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

Arciero, R.

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Chapter 4 – Methodology

4. Overview

Over the last years, a number of archaeological studies have systematically investigated water resources and ancient irrigation systems in the Near East and Central Asia (Adrianov 1969; Ur 2002; Wilkinson 2003; Jotheri and Allen 2020; Orengo and Petrie 20017; Kühne 2018). These studies often combine several techniques of archaeological research. Building upon these earlier approaches, this study investigates the hydrological and agricultural management of the Murghab region using three lines of investigation that will be further discussed in the next paragraphs.

First, the desk-based research consists of a remote study of the ancient channel distribution in the local areas of Togolok and Ojakly through satellite images, aerial photos, and maps using GIS tools and analysis.

Second, the field research aims to ground truth[28] the channel system, integrated with an intensive survey along the ancient river channels. The aim is to verify the channel properties and to gather additional data on the settlements and field systems situated along the watercourses. In addition, the survey aims to provide chronological data of the sites along the channels. Dating these sites provides alternative tools for estimating when these channels were active.

Third, more detailed research includes the investigation of the channel system with core cross-sections, test trenches, and OSL dating, as well as software modelling of selected channels, in order to gain additional information on possible water delivery systems.

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[28] The ground truthing evaluates the precision of remote sensing analysis with a comparison with on-site physical measurements gathered at ground level.

A further stage of analysis, not previously envisioned at the beginning of the project, emerged during the excavation of the site of Togolok 1 by the TAP team (*Togolok Archaeological Project*) (see Chapter 6). Selected archaeobotanical assemblages from both Middle and Late Bronze Age layers from Togolok 1 were made available by the TAP and selected for carbon isotope analysis ($\delta^{13}C$ and $\delta^{15}N$). This analysis will shed further light on different irrigation and manuring practices at Togolok during the Bronze Age.
Having introduced the general lines of investigation, I will now discuss the methodological approaches in more detail.

4.1 GIS Analysis

GIS (Geographic Information System) is now a pivotal instrument designed for the integration and acquisition of diverse spatial datasets, encompassing maps, land morphology, geophysical data, and archaeological plans. Its versatility lies in its capacity to assembling these varied sources, offering archaeologists a comprehensive platform for spatial data analysis.

Among its array of characteristics, GIS facilitates different types of analysis, allowing researchers to delve into intricate patterns and relationships within archaeological landscapes. By overlaying spatial data layers, scholars can unravel qualitative and quantitative data of human activities and environmental dynamics (Conolly and Lake 2006).

Over the last two decades, GIS has solidified its position as an indispensable tool in archaeological fieldwork and analysis. Its application spans from surveying to excavation planning, and post-excavation analysis. Using GIS software, archaeologists can effectively visualize, interpret, and communicate complex spatial information, and enrich our understanding of the collected data. GIS also allows us to visualize spatial data in innovative way that can foster additional research (Conolly and Lake 2006: 13). For instance, it can combine spatial data from different instruments such as satellite platforms, drones, total stations, GPS and D-GPS, which are crucial equipment during any modern archaeological fieldwork. The data obtained using these instruments can later be imported into GIS software, enabling various analyses. GIS software can be purchased (such as ArcGIS) or is available for free (such as QGIS). For this study, I utilized the free QGIS software, enabling a multi-layer analysis of satellite imagery, aerial photographs, and cartographic maps of the Murghab region as well as data from field survey. In the context of this thesis, GIS has been utilized to analyze two distinct aspects.

First, the integration of satellite images and cartographic maps into a GIS entailed importing them as raster data, thereby generating overlapping layers within the GIS system. This strategic layering facilitated the simultaneous visual analysis of the area, leveraging all available data sources. Such an approach streamlined and enabled a concurrent examination of preserved ancient channels, enhancing interpretation accuracy and expediting our knowledge about the past hydrological landscape (Orengo and Petrie 2017).

Second, GIS has been used for integrating all spatial data sources. Notably, all spatial data gathered by the AMMD have been merged into a unified GIS project. Furthermore, the data collected during the surveys conducted in Togolok and Ojakly areas have been seamlessly incorporated into the same GIS project. This strategic integration has paved the way for multifaceted spatial analyses of archaeological sites and preserved ancient channels, which will be extensively discussed in Chapters 5 and 6 of the thesis. Beyond data aggregation, the utilization of GIS has enabled a deeper understanding of the dynamics of human–water interactions during the transition period between the 3rd and 2nd millennium BCE. By analyzing the diverse spatial datasets within a GIS platform, one can gain better insights into the evolving patterns of settlement, environment, and water resources. Such insights have been instrumental in reconstructing and understanding the hydrological landscape and its land use.

4.2 Remote Sensing

4.2.1 A Short Introduction to Aerial Photo Interpretation and Remote Sensing

The idea of using remote sensing imagery in archaeology is not recent. Aerial photography has been a common technique to study ancient landscapes. One of the first pioneers of Central Asia, Sir Aurel Stein, had already realized the enormous potential of this technique at the beginning of the 20th century and how it can “greatly reduce the obstacles” of archaeological fieldwork (Stein 1921:3).

A boost in aerial photography in archaeology, however, took place during – and immediately after – World War I, among other times, with flights by Theodor Wiegand over Palestine, the aerial photos of Petra by Alexander Kennedy, and exploration of Mesopotamia, Transjordan, and Palestine by Crawford and Beazley (Crawford 1923; Kennedy 1925:15; Beazley 1920). Already in those years the potential of aerial photography for landscape archaeology was appreciated (Collier 1994). Aerial photos taken in 1932 of the floodplain near Tell el-Amarna in Egypt, for instance, revealed crop marks suggesting walls (Parcak 2009:16).

In Central Asia, as discussed in Chapter 3 (section 3.4.3), the Khorezm Archaeological-Ethnographic Expedition (KhAEE) was set up by S. P. Tolstov in 1937 (Tolstov 1952). It was the first archaeological expedition using a multidisciplinary approach in the region. Several specialists worked together, including geomorphologists, geologists, and geographers (Bolelov 2016:7). The use and interpretation of aerial photos proved to be crucial for the investigation of the Aral region and its hydrological system. This methodology was later adopted by Adrianov (2016) to specifically target and map ancient watercourses in the region.

The importance of aerial photography for archaeology was bolstered by the publication of *Ancient Landscapes* by John Bradford (Bradford 1957). However, while aerial photography was at its peak in the 1950s and 1960s, new revolutionary technologies were on the horizon. On the 4th of October 1957, the Soviet Union launched the first satellite, *Sputnik*. The event triggered a "space race" between the Soviet Union and the United States (Cadbury 2006). As remote sensing was evolving, it became evident to archaeologists that many sites correlated with landscape geomorphology. In particular, in the desert and semi-desert areas of Western and Central Asia, many sites were related to the available water resources (Adams 1981; Wilkinson 2003).

In the last decades, several types of satellite images have been used in archaeology, including CORONA, Landsat, SPOT, IKONOS, as well as ASTER[29] images. More recently, LIDAR[30] images have become popular, in particular in densely forested areas due to their ability to penetrate vegetation (e.g., Southern Europe and Central America) (von Schwerin et al. 2016; Masini et al. 2018). In West Asian archaeology, the use of satellite images, including declassified images such as CORONA, turned out to be crucial in many projects (e.g., Ur 2013).

Many survey projects have included satellite images. The availability of those satellite images is generally crucial in the initial stage of landscape projects – along with their costs. Images are often carefully selected based on their potential. For instance, in the Murghab, the relatively flat morphology of channels tracing the northern fringe cannot be well detected in digital elevation models. Despite providing good results for identifying larger ancient channels in the Murghab, ASTER GDEM images turned out to be less suitable for small and shallow paleochannels (Cerasetti and Maiuri 2002).

In addition to the appropriate images, other criteria, such as year and season of acquisition, need to be considered while selecting satellite images. The potential to have several images covering the same area to overcome visibility issues can be crucial (e.g., Orengo and Patrie 2017).

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[29] ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer.
[30] LIDAR: Light Detection and Ranging.

A number of satellites and aerial photos that could be expected to yield good data were selected for this study. In addition, a number of maps that provide data on anthropogenic features in the landscape were also incorporated into the analysis.

4.2.2 CORONA Images

The CORONA project started in 1958 with reconnaissance satellites operated by the Central Intelligence Agency. They were used for photographic surveillance of the former Soviet Union, the People’s Republic of China, and other parts of the globe, including West Asia. The aim was to acquire photographs of military interest. The former Soviet Union and West Asia were photographed many times over several years, only a few months apart. The photographs were black and white panchromatic pictures produced as negative film strips in stereo pairs (Hritz 2014). Each CORONA strip covers an area of roughly 20 by 80 km (Figure 4.1). The program operated with different cameras and resolution qualities that often depended on the condition of the landscape and the time they were acquired (Fowler 1996). Despite its use starting in the 1960s, the full archaeological impact of these images only became apparent in the mid-1990s.

Figure 4.1 Example of a CORONA image strip (Parcak 2009:53).

In 1995 the U.S. government decided to declassify the CORONA images and make them available for purchase. The images were available at a low cost compared to the multispectral satellite images at that moment. Today, the images can be purchased – among other things – from the USGS website[31] or downloaded for free on CORONA Atlas[32] (but only selected images and regions are available). Apart from their price – cheaper than many other satellite images – the high resolution of CORONA photographs triggered much archaeological research, especially in Western and Central Asian landscape archaeology. New panchromatic landscape images were now available, including the areas in which aerial photographs had not been accessible, difficult to obtain, or simply did not exist (Hritz 2014). Further, many CORONA images were taken before the development of modern settlements and agricultural expansion that have masked or destroyed much archaeological evidence in Western and Central Asia.

Despite good results obtained with CORONA images in West Asian archaeology (Beck at al. 2007a; Challis et al. 2002; Kennedy 1998; Philip at al. 2002; Pournelle 2007; Ur 2003), some limitations need to be taken into account. Analogue CORONA images are scanned and digitized, and they do not possess a spatial referencing system with which they can be uploaded into a Geographical Information System (GIS). This problem can be rectified by using software to georeference the photographs, such as ArcGIS, Qgis, or Global Mapper. However, when using panoramic cameras such as CORONA, distortions are inevitable and sometimes difficult to correct (Altmaier and Kany 2002:228; Sohn et al. 2004:53).

Five CORONA-KH4 (1963) strips acquired by the AMMD project in the late 90s cover almost the entire alluvial fan and were used in this study (Figure 4.2). In addition, one CORONA KH-4A (1964) strip was downloaded from CORONA Atlas (Corona@CAST)[33] that covers the Ojkaly area.

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[31] earthexplorer.usgs.gov (last accessed April 2024)

[32] corona.cast.uark.edu/ (last accessed April 2024)

[33] More information about the project can be found at the CORONA Atlas website. Images from the CORONA Atlas are automatically georectified once downloaded.

The AMMD team georeferenced the CORONA KH4 images, which do have significant distortions, however. Because of the strip format of CORONA images, coordinates are most precise at the center of the image. In addition, because of the gap in the time period between the CORONA images and the more recent satellite imagery, georeferencing using modern landmarks can be challenging (Altmaier and Kany 2002:27). Fortunately, in the case of Ojakly and Togolok, the areas are not located at the edges of the strips and do not have significant distortions.

A further great advantage of using CORONA images in Turkmenistan is the time they were captured. These images were taken before mechanized agriculture expanded during the 1980s and, as mentioned above, has hidden or destroyed many archaeological sites. This aspect makes the CORONA images of the Murghab especially useful for archaeological investigations of the landscape.

