Received: 15 March 2022 | Revised: 21 December 2023 | Accepted: 31 December 2023

DOI: 10.1002/gea.21992

RESEARCH ARTICLE

Geoarchaeology An International Journal WILEY

# Development of water management strategies in southern Mesopotamia during the fourth and third millennium B.C.E.

Simone Mantellini[1] | Vincenzo Picotti[2] | Abbas Al-Hussainy[3] | Nicolò Marchetti[4] | Federico Zaina[5,6]

[1]Department of History and Cultures, University of Bologna, Ravenna, Italy

[2]Department of Earth Sciences, ETH Zurich, Zürich, Switzerland

[3]College of Archaeology, University of Al-Qadisiyah, Diwaniyah, Iraq

[4]Department of History and Cultures, University of Bologna, Bologna, Italy

[5]Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy

[6]Fondazione Museo delle Antichità Egizie di Torino, Turin, Italy

**Correspondence**

Simone Mantellini, Department of History and Cultures, University of Bologna, Via San Vitale 28, 48100 Ravenna, Italy.
Email: simone.mantellini@unibo.it

Scientific editing by Kevin Walsh.

**Funding information**

Alma Mater Studiorum—University of Bologna; Italian Ministry of Foreign Affairs and International Cooperation (DGDP Directorate—6th Office); EDUU—Educational and Cultural Heritage Enhancement for Social Cohesion in Iraq (EuropeAid CSO-LA/2016/382-631)

## Abstract

The last two decades witnessed increasing scholarly interest in the history of water management in southern Mesopotamia. Thanks to many geoarchaeological research projects conducted throughout the central and southern Iraqi floodplains, a general understanding of the macrophases of anthropogenic manipulation of this vast hydraulic landscape has been achieved. However, current narratives mostly rely on studies at a regional scale and are based on excessively long chronological phases (often spanning a whole millennium). A finer-tuned analysis at a submillennial scale is needed to better appreciate the dynamics that led to the development of artificial canals and irrigation systems and the creation of harbours in cities and other navigation-related facilities. The Iraqi-Italian QADIS project is addressing this issue through a systematic geoarchaeological investigation in the south-eastern area of the Qadisiyah province. We aim to update the current narrative by analysing case studies involving specific periods of occupation. We performed 17 boreholes to propose a date on the functioning period of the hydraulic works in five selected archaeological sites of this region. This approach allowed us to understand changes in water management strategies in both the short and the medium term (i.e., on a scale of centuries). In this paper, we present the results for the fourth and third millennia B.C.E. This period witnessed a crucial passage from the basic exploitation of natural watercourses for irrigation and occasional navigation to the emergence of the first system of artificial canals and intraurban harbours.

KEYWORDS

boreholes, city harbours, geoarchaeology, hydraulic landscape, Mesopotamia, Qadisiyah

## 1 | INTRODUCTION AND AIMS

Over the last two decades, the history of water management in Mesopotamia has received increasing attention from scholars internationally. This interest is due to the topic's relevance for the reconstruction of irrigation, transport systems, trade networks and land management by ancient states and empires. Pioneering studies in the 1990s (Gasche, 1998; Wilkinson, 1990) first shed light on the hydraulic landscapes of the Mesopotamian floodplain. Today, increasing emphasis on multidisciplinary approaches since the early 2000s (Geyer & Monchambert, 2014; Heyvaert et al., 2012; Jotheri et al., 2016; Morozova, 2005; Pournelle, 2003; Walstra et al., 2008; Wilkinson, 2003; Wilkinson & Jotheri, 2021; Wilkinson et al., 2015) has paved the way for a new season of research. Research in water management is also relevant in nearby areas, such as the Nile Valley (e.g., Dalton et al., 2023).

This paper aims to provide new glimpses into the history of water management in early southern Mesopotamia from the perspective of an Iraqi-Italian QADIS survey project conducted in the eastern part of the Qadisiyah region between 2016 and 2020. We focus on a specific period, spanning the fourth and early third millennium B.C.E., which saw a crucial transition in the Holocene climate—possibly linked to the global climate and the local drying of the Sahara (e.g., Sun et al., 2021; Thompson & Zakhirova, 2021; Weiss, 2000)—when annual precipitation in the Fertile Crescent dropped dramatically and new climatic patterns forced agricultural societies to rethink and improve their water management skills and strategies (Anderson et al., 2007; Kennett & Kennett, 2006; Weiss, 2017).

The study area was chosen for the availability of pre-existing mapping of anthropic hydraulic evidence, based on several airborne and spaceborne data sets followed by intensive ground truthing, and obtaining an updated chronology from surface ceramic materials (Marchetti et al., 2017, 2019; Marchetti & Zaina, 2020). Starting from this well-established approach, the most promising cases of ancient canals and intraurban harbours were selected for auger drillings aiming to date these hydraulic structures. The results obtained from the boreholes were compared with those available from previous fieldwork outside the QADIS area to outline the historical development of water management both at the targeted sites and at the regional level.

Although the narratives described above have been confirmed in recent decades, these interpretations mostly rely on regional studies (Adams, 1981; Aqrawi, 2001; Jotheri et al., 2016; Pournelle, 2003) and ample chronological phases often working at a millennial scale (Jotheri et al., 2018; Morozova, 2005; Wilkinson & Rayne, 2010; Wilkinson et al., 2015). Our goal, instead, was to update the current narrative by analysing a specific area (Marchetti et al., 2017, 2019; Marchetti & Zaina, 2020). Furthermore, our case studies cover specific periods of occupation, thus allowing fine-tuned analysis of water management changes in a short- and medium-term perspective (spanning centuries rather than millennia).

We aimed to investigate, at a submillennial level of detail, the historical period including the fourth and the third millennium B.C.E. in Mesopotamia, which saw a crucial transition from the basic exploitation of natural watercourses for irrigation and navigation to the building of the first artificial canals and intraurban harbours. Two main research questions drive the present work:

1. What was the relationship between settlements and waterways in the fourth and third millennia B.C.E.?
2. When did the first fluvial harbours develop, what did they look like and where were they located within urban centres?

## 2 | GEOGRAPHICAL SETTING AND HISTORICAL AND ARCHAEOLOGICAL BACKGROUND

The southern Mesopotamian floodplain is a dynamic system (Wilkinson et al., 2013) (Figure 1). The current topography is a result of the deposition of sediments, mainly from the Euphrates, Tigris, Diyala and Karun rivers, in a subsiding basin created by the Zagros foreland (see, e.g., Jotheri et al., 2016; Morozova, 2005; Pournelle, 2003, 2013; Wilkinson, 2003). At the end of the Last Glacial Maximum (around 15,000 B.P.) the sea-level rise impacted the floodplain, triggering a major marine transgression that brought coastal environments some 250 km north of the present-day shore for most of the following period (the early-to-middle Holocene) (e.g., Aqrawi, 2001; Kennett & Kennett, 2006). This long-term process, together with a wide range of autogenic, allogenic and human-induced actions, triggered significant variations in hydrology and resulted in a physical landscape characterised by highly diversified geomorphological regions (Wilkinson, 2003). Moreover, during the past millennia, the Euphrates and Tigris main courses gradually shifted eastward and westward, respectively, from their initial location in the central part of the floodplain, thus increasing the extent of the available alluvial area between the Zagros belt and the western Arabian plateau (Jotheri et al., 2016). This process co-occurred with significant climate instability in the region, as confirmed by at least six periods of 'rapid climate change' (Anderson et al., 2007; Mayewski et al., 2004; Thompson & Zakhirova, 2021). This entangled flux of natural events played a primary role in influencing human decision-making and thus shaping the region's long-term urban and population dynamics and hydraulic landscape (Kennett & Kennett, 2006; Weiss, 2017). Rather than being hampered by shifting watercourses, Mesopotamian societies took advantage of the natural fluvial dynamics of the Euphrates and Tigris, manipulating their avulsions and crevasse splays to expand cultivated and settled areas as well as creating new routes along navigable channels (Pournelle, 2003; Wilkinson, 2003; Wilkinson et al., 2015).

In this complex scenario, the QADIS team focused on a large portion of the middle-to-late Holocene floodplain, located in the mid-lower reaches of the Euphrates and Tigris (e.g., An Heyvaert & Baeteman, 2008; Morozova, 2005) (see Figure 1). This area is characterised by a rich network of channels associated with fluvial ridges and intervening depressions, which have significantly

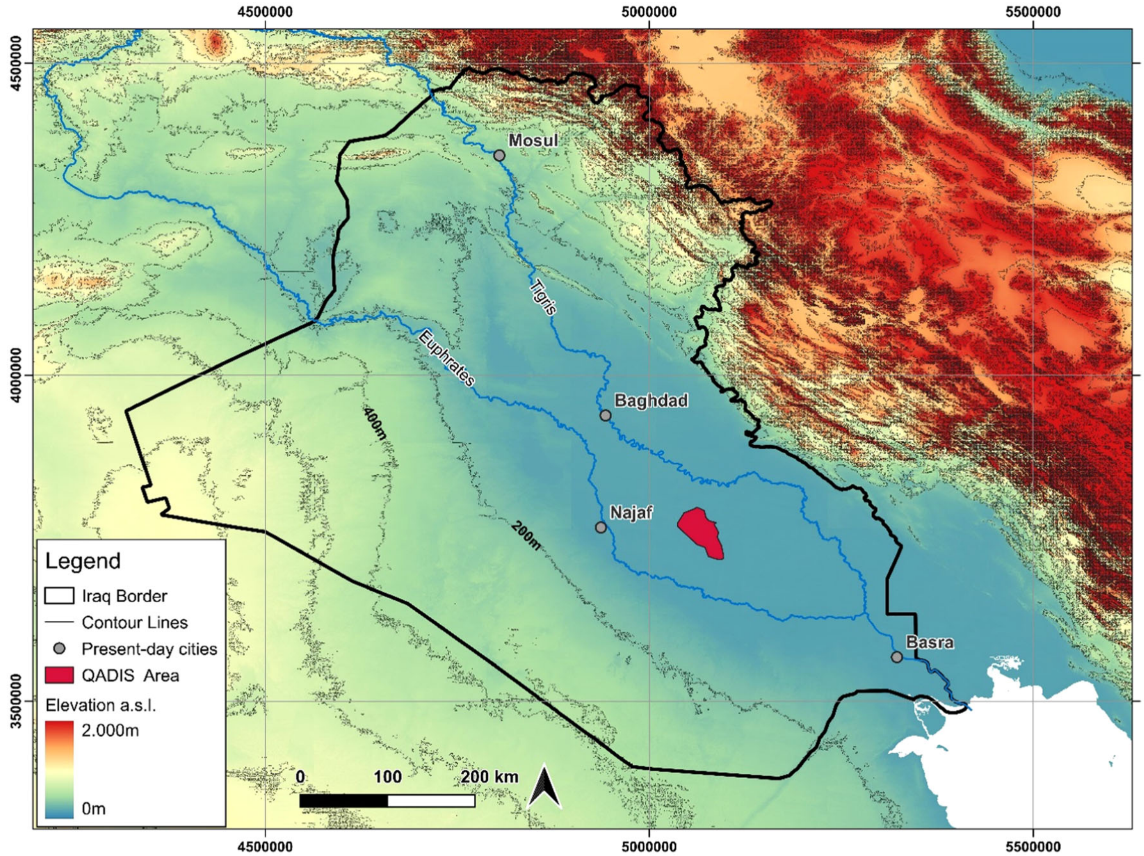


**FIGURE 1** The Mesopotamia and the QADIS Project area of investigation on a GT30E020N40 map, December 1996 (courtesy of USGS, Eros Center; data processing by the QADIS project).

determined settlement distribution for millennia (Altaweel, 2019; Jotheri et al., 2018; Wilkinson, 2003; Wilkinson et al., 2015). The sediments, transported by the channels of the Tigris and Euphrates, were vertically aggrading during the early stages of the middle Holocene transgression. In the late Holocene, with stable to decreasing sea levels (e.g., Pirazzoli, 2005), the space available for accommodation of sediment in the floodplain decreased, while avulsions and channel mobility increased. Consequently, the thickness of the Upper Holocene (Walker et al., 2012) sediments is limited and the late Holocene archaeological landscape is hence still well-preserved (Engel & Brückner, 2021).

## 2.1 | Origins: The fourth millennium B.C.E. (4000–2900 B.C.E., Early/Middle Uruk to Jemdet Nasr periods)

The fourth millennium B.C.E. saw rapid social and political changes, well attested in the archaeological record (Algaze, 2008; Altaweel, 2019; Rothman, 2004; Weiss, 2000). Irrigation was most likely done simply by breaching the levees of natural water courses (Wilkinson, 2003). Early forms of irrigation may have mainly exploited the small distributary fans or crevasse splays formed through natural levee breaches. The system first developed into spur canals, requiring moderate levels of maintenance by small communities, and then evolved into a web of narrow fields arranged in a herringbone pattern (Wilkinson et al., 2015). According to Rost (2017), the earliest artificial watercourses probably emerged only during the Jemdet Nasr period (3100–2900 B.C.E.).

From the late fourth millennium B.C.E. onward, archaeological research revealed a settlement strategy mostly based on small villages scattered along minor riverine streams (Adams, 1981; Adams & Nissen, 1972; Marchetti et al., 2019; Ur, 2013a). These primaeval water systems, mainly managed by kinship groups (Wilkinson, 2003; Wilkinson et al., 2015), also fostered early fluvial navigation, which facilitated the movement of goods and people between early cities (Altaweel, 2019).

## 2.2 | Coming of age: The early and mid-third millennium B.C.E. (2900–2200 B.C.E., Early Dynastic to Akkadian periods)

This period saw a more formalised water management system, based on canals and other water-control devices, systematically supplying water to irrigated fields (Rost, 2017; Wilkinson, 2003). Settlements are now mostly distributed along both the Euphrates and Tigris and new major canals (Adams, 1981; Marchetti et al., 2019;

Pournelle, 2003). Recent archaeological research identified as harbours some geometrically shaped basins in large urban centres from the Early Dynastic III period (2600–2450 B.C.E.) onward (Adams, 2008; Rey, 2016; Romano & D'Agostino, 2018). These new facilities and control over the large watercourses may have facilitated the development of new megacities exceeding 200 ha, such as Adab, Karkara, Fara, Kish and Umma (Adams, 2008; Marchetti et al., 2019; Rost, 2017).

This renewed hydraulic landscape was subjected to different management strategies over time. During the entire Early Dynastic periods I–III (2900–2350 B.C.E.), digging and maintenance of waterways and irrigated lands were in the hands of city-states (Benati et al., 2021, 2022; Richardson, 2012; Schrakamp, 2018; Ur, 2013a; Weiss, 2003). With the emergence of the Akkadian large-scale polity (ca. 2350–2200 B.C.E.), its rulers adopted a new land tenure structure including indirect exploitation of arable land (Rost, 2017).

### 2.3 | New developments: The late third millennium B.C.E. (2200–2000 B.C.E., Neo-Sumerian period)

During the Ur III period, water management strategies in southern Mesopotamia reached their maturity (Molina, 2008; Rost, 2017).

The Mesopotamian floodplain became characterised by a complex network of artificial canals and fluvial harbours (e.g., at Ur: Di Giacomo & Scardozzi, 2012; Hammer, 2019), evenly distributed over the entire region (Adams, 1981; Adams & Nissen, 1972).

The settlement patterns mirror the new layout of the hydraulic landscape. The countryside was dotted by an increasing number of newly founded 1- to 4-ha rural villages strategically located along the main watercourses (Steinkeller, 2007; Ur, 2013a; see below), while medium- and large-scale centres mostly stood along the twin rivers (Adams, 1981; Steinkeller, 2001; Ur, 2013a).

The exploitation of arable land and water management under the direct control of centralised state institutions became the dominant mode of agricultural production (Benati et al., 2021, 2022; Rost, 2017) again. This is well-illustrated by the archives of ancient Umma (Molina, 2008), which bear witness to a complex system organised around the bureau of agriculture with its hierarchy of administrators.

## 3 | THE QADIS SURVEY PROJECT

Since we intended to improve current narratives based on the research questions that have emerged thus far, we decided to take into account robust geoarchaeological work within the Iraqi-Italian joint QADIS survey project conducted between 2016 and 2020 in the eastern Qadisiyah governorate (Marchetti et al., 2017, 2019, 2020; Marchetti & Zaina, 2020).

The aim of the QADIS project was to update our understanding of the complex interplay between humans and the environment from later Prehistory until the Ottoman period in a given area. This broader scope called for a multidisciplinary approach integrating archaeology, philology, geoarchaeology and geomatics. Our investigations led to a new understanding of the multilayered historical landscape extending from the ancient site of Nippur to the north to Tell Jidr/Karkara to the south (Marchetti & Zaina, 2020). We selected this portion of the Mesopotamian floodplain, extending over 1829 km$^2$ (Figure 2), for its high relevance for the study of the early history of the region, as it includes both the Euphrates and Tigris watercourses, as well as some of the most important Mesopotamian centres, such as Adab, Puzrish-Dagan, Karkara and Mashkan-ili-Akkade. Besides this advantage, our selection of this area was prompted by multiple factors, such as (1) ample available data about settlements and waterways distributed across the entire historico-chronological range; (2) a wide range of site sizes for each chronological phase and (3) evidence from new unrecorded sites to be integrated into the existing data set (Marchetti et al., 2019).

Below is a short description of the activities conducted and the results obtained by the QADIS project, which provided the basis for the geoarchaeological research discussed in this paper.

### 3.1 | Desktop assessment

During the past decades, remote sensing techniques became fundamental for scholars dealing with the cultural landscape and paleoecology of ancient Mesopotamia (Cole et al., 1998; Hritz, 2010; Pournelle, 2003; Wilkinson et al., 2013; Ur, 2013b, 2022), as well as of other areas, such as the Nile valley (Macklin et al., 2013; Toonen et al., 2018). The possibility of integrating various spatial data sets and past archaeological surveys within geographic information system (GIS) platforms has been broadly recognised as crucial for archaeological investigations at any scale (Hritz, 2010; Pournelle, 2003; Menze et al. 2006; Ur, 2013a; Wilkinson, 2003).

The satellite data sets used during the QADIS project (Marchetti et al., 2017, 2019) consisted of open-access imagery, including Landsat, SRTM and CORONA (thanks to the United States Geological Survey and the Corona Atlas & Referencing System), as well as more recent Very High Resolution (VHR; Williamson, 1997) imagery acquired from on-line platforms, such as Google Earth Pro and Bing Maps. These were integrated with different topographic and archaeological maps by the Iraqi State Board of Antiquities (Iraqi Directorate General of Antiquities, 1976) and previous archaeological fieldwork (Adams, 1981; Al-Shukri, 1974).

Thanks to this large data set (Table 1), we conducted a desktop assessment for the QADIS survey area (Marchetti et al., 2017, 2019) including digitisation of previously identified archaeological sites and waterways, as well as preliminary identification of potential new archaeological sites (208 anomalies subsequently validated on the ground, see below) and the recording of more than 700 possible abandoned canals and harbours (see Figure 2b). These artificial watercourses belong to different periods, generally originating from the Tigris and Euphrates rivers or major canals. Their association with specific periods and their connection with settlements has been discussed elsewhere (Marchetti et al., 2019; Marchetti & Zaina, 2020).

