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CHAPTER NUMBER

HOLOCENE CLIMATE VARIABILITY OF MESOPOTAMIA AND ITS IMPACT ON THE HISTORY OF CIVILISATION[1]

MAX ENGEL AND HELMUT BRÜCKNER

Abstract

Mesopotamia, known as the cradle of civilisation, gave rise to the first complex, urban-type societies with sophisticated political hierarchies. Its rich history full of important cultural achievements was accompanied by fundamental environmental changes over the Holocene. While geo-bio-archives from the broader region reflect slightly varying climate histories, there is a clear consensus on a more humid climate regime during the Early Holocene, triggering early rain-fed agricultural practices in Northern Mesopotamia representing the foundation of initial urbanisation. In the southern basin, declining rainfall and higher competition for natural resources at a somewhat later stage in combination with the development of irrigation techniques and the transgression of the Arabian Gulf seem to have contributed to the formation of complex societies at sites such as Eridu, Ur, and Uruk, where landscape dynamics are well-preserved in the stratigraphic record. Against the background of long-term climate trends, it seems that also Rapid Climate Change events—short-term climatic anomalies such as identified around 8,200, 5,200, or 4,200 BP—have taken their toll on Mesopotamian people.

Many links between changes in climate and landscape, and socio-technical adaptation based on interdisciplinary research seem straightforward, especially where confirmation exists by cuneiform texts or archaeological evidence. The gap in chronological resolution between rather precise information on historical social development on the one hand, and on climatic changes with a much higher uncertainty on the other hand, may generate an elusive fit between records and requires caution in any attempt of environmental determinism when trying to explain cultural history.

1. *Introduction*

Ancient Mesopotamia, homeland of the oldest complex, urban-type societies and the nucleus of early civilisation, covers most of the catchment of the two great rivers Euphrates and Tigris and extends from

[1]ME is supported by Deutsche Forschungsgemeinschaft, grant No. EN 977/2-1 (Project CLEAR). Thorough remarks by Thomas Götzelt are gratefully acknowledged.

southeastern Turkey over Syria and the territory of modern Iraq down to the shores of the Arabian Gulf (Figure 1). The first mention of Mesopotamia as a geographic entity occurred in the 2nd century AD, appearing in Arrian of Nicomedia's *Anabasis of Alexander* where it is associated with the part of Syria which is located between the two rivers. It is further stated that, even though the administrative unit was first established by Alexander, the name itself emenates from the inhabitants and goes back at least to the 4th century BC, before it was translated from Aramaic into Greek.[2]

1.1. *Landscapes of Mesopotamia*

The Euphrates River, formed by the confluence of the Kara Su and Murat rivers north of Lake Van (site 4 in Figure 1), is the longest stream in southwestern Asia (2,700 kilometres), fed by winter rainfall in the southeastern Taurus Mountains. The second longest river in this part of the world is the Tigris River (1,840 kilometres), which also has its source in the southeasternmost Taurus and receives contributions by several tributaries joining from the east along its way.[3] While the Tigris occupies an entrenched valley and is limited to a single stream, the Euphrates tends to separate into a number of channels.[4] There are two major flooding peaks over the year, i.e. November to March resulting from immediate surface runoff, and April to May mainly related to snowmelt.[5] Interannual discharge variability is high, ranging from 1.9×10^{10} to $6.3\times10^{10} m^3$ (Tigris) and 1.0×10^{10} to $3.6\times10^{10} m^3$ (Euphrates), measured during relatively unaltered streamflow settings between 1924 and 1946 (Figure 2a).[6]

[2] Finkelstein, Jacob J., "Mesopotamia." *Journal of Near Eastern Studies* 21 (1962): 73. doi:10.1086/371676.

[3] Berry, Richard W., Gerald P. Brophy, and Adnan Naqash, "Mineralogy of the Suspended Sediment in the Tigris, Euphrates, and Shatt-al-Arab Rivers of Iraq, and the Recent History of the Mesopotamian Plain," *Journal of Sedimentary Research* 40 (1970): 131. doi:10.1306/74D71F05-2B21-11D7-8648000102C1865D; Cullen, Heidi M., and Peter B. deMenocal, "North Atlantic Influence on Tigris–Euphrates Streamflow." *International Journal of Climatology* 20 (2000): 856. doi:10.1002/1097-0088(20000630)20:8<853::AID-JOC497>3.0.CO;2-M.

