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## **From the Paleolithic to the Islamic Era in Wilayat Yanqul: The Archaeological Water Histories of Oman (ArWHO) Project Survey 2011-2018**

Michael J. Harrower, Smiti Nathan, Ioana A. Dumitru, Joseph W. Lehner, Paige Paulsen, Eli Dollarhide, Frances Wiig, Alexander J. Sivitskis, H el ene David-Cuny, Jennifer L. Swerida, et al.

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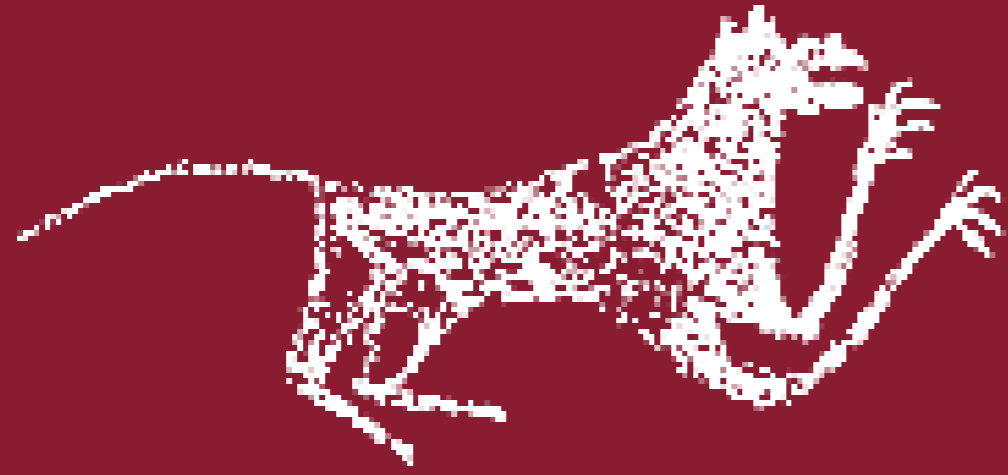
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# مجلة الدراسات العُمانية

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The Journal of  
**Oman**  
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MAP OF THE SULTANATE OF OMAN

## GUIDE TO AUTHORS

The Journal of Oman Studies was established in 1975. It is published by the Ministry of Heritage and Tourism in the Sultanate of Oman. It is a scholarly journal that publishes original and refereed research in both Arabic and English in areas relating to natural and cultural heritage relevant to the Sultanate of Oman. The journal publishes research in various areas of tangible and intangible cultural heritage. For example, the journal publishes research in various kinds of movable and non-movable archaeology, rock art, inscriptions and writings, sculpture, traditional architectures such as forts, castles and old neighborhoods. The journal also publishes research on modern buildings with unique architecture specific to Oman. It also publishes research on intangible cultural heritage such as research in the areas of Omani traditions and customs, different forms of expression including language and oral practices, various forms of performance arts, rituals, ceremonials, social practices, various forms of interaction with nature such as agriculture, falaj and irrigation system, traditional medicine, skills related to Oman's traditional handicrafts and others. The journal also publishes research dealing with topics related to Oman's natural heritage and these include studies of natural landscape, geological structure, natural sites like mountains, wadis, caves, flora and fauna of Oman. The journal also invites book reviews in relevant areas.

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The submission should include an abstract in both English and Arabic and it should not exceed 250 words in each language. The abstract should give a summary of the content, significance, methodology, contribution and the main findings of the study. The abstract should also provide 5 keywords.

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# Foreword

The Ministry of Heritage and Tourism works on documenting the cultural and natural heritage of the Sultanate of Oman in a number of publications, the most important of which is The Journal of Oman Studies published annually by this ministry. The Journal has been publishing new original research that is carefully selected through a rigorous academic review process. What characterizes the research published in this Journal is that it presents the findings of fieldwork excavations carried out by a number of archaeological missions operating in different regions of the Sultanate of Oman and presenting their discoveries in the form of research papers exclusively submitted for this Journal.

Continuing these significant efforts, we are pleased to present to our readers the 22<sup>nd</sup> volume of the Journal of Oman Studies, which includes eleven research articles covering a timeframe extending from the Paleolithic to the Islamic periods. These research articles address various topics in the cultural heritage of the Sultanate Oman, including the study of water history in Oman throughout the ages, in addition to the study of the settlement landscape of the Early Bronze Age, and the burial practices of the Early, Middle and Late Bronze Age (Hafit, Umm an-Nar, and Wadi Suq periods). The topics also include the study of evidence on Iron Age settlements and tombs, ritual complexes from the Early Iron Age, and the trilith monuments from the Iron Age, in addition to the aflaj system and the use of stars in the timing of this system. The linguistic research as part of the cultural heritage of Oman focuses in this volume on the current linguistic situation of the South Arabian Languages in southern Oman. The articles also include the results of using the latest digital technologies in the field of archaeological investigation in the Sultanate of Oman, such as the three-dimensional digital documentation of archaeological monuments. It should be noted that these articles provide high quality visual illustrations which help the reader to easily follow and understand the discussions and arguments. The research articles cover a wide range of different geographical regions of Oman such as the archaeological sites in the governorates of Al Dhahirah, North and South Al Batinah, Al Dakhiliyah, Dhofar, Al Wusta, and South Al Sharqiyah.

I hope that the general readers and specialist researchers will find this volume useful and the information included therein about the cultural and natural heritage of the Sultanate of Oman beneficial. The Journal, its editorial board and its support team deserve our thanks for their efforts in promoting this Journal and achieving its vision and will continue to receive our fullest support.

**Salem bin Mohammed Al Mahrouqi**  
**Minister of Heritage and Tourism**



# From the Paleolithic to the Islamic Era in Wilayat Yanqul: The Archaeological Water Histories of Oman (ArWHO) Project Survey 2011-2018

*Michael J. Harrower, Smiti Nathan, Ioana A. Dumitru, Joseph W. Lehner, Paige Paulsen, Eli Dollarhide, Frances Wiig, Alexander J. Sivitskis, H  l  ne David-Cuny, Jennifer L. Sverida, Joseph C. Maz  ziello, R  my Crassard, Abigail Buffington, Sean P. Taylor, Martha C. Anderson & Suleiman Al-Jabri*

## ABSTRACT:

The Archaeological Water Histories of Oman (ArWHO) Project began in 2011 with a focus on the role of water availability in the long-term trajectories of ancient civilizations. From 2011 to 2018, the project surveyed Wilayat Yanqul and adjacent areas. This included wide-area reconnaissance survey as well as systematic sampling of a 100 km<sup>2</sup> area northeast of the town of Yanqul. This paper reports basic results of the survey, including numbers of archaeological sites documented, and baseline analysis of associations with water resources. Important results include Paleolithic finds, discovery of new Neolithic sites, insights about Bronze Age monuments, new understanding of Iron Age trade, and broader understanding of small Islamic era settlements in mountainous hinterlands.