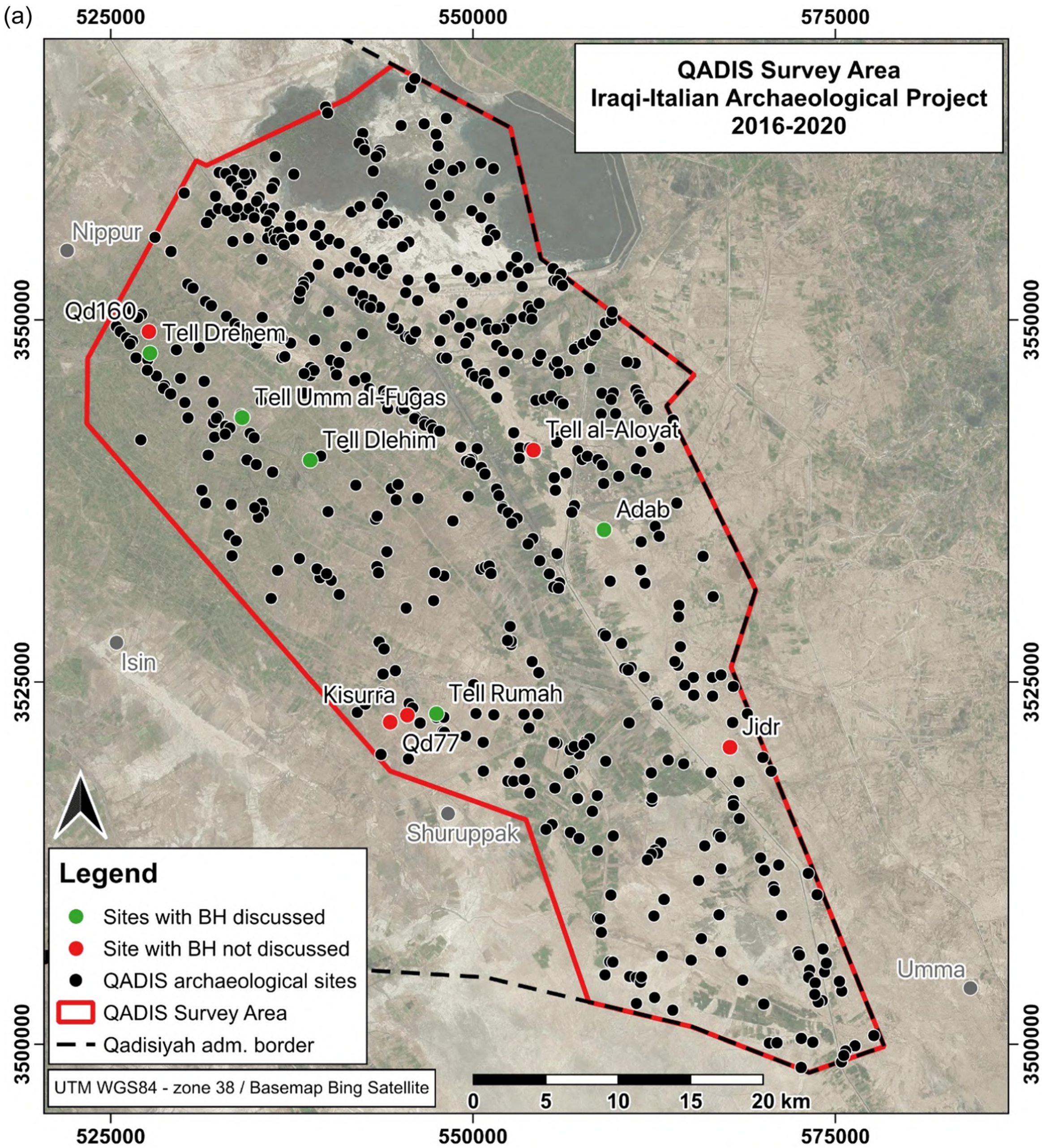


**FIGURE 2** The area investigated by the QADIS project, with the sites selected for boreholes (background: semitransparency Bing satellite imagery; data processing by the QADIS project): (a) QADIS sites; (b) mapping of the artificial canals.

## 3.2 | Archaeological survey

Our field survey in the QADIS area aimed at validating the preliminary evidence identified through remote sensing. This was achieved via both non-intensive and intensive surveys, and a survey–resurvey strategy (Banning et al., 2017) applied at 57 previously documented sites (Marchetti et al., 2019). Non-intensive surveys were carried out at all the visited sites. They consisted of a random collection of surface materials (divided between pottery, small finds and organic/inorganic samples) to provide an updated chronology for the sites in that area. At sites with highly visible remote-sensed structural evidence and limited chronological occupation, we carried out intensive collection (Marchetti et al., 2019), dividing each site into 50-to-100 m interval square grids depending on the site size and terrain morphology. We applied this method at the medium-to-large sites of Tell Rumah, Tell Umm al-Fugas, Bismaya/Adab, Tell el-Ahmar, Tell Dlehim/Tummal, Tell Drehem/Puzrish-Dagan, Tell Abu Hatab/Kisurra and Tell Jidr/Karkara. We were thus able to precisely date visible houses and large buildings, city walls, fortresses and hydraulic features inside and outside the city limits (Marchetti et al., 2017, 2019). Fieldwork included the performing of low-altitude unmanned aerial vehicle (UAV) orthophotogrammetry, used to produce accurate digital elevation models (DEMs), and the

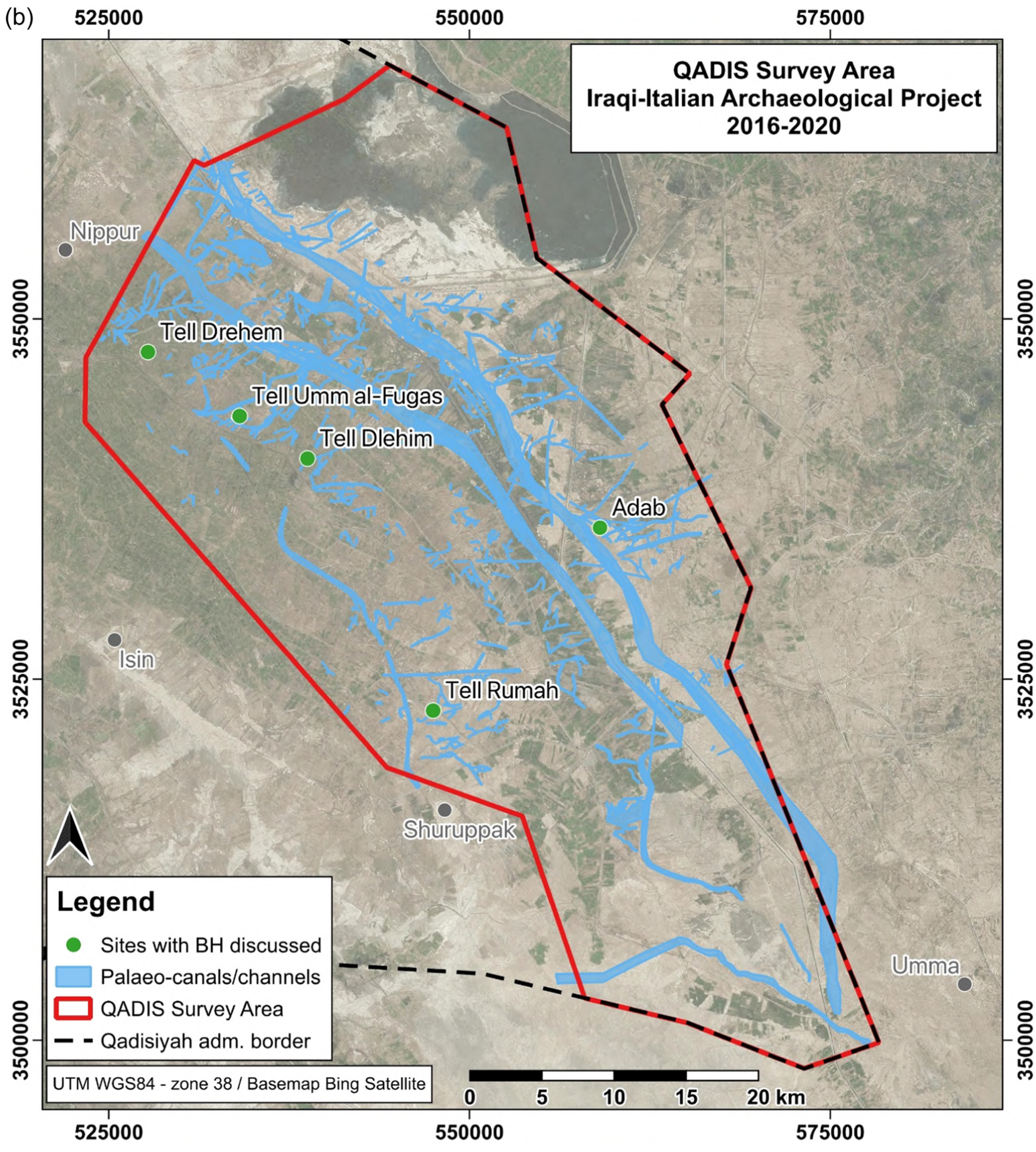


**FIGURE 2** (Continued)

creation of extremely precise profiles, useful to compare differences in elevation of main features or to determine the limits of artificial basins (Marchetti et al., 2019).

## 3.3 | Results

Thanks to our research, the total number of archaeological sites in the region increased by 28%, from the 415 already documented by previous surveys (Adams, 1981; Al-Shukri, 1974) to 535 (120 new sites found by the QADIS project out of the 208 anomalies identified through desktop assessment; see Figure 2a). This improved our understanding of the long-term settlement pattern and population dynamics in one of the core areas of the Mesopotamian floodplain. While the results have been extensively discussed elsewhere (Marchetti et al., 2019; Marchetti & Zaina, 2020), for the purpose of this paper we briefly outline the most significant outcomes regarding the fourth and third millennium B.C.E. (Figure 3).

In the earliest Uruk phases, most sites were located along the two main branches of the Tigris and the Euphrates. During the Late Uruk period, the settlement density and population decreased, especially along the watersheds of the northern Tigris and the Euphrates. These changes were possibly the result of a century-long period of aridity—the 5.2 ka B.P. event (Clarke et al., 2016; Roland et al., 2015)—which may have severely impacted irrigation agriculture in southern Mesopotamia (Staubwasser & Weiss, 2006). This

**TABLE 1** Satellite imagery and topographic maps were used to create the base map for the QADIS survey project.

| Name | Type | Date(s) | Resolution | Quality of information | Source |
|---|---|---|---|---|---|
| Bing Maps Tile System | Satellite | 2016 | Variable | High detail. Local scale | https://www.bing.com/maps |
| ESRI World Imagery | Satellite | 2008 | Variable | High detail. Local scale | Through ArcGIS© |
| Landsat | Satellite | 1972–2016 | 60–30 m | Medium-high detail. Local scale | https://earthexplorer.usgs.gov/ |
| Declassified CORONA | Satellite | 1968–1969 | 2–3 m | Medium-high detail. Regional and subregional scale | http://corona.cast.uark.edu |
| SRTM | Satellite | 2000 | 30 m | Low detail. Regional scale | https://earthexplorer.usgs.gov/ |
| Soviet Military Topographic Maps | Topographic maps | 1970s | 1:200,000 | Low detail. Regional scale | https://maps.vlasenko.net/soviet-military-topographic-map/ |
| Atlas of Archaeological Sites of Iraq | Topographic maps | 1960s–1970s | From 1:150,000 to 1:400,000 | High detail. National scale | Iraqi Directorate General of Antiquities 1976 |

situation continued through the Jemdet Nasr period until Early Dynastic periods I–II, when we observe a more widespread distribution of settlements and the total population seems to be almost equally split between urban and rural centres.

The ensuing period (Early Dynastic III) was marked by the abandonment of small sites scattered all over the countryside and a shift of the population towards major urban centres, such as Nippur, Adab and Shuruppak, aligned along the main rivers. After the collapse of the Akkadian empire, the rural population increased, and a more even distribution of people between urban sites (50%–70%) and villages (20%–40%) can be observed (see Figure 3).

The emergence of the Third Dynasty of Ur and the re-establishment of control over the entire region went hand in hand with a renewed increase in settlement number and population, with a highly diffuse distribution all over the floodplain, concomitant with the reopening of many earlier waterways. The region was probably controlled through several newly (re)founded management centres, such as Puzrish-Dagan, Tummal and Kisurra, and older cities like Nippur and Karkara.

## 4 | METHODS

Following a well-established approach in similar projects in Mesopotamia, as well as in the rest of the Near East, our reconstruction of hydraulic landscapes in the eastern Qadisiyah region was based on the combination of archaeological and geological records (Jotheri et al., 2016, 2018; Pournelle, 2003; Rost, 2017; Wilkinson, 2003; Wilkinson et al., 2015) (cf. also Section 2).

### 4.1 | Selection strategy

To improve the results hitherto achieved during the archaeological survey, we drilled 29 boreholes at 10 sites during the 2017 and 2018 campaigns (Table 2, see Figure 2 for the location of boreholes). Based on available maps of the archaeological sites and associated canals and city harbours, the boreholes were made at sites that had been occupied for limited periods, to make a chronological order possible. The main goal was to date the previously identified relevant hydraulic structures based on material culture (pottery) and radiometric dating of organic samples (charcoal and bones). This paper discusses five out of the nine sites investigated (16 boreholes out of 29, see Supporting Information S1: 1), all dated within the fourth and third millennia B.C.E.

#### 4.1.1 | Tell Rumah (3500–3100 B.C.E.)

Both earlier surveys (Adams, 1981; Adams & Nissen, 1972; Wright, 1981) and new results from the QADIS project (Marchetti, 2018; Marchetti et al., 2019; Marchetti & Zaina, 2020) have shown that most of the sites from this period are smaller than 4 ha, and only a handful of them may have exceeded 10 ha. For this

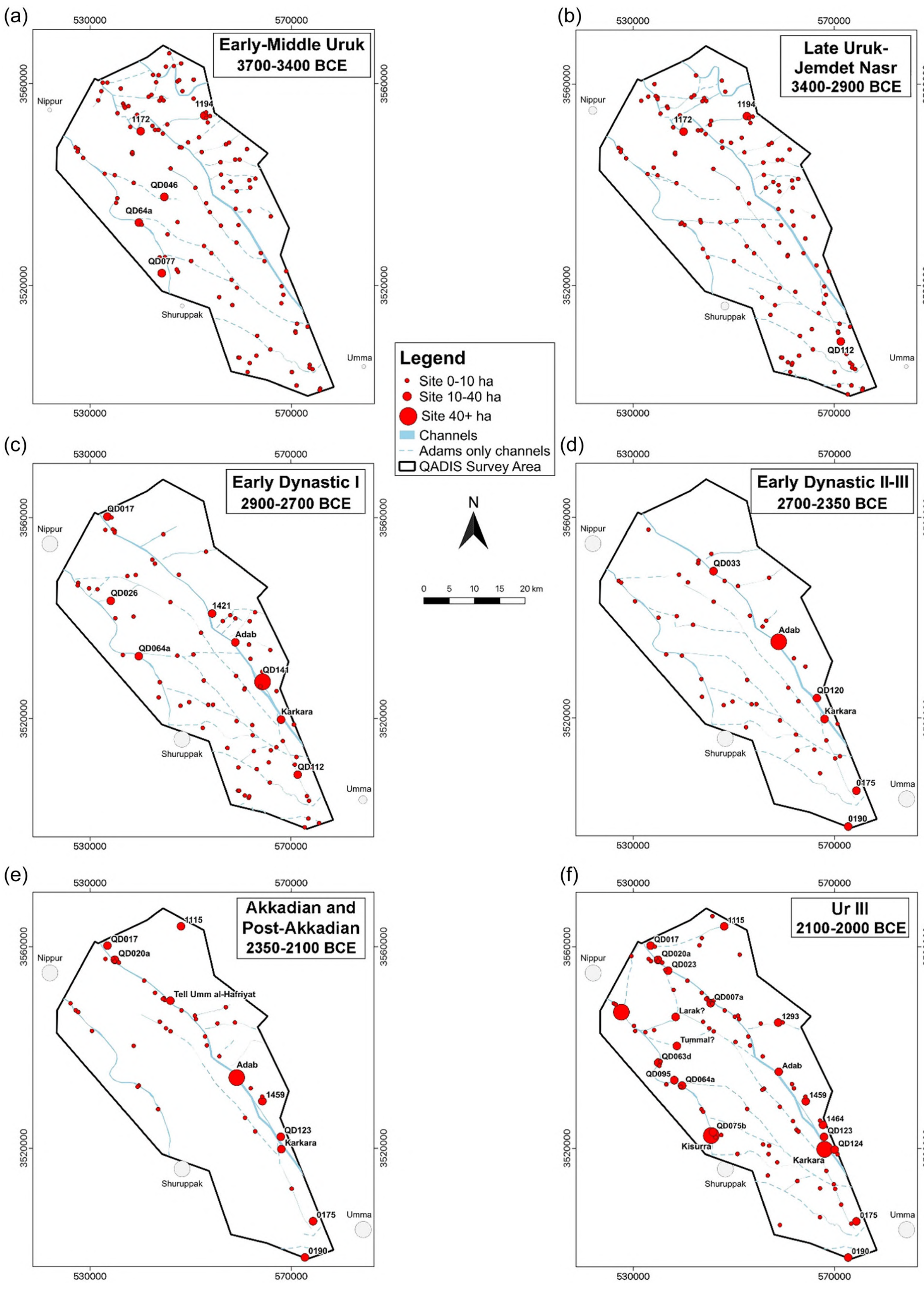


**FIGURE 3** Diachronic development of the settlement patterns in the QADIS area of investigation (from Marchetti et al. 2019: figure 8): (a) Early-Middle Uruk; (b) Late Uruk - Jemdet Nasr; (c) Early Dynastic I; (d) Early Dynastic II-III; (e) Akkadian and Post-Akkadian; (f) Ur III.

**TABLE 2** List of the boreholes of the 2017 and 2018 QADIS survey campaigns (only those discussed in the present paper; see the full list in Supporting Information S1: 1).

| BH | Season | Site | Location | East | North | Elevation (masl) | Depth (m) |
|---|---|---|---|---|---|---|---|
| BH.01 | 2017 | Tell Umm al-Fugas | Intrasite canal | 533892 | 3543489 | 15.78 | 4.50 |
| BH.02 | 2017 | Tell Umm al-Fugas | Outer canal | 534082 | 3543428 | 16.06 | 4.50 |
| BH.04 | 2017 | Tell Dlehim/ Tummal (?) | Basin | 538736 | 3540359 | 15.58 | 9.00 |
| BH.05 | 2017 | Tell Dlehim/ Tummal (?) | Intrasite | 538782 | 3540246 | 18.32 | 5.00 |
| BH.06 | 2017 | Bismaya/Adab | Basin | 558870 | 3535453 | 9.59 | 8.00 |
| BH.10 | 2017 | Tell Drehem/ Puzrish-Dagan | Basin | 527550 | 3547504 | 18.40 | 7.00 |
| BH.11 | 2017 | Bismaya/Adab | Paleo Tigris | 557788 | 3535843 | 8.41 | 5.40 |
| BH.17 | 2018 | Tell Rumah | Intrasite (?) | 547543 | 3522877 | 4.05 | 3.00 |
| BH.18 | 2018 | Tell Rumah | Intrasite canal | 547418 | 3522769 | 4.05 | 5.00 |
| BH.19 | 2018 | Tell Rumah | Intrasite | 547300 | 3522685 | 4.23 | 3.00 |
| BH.20 | 2018 | Tell Rumah | Outer site | 547211 | 3522635 | 4.20 | 3.00 |
| BH.21 | 2018 | Bismaya/Adab | Dock | 558903 | 3535490 | 8.60 | 6.00 |
| BH.22 | 2018 | Bismaya/Adab | Basin | 558892 | 3535451 | 9.18 | 5.70 |
| BH.23 | 2018 | Tell Drehem/ Puzrish-Dagan | Outer canal | 527487 | 3547842 | 21.10 | 6.00 |
| BH.24 | 2018 | Tell Drehem/ Puzrish-Dagan | Outer canal | 527908 | 3547672 | 20.15 | 5.00 |
| BH.26 | 2018 | Bismaya/Adab | Basin | 558960 | 3535443 | 9.13 | 8.00 |
| BH.27 | 2018 | Bismaya/Adab | Intrasite canal | 559358 | 3535339 | 7.03 | 7.00 |

Abbreviation: BH, borehole.

period, we targeted the medium-sized (7–8 ha) twin settlements at Tell Rumah (QD117a–b), newly identified by the QADIS project in 2018. The material culture retrieved from the intensive surface survey indicates that they were occupied during the second half of the fourth millennium B.C.E. (3500–3100 B.C.E.), that is, between the Middle and the Late Uruk periods (Marchetti et al., 2019). Preliminary remote-sensing analysis of both the satellite imagery and the DEM extracted from UAV VHR imagery revealed a 10-m-wide ancient canal passing between the two sites (Figure 4).

