Irrigating the desert: water management, agricultural practices, and social complexity in Southern Turkmenistan during the Bronze Age

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Chapter 2 – The Geology and Climate of Southern Turkmenistan

2. Overview

In this chapter, I will outline the physical and geological setting of southern Turkmenistan, and in particular, the Murghab alluvial fan, along with its current climate. I will then discuss the paleoclimatic data available for the region that will be later revisited in relation to data from this research in Chapter 7. I will also present data on the present hydrological system of the Murghab and discuss how these data are relevant to this project. I will address the problem of dune movement in the Murghab, and the role of takyr surfaces in the agricultural and ancient hydrological system. Finally, traditional irrigation farming, which provides insight into local water management, will be introduced and discussed.

2.1 The Climate of the Murghab Region

Modern Turkmenistan is located between the Aral Sea depression in the north, the Inner Asian mountains in the east, the Iranian Plateau in the south-west, and the Caspian Sea basin in the north-west. Lowland Turkmenistan is characterized by a continental and extremely dry climate (Suslov 1961) due to its significant distance from the ocean, the atmospheric circulation, and the presence of high mountains both to the south-southwest and the southeast (Orlovsky 1994:25). The climate of this region (which includes the Murghab alluvial fan) can be divided into two main seasons: 1) a very dry summer period with stable hot weather, and 2) a relatively humid winter season with extremely unstable weather. Although considerable differences occur in temperature between different regions in Turkmenistan, during the winter season (December to February), average temperatures generally fall below 0°C, while in the spring season (March to May), they increase to 7°–10°C (Table 2.1).

The highest temperatures occur during the summer (June to August) when the weather is generally characterized by monotonous hot temperatures that can reach up to 40°C in the Karakum. During the fall (September to November), the average monthly temperature ranges between 4°C and 21°C. Due to the dry climate, almost all incoming solar radiation is stored in the soil (Orlovsky 1994:26). Although a systematic climatic dataset of the past decades is almost absent in Central Asia, a series of droughts have affected the region of Turkmenistan and Central Asia since 2000. In addition, due to global warming, by 2080, temperatures are expected to increase in Central Asia by 3–4 °C which will have a significant impact on agricultural affordances (Lioubimtseva and Henebry 2009).

Like in other Central Asian countries,[9] most cropland in Turkmenistan is irrigated. The average annual precipitation varies from 110 mm to 398 mm in different parts of the country and occurs predominantly from October to May. However, the mean annual precipitation in the Murghab region is less than 150 mm, and between July and August, only 4% of the annual precipitation occurs.

SEASON	**AVERAGE TEMPERATURE**
Winter	From to -9°C to -1°C
Spring	From 7°C to 10°C
Summer	From 35°C to 40°C
Fall	From 4°C to 21°C

Table 2.1 Average temperatures in Turkmenistan during the year (data from Orlovsky 1994). However, considerable differences exist between the different regions of Turkmenistan.

Precipitation hardly occurs in the central Karakum, making agriculture impossible without artificial irrigation (Orlovsky 1994). As such, the future rise in temperatures in the region will potentially increase evapotranspiration, creating severe water stress and increasing agricultural risks, making a tremendous impact on the agricultural economy.

[9] The term “Central Asia” is often used to define the five former Soviet republics (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan) located in the Middle Asian region (Cowan 2007). While acknowledging the complexity of the term, in this thesis I will refer to the same geographical definition when using the term “Central Asia.”

Climatic changes in the region, however, have also been recorded in the past. Climatic variability, including moister periods, as well as periods of drought, likely characterized Central Asia throughout the Holocene and had a serious impact on agricultural and social developments. As such, paleoclimatic data for the region, although limited, are crucial for future discussion in this thesis and will be briefly presented below.

2.1.1 The Paleoclimate during the Holocene in Central Asia

The paleoclimate of West Asia has been well-researched over the last few decades, while data from Central Asian regions and, in particular, southwest Central Asia remain patchy (Mayewski et al. 2004; An et al. 2011; Cheng et al. 2015; Sharifi et al. 2015; Shaikh Baikloo Islam et al. 2020). Nevertheless, the paleoclimate of the Middle and Late Holocene in Central Asia has been addressed by various authors.
For the region of Central Asia, and in particular in Uzbekistan and Turkmenistan, the period between 6000 and 3000 BCE (Middle Holocene) is known as the "Ljavljakan pluvial phase." Most authors agree that during this period, the climate was relatively humid, with an annual mean rainfall average as high as 300 mm in the region (Vinogradov and Mamedov 1975; Lioubimtseva et al. 1998; 2014; Varushchenko et al. 1987).

Radiocarbon dates along with palynological analysis have been conducted in the Middle Caspian basin (Leroy et al. 2007; 2014). The data show a desert vegetation with a low presence of trees but with a presence of shrubs such as *Ephedra* and *Calligonum*, which have been radiocarbon dated to 7240-6240 cal. BCE (see full pollen data percentage in Leroy et al. 2014:Fig. 4 and full radiocarbon dates at Tab. 2). After this period, data from the Middle Holocene show a dominance of trees in the coring. In the subsequent period the pollen analysis suggests a steppe-like vegetation from ca. 2160 cal BCE, when there is a change in the botanical assemblage. Leroy et al. (2014) connects this period and the drop in recorded sea level to a broad paleoclimatic change in West Asia, the so-called "4.2 ka BP event".

The 4.2 ka BP dry event has been recorded in various locations in West Asia and other parts of the globe. In the Sistan region of Iran, for instance, the 4.2 ka BP event has been correlated with a dry phase (Hamzeh et al. 2016). This interpretation is reflected in the data of the $\delta^{18}O$ record from a lake (Hamzeh et al. 2016:Fig. 4). In the two cores taken in the lake, the facies C2 (corresponding to the 4.2 ka BP event) is characterized by the absence of any flora and fauna.[10] While the 4.2 ka BP event is largely accepted as a broader event (Bini et al. 2019), its regional impacts remain unclear as, in many cases, paleoclimate records fail to show such evidence. Some scholars argue for a series of dry and wet events with strong regional variation rather than one blanket dry period for the whole region (see Magny et al. 2011; Railsback et al. 2018).

Further paleoclimatic data from the region suggest an increased aridity from the late Middle Holocene. AMS radiocarbon data from Lake Issyk Kul in Kyrgyzstan suggest increased aridity from as early as 4950 cal. BCE. The analysis of the geochemistry of ostracode shells and their stable isotopes show a rapid increase of $\delta^{18}O$ and Sr/Ca values along with a decrease of U/Ca values between 4950 BCE and 2950 cal. BCE (see full data in Ricketts et al. 2001). This has been interpreted by Ricketts et al. (2001) as an evolution from a freshwater and open lake to a saline and closed lake.

In other regions of Central Asia, such as Central Kyrgyzstan, data from Lake Son Kol shows dry interval events between 3000 and 1950 cal. BCE. Data was retrieved from five cores around the lake from which stable isotope, (bio)geochemical and pollen analyses were conducted and AMS radiocarbon dating were derived. Such data show depleted $\delta D_{n\text{-}C29}$ values dated between 4050 and 3000 BCE suggesting a predominantly humid period. From 3000 BCE, however, the data show an increase in the amount of $\delta D_{n\text{-}C29}$ suggesting a pronounced dry episode until 1950 BCE (Lauterbach et al. 2014) (Figure 2.1).

[10] In contrast to this interpretation, this absence may be caused by degradation (oxidation) of material present in a later dry period (J. Moll pers. comm.).