**KEYWORDS:** Arabia; Water History; GIS; Settlement Patterns; Archaeological Survey

## من العصر الحجري القديم إلى العصر الإسلامي في ولاية ينقل: المسح الأثري لتاريخ المياه في عمان (ArWHO) ٢٠١١-٢٠١٨م

مايكل ج هارور، وسميتي ناثان، وإيوانا إيه دوميترو، وجوزيف دبلولينير، وبيج بولسن، وإيلي دولارهايد، ورائيس ويغ، وألكسندر ج سيفيتسكيس، وهيلين ديفيد-كوني، وجينيفر إل سويريدا، وجوزيف سي ماتزاريللو، وريمي كراسارد، وأبيجيل بافينجتون، وشون بي تايلور، ومارثا سي أندرسون، وسليمان الجابري.

## الملخص:

بدأ المشروع الأثري لتاريخ المياه في عمان (ArWHO) في عام ٢٠١١م، مع التركيز على دور توافر المياه في المسارات طويلة المدى للحضارات القديمة. قام المشروع من عام ٢٠١١ إلى ٢٠١٨م والمناطق المجاورة لها. وشمل ذلك مسح استطلاعي واسع النطاق، وكذلك أخذ عينات منهجية لمساحة ١٠٠ كيلومتر مربع شمال شرق مدينة ينقل. يعرض هذا البحث النتائج الأساسية للمسح، بما في ذلك عدد المواقع الأثرية المؤتقة، والتحليل الأساسي للارتباطات بالموارد المائية. وتشمل النتائج المهمة لقي من العصر الحجري القديم، واكتشاف مواقع جديدة من العصر الحجري الحديث، ورؤى حول المعالم المعمارية من العصر البرونزي، وفهم جديد لتجارة العصر الحديدي، وفهم أوسع لمستوطنات العصر الإسلامي الصغيرة في المناطق الجبلية الداخلية.

**الكلمات المفتاحية:** الجزيرة العربية؛ تاريخ المياه؛ نظم المعلومات الجغرافية؛ أنماط الاستيطان؛ المسح الأثري

## INTRODUCTION

How were water availability and irrigation interconnected with the origins and long-term trajectories of ancient civilizations? Archaeologists have long identified irrigation as one of several primary factors involved in the origins of agriculture and rise of the worlds' earliest civilizations, but the role of water widely differs across different times in different regions (Holt 2018; Rost in press; Sulas and Pikirayi 2018). Oman offers a wide range of opportunities to study the unique role of water in the development of civilization. Throughout the ancient past, Oman's far-reaching interconnections contributed to the origins and spread of new lifeways, technologies, and ideas; yet Oman also maintained its own unique cultural traditions and historical trajectories. Water availability and human management of water resources played an important role in humans' arrival in Arabia, the appearance of domesticated plants and animals, the emergence of complex polities in Oman, and subsequent Iron Age and Islamic societies. Although we know relatively little about the subsistence strategies of Paleolithic peoples in Arabia, recent research has begun to clarify the importance of hydrology in structuring early patterns of movement and migration (e.g. Breeze *et al.* 2015, 2017). Domesticated animals, including sheep, goat, cattle first appear in southern Arabia as early as the late 7<sup>th</sup> millennium BC (Crassard *et al.* 2020; Martin *et al.* 2009; Makarewicz 2020; Uerpman *et al.* 2013). The earliest water management in southern Arabia appears during the early 4<sup>th</sup> millennium (Harrower 2020) with definitive evidence of domesticated crops during the 3<sup>rd</sup> millennium BC (Ekstrom and Edens 2002; Tengberg 2003). By the late 4<sup>th</sup> millennium, small Hafit tombs also start to appear across the region, followed by much larger Umm an-Nar tombs and towers appearing, most often at oases, during the latter half of the 3<sup>rd</sup> millennium (Williams and Gregoricka 2019). As markers inscribing landscapes, these tombs and towers played an important role in claims to arable land and water resources (Deadman 2012; Harrower 2008; Harrower *et al.* 2014; Nathan 2017). A great deal

can be learned through examination of Islamic era water management practices and technologies, but it is important to recognize that irrigation practices and oasis agriculture changed considerably through time and far less is known about Bronze, Iron, and Late Pre-Islamic era practices (Charbonnier 2017).

From 2011 to 2018, the Archaeological Water Histories of Oman (ArWHO) Project adapted archaeological survey, satellite imagery, and geospatial analysis to examine the role of water availability and irrigation in the long-term histories of ancient societies in Al-Dhahirah Governorate of Oman (Figure 1). The ArWHO survey has focused on identifying the spatial distribution of human activities, hypothesizing that access to water was an important element in the location of many of these activities. The ArWHO project conducted a broad range of activities, including archaeological survey, excavations, geospatial analysis, ethnoarchaeology, and 3D modeling (Dumitru, 2019; Dumitru and Harrower 2018a, 2018b; Harrower *et al.* 2014, 2016; Nathan 2017; Sivitskis *et al.* 2018, 2019; Wiig *et al.* 2018). One of our key objectives – a focus of this paper – involved comparing archaeological survey data with satellite imagery derived measures of wetness and evapotranspiration to evaluate spatial patterning of human activities relative to water. As further described below, two main types of map layers quantifying water availability were generated from satellite imagery: wetness estimated by the Compound Topographic Index (CTI), and evapotranspiration estimated by Disaggregated Atmosphere-Land Exchange Inverse (DisALEXI).