[4] Morozova, Galina S., "A Review of Holocene Avulsions of the Tigris and Euphrates Rivers and Possible Effects on the Evolution of Civilizations in Lower Mesopotamia," *Geoarchaeology* 20 (2005): 406. doi:10.1002/gea.20057.

[5] Cullen, and deMenocal, "Influence on Tigris–Euphrates Streamflow," 856.

[6] Al-Khashab, Wafiq H. *The Water Budget of the Tigris and Euphrates Basin* (Chicago: University of Chicago Press, 1958), 48.

Geographically, Mesopotamia is separated into five main physiographic regions: 1) The northern and northeastern mountain region, 2) the foothills, 3) the western desert, 4) the central *Jazīra* region, and 5) the southern lowlands.[7] These regions are usually grouped to form Upper (~1–4, where 2 and 4 form the core region) and Lower (~5) Mesopotamia. Upper Mesopotamia mainly comprises steppe vegetation and desert shrub rangelands and was mainly characterised by extensive rain-fed farming in ancient times.[8] The northern and northeastern mountains comprise the northern part of the northwest-southeast-trending folded Upper Palaeozoic and Mesozoic Zagros Mountains and the southern part of the east–west-oriented Taurus fold belt, reaching elevations of up to 3,500 metres above mean sea level (a.s.l.) (Figure 1). They are separated from the central *Jazīra* region by the gently folded foothill zone of Upper Miocene to Pliocene coarse debris.[9] The *Jazīra* region consists of a low, undulating plateau dropping westwards from five hundred metres at Jabal Sinjār to less than one hundred metres a.s.l. (Figure 1). Surface deposits are of Miocene age and comprise sands, silts, clays, limestones, and gypsum, the latter concentrated in numerous salt pans.[10]

[7] Al-Khashab, *Water Budget of the Tigris and Euphrate Basins*, 4.

[8] Wilkinson, Tony J., "Regional Approaches to Mesopotamian Archaeology: The Contribution of Archaeological Surveys," *Journal of Archaeological Research* 8 (2000): 222. doi:10.1023/A:1009487620969; Wilkinson, Tony J. et al., "Contextualizing Early Urbanization: Settlement Cores, Early States and Agro-pastoral Strategies in the Fertile Crescent During the Fourth and Third Millennia BC," *Journal of World Prehistory* 27 (2014): 95. doi:10.1007/s10963-014-9072-2.

[9] Berry, Brophy, and Naqash, "Mineralogy of rivers of Iraq," 131.

[10] Thalen, Derk C.P., *Ecology and Utilization of Desert Shrub Rangelands in Iraq* (The Hague: Dr. W. Junk Publishers, 1979), 73–74. doi:10.1007/978-94-009-9622-9.