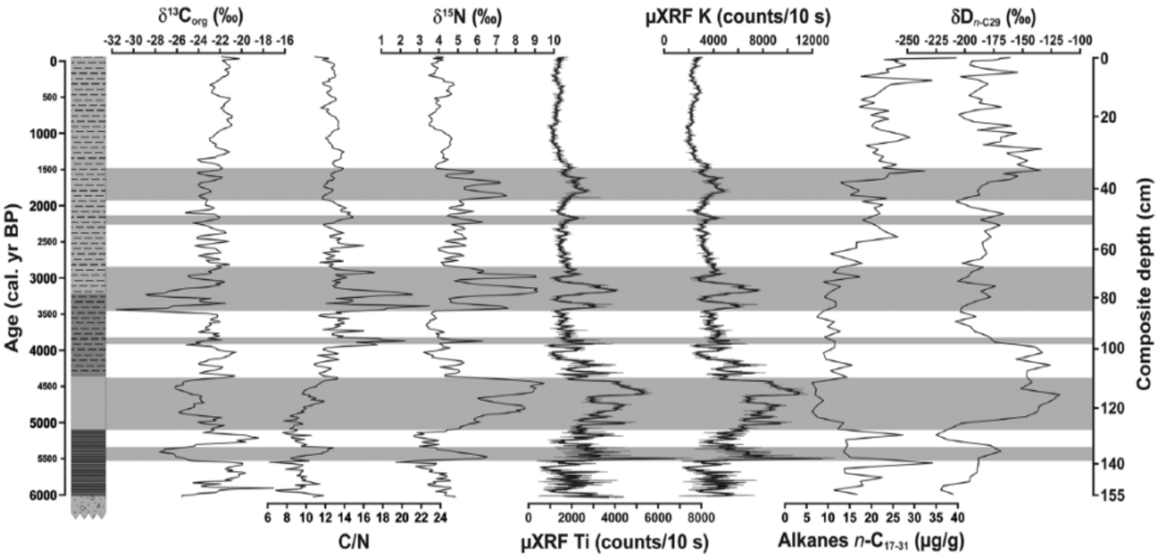


Figure 2.1 The figure shows the results of (bio)geochemical and stable isotope analyses on the sediments of a composite profile (SONK_11_D1/2) from Son Kol (Kyrgyzstan) (images from Lauterbach et al. 2014:Fig. 5).

These dry periods in Central Asia seem to occur in the Aral Sea region as well, between 2000 and 500 BCE. During these periods (which correspond to the Bronze and Early Iron Age in the region), the water level only reached 42–43 m a.s.l., which is low compared to previous and subsequent periods (Boroffka et al. 2006:Fig. 4). This interpretation is derived from the analysis of the Ca element in the sediment core that reflects the abundance of gypsum, which is formed during extensive evaporation (Cotellucci et al. 2023). The Ca fluctuation, which is a parameter for climatological lake-level change, is indicative of a lower water level. However, water bodies connected to far away rivers might be impacted by river dynamics that are the result of various factors, including changes that occur where the river originates and this can be far away from the water body, as in the case of the Aral Sea (Boomer et al. 2009). According to Boroffka et al. (2006), however, the river systems of Jana Darya and Akcha Darya were regularly discharging into the Aral Sea during that period, such as before and after.

Similar patterns, with relatively warmer conditions, are also attested in Lake Karakul in Tajikistan from the late 3rd and 2nd millennium BCE. Samples were collected from sediment cores from Lake Karakul and its catchment area and show that in the interval between 2250 and 1550 cal. BCE there are low $\delta^{18}O$ values that have been interpreted by Mischke et al. (2010:Fig. 6) as a result of a relatively high lake level due to high freshwater discharge, probably a meltwater supply as a result of warmer climatic conditions. All in all, although data points across Central Asia have increased in the last decades (summarized in Table 2.2; Figure 2.2), climate change is still a debated topic, and local differences in climate evolution are still insufficiently documented and sometimes contrasting.

Recently, Fouache et al. (2021) outlined a general climatic history for southwestern Central Asia from various proxy data. According to the authors, during the Middle Holocene, 6000–3000 BCE, climatic data suggest a more humid phase characterized by the presence of shrubby vegetation and a subhumid steppe (Maman et al. 2021a). This interpretation is based on data suggesting high water levels in lakes, such as the Aral and Caspian Seas (Fouache et al. 2021). This period is followed by a less humid period compared to the previous one, with a tendency for more arid climatic conditions during the Late Holocene from approximately 3000 BCE. In his study, Fouache et al. (2021) identified three major short-term arid events between 2800–2400 BCE, 1500–900 BCE, and 500–200 BCE.

For the Murghab, there are little paleoclimatic proxy data available. However, data from exposed channels (see below) collected by the AMMD project are indicative of a more dry phase from ca. 2000 BCE (Cremaschi 1998). In the area of Takhirbaj an ancient channel which has a basal deposit characterized by laminated sand overlapped by a colluvial deposit covered by aeolian sand. The colluvial deposit was radiocarbon dated to 1505-1345 cal. BCE, after which the sediment was covered by aeolian sand. Similarly, a channel west of site n.55 in the Murghab has a stratigraphic sequence of thin laminated sand and clayey organic silt. This fluvial sediment was radiocarbon dated by Cremaschi (1998) to 2055-1805 cal. BCE and was sealed by aeolian sand as well (see Cremaschi 1998:Table 1 for radiocarbon data). All in all, these data point towards drier conditions by the mid-2nd millennium BCE in the Murghab. However, data from the present research from Togolok and Ojakly indicate that this dry phase likely started earlier, by the end to the first short-term arid event (2800–2400 BCE) proposed by Fouache et al. (2021) (see Chapter 7 for discussion).

Region	Period of Dry Phases (cal. BCE)	Reference
CENTRAL ASIA		
Lake Issyk Kul, Kyrgyztan	From ca. 4950 BCE	Ricketts et al. (2001)
Lake Son Kol, Kyrgystan	3000–1950 BCE	Lauterbach et al. (2014)
Lake Karakul, Tajikistan	2250–1550 BCE	Heinecke et al. (2016); Mischke et al. (2010)
Altai mountains, Mongolia	From 3050 BCE	Rudaya et al. (2008)
Lake Balikum, Xinjiang region, China	2350–3850 BCE	An et al. (2011)
Caspian Sea region	2050–350 BCE	Rychagov (1997); Kakroodi (2012); Boroffka and Oberhansli (2006)

Table 2.2 The table shows the dry periods recorded in the Central Asia region according to different paleoclimatic records.

Paleoclimate data for the local Murghab region are still scarce, often not easily accessible in the West[11], and inadequate to establish a solid paleoclimatic interpretation. Nevertheless, a change towards a less humid phase and a drier environment by the end of the 3rd to early 2nd millennium BCE, as I will argue later, substantially affected BMAC communities in terms of water and agricultural management, as well as the Murghab's hydrological stability. In particular, the hydrological network and the availability of water resources are likely to have played a role in the settlement pattern of the region between the Middle and Late Bronze Ages. As such, the relevance of this research is the investigation of local-scale dynamics that might relate to paleoclimate and hydrological

[11] This is the case with the data from the 'Desert Institute' in Ashgabat

change, as local-scale paleoclimate data are crucial in any research in Central Asia. When considering settlements and social pattern evolution, local climatic variations are pivotal aspects to consider in addition to broader proxy data of the regions that encompass different ecological zones.