### 4.1.2 | Tell Umm al-Fugas (3100–2700 B.C.E.)

For the fourth to third millennium B.C.E. transition, we targeted the medium-sized, twin-mound site of Tell Umm al-Fugas (Adams, 1981, p. 272, no. 1096; Marchetti et al., 2017, 2019, 2020). This site, which extends over 31 ha, has many visible architectural features and a limited occupation time span. Our intensive archaeological survey confirmed that it was inhabited from the Jemdet Nasr period (3100–2900 B.C.E.) onward, with a peak of occupation in the Early Dynastic I (2900–2700 B.C.E.) (Marchetti et al., 2019; Marchetti & Zaina, 2020). The QADIS integrated survey allowed us to reconstruct its plan and trace its main waterways, thus making it a perfect candidate for geoarchaeological investigations (Figure 5). Remote sensing was particularly helpful. We used both CORONA and VHR satellite imagery from Google Earth. By comparing the different colours of the soil due to moisture variation, we were able to detect two potential canals, about 30 m wide and 1.5 km long, both inside and outside the ancient city (Marchetti et al., 2019; Marchetti & Zaina, 2020).

### 4.1.3 | Bismaya/Adab (2900–2200 B.C.E.)

Bismaya, the ancient city of Adab, is one of the main archaeological sites of the region, exceeding 400 ha in size. The city was playing a major role in the political scenario of Mesopotamia by the mid-third millennium B.C.E. (Marchetti et al., 2019; Marchetti & Zaina, 2020; Wilson, 2012). Within its long period of occupation (ca. 3500 B.C.E.–1500 C.E.), the thickest archaeological deposits date to the Early Dynastic III (2600–2350 B.C.E.) and the Akkadian (2350-2100 B.C.E.) periods.

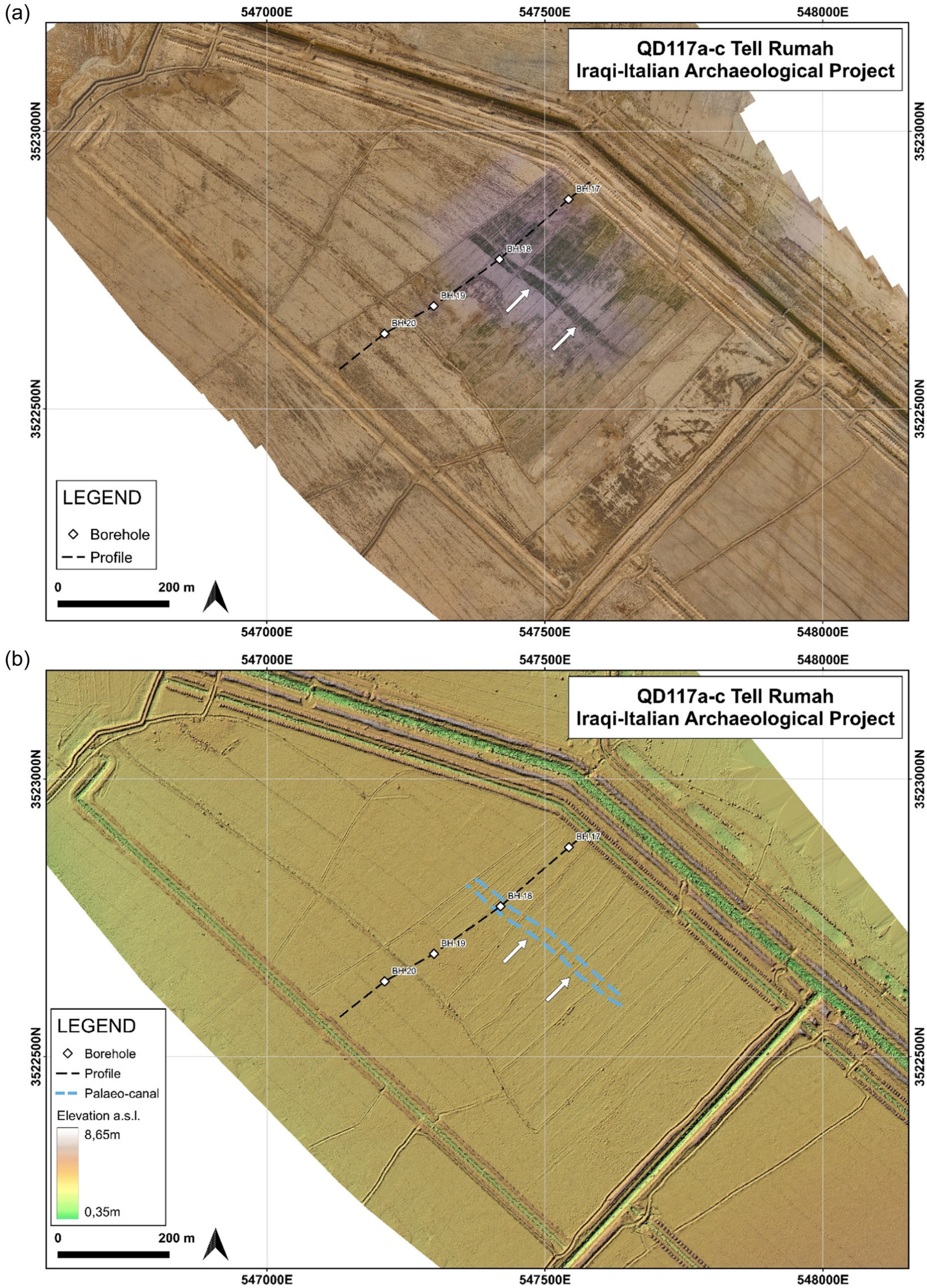


**FIGURE 4** Tell Rumah (second half of fourth millennium B.C.E.), location of boreholes and profile, with white arrows indicating the artificial canal (data acquisition and processing by the QADIS project): (a) on the unmanned aerial vehicle (UAV) image 2017; (b) on the UAV image-derived digital elevation model.

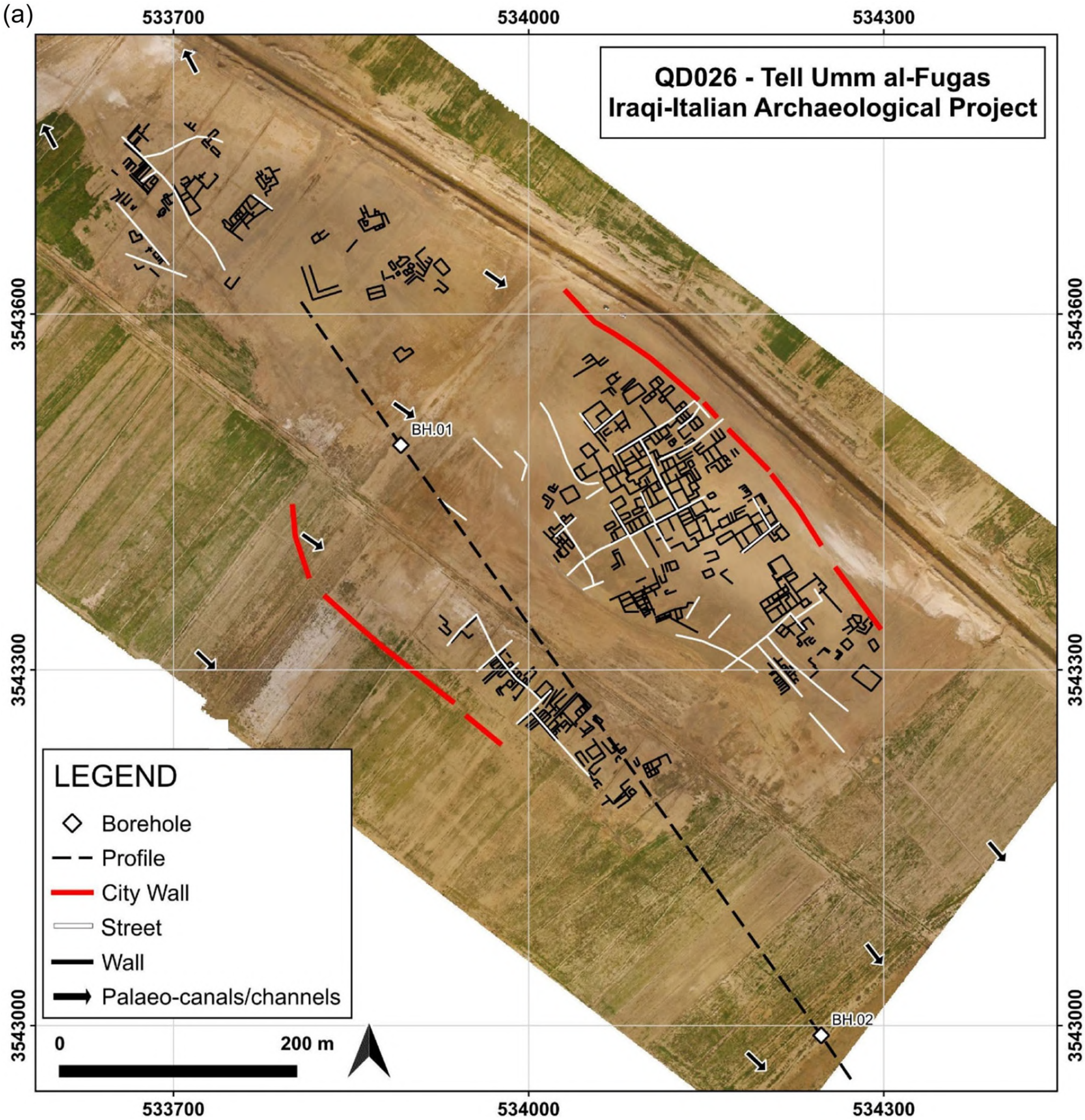


**FIGURE 5** Tell Umm al-Fugas (late fourth–first half of third millennium B.C.E.), location of boreholes and profile with the main anthropic evidence identified through remote sensing and field surveys (data acquisition and processing by the QADIS project): (a) on the unmanned aerial vehicle (UAV) image 2016; (b) on the UAV image-derived digital elevation model.

Our analysis of VHR satellite imagery and DEM extracted from UAV georeferenced images suggests the presence of a harbour at the centre of the settlement, about 24 ha in extension, with a maximum length of 240 m and a maximum width of 215 m (Figure 6). This area is limited to the north by an earthen feature, open in the middle, ca. 200 m long and east-southeast–west-northwest oriented, which may have arguably served as a breakwater and dock. The harbour was probably connected to the Tigris by a 100 m wide canal running at the foot of the main settlement. The light brownish pattern characterising the basin and the canal on the remote-sensed data sets was emphasised during the ground-truthing investigation by the smooth sandy surface, rich in mollusc shells, which is remarkably different from that of the urbanised area.

### 4.1.4 | Tell Drehem/Puzrish-Dagan (2100–1900 B.C.E.)

Tell Drehem, the ancient city of Puzrish-Dagan, was founded during the second half of the third millennium B.C.E. (around 2450 B.C.E.) and became one of the main centres of the Third Dynasty of Ur III period (2100–2000 B.C.E.). During this period, it was a large (80 ha) management and distribution centre for food supplies and livestock (Al-Mutawalli et al., 2017; Hilgert & Reichel, 2003; Sigrist, 1992), with numerous public and religious buildings, including a low ziggurat.

Intensive surface collection combined with satellite and UAV remote sensing analysis significantly enhanced our understanding

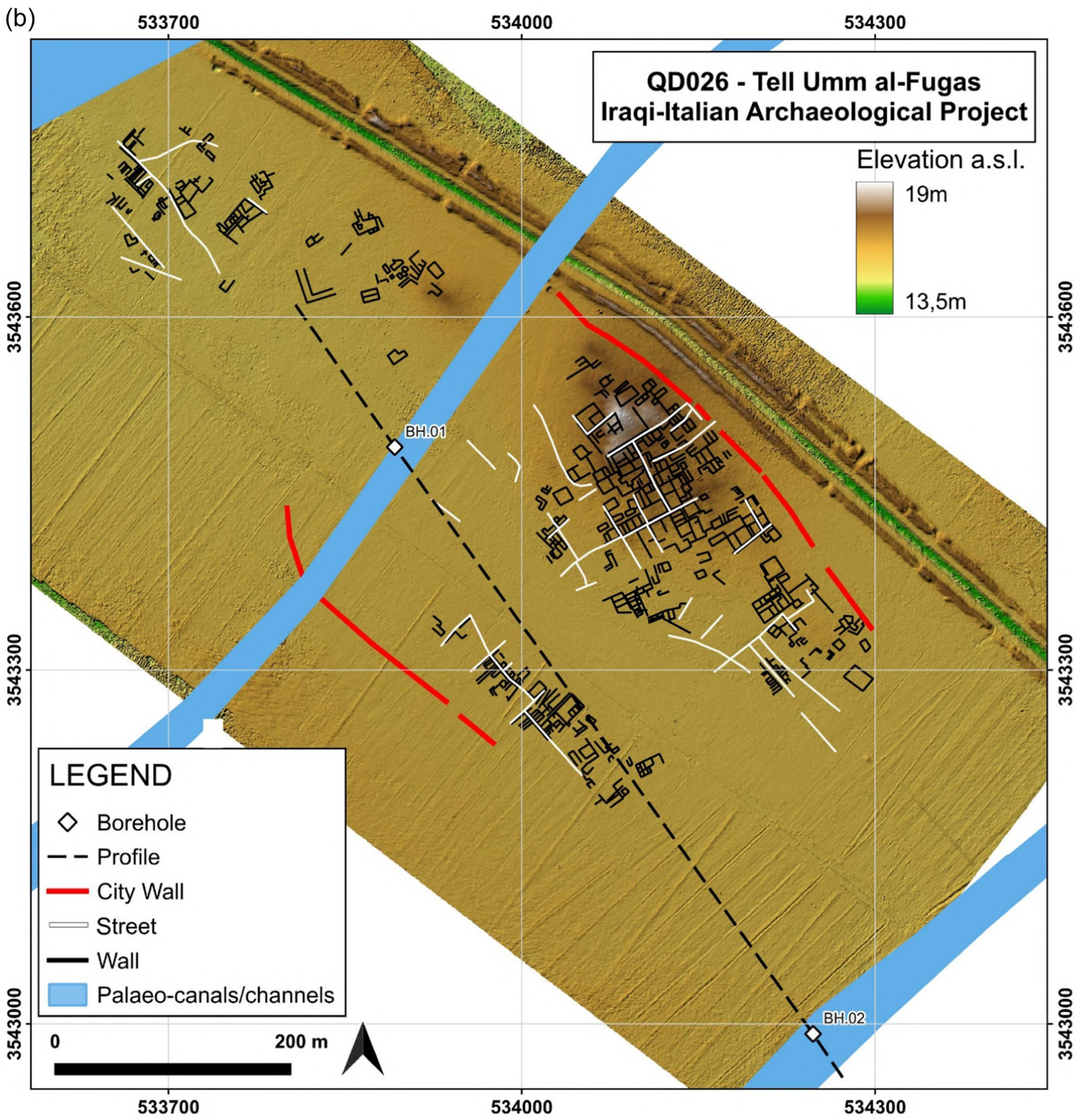


**FIGURE 5** (Continued)

of the urban history of this site, for several reasons (Marchetti et al., 2019; Marchetti & Zaina, 2020). First, it caused us to more than double our estimate of the maximum size of Tell Drehem, from less than 30 to 80 ha. Second, it provided a fine-tuned reconstruction of the spatial evolution of the site through time (Figure 7). Third, it provided detailed mapping of two artificial watercourses (between 60 and 90 m in width) to the North and East, previously recognised by Adams (1981). Finally, an analysis of CORONA satellite imagery taken during both humid and dry seasons in 1968 and 1969 highlighted an almost rectangular dark spot (320 × 280 m, prevailing orientation south-southeast–north-northwest [NNW]) located along what was possibly a large artificial watercourse immediately to the north of the settlement, a perfect candidate for a city harbour (Figure 8).

#### 4.1.5 | Tell Dlehim/Tummal (?) (2100–1900 B.C.E.)

Tell Dlehim, probably the ancient city of Tummal, is another important centre of the late third millennium B.C.E., one which played a primary political role within the Ur III state (Steinkeller, 2015). The systematic research conducted by the QADIS team unveiled a complex urban plan characterised by residential districts, well-organised along regularly spaced streets, interspersed by squares and separated by large monumental buildings (Figure 9) (Marchetti et al., 2017, 2019). Surface finds and test soundings up to 80 cm deep allowed us to date this evidence to the Ur III period (2100–2000 B.C.E.). Moreover, similar to Adab, VHR satellite imagery and DEM extracted from UAV mapping highlighted the presence of a 50-m-wide canal crossing the city in an NNW direction and a

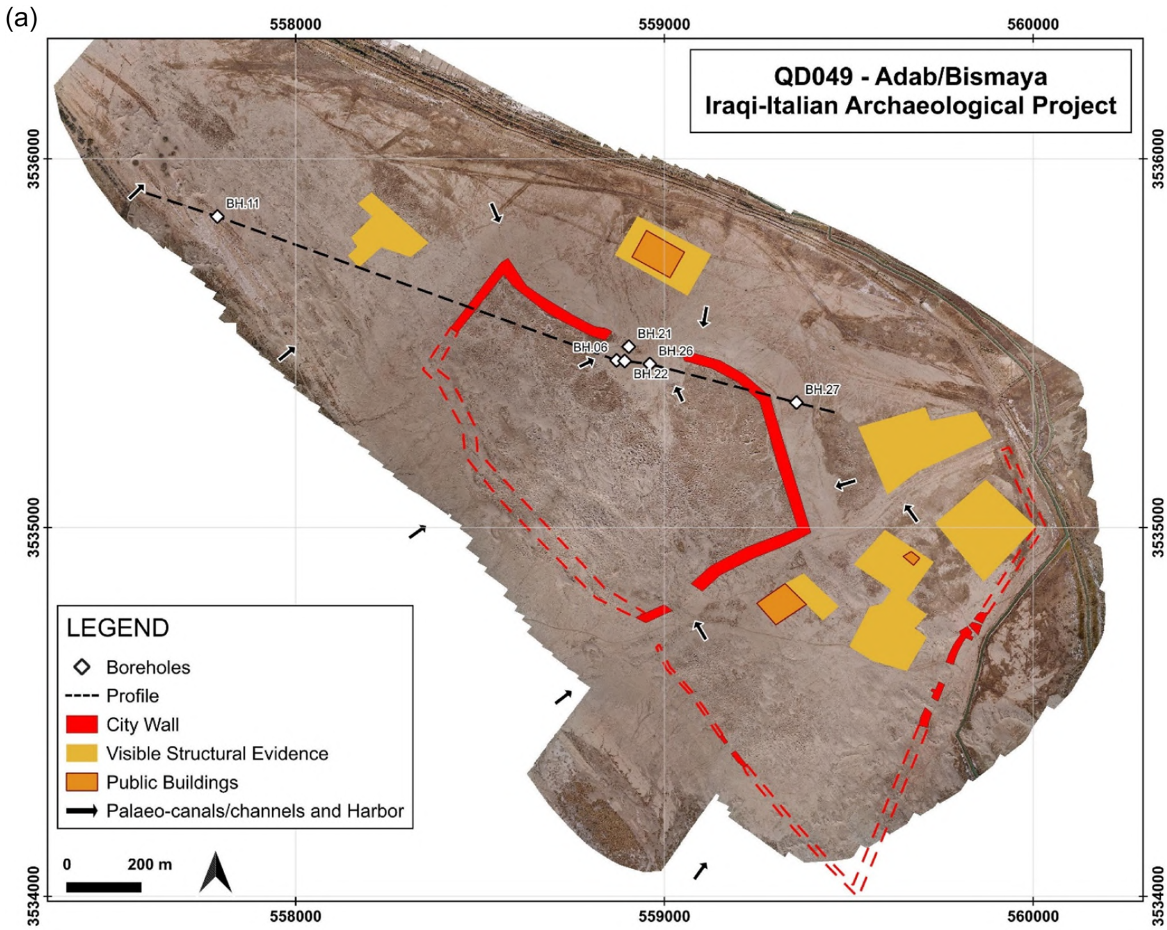


**FIGURE 6** Adab/Bismaya (third millennium B.C.E.), location of boreholes and profile with the main anthropic evidence identified through remote sensing and field surveys (data acquisition and processing by the QADIS project): (a) on the unmanned aerial vehicle (UAV) image 2017; (b) on the UAV image-derived digital elevation model.

pseudorectangular depression (150 × 80 m). The latter is located in the middle of the settlement and has the same pale brown colour as the canal. It was preliminarily interpreted as the harbour of the city.