## BACKGROUND

Wilayat Yanqul has previously seen some significant archaeological research, and insights gleaned from research in nearby parts of Oman and the United Arab Emirates provides important background context. Until recently the Paleolithic of northern Oman was scantily known, but investigations in Wilayat Ibri have shed new light on the Middle and Late Paleolithic (Kondo *et al.* 2014, 2018) and research near Bisya has revealed Lower Paleolithic Acheulean-type lithics (Beshkani *et al.* 2017). These finds are greatly complemented

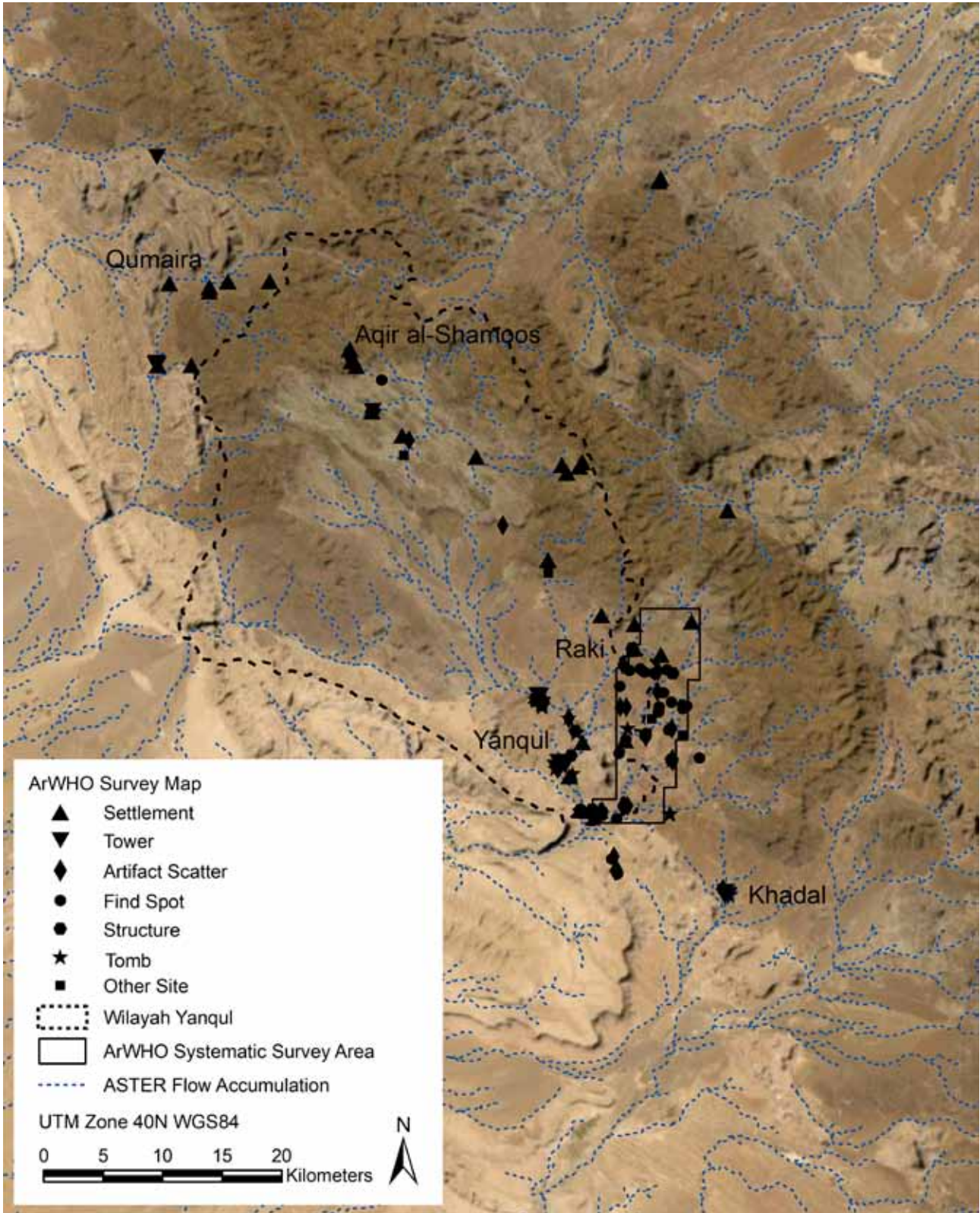


Figure 1: Sites documented by ArWHO survey from 2011 to 2018. Blue lines show drainage network derived from ASTER GDEM.

by investigations in Sharjah, UAE at Jebel Faya (Armitage et al. 2011; Bretzke et al. 2013, 2014) and Suhailah (Bretzke et al. 2018), which have generated critical new understanding the Middle and Lower Paleolithic, respectively.

Similarly, Neolithic finds in Al-Dhahirah have traditionally been rather rare, but recent research has dramatically expanded data on early Holocene occupations in the region. Discoveries include Neolithic sites in Wilayat Ibri (Kondo et al. 2018; Parton and Bretzke 2020), near Rustaq (Bretzke et al. 2018), and near Qumayrah (Bialowarczuk 2017; Bialowarczuk and Szymczak 2018). Further afield, important Neolithic sites in the Al-Hajar Mountains include Jebel Buhais 18 and numerous Jebel Faya sites, which attest to social relations and a pastoral economy (Uerpmann et al. 2013).

Al-Dhahirah has long been known for a vast array of important Bronze Age sites; and new Hafit, Umm an-Nar, and Wadi Suq period sites are readily being discovered in Wilayat Yanqul. Most famously, the UNESCO World Heritage Site of Bat, Al-Khutm, and Al-Ayn have yielded a tremendous wealth of information about Bronze Age Oman (e.g. Cable and Al-Jabri 2019; Cocca et al. 2019; Swerida and Thornton 2019; Thornton et al. 2017), including claims of irrigation during the 4<sup>th</sup> millennium BC (Desruelles et al. 2016). A team led by Paolo Costa conducted two seasons of archaeological survey focused on Wilayat Dhank, including Qumayrah, in the late 1990s and reported a number of sites of different and sometimes indeterminate ages (Costa 2006). Following up on Bronze Age sites in the village of Al-Ayn reported by Costa, excavations of an Umm an-Nar tomb in 2016 yielded an informative collection of pottery, beads, softstone vessel fragments, and metal (Rutkowski 2017). The Social, Spatial and Bioarchaeological Histories of Ancient Oman (SoBO) project has concentrated work in Wilayat Dhank focusing mostly on tombs and their contents (Williams and Gregoricka 2013). Yule and Weisgerber (1998: 197-199) reported Bronze Age towers at Safri in the modern town of Yanqul. The best preserved tower, Safri 1, was the subject of mapping and 3D modeling by ArWHO

to evaluate its original design, construction, and function (Harrower et al. 2014).

