and desertification during the last 50 years.

Human activities have changed the level and volume of the Aral Sea and Balkhash Lake; the regulation of the Syrdarya, Amudarya, and Ile rivers, provoked land and soil degradation, and contributed to the development of intensive soil deflation as a result of dust and sand storms as well as desertification processes. In addition, all human actions seriously destroy environmental processes and lead to the rapid forms of soil and land degradation as well as desertification processes.

Dust and sand storms are both a symptom and cause of desertification. In other words, we can call the process “aeolian desertification”. Aeolian desertification is the most serious environmental and socio-economic problems at a global scale. The problem especially concerns the arid, semi-arid, and dry sub-humid areas of Africa, Australia, North and Northwest China, and Central Asia. Anthropogenic desertification has resulted in deflation as dust and sand storms and the deposition of sediments from sandy and solonchak deserts in Kazakhstan. The Aralkum Desert has become an active powerful source of salt, dust, and sand storms. In the Aral Sea region, anthropogenic causes are playing a major role in the origin of dust, sand, and salt storms compared with the southern Pre-Balkhash Desert.

The study of aeolian process as dust and sand storms in the desert zone of Kazakhstan allows qualitative assessment of the intensity of modern deflation processes in the area. According to the study results, it is possible to perform a quantitative assessment of the sand, dust, and salt transferred by the wind; to predict the possibility of the sand-moving process in the region, and to develop anti-deflation activities and measures.

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