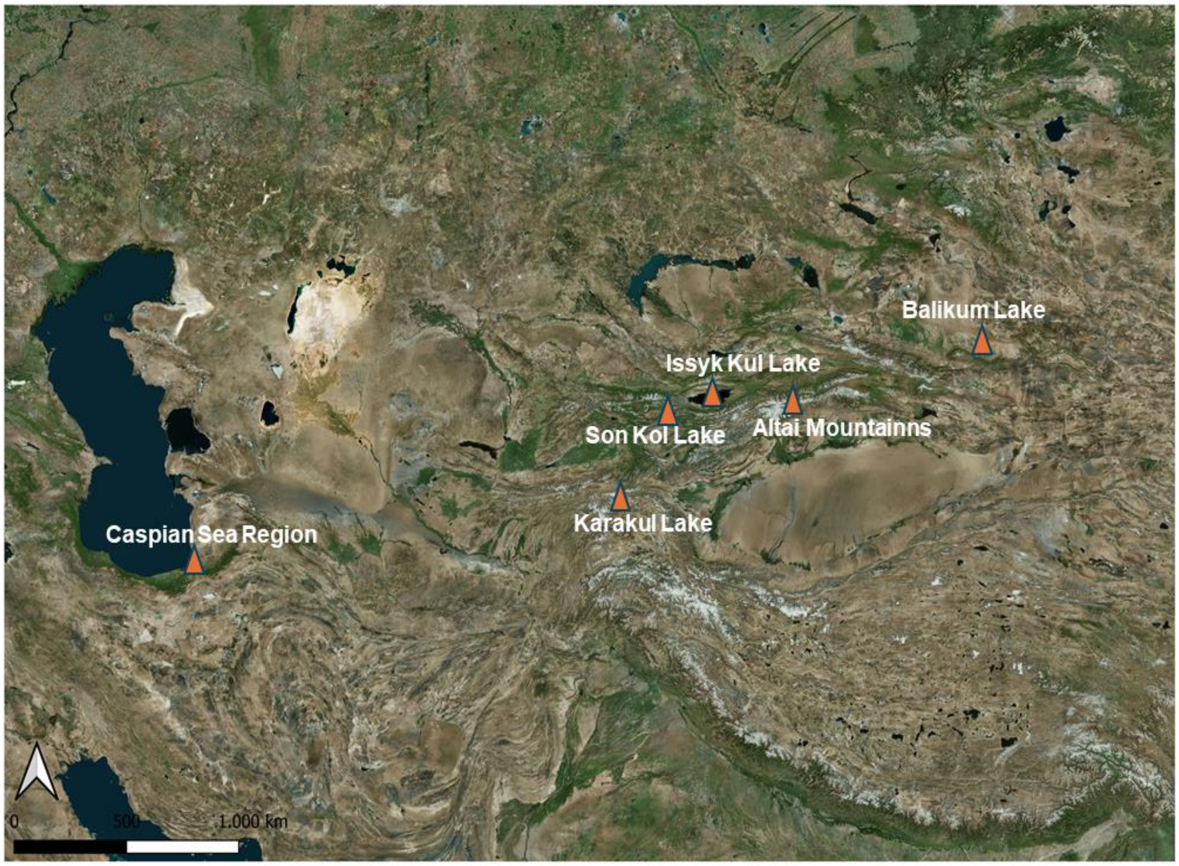


Figure 2.2 The figure shows the locations of the paleoclimatic records from Table 2.2.

2.2 The Geomorphological Setting of the Murghab Region and its Hydrology

Alluvial fans are characterized by a conical landform that radiates from where the main stream of the river leaves the source area (Bull 1977). This conical landform develops through sediment aggradation. The alluvial fan's formation is composed by a) a primary process that transports sediment to the catchment area of the fan and b) secondary processes that change sediments previously deposited (Blair and McPherson 2009). According to Blair and McPherson (2009), the condition for the development of an alluvial fan are the topography of the region where an upland catchment drains towards the valley, and enough sediment to construct the fan. A catchment drainage area is characterized by three levels of channels. The first are the main channels, lacking any tributaries, followed by second-level channels downslope, followed by smaller third-level channels. During the accumulation phase of the fan, shifts of the channels may occur across the fan (Bull 1977).

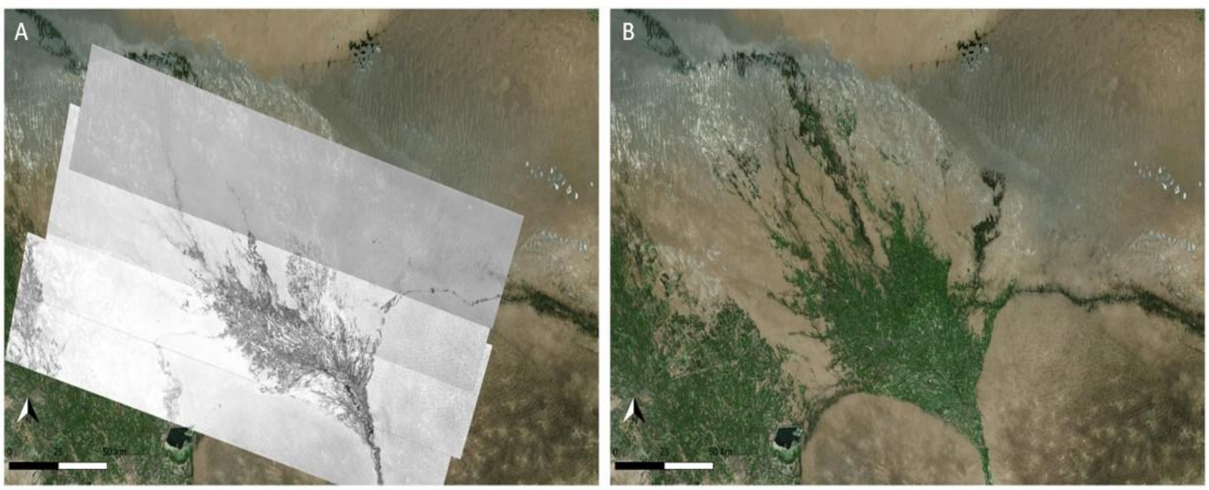


Figure 2.3 The figure depicts (A) the expansion of the Murghab alluvial fan in the CORONA KH-4A (Sep 18, 1964) image and a (B)contemporary satellite image from Bing Map. Following the final costruction of the Karakum Canal in the late 1980s, the northeastern region has become active again in terms of waterchhannels and agriculture.

The Murghab fan region is mostly formed by loam, loamy sand, and sandy sediments, generally 1 or 2 m thick (Cremaschi 1998). According to Dolukhanov (1981:361–362), the region has four terraces dating to the Middle and Upper Pleistocene, preserved only in the Kopet-Dag area. The modern Murghab floodplain has an average slope of 1.93‰, with a mean value of 1.16‰, and a standard deviation of 1.57‰, which makes the Murghab an almost flat region (Ninfo 2007).

The present annual mean discharge of the river at Qala-i-Niazkhan station[12] (before the river enters Turkmenistan and without any tributaries) was 46.8 m^3/s (between 1966 and 1976), with a peak in discharge between the months of April and May due to the melting of ice in the mountains (Olson and Williams-Sether 2010:266). However, the annual discharge can vary considerably (Table 2.3). Between 1967 and 1978, the annual mean discharge was between 40 and 50 m^3/s, with a high peak in 1969 with a discharge of nearly 90 m^3/s and a lower flow in 1971 of less than 30 m^3/s. While the up-stream areas of the fan might have had limited impact of lower discharge, effects might have been especially pronounced on the northern distal fringe of the Murghab.

The modern Murghab alluvial fan has been minimally investigated in terms of its fan and hydrological characteristics. The distal part of the alluvial fan is interspersed with mud plains which are characterized by fluvial silt and clay material (Ghassemi and Garzanti 2019). However, the modern fan is the result of the construction of the Karakum Canal which was completed in 1980s (Zonn 2014). The canal takes water from the Amu Darya River and, in the last forty years, the water has started flowing again in much of the old fan, in particular in the northeast sector. Before the construction of the Karakum Canal, the extent of the alluvial fan was much reduced compared to the modern Murghab (Figure 2.3).