Iron Age and Islamic Era copper mining sites in the vicinity of Wadi Raki northeast of Yanqul are some of the most important archaeological sites in Wilayat Yanqul. In the 1970s, early geological investigations identified the Wadi Raki area as a locus of ancient copper production based on massive scatters of slag at three main sites, Raki 1, Raki 2, and Tawi Raki (Coleman and Bailey 1981; Berthoud et al. 1978). As part of research focused at Bat, some limited archaeological reconnaissance was made by Pierre Gentelle and Karen Frifelt in 1984-1985 as far north as Raki, and they also reported Hafit tombs on the southern side of Yanqul (Gentelle and Frifelt 1989: 124). Survey and excavations of the aforementioned Raki sites in the mid-1990s led by Gerd Weisgerber and Paul Yule revealed occupations and copper production during the Iron Age and early Islamic period (Weisgerber and Yule 1999). Beginning in the late-1980s, H el ene David-Cuny analyzed chlorite and searched for sources in many areas and discovered a shaft where chlorite was extracted north of Yanqul (David et al. 2002: 322-327). In 2015, the Ministry of Heritage and Culture and ArWHO Project discovered Aqir al-Shamoos, the first documented ancient site with softstone (chlorite) vessel production in Arabia (Harrower et al. 2016). In collaboration with David-Cuny, the ArWHO team subsequently re-located the aforementioned chlorite mining shaft (local name is Swaghi) and collected samples as part of ongoing efforts to track chlorite extraction and trade (Sivitskis et al. 2018). The ArWHO Project, in conjunction with remote sensing at the copper working site of ‘Uqdat al-Bakrah (Wiig et al. 2018), has also continued investigations of the Raki sites with a particular focus in the area in 2018, 2019, and 2020 (Sivitskis et al. 2019)

## METHODS

The ArWHO project employed a combination of systematic and judgmental archaeological survey. Judgmental reconnaissance involved discovery of sites over a wide area using satellite imagery, input from local residents, and surveyors’ knowledge of



likely site locations. This work concentrated mostly in Wilayat Yanqul but also involved investigations of sites in neighboring Dhank and Ibri Wilayats.. Systematic survey involved stratified random sampling of a 100 square km area northeast of the town of Yanqul, which was completed in two

winter field seasons 2012-2013 and 2014-2015 (Figure 2). The use of stratified random sampling generated a representative sample that allows for greater confidence in reconstructions of site density, patterning with respect to water, and other spatial analyses.

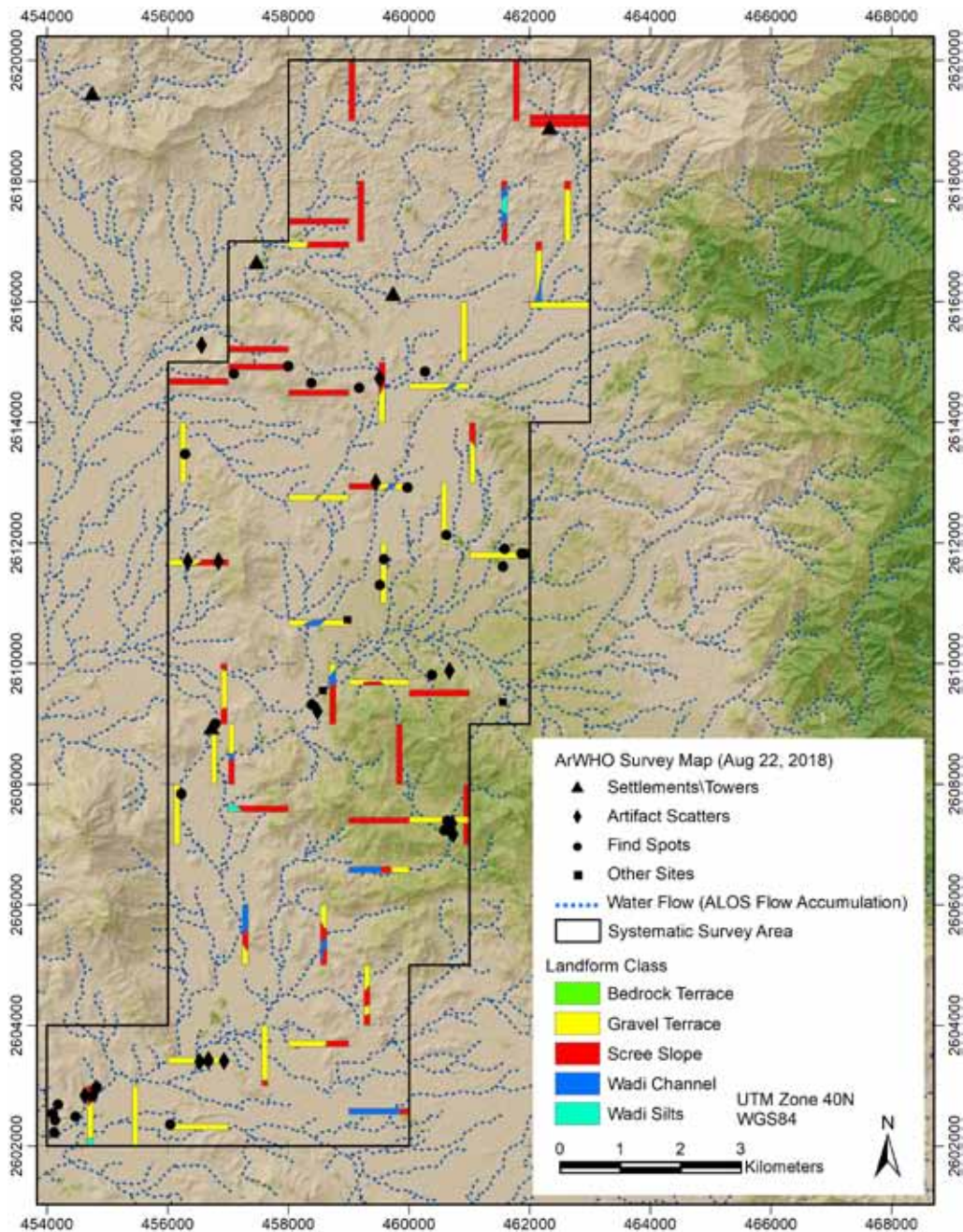


Figure 2: Archaeological sites and survey transects in the 100 km<sup>2</sup> systematic survey area northeast of Yanqul overlaid on a 30-m resolution DisALEXI evapotranspiration image for May 24, 2013, with topography and water flow accumulation derived from an ALOS-PRISM 5-m DSM.