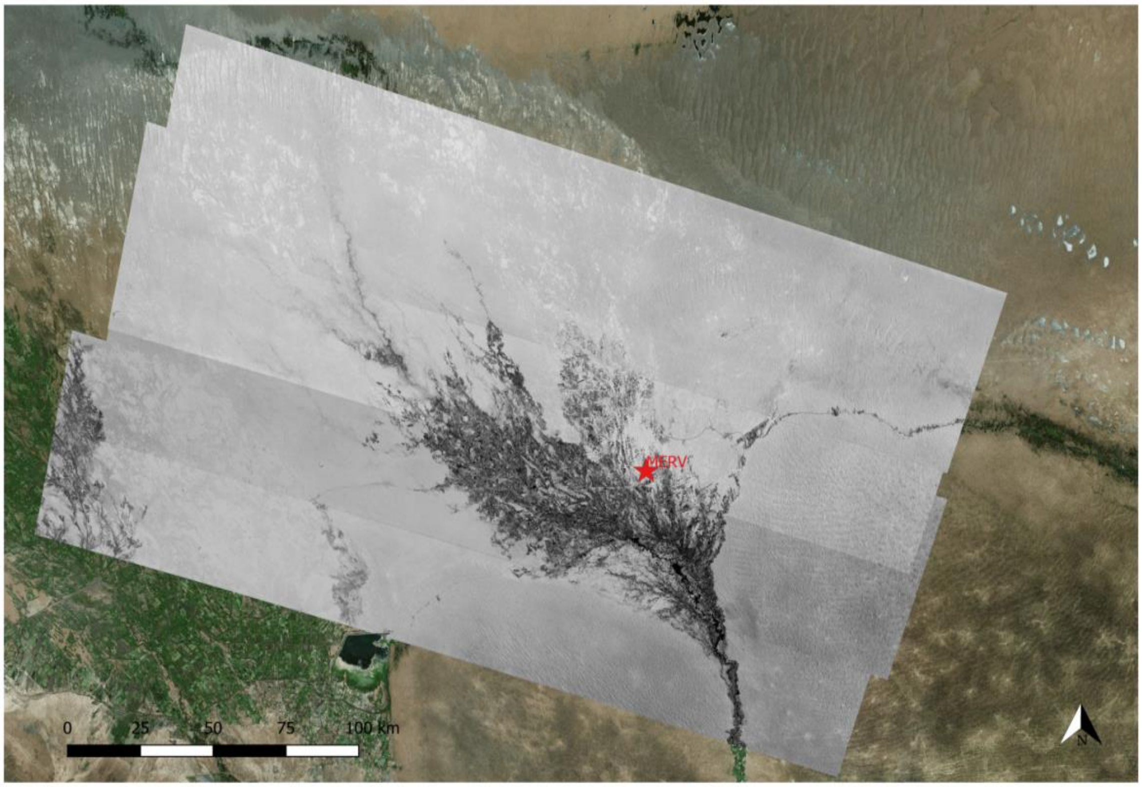

Figure 4.2 The image displays the four CORONA KH4 (1963) images (black and white panchromatic) covering the Murghab alluvial fan. It is evident that most of the region northeast of the ancient city of Merv was not cultivated during the 1960s and 1970s.

4.2.3 LANDSAT Images

The first NASA/USGS program for earth observation started in 1967, and the first Earth Resources Technology Satellite, better known as “Landsat,” was launched into orbit on the 23rd of July 1972. The program’s main goal was to acquire multispectral information on the Earth’s surface for scientific purposes. The project had a big impact on archaeological landscape research (Giardino 2011). The main advantage of Landsat satellite images was its free acquisition of processed images along with multiple copies of satellite images available for one single area. The Landsat program is still operating with Landsat 8, and the latest Landsat 9 launched on the 27th of September 27th 2021.

For the present project, several Landsat images were downloaded from the USGS website that cover the Murghab alluvial fan with various resolutions. In particular, Landsat 5 (MSS) (1989), Landsat 7 ETM+ (*Enhanced Thematic Mapper Plus*) (2001), and Landsat 8 (2019) have been used for the detection of ancient channels as they cover the entire Murghab fan and turned out to be crucial in the verification process. Although most of the Landsat bands do not provide adequate ground resolution for site identification, they proved to be effective for identifying the main channel traces in both the Togolok and Ojakly areas.

4.2.4 Sentinel Images

Sentinel images are part of the Copernicus Programme from the European Union. The program provides high-quality and continuous earth images. The program, which began in 2014 with the first launch, aims to operate over several years and involves the launch of numerous satellites which will cover different aspects of earth monitoring, such as climate change, land use, and vegetation.[34]

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[34] Details on the earth monitoring services provided by the Sentinel program can be found at copernicus.eu/en (last accessed April 2024)

The Sentinel 2 program was specifically designed for land monitoring, with Sentinel 2A launched on the 23rd of June 2015, and Sentinel 2B launched on the 7th of March 2017. Like with Landsat images, one of the main advantages of using Sentinel images in archaeology is its free availability. Sentinel images are free of charge and can be downloaded from the dedicated ESA website[35] or using QGis; the *Semi-Automatic Plugin Classification* can be used to download Sentinel images (including Landsat and ASTER). Depending on the bands, Sentinel 2 can range between 10 and 60 m resolution on the ground. A further advantage of Sentinel images also derives from its land monitoring program, which combines hundreds of images for the same area. In fact, Sentinel images cover the same region approximately every five days. As a result, by selecting one specific season and region, the user is able to obtain several images (up to six images per month) and up to approximately 72 images for a single year, which forms a considerable database for monitoring and protecting archaeological heritage (Abate and Lasaponara 2019; Khalaf and Insol 2019). In addition, recent projects in Upper Mesopotamia, such as that by Kalayci et al. (2019), have successfully analyzed the spectral signature of ground futures, such as hollow ways, using Sentinel images.

Sentinel 1 and 2 ground resolution for the Murghab region, however, is up to 10 m only for selected bands, making these images less helpful for paleochannel recognition. As a result, Sentinel 2A (2018) images downloaded for this project have only been used for fieldwork preparation and have been useful mainly to select areas not currently under modern cultivation.

4.2.5 Aerial Photos

In the late 1990s and early 2000s, the AMMD project acquired aerial photos that cover large parts of the Murghab alluvial fan. The panchromatic aerial photos were captured during the 1950s with an average scale of 1:25,000 and high ground resolution of approximately half a meter (Marcolongo e Mozzi 1998: 8). They provide useful landscape information on remote areas, such as Ojakly, which was partially untouched by

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[35] See https://dataspace.copernicus.eu/ (last accessed April 2024)

agricultural exploitation at that time. Each photo is part of a series with a specific number (Figure 4.3).

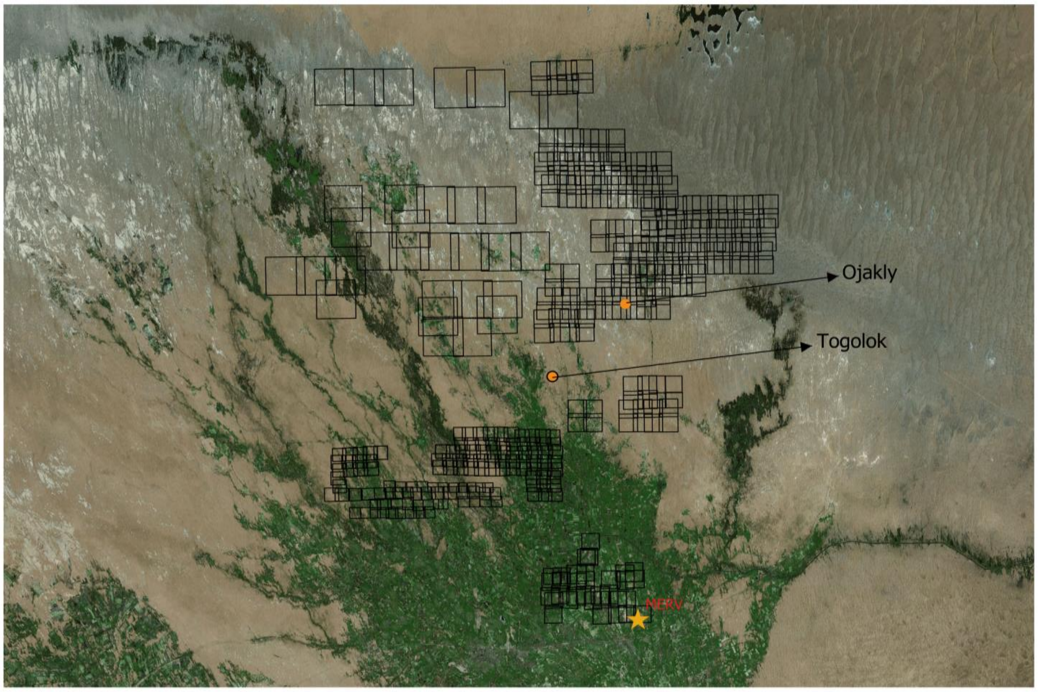

Figure 4.3 The image shows the distribution of the Aerial photos in the Murghab (black square) acquired by the AMMD team. The site of Togolok is not covered by the aerial photos.

The progressive numbers of the photos suggest that the Soviet flights had east-to-west and west-to-east directions. Every single aerial photo covers an area of approximately 98 km^2 and is labeled with a specific serial number (Figure 4.4). Although the aerial photos by the USSR likely covered the entire Murghab region, not all the serial numbers were acquired by the AMMD project. As a result, the area of Togolok is not covered by the aerial photos, while the area of Ojakly is covered by the B532 series that have been used in this study (Figure 4.3). As with CORONA images, the georeferencing process of aerial photos can be difficult. While the Landsat images are automatically georeferenced when downloaded from the USGS website, the CORONA images are manually georeferenced. Ground control points present in CORONA images are also crucial for georeferencing aerial photos from the Murghab. In fact, in the remote areas of the Murghab alluvial fan, the most reliable ground control points are constituted by the large takyrs that are present in both Aerial and CORONA images. For the present project, several aerial photos were georeferenced by the author using both CORONA and Landsat images.

Despite their great value, aerial photograph have some limitations. Importing old aerial photographs into GIS platforms can be time-consuming and scanning the images can potentially lead to a lower image quality. Acquiring and producing new digital aerial photos over large areas can be expensive as well. However, aerial photographs can be very informative. Many examples in the last two decades can be found in Italy (Campana et al. 2006), the UK (Halkon 2006), and France (Bezori et al. 2002). In West Asia, for instance in Jordan, extensive aerial reconnaissance photography for archaeological purposes has taken place for decades (Kennedy et al. 2011; Bewley and Kennedy 2013).

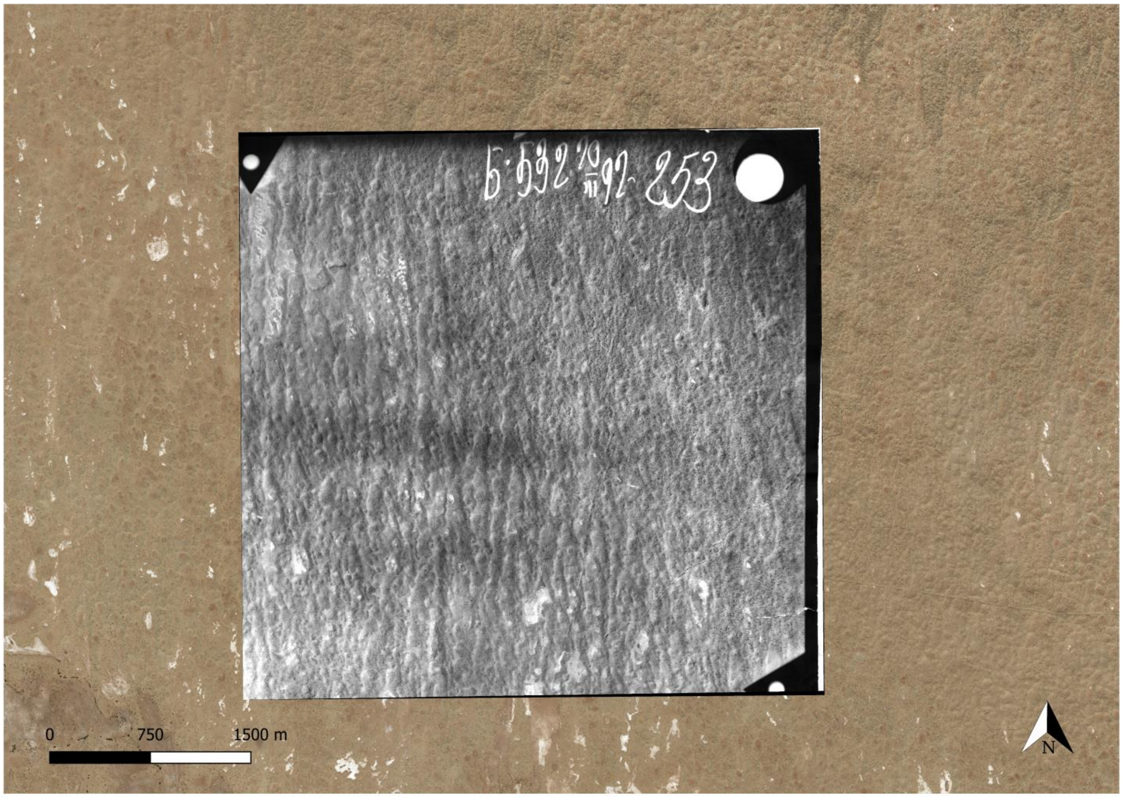

Figure 4.4 Example of an aerial photo with a size of ca. 98 km2 and a scale of scale of 1:25,000.