The modern alluvial fan, as mentioned above, ends its journey inland rather than in a lake or sea. Most of the inland fan is located in drylands, such as the Karakum Desert. The river rises in the Paropamisus Mountains (western Afghanistan), while the fan ends in a dry area (Seely et al. 2003) and has specific characteristics. The central part of the fan is characterized by perennial channels with a presence of three levels of channels discussed above in this section. Even before the construction of the Karakum Canal, this central part of the fan was reached by sufficient water. However, the northern or distal area of the fan was characterized by ephemeral channels with intermittent water. Aridity, along with its accompanying fluctuations in rainfall, plays a crucial role in the temporary nature of rivers, as does the exceptionally high rate of evaporation. Flood rivers typically result

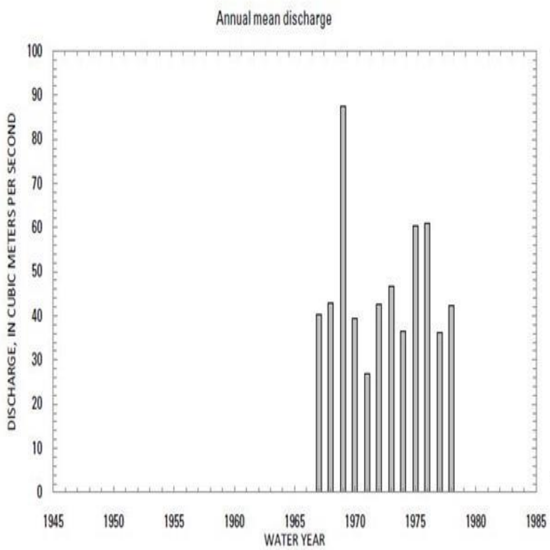
[12] This station is located in northeastern Afghanistan (35º02'N, 64º01'E)

from intense downpours that allow minimal time for water to seep into the soil (Jacobson et al. 1995). In addition, due to restricted water flow, there is a buildup of salt, allowing only salt-tolerant species of vegetation to thrive in the vicinity of these springs and wetlands (Seely et al. 2003).

The resumption of water flow of the Murghab fan, and the expansion of agricultural areas, has led to a significant reduction in the number of ephemeral channels. Nonetheless, in distant regions where arid conditions persist, such as the research sites of Ojakly and Togolok, ephemeral watercourses still exist. During the autumn and winter seasons, flash flood events occur, temporarily activating water channels. However, as indicated by Cremaschi (1998) and Ninfo and Perego (2006), this section of the alluvial fan was marked by the existence of a perennial river system within a humid environment until the 3rd millennium BCE. It is only by the 2nd millennium BCE, and potentially even as early as the late 3rd millennium BCE, as I will argue in this thesis, that the region underwent a process of aridification. During this period, it is probable that some sections of the fan featured permanent channels, while elsewhere ephemeral channels began to increase. The presence of perennial channels during the Late Bronze Age sustained numerous sites, including major tepes. It seems that from the mid-1st millennium BCE the landscape started to resemble the modern one with the presence of large arid areas in the northeast of the fan.

In addition to the occurrence of flash floods in the remote regions of the contemporary fan, the presence of takyr surfaces is also widespread. These features, as I will elaborate on in the following paragraph, hold significant importance in various respects. They serve as drainage basins (comparable to playas in the USA) where water accumulates and have played a crucial role in crop cultivation and animal husbandry. *Takyrs* are situated along dry channels and in interdune areas, and they are prevalent throughout the region (Fleskens et al. 2007) (see section 2.3.1 of this Chapter for discussion).

While the contemporary distal fan exhibits a dry landscape featuring ephemeral streams, the situation during the 3rd and 2nd millennium BCE was different. In this thesis, I will examine the ancient hydrological system and analyze sections of two former channels. Reconstructing the channel system in Togolok and Ojakly is essential to corroborate certain hypotheses regarding the ancient hydrological system, such as whether it was braided or anabranching, and whether they might have resembled the present-day alluvial fan in its active sectors.



Month	Maximum		Minimum		Mean			
	Discharge (m^3/s)	Water year of occurrence	Discharge (m^3/s)	Water year of occurrence	Discharge (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual discharge
October	44.3	1976	19.9	1972	32.7	7.17	0.22	5.94
November	43.2	1970	22.3	1972	31.5	6.31	0.20	5.73
December	37.0	1976	22.2	1972	29.5	5.23	0.18	5.36
January	35.5	1976	22.4	1971	28.7	4.13	0.14	5.21
February	39.3	1976	20.3	1972	28.4	4.97	0.18	5.16
March	113	1969	26.6	1971	41.2	22.3	0.54	7.49
April	214	1969	42.0	1966	80.3	46.4	0.58	14.6
May	202	1969	36.8	1971	92.0	50.6	0.55	16.7
June	146	1969	28.5	1971	67.5	34.1	0.50	12.3
July	89.0	1969	24.9	1971	45.9	17.4	0.38	8.35
August	59.2	1969	22.9	1971	37.6	10.6	0.28	6.84
September	48.2	1975	21.1	1971	34.7	8.31	0.24	6.31
Annual	87.3	1969	26.9	1971	46.8	16.0	0.34	100

Table 2.3 The table shows the annual and monthly mean discharge of the Murghab River between 1966 and 1976 at Qala-i-Niazkhan station (USGS Report 2010, Olson and Williams-Sether 2010:266).

Availability of water discharge data in Central Asia is often constrained by early Soviet studies (Mitgartz and Shevchenko, 1972) and typically spans no more than 60–70 years. (Table 2.3). Moreover, fluctuations in the size of the Murghab fan can be reconstructed on the basis of historical maps and, more recently, from satellite images. A preliminary study focusing on the period between 1881 and 2001 shows considerable fluctuations in the extent of the alluvial fan with a marked reduction in size at the beginning of the 20th century (Tosi and Cerasetti 2010:Fig. 16). Tosi and Cerasetti reconstructed an expanse of irrigated areas in the Murghab region between 4000 and 6000 km^2 during the 20th century. The study shows that in the course of a century, several fluctuations significantly affected the size of the fan and, as a result, the agricultural potential of the region. In ancient times, such fluctuations of discharge might also have impacted the potential for agricultural production and the irrigated lands.

- **Tectonic Movement and Hydrological Change**

Around 70% of modern Turkmenistan is occupied by desert, namely the Karakum (black sand) Desert. This area is the most significant geomorphologic feature in the country and is characterized by deserts of salt, sand, loess, clay, and stone (Ghassemi and Garzanti 2019) (Figure 2.4). Both the Murghab and its adjacent alluvial fan to the west, the Tedjen, are part of the Turan plate and were formed in the second half of the Quaternary Period (Atamuradov 1994:62). However, the Murghab fan has also been shaped by subsequent events. The area is part of a tilted fault block which appears to be colliding with the western side of the Khiva Depression at its eastern limit (Kozolov 1991; Marcolongo and Mozzi 1998:2). Quaternary tectonic movement, as well as reduction in water discharge in this region, has significantly impacted the hydrological system of the Murghab (Rustanov 2014a:14).

An analysis by Marcolongo and Mozzi (1998) presents a tilted fault block, the "Turan Plate," covering much of central and eastern Turkmenistan, which is rising in the east. According to the authors, the late Quaternary geomorphological features appear to be components of a tilted fault block, exhibiting an elevated eastern side and gradually dipping towards the area presumed to be subsiding, situated between the Kopet-Dag and the central Karakum plateau, referred to as the "Turcoman trough" (Marcolongo and Mozzi 1998:1). This tectonic movement led to a westward shift of the entire hydrological fan of the Murghab, likely occurring during the 1st millennium BCE (Marcolongo and Mozzi 1998).