Our survey documented settlements, artifact scatters, find spots, tombs, structures, water management structures, rockshelters, rockart sites, and chlorite and copper source locations.

Satellite imagery sources consulted include Google Earth, ASTER imagery, ASTER-based water flow accumulation models, Worldview-2 and 3 imagery, as well as Hyperion hyperspectral imagery (with a focus on chlorite and copper source identification). We also analyzed satellite radar data (including TerraSAR-X, TanDEM-X, RADARSAT-2) for the site of 'Uqdat al-Bakrah (Wiig et al. 2018). Due to the large number of tombs in some areas, tombs were only recorded when other archaeological remains were identified nearby.

The systematic survey area was divided into 1 km x 1 km sectors in order to produce a stratified random sample of 5%. Fifty sectors were randomly selected, the orientation of the survey (north-south or east-west) was decided by a simulated coin toss, and a 100 m by 1000 m transect was surveyed in each of the 50 selected sectors. The last three digits of the UTM coordinates for each transect was random within each 1 km x 1 km sector. Each transect was surveyed by six team members 17m apart walking in parallel. Individual survey units within each transect were defined by landform type according to the following classification:

- 1) Bedrock Slope – Greater than 15-degree slope or cliff (sometimes partially covered in talus or scree) that often separates upland plateaus from other landform classes.
- 2) Scree Slope – Angular clasts often on a low (<20 degree) gradient between bedrock slopes, terraces, and wadi sediments.
- 3) Plateau – Upland bedrock surfaces above bedrock slopes and cliffs, primarily covered in small cobble size clasts.
- 4) Gravel Terrace – Sub-rounded to rounded clasts often capping wadi silts and/or in close proximity to wadi channels.
- 5) Bedrock Terrace – Low angle (<5 degree) or horizontal bedrock surface adjacent to wadi sediments and/or scree slopes primarily covered in small cobble size clasts.
- 6) Wadi Silts – Pinkish tan colored areas of very fine sand and silt above wadi channels, which often contain isolated lenses and scattered cover of gravel and/or scree.
- 7) Wadi Channel – The lowest and most fluvially active area often demarcated by whitish grey rounded cobbles, boulders and more prevalent vegetation.

Archaeological sites were discovered and recorded as one of the eleven types, listed below. The numbering for all sites begins with a 3-digit survey unit code (starting from 0 and ascending for systematically surveyed sectors and starting from 999 and descending for judgmentally selected survey units) followed by a 3-digit site code, assigned sequentially starting at 001.

- 1) Settlements: Sites that are generally larger than one hectare in size and exhibit high artifact densities, walls, hearths, metallurgical slag, or other evidence of long term or periodic occupation are designated settlements. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site. Areal extent was mapped as a GPS polygon.
- 2) Artifact Scatters: Sites exhibiting higher artifact densities than find spots and a definable areal extent that is generally no more than two hectares. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site. Areal extent was mapped as a GPS polygon.

- 3) Find Spots: Isolated small sites with no discernable areal extent that yielded at least 15 artifacts from different objects (most commonly pottery sherds or lithics) within roughly 5 minutes. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site.
- 4) Structure: Individual structures were documented and given six-digit site numbers, sometimes within the boundaries of a larger settlement. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site. The dimensions, height, construction materials, and state of preservation were also evaluated.
- 5) Tower: To differentiate them from structures, towers were given an independent designation. Most notably Umm an-Nar period towers were documented in a number of locations. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site. The diameter, height, construction materials, and state of preservation were also evaluated.
- 6) Tomb: To differentiate them from structures, tombs were given an independent designation. Most notably, Hafit, Umm an-Nar, and Wadi Suq period tombs were documented in a number of locations. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site. The dimensions, height, construction materials, and state of preservation were also evaluated.
- 7) Rockart: Pecked and painted rockart was recorded in a number of locations. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken as close as possible to the center of each site.
- 8) Rockshelter: Occupation of a rockshelter was recorded. A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken as close as possible to the center of the site.
- 9) Copper Location: This designation was used for locations where copper slag was discovered. Locations with copper ore but no evidence of human activity were recorded but were not designated archaeological sites and were not given a six-digit survey unit-site number.
- 10) Water Management: This designation was used for wells, dams, canals, water diversion channels and other vestiges of irrigation and water management. A Trimble GPS point or line that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center or along the length of each site.
- 11) Other Sites: In addition to aforementioned site types, these additional remains were designated as individual sites (sometimes within the areal extent of a larger settlement). A Trimble GPS point that includes a six-digit survey unit-site number as well as information on landform, photographs, estimated age, and bags of artifacts collected was taken at the center of each site.

## SPATIAL PATTERNING OF SITES AND WATER

Two main types of map data were generated to evaluate spatial patterning of archaeological sites with respect to water availability: 1) DisALEXI satellite imagery-derived estimates of evapotranspiration, and 2) Compound Topographic Index (CTI) estimates of soil wetness based on terrain. These two different measures reflect different aspects of the hydrological regime. DisALEXI is a surface energy balance algorithm that uses land-surface temperature from the thermal band of remotely-sensed imagery (in this case ASTER satellite imagery) to estimate evapotranspiration (Anderson et al. 2011, 2018). High evapotranspiration reflects high soil moisture (Hain et al. 2009), which can be used to identify irrigation and shallow groundwater resources (Hain et al. 2015). In this case DisALEXI layers are 30m spatial resolution based on ASTER satellite imagery for ten days in 2013: May 24, June 9, June 25, July 11, August 12, August 28, September 13, October 15, October 31, and December 2. Although these ten days certainly do not, of course, precisely reflect ancient evapotranspiration, in a broad sense they reflect spatial patterning of areas of relatively higher or lower water availability. The CTI measure reflects soil wetness based on potential water accumulation across a landscape based on terrain (Gessler et al. 1995; Moore et al. 1991) a period. CTI is a steady-state wetness index based on slope and upstream contributing area, which are strongly correlated with soil wetness (Chaplot and Curmi 2000). In this case the CTI layer was produced using the ArcHydro module for ArcGIS (Maidment 2002) and the raster calculator function of ArcGIS 10.6 with a 5m spatial resolution ALOS PRISM DSM (Digital Surface Model) acquired by ArWHO with NASA funding (Figure 2).