Recently, in the Murghab region, new aerial photos have been produced using a fixed-wing UAV within the “Merv project,” which aims to study the Islamic city of Merv and its water system (Williams 2012:2018).

During the 2017 field campaign of the PAM project (*Project for the Ancient Murghab*) aerial photos of the Togolok and Ojakly areas were produced using a MAVIC-pro drone as part of a pilot project in the region (Olson and Rouse 2018). Although these aerial photos have not been used for paleochannel identification in the present study, as they cover a limited area, their detailed scale facilitated the ground truthing of takyr channel surfaces and were used for identifying possible limits of paleochannels.

4.2.6 Cartography

Projects aiming to detect archaeological evidence have mainly adopted satellite-based investigations in recent years. However, although not often examined, cartographic maps can provide useful additional information (Hritz 2010). In channel identification, cartographic maps can offer crucial clues for better interpreting the landscape. Thus, integrating maps within a GIS-based approach can lead to a better interpretation of possible archaeological features.

In the case of the Murghab region, modern canals and off-roads, often reported on maps, helps to distinguish ancient features from more modern ones. Until the 1980s, the arid landscape northeast of the ancient city of Merv was characterized by the presence of water reservoirs, locally known as ‘*khak*’ (Figure 4.5). As discussed in Chapter 2 (section 2.3.2), these reservoirs formed key resources for irrigation and animal husbandry in the past and were often connected to artificial canals bringing water to the fields (Fleskens et al. 2007). Yet, most of these recent canals ran dry in the last 25 years and can easily be misinterpreted as ancient canals in satellite analysis.

In the 1990s, the AMMD team acquired numerous soviet maps of Turkmenistan at different scales ranging from 1:10,000 to 1:1,000,000. These maps were georeferenced and have been used in the Togolok and Ojakly areas as additional data for reconstruction and interpretation of the ancient hydrological system.[36]

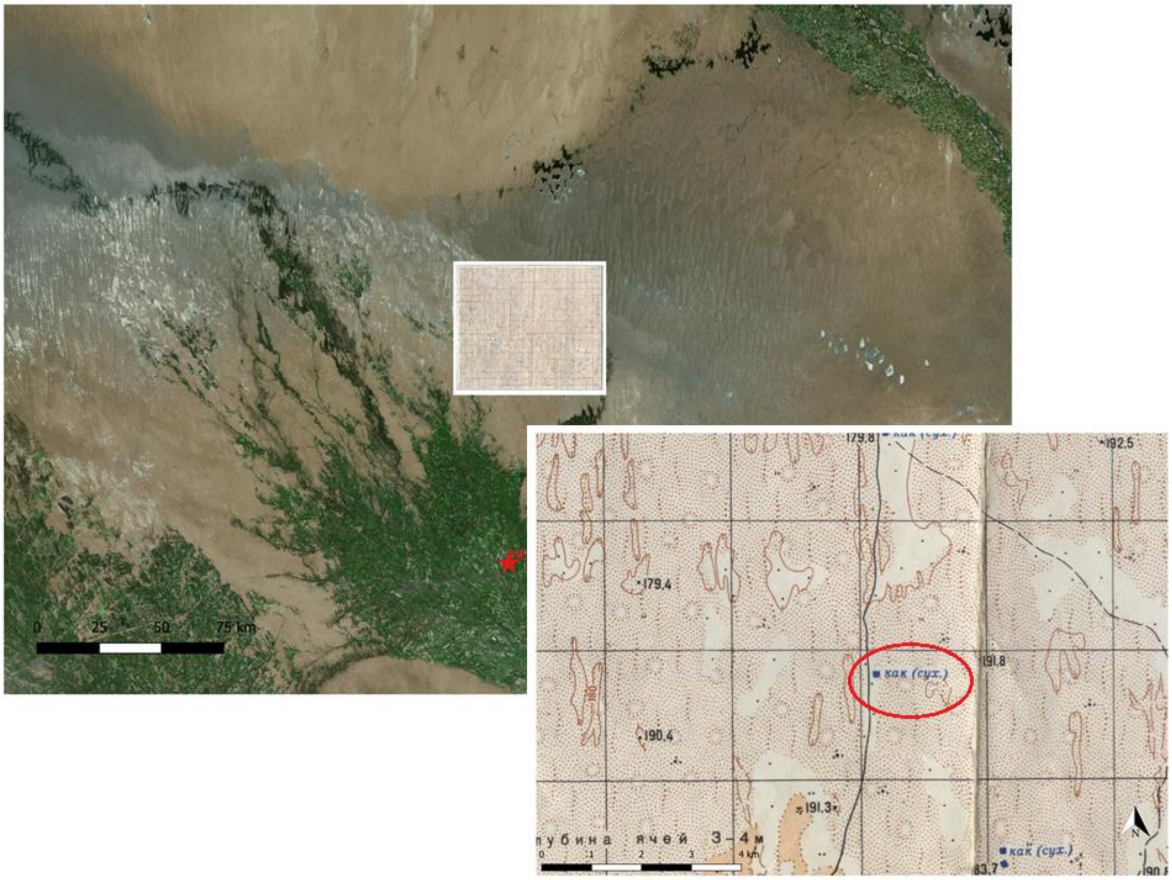

Figure 4.5 Cartographic map, scale 1:100,000. The red circle indicates the location of a "khak."

4.2.7 Image Analysis and Interpretation

The analysis and the interpretation of channels in the areas of Togolok and Ojakly has been carried out with an integrated approach into the GIS environment combining satellite images, aerial photos, and cartographic maps. Previous reconstructions in West Asia and elsewhere have likewise applied methods such as visual analysis and satellite images to reconstruct and map paleo-rivers (e.g., Ur 2005; Rayne and Donoghue 2018).

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[36] The interpretation and the reading of the maps and their symbols have been facilitated by using "Soviet Topographic Maps Symbols TM 30-548" from the U.S. Army Department.

However, the selection of specific analysis is always bounded to the characteristics of the research area. Considerable anthropogenic activities or thick vegetation might cover ancient watercourses. The analysis, interpretation, and detection of channel traces (more often a single channel trace) needs to take into account the visibility of the past hydrological systems. For instance, a methodological approach using single multispectral satellite analysis, including LIDAR images, has been applied in environments with consistent anthropogenic activity and vegetation coverage (Salvini et al. 2006; Wang et al. 2012). Likewise, a recent archaeological project carried out in northwest India integrated a multi-temporal and seasonal approach using Landsat 5 images over a period of 28 years, to filter out more recent use of the landscape for agriculture (Orengo and Petrie 2017).

Despite potential problems, arid landscapes can yield good results of preserved ancient hydrological segments. In the last decades, projects using satellite images, including SRTM images, have successfully reconstructed paleochannels in desert or semi-desert areas (e.g., Hritz and Wilkinson 2006; Hritz 2010; Jotheri and Allen 2020; Hu et al. 2017) and distinguished between artificial canals and natural channels (Jotheri 2018).

The analysis and the reconstruction of the ancient channel system in the areas of Togolok and Ojakly has been done through visual interpretation. This is often a crucial step in any analysis involving satellite images or aerial photos; the interpreter has to define specific characteristics that support the identification of an archaeological feature, such as a mound or, in this case, ancient water channels. Single or multiple classes of objects are identified which form the basis of the analysis, including, in some cases, the automated detection of objects. In automated object detection, the targeted objects have specific visual, geometrical, and spectral characteristics, which can be used to generate a series of algorithms (e.g., Beck et al. 2007b; Da Pelo and D’Orazio 2013). Considering that in satellite images objects have diverse properties, the rules that need to be established by the algorithms might vary greatly, and “writing” a successful algorithm can be time-consuming (Orengo and Petrie 2017). Likewise, automated detection needs a training area for testing the algorithms, and in which previous field surveys have already established the position of a large number of archaeological sites. The positive objects generated by the algorithm (understood as archaeological evidence) can be tested against the false positives based on previous field observations. In the case of paleochannels, considering the high irregularity of channel traces, along with their variables tones, shape, orientation, and relative size, visual interpretation was the most effective and the least time-consuming detection method for both the Togolok and the Ojakly areas considering their size.

As discussed previously, the visual interpretation was conducted within a multilayer approach of all available remote data. In this case a GIS-based analysis was crucial in this study. Initially, each identified paleochannel trace was assigned a code in Roman numerals (e.g., Ch_IV).[37] Subsequently, all paleochannel traces were analyzed to ascertain potential connections. When multiple traces were deemed to be part of the same paleochannel, a new code number in Arabic numerals was assigned to these traces (e.g., Paleochannel 2). Consequently, a channel number could comprise more than one channel trace (see Appendices).

- Interpretation

The visual analysis of features in satellite images usually involves several characteristics. The features can be classified by their texture, tone or color, pattern, size, and shadows (Joseph 2005; Lillesand et al. 2008; Lasaponara and Masini 2012). Jotheri and Allen (2017) have applied a similar approach for recognizing ancient channels in Mesopotamia using various satellite images, including CORONA. A similar approach has been used for the present research as well.

The modern alluvial fan channel network in the Murghab region presents two major channel categories: the main channels, often more than 10 m in width, and second-level branch channels (often 5 to 8 m in width) connected to the main channel. The

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[37] Prior to the channel number, a prefix code indicating either Ojakly (OJK) or Togolok 1 (TGK1) was included (e.g., TGK1_ChIV).

northeastern area of the Murghab, now an arid landscape, seems to present a similar channel structure in the past detected by satellite images. However, while traces of the main ancient channels are easy to identify on satellite and aerial photos, as they survive in the form of takyr surfaces (see below), secondary channels or artificial canals of less than 5 m in width have hardly been identified so far.

In the present analyses, several characteristics have been combined for recognizing paleochannels[38], and these form the basis of the analysis in the Togolok and Ojakly areas. These characteristics are:

Size – The ancient channels range between 5 to 25 m in width. Similar features – such as off-road paths – which are usually between 2 and 5 m in width in the Murghab, can be interpreted as modern features due to their more narrow widths. However, small channels or artificial canals can sometimes have a width similar to off-road paths which can complicate their reconstruction.

Direction – Direction is a crucial element to consider while analyzing the images. The channels identified by the satellite images have a general north/northwest direction. The modern expansion of agriculture has massively affected the Murghab region in the last three decades. The high temperature, and the relatively shallow depth of modern canals that bring water to the fields have resulted in the fast abandonment of many modern channels in the northeast areas of the Murghab. Yet, their becoming inactive and slow dune movement have generated old traces of modern canals that could be misinterpreted as ancient channels during the analysis. However, very often, modern canals in the Murghab have linear directions that do not follow the gradient of the landscape. In contrast, ancient channels follow the natural landscape gradient. In the Murghab, almost all linear features that have an east–west direction can be considered modern features.

Shape – Shape is an important parameter in visual interpretation and refers to the form of the channels. A meandering shape suggests the presence of a watercourse of a natural

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[38] These characteristics have been outlined and successfully applied by Jotheri (2016)

origin. However, an alluvial fan can also include channels with a limited meander. In contrast, extremely straight lines can be associated with man-made channels (or pipelines). Unmanaged artificial canals, however, can also acquire a meandering form within some years, complicating the distinction between natural and artificial watercourses.

Sediments – One of the most effective characteristics for identifying channels in the northeastern area of the Murghab alluvial fan are the takyr surfaces discussed in Chapter 3. The takyr is a polygonally cracked surface, often characterized by an irregular shape. In addition, it can be distinguished from its surrounding area as it often has very little vegetation on it (Fleskens et al. 2007). Takyrs can form naturally in the Murghab, and they are usually formed in drainage areas in an ovoid shape similar to playas or salt flats in the United States or sabkha in West Asia (see section 2.3.1 in Chapter 2). However, when they occur in elongated or meandering forms, they often represent a part of old dried channels (Gerasimov 1978).

Tone – Takyr surface have a specific tone (or color) in panchromatic images, such as CORONA and aerial photos. The elongated features commonly associated with channel traces have a light or color compared to the darker color elsewhere. Likewise, in panchromatic images, the elongated dunes have a darker color, which is absent on the takyr surfaces. As such, light reflectance and color can point to old watercourses.

An additional parameter often mentioned in the visual interpretations is *association*. This concerns features that occur in proximity or in association with our targeted objects (Lasaponara and Masini 2012). In site detection, several features can be associated with archaeological sites, depending on the landscape, that constitute proximity objects for visual interpretation. In the case of paleochannels, several features can be seen in proximity to watercourses. In the Murghab, green vegetation that occurs along linear or meandering features are a good indicator for ancient channels. Recently inactive channels are still able to retain water along their former banks. These features thus stand out through linear bands of vegetation. Ancient channels can sometimes become active again by modern canals and are subsequently abandoned after a few years. Due to becoming active again, these meandering channels can have green vegetation along both sides of the former watercourse, clearly distinguishable on satellite images. In this case, comparative analysis made on the GIS platform of older and new images, such as CORONA and updated SENTINEL images, is crucial in separating older channels that have started flowing again from more recent ones.