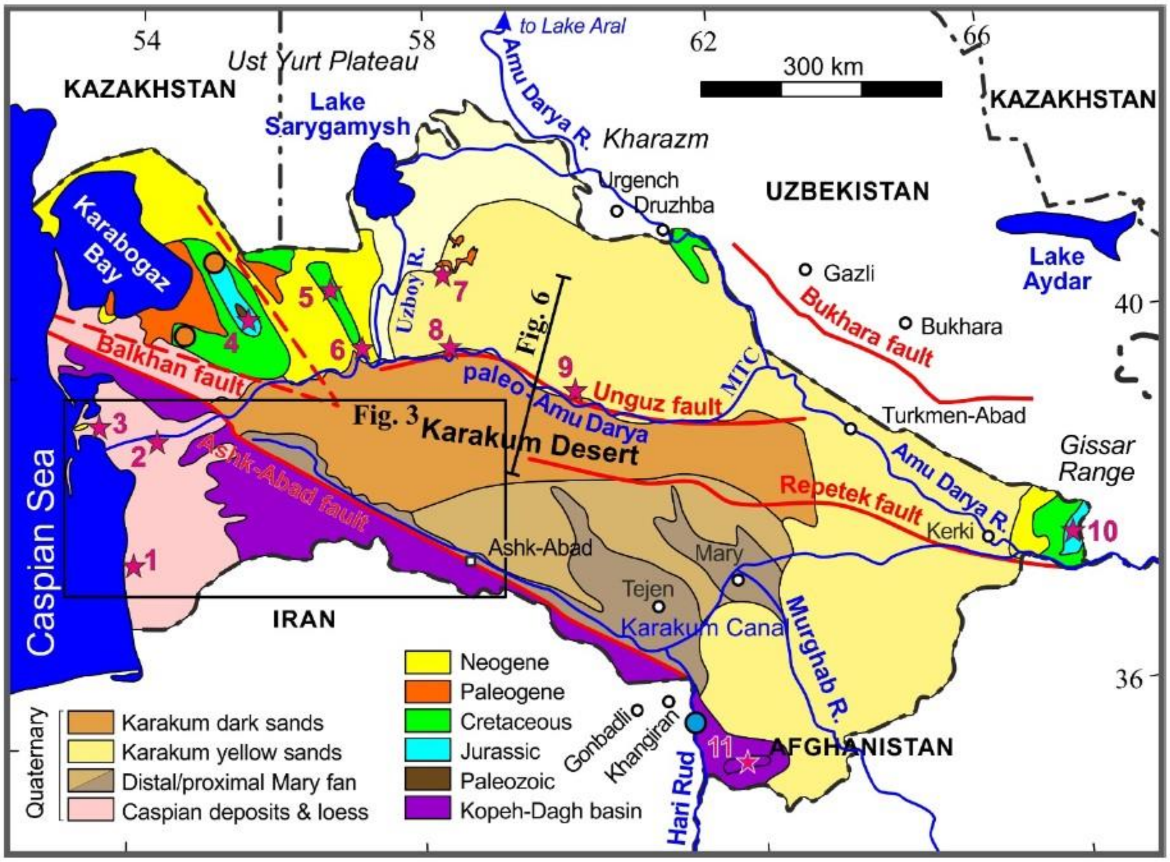


Figure 2.4 The figure shows the general geological map of Turkmenistan, compiled by Ghassemi and Garzanti (2019:Fig. 2).

A second process that generated ancient channel systems was the contraction of the water supply of the Murghab. The decrease in water discharge resulted in the many river channels becoming inactive in the northeastern fringe of the fan. The analysis of the high-resolution elevation data (SRTM images)[13] shows the presence of two overlapping fans in the Murghab: the northeastern "Bayram-Ali" Fan and the younger "Mary" Fan to the west.[14] The shift towards the Mary Fan resulted from the tectonic changes discussed above (Figure 2.5). When exactly this shift took place is unclear. Tosi and Cerasetti (2010), considering the presence of the Iron Age main settlement of Yaz-Depe, on the southwest end of the older Bayram-Ali fan, tentatively proposed a shift, particularly a southward shift of the population, not before the end of the Iron Age.

[13] Shuttle Radar Topography Mission (SRTM).

[14] Atamuradov (1994:62) citing Fedorovich and Kes (1934) state that "four subsequent deltas, partially overlapping, have been found in the lower reaches of the Murghab."

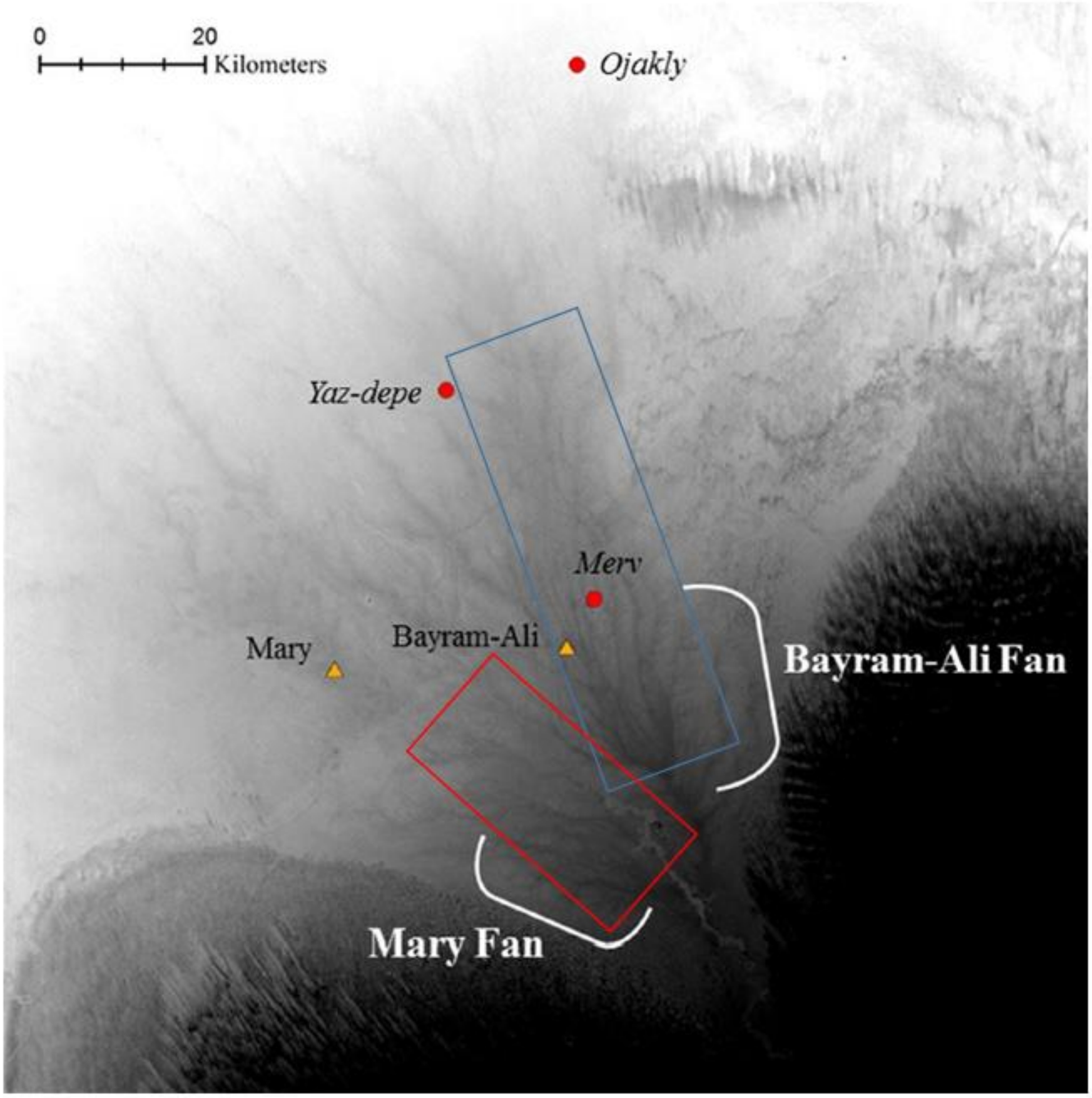


Figure 2.5 The SRTM image shows the northeastern Bayram-Ali Fan (blue rectangle) and the youngest Mary Fan (red rectangle) (adapted from Rouse 2015:Fig. 3.4).