To compare CTI and DisALEXI values for archaeological sites with those of the surrounding landscape, one thousand random points were generated in ArWHO's 100 km<sup>2</sup> systematic survey area. Values for CTI and DisALEXI were converted to mean values within 500m radii using the ArcGIS Spatial Analyst – Neighborhood – Focal Statistics function to summarize water availability in the immediate vicinity of each site or random point. Data for DisALEXI and CTI (mean in 500m radii) was then extracted to map layers for sites documented by ArWHO in the systematic survey area as well as for the 1000 random points. A Kolmogorov-Smirnov (K-S) test was then performed using SPSS software to compare each set of values for the sites with those for the random points.

## RESULTS

The ArWHO survey, both systematic and judgmental, documented a total of 227 archaeological sites from 2011 to 2018 (Table 1 and 2). All but eight sites could be assigned to the Paleolithic, Holocene, Neolithic, Bronze Age, Iron Age, and/or Islamic periods based on diagnostic artifacts and/or construction techniques. Although it is not a conventional designation, the term Holocene is used for sites with lithics that cannot be assigned to a specific time period but are definitively Neolithic or later. Seventy-two sites fell within the 100 km<sup>2</sup> systematic survey area, 20 of those within the 50 randomly selected transects that covered 5 km<sup>2</sup>, resulting in a site density of 4.0 sites per km<sup>2</sup>. Extrapolating this density across the entirety of systematic survey area suggests that we have achieved an 18% sample of all sites (72 located of 400 estimated) with 28% of sites (20 found randomly of 72 within the area) discovered via randomly selected survey transects.

Table 1: *Sites documented by ArWHO from 2011-2018 by site type.*

Type	Count
Settlement	36
Artifact Scatter	22
Find Spot	40
Structure	28
Tower	14
Tomb	61
Rockart	2
Rockshelter	1
Copper Location	10
Water Management	5
Other Site	8
<b>Total</b>	<b>227</b>

Table 2: *Sites documented by ArWHO from 2011 to 2018 by time period. Importantly, there are far more than 227 sites shown here because many sites are occupied during multiple time periods.*

Period	Count
Paleolithic	33
Neolithic	10
Holocene	49
Bronze Age	91
Iron Age	63
Islamic	95
Indeterminate	8
<b>Total</b>	<b>349</b>

The relatively large number of Paleolithic sites is notable; but unfortunately none of these sites appear to have stratified deposits that would allow excavations. Most Paleolithic sites were found within the systematic area – probably because they are less visible from a distance and less often recognized during judgmental survey. However, this perhaps does represent

a higher density of Paleolithic activity in the systematic survey area, a possibility worth further examining in the future. One of the most diagnostic finds – a Levallois retouched predetermined flake (Figure 3) – comes from the site of Abu Suwaih (997-035) northwest of Yanqul. This area also yielded a range of Bronze Age, Iron Age and Islamic material.

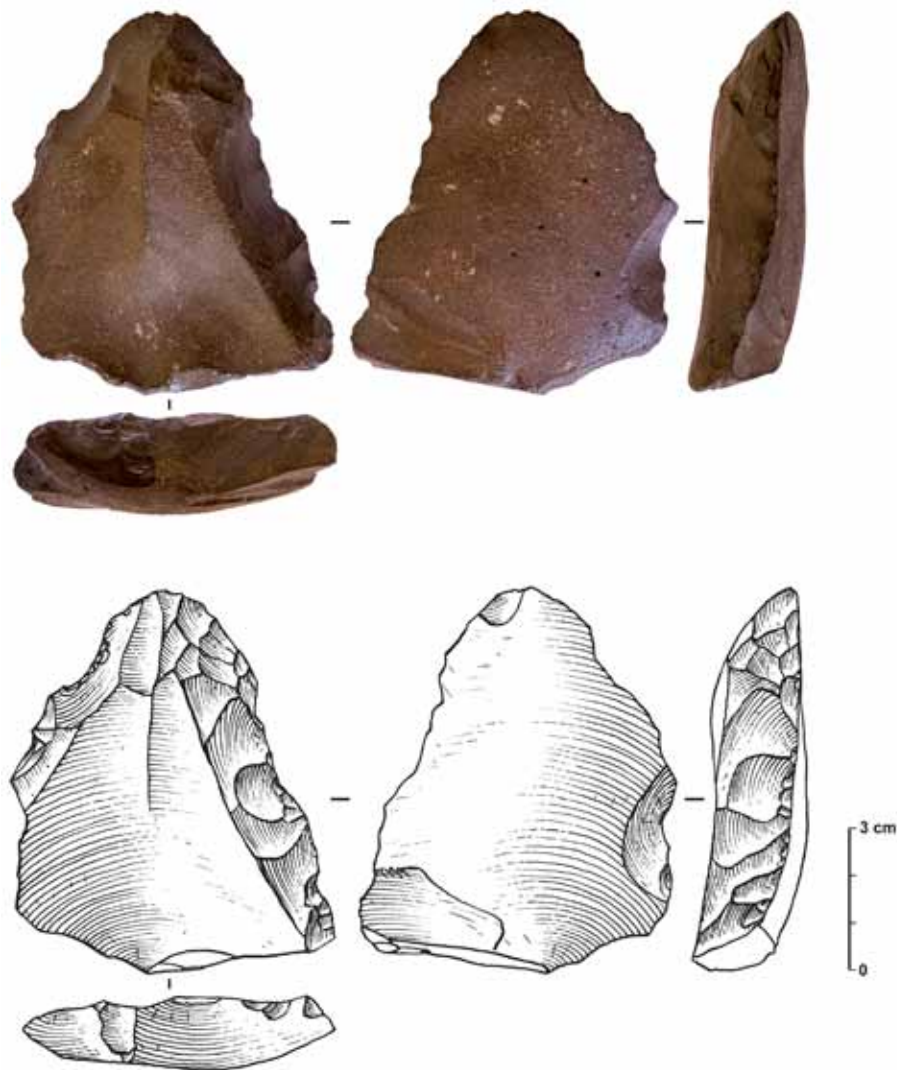


Figure 3: *Levallois retouched predetermined flake found at Abu Suwaih (997-035).*