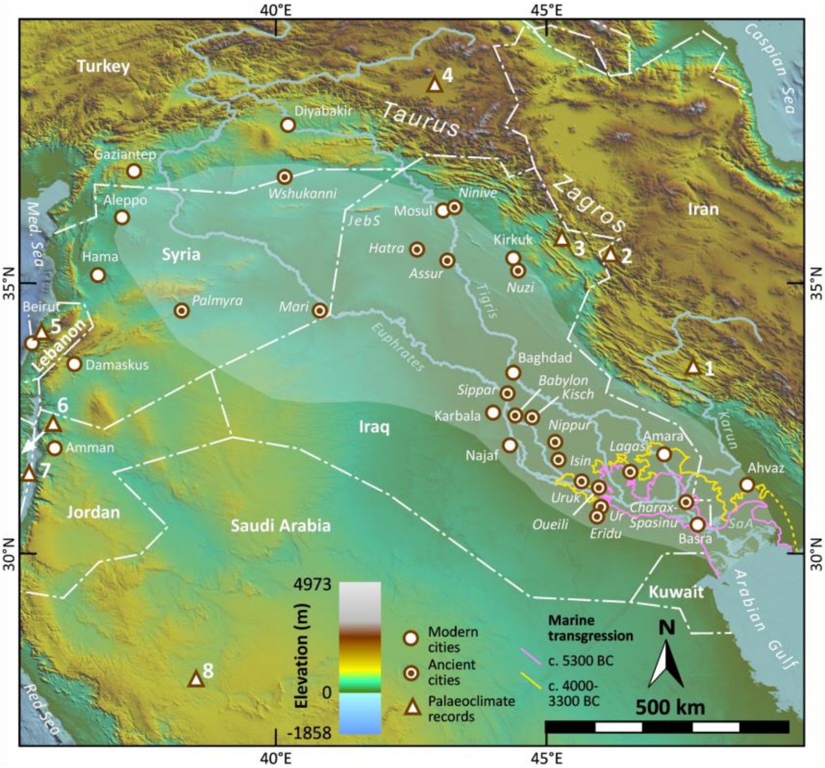

Figure 1. Overview of Mesopotamia (shaded area) and surrounding regions showing important ancient and modern cities, as well as sites of relevant palaeoclimate records. On the Mesopotamian delta plain, reconstructed shorelines of the Mid-Holocene transgression (5,300 BC and 4,000–3,300 BC)[11] are shown. The map is based on the GEBCO_2014[12] grid and SRTM30[13] data provided by the US Geological Survey. 1=Lake Mirabad (Iran); 2=Lake Zeribar (Iran); 3=Geijkar Cave (Iraq); 4=Lake Van (Turkey); 5=Jeita Cave (Lebanon); 6=Soreq Cave (Israel); 7=Dead Sea (Israel); 8=Tayma (Saudi Arabia). SaA=Shatt al-Arab. JebS=Jabal Sinjār.

[11] Pournelle, Jennifer R. "Marshland of Cities: Deltaic Landscapes and the Evolution of Early Mesopotamian Civilization" (PhD diss., University of California, San Diego, 2003), 123–124. doi:10.6067/XCV8J67GK3.

[12] Weatherall, Pauline et al., "A New Digital Bathymetric Model of the World's Oceans," *Earth and Space Science* 2 (2015): 331–345. doi:10.1002/2015EA000107.

[13] Farr, Tom G. et al., "The Shuttle Radar Topography Mission," *Reviews of Geophysics* 45 (2007): RG2004. doi:10.1029/2005RG000183.

The alluvial and deltaic landscapes of Lower Mesopotamia cover much of the Mesopotamian depression, a flexure zone created by the upward-thrusting Zagros Mountains to the northeast and framed by the Arabian Shield to the southwest.[14] They are dominated by active and abandoned, low-gradient alluvial plains, braided, anastomosing, and meandering river channel patterns, levees rising up to three to four metres above the surrounding flood basins, as well as numerous crevasse splays (alluvial fan formed at a levee break).[15] Arid landforms such as sand dunes, deflation basins and salt pans are expanding[16] where areas have been cut off from alluvial influence through the migration of channels (avulsion processes) induced by flash floods and long-term channel deposition over the last centuries and millennia,[17] and by an increase in irrigation measures further up the rivers[18]. The southern part of Lower Mesopotamia is occupied by large-scale wetlands (*ahwar*) at the confluence of the Euphrates and the Tigris, which, however, have been extensively drained and reduced to approximately ten percent of their original size.[19] The delta

[14] Uchupi, Elazar, Stephen. A. Swift, and David A. Ross, "Late Quaternary Stratigraphy, Paleoclimate and Neotectonism of the Persian (Arabian) Gulf Region," *Marine Geology* 160 (1999): 1. doi:10.1016/S0025-3227(99)00011-0; Pournelle, Jennifer R., "Physical Geography," in *The Sumerian World*, ed. Harriet Crawford (London: Routledge, 2013), 13. doi:10.4324/9780203096604.ch1.