As mentioned earlier, an additional problem is a loss in surface water due to evaporation. Evaporation is a key process and the main way rivers lose heat (Maheu et al. 2013). According to Lyapin (1996), in order to overcome water shortages and reduce agricultural production, dams were constructed in the Murghab, probably during the 3rd and 2nd century BCE. Dam construction potentially led to an increase in agricultural production and population growth, especially in the Merv Oasis. However, although small dams could have been in place during the 3rd and 2nd century BCE, there is no convincing evidence for them at present. In fact, it is not until the Arab conquest (8th century CE) that we have clear evidence (from literary sources) for the construction and maintenance of dams along the Murghab River. These sources also provide evidence for state service and the maintenance of large dams (Bader et al. 1996). The vital importance of the Murghab dams for agricultural production in the Merv Oasis is also evident during the Mongol occupation. The Mongols destroyed major cities in the region, such as Merv and Nisa, as well as dams along the Murghab, which led to a decrease in agricultural production and a reduction in settlement numbers and size (Bader et al. 1996).

For the preceding periods there is no archaeological evidence for dams in the Murghab, although the location of Achaemenid “fortresses” in the northeastern region of the Murghab may suggest that the main channels of the alluvial fan were still active in that period (Cerasetti and Mauri 2002:Fig. 7; Lyapin 1996). The northeastern part of the Murghab fan system only fully resumed flowing in the 20th century with the construction of the Karakum Canal, which increased the agricultural potential of the region tremendously (Figure 2.1).

The retreat of the Murghab in the 2nd millennium BCE and its shift later to the west due to tectonic movement created a preserved landscape that can be appreciated through satellite images and aerial photos (Cremaschi 1998; Salvatori 2008a:67). In terms of archaeological research, this landscape offers great potential for investigating past human–water relationships. However, while the investigation of the overall ancient hydrological system of the Murghab has been extensive, targeted investigations of specific channel systems that can foster a thorough understanding of this relationship have not yet been undertaken.

2.3 Dune Movement and Soil

The northeastern fringe of the Murghab alluvial fan has been cultivated since the 1960s, and this process accelerated in the 1990s (Zonn 2014) (Figure 2.1). However, up to the 1950s, the central north area of the Murghab was covered mostly by active linear dunes, which are still predominant in the northern part, along with ephemeral run-off water reservoirs forming takyr surface (see below). The desert dunes in the Murghab vary in their form and activity from north to south of the fan. The north of the no longer active fan is characterized by large ridge dunes with an N–S or NNW–SSE direction. They are stable or semi-stable sandy hills or ridges (Maman et al. 2011a). They can measure some kilometers in length, are about 50 m wide, and 10 m high (Cremaschi 1998). In the eastern and southern regions in particular, the dunes take the form of small "barchanoids"[15] with a relatively long shape when occurring in a group (Suslov 1961). In the central south part of the fan, the presence of bush vegetation (mainly *black saxaul*; see section 2.4 of this Chapter) stabilizes dune movement (Cremaschi 1998). These dunes, both in the central and more distant part of the fan, partially cover the ancient landscape, obscuring channels and archaeological sites and have a considerable impact on archaeological and geoarchaeological investigations (Bondioli and Tosi 1998:1).

2.3.1 Takyr Surfaces

Takyr surfaces are common in the Murghab region and Central Asia deserts and they are of a crucial economic importance (Dolukhanov 1981). Although sometimes referred to as soil, takyr is not classified as soil by the World Reference Base for Soil Resources. It is a surface with specific and defined properties (Food and Agriculture Organization 1998:7). Takyr generally occur in drainage areas of the former Murghab alluvial fan or in areas that were irrigated and are characterized by a slightly sloping or flat surface with dense clay-loam soils, often with a polygonally cracked surface (Fleskens et al. 2007; see characteristics in Food and Agriculture Organization 1998:73–74) (Figure 2.6). These surfaces occur in various dimensions and are similar to *playa* in the United States, or the *sabkha*/*qaa* in West Asia, although some differences exist (see Briere 2000). According to Bazilevich et al. (1956), the formation of takyr surfaces in the Murghab occurs mainly during the spring flood. They concentrate on slightly sloping surfaces where water can accumulate and can be found along former water channels as well as in interdune areas.

[15] Barchanoid derives from name *barchan* which means "crescent dune." They are wavy dune ridges often with asymmetrical geometry and with parallel rows oriented transverse to the direction of the predominant wind. They often move forward from their position during the winter in the Murghab (Tirsch 2014).

Therefore, takyr surfaces can occur in any part of the ancient dried alluvial Murghab fan, and in particular in the central north part.

Figure 2.6 The picture shows A) a classic takyr surface (red circle) in the northeastern region of the Murghab alluvial fan and B) detail of a takyr surface.

Lebedeva-Verba and Gerasimova (2010) have described the micromorphology of the formation of takyr and the role of terrestrial and aquatic microorganisms. In short, the accumulated water (waterlogging) on sloping surfaces during the spring and autumn (when there is more rainfall) causes an outbreak of different algae and microorganisms that were previously formed, along with processes of alternating alkalinization and salinization. In the warm and hot seasons, there is a drying out with cracking and shrinking of the surface as well as active deposition of eolian sands and activities of microorganisms, such as zooplankton and blue-green algae, resulting in the formation of a new takyr surface (Lebedeva-Verba and Gerasimova 2010). Takyrs often covers large areas and are often associated with algae and lichens on the surface during the dry season

(Dregne 1976; Orlovsky et al. 2004). For generations, people in the Murghab have used the water accumulating on this surface for various purposes (see below).

It has been estimated that in Central Asia between 130,000 and 318,000 km^2 of land comprise of takyr surfaces, of which 31,000 and 40,000 km^2 are present in the Karakum Desert (Prasolov 1933; Lezhinsky 1974; Babaev and Vitkovskya 1985; Lavrov et al. 1976). An analysis by Maman et al. (2011b) demonstrates a loss of 20% of these surfaces in the last 40 years, which has considerably reduced their potential as temporary water reservoirs. Of particular interest for the current study are the possible uses in the past of takyr surfaces.

2.3.2 The Role of Takyrs in Modern Crop Cultivation and Animal Husbandry

Takyr surfaces have been widely used for crop cultivation and animal husbandry in the Murghab. Fleskens et al. (2007) have grouped the different systems that have been developed for the exploitation of water resources from takyr surfaces. One of the most common systems indicated on historical maps is that of *khaks*, which are one of the most efficient ways of storing water in the Karakum Desert and are widespread in the Murghab. Ethnographic study also indicates how these places, able to collect water for some period, were crucial in the Turkmen economy both for crop cultivation, including opportunistic fields, and animal husbandry (Lalymenko 1989). The *khaks* are dug into the takyr surface to collect water, which can be stored between two and four months. The capacity of *khaks* for storing water can vary from 2 to 100 m^3 (Fleskens et al. 2007). These structures are also used for watering livestock, as well as for human consumption (at present, *khaks* have almost disappeared in the northeastern part of the Murghab). It has been estimated that the average total volume of runoff water on takyr surfaces is between 350 and 450 million m^3 per year in Turkmenistan (Fleskens et al. 2007). Finally, takyr surfaces facilitate water retention, and many takyrs have been directly ploughed and used in agriculture. While till the 1980s takyrs were used only as watering places for crop cultivation and animal husbandry (Emeljanenko 1994), the use of modern canals excavated with machines in a short time period have drastically reduced their importance. As result, takyrs have been destroyed and ploughed because of the water retention that make these surfaces a good spot for cultivation. This is also evident in satellite images where takyrs are reached by modern canals and are often completely converted into agricultural areas. This destructive practice, as well as the use of heavy vehicles, has resulted in the loss of many takyr surfaces in the Murghab over the last few decades (Fleskens et al. 2007).

In the past, water on takyrs was also crucial for caravan routes. Fleskens et al. (2007:Fig. 2) mention that *kahks* determined the seasonal trekking routes of shepherds north of the city of Ashgabat that extended over 200 km. However, at present, takyrs no longer serve as water storage places and have almost lost their crucial importance. Water can be easily brought to the field by the construction of fast and modern canals.