A further element on the basis of remote sensing analysis is the distinction between natural channels and canals. In this thesis I refer to channels for natural watercourses, while canals are meant for artificial features. Jotheri (2018) recently delineated fundamental characteristics useful for distinguishing between natural and artificial watercourses. While part of this analysis relies on geoarchaeological analyses, like test trenching and coring, which were not conducted in our research for all identified paleochannels, other aspects remain relevant for differentiation. As previously discussed, direction and morphology serve as pivotal factors for discerning based on satellite imagery. Canals often exhibit unnatural orientations, such as east to west in the Murghab region, indicative of artificial watercourses. Additionally, they typically display linear configurations and are unlikely to manifest meandering patterns. These attributes offer valuable clues for discriminating between channels and canals at the remote sensing level.

4.3 Field Work

4.3.1 A Short Introduction to The History of Investigating Ancient Channels

Remote sensing and GIS analysis can provide the first identification of an ancient river system. However, survey of these features and their associated archaeological sites is crucial for a correct reconstruction of ancient farming systems. A survey’s aim is to ground truth paleochannel traces to verify their presence and acquire key characteristics of the landscape. This method has been extensively used in West Asia since the mid-1960s.

The publication of *Heartland of Cities* by Adams (1981) marked a milestone in the research done between the 1960s and 1980s on irrigation and fluvial systems in West Asia. For instance, research by Jacobsen (1960) suggested that the Tigris shifted its course in the 5th and 3rd millennia BCE. Seminal works by Adrianov (1969) and Lisitsina (1969) in Central Asia marked an equally significant turning point in our understanding of the relationship between hydrological systems and settlement patterns. Moreover, the link between the irrigation system and the Bronze Age Tazabagyab settlements in the Aral area, studied by Adrianov, provides crucial proxy data for understanding the possible management of water resources by Andronovo (ICW) pottery sites in the Murghab, that will be further discussed in Chapter 7.

In Mesopotamia, the works by Adams truly influenced the investigation of the landscape by Wilkinson (2003: XIII). Wilkinson's work focused on the "development of the cultural landscape and its features in light of the physical, cultural, and historical context" (Wilkinson 2003:11). The landscape was investigated as a component formed by several elements, the study of which would disclose the social and economic layout of ancient societies. The analysis of Mesopotamian landscapes, their irrigation, and agricultural systems were examined with a multidisciplinary approach that included the site survey, off-site archaeology, and satellite and aerial image investigation, along with geomorphological investigation of channels. This growth of new research projects in Mesopotamia led Wilkinson to found the *Center for Ancient Middle Eastern Landscapes* (CAMEL) at the Oriental Institute in Chicago in the 1990s (Gibson 2020:3). The new center gave a boost to the discipline with new landscape-scale research projects with innovative approaches and served as a training center for a new generation of scholars.

In addition to archaeological research, investigation into textual sources from Mesopotamia led to a better understanding of the management of water resources (Rost 2015; 2017). In the early 2000s, works such as that by Steinkeller (2001) have effectively described the functions and location of irrigation networks based on the Ur III period texts from Umma. More recently, archaeological investigations by various authors have boosted research of irrigation systems in the Mesopotamian landscape. Investigations from Ur (2003; 2005) and Hritz (2014), for instance, integrated past survey data with newly identified sites and paleochannel systems with the use of declassified satellite images (e.g., CORONA) and digital elevation models (DEM). Likewise, more recent geoarchaeological investigations, such as by Yacoub (2011) and Jotheri et al. (2018), effectively use a multidisciplinary approach in the study of past hydrological systems in Mesopotamia. Those studies have effectively built a well-defined methodology that will be later discussed in the present chapter.

4.3.2 Previous and Current Survey Projects of the Murghab Region

The archaeological and topographical exploration of the ancient city of Merv in the Murghab region began in 1946 with the establishment of the YuTAKE (*South Turkmenistan Archaeological Complex Expedition*). From 1950 onwards, the YuTAKE team led by V. M. Masson concentrated their studies on the settlements along the Kopet-Dag Mountains (southern Turkmenistan) (Tosi and Cerasetti 2010). The exploration of the Murghab region intensified throughout the 1960s and 1970s, while the most important discovery occurred in 1972 with the identification of Gonur-tepe (Sarianidi 1981). The surveys in the Murghab region by Soviet scholars comprised an area of more than 5,000 km^2 until the 1980s and was mainly devoted to the identification and investigation of mounds sites, such as Kelleli, Togolok 1, and Togolok 21 (Hiebert 1994).

In the 1980s, the Institute of Archaeology of the USSR Academy of Science began to investigate more areas of the central and northern–eastern sector of the Murghab alluvial fan (Gubaev et al. 1998:201–267). However, one of the most crucial limitations of these surveys was the research method and the relatively limited interest in a multidisciplinary investigation (see Chapter 3). Towards the end of the 1980s, and with the collapse of the Soviet Union, Western teams started their collaborative investigations in the region.

In 1989, the first scientific protocol between the Institute of Archaeology of the USSR Academy of Sciences and the Italian team from IsMEO (*Istituto Italiano per il Medio ed Estremo Oriente*) was signed. This protocol eventually led to the establishment of the AMMD project (*Archaeological Map of Murghab Delta Project*) between Italian and Turkmen colleagues. The AMMD project started a multidisciplinary investigation of the northeastern part of the Murghab alluvial fan with intensive surveys and geomorphological investigation. The flat region was divided into two sectors and explored mainly by a walking transect survey and by helicopter for aerial photos (Tosi and Cerasetti 2010). The first preliminary archaeological map of the region was completed in the mid-1990s (Gubaev et al. 1998) and integrated with new investigations and archaeological excavations in the mid-2000s (Salvatori at al. 2008). The survey in the 1990s and 2000s led to the identification of hundreds of new sites dated from the Bronze Age to the Sasanian and Islamic periods. The sites were mainly dated based on the pottery assemblages and their types were categorized based on three aspects that will be further discussed in section 4.3.4. The AMMD project also fostered investigation into the early hydrological and water channel system of the Murghab, providing the first radiocarbon dating of ancient channels (Cremaschi 1998), along with the first macro-scale reconstruction of the main ancient watercourses of the alluvial fan (Cerasetti 2008). The AMMD project ended in 2013 while in 2014, the new joint project (TAP - *Togolok Archaeological Project*)[39] started to excavate the large mound of Togolok 1 (Cerasetti et al. 2019; 2022). Meanwhile, other teams from Switzerland started a collaborative project at Gonur,[40] while a new Russian team continued the excavation at same site.[41]

Building upon the previous survey projects, the recent PAM project (*Project for the Ancient Murghab*) started in 2016[42] and aims to investigate the intra-sites relationship in specific micro-regions of the Murghab, including that of Togolok. The project wants to integrate past survey data with additional data from further surveys, using drone

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[39] The TAP (*Togolok Archaeological Project*) is directed by Dr. B. Cerasetti from ISMEO (*Associazione Internazionale di Studi sul Mediterraneo e l'Oriente*) and FU-Berlin.

[40] The Swiss project, directed by Prof. M. Novák, started a new excavation project at Gonur.

[41] The Russian team is directed by Prof. N. Dubova from the Russian Academy of Science-Moscow.

[42] The PAM project (*Project for the Ancient Murghab*) is directed by Dr. L. M. Rouse from Washington University in Saint Louis and the German Archaeological Institute.

platforms and pedestrian surveys to better define the under-researched relationship between sites and intra-sites (Olson and Rouse 2018). Likewise, the project wants to integrate a detailed investigation of the geomorphology of selected areas of the Murghab, along with several targeted investigations, such as palynological analysis, that can contribute to disentangling the human–environmental relationship in the Murghab during the Bronze and Iron Ages.

4.3.3 Pottery Clusters: What Do They Represent?

The identification of archaeological sites across the Murghab landscape and their relative chronology was established from the surface spreads of archaeological material and mound formation. The majority of the sites in the region (c. 70–80%) have shallow deposits less than 1 m deep (Cattani et al. 2008:41) with materials from a single period on the surface. However, the interpretation of surface concentrations can be problematic.

How to interpret surface concentrations remains difficult, and sparks the question of to what extent surface scatters represent settlements or the result of post-depositional processes (Bintliff and Snodgrass 1988; Taylor 1973; Taylor 2000). For instance, the distribution over several kilometers of low-density abraded pottery in Mesopotamia has been interpreted by Wilkinson (1982) as the result of manuring practices. There, settlement-derived debris was spread as manure around settlements in agricultural fields to increase crop productivity (Wilkinson et al. 2004). In one of his recent papers, Wilkinson attempts to differentiate between pottery concentrations that signify the remnants of houses or local farmsteads, and small abraded pieces of pottery within extensive scatters areas that might support the general interpretation of manuring practice (Wilkinson 2014). In this context, Wilkinson attempted to distinguish between "site" and "manuring" assemblages in the Murghab on the basis of comparative data from the Balikh Valley. In this case, he distinguishes between raised areas and lower areas. The "raised areas (with high scatter densities) above lower ground (with sparse scatters) are likely to indicate in situ habitation." In contrast, "where lower areas are associated with moderate to high scatter densities [and] are adjacent to raised areas with low-density scatters, these probably relate to manuring” (Wilkinson 2014). Certainly, the vast quantity of sherds that Wilkinson found around sites such as Sohar in Oman and Tell Sweyhat in Syria, that gradually decrease in density away from the sites, can be potentially attributed to manuring (Wilkinson 1982). A similar picture has been described by Cleziou (et al. 1998) for the site of Togolok 1 that will be discussed in Chapter 6. Besides manuring, several natural as well as anthropogenic factors might affect distributions in the region, including research strategies and post-depositional processes (Wilkinson and Tucker 1995:17; Banning 2002:72; Ur 2002). The first factor that might obscure the visibility of the archaeological materials is shifting sands. Aeolian deposits might completely cover surface assemblages or channel traces.

However, in the Murghab it is unlikely that mounds would be completely covered. A second factor in a former fan environment is alluvial deposition. The accumulation of alluvial sediments contributed to masking archaeological evidence (Cremaschi 1998; Salvatori and Tosi 2008). According to Tosi and Cerasetti (2010), alluvial and aeolian deposits in the northern area of the Murghab might cover more than 60% of the landscape. In addition, the alluvial deposits in the south of the alluvial fan might explain the scarcity of Middle Bronze Age sites which are possibly buried under 4 to 6 m of deposits (Bondioli and Tosi 1998). Although Togolok and Ojakly are located in the central and distal areas of the fan, and were less affected by alluvial deposits, part of the archaeological evidence and channel traces might have been obscured as well.

Natural elements, however, are not the only factors that influence pottery visibility. A third factor is agriculture. The recent agricultural expansion in the Murghab, as in other areas of West Asia, strongly hampers site detection and preservation (Rouse and Cerasetti 2018:Fig.3). Although quantitative and risk assessment analysis of site destruction has never been attempted for the Murghab region (e.g., Zaina 2019), the fast expansion of mechanical excavators in the Murghab is evident from satellite images from the last decades. Although mechanized agriculture did not significantly affect the large mounds, such as Togolok 1, ploughing has led to the destruction of many flat sites and features in the region.

In addition to site visibility and site destruction, additional elements might bias our understanding of the past landscape. Archaeological materials present on the surface, such as pottery, are subject to erosion and aeolian deflation. As such, transport, transformation, and in some cases destruction of the deposit, can alter and create *false* patterns (Foley 1981: 162–63; Sabori et al. 2018). In parts of the southern Levant, for instance, sediments from hilltops were eroded, resulting in the concentration of sediment downslopes covering archaeological material or in the exposure of architectural remains on top of the mounds (Banning 2002:72). In the Murghab, aeolian deflation – particularly in the winter periods – may be responsible for the redeposition of archaeological materials or *mixing* of materials from different periods of occupation. Moreover, analysis by Markofsky and Bevan (2012) on directional influences and spatial autocorrelation of pottery material in the Egri Bogaz area, suggests that watercourses may have influenced the distribution of surface pottery assemblages.