One particularly noteworthy find, a Fasad projectile point, was found at the multi-period site of Muwiyh (Figure 4). Muwiyh – a small island of alluvium in the middle of Wadi Yanqul approximately 1.5km northwest of the junction with Wadi Fida – preserves an important wealth of archaeological remains. The Fasad point marks the earliest find at Muwiyh and based on research of Fasad points elsewhere may date as early as the 9<sup>th</sup> millennium BC (Charpentier et al. 2016). Even though these points have been found across Southwest and Southeast Arabia, we still know relatively little about the lifeways and livelihoods of the peoples who crafted this

highly recognizable tool. Recent discovery of Fasad-type assemblage at a rockshelter near Ibri (Bretzke et al. 2018; Parton and Bretzke 2020) is poised to help clarify the lives of peoples who produced Fasad points. At Muwiyh the Fasad point was found in loose sediment eroding out of a natural cut-bank immediately below a slab-lined circular structure (974-004, Figure 5). This structure is quite similar in construction to examples excavated in Yemen (McCorriston and Harrower 2020) and Dhofar (McCorriston et al. 2014) that date to the 5<sup>th</sup> millennium BC – the Fasad point found roughly a meter downslope below it is undoubtedly much earlier.



Figure 4: *Fasad* projectile point found at Muwiyh.



Figure 5: *Circular slab-lined structure 974-006 at Muwiyh, similar to 974-004 (below which Fasad point was found).*

Although only ten sites are designated as Neolithic, many more (49) are designated Holocene and some of them might date to the Neolithic. Probably most importantly, the site of Wadi Al-Lathli (061-001) yielded a sizable collection of stone tools and debris covering 3.17 hectares (ha) dated to the Neolithic and the Holocene, including flakes, cores, and bifacial tools. No structures were evident on the surface, but given the site's substantial size, diversity of materials present, and ongoing threats posed by farming, further investigations are warranted.

Bronze Age sites documented by the ArWHO Project yielded a wide range of important new information. Mostly significantly, fourteen Umm an-Nar period towers were documented, including some that were previously reported and some newly discovered. The distribution of these towers and associated agricultural practices was a key topic of a PhD Dissertation completed by Smiti Nathan (2017). Many of these Umm an-Nar tower sites were probably surrounded by settlements and formed agricultural oases, but many of these areas were occupied during later periods and some remain occupied today obscuring the earliest human activities. Numerous tombs were also documented, including 30 Hafit tombs, 4 possible Hafit tombs, 23 Umm an-Nar tombs, 2 Wadi Suq tombs, one Islamic grave, and one indeterminate possible tomb. The vast majority of tombs recorded (i.e. 24 Hafit tombs and 14 Umm an-Nar tombs) are located at the site of Abu Suwaih (survey units 997, 987, 986). Many more Hafit tombs were visible on hills above the modern graveyard located just south of Yanqul (near Al-Joghna) but these tombs were not mapped in detail due to time constraints; we plan further work on them in the future. One very poorly preserved Umm an-Nar period megalithic tower was found at Al-Joghna (960-001) and two more megalithic towers Safri-1 (989-001) and Safri-3 (989-003) across the wadi attest to the importance of this waterway and travel corridor. Mapping and 3D modeling-based reconstruction of the Safri-1 tower shows that at least 118 metric tons of limestone with an average boulder weight of 386 kg

was used to build a monument at least 4 meters high (Harrower et al. 2014). Comparable Umm an-Nar period megalithic towers were documented at Wadi Hareem (973-002), Abu Suwaih (997-001 and 997-009), Khadal (971-001, 971-002, 971-003), and Ajran (917-001).

Research by ArWHO at several Iron Age sites has already been published, including mapping at the copper mining sites of Raki 1, Raki 2, and Tawi Raki (Sivitskis et al. 2019), analysis of material from Aqir al-Shamoos, a small Iron Age site with the first evidence of chlorite production found in Arabia (Harrower et al. 2016; Sivitskis et al. 2018), and remote sensing work at the metal workshop site of 'Uqdat al-Bakrah (Wiig et al. 2018).

A number of other important Iron Age sites were documented including Hayy Ukur (994-001) in the mountains east of the town of Waqba. Although agricultural fields adjacent to the site are still cultivated today, copious Iron Age pottery along with some slag and cobbles of chlorite indicate that architecture at the site was occupied predominantly during the Iron Age. A single sherd of Wadi Suq period pottery suggests the site witnessed at least minimal activity during the Bronze Age. The ArWHO team conducted a small test excavation to evaluate stratigraphy at the site. Mostly Islamic pottery was recovered and a radiocarbon date of 440 +/- 30 <sup>14</sup>C yrs BP (Beta 317410, AD 1430 to 1470) shows the site was also occupied long after the Iron Age. Even so, other areas of the site may still hold potential to yield significant information about Iron Age human activities. Other Iron Age sites of importance include the hillfort of Husn Al-Khutam (999-001) that sits on a high ridge overlooking the modern town of Yanqul. This location clearly offered commanding views of the area (Figure 6) and was occupied during the Iron Age and Islamic periods. An important collection of petroglyphic rockart, Wadi Al-Lathli 2 (061-002), was discovered on boulders near a (now dry) natural spring. Dozens of images are pecked on massive boulders at Wadi Al-Lathli 2 near a (now dry) spring. Although there are some clearly modern examples, the older petroglyphs can be



approximately dated to the Iron Age or later based on depictions of equids ridden by and camels led by humans. This rockart closely resembles that found on Umm an-Nar towers Safri-1 and Safri-3

(Harrower et al. 2014), and similarities between boat at Safri 1 and boat Wadi Al-Lathli 2 (sites that are 8 km apart) demonstrates knowledge and interest in maritime travel (Figure 7).