[15] Verhoeven, Kristiaan, "Changing Watercourses in Babylonia," in *Geomorphological Research in the Mesopotamian Flood Plain Changing Watercourses in Babylonia. Towards a Reconstruction of the Ancient Environment in Lower Mesopotamia, Vol. I*, ed. Hermann Gasche, and Michel Tanret (Chicago: University of Chicago Press, 1998), 160–168; Wilkinson, "Regional Approaches to Mesopotamian Archaeology," 222; Morozova, "Holocene Avulsions," 405.

[16] Morozova, "Holocene Avulsions," 405.

[17] Heyvaert, Vanessa M.A., and Cecile Baeteman. "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 (2008): 2401. doi:10.1016/j.quascirev.2008.08.024; Jotheri, Jaafar, Mark B. Allen, and Tony J. Wilkinson, "Holocene Avulsions of the Euphrates River in the Najaf Area of Western Mesopotamia: Impacts on Human Settlement Patterns", *Geoarchaeology* 31 (2016): 183ff. doi:10.1002/gea.21548.

[18] Aqrawi, Adnan A.M., "Stratigraphic Signatures of Climatic Change during the Holocene Evolution of the Tigris–Euphrates Delta, Lower Mesopotamia," *Global and Planetary Change* 28 (2001): 269. doi:10.1016/S0921-8181(00)00078-3.

[19] Aqrawi, "Holocene Evolution of the Tigris–Euphrates Delta," 268–269; Morozova, "Holocene Avulsions," 405; Hamdan, Mohamed A. et al., "Vegetation Response to Re-flooding in the Mesopotamian Wetlands, Southern Iraq," *Wetlands* 30 (2010): 178. doi:10.1007/s13157-010-0035-9.

of the Shatt al-Arab River consists of very young, late Holocene deposits[20] and its progradation is the result of relative sea-level fall in the Arabian Gulf after c. 6,000–5,000 BP[21] in combination with high sediment loads, in particular supplied by the Karun River with its catchment reaching up into the Zagros Mountains[22] (Figure 1).

1.2. *Cornerstones of Mesopotamian History*

These differences in physical settings are to some extent reflected by asynchronous settlement patterns in both parts of Mesopotamia. Even though strong ties existed throughout history between the upper and the lower basin, a more or less distinct cultural boundary can be drawn immediately north of present-day Baghdad along Jabal Sinjār.[23] The more humid north provided the opportunity for rain-fed agriculture and shows a higher density of Early Ubaid sites (Figure 3), even though lower counts in the south may be related to high rates of alluvial deposition and burying of sites.[24] Settlement trends in the north during the Chalcolithic show intraregional variability followed by a supraregional trend in centralisation and increased population density in the hinterland during the Early Bronze Age. However, across both phases agro-pastoralism may still have played a significant role, in particular in more arid areas of the east and southeast.[25] It appears that population growth first emerged in the

[20] Uchupi. “Stratigraphy, Paleoclimate and Neotectonism,” 12.

[21] Lambeck, Kurt. “Shoreline Reconstructions for the Persian Gulf since the Last Glacial Maximum,” *Earth and Planetary Science Letters* 142 (1996): 47. doi:10.1016/0012-821X(96)00069-6; Engel, Max, and Helmut Brückner. “The South Qatar Survey Project (SQSP)—Preliminary Findings on Holocene Coastal Changes and Geoarchaeological Archives,” *Zeitschrift für Orient-Archäologie* 7 (2014): 299.

[22] Aqrawi, “Holocene Evolution of the Tigris–Euphrates Delta,” 279; Heyvaert, Vanessa M.A., and Cecile Baeteman, “Holocene Sedimentary Evolution and Palaeocoastlines of the Lower Khuzestan Plain (Southwest Iran),” *Marine Geology* 242 (2007): 102–105. doi:10.1016/j.margeo.2007.01.008. For further reading, the most comprehensive overview of the fluvial landscapes of the Mesopotamian lowlands is provided by Verhoeven, “Changing Watercourses in Babylonia,” 160–181.