2.3.3 The Role of Takyrs in an Archaeological Context

The importance of takyrs for archaeology has been highlighted by various authors. Cremaschi (1998), while describing takyrs, reported that some takyrs might date to the Bronze Age. According to the author, takyrs can be ancient topographic surfaces which were covered by dunes and were later uncovered again by wind erosion. In fact, in the preliminary AMMD survey of Iron Age sites it is reported that the “Low Lying Depositional Areas” (LLDA), often consist of large takyr surfaces (Genito 1998). Lyapin (1990) claimed that takyr surfaces were often correlated with Bronze Age material. However, no further sedimentological studies have been published that correlates takyr surfaces with a Bronze Age formation, and thus they could have been formed at later stage. In addition, as reported by Markofsky (2010:286) in the Egri Bogaz area, some takyrs that showed Bronze Age materials on the surface failed to show significant evidence of archaeological deposits below such surface level. Thus, Bronze Age materials on takyrs might have been the result of post-depositional processes.

Critical for the present research, however, is the association of takyr surfaces with possible ancient agricultural fields. Takyr surfaces forms naturally in the Murghab region, and they are often the result of the drainage of water and subsequent formation processes, as mentioned above. However, takyr surfaces may also form as the result of anthropogenic activities (i.e., waterlogging). Considering the takyr formation process outlined earlier, it is conceivable that the formation of takyr surfaces may result from agricultural practices and intentional flooding carried out repeatedly (Fleskens pers. comm.). Intentional flooding is still a common irrigation practice in the Murghab. Thus, takyr surfaces might also be the result of irrigation practices in intense cultivation areas. Lisitsina (1976) explored this hypothesis by investigating the salt content of different takyr or takyr-like surfaces in southern Turkmenistan. The comparison between different takyr surfaces (natural vs. anthropogenic) indicates that takyr deposits in areas identified as ancient fields dated to the 3rd millennium BCE show a lower percentage of salt content compared to naturally accumulated takyr deposits. The analysis by Lisitsina (1976:60) suggests, therefore, that some takyr surfaces in southern Turkmenistan can indeed be linked and formed from ancient farming and irrigation practices.

Additional proxy evidence linking takyr formation and ancient irrigated land, although from a different geomorphological landscapes, is provided by investigations in the Prisarykamysh alluvial–deltaic plain (southern part of the Aral Sea region). Research by Tsvetsinskaya et al. (2002) suggests a direct relationship between the time at which farming irrigation land ceased and the current state of the landscape. Although post-irrigation desertification processes in Central Asia have been much researched (e.g., Minashina 1978), the authors provide local evidence of a direct link in which more ancient irrigated landscapes (from the 4th century BCE) evolved into takyr surfaces.

These data provide an indication of the role as a marker for some takyr surfaces in the northeastern Murghab region and their link to ancient arable and irrigated land. These aspects are further explored in Chapters 5 and 6.

2.3.4 Takyrs and Ancient Watercourses

As discussed above, takyr surfaces in the Murghab are generally characterized by sloping flat surfaces or depressions where runoff water can be retained for months and are used for agriculture (Fleskens et al. 2007). Their size can vary from a small takyr (0.5 km^2) to a very large one in western Karakum (>100 km^2) (Maman et al. 2011b). These shallow depressions usually take an ellipsoidal or circular form. However, takyr surfaces can also take other forms. In Central Asia, elongated and meandering takyr surfaces have been interpreted as evidence for ancient river channels. The "Khorezm Archaeological-Ethnographical Expedition" by Andrianov (1969) in the Aral Sea area, specifically targeted takyr surfaces for reconstructing ancient irrigation (see section 4.2.1 in Chapter 4). The linear traces, visible in the aerial photos, were interpreted as ancient watercourses and had cracked clay surfaces in linear shapes, sand dunes at their edge, and vegetation in the center (Andrianov 2016:89).

In southern Turkmenistan, the irrigation system of the Geoksyur Oasis, located east of the Tedjen River, has been dated to the Chalcolithic period. Also in this case, Lisitsina (1965:30–35) interpreted the elongated form of takyr surfaces as ancient watercourses and artificial canals. The excavation of such features revealed clear cross-section profiles of channels with a sequence of soil layers associated with ancient watercourses underneath a takyr layer of approximately 30 cm (see Lisitsina 1969:Fig. 4).

In the Murghab, a macro reconstruction of the hydrological system of the ancient alluvial plain only began in the 1990s by the AMMD (Cremaschi 1998; Cerasetti 2008). However, the nature of the takyrs and their association with ancient water channels in the Murghab remains elusive. Only limited investigations have been conducted on the takyr as traces of ancient water channels (Cerasetti 2008; Markofsky et al. 2017). Likewise, ancient watercourses in general, such as at Gonur-tepe and Chopantam, were both investigated by chance as part of the archaeological excavations but no systematic studies have been done (Sataev 2008; Cattani 2008a). In this context, the objective of this study is to delve deeper into the connection between takyr surfaces, ancient watercourses, and their location within the Murghab alluvial fan.

2.4 The Local Desert Environment

Turkmenistan, and in particular the Murghab alluvial fan, constitutes a unique ecosystem with a large biodiversity (Rustamov 1994). The modern flora and fauna can provide insights into the ancient landscape. The Karakum Desert constitutes the vast majority of modern Turkmenistan, and most of the vegetation in the lowlands consists of small semi-shrubs, shrub psammophyte, or sagebrush-halophyte communities (Orlovsky et al. 2004; Babaev 1994). Among the shrubs and small trees, the most remarkable is the saxaul (Figure 2.7), which includes the white saxaul (*Haloxylon persicum*) and the black saxaul (*Haloxylon aphyllum*).

Figure 2.7 The black saxaul (Haloxylon aphyllum) in the modern Murghab landscape. Evidence of saxaul has been found at Gonur North and was probably used as a fuel source.

Interestingly, black saxaul occurs in association with groundwater or surface water such as takyr soils or along water channels (Rustamov 1994: 94). Botanical remains from Gonur-tepe include saxaul (*Haloxylon* sp.) probably used as fuel, along with shrubby thistle (*Salsola* sp.), willow (*Salix* sp.), and tamarisk (*Tamarix* sp.) (Sataeva and Sataev 2014). The latter is still present in Turkmenistan and is particularly salt-tolerant, along with trees like *Populus euphratica* and *Populus pruinosa*. This *tugai*[16] vegetation, and in particular saxaul, was likely more widespread in antiquity and formed a source for fuel or building construction (Sataeva and Sataev 2014). However, the *tugai* coverage has been mostly depleted in the last decades in the wake of new agricultural expansion.

The fauna of Turkmenistan mainly consists of animals endemic to desert or semi-desert landscapes. Among the mammals, the most typical species that can be found in the sandy landscape are foxes (*Vulpes vulpes*), long-eared hedgehogs (*Hemiechinus auritus*), desert hares (*Lepus capensis*), and sand cats (*Felis margarita*). Wild sheep (*Ovis ammon*), gazelle (*Gazella subgutturosa*), and wild boar (*Sus serofa nigripes*) can also be found, including onager (*Equus onager*), although both onager and gazelle have been decimated in recent decades (Rustanov 2014b). Among the various reptiles endemic to the lowlands in Turkmenistan, the steppe tortoise (*Testudo horsfieldi*), also known as the Russian or Afghan tortoise, can be found in the Murghab in areas less disturbed by anthropogenic activities such as the Ojakly area (pers. observation). Interestingly, tortoises, together with gazelle, fox, and hare (*Lepus* cf. *tolai*), were found in the 2018 Togolok 1 faunal assemblage. These animals, endemic to the modern semi-desert Murghab environment, are an indicator of an increasingly dry climate at the end of the 3rd to early 2nd millennium BCE (Cerasetti et al. 2022). Similar finds are reported at the Bronze Age site of Gonur-tepe as well, further supporting this interpretation. The zooarchaeological analysis also reported the presence of wild boar, hare, small rodents, tortoise, and gazelle that were likely hunted at Gonur, although they are a minor component in the assemblage (> 5%) compared to domestic species (Moore et al. 1994; Sataev 2021a).