## 4.2 | Data acquisition and processing

Our activities were organised in the following steps:

1. *Fieldwork*: Manual boreholes were drilled by two workers with an iron auger (40 cm long and 10 cm maximum in diameter) and the samples were stored inside PVC tubes. A stratigraphic unit (hereafter SU) was assigned to every change in lithology, such as grain size, colour, carbonate content, inclusions, and so forth. To measure the real depth of the drilling, each pole of the auger had been graduated. We therefore allow for an error of ca. ±5 cm in the depth of both the SUs and the samples. On-site collection was limited to the largest organic materials or ceramic sherds, each marked with their SU and depth. Depending on soil texture and distance from the water table, the boreholes' depth ranged from 1 m in the sandy paleo-Tigris at Tell Jidr/Karkara (BH.09) to 9 m in the inferred harbour of Tell Dlehim (BH.04), with an average depth of 4.9 m. As for the rest of the QADIS survey, each borehole was positioned with an accuracy of 3–5 cm thanks to a kinematic GPS (Marchetti et al., 2019).
2. *Sampling*: More accurate sampling was then conducted at the local seat of the State Board of Antiquities and Heritage in Afak (Qadisiyah governorate). A total of 836 pottery sherds and 15 radiocarbon determinations were integrated and compared to the chronological attributions provided by the other survey activities, thus offering a rather coherent and solid temporal framework. Samples for $^{14}$C dating were collected either directly in the field or later during lab work. All of them consist of charcoal, which was analysed at the Center for Applied Isotope Studies, University of Georgia (Supporting Information S1: 2).
3. *Pottery analysis*: The pottery assemblage from the geoarchaeological boreholes is presented here for the first time. In this paper, we provide a description of the diagnostic specimens (Supporting Information S1: 3). Their dating is based on parallels with the rest of the pottery assemblage recovered from the survey and for which typological plates have already been published elsewhere (Marchetti et al., 2017, 2020).

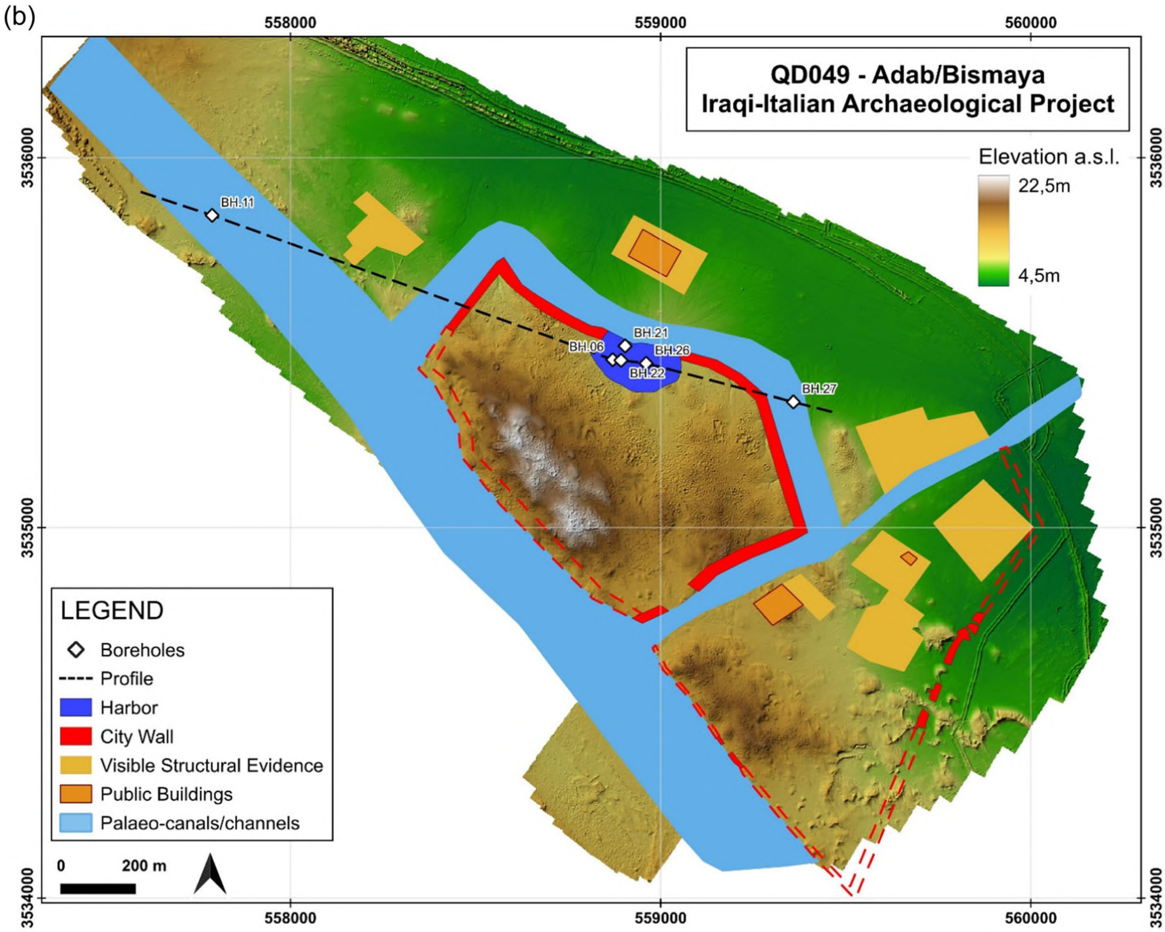


**FIGURE 6** (Continued)

4. *Data processing*: The main geological features of each sediment sample were described, interpreted and represented in logs employing SedLog shareware v. 3.1 (Supporting Information S1: 4). The chronology of the stratigraphic units was established, when available, based on both pottery sherds and radiocarbon dating. The main target of this work was to explore selected basins and canals to date them. In some boreholes, the abundance of ceramic sherds was such that we could confidently assign an age to the fillings down to 6–7 m below the surface (such as at Adab). The absence of pottery characterises boreholes drilled outside anthropic structures, as well as the deepest parts of the drilled basins/canals. The latter showed an increased frequency of peculiar facies characters, including a higher degree of compaction, associated with clay-coated vertical fractures; mottling intensity and relative abundance of pedogenic carbonates, diffuse or, more often, forming caliches of 1–10 mm; and, finally, local gypsum laths (Figure 10). We are aware that the facies characters of the hydraulic structure fillings are mostly identical to those occurring in the vast alluvial plain surrounding them. Although with some uncertainties, the transition from their filling to the prehydraulic substrate was recognised by using a combination of the absence of ceramics, sample elevation above sea level and facies. The deposits within the harbours and canals display different lithologies, related to different hydraulic regimes, but formed in the same artificial environment. For this reason, we could not adopt facies schemes proposed for natural environments, such as Miall (1985).
5. *Topographic analysis*: The low-altitude UAV orthophotogrammetry on the targeted sites allowed us to frame the information from each borehole within an extremely accurate georeferenced topographic system. Orthophotographs pinpointed the position and dimensions (length, width) of canals and potential harbours, and the digital elevation models served as a basis for very accurate topographic profiles created using the QGIS plugin Profile Tool (v. 4.1). This tool plotted profile lines along the boreholes and the broader context of the hydraulic structure (canal/basin) associated with them. Stratigraphic correlations were based on the main facies and lithological intervals of the filling of the hydraulic structure (canal/harbour), the hydraulic structure itself and the substrate preceding it. The elevation of the boreholes (expressed in masl) was calculated through GIS raster analysis 'sample raster values', using the UAV image-derived DEM available for each site.

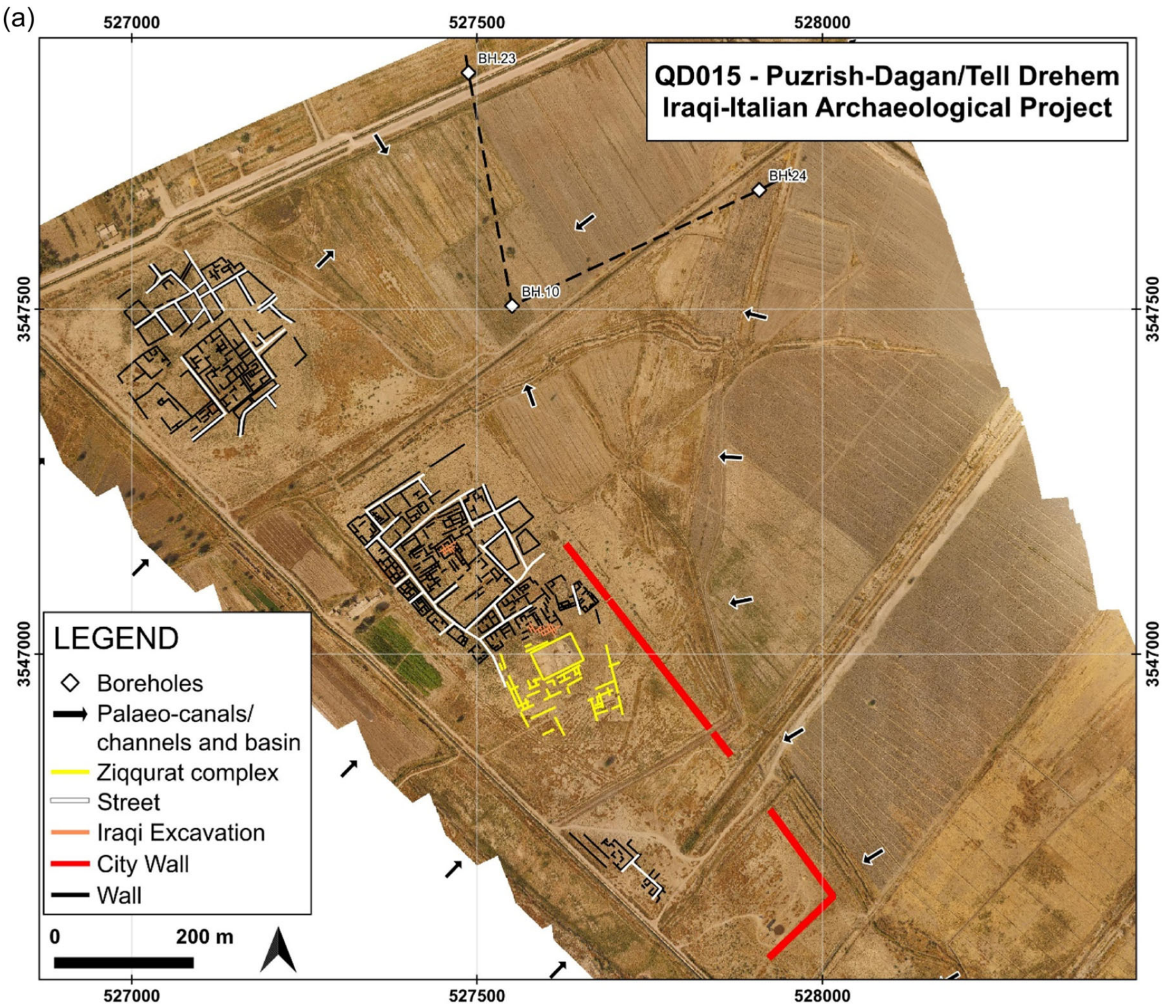


**FIGURE 7** Puzrish-Dagan/Tell Drehem (third to second millennium B.C.E.), location of boreholes and profile with the main anthropic evidence identified through remote sensing and field surveys (data acquisition and processing by the QADIS project): (a) on the unmanned aerial vehicle (UAV) image 2016; (b) on the UAV image-derived digital elevation model.

## 5 | RESULTS

We present here the results of selected geoarchaeological investigations we carried out within the QADIS area, following the chronological order of results.

### 5.1 | Tell Rumah

We examined four boreholes along a 460 m long north-east/south-west transect intersecting a 25-m-wide canal along which the two settlements were established (see Figure 4 and Supporting Information for the borehole details). We observed well-sorted fine sand in BH.18, between 0 and 0.80 m (SU 223) and −1.90 to 2.90 m (SUs 226–228), followed downwards by mud with pedogenic carbonates and local gypsum laths (Figure 11). In BH.19, drilled within the settlement, ceramics were found down to ca. −1.40 m (SU 235). Medium-to-fine and well-sorted sand was also observed in BH.20 (SU 240, −1.25/3.00 m). In this last borehole, the absence of ceramics and its location outside the main settlement suggests a natural origin for these deposits, which could be possibly interpreted as channel avulsion or a crevasse that was formed during the middle Holocene, long before the establishment of the settlement, as suggested by the radiocarbon date of sample BH.18.s.039 (see Table 3).

### 5.2 | Tell Umm al-Fugas

Two boreholes (BH.01 and BH.02) were drilled at Umm al-Fugas, the first one (BH.01) in the middle of the watercourse running inside the settlement, and the second one (BH.02) in the watercourse passing next to the eastern end of the settlement (see Figure 5 and Supporting Information for the borehole details). The BH.02 core did not provide sufficient information, whereas in BH.01 we recognise prehydraulic evidence from −3.70 m to the bottom of the core (SU 23), consisting of compact grey-greenish clay, with a blocky structure and reddish mottles, devoid of ceramic fragments (Figure 12). This lower SU is followed upcore by ceramic-rich dark mud and silt,

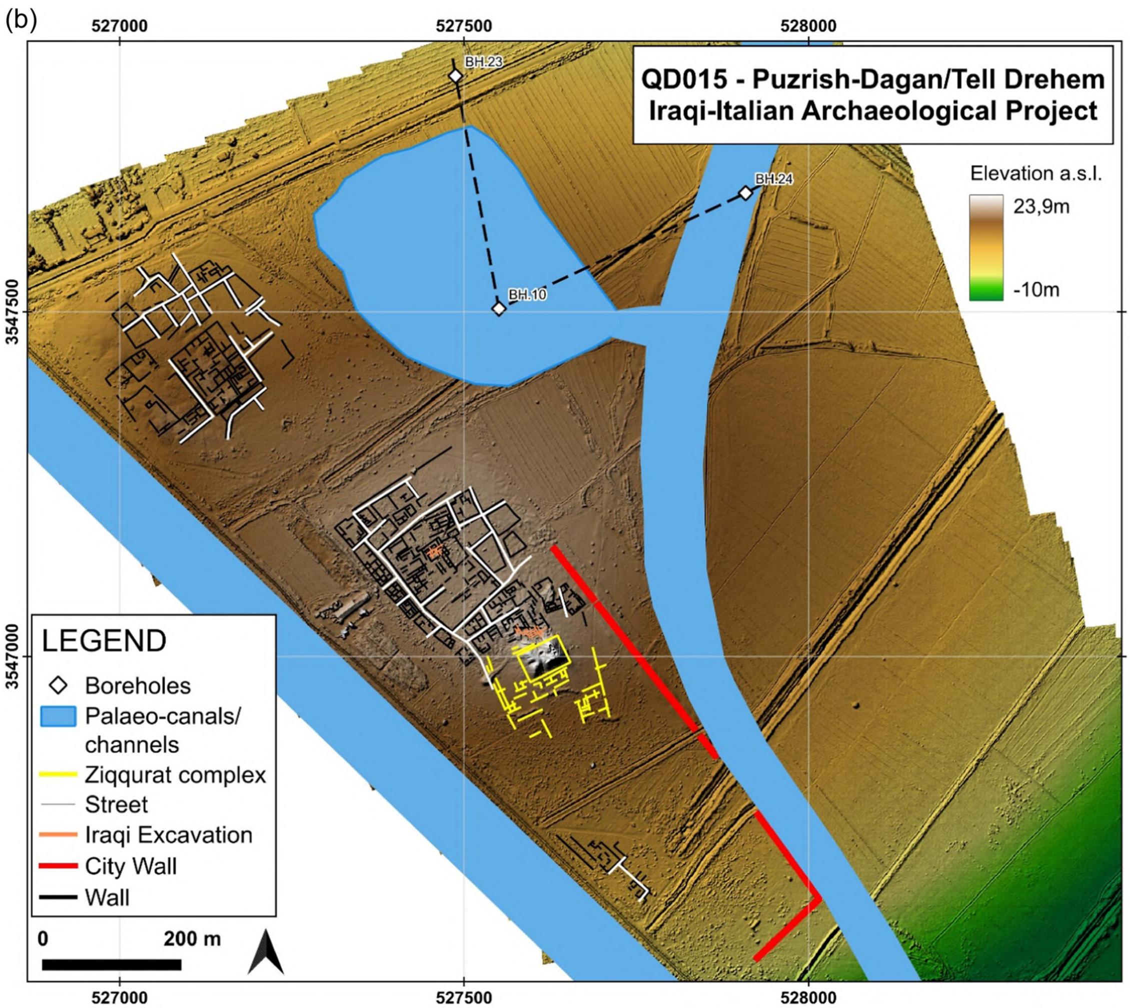


**FIGURE 7** (Continued)

up to −1.40 m (SUs 7–12), and by well-sorted medium-fine sand, dark until −0.20 m and light grey and loose above that. The chronology of the watercourse filling in BH.01 shows Early Uruk materials at around −3.00 m (SU 11), preceded by Early Dynastic I materials between −1.10 and −2.80 m (SUs 6–10). The uppermost sandy filling has no pottery or diagnostic material, suggesting that this coarse filling was deposited after the site's abandonment.

The almost regular shape of both watercourses inferred from remote sensing, together with the stratigraphic evidence obtained through the geoarchaeological analysis, supports the hypothesis that they are artificial, possibly fed by the Euphrates (Marchetti et al., 2019), and exploited for a long time. The radiocarbon dating of 2584–2470 cal. B.C.E. of the central SU associated with the intrasite canal (BH.01) would rather fit with the Early Dynastic III period. However, the rich pottery assemblage from the said SU and the following ones of BH.01 dates to the Early Dynastic I. This datum, coupled with the total absence of Early Dynastic III materials from the survey and sounding at the site, supports the possible reuse of the dated charcoal. The lowermost radiocarbon date (4789–4653 cal. B.C.E.) is far too much older than the archaeological context and is thus also suggestive of reuse.

## 5.3 | Bismaya/Adab

We drilled six boreholes at Adab to explore and date the canals and intraurban harbour mentioned above along a 1700-m-long NW-oriented transect. BH.11 was drilled in an abandoned Tigris channel bed, BH.27 in the abandoned bed of the canal and BH.06, BH.22 and BH.26 inside the possible harbour and breakwater (BH.21) (see Figure 6 and Supporting Information for the borehole details).