[23] Van Ess, Margarete, Helmut Becker, and Jörg Fassbinder, “Uruk—Verortung in Raum und Zeit,” in *Uruk. 5000 Jahre Megacity. Begleitband zur Ausstellung „Uruk—5000 Jahre Megacity“ im Pergamonmuseum. Curt-Engelhorn-Stiftung für die Reiss-Engelhorn-Museen Mannheim, dem Deutschen Archäologischen Institut—Orient-Abteilung, der Deutschen Orient-Gesellschaft e. V. und dem Vorderasiatischen Museum—Staatliche Museen zu Berlin,* ed. Nicole Crüsemann et al. (Petersberg: Imhof Verlag, 2013), 42.

[24] Wilkinson, “Regional Approaches to Mesopotamian Archaeology,” 243–244.

[25] Wilkinson, "Contextualizing Early Urbanization," 57ff, 73.

steppe environments outside the alluvial plain, but rapidly reached Lower Mesopotamia, where a settlement hierarchy seems to have developed throughout the Ubaid period into the 4th millennium BC. At that time, urban-type structures have been identified in Lower Mesopotamia by some authors,[26] as well as a similar degree of urbanisation in Upper Mesopotamia from c. 2,600 BC. Diverging opinions exist on the Early Dynastic II/III times and later, where Wilkinson places the peak state of urban-type centralisation in both parts of Mesopotamia lasting until the termination of the Old Babylonian period.[27] Brinkman, however, emphasises a quasi-continuous reduction of the settled area and an increase in the number of rural settlements (<10 ha) already at that time,[28] which, in other sources, is often linked only with the mid-2nd millennium BC and later phases. Politically induced internal migration and dispersal during the Middle and Late Assyrian period resulted in further decentralisation towards the 9th–7th centuries BC. Population then increased during the late 1st millennium BC to the early 1st millennium AD, in particular in Lower Mesopotamia, where water management practices provided the foundation for higher settlement densities and a moderate re-establishment of more centralised settlement structures. Demographic stability persisted until the turn of the millennium, when population across Mesopotamia decreased (Figure 3) in favour of newly expanding centres in the region, such as Baghdad, Samarra (both Iraq), and Raqqa (Syria).[29]

[26] Kennett, Douglas J., and James P. Kennett, "Influence of Holocene Marine Transgression and Climate Change on Cultural Evolution in Southern Mesopotamia," in *Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions*, ed. David G. Anderson, Kirk A. Maasch, and Daniel H. Sandweiss, 230 (San Diego: Academic Press, 2007). doi:10.1016/B978-012088390-5.50012-1.

[27] Wilkinson, "Regional Approaches to Mesopotamian Archaeology," 243–247.

[28] Brinkman, John A., "Settlement Surveys and Documentary Evidence: Regional Variation and Secular Trend in Mesopotamian Demography," *Journal of Near Eastern Studies* 43 (1984): 172–174. doi:10.1086/373078.

[29] Wilkinson, "Regional Approaches to Mesopotamian Archaeology," 243–247.