4.3.4 The Definition and Categorization of "Site"

As mentioned in the previous section, the definition of a *site* is problematic, and it is often not clear how to define a site on the ground. Certainly, the identification and definition of a *site* in the Murghab (and in Western and Central Asia) is straightforward when applied to large mounds that represent stratified deposits (e.g., Togolok 1). However, the definition and identification of a site has become less straightforward when dealing with artifact clusters (mainly small or larger concentrations of pottery). The definition of a *site* in these cases can be context-dependent and ambiguous. In this project, a considerable surface scatter of materials (at least 25m^2) is defined as a *site* and "is regarded as a locus of concentrated human activity" (Wilkison et al. 2004). As such, smaller surface clusters or isolated finds have not been considered nor registered during the survey (see below for methodology).

The categorization of sites for the present project follows that adopted by the AMMD project between 1990 and 2008 (see below) (Bondioli and Tosi 1998; Cattani et al. 2008).

Likewise, site numbering follows the AMMD sequence, as a new register of sites would have created confusion. The data generated by this study have also been integrated with the site data from the previous AMMD survey (Gubaev et al. 1998; Salvatori et al. 2008) along with the sites recorded in Soviet surveys in the areas of Togolok and Ojakly. A publication by Sarianidi (1990a) shows an overview of sites recorded by YuTAKE team in the Murghab, although these data are often fragmentary and not well published, and they lack raw data. Between 1994 and 2005, the AMMD surveyed large areas of the Murghab alluvial fan (Clezious et al. 1998:26–34; Cattani and Salvatori 2008:1–27) (Figure 4.6). The first surveys in the 1990s concentrated in the southern part of the alluvial fan in the area of Togolok.

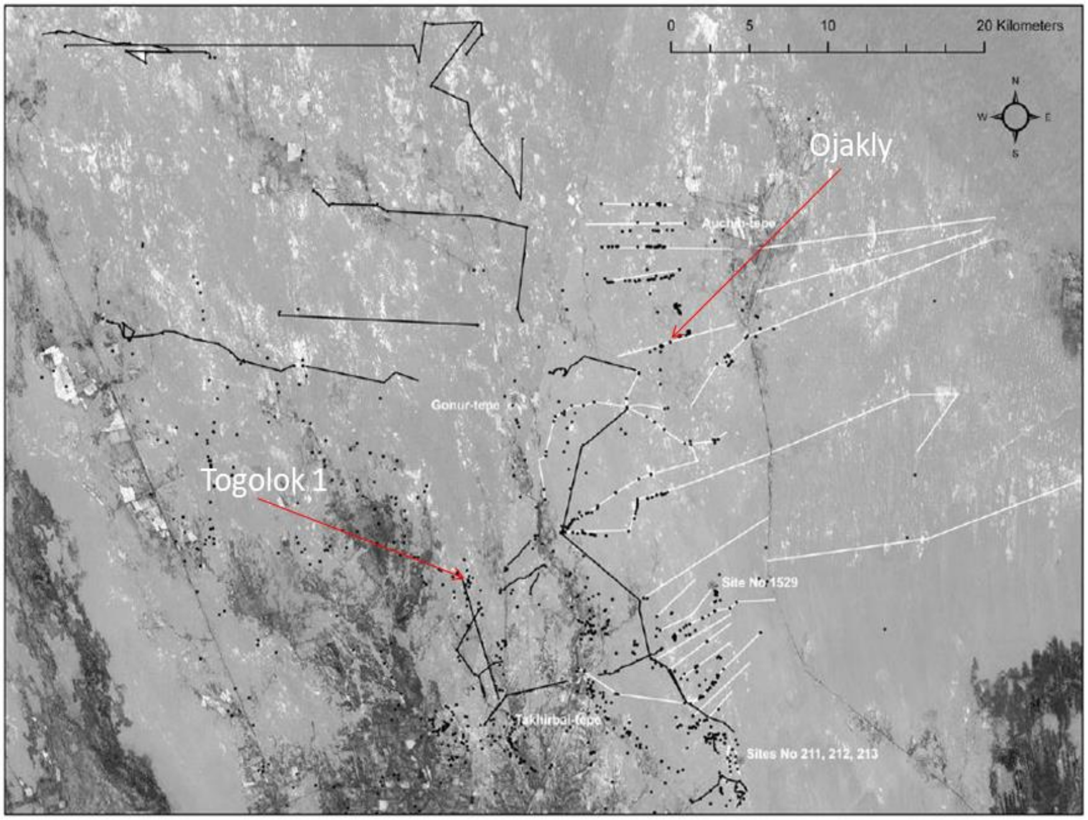

Figure 4.6 The figure shows the AMMD walking transects conducted in the northeastern region of the Murghab alluvial fan. The black lines represent surveys conducted from 1994 to 2005, while the white lines show surveys conducted from 2006 to 2009. These transects were planned to navigate around natural obstacles, such as canals, and anthropogenic features, such as agricultural fields, within the alluvial fan (adapted from Cerasetti 2012).

In the following years, the transects were expanded to the areas between Taip and Gonur North, and between Kelleli and Egri Bogaz. During the early 2000s, the survey extended further east, covering areas east and west of Auchin and west of Gonur North, and Takhirbaj. These latest surveys led to the discovery of numerous Andronovo (ICW) pottery sites, which eventually culminated in the investigation of Chopantam and Ojakly, excavated in 2006 and 2009–2010, respectively (Cattani 2008a; Rouse and Cerasetti 2014). Sites were categorized by the AMMD according to the extent of the pottery distribution and mounds, and were grouped into four main site categories.

The *tepe* (or *depe*) is the most prominent site category (as they represent solid anthropogenic mounds) and are highly visible across the landscape (up to 5–7 m in elevation and ca. 5 to 10 ha in extent). They generally have a high density of pottery, such as at Togolok 1 (Cleziou 1998). They often represent multi-period sites with mudbrick fortified structures that have been associated with administrative or religious use, such as at Adji Kui 9 or Togolok 21 (Sarianidi 1990b; Bondioli and Tosi 1998: IX; Rossi Osmida 2007). In this research, no new mounds (tepe) were recorded as their presence was already known.

In addition to the mounds, three more site categories were recorded by AMMD: the a) *Elevated Depositional Area* (EDA), b) *Low-Lying Depositional Area* (LLDA), and c) *Scatters* (Bondioli and Tosi 1998: IX–XIX).

EDA sites are characterized by a slightly elevated surface (<1 m) and have a large densities of surface materials. They are considered single-period sites associated with mudbricks strictures and possibly kiln structures. They can range between 1 or 2 ha. Several of these sites in the AMMD database have pottery from the Middle and Late Bronze Age and Iron Age.

LLDA sites are flat area and have artifacts covering <1 hectare. Defining the border of LLDA sites was often difficult and subject to the interpretation of the surveyors. This depends on the boundaries which are not always straightforward to interpret in the field (Plog et al. 1978; Banning 2002:200).

Scatter sites or artifact clusters are the most ubiquitous categories in the Murghab. They are small areas of artifacts (between 0.1 and 0.5 ha) with a moderate or low density of materials on a flat area, sometimes associated with takyr surfaces but also present in sandy areas. They are often associated with pastoral or seasonal use, such as at Gonur N., as most of these sites lack evidence for mudbrick structures (Hiebert and Moore 2004). The vast majority of these sites remain unexcavated and little is known about them. A further category in the AMMD dataset, not representing sites, is *potsherd* which represents isolated finds. This category was not considered in this research.

For the present project, sites were recorded adopting a similar categorization of the AMMD dataset. Their category names, however, have been changed to facilitate their recording and analysis (Table 4.1).

New Site Category	Description	Former AMMD category
Tepe	Artificial mound (up to 7 m) with a high density of pottery dispersal (>5 ha)	Tepe
Low Mound	Slightly elevated surface (<1 m) with the presence of a large density of surface materials (1–2 ha)	Elevated Depositional Area (EDA)
Large Cluster	Flat areas with a high distribution of artifacts (<1 ha)	Low-Lying Depositional Area (LLDA)
Small Cluster	Flat area with distribution of artifacts (<0.5 ha)	Scatters

Table 4.1 The table shows the four-site categorization of the present project and how they correspond to the previous AMMD categories (Gubaev et al. 1998; Tosi et al. 2008).

The dataset from the AMMD survey has been integrated into this research and provided crucial information for settlement distribution analysis in relation to water resources (see Chapters 5 and 6). However, detailed description of sites in the AMMD database are usually reserved for larger sites, such as low mounds (i.e., EDA) or large cluster sites (i.e., LLDA). As a result, small cluster sites often lack additional information. Likewise, many sites from the early 1990s survey also lack descriptions in the database.

In addition to AMMD data, past Soviet surveys have also been integrated into the project database and uploaded into the GIS platform (Sarianidi 1990a). The main problem with the Soviet data is the overall categorization of any settlement under the broad definition of *site*, without any further data or sub-division into site categories. This creates a *false* homogeneity of the data collected. However, when a description of these sites is provided elsewhere, the sites have been tentatively categorized under the site categories of the thesis (Table 4.1). Small and large clusters of sites are often not represented in Soviet survey data as the main focus of the early survey was on the main archaeological sites (i.e., tepe and low mounds).

4.3.5 Field Survey

The field survey aimed to ground truth the channel traces identified in the remote sensing stage. The main objective was to acquire dating evidence for the use of water channels and more data on their characteristics. In addition, it aimed to identify settlements that may inform us about irrigation and agricultural practices in the Bronze and Iron Ages.

The fieldwork surveys were conducted in two field season for a total of seven weeks under the umbrella of the PAM project (*Project for the Ancient Murghab*). The TAP project (*Togolok Archaeological Project*), which excavated the Togolok 1 site during the 2014, 2015, and 2018 field seasons, was also instrumental both for the preparation and logistics of the fieldwork. In addition, TAP provided archaeobotanical samples for carbon isotope analysis from Middle and Late Bronze Age layers (see section 4.5 of this Chapter). The fieldwork was the second stage of analysis of the fluvial system and was divided into two parts.

The first part of the fieldwork was composed by the reconnaissance of the paleochannels analyzed via remote sensing, while the second part was characterized by a transect-based field survey to record additional sites along the former channels.

As discussed above, the introduction of mechanized agriculture has led to drastic changes in the central Murghab, which have recently started to affect the distal areas of the fan as well. This situation and the construction of small canals to irrigate new fields is an ongoing process that generates an unpredictable landscape. As a result, it produces natural and artificial barriers to fieldwork surveys that need to be taken into account during fieldwork preparation.

4.3.5.1 Ancient Channel Scouting and Recording

The first transect-based channel reconnaissance was conducted east of Ojakly. The transect comprised about 4 km up to the Auchin canal. The walking team was composed of five members,[43] located 100 m apart. After having completed this first transect, where we detected several traces of old channels, the team obtained a better understanding of the landscape and its channel structure.

During the field walking, the locations of paleochannels were recorded, and the GPS data were imported into the GIS.[44] Because of the limited size of the screen of the GPS, we printed maps of the paleochannels as well, facilitating their reconnaissance. For each channel we documented its characteristics and took photographs.

After the first pedestrian reconnaissance, it was clear that channel traces – often between 5 to 10 m in width, and with the specific takyr surface and almost no vegetation – were visible from a car as well. Therefore, it was decided that we would proceed with the scouting of channels by car. The method turned out to be faster and more efficient and allowed the team to verify and record the same channel at various locations in the

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[43] The fieldwork team was composed of four members from the PAM project and two expert desert drivers with a 4x4 UAZ car who were hired thanks to cooperation with archaeologists from the Merv Archaeological Park near the modern city of Bayram-Ali. One of the drivers, who also collaborated in past excavations with the AMMD as an experienced worker, was the fifth member of the walking team.

[44] The team was equipped with two GPS Garmin GPSMAP 64s to record the exact location of the observed paleochannels. The use of GPS allowed the uploading of raster and vector data. As such, satellite images and the desk-based reconstruction of paleochannels network were uploaded onto the two devices.

Togolok and Ojakly areas. Several east–west and vice versa transects were made by car both in the Ojakly and Togolok areas.

Moreover, the information we could obtain from the driver and local shepherds about the current situation of desert roads and passages across modern canals was crucial at this stage. This is because the fast development of agricultural expansion with the creation of new field systems (particularly in the Togolok area) and the construction of small and large modern canals (Figure 4.7) impeded access to parts of the landscape the team planned to survey. Therefore, designing survey routes in collaboration with local drivers was vital.

Figure 4.7 The rapid expansion of field systems in the northern regions of the Murghab, along with the modern machine excavation of canals, frequently obstructed passage during the survey. Furthermore, cultivated fields and canals often result in the destruction of archaeological evidence. The image depicts a canal excavated in the vicinity of Togolok.