The 5.40-m-deep BH.11 in the middle of the Tigris paleochannel shows well-sorted coarse sand, interbedded with mud and clay, compact at the top—possibly due to the stacking of the naturally migrating channel and associated abandonment facies (clay plugs) of the river—and devoid of pottery (Figure 13). This canal, fed by the Tigris and crowning the central part of the city in BH.27, at the southwestern end of the transect, also shows 3.90 m (SUs 293–295)

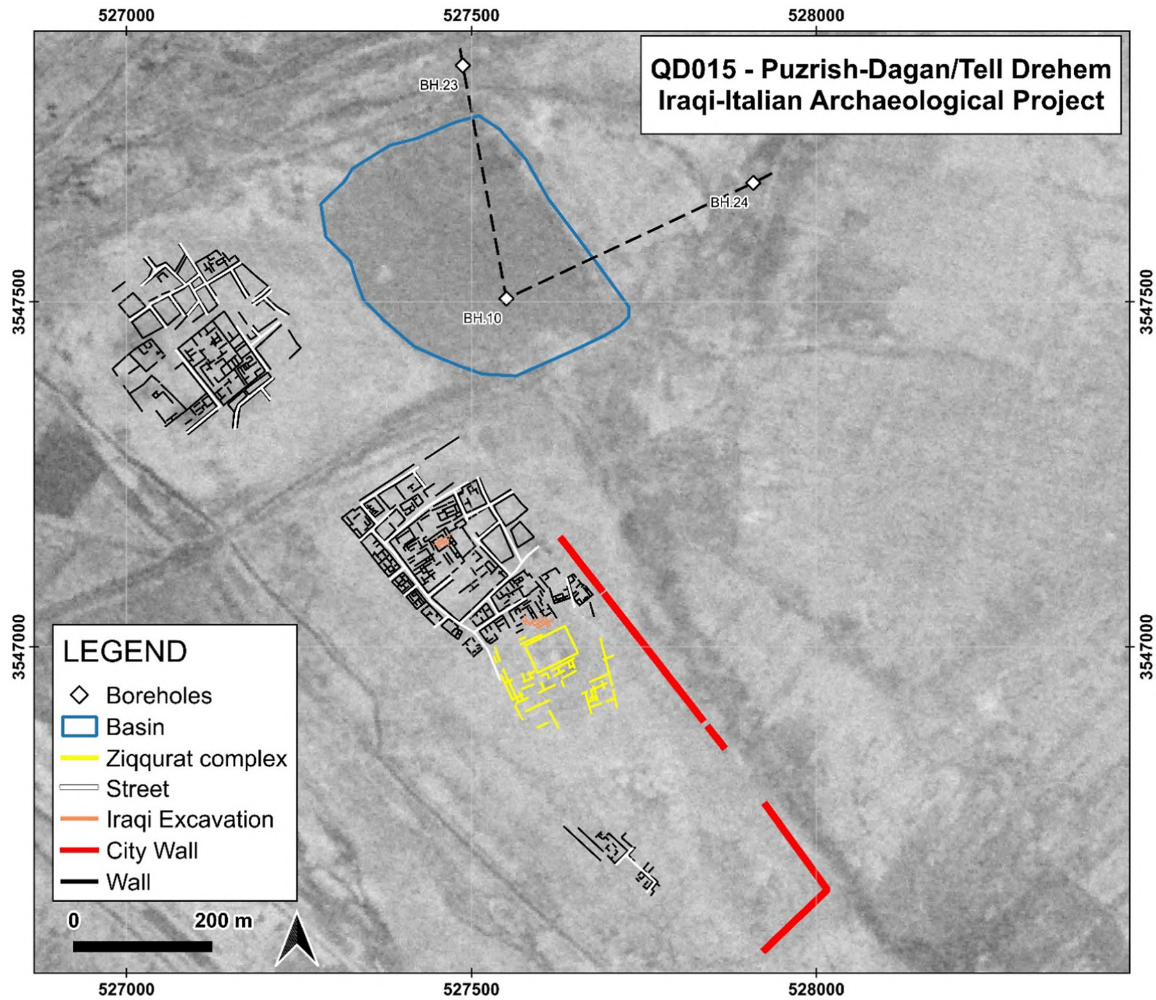


**FIGURE 8** Puzrish-Dagan/Tell Drehem (third to second millennium B.C.E.), location of boreholes and profile with the main anthropic evidence identified on the CORONA satellite imagery (DS1104-2138df040, 1969, courtesy of the Center for Advanced Spatial Technologies, University of Arkansas/US Geological Survey) and field survey (data acquisition and processing by the QADIS project).

of ceramic-free well-sorted and homogeneous coarse sand (*Unio crassus* shells at −3.40 m, SU 295), covering a sequence of very compact silt and fine sand with a radiocarbon date of 4408–4340 cal. B.C.E. (SU 299), possibly belonging to the natural prehydraulic structure substrate. Of most significant interest were the results provided by the four boreholes made in the possible area of the harbour (Figure 14), although possibly only one of them reached the prehydraulic structure substrate due to the depth limitations of the manual auger. The filling deposits show variable grain size along metre-deep units and frequent ceramic sherds along the cores. The caliche, blocky structure and mottles typical of the prehydraulic structure substrate of other cores were not observed in the ones drilled within the harbour. Only in the last 1.20 m of BH.26 did we observe more compact mud with reddish mottles on the top, which we interpreted as prehydraulic substrate. These data corroborate the hypothesis that there was an urban harbour here, which must have been as deep as the 8 m reached in BH.06. The uppermost 2–3 m of boreholes BH.06, BH.22 and BH.26 contained abundant small ceramic sherds from several periods, as well as charcoal with radiocarbon ages earlier than the settlement. This mixing in the uppermost part of the internal basin filling was probably produced by run-off events from the settled areas around the basin. This hypothesis is plausible, based on both the existence of a topographic depression here and the high concentration of pottery, which included both weathered sherds and, in larger quantities, well-preserved diagnostic sherds, such as rims, decorated sherds and bases. BH.21, drilled in the northern limit of the basin (see Figure 6b), displays a coarse-grained succession with rare ceramics up to −5.20 m (SU 246) and a finer sandy bottom at around −6.00 m (SU 324), with abundant carbonates and gypsum laths. We interpreted this succession of layers, so different from that of the nearby basin, as belonging to the harbour's breakwater structure.

The boreholes projected on the profile from the high-resolution DEM provide further insights for identifying the waterways and the harbour (see Figure 6b). The current surface level of the harbour lies 4 m below the maximum elevation attested for the settled area to the west of it, while the current surface of the main canal is −14 m from the top of the settled area and −9 m from the basin. This significant

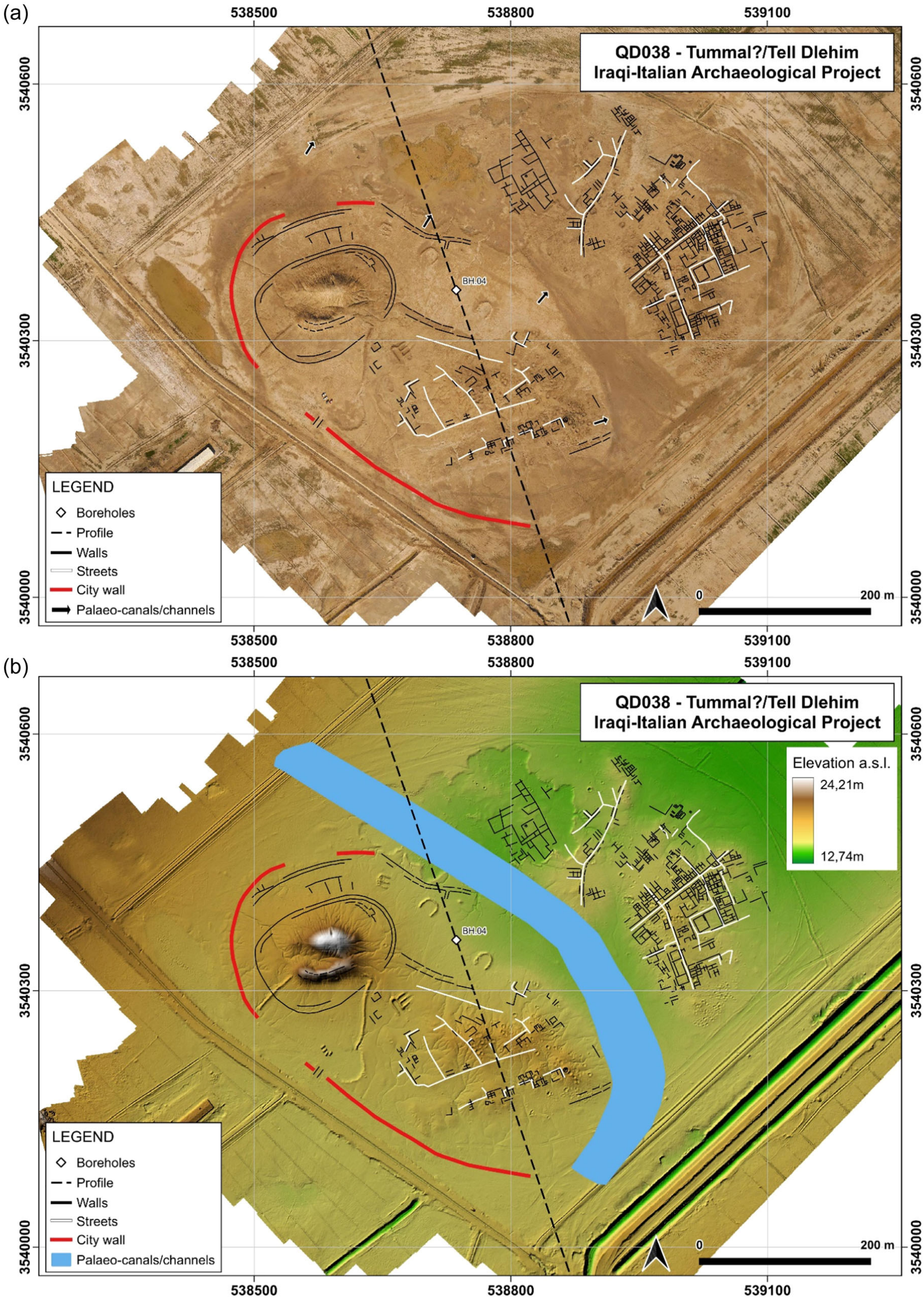


**FIGURE 9** Tummal (?)/Tell Dlehim (late third–early second millennium B.C.E.), location of boreholes and profile with the main anthropic evidence identified through remote sensing and field survey (data acquisition and processing by the QADIS project): (a) on the unmanned aerial vehicle (UAV) image 2016; (b) on the UAV image-derived digital elevation model.


FIGURE 10 Example of core material retrieved by an auger (BH.04, Tell Dlehim): (a) Dark brown well-sorted sandy silt (SU 27, −2.50 m); (b) grey-greenish fine clay with brownish mottles (SU 28, −4.50 m).

difference in elevation between the harbour and the site area surrounding the basin could explain the observed mix of archaeological deposits interpreted as colluvium. This interpretation is further strengthened by analysis of UAV imagery and ground truthing, which show the presence of recent rills created by seasonal rains sloping from the site towards the harbour. It is worth noting that, in our interpretation, the natural bottom of the canal lies 2–3 m higher than the bottom of the harbour basin.

While the deposits observed in the cores confirmed our preliminary functional interpretation of this area of the site as an intraurban harbour, $^{14}$C determination and the study of the pottery sherds yielded unexpected dates. While the Early Dynastic III is widely recognised as the main period of occupation of the site (see above), the greater majority of the diagnostic pottery sherds retrieved in the SUs of the three cores (BH.06, BH.22 and BH.26) can be safely assigned to the Early Dynastic I (with only a few possibly ranging up into the Early Dynastic III and just a handful dating to the Middle Uruk period). This datum is supported by a radiocarbon determination from BH.06 (SU 42) at −5.10 m of 2780–2621 cal. B.C.E., corresponding to the late Early Dynastic I (Table 3). We may therefore presume that the intraurban harbour (and most likely the artificial canal) was already built during the late Early Dynastic I and remained in use at least until the Early Dynastic III. The radiocarbon analyses from the intraurban harbour area and the breakwater also yielded three somewhat coherent dates around the mid-fourth millennium B.C.E., which coincides with the Middle Uruk period (Table 3). We interpreted these samples as pertaining to the earliest settlement documented during the intensive survey, dating to the Early Dynastic I (Marchetti et al., 2019, 2020). The presence of a radiocarbon sample from the same period in the breakwater further supports the hypothesis that some earlier materials were reused for its construction.

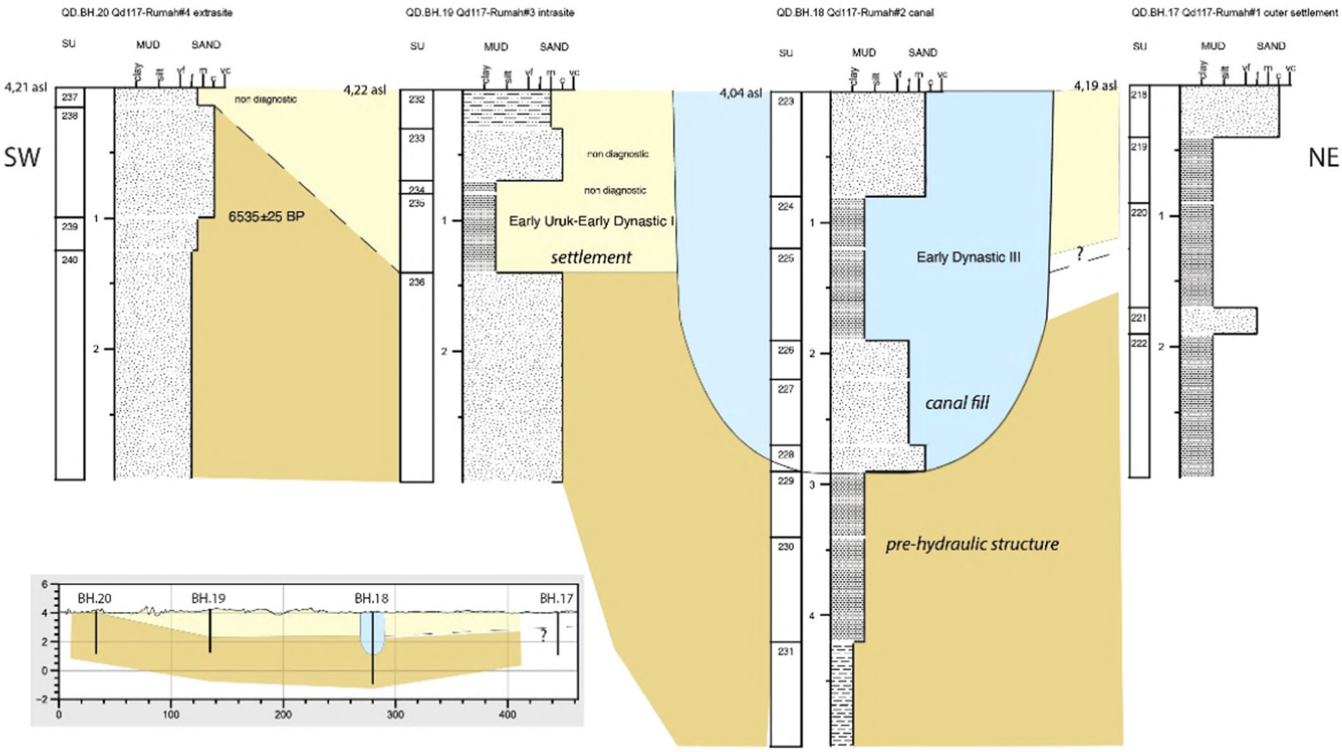


**FIGURE 11** Tell Rumah (4th millennium B.C.E.): Correlation between the four boreholes, with the indication of the stratigraphic units, the occurrence of radiocarbon and ceramic dating and the main interpretations: settlement, prehydraulic structure substrate and canal filling. In the inset, the boreholes are projected on a high-resolution topographic profile, to show the real geometry (*x* = distance as m; *y* = elevation as m asl).

## 5.4 | Tell Drehem/Puzrish-Dagan

We drilled three boreholes along a 750 m North–South transect, then a southwest–northeast of equal length, to explore and date two previously identified canals to the North and East (BH.23 and BH.24, respectively), as well as a potential intraurban harbour (BH.10) detected through remote sensing and ground truthing (see Figure 7 and Supporting Infromation for the borehole details).

Between −0.60 and −2.90 m (SUs 268–271), BH.24 shows a succession of very fine sand and mud, locally rich in carbonates and associated with highly weathered mid-to-late third millennium B.C.E. pottery sherds (at the bottom of the unit), followed downwards by a continuous sequence of muds (SU 272) ending with very compact mud with carbonates and mottles (SU 321) (Figure 15). Collectively, these elements confirm the existence of a canal to the east of the site that was in use as early as the Early Dynastic III, based on the pottery assemblage. BH.23 shows a similar pattern to BH.24, characterised by fine-to-medium sand and local silty interbeds from the surface down to −2.20 m (SUs 257–262), with local carbonates and scattered small non-diagnostic pottery sherds. A monotonous unit of silt and mud follows underneath, locally with a darker colour and vertical fractures (SU 263). These data confirm the existence of a large canal north of the site, although further ground research is needed to provide a clear date for it. BH.10 was drilled in the centre of the area, preliminarily identified as the city's harbour. The borehole's stratification showed a sharp and clear boundary at around −5.00 m (SU 69) between the monotonous mud of the prehydraulic structure substrate and the canal-filling succession, showing brownish silt to fine sand, with sparse occurrence of ceramics. Similar brownish silt has been described in the harbour of Ostia (Goiran et al., 2014).

The correlation between the diagnostic pottery assemblage and the radiocarbon determination provided another interesting, unexpected result. Two radiocarbon dates from SUs 67 and 68 yielded coherent dates (3106–3001 and 3029–2911 cal. B.C.E.) coinciding with those of the Jemdet Nasr period (3100–2900 B.C.E.). The pottery assemblage also confirms this datum from SU 67, as it includes both Jemdet Nasr and Early Dynastic I specimens. We may therefore presume that an artificial basin, possibly used as a fluvial harbour, was already present at Tell Drehem during the Jemdet Nasr period, about a century before the one at Adab (see above). The presence of this harbour matches the evidence from the intensive survey conducted between 2016 and 2017 at the site (Marchetti et al., 2019), which confirmed the existence of a small settlement in the two main southern mounds as early as the fourth millennium B.C.E. It is impossible to determine the size of this early harbour. However, the limited size of the Jemdet Nasr settlement suggests that it was of a size proportional to it, which expanded during the third millennium B.C.E., probably reaching its maximum extent (the one visible from satellite imagery) during the Ur III period.

**TABLE 3** Results of the $^{14}C$ analyses of the samples from the boreholes discussed in the present paper (full list available in Supporting Information S1: 2).

| Laboratory code (QADIS sample) | Season | Site | Borehole | Location | Provenance | $\delta^{13}C$ (‰) | $^{14}C$ age years (B.P.) | Date cal. B.C. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | From | To | % |
| UGAMS46276 (BH.17.s.012) | 2017 | Tell Umm al-Fugas | BH.01 | Canal | SU 10 (−2.50 m) | −25.7 | 4027 ± 25 | 2584 | 2470 | 90.5 |
| UGAMS46277 (BH.17.s.013) | 2017 | Tell Umm al-Fugas | BH.01 | Canal | SU 11 (−3.00 m) | −25.1 | 5840 ± 25 | 4789 | 4653 | 86.6 |
| UGAMS46278 (BH.17.s.070) | 2017 | Bismaya/Adab | BH.06 | Basin | SU 41 (−4.50 m) | −24.0 | 4875 ± 25 | 3661 | 3632 | 62.3 |
| UGAMS46279 (BH.17.s.072) | 2017 | Bismaya/Adab | BH.06 | Basin | SU 42 (−5.10 m) | −25.9 | 4133 ± 25 | 2780 | 2621 | 62.8 |
| UGAMS46281 (BH.17.s.108) | 2017 | Tell Drehem/Puzrish-Dagan | BH.10 | Basin | SU 67 (−3.80 m) | −24.1 | 4426 ± 25 | 3106 | 3001 | 61.7 |
| UGAMS46282 (BH.17.s.142) | 2017 | Tell Drehem/Puzrish-Dagan | BH.10 | Basin | SU 68 (−3.90 m) | −23.7 | 4371 ± 25 | 3029 | 2911 | 88.7 |
| UGAMS46283 (BH.18.s.003) | 2018 | Bismaya/Adab | BH.21 | Breakwater | SU 242 (−1.40 m) | −27.1 | 28,117 ± 80 | 30,322 | 29,769 | 82.9 |
| UGAMS46284 (BH.18.s.016) | 2018 | Bismaya/Adab | BH.22 | Basin | SU 251 (1-80 m) | −24.7 | 4914 ± 25 | 3715 | 3640 | 87.1 |
| UGAMS46285 (BH.18.s.039) | 2018 | Tell Rumah | BH.20 | Outer settlement | SU 238 (−1.00 m) | −24.6 | 6535 ± 25 | 5561 | 5471 | 89.1 |
| UGAMS46286 (BH.18.s.086) | 2018 | Bismaya/Adab | BH.26 | Basin | SU 282 (−3.80 m) | −21.4 | 4936 ± 25 | 3771 | 3647 | 95.4 |
| UGAMS46288 (BH.18.s.133) | 2018 | Bismaya/Adab | BH.27 | Canal | SU 299 (−6.90 m) | −25.0 | 5535 ± 25 | 4408 | 4340 | 63.8 |
| UGAMS46289 (BH.18.s.141) | 2018 | Tell Drehem/Puzrish-Dagan | BH.23 | Canal | SU 264 (−2.60 m) | −26.6 | 3570 ± 25 | 1980 | 1877 | 82.3 |
| UGAMS46290 (BH.18.s.154) | 2018 | Tell Drehem/Puzrish-Dagan | BH.24 | Canal | SU 271 (−2.70 m) | −23.8 | 5221 ± 25 | 4055 | 3966 | 87.6 |

*Note*: Radiocarbon calibration through OxCal 4.4 v. 2021 using IntCal20curve resolution 5.