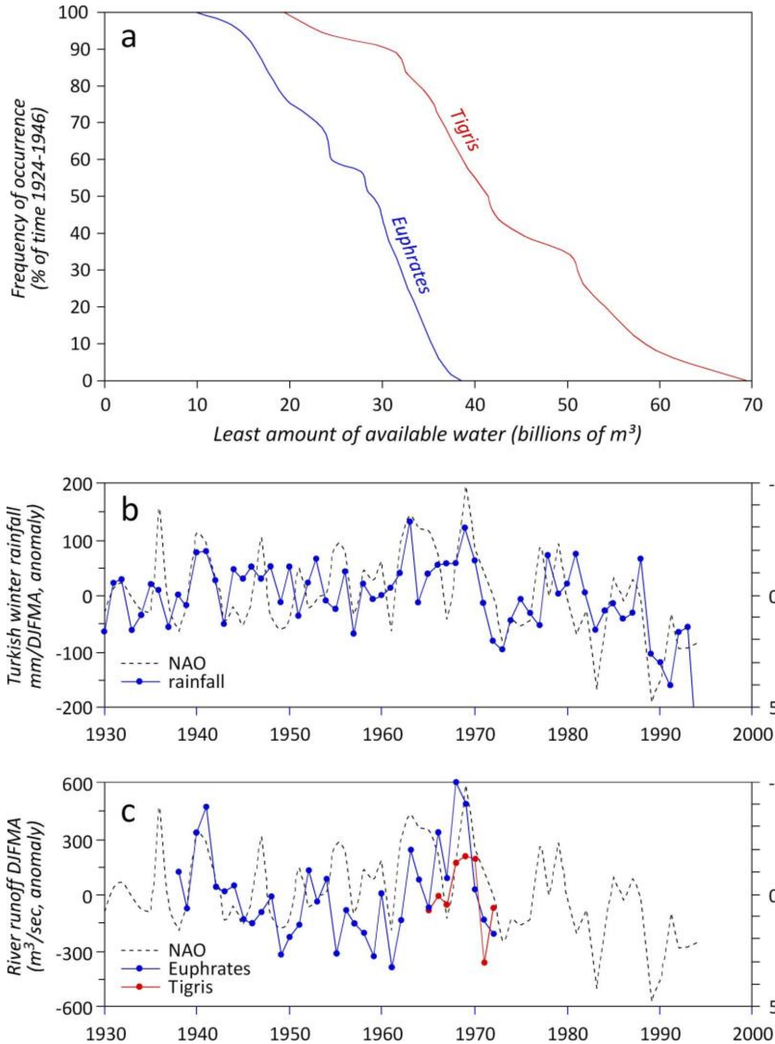

Figure 2. a) Frequency of occurrence of annual water supply by the Ephrates and Tigris rivers between 1924–1946 showing a broad range and high interannual variability;[30] b) correlation between the North Atlantic Oscillation (NAO) and winter rainfall over Turkey from December to April. Activity of the NAO is deduced from an index considering the difference between the normalized mean winter air pressure at sea level between Lisbon, Portugal (Azores High), and Stykkisholmur, Iceland (Icelandic Low) (NAOslp). The NAOslp is

[30] Al-Khashab, *Water Budget of the Tigris and Euphrates Basin*, 48–49.

multiplied by -1 for better comparison; c) correlation between NAOslp and average streamflow of the Euphrates and Tigris rivers during December–April.[31]

1.3. *Aims*

In this contribution, we follow the geoarchaeological approach, i.e. to investigate how the evolution of landscapes and ecosystems inferred from analyses of geo-bio-archives may have influenced settlement patterns, cultural developments, and land use.[32] We review state-of-the-art data on Holocene climatic changes in Mesopotamia and adjacent regions, summarise their impact on vegetation, hydrology, sedimentation, and landforms, and relate these natural dynamics to human reponses as deduced from historical and archaeological sources by putting a focus on Uruk in Lower Mesopotamia. In the sense of Verhoeven et al.[33], we hypothesise that the "flood plain processes must have determined […] the possibilities and limits of the Hydraulic Civilizations of the Mesopotamian Plain."

2. *Holocene Climates of Mesopotamia and Adjacent Regions*

Mesopotamia is situated within the subtropical high-pressure belt, associated with an arid to semiarid climate (Figure 4). Cyclones migrating from the Mediterranean into the Levant during winter provide rainfall for Upper Mesopotamia and, to a lesser extent, to Lower Mesopotamia. These low-pressure systems may even penetrate as far as Afghanistan in the east and Oman in the southeast. In summer, the moist westerlies move northwards and are replaced by downwelling air masses, which induce high atmospheric pressure and generally hot and dry conditions.[34] The arid climate follows a long-term, gradual trend: Flohr et al. found that the magnitude of the drought events of 1998–2000 and 2007–2010 were

[31] Cullen, and deMenocal, "Influence on Tigris–Euphrates Streamflow," 860.

[32] Engel, Max, and Helmut Brückner, "Late Quaternary Environments and Societies: Progress in Geoarchaeology," *Zeitschrift für Geomorphologie N.F* 58.2 (2014): 1. doi:10.1127/0372-8854/2014/S-00168.

[33] Verhoeven, "Changing Watercourses in Babylonia," 162.