Figure 6: *The Iron Age and Islamic hillfort of Husn Al-Khutam with Yanqul Mountain in the background.*



Figure 7: *Petroglyphic rockart near Yanqul: a) Safri-1 Umm an-Nar tower, boat (upper left), and b) Wadi al-Lathli-2 large boulders, boat (upper right), person leading camel (bottom left), person riding equid with spear (bottom right).*



Figure 8: *Incense burner recovered from the site of Hayl Manathrah (953-005).*



Figure 9: *The remote Islamic to modern era mountain settlement of Hayy Beni Kathir.*

## SPATIAL PATTERNING OF SITES AND WATER

Analysis of spatial patterning of sites in the systematic survey area relative to water availability yielded mixed results depending on the measure of water availability employed. As might be expected,

CTI wetness values for the 72 sites were significantly different from the CTI values of the 1000 random points as measured by Kolmogorov-Smirnov test (Table 3). As CTI reflects topographic position in the landscape, this result suggests that sites are more likely to be in areas that have a higher water flow potential than would be expected at random.

Table 3: *Kolmogorov-Smirnov test results for CTI*

wetness index in 500m radii around 72 sites compared with CTI in 500m radii around 1000 random points. A significance value of less than 0.05 indicates a statistically significant difference between samples.

Difference	Z-value	Significance Value (2-tail)
0.254	2.081	0.000

Results for DisALEXI estimates of evapotranspiration values for the 72 sites were not consistently significantly different statistically from DisALEXI values for the 1000 random points. Four of the ten days we tested showed statistically significant differences, while 6 days did not (Table 4). This appears to be a function of the fact that in the present

day remote rugged mountainous areas have slightly more natural vegetation cover and consequently higher evapotranspiration. This probably does not reflect conditions in ancient times. Although we only evaluated 10 days in 2013, this analysis shows no consistent correlation between evapotranspiration values and archaeological site locations.

Table 4: *Kolmogorov-Smirnov test results for DisALEXI*

evapotranspiration in 500m radii around 72 sites compared with DisALEXI in 500m radii around 1000 random points. A significance value of less than 0.05 indicates a statistically significant difference between samples.

Date	Difference	Z-value	Significance Value (2-tail)
24-May-2013	0.056	0.459	0.984
9-Jun-2013	0.250	2.049	0.000
25-Jun-2013	0.223	1.825	0.003
11-Jul-2013	0.145	1.191	0.117
12-Aug-2013	0.135	1.108	0.171
28-Aug-2013	0.215	1.760	0.004
13-Sep-2013	0.254	2.081	0.000
15-Oct-2013	0.131	1.075	0.199
31-Oct-2013	0.163	1.337	0.056
2-Dec-2013	0.071	0.580	0.890

## DISCUSSION

Moving forward, targeted analyses of specific types of sites, or sites of particular time periods, will help further clarify associations between human activity and water availability. Indeed, analysis of associations between water flow accumulation (derived from ASTER GDEM data) and Umm an-Nar period settlements with towers conducted as part of a PhD Dissertation completed by Smiti Nathan (2017) showed clear statistically significant associations between sites and water. A journal article manuscript that will present these results is currently in preparation.

Importantly, it is not only water itself, but water availability in combination with other valuable resources and landscape characteristics that most influenced ancient human decision making and geography. High visibility locations along waterways were also important in establishing control of water and territory. Umm an-Nar period towers were not only built in areas with water, but also most often in highly visible locations where they served as monuments dominating landscapes suitable for farming. Copper production required water to sustain the plants and animals needed to feed workers, and large numbers of trees were needed to supply wood charcoal fuel for smelting – an issue we are currently investigating. The aforementioned Iron Age hillfort Husn Al-Khutam is located at a constriction of terrain near the modern town of Yanqul where water from a massive 540 square km watershed accumulates; this hilltop position also affords a nearly 360-degree view of surrounding terrain (Figure 6). Even so, the highly permeable nature of the ophiolite mountains and gravel plains of this watershed mean that most water infiltrates and groundwater from wells, rather than dams or diversion of overland flows, predominates (see also Charbonnier 2015). In addition to some high visibility locations where major sites overlooked landscapes, secluded settings also became important places for villages in Iron Age and later times. Sites such as Aqir al-Shamoos and Hayy Ukur were supported by small-scale farming enabled by

diverting water from small wadis. The very remote positioning of these sites in heavily dissected, mountainous terrain also affords an element of security making residents less vulnerable to attack. Thus, understanding the role of water involves far more than merely analysis of water itself, but more broadly its interrelationships with other social and environmental factors.

## CONCLUDING REMARKS AND FUTURE RESEARCH

The ArWHO project survey has discovered a wide range of archaeological sites and generated important new data. In arid environments it is not particularly surprising that the archaeological remains left by human activity are correlated with water resources. However, the details with regard to particular types of sites and of changes in spatial patterning through time are deeply important to understanding the long-term role of water among human societies. Indeed, similar analysis of Aksumite sites in Ethiopia very unexpectedly showed that – despite past assertions that large-scale irrigation technologies introduced from Arabia were critically important – the Yeha area did not rely on large-scale irrigation and sites surveyed are not spatially patterned according to water (Harrower et al. 2020). That certainly does not mean that water was not important, but it does mean that factors influencing human decision making across landscapes are complex and are influenced by a wide variety of factors at different spatial and temporal scales.

Current ArWHO project research builds on results of our survey with a focus on copper and chlorite sourcing and trade network analysis. In 2019 and 2020, the ArWHO team focused on copper production at the Raki sites to improve understanding of chronologies, technologies, trade networks. Our closely related, ongoing work on water, vegetation, and ancient metallurgy at ‘Uqdat al-Bakrah (Safah) also continues to yield new insights with a recent focus on Ground Penetrating Radar. In conjunction the discovery of Aqir al-

Shamoos, we are similarly expanding our research on chlorite sourcing and associated trade network analysis. On these and other topics, the prospects for new discoveries and insights about the ancient past make Oman an exciting center-point of archaeological research.

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