4.3.5.2 Pedestrian Survey

The pedestrian field season had two main objectives: a) survey along the former channels in both the Togolok and Ojakly areas for site identification and dating, b) the coring and excavation of the channel test trenches to investigate their stratigraphic sequence and to obtain absolute dates with OSL analysis. Building upon the experience of the first field season and the difficulties of accessing some areas, a preliminary verification in the Netherlands of the field walking areas turned out to be pivotal. Considering the time, the budget, and the people involved, it was crucial to set up efficient planning. Preliminary desk-based assessment of the Togolok and Ojakly areas was conducted by analyzing three up to date Sentinel 2 images. As a result, green areas representing current field systems or areas with major modern canals were deselected as potential target for survey.

As Adams (1981) argued, the chronology of sites situated along the canals in Mesopotamia can provide general dates of the irrigation system and when it was in use. The “dating by association” method remains the most efficient one for archaeologists to suggest a chronological period for paleochannels in the absence of any additional analysis (Wilkinson 2003:83). In this case, the dates of the sites located along the channels suggest when the watercourses were at least active. This provides an indirect relative chronology of the paleochannels, suggesting possible periods of activity. In this context, the aim of the survey was to detect and date sites aligned along the paleochannels that could suggest periods of activity. The extensive transect-based survey previously conducted by AMMD, while revealing the presence of numerous settlements possibly aligned along channels, did not target any channels. Most of the ancient channels recorded in AMMD transects were accidental discoveries (Cattani et al. 2008; Ninfo and Perego 2006), and no further research has been undertaken.

Prior to the fieldwork, several survey areas were selected on the basis of Sentinel 2 images discussed above. Transects were created both for Togolok and Ojakly regions. At Togolok, a total of six survey areas were created, while at Ojakly, a total of eleven survey areas were drafted on a GIS platform. Each area extends for ca. 500 m to the left and right of the former watercourses and followed the natural meandering forms of the channels (Figure 4.8). In this context, 500 m can be considered an adequate distance to detect sites located in proximity to the water channels. The distance between sites and water channels will be further assessed later in this study (see Chapters 5 and 6 for the analysis).

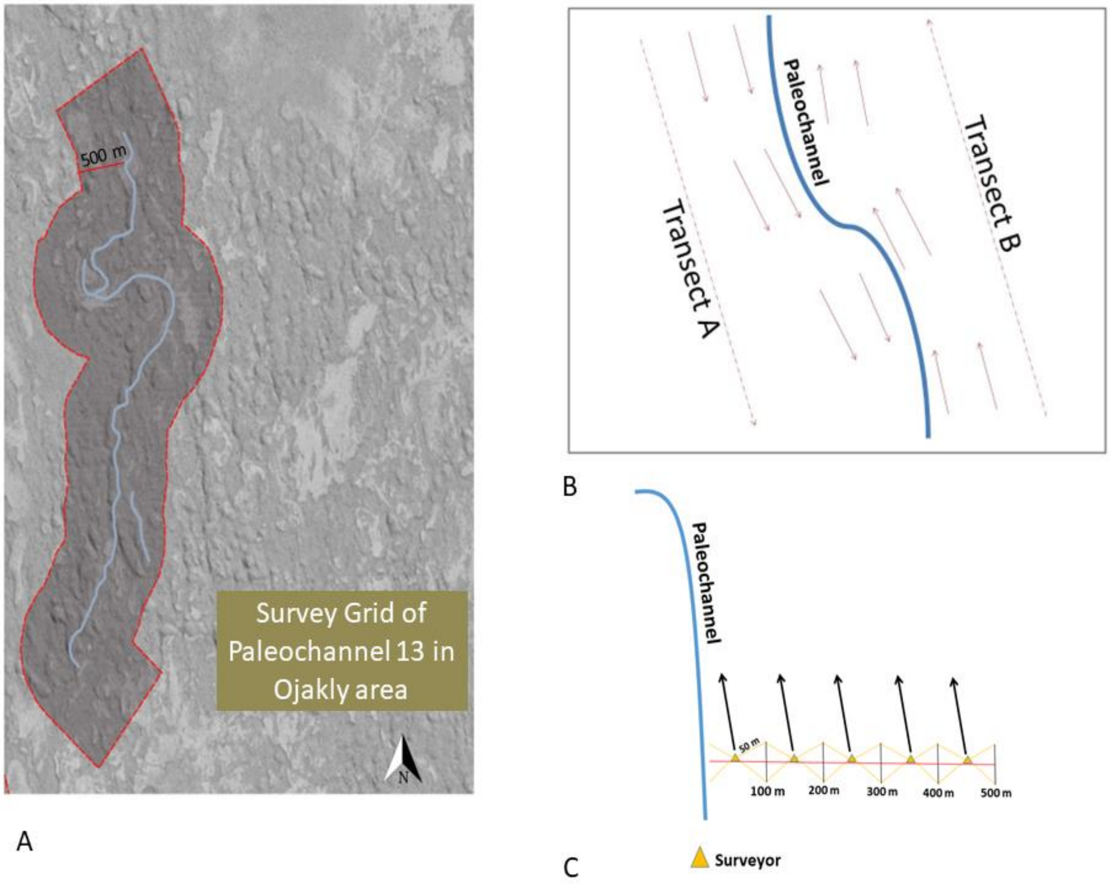

Figure 4.8 The figure shows A) the survey area from Paleochannel 13 in Ojakly, B) a schematic representation of walking transects A and B along a former channel, and C) the walking survey method. The paleochannel was surveyed on both the left and right of the the paleo-bank.

The field-walkers were spaced 100 meters apart from each other.[45] The ancient channels were surveyed both on the left and the right (transect A and B). Prior to the survey, the

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[45] The walking team was composed of three team members from the PAM project and two team members from the TAP project, in addition to the drivers and a few other workers that had worked extensively with the AMMD team in the past.

walking transects were uploaded on a GPS in the form of raster polylines, including the channels. Admittedly, when compared with other survey methodologies and resolutions, particularly in the Mediterranean region (Cherry 1983), the walking transects are spaced far apart. However, a similar methodology has been applied in arid regions of West Asia with good results. It was determined that a similar distance was suitable for achieving the desired results (Wilkinson et al. 2004:196). Also, during the autumn season, there is minimal green vegetation, and visibility is excellent.

During the field walking survey, each walker carried bags for pottery collection. As the general strategy of the field survey was to obtain a relative chronology of sites near the channels, single finds were not recorded as they do not make assessments on activities. In contrast, concentrations of archaeological materials on the basis of site typologies described in Table 4.1 was recorded.

When a site was encountered, the team halted for the recording.[46] Given the high number of pottery fragments and considering that archaeological materials were collected to date the sites, only a selection of diagnostic pottery was collected.[47] Rims, bases, decorated pottery, and handles, as well as small finds, were collected. These items were later entered into the databases, photographed, and drawn at the basecamp.

The analysis of the pottery and its chronology is limited by uncertainties concerning the Murghab ceramic sequence. The chronology of the Bronze and Iron Age is still under discussion and various chronological sequences have been proposed. There are significant problems in the study of Bronze Age pottery in Turkmenistan that have not been overcome (see Hiebert 1994a:39–73; Cattani and Genito 1998:75–87; Luneau 2010 for further discussion). In this study, the diagnostic pottery has been assessed as dating to the chronological periods of the Murghab (i.e., Middle Bronze Age, Late Bronze Age,

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[46] The paper recording form included 1) date, 2) name of the survey area, 3) number of the survey area, 4) paleochannel trace number, 5) new site number, 6) uniquely raw photo number, 7) GPS point number, 8) brief description of the site, 9) registration of the bag number of the collected pottery associated with the site, 9) extra notes or any other relevant details.

[47] On each bag there was the number of the new site associated with the pottery and the GPS point with UTM coordinates.

etc.).[48] Pottery data were entered into the pottery database and saved on two backup hard disks in addition to the project laptop. In addition, all the data produced for this study will be stored with DANS (*Data Archiving and Network Services*)[49] in collaboration with Leiden University and will be available open access.[50]

Lastly, to avoid any possible confusion the number of newly recorded sites in the field follows the AMMD sequence. In the past, the surveys by the Soviets and that of the AMMD team created two different identification systems. Considering that the vast majority of sites in the Murghab have been numbered by the AMMD team in the last two decades of research, it was logical to adhere to the AMMD site sequence.

4.3.6 Paleochannel Investigations

In order to further explore the hydrological system of the Ojakly and Togolok areas, two channel traces were chosen for coring and test trench investigation. The objective was to analyze both a small and a large channel to examine their hydrological characteristics and determine the absolute dates of the channels using OSL analysis. Prior to the fieldwork, a preliminary survey by car was conducted to assess various channels identified through ground truthing. Eventually, after evaluating several options, Paleochannel TGK1_Ch_IX in Togolok and OJK_Ch_V in Ojakly were identified as the most suitable candidates for coring and test trench investigations.

4.3.6.1 Hydrological System and Geoarchaeological Approach

In Chapter 2 (section 2.2) I discussed the characteristics of the Murghab alluvial fan. In short, the Murghab fan concludes its journey inland, and its modern shape is determined to a large degree by the construction of the Karakum Canal. The remote regions of the fan are marked by temporary streams that become active during the autumn and winter

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[48] The pottery assemblages were mainly analyzed by Dr. E. Luneau from the German Archaeological Institute (DAI) and members of the PAM and TAP teams.

[49] https://dans.knaw.nl/en/data-stations/archaeology/ (last accessed April 2024)

[50] DANS use an open access license CC-BY-4.0.

seasons. Conversely, the central portion of the fan, such as the Merv area, features permanent channels. However, prior to the construction of the Karakum Canal in the 1980s, much of the northeastern section of the fan had dried out, with only temporary channels subject to flash flooding events.

During the Bronze Age the northeastern sector of the fan witnessed significant development, with sites like Gonur North, and Adji Kui 9. These sites were situated along the primary branches of the former fan (Sarianidi 1990a; Salvatori et al. 2008), which had a hydrological system characterized by a network of main channels and small streams. This particular scenario makes the northern areas of the Murghab fan highly suitable for geoarchaeological investigation.

In section 4.3.1, I explored a multidisciplinary approach to studying landscapes in West and Central Asia, incorporating archaeology, remote sensing, and geoarchaeology. In recent decades, geoarchaeological analysis has emerged as indispensable for investigating and dating past hydrological systems (e.g., Wilkinson 2003; Fouache et al. 2012; Malatesta et al. 2012; Jotheri et al. 2018; Rashidian 2021). In arid landscapes in particular, geoarchaeological investigations play a central role in reconstructing relationships (Wilkinson et al. 2010). As such, ancient fluvial systems hold significant relevance in West and Central Asia, often featuring archaeological evidence along their courses. Studying such systems can shed light on the relationship between local communities and water resources. In addition, analyzing various aspects of the fluvial system can help clarify why sites are situated in specific locations and the extent of their access to water resources. For example, in Mesopotamia, scholars like Jotheri et al. (2018; 2022) have focused their research on riverine sub-environments such as crevasse splays, marshes, and irrigated soils, which are essential for comprehending past human–environmental interactions in Mesopotamia. A similar geoarchaeological approach can also illuminate the water dynamics in the Murghab region.

Among the most prevalent fluvial landscapes are floodplains characterized by flat beds with stream channels (Goldberg and Macphail 2006:91). As outlined in Chapter 2, floodplains are found across various regions worldwide, including arid areas. Essential for understanding human–environment interactions is the study of floodplain evolution, which involves analyzing different sedimentary processes, deposits, and facies that undergo changes over time (Brown 1997). This holds particular significance in regions where civilizations originated along river branches, as seen in the cases of Mesopotamia, the Indus Valley, and the Murghab.

In this context, the investigation of stream deposits and channel patterns can provide valuable insights into the development of a hydrological system. Analyzing channels can help us understand the history of watercourses (Costanzo et al. 2023). Coring and test trenches of channels are optimal methods for investigating ancient watercourses (Jotheri 2016). Employing hand augers for coring channels at various points, as I will discuss in the following paragraph, is a crucial method to examine channel cross-sections. Trench excavations can offer insight into the stratigraphic sequence of channels and their evolution. Through this method, the different stages and stream velocity of channels can be inferred from the materials transported, technically defined as *sediment load* (Goldberg and Macphail 2006).

The reconstruction of the former paleochannel system in Togolok and Ojakly, understood as traces of its system, can shed light on the possible forms of the past hydrological system. As we know from modern fluvial system, the morphology of channels can vary depending on the sediment transported and flow conditions. Leopold and Wolman (1957) classified fluvial channels as straight, meandering, and braided patterns. Despite undergoing scrutiny in recent decades, these channel typologies remain relevant. While remote sensing analysis in this study is limited to channel traces, it nonetheless can provide some insights into the typology of the channel system.