[16] The term *Tugai* refers to forest and riparian vegetation that is present in Central Asia along major rivers.

In addition to animal husbandry, fishing is also part of the modern Turkmen economy, although its economic importance is relatively low. With the ultimate construction of the Karakum Canal, however, new fish species have been introduced in the Murghab and the Tedjen alluvial fan. Fish might have been a minor part of the dietary economy during the Bronze Age as well. Indication of fish are provided by Adji Kui 1 finds, where small fish vertebrae have been identified belonging to the Nemacheilidae family (*Paracobitis* sp.), probably from a small fish variety such as sardine (Spengler et al. 2018). Interestingly, one of the fish bones was partially carbonized, suggesting that they were cooked as part of the diet. In addition to Adji Kui 1, fish bones have also been identified in the Togolok 1 assemblages, suggesting that limited fishing was possibly practiced by BMAC communities (Billing et al. 2022:Fig.10). Likewise, proxy zooarchaeological data from several areas of Eurasia further suggest that fish was part of the diet during the Bronze Age (O'Connell et al. 2003; Gayduchenko 2002).

2.5 Traditional Pastoralism and Irrigation Farming in the Murghab

In the 19th and early 20th centuries, most Turkmen were active both in animal husbandry and crop cultivation. These traditional agricultural practices can provide insights into past land and water management in the region.

Over the last two centuries, most of the tribes in the region were semi-sedentary, and only a few were fully nomadic livestock breeders (Ovezberdyev 1962). Before collectivisation of Turkmenistan and the nationalization of lands with the introduction of *sovkhoz* and *kolkhoz farms*, pastures, as well as routes, were divided among tribes (Emeljanenko 1994:42). The division by clans or tribes seems to have also existed for the irrigation system. O'Donovan, who visited the Merv Oasis in 1879–1881, informed us that watercourses were divided among the Turcoman clans (O'Donovan, 1882 II:193). The control of the irrigation system by local tribes, however, was over the main dams and canals only. For instance, O'Donovan reports that all the operations of the dam and main canals at Benti (one of the main dams of Merv Oasis at that time) were under the control of a local *Kethkoda*.[17] The village of Benti consisted of a group of houses along the canal and its inhabitants had to manage and maintain the dam and sluice (O'Donovan 1882 II:189).

Colonel Stewart, who visited Merv and Benti Dam during the same years as O'Donovan, report that, on the eastern side of the Murghab, the Beg and Wakil[18] were the persons who could decide first over the Murghab waters (Stewart 1881:541). In these historical sources, the power among the clans appears to have been horizontally rather than vertically distributed. According to Stewart, policies were discussed among the *Kethkodas*, who also had family rights over water management (Stewart 1881:542).

In Merv, at the time of the visit by Stewart, there were more than 24 *Kethkodas* who would unite and appoint a chief only in case of danger and for a limited time. Likewise, the organization of the irrigation system was not top-down management. It was performed and managed at the family level by local agents. For instance, while describing the everyday life of a Turcoman, O' Donovan (1882 II:189, 350) affirms that the younger members of the families were the ones in charge of digging the irrigation canals and taking care of the fields during the harvest season. The irrigation system of the Merv Oasis was managed by the local clans, while only the major dams were controlled by a regional authority. Similarly, in the neighboring Oasis of Bukhara (Uzbekistan) the control over the irrigation system was also performed by local tribes and only to a minor extent by the governor (*Emir*) (Schuyler 1876:305 in Lamberg-Karlovsky 2016).

O'Donovan also reports that in Merv canal management was not always efficient. While the canals in proximity of the oases were well maintained, irrigation systems in rural areas were not, and small – minor – canals shifted their courses quite often without proper maintenance (O'Donovan 1882 II:194). His report suggested that differences

[17] *Kethkoda* is a Persian word for a person who has judicial competence but is not part of state apparatus, and usually operates in a tribal context (Barendese 2009:1756).
[18] These are titles for a chief or representative person.

existed in levels of water management between the oasis core and marginal fields, and that the priority of the maintenance was for the canals in the center of the oases.

How the water was distributed in Merv is also described by earlier travellers. The 10th-century Arab geographer and writer Al-Istakhri described that in Merv, each district and street had artificial canals (called *little rivers* in the text) equipped with wooden sluices to fairly distribute water in the case of both increases and shortages of water (in Kennedy and Moore 1999:123). The distribution was efficient and fair. In charge of the distribution of water was an *Amir* (local officer).

Another Arab geographer, Al-Muqaddasī, who visited Merv during the same century, reports that watercourses far from the main city and in marginal areas were often poorly maintained (in Kennedy and Moore 1999:124). In contrast, recent investigations of the main water canal inside the Islamic city of Sultan Kala in the Merv Oasis confirmed that the canal was well maintained and constantly cleaned over a period of 470 years of activity, as its base had not accumulated any silt layers (Williams 2018). This suggests that control and management over the main dams and canals was probably well regulated in the oasis. In contrast, the maintenance of the peripheral irrigation systems by local agents was probably less systematic.

Several reports from travellers and historians report how famous the Merv Oasis was for its agricultural produce. For instance, the records of Du Huan, a Chinese traveller and officer who visited the Merv Oasis during the Tang dynasty (618–907 CE), inform us about the great varieties of fruits and vegetables that were cultivated at Merv. These include apples, red peaches, and grapes, but also onions, radishes, shallots, gourds, and melons (in Kennedy and Moore 1999:121). Likewise, the Arab geographer al-Istakhri reports that Merv produced the best quality dried fruits and melons. The melons, cut in strips and dried, were exported as far as Iraq. The export of melons, both fresh and dry, is also mentioned by Stewart (1881:532) in the 19th century. Together, these sources describe a well-structured agricultural system where, in addition to staple crops (wheat, barley, and rice), a good variety of garden fruits were also cultivated.

Besides crop cultivation, the second main economic activity in the Murghab was animal husbandry. However, Obzorv, who also visited the Caspian region at the end of the 19th century, reports that most of the Turkmen tribes were not real pastoral nomads, and crop cultivation was also practiced (Obzorv 1897:25–26 in Emeljanenko 1994:41).

Further away from the oases, however, pastures and farming were mainly dictated by the presence of wells. For instance, the Tekyns in the Akhal tribe area lived for most of the year around wells and moved only three times a year. Wells were usually constructed and managed by families who practically owned the wells. However, despite being "private," the use of the wells was free, provided that the users were able to take part in cleaning and repairing of the well on the basis of mutual aid customs (Emeljanenko 1994:43–44).

All in all, reports from medieval and more recent times suggest that traditional farming and pastoralism in the Murghab was part of a complex system in which local communities were involved in various mixtures of agropastoral activities and differences existed between oasis-based and more peripheral irrigation and crop cultivation.

2.6 Summary

The chapter presents an overview of modern Turkmenistan's physical and geographical settings, its climate, and the relevant modern fauna, some of which have also been found in the archaeological record and are indicative of a dry region from the 2nd millennium BCE onwards. Likewise, the general paleoclimate data from the Central Asia region discussed above also suggest a drier environment during the Bronze Age. However, the local impacts of climate change on the agricultural and water management system will be discussed in the next chapters. It is likely that changes in the geomorphology of the alluvial plain and climate over the 3rd and 2nd millennium BCE considerably impacted the fluvial regions and water discharge. As I will argue in the case study chapters, this had an effect on BMAC communities and their subsistence economy. In this context, the formation of takyr surfaces, their relation to former channels, and their use for crop cultivation and animal husbandry are of crucial importance in the BMAC context and will be further discussed in Chapters 5 and 6.

Finally, traditional pastoralism and the management of irrigation systems in the region during Islamic and more recent times offer crucial insights into landscape management in the region. Their relevance and implications will be further discussed in the conclusion chapter (Chapter 7). Having presented the problems and the aims of this research and the geographical and geological settings of the region in the first two chapters, in the next one, I will discuss the relevant archaeological context and the theoretical framework of the research.