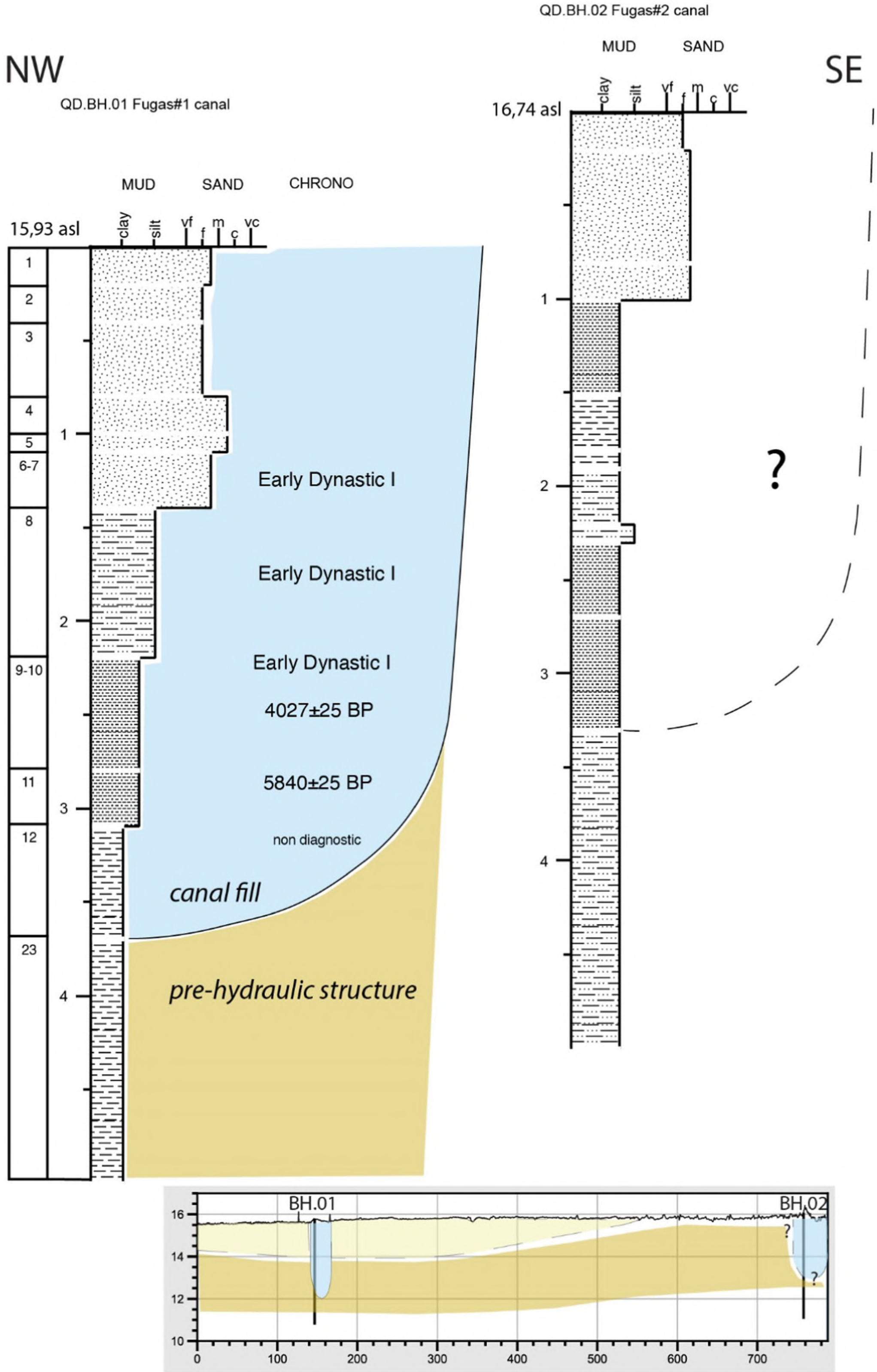


FIGURE 12 Tell Umm al-Fugas (fourth to third millennium B.C.E.): Correlation between the two boreholes, with the indication of the stratigraphic units, the occurrence of radiocarbon and ceramic dating and the main interpretations: settlement, prehydraulic structure substrate and canal filling. In the inset, the boreholes are projected on a high-resolution topographic profile, to show the real geometry (*x* = distance as m; *y* = elevation as masl).

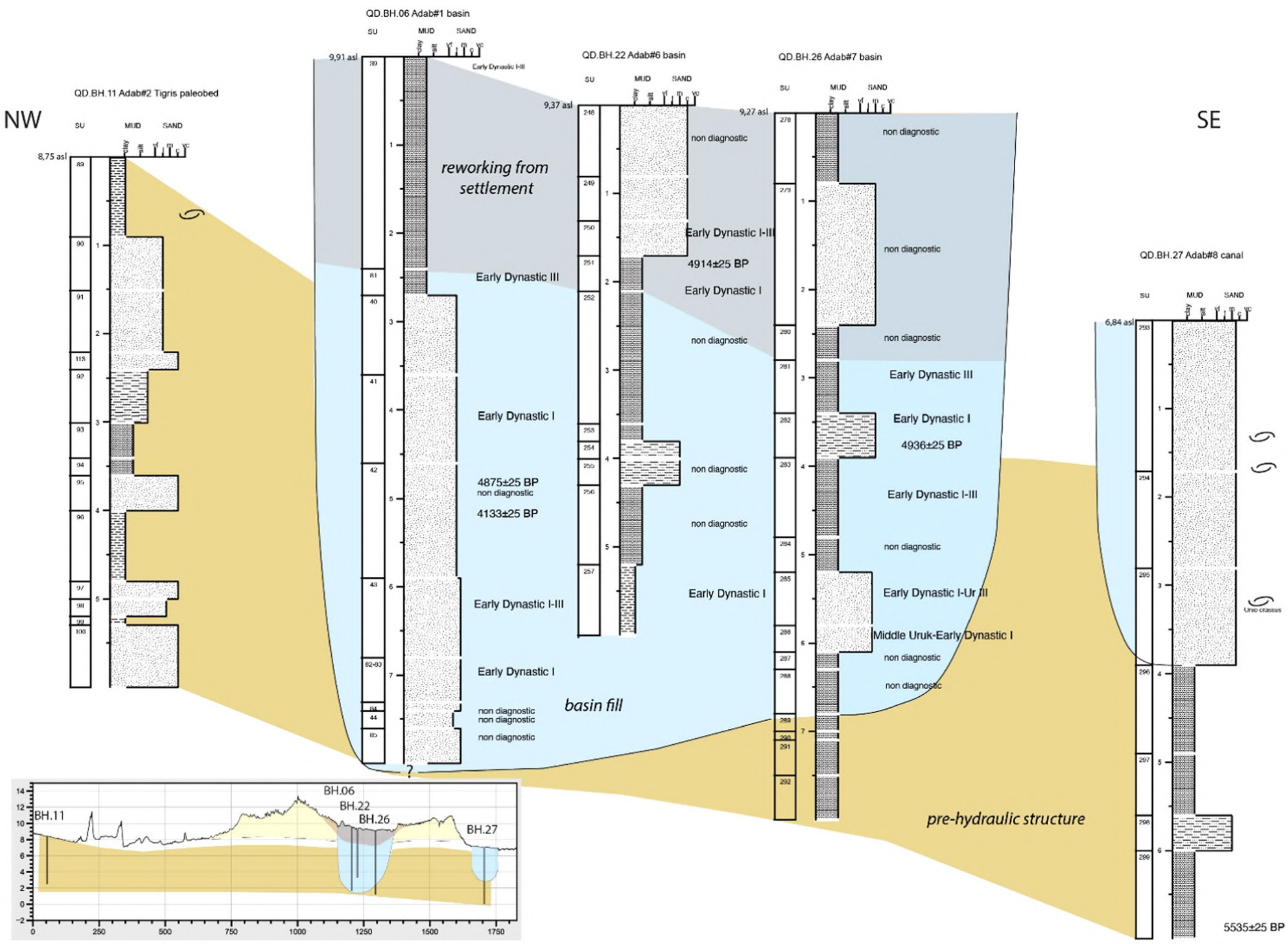


**FIGURE 13** Adab/Bismaya (third millennium B.C.E.): Correlation between the five boreholes, with the indication of the stratigraphic units, the occurrence of radiocarbon and ceramic dating and the main interpretations: settlement, prehydraulic structure substrate, canal and harbour filling, with possible reworked material on the top. In the inset, the boreholes are projected on a high-resolution topographic profile, to show the real geometry ($x$ = distance as m; $y$ = elevation as masl).

## 5.5 | Tell Dlehim/Tummal (?)

At Tell Dlehim we drilled a single 9-m-deep borehole (BH.04) in the centre of an area preliminarily interpreted as a harbour based on the UAV high-resolution imagery and the DEM, which showed a depression bordered by banks (see Figure 8 and Supporting Information for the borehole details). From the ground surface to −3.30 m (SU 27) there is soft brownish well-sorted fine silty sand. Below it, one observes a sharp change in lithology: an interval of compact clay, yellowish to brownish-reddish (SUs 28–30, 78–79), with evidence of gypsum laths and caliches (Figure 16). This interval is possibly the bottom of the basin/harbour filling. In light of the geoarchaeological analysis, the evidence between the harbour and the canal, detected through remote sensing and initially identified as a street, may be interpreted a breakwater instead. The identification of a structure through remote sensing supports this interpretation. Unfortunately, the absence of diagnostic materials from the core makes it impossible to date the harbour; its dating to the city's main occupation phase (Ur III, 2100–2000 B.C.E.) is hence still reliant on the surface materials collected during the survey (Marchetti et al., 2019, 2020).

## 6 | DISCUSSION

The results of our research can be placed in the context of both natural and anthropogenic events of the relevant historical phases. If we compare them with the current narratives, the results of the QADIS case studies pertain to three different phases of the early development of hydraulic landscapes in Mesopotamia: (1) the Late Uruk period (3500–3100 B.C.E.); (2) the period around the transition from the fourth to the third millennium B.C.E. (3100–2700 B.C.E., Jemdet Nasr and ED I periods); (3) the mid-late third millennium B.C.E., corresponding to the later history of city-states and the first empires (2700–2000 B.C.E.). The following discussion will consider these three phases in relation to the two initial research questions.

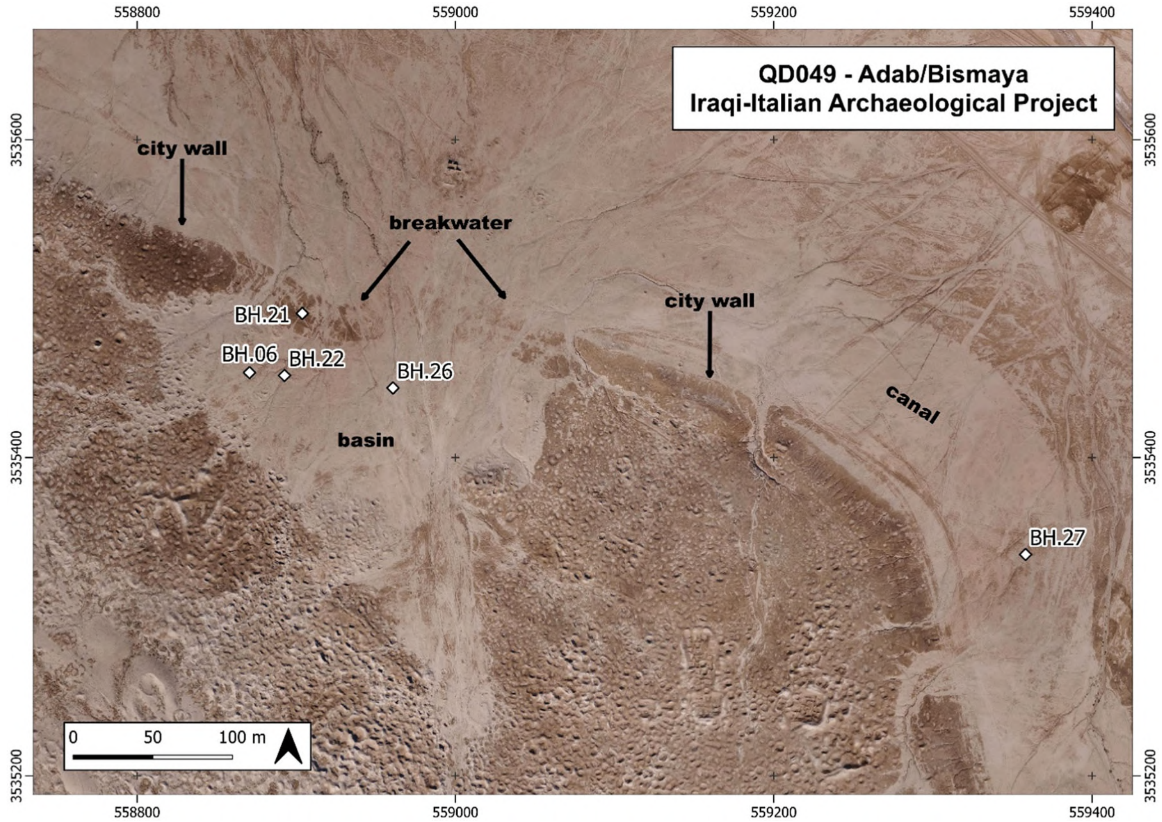


**FIGURE 14** Adab/Bismaya (third millennium B.C.E.): Detail of the boreholes in the intraurban harbour (basin) and the main artificial canal on a 2021 BING satellite image.

## 6.1 | Early attempts at watercourse manipulation. The Late Uruk formative period (3500–3100 B.C.E.)

Data from Tell Rumah allowed us to identify two small settlements located along two almost straight and regular canals, bearing witness to careful planning and improved water management capacity compared to the limited exploitation of natural crevasse splays in previous periods (Rost, 2017; Wilkinson, 2003). However, the lack of visible fields from satellite imagery restricts us from providing more details, such as the presence of a clearly defined multicanal irrigation system or a single spur canal (Wilkinson et al., 2015). Furthermore, this trend does not yet apply to all settlements. As observed in the QADIS area and in the wider Mesopotamian floodplain, during the fourth millennium B.C.E., numerous settlements only or mainly exploited natural waterways. These settlements lacked harbour facilities, generally represented elsewhere by large pseudorectangular basins located within the town (Adams, 2008; Di Giacomo & Scardozzi, 2012; Romano & D'Agostino, 2018; Stone & Zimansky, 2004).

If the data collected from Tell Rumah do not allow precise assessment of the attained level of water management, they contribute to predate the emergence of the earliest artificial watercourses. Therefore, while current narratives (Adams & Nissen, 1972; Pournelle, 2003; Rost, 2017) indicate the Jemdet Nasr period (3100–2900 B.C.E.) as the one witnessing the earliest small-scale attempts for manipulating natural waterway's artificial courses, our geoarchaeological results at Tell Rumah suggest an earlier origin of local-scale small canals, as early as the Middle–Late Uruk period (3500–3100 B.C.E.).

## 6.2 | Large artificial watercourses and harbours: Towards a formalised hydraulic landscape (3100–2700 B.C.E.)

The results achieved at Umm al-Fugas and Adab underline the sociopolitical importance of the fourth to third millennium B.C.E. transition and allow for the construction of an updated narrative on the development of waterscape management strategies in the Mesopotamian alluvium.

Umm al-Fugas confirms the presence of multiple artificial waterways running through the settlement, which had been used for irrigation perhaps as early as the Jemdet Nasr (3100–2900 B.C.E.) and certainly since the Early Dynastic I (2900–2700 B.C.E.). The absence of a city basin/harbour at Fugas does not allow us to hypothesise whether these canals were used for navigation purposes already at that time. On the contrary, both Tell Drehem and Adab revealed a complex system of waterworks, including an artificial basin where boats were docked. The earliest recorded attempt was made around 3100–2900 B.C.E. at the small settlement of Tell Drehem,

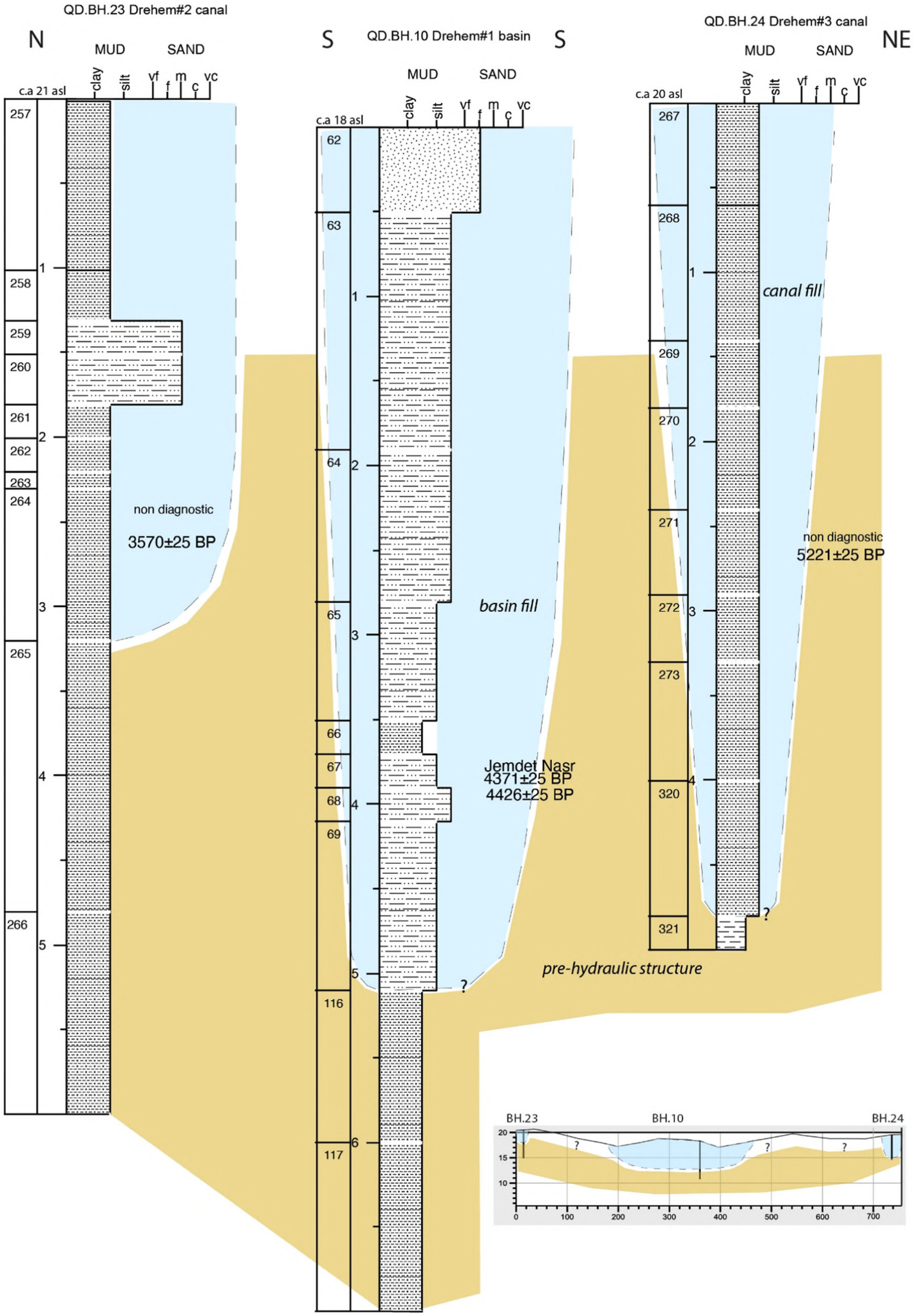


**FIGURE 15** Puzrish-Dagan/Tell Drehem (third to second millennium B.C.E.): Correlation between the three boreholes, with the indication of the stratigraphic units, the occurrence of radiocarbon and ceramic dating and the main interpretations: settlement, prehydraulic structure substrate, harbour and canal filling. In the inset, the boreholes are projected on a topographic profile, to show the real geometry (*x* = distance as m; *y* = elevation as masl).