Channel types depend on hydraulic and sedimentary factors (Knighton 1998:208) (Figure 4.9). The first channel category is composed by straight singular channel. This type is rare and generally takes this form because little erosion occurs along the banks (Goldberg and Macphail 2006:89).

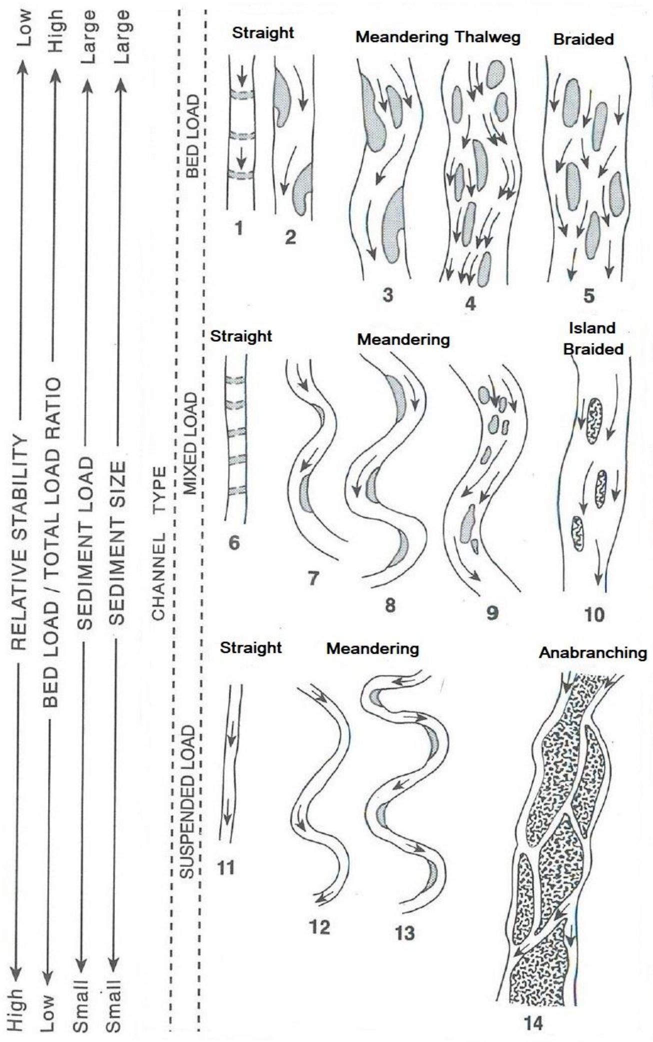

Figure 4.9 The figure shows the main classification of channel patterns (adapted from Knighton 1998:Fig. 5.16).

The second category is the meandering channel. Meandering watercourses, according to Kellerhals et al. (1976) can have a series of meanders with a different deviation angle. Asymmetry of the meanders can be regarded as inherent characteristics (Carson and Lapointe 1983, Knighton 1998:213).

The third category of multichannel rivers regularly form floodplains. According to Knighton (1998) multichannel rivers can be grouped into two main categories of a) braided rivers and b) anabranching rivers. The anabranching rivers are composed by subgroups of which the most common is the anastomosing, characterized by low-energy flood plains[51] (Nanson 2013) (see below for definition).

Braided rivers are characterized by repeated convergence, divergence, and joining of the channels (Bristow 1987). Braided channels occur in alluvial fans in a semi-arid or arid environment, in particular where rapid change of water discharge can occur with easily eroded stream banks (Boggs 2001). In a braided system, channels are separated by islands or bars. Bars do not have vegetation and are unstable, while islands are usually stable and vegetation occurs (Knighton 1998:230). In anabranching rivers, islands are quite large, vegetated, and stable compared to the braided ones that are considered as in-channel features (Makaske 2001).

Within anabranching systems, single channels are often independent of one another, while their specific characteristics vary. In fact, single channels can form straight, meandering, or braided channels (Schumm 1968; Brice 1984). The sinuosity of the anabranching channels can vary, but they are generally characterized by a low gradient and low width–depth ratio (Knighton 1998:Table 5.10).

One of the characteristics of channels in flood plain is their capacity to shift. It is usually regarded as a slow process, mostly due to avulsion (Smith and Smith 1980; Makaske 1998:70–76). Avulsion occurs when a channel breaks the banks, often during a period of high discharge, and forms a new channel while abandoning its former channel. Similarly, erosion of the outer banks of a meander can lead to the formation of an oxbow lake that is a result of a meander being cut off (Goldberg and Macphail 2006:91). In the context of the formation of a new channel, anabranching rivers are characterized by the presence of three categories of channels (i.e., primary, secondary and tertiary). As discussed in Chapter 2, the modern Murghab alluvial fan presents these three categories with low levees, and this is evident in the modern fluvial system. Similarly, even though only sections of former channels may be discernible through satellite imagery in the Murghab,

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[51] It is important to stress that some authors (i.e. Brice et al. 1978, in Schumm 1985) consider anabranching and anastomosing as synonyms. However, there is often no consensus on terminology as it is difficult to incorporate a definition based on channel pattern only (Makaske 2001).

one would expect a comparable pattern from the Bronze Age period as well (see discussion in Chapters 5 and 6).

Although rivers can be categorized as meandering, braided, or anabranching systems, as discussed above, very large and long rivers, such as the Tigris and Euphrates in Mesopotamia, can exhibit diverse patterns. Jotheri (2016) argues that the Euphrates shows an anastomosing pattern from Shinifiyah to the marshland area, while the sections from Dhuluiya to Kut, or from Kut to Qurnah show a meandering pattern, for instance. Determining the typology of the ancient hydrological system can offer profound insights into various aspects of the settlement pattern during the Bronze Age. Also, understanding the configuration of the channel system provides valuable clues about the location of archaeological sites and key areas of human activity and economic strategies.

The presence of archaeological sites along abandoned meandering, braided, and anabranching stream deposits underscores the importance of geoarchaeological investigation. Identifying the timing and causes of river evolution and its relationship to settlement patterns is crucial. Similarly, comprehending how human activities interacted with a specific river morphology is essential for any further inquiry (Rashidian 2021). In Mesopotamia, for example, geoarchaeological studies revealed the timing of levee aggradation in channels, leading to the interpretation of favorable conditions for irrigated agriculture (Jotheri 2016).

Therefore, conducting geoarchaeological investigations, which involve employing cores and test trenches to examine the ancient channel system within the research areas, is essential for comprehending the relationship between channels and local communities, as well as their potential attributes. These investigations will allow researchers to analyze sedimentary deposits, stratigraphic layers, and other geological features associated with ancient channels, providing valuable insights into past land use, water management practices, and human interactions with the environment. Likewise, such investigations can shed light on why particular channels were selected, the reasons for their abandonment, their water capacity, and their overall evolution (Mantellini et al. 2008).

4.3.6.2 Channel Cores

Before initiating the excavation of the test trenches in Togolok and Ojakly some preliminary analyses were conducted in the field. The surface elevations of the paleochannel cross-sections were obtained with a total station.[52] To investigate the stratigraphic sequence of the channels, several cores along the cross-sections of the channels were taken with the use of a hand auger. The aim of the cores were a) to have a preliminary idea of the stratigraphic sequence of the identified channels before excavating the test trench and b) with a series of transect cores perpendicular to the paleoflow of the channels, obtain its cross-section. The data obtained were crucial to a preliminary understanding of the channel sequence.

In total, nine cores were taken at both channels in Ojakly and Togolok. Two different hand augers from Leiden University suitable for mud to more compact soils were used. An extra hand auger head was acquired in the Netherlands. While it was crucial to have a hand auger that could assure a minimum of friction during penetration into the soil, it was equally important that the head could hold potential sand or sandy deposits common in this region. Therefore, it was pivotal to evaluate the different deposit types the team could have encountered during the drilling and decide the selection of hand augers based on these potential parameters. As such, a new hand auger with a 7 cm head suited for sand deposits was acquired.[53] The head had extra wings on the sides that keep the soil in and prevent coarse or fine sand from falling out during the extraction of the hand auger from the core.

Before starting coring on the basis of the line perpendicular to the paleoflow created on the GIS platform and with the aid of a GPS, several points were selected for cores along the cross-section of the paleochannels. While coring with the hand auger, a sample bag with sediments was taken when a change in the sediment was observed, such as texture, color, or any other characteristics (e.g., pottery, shell, etc.). The sediments for each core

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[52] The measurements were obtained using a total station TOPCON GTS 250W

[53] Specifically, an Edelman auger, sand type was acquired.

were described in the field based on their texture, grain size, and color. On the basis of field observations, a drawing of the cores was produced in the field and later upgraded at Leiden University. The draws of the cores were later integrated into the channel cross-section obtained with the total station lining up the different stratigraphic sequences of the channel.

4.3.6.3 Channel Trenches

After having obtained a preliminary cross-section of the channels with cores, test trenches were excavated at the center of the former channels. The trenches both in Togolok and at Ojakly measured 2 by 3 m and approximately 2 m in depth (Figure 4.10). They were excavated without any mechanical excavator.[54] During the fieldwork, two profiles (west and south) for each trench were described, analyzed, and drawn in the field. The stratigraphic layers of the profiles were analyzed on the basis of their macroscopic properties, such as their composition, texture, color, and macrofossils. In order to obtain an absolute chronological sequence of the channels, and its fluvial evolution, samples for Optically Stimulated Luminescence (OSL) analysis were taken at different points from the profile sections of two ancient channels (see Chapters 5 and 6 for sampling details). OSL analysis proved to be an effective methodology to date ancient watercourses in other fluvial contexts (e.g., Berking et al. 2017; Fouache et al. 2012; Toonen at al. 2020).

In total, seven OSL samples were retrieved from both trenches. The sediment layers were sampled with a metal tube (20 cm long with 5 cm diameter). Likewise, dosimetry samples were collected for each retrieved sediment tube for the dosimetry analysis. In the OSL laboratory, an approximately 5 cm slice of sediment from both edges of the tubes was withdrawn. This is because, during the sampling, particles from both ends of the tubes might have been exposed to daylight, which would zero the luminescence signal.

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[54] Although the use of a mechanical excavator would have sped up the fieldwork, there was no excavator available at that time in the field. In addition, both areas are far from the nearest farming villages (namely the former "Sovkhoz" of Bayram-Ali), and the cost of bringing an excavator and a specialized worker into the desert for at least a week was prohibitive with the current budget.

Indeed, the OSL dates the time since particles (quarts or polyminerals – mainly feldspar) were deposited and received no further sun light. Both the OSL sampling in the field and the subsequent analysis in the laboratory were conducted by Dr. Daniela Müller at the Institute of Earth and Environmental Sciences – Geology, Albert-Ludwigs-Universität Freiburg (Germany). The OSL analysis from both Ojakly and Togolok samples follow Lamothe et al. (2003) and Preusser et al. (2014) for laboratory methodology and correction procedures.

The OSL dates are presented in Chapters 5 and 6 in BCE with corresponding date in BP[55]. However, BCE dates are integrated into the text to better correlate the ages with the BMAC context.

Figure 4.10 The figure shows the early stage of excavation of the Togolok test trench on Paleochannel 7.

4.4 Modeling of a Water Channel

The importance of water resources for the BMAC civilization has triggered numerous discussions in the last decade (Lamberg-Karlowsky 2013; Salvatori 2008a; Sarianidi 2009). In Chapter 3, I have discussed the importance of hydrological systems in a theoretical context. The relevance of the organization of an irrigation system and its

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[55] The OSL were retrived in 2018.

development and maintenance have been long discussed in Near Eastern archaeology (see Mori 2020 for an updated discussion). In addition, although many irrigation systems were envisioned, constructed, and organized by central authorities, other systems – even of large scales – were not (Wilkinson and Rayne 2010; Berking 2018; Morandi Bonacossi 2017; cf. Hunt 1988; Wilkinson et al. 2012; 2015).

In the last decade, to analyze the management of ancient irrigation systems, scholars have applied modeling software that imitates such systems (Ji et al. 2003; Ertsen 2010; Tianduowa et al. 2018). These models allow for the design and analysis of the different degrees of management by calculating scenarios of management of a water channel system. By running possible scenarios of water management, this allows us to estimate the complexity and coordination of a water channel system.