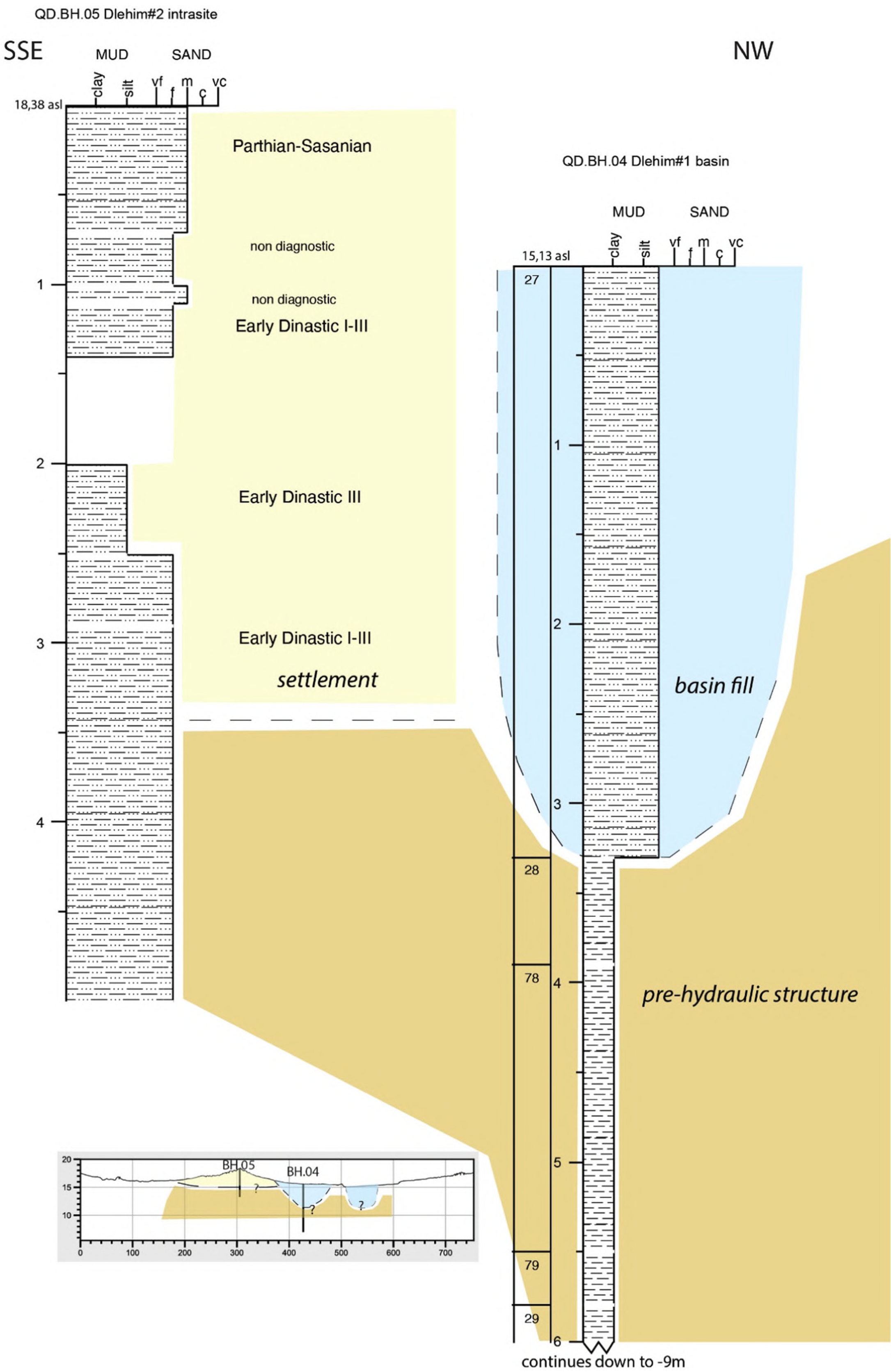


**FIGURE 16** Tummal (?)/Tell Dlehim (third to second millennium B.C.E.): Correlation between the two boreholes, with the indication of the stratigraphic units, the occurrence of radiocarbon and ceramic dating and the main interpretations: settlement, prehydraulic structure substrate, harbour filling. In the inset, the boreholes are projected on a high-resolution topographic profile, to show the real geometry (*x* = distance as m; *y* = elevation as masl).

where a water basin was opened along a canal originating from the Euphrates River. Considering the limited size of the settlement (not exceeding 10 ha), the intraurban harbour must have also been small.

The experience at Tell Drehem might have been improved about a century later; a similar pattern on a larger scale is attested in the late Early Dynastic I at Adab. The cityscape of that town indicates a close interconnection between the plan of the settlement and the canals fed by the Tigris and protecting the settlement from floods. Although it is not possible to determine when this harbour reached its maximum expansion, the results of our drillings strongly argue for construction as early as 2800 B.C.E.

The evidence from Tell Drehem and Adab predates current paradigms identifying the emergence of the first harbours during the mid-third millennium B.C.E., that is, during the Early Dynastic III (Romano & D'Agostino, 2018). Therefore, we may presume that there were early experimental attempts to develop complex artificial canal systems including small intra-site harbours as early as the Jemdet Nasr period, whereas it is during the Early Dynastic I that a more formalised hydraulic landscape emerged, as confirmed by the wide and regular artificial canals and the large harbour at Adab. This new discovery also makes sense in light of the long and important urban history of both cities. At Adab, the harbour must have contributed substantially to the development of the city during the following centuries. It eventually reached an extension of 400 ha around the mid-third millennium B.C.E. (Marchetti et al., 2019).

This new scenario invites observations on the following three research topics: (1) environment, (2) urban development and (3) religious/economic processes.

1. The observations about the environment concern the arid phase documented throughout the Mediterranean and the Middle East at the turn of the millennium (between 3300 and 2800 B.C.E.), known as the 5.2 ka B.P. event (Bar-Matthews et al., 1999; Benati et al., 2021; Danti, 2010; Parker et al., 2006; Riehl et al., 2009; Weiss, 2000; Zanchetta et al., 2014). Although the effects of this long event were different in the various regions of the Near East, its impact on the Mesopotamian alluvium has been confirmed by recent studies (Clarke et al., 2016; Palmisano et al., 2021; Weiss, 2017). The long-term reduction of the river discharge made it possible, or necessary, to engineer the channel banks and make a transition from mere exploitation of crevasse splays to the development of spur canals and eventually the introduction of a more complex herringbone pattern of irrigated fields (Rost, 2017).
2. Significant changes in urbanisation and landscape manipulation in the QADIS region have been recently highlighted (Marchetti et al., 2019). The picture that has emerged shows the culmination of the long-term dwindling of the rural population around 2900 B.C.E., based on evidence that is both archaeological (Algaze, 2017; Wilkinson et al., 2013) and textual (Pollock, 1999; Steinkeller, 2007), and a concomitant increase of the urban population. This increase and shift went hand in hand with a series of complex water and land management processes, as also hypothesised by Wilkinson et al. (2015, fig. 13).
3. The geoarchaeological evidence for the emergence of regulated intercity cooperation in the QADIS region between 3200 and 2700 B.C.E. is confirmed by the evidence of a religious-economic nature, the so-called 'city seals' from the Jemdet Nasr and Early Dynastic I periods (Matthews, 1993; Matthews & Richardson, 2018), that is, impressions made by cylinder seals on clay bureaucratic artefacts—both inscribed tablets and sealings. This evidence may bear witness to an attempt at cultic resilience and possibly to economic interaction among different cities of the Mesopotamian alluvial plain. The seal impressions feature signs representing the names of ancient Mesopotamian cities, many of which can be identified with archaeological sites, including Adab (Matthews & Richardson, 2018, fig. 1).

Our research further stresses how the fourth to third millennium B.C.E. transition was a pivotal moment in the hydraulic history of Mesopotamia. We may hypothesise that the arid phase peaking at around 3200 B.C.E. contributed to inducing deep changes and stimulated the adoption of resilient practices coping with it. During this period, the urban population came to equal the rural one as the latter slowly moved towards the large centres, which were more stable in terms of subsistence and were located along the Tigris and Euphrates. In this context of arid climate and water regulation, new artificial canals spread in a capillary and organised fashion. The growth of urban centres must have fostered forms of intercity economic collaboration and societal resilience, such as those attested by the city seals (Matthews, 1993; Matthews & Richardson, 2018). Therefore, the planning of these large new centres had to take into account people fluxes, the resulting economic needs and the organisation of spaces, which included building harbours and related infrastructure to accommodate and store goods from the growing economic exchanges.

### 6.3 | Reaching maturity: Systematic hydraulic landscape management (2700–2000 B.C.E.)

Textual evidence bears witness to the digging of canals for both irrigation and navigation in the Early Dynastic III (2600–2350 B.C.E.). This became a crucial activity celebrated by local rulers in their propaganda (Richardson, 2012; Rost, 2017; Steinkeller, 2001). Although during this period large sectors of the countryside were depopulated and most of the settlements were distributed along the main watercourses (Adams, 1981; Rost, 2017; Ur, 2013), archaeological and geoarchaeological research confirms that numerous large artificial canals contributed to shape the plans of the emerging large cities. Within the QADIS area, this is certainly true of Tell Drehem and Adab, and probably of Tell Dlehim, during the Ur III period (2100–2000 B.C.E.).

The QADIS geoarchaeological survey has revealed new fluvial harbours, enriching the data set of sites with such structures (Table 1). The most remarkable case is Adab, which in this period was one of the largest regional urban centres (over 400 ha), with its

**TABLE 4** List of documented intraurban harbours in southern Mesopotamia (after Adams, 2008; Di Giacomo & Scardozzi, 2012; Hammer, 2019; Romano & D'Agostino, 2018; Stone & Zimansky 2004; Ur, 2013).

| Site name | Site size | Harbour position | Harbour chronology | Harbour dimensions (approximate) Maximum length (m) | Maximum width (m) | Approximate area (ha) |
|---|---|---|---|---|---|---|
| Tell Drehem/Puzrish-Dagan | 80 | Along a secondary channel inside the city | 3100 B.C.E. onwards | 320 | 280 | 9 |
| Bismaya/Adab | 462 | Along a secondary channel inside the city | 2800 B.C.E. onwards | 242 | 125 | 24 |
| Tell Dlehim/Tummal (?) | 36 | Along the main channel inside the city | 2100 B.C.E. (?) onwards | 150 | 90 | 1.3 |
| Abu Tbeirah | 42 | Along the main channel inside the city | 2600 B.C.E. (?) onwards | 210 | 90 | 1.7 |
| Tell Jokha/Umma | 176 | Along the main channel inside the city | 2600 B.C.E. (?) onwards | 340 | 120 | 14 |
| Tell Lawh/Girsu | 200–500 | Along a secondary channel inside the city | 2600 B.C.E. (?) onwards | 340 | 170 | 5.8 |
| Tell Abu Duwari/Mashkhan-Shapir (western harbour) | 72 | Along a secondary channel inside the city | 1800 B.C.E. onwards | 160 | 85 | 1.4 |
| Tell Abu Duwari/Mashkhan-Shapir (eastern harbour) | 72 | Along a secondary channel inside the city | 1800 B.C.E. onwards | 130 | 65 | 0.8 |
| Tell al-Muqayar/Ur (western harbour) | 120–500 | Along a secondary channel inside the city | Late third millennium B.C.E. onwards | 100 | 80 | 1.3 |
| Tell al-Muqayar/Ur (northern harbour) | 120–500 | Along a secondary channel inside the city | Late third millennium B.C.E. onwards | 145 | 135 | 3.5 |

*Note*: If not available from previous publications, the area of each harbour has been calculated through remote sensing (Google Earth satellite imagery).

harbour being the largest currently known (24 ha). A similar long-term trend may be also supposed for Tell Drehem (although more data are necessary to confirm this hypothesis), which began to slowly grow in the mid-third millennium B.C.E. to eventually exceed 80 ha during the Ur III period. This trend continued and spread further in subsequent periods, as the fluvial harbours of Mashkan Shapir and Ur bear out (Table 4; Di Giacomo & Scardozzi, 2012; Stone & Zimansky, 2004), as well as the port identified by the QADIS project at Tell Dlehim/Tummal.

An analysis of the shape and location of intraurban harbours suggests a shared strategy. All are pseudorectangular and their size is generally proportional to that of the city. Moreover, they are located in the inner part of the town and connected with the main river through an artificial canal, possibly to protect boats and fluvial infrastructure from seasonal floods.

The new data presented here, combined with archaeological and textual evidence, show that the changes that began during the fourth to third millennium B.C.E. transition came to maturity as early as the Early Dynastic II–III (2700–2350 B.C.E.), and that fluvial harbours were widespread both in large and small towns.

## 7 | CONCLUSIONS AND FUTURE TRAJECTORIES

Our research has cast new light on the development of the hydraulic landscape in southern Mesopotamia between the Middle Uruk and Ur III periods (3500–2000 B.C.E.). We built on previous paradigms and narratives developed by regional studies (Rost, 2017; Wilkinson, 2003; Wilkinson et al., 2013) and recent local survey projects (Marchetti et al., 2017, 2019, 2020; Marchetti & Zaina, 2020) to tackle issues regarding the development of Mesopotamian waterscapes, including the creation of artificial canals and urban fluvial harbours. We selected case studies representing specific historical phases and integrated different research methods, including intensive archaeological surface collection, remote sensing of VHR airborne and spaceborne imagery, UAV orthophotos, subsurface drilling and sample analysis.

The results achieved by the QADIS project suggest that the transition between the fourth and third millennium B.C.E. (from the Jemdet Nasr to the Early Dynastic I period) was a crucial phase for advances in water management in southern Mesopotamia. At that time, canals were successfully implemented for the first time and started spreading in a more comprehensive and systematic way, as the cases of Umm al-Fugas, Tell Drehem and Adab bear out. These findings confirm, at a greater level of detail, a trend already documented within the entire QADIS project area as inferred from the distribution of sites and paleochannels (Marchetti et al., 2019). The harbours of Tell Drehem and Adab and their attribution respectively to the Jemdet Nasr (3100–2900 B.C.E.) and the Early Dynastic I (2900–2700 B.C.E.) are currently the earliest documented in the Mesopotamian plain (Table 4), also pre-dating by several centuries the complex dynamics that led to the formalisation of hydraulic landscapes.

Although the regional commercial network documented by city seals (Matthews, 1993; Matthews & Richardson, 2018) offers important historical support to the evidence provided by our geoarchaeological and archaeological analysis, the Jemdet Nasr and Early Dynastic I periods still remain insufficiently understood. Several questions remain to be answered before we can claim to have fully understood the development of the hydraulic landscape of ancient Mesopotamia. Notably, although historical (Civil, 1994; Rost, 2015), geoarchaeological (An Heyvaert & Baeteman, 2008; Cole et al., 1998; Morozova, 2005) and ethnographic studies (Fernea, 1970; Rost et al., 2011) have stressed the importance of understanding flood-control systems and devices (e.g., dikes, field embankments, lowlands and marshlands), no attempt has been made so far to detect their presence on the ground. To do so would add another small but crucial piece to the current narrative, and contribute to enrich our understanding of the long-term anthropization of the southern Mesopotamian landscape. Such investigations have already been successfully carried out in the Levant (Geyer & Monchambert, 2003; Giaime et al., 2019) and the Middle Euphrates (Geyer, 2012). In this perspective, a potential offshoot of the QADIS project could be an investigation to ascertain whether there existed basins and lowlands upstream of the cities suitable for being used to manage river water.

### AUTHOR CONTRIBUTIONS

**Simone Mantellini**: Conceptualisation; investigation; writing—original draft; methodology; software; writing—review and editing; formal analysis; data curation; validation. **Vincenzo Picotti**: Writing—review and editing; writing—original draft; data curation; software; methodology; formal analysis; conceptualisation; investigation. **Abbas Al-Hussainy**: Supervision; investigation; methodology; writing—original draft; writing—review and editing. **Nicolò Marchetti**: Conceptualisation; project administration; supervision; resources; funding acquisition; writing—original draft; writing—review and editing; methodology; visualisation. **Federico Zaina**: Data curation; writing—review and editing; writing—original draft; investigation; validation; methodology; formal analysis; conceptualisation; software.

### ACKNOWLEDGEMENTS

At the State Board of Antiquities and Heritage in Baghdad, the friendly and unfailing cooperation of the former Chairmen Qais H. Rasheed and Laith Majeed Hussein, the current Chairman Ali Obeid Shalgham, and all the colleagues is here gratefully acknowledged. The QADIS project is directed by N. Marchetti. Funding for the six survey seasons (carried out each January and October between 2016 and 2018 with additional study seasons in 2019 and 2020) was provided by the Alma Mater Studiorum University of Bologna and the Italian Ministry of Foreign Affairs and International Cooperation (DGDP Directorate, 6th Office). The results presented here were analysed in the framework of the EU-funded project 'EDUU—Educational and Cultural Heritage Enhancement for Social Cohesion in Iraq' (EuropeAid CSO-LA/2016/382-631, https://www.eduu.unibo.it, coordinator N. Marchetti). The radiocarbon determinations were conducted in the framework of the CRANE 2.0 project of Toronto University (https://www.crane.utoronto.ca, coordinator Timothy Harrison) in collaboration with Sturt Manning (Cornell University) and performed at the Center for Applied Isotope Studies, University of Georgia (USA). Thanks are also due to Giampaolo Luglio for UAV data acquisition and processing, and Marco Valeri for the field topographic surveys and the production of maps. We are very grateful to the local authorities and the many friends in Diwaniyah and Afak for their warm reception and constant support. The ongoing project 'KALAM. Analysis, protection and development of archaeological landscapes in Iraq and Uzbekistan through ICTs and community-based approaches', funded by the Volkswagen Foundation and coordinated by N. Marchetti, https://www.kalam.unibo.it, contributed to financing the research presented in this paper. The authors wish to thank the two anonymous reviewers of this paper, who made a significant contribution to its improvement.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in QADIS boreholes 2017–2018 (EDUU Project) at http://www.amsacta.unibo.it/id/eprint/6880/, reference number 10.6092/unibo/amsacta/6880.

## ORCID

*Simone Mantellini* http://orcid.org/0000-0001-8261-6500

## REFERENCES

Adams, R. M. C. (1981). *Heartland of cities. Surveys of ancient settlement and land use on the central floodplain of the Euphrates*. University Press.

Adams, R. M. C. (2008). An interdisciplinary overview of a Mesopotamian city and its hinterlands. *Cuneiform Digital Library Journal*, *2008*(1), 1–23.

Adams, R. M. C., & Nissen, H. J. (1972). *The Uruk countryside: The natural setting of urban societies*. University Press.

Al-Shukri, S. J. (1974). Archaeological survey in the region of Afak area. *Sumer*, *30*, 297–309.

Algaze, G. (2008). *Ancient Mesopotamia at the dawn of civilization: The evolution of an urban landscape*. University Press.

Algaze, G. (2017). Demographic trends in early Mesopotamian urbanism. In C. Maner, M. T. Horowitz, & A. S. Gilbert (Eds.), *Overturning certainties in Near Eastern archaeology. A Festschrift in honor of K. Aslıhan Yener, Leiden* (pp. 25–33). Brill. https://doi.org/10.1163/9789004353572_003

Al-Mutawalli, N., Sallaberger, W., & Shalkham, A. U. (2017). The Cuneiform documents from the Iraqi excavation at Drehem. *Zeitschrift für Assyriologie und vorderasiatische Archäologie*, *107*, 151–217.