4.4.1 SOBEK Software Analysis

In order to estimate different degrees of water management, one ancient channel trace identified in the Ojakly area was modeled using SOBEK-Rural software (1D).[56] The software is a modeling suite that creates one or two-dimensional grids (1D-2D) and simulates different flows and water processes in several irrigation and channel systems. The software has been used for archaeological and non-archaeological analysis to simulate floods and create scenarios within water systems with good results (Laserna 2003; Ertsen 2010; Prinsen and Becker 2011; Musa et al. 2015; Tianduowa et al. 2018). Among other things, the software can create different forms of canal cross-sections, including closed and open-air canals (similar to natural channels). It can model different inflows of water (Q) into a given channel. The water inflow can vary over time (i.e., from a few hours to days), simulating different scenarios in which there are different levels of water intake. Of crucial interest for this study is that the water level and water discharge passing through the canals can be calculated by the software at specific points and times throughout the canals. Likewise, the program can calculate the different water levels and

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[56] The software was developed by the Deltares - *Dutch Research Institute*. The full version of the software was made available through collaboration with TU-Delft, thanks to Dr. M. Ertsen.

discharge trend of a given canal over a determined time period (e.g., showing the different water levels reached by a canal over 24 hours).

In addition, the SOBEK software allows us to study a wide range of characteristics of an irrigation system, including the modeling of weirs, gates, pumps, or culverts – although most of these tools have not been used for the present channel model. Notably, the software can calculate the management of an irrigation system, such as opening/closing of the gates and weirs at a given time, including coordination between gates within a specific time frame that simulates the management of human agents (see Chapter 5).[57]

Among the numerous channel traces, both in Togolok and Ojakly, one channel trace (Paleochannel 10) in the Ojakly area was modeled using SOBEK software. The channel represents one of the longest known channel traces identified in the area (>4 km). The selected section was likely part of the Murghab alluvial channels system (see Chapter 5). Yet, linking the different channel traces identified in Ojakly with reconstructed channels on an arbitrary level using the software would have produced unreliable results and scenarios. Therefore, only one channel trace was modeled with SOBEK.

The model aims to test various scenarios of management. While the results from these scenarios pertain to a single channel, they give rise to several broad aspects of discussion regarding the potential degrees of cooperation among BMAC communities. These aspects are further elaborated upon in Chapters 5 and 7, where the implications of the different scenarios are examined and discussed.

4.5 Isotope Analysis

Over the last two decades, stable carbon isotope analysis has been used in archaeology as an effective tool to analyze the relationship between crops, ancient irrigation practices, and water use (Araus et al. 1999; Flohr et al. 2011; Riehl 2008; Riehl et al. 2008; Stokes et al. 2011; Wallace et al. 2013). The analysis of δ^{13} C is derived from the stress that

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[57] For more details visit https://www.deltares.nl/en/software/module/sobek-1dflow-rural/ (last accessed April 2024).

occurs in the plants when they do not receive sufficient water in the form of either rainfall or irrigation (Stokes et al. 2011).

The utilization of stable carbon isotope discrimination ($\delta^{13}C$) from archaeobotanical remains has become a standard method since the 1990s (Araus et al. 2007; Fiorentino et al. 2008). By integrating isotope results with paleoclimate data from the relevant time period, one can infer water management practices by interpreting level of $\delta^{13}C$. For instance, if the $\delta^{13}C$ of the crop indicates that the plant received sufficient water in an arid environment, this strongly suggests that the crops likely received water from other sources, like irrigation (Flohr et al. 2019).

Although comparative modern data from the Murghab region are not available, Wallace et al. (2013) have recently assessed the reliability of stable carbon isotopes by investigating present-day crops (wheat, barley, and lentils) in multiple locations in Southwest Asia and the Mediterranean, with a particular focus on marginal and arid environments. These experiments provided reliable modern references, in terms of $\delta^{13}C$ levels, from arid environments and from crops that are grown under known hydrological and climatic conditions. As such, as an interpretative framework to comprehend crop $\delta^{13}C$ values Wallace et al. (2013) introduced a model consisting of bands representing broad levels of crops in relation to water (i.e., poorly-watered, moderately-watered, well-watered). Likewise, an additional experiment by Flohr et al. (2019) also confirmed the validity of the $\delta^{13}C$ bands values proposed by Wallace et al. (2013). Those data are crucial for a correct assessment and interpretation of the isotope results in this thesis. However, while it is theoretically possible to interpret the data by comparing plant isotope results with the estimated amount of naturally available water for a specific crop, this operation is far from straightforward. Different factors can affect plant $\delta^{13}C$ values, including climate fluctuations and the agriculture cycle which might result in an unreliable interpretation, which has raised concern (Stokes et al. 2011; Flohr et al. 2019).

Nevertheless, by comparing available paleoclimate data, modern regional data from the same crops, and other non-irrigated or wild plant data from the same site, it is possible to infer various irrigation practices and plant management to some degree (Ferrio et al. 2005). Likewise, irrigation practices and water management can be inferred by looking at variations between isotope results from various sites from the same region, and from different chronological layers from the same site, as in the case of Togolok 1 (see Chapter 6).

Agricultural management in arid lands, however, is not limited to irrigation. As pointed out in this chapter, the extensive distribution of pottery in the Murghab around the major sites has been interpreted by Wilkinson (2014) as possible evidence for manuring. In plants, manuring has an effect on the value of N in isotope composition ($\delta^{15}N$) that can be analyzed in the laboratory on archaeobotanical samples. In short, by analyzing the $\delta^{15}N$ results from the archaeobotanical assemblages and comparing these results with proxy data from arid regions, some general conclusions can be drawn about possible manuring practices (Kanstrup et al. 2011).

4.5.1 Togolok Botanical Samples

In September 2014, the TAP (*Togolok Archaeological Project*) started the excavation of the northern mound of Togolok 1 (Cerasetti et al. 2019; see Chapter 6). Although the excavation is still in its early stages, the trench excavated in the central northern area of the mound reached the Middle Bronze Age layers of the settlements (Cerasetti et al. 2022; see Chapter 6). During the excavation, several sediment samples for archaeobotanical analysis were collected from the Middle and Late Bronze Age layers (see Chapter 5 for ^{14}C dates and botanical contexts). Among these, 22 seeds have been selected for carbon isotope analyses from several botanical assemblages of different stratigraphic units. The analysis on the $\delta^{13}C$ and $\delta^{15}N$ samples was conducted at the Max Planck Institute of Geoanthropology in Jena (Germany).[58] The methodology applied to the analysis of the samples follows Wallace et al. (2013).

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[58] The analyses were conducted by Ayushi Nayak from the Max Planck Institute of Geoanthropology (Jena, Germany). This is a preliminary analysis based on limited samples. A more comprehensive study, incorporating additional samples from both the Middle and Late Bronze Age layers, as well as samples from other sites in the Murghab region, will soon be published by the team led by Dr. R. Spengler.

The analysis of isotope results derived from botanical samples representing various crop categories offers valuable insights into the practices of manuring and water management prevalent during the Middle and Late Bronze Age. By examining the isotopic signatures present in these samples, one can discern patterns indicative of agricultural strategies, including the use of manure as fertilizer and the different water inputs between the Middle and Late Bronze Age. Understanding the nuances of water management practices is crucial for reconstructing the agricultural systems of the BMAC and understanding their socio-economic dynamics. These possible degrees of variability in water channel systems will be further discussed in Chapters 5 and 7.

4.6 Summary

This chapter presented the theoretical framework and the methodology applied by this research. The methodological and analytical approach is composed of several steps outlined in Figure 4.11.

In the first step, a remote sensing analysis is used to map and reconstruct the ancient hydrological system on both case study areas of Togolok and Ojakly. Subsequently, the field investigation included the reconnaissance of the remotely identified ancient channels, while a transect-based survey served to identify sites located along ancient watercourses. By dating these sites through their surface material, it is possible to estimate by association the possible periods of activity of the channels. This provides a relative chronology of when these watercourses were active.

The analysis of the ancient channels and their evolution was also investigated by means of channel cores with a hand auger and test trenches. This aim of the cores and test trenches is to further analyze the stratigraphic sequence of the channels and their fluvial evolution. In addition, OSL samples were retrieved from both trenches to obtain absolute dates of two channels.

The last two steps in the analysis of the ancient agriculture and channel system are the use of an agent-based model (SOBEK software) and stable carbon isotope analysis from Togolok 1 botanical samples. This analysis aims to further investigate the different degrees of water management based on possible agent-based modeling scenarios and different levels of water stress in plants between the Middle and Late Bronze Age.

All in all, the methodology of the current study includes a holistic approach that combines different data both from remote sensing and survey methods, with the addition of a geoarchaeological analysis. As discussed in this chapter, this multidisciplinary analysis has been successfully applied elsewhere in West Asia and has the potential to shed new light on and disentangle the complexity of the land and hydrological exploitation in the Murghab during the Bronze Age.

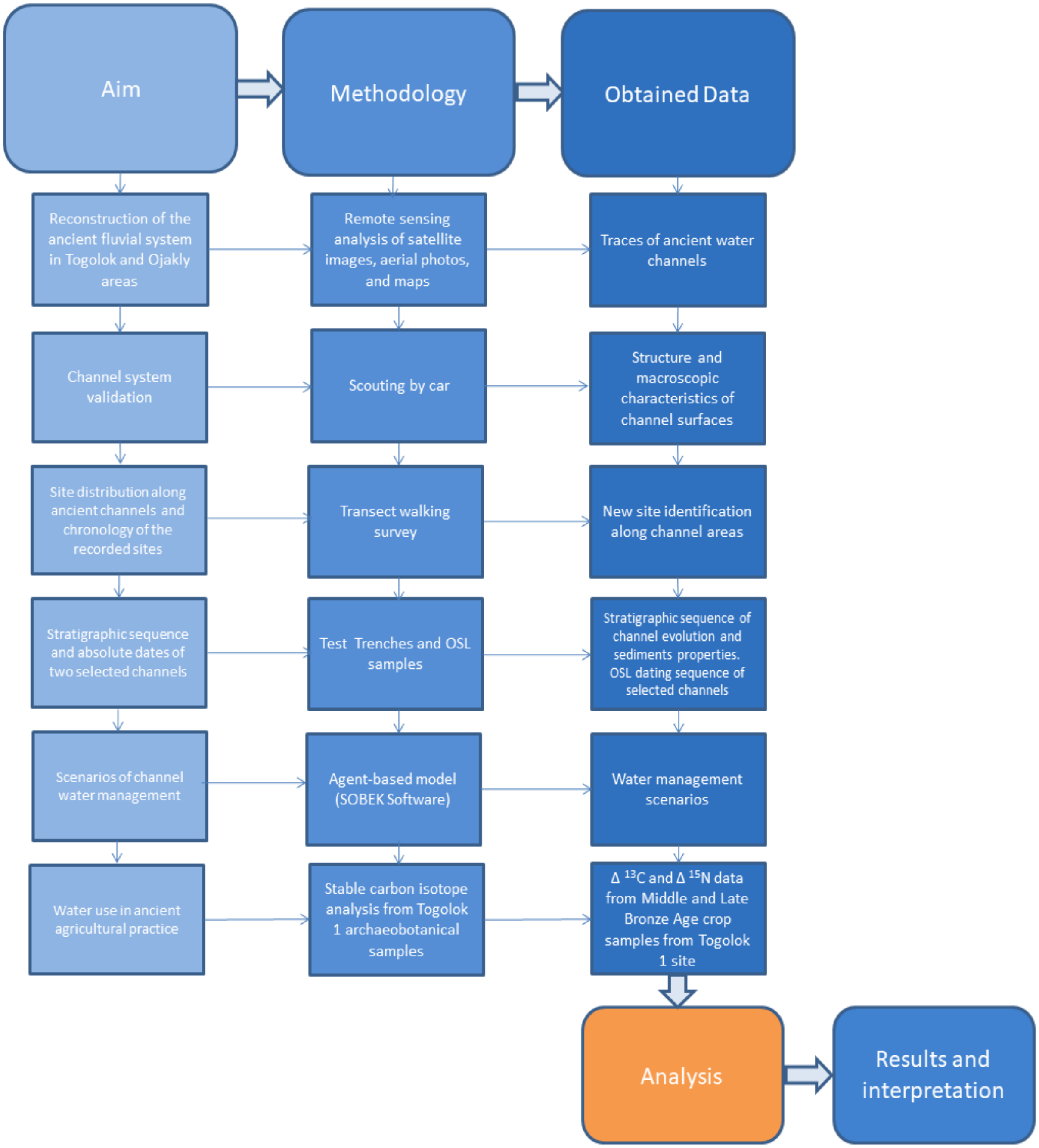

Figure 4.11 Schematic chart displaying the methodology and data obtained from the present project.