Altaweel, M. (2019). Southern Mesopotamia: Water and the rise of urbanism. *WIREs Water*, *6*, e1362.

An Heyvaert, V. M., & Baeteman, C. (2008). A middle to late Holocene avulsion history of the Euphrates River: A case study from Tell ed-Dēr, Iraq, Lower Mesopotamia. *Quaternary Science Reviews*, *27*, 2401–2410.

Anderson, D. G., Maasch, K. A., Sandweiss, D. H., & Mayewski, P. A. (2007). Climate and culture change: Exploring Holocene transitions. In D. G. Anderson, K. Maasch, & D. H. Sandweiss (Eds.), *Climate change and cultural dynamics: A global perspective on mid-Holocene transitions* (pp. 1–23). Elsevier Academic Press.

Aqrawi, A. (2001). Stratigraphic signatures of climatic change during the Holocene evolution of the Tigris–Euphrates Delta, Lower Mesopotamia. *Global and Planetary Change*, *28*, 267–283.

Banning, E. B., Hawkins, A. L., Stewart, S. T., Hitchings, P., & Edwards, S. (2017). Quality assurance in archaeological survey. *Journal of Archaeological Method and Theory*, *24*(2), 466–488.

Bar-Matthews, M., Ayalon, A., Kaufman, A., & Wasserburg, G. J. (1999). The eastern Mediterranean paleoclimate as a reflection of regional events: Soreq cave, Israel. *Earth and Planetary Science Letters*, *166*(1–2), 85–95.

Benati, G., Guerriero, C., & Zaina, F. (2021). The economic and institutional determinants of trade expansion in Bronze Age Greater Mesopotamia. *Journal of Archaeological Science*, *131*, 105398.

Benati, G., Guerriero, C., & Zaina, F. (2022). The origins of political institutions and property rights. *Journal of Comparative Economics*, *50*(3), 946–968.

Civil, M. (1994). *The farmer's instructions: A Sumerian agricultural manual*. Editorial Ausa.

Clarke, J., Brooks, N., Banning, E. B., Bar-Matthews, M., Campbell, S., Clare, L., Cremaschi, M., di Lernia, S., Drake, N., Gallinaro, M., Manning, S., Nicoll, K., Philip, G., Rosen, S., Schoop, U. D., Tafuri, M. A., Weninger, B., & Zerboni, A. (2016). Climatic changes and social transformations in the Near East and North Africa during the 'long' 4th millennium BC: A comparative study of environmental and archaeological evidence. *Quaternary Science Reviews*, *136*, 96–121.

Cole, S. H., Gasche, H., & Verhoeven, K. (1998). Second and first millennium BC rivers in Northern Babylonia. In H. Gasche & M. Tanret (Eds.), *Changing watercourses in Babylonia: Towards a reconstruction of the ancient environment in Lower Mesopotamia* (Vol. 1, pp. 1–64). University Press.

Dalton, M., Spencer, N., Macklin, M. G., Woodward, J. C., & Ryan, P. (2023). Three thousand years of river channel engineering in the Nile Valley. *Geoarchaeology*, *38*, 565–587.

Danti, M. (2010). Late Middle Holocene climate and Northern Mesopotamia: Varying cultural responses to the 5.2 and 4.2 ka aridification events. In A. B. Manwaring, R. Giegengack, & C. Vita-Finzi (Eds.), *Climate crises in human history* (pp. 139–172). Transactions of the American Philosophical Society.

Engel, M., & Brückner, H. (2021). Holocene climate variability of Mesopotamia and its impact on the history of civilisation. In E. Ehlers & K. Amirpur (Eds.), *Middle East and North Africa* (pp. 77–113). Brill. https://doi.org/10.1163/9789004444973_005

Fernea, R. A. (1970). *Shaykh and Effendi: Changing patterns of authority among the El Shabana of Southern Iraq*. Harvard University Press.

Gasche, H. (1998). *Changing watercourses in Babylonia: Towards a reconstruction of the ancient environment in Lower Mesopotamia*. University of Ghent.

Geyer, B. (2012). Ressources en eau et aménagements hydrauliques en Ougarit: état de la recherche. In V. Matoïan, M. al-Maqdissi, & Y. Calvet (Eds.), *Études ougaritiques II*. RSO XX, Éd. (pp. 11–18). Peeters.

Geyer, B., & Monchambert, J.-Y. (2003). Les aménagements hydrauliques. In B. Geyer & J.-Y. Monchambert (Eds.), *La basse vallée de l'Euphrate syrien du Néolithique à l'avènement de l'islam: géographie, archéologie et histoire*. BAH t. 166 (Vol. 1, pp. 175–231). IFAPO.

Geyer, B., & Monchambert, J.-Y. (2014). Canals and water supply in the lower Euphrates valley. *Water History*, *7*, 11–37. https://doi.org/10.1007/s12685-014-0108-4

Di Giacomo, G., & Scardozzi, G. (2012). Multitemporal high-resolution satellite images for the study and monitoring of an ancient Mesopotamian city and its surrounding landscape: The case of Ur. *International Journal of Geophysics*, *2012*, 1–14.

Giaime, M., Marriner, N., & Morhange, C. (2019). Evolution of ancient harbours in deltaic contexts: A geoarchaeological typology. *Earth-Science Reviews*, *191*, 141–167.

Goiran, J. P., Salomon, F., Mazzini, I., Bravard, J. P., Pleuger, E., Vittori, C., Boetto, G., Christiansen, J., Arnaud, P., Pellegrino, A., Pepe, C., & Sadori, L. (2014). Geoarchaeology confirms location of the ancient harbour basin of Ostia (Italy). *Journal of Archaeological Science*, *41*, 389–398.

Hammer, E. (2019). The city and landscape of Ur: An aerial, satellite, and ground reassessment. *Iraq*, *81*, 173–206.

Heyvaert, V. M., Walstra, J., Verkinderen, P., Weerts, H. J., & Ooghe, B. (2012). The role of human interference on the channel shifting of the Karkheh River in the Lower Khuzestan plain (Mesopotamia, SW Iran). *Quaternary International*, *251*, 52–63.

Hilgert, M., & Reichel, C. D. (2003). *Drehem administrative documents from the reign of Amar-Suena*. University Press.

Hritz, C. (2010). Tracing settlement patterns and channel systems in southern Mesopotamia using remote sensing. *Journal of Field Archaeology*, *35*(2), 184–203.

Iraqi Directorate General of Antiquities. (1976). *Atlas of archaeological sites in Iraq*. Ministry of Information, Directorate General of Antiquities.

Jotheri, J., Allen, M. B., & Wilkinson, T. J. (2016). Holocene avulsions of the Euphrates River in the Najaf Area of Western Mesopotamia: Impacts on human settlement patterns. *Geoarchaeology*, *31*, 175–193.

Jotheri, J., Altaweel, M., Tuji, A., Anma, R., Pennington, B., Rost, S., & Watanabe, C. (2018). Holocene fluvial and anthropogenic processes in the region of Uruk in southern Mesopotamia. *Quaternary International*, *483*, 57–69.

Kennett, D. J., & Kennett, J. P. (2006). Early state formation in southern Mesopotamia: Sea levels, shorelines, and climate change. *Journal of Island & Coastal Archaeology*, *1*, 67–99.

Macklin, M. G., Woodward, J. C., Welsby, D. A., Duller, G. A. T., Williams, F. M., & Williams, M. A. J. (2013). Reach-scale river dynamics moderate the impact of rapid Holocene climate change on floodwater farming in the desert Nile. *Geology*, *41*(6), 695–698.

Marchetti, N. (2018). Wandering through early urbanized landscapes in Syro-Mesopotamia. In N. Marchetti & D. Domenici (Eds.), *Urbanized landscapes in early Syro-Mesopotamia and Prehispanic Mesoamerica. Papers of a cross-cultural seminar held in honor of Robert McCormick Adams* (pp. 145–168). Harrassowitz.

Marchetti, N., Al-Hussainy, A., Benati, G., Luglio, G., Scazzosi, G., Valeri, M., & Zaina, F. (2019). The rise of urbanized landscapes in Mesopotamia: The QADIS integrated survey results and the interpretation of multi-layered historical landscapes. *Zeitschrift für Assyriologie und Vorderasiatische Archäologie*, *109*, 214–237.

Marchetti, N., Campeggi, M., D'Orazio, C., Gallerani, V., Giacosa, G., Al-Hussainy, A., Luglio, G., Mantellini, S., Mariani, E., Monastero, J., Valeri, M., & Zaina, F. (2020). The Iraqi-Italian Qadis project: Report on six seasons of integrated survey. *Sumer*, *LXVI*, 177–218.

Marchetti, N., Einwag, B., al-Hussainy, A., Leoni, E., Luglio, G., Marchesi, G., Otto, A., Scazzosi, G., Valeri, M., & Zaina, F. (2017). QADIS. The 2016 Iraqi-Italian survey season in the south-eastern region of Qadisiyah. *Sumer*, *LXIII*, 63–92.

Marchetti, N., & Zaina, F. (2020). Rediscovering the heartland of cities: Early Southern Mesopotamian States in their setting through new field research. *Near Eastern Archaeology*, *83*, 210–221.

Matthews, R. (1993). *Cities, seals and writing: Archaic seal impressions from Jemdet Nasr and Ur*. Gebr. Mann.

Matthews, R., & Richardson, A. (2018). Cultic resilience and inter-city engagement at the dawn of urban history: Protohistoric Mesopotamia and the 'city seals', 3200–2750 BC. *World Archaeology*, *50*, 723–747.

Mayewski, P. A., Rohling, E. E., Curt Stager, J., Karlén, W., Maasch, K. A., Meeker, L. D., Meyerson, E. A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R. R., & Steig, E. J. (2004). Holocene climate variability. *Quaternary Research*, *62*, 243–255.

Menze, B. H., Ur, J. A., & Sherratt, A. G. (2006). Detection of ancient settlement mounds. *Photogrammetric Engineering & Remote Sensing*, *72*(3), 321–327.

Miall, A. D. (1985). Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. *Earth-Science Reviews*, *22*(4), 261–308.

Molina, M. (2008). The corpus of Neo-Sumerian tablets: An overview. In S. J. Garfinkel & J. C. Johnson (Eds.), *The growth of an early state in Mesopotamia: Studies in Ur III administration: Proceedings of the first and second Ur III workshops at the 49th and 51st Rencontre Assyriologique Internationale, London, 10 July, 2003 and Chicago 19 July, 2005* (pp. 19–54). Consejo Superior de Investigaciones Científicas.

Morozova, G. S. (2005). A review of Holocene avulsions of the Tigris and Euphrates rivers and possible effects on the evolution of civilizations in lower Mesopotamia. *Geoarchaeology*, *20*, 401–423.

Palmisano, A., Lawrence, D., de Gruchy, M. W., Bevan, A., & Shennan, S. (2021). Holocene regional population dynamics and climatic trends in the Near East: A first comparison using archaeo-demographic proxies. *Quaternary Science Reviews*, *252*, 106739.

Parker, A. G., Goudie, A. S., Stokes, S., White, K., Hodson, M. J., Manning, M., & Kennet, D. (2006). A record of Holocene climate change from lake geochemical analyses in southeastern Arabia. *Quaternary Research*, *66*, 465–476.

Pirazzoli, P. A. (2005). A review of possible eustatic, isostatic and tectonic contributions in eight late-Holocene relative sea-level histories from the Mediterranean area. *Quaternary Science Reviews*, *24*(18–19), 1989–2001.

Pollock, S. (1999). *Ancient Mesopotamia*. Cambridge University Press.

Pournelle, J. (2003). *Marshland of cities: Deltaic landscapes and the evolution of Early Mesopotamian Civilization* [PhD dissertation, University of California].

Pournelle, J. (2013). Physical geography. In H. Crawford, *The Sumerian world* (pp. 13–32). Routledge.

Rey, S. (2016). *For the gods of Girsu. City-state formation in Ancient Sumer*. Oxbow.

Richardson, S. (2012). Early Mesopotamia: The presumptive state. *Past & Present*, *215*, 3–49.

Riehl, S., Pustovoytov, K. E., Hotchkiss, S., & Bryson, R. A. (2009). Local Holocene environmental indicators in Upper Mesopotamia: Pedogenic carbonate record vs. archaeobotanical data and archaeo-climatological models. *Quaternary International*, *209*(1–2), 154–162.

Roland, T. P., Daley, T. J., Caseldine, C. J., Charman, D. J., Turney, C. S. M., Amesbury, M. J., Thompson, G. J., & Woodley, E. J. (2015). The 5.2 ka climate event: Evidence from stable isotope and multi-proxy palaeoecological peatland records in Ireland. *Quaternary Science Reviews*, *124*, 209–223.

Romano, L., & D'Agostino, F. (2018). The harbour of Abu Tbeirah and the Southern Mesopotamian landscape in the 3rd mill. BC: Preliminary considerations. *Rivista di Studi Orientali*, *91*, 33–45.

Rost, S. (2015). *Watercourse management and political centralization in third-millennium BC Southern Mesopotamia: A case study of the Umma Province of the Ur III period (2112–2004 BC)* [PhD dissertation, Stony Brook University].

Rost, S. (2017). Water management in Mesopotamia from the sixth till the first millennium B.C. *WIREs Water*, *4*, 1–23.

Rost, S., Hamdani, A., & George, S. (2011). Traditional dam construction in modern Iraq: A possible analogy for ancient Mesopotamian irrigation practices. *Iraq*, *73*, 201–220.

Rothman, M. S. (2004). Studying the development of complex society: Mesopotamia in the late fifth and fourth millennia BC. *Journal of Archaeological Research*, *12*, 75–119.

Schrakamp, I. (2018). Irrigation in 3rd millennium Southern Mesopotamia: Cuneiform evidence from the Early Dynastic IIIb city-state of Lagash (2475–2315 B.C.). In J. Berking (Ed.), *Water management in ancient*

*civilizations. Proceedings of the Topoi water management workshop 2016* (pp. 117–195). Edition Topoi.
Sigrist, M. (1992). *Drehem*. CDL Press.
Steinkeller, P. (2001). New light on the hydrology and topography of Southern Babylonia in the third millennium. *Zeitschrift für Assyriologie und Vorderasiatische Archäologie*, *91*, 22–84.
Steinkeller, P. (2007). City and countryside in third-millennium Southern Babylonia. In E. Stone (Ed.), *Settlement and society: Essays dedicated to Robert McCormick Adams* (pp. 185–211). Cotsen Institute of Archaeology.
Steinkeller, P. (2015). The employment of labor on national building projects in the Ur III period. In P. Steinkeller & M. Hudson (Eds.), *Labor in the ancient world: A colloquium held at Hirschbach (Saxony), April 2005. The International Scholars Conference on Ancient Near Eastern Economies 5* (pp. 137–236). ISLET.
Stone, E. C., & Zimansky, P. E. (2004). The anatomy of a Mesopotamian city: Survey and soundings at Mashkan-shapir. Eisenbrauns.
Sun, W., Wang, B., Zhang, Q., Chen, D., Lu, G., & Liu, J. (2021). Middle east climate response to the saharan vegetation collapse during the mid-holocene. *Journal of Climate*, *34*(1), 229–242.
Thompson, W. R., & Zakhirova, L. (2021). *Climate change in the Middle East and North Africa. 15,000 years of crises, setbacks, and adaptation*. Routledge.
Toonen, W. H. J., Graham, A., Pennington, B. T., Hunter, M. A., Strutt, K. D., Barker, D. S., Masson-Berghoff, A., & Emery, V. L. (2018). Holocene fluvial history of the Nile's west bank at ancient Thebes, Luxor, Egypt, and its relation with cultural dynamics and basin-wide hydroclimatic variability. *Geoarchaeology*, *33*(3), 273–290.
Ur, J. (2013a). Patterns of settlement in Sumer and Akkad. In H. Crawford (Ed.), *The Sumerian world* (pp. 131–155). Routledge.
Ur, J. (2013b). CORONA satellite imagery and ancient Near Eastern landscapes. In D. C. Comer & M. J. Harrower (Eds.), *Mapping archaeological landscapes from space* (pp. 21–32). Springer Science + Business Media.
Ur, J. (2022). Remote sensing of ancient canal and irrigation systems. In S. Rost (Ed.), *Irrigation in early states. New directions* (pp. 65–81). The Oriental Institute of the University of Chicago (OIS 13).
Walker, M. J. C., Berkelhammer, M., Björck, S., Cwynar, L. C., Fisher, D. A., Long, A. J., Lowe, J. J., Newnham, R. M., Rasmussen, S. O., & Weiss, H. (2012). Formal subdivision of the Holocene series/epoch: A discussion paper by a working group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the subcommission on Quaternary stratigraphy (International Commission on Stratigraphy). *Journal of Quaternary Science*, *27*(7), 649–659.
Walstra, J., Heyvaert, V. M. A., & Verkinderen, P. (2008). Remote sensing for recording past landscapes of the Mesopotamian alluvial plain. In Advances on Remote Sensing for Archaeology and Cultural Heritage Management (379–382).
Weiss, H. (2000). Beyond the Younger Dryas: Collapse as adaptation to abrupt climate change in Ancient West Asia and the Eastern Mediterranean. In G. Bawden & R. Reycraft (Eds.), *Confronting natural disaster: Engaging the past to understand the future* (Vol. 2000, pp. 75–98). University of New Mexico Press.
Weiss, H. (2003). Ninevite periods and processes. In E. Rova & H. Weiss (Eds.), *The origins of North Mesopotamian Civilization* (pp. 593–624). Subartu IX.
Weiss, H. (2017). 4.2 ka BP Megadrought and the Akkadian Collapse. In H. Weiss (Ed.), *Megadrought and collapse. From early agriculture to Angkor* (pp. 93–160). University Press.
Wilkinson, T. J. (1990). Early channels and landscape development around Abu Salabikh, a preliminary report. Iraq, *52*, 75–83.
Wilkinson, T. J. (2003). *Archaeological landscapes of the Near East*. University of Arizona.
Wilkinson, T. J., & Jotheri, J. (2021). The origins of levee and levee-based irrigation in the Nippur Area–Southern Mesopotamia. In M. Altaweel & C. Hritz (Eds.), *From sherds to landscapes: Studies in honor of McGuire Gibson*. Studies in Ancient Oriental Civilizations (Vol. 71, pp. 243–258). University of Chicago, Oriental Institute.
Wilkinson, T. J., & Rayne, L. (2010). Hydraulic landscapes and imperial power in the Near East. *Water History*, *2*, 115–144.
Wilkinson, T. J., Rayne, L., & Jotheri, J. (2015). Hydraulic landscapes in Mesopotamia: The role of human niche construction. *Water History*, *7*, 397–418.
Wilkinson, T. J., Ur, J., & Hritz, C. (2013). Settlement archaeology of Mesopotamia. In T. J. Wilkinson, G. Mc Gibson, & M. Widell (Eds.), *Models of Mesopotamian landscapes. How small-scale processes contributed to the growth of early civilizations*. BAR International Series (Vol. 2552, pp. 34–55). Archaeopress.
Williamson, R. A. (1997). *The Landsat legacy: Remote sensing policy and the development of commercial remote sensing*. ASPRS.
Wilson, K. (2012). *Bismaya. Recovering the lost city of Adab*. Oriental Institute Publication 138. University Press.
Wright, H. (1981). The southern margins of Sumer: Archaeological survey of the area of Eridu and Ur. In R. Mc Adams (Ed.), *Heartland of cities. Surveys of ancient settlement and land use on the central floodplain of the Euphrates* (pp. 295–345). University Press.
Zanchetta, G., Bar-Matthews, M., Drysdale, R. N., Lionello, P., Ayalon, A., Hellstrom, J. C., Isola, I., & Regattieri, E. (2014). Coeval dry events in the central and eastern Mediterranean basin at 5.2 and 5.6 ka recorded in Corchia (Italy) and Soreq caves (Israel) speleothems. *Global and Planetary Change*, *122*, 130–139.

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Mantellini, S., Picotti, V., Al-Hussainy, A., Marchetti, N., & Zaina, F. (2024). Development of water management strategies in southern Mesopotamia during the fourth and third millennium B.C.E. *Geoarchaeology*, 1–32. https://doi.org/10.1002/gea.21992