[34] Wilkinson, Tony J., *Archaeological Landscapes of the Near East* (University of Arizona Press, 2003), 17.

unprecedented since AD 950 based on a speleothem record of climate covering the Common Era.[35]

Rainfall in Upper Mesopotamia amounts to more than 250 mm a^{-1} in most parts. From Mossul in the north, situated on the Tigris, down to Baghdad at the border between Upper and Lower Mesopotamia the rainfall gradient ranges from more than 400 to 150 mm a^{-1}, while interannual variability is high. Seasonal variability in mean temperatures is high as well, ranging from 7°C in January to 33°C in July for Mossul and 10°C in January to 35°C in July for Baghdad (Figure 4). Evaporation is substantial, in particular during the summer months, adding up to more than 3,000 mm a^{-1}.[36]

Lower Mesopotamia has a much drier climate. Annual rainfall decreases to 140 mm a^{-1} at Basra in the Shatt al-Arab region, where the two great rivers merge less than one hundred kilometres away from the Gulf coastline. Mean temperatures measured at Basra range from 12.2°C in January to 34.5°C in July[37], when the area is subject to dust storms[38] and some of the most severe heat waves worldwide.[39] Evaporation is significantly lower in Lower Mesopotamia, reaching around 2,000 mm a^{-1} at Basra, where relative air humidity is among the highest in Iraq throughout the year due to its proximity to the Arabian Gulf coast.[40]

2.1. *General Climate Trends during the Holocene*

As climate, and in particular rainfall and its interannual variability, strongly influences surface hydrology and strategies in crop cultivaton and pastoralism especially in prehistorical and historical times, reliable records of climatic changes during the last millennia are crucial to understand ancient land use patterns. The most complete datasets stem

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[35] Flohr, Pascal, et al., "Late Holocene Droughts in the Fertile Crescent Recorded in a Speleothem from Northern Iraq," *Geophysical Research Letters* 44 (2017): 1534. doi:10.1002/2016GL071786.

[36] Thalen, *Desert Shrub Rangelands in Iraq*, 56, 60, 66.

[37] Hamdan et al., "Mesopotamian Wetlands," 178.

[38] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 231.

[39] Schär, Christoph, "Climate Extremes: The Worst Heat Waves to Come," *Nature Climate Change* 6 (2016): 129. doi:10.1038/nclimate2864.

[40] Thalen, *Desert Shrub Rangelands in Iraq*, 64–66.

from geo-bio-archives such as (palaeo-)lake basins[41] and caves[42] to the north, and west of the Mesopotamian heartland, and marine records from the eastern Mediterranean Basin[43] or the northern Red Sea[44]. Nearby records from the Zagros Mountains, such as those from the lakes of Mirabad and Zeribar, however, do not seem to adequately reflect lowland Mesopotamian climate as these sites received significant amounts of spring rainfall from continental sources before and after the expansion of

[41] Wick, Lucia, Gerry Lemcke, and Michael Sturm, "Evidence of Lateglacial and Holocene Climatic Change and Human Impact in Eastern Anatolia: High-resolution Pollen, Charcoal, Isotopic and Geochemical Records from the Laminated Sediments of Lake Van, Turkey," *The Holocene* 13 (2003): 665–675. doi:10.1191/0959683603hl653rp; Engel, Max et al., "The Early Holocene Humid Period in NW Saudi Arabia—Evidence from Sediments, Microfossils and Palaeo-hydrological Modelling," *Quaternary International* 266 (2012): 131–141. doi:10.1016/j.quaint.2011.04.028; Litt, Thomas et al., "Holocene Climate Variability in the Levant from the Dead Sea Pollen Record," *Quaternary Science Reviews* 49 (2012): 95–105. doi:10.1016/j.quascirev.2012.06.012; Dinies, Michèle et al., "When the Desert was Green: Grassland Expansion during the Early Holocene in Northwestern Arabia," *Quaternary International* 382 (2015), 293–302. doi:10.1016/j.quaint.2015.03.007; Dinies, Michèle et al., "Holocene Vegetation in Northwestern Arabia—Changing Natural Resources," in *Actualités des recherches archéologiques en Arabie*, ed. Julie Goy et al. (Paris: Routes de l'Orient, 2016), 1–19.

[42] Bar-Matthews, Miryam, and Avner Ayalon. "Mid-Holocene Climate Variations Revealed by High-resolution Speleothem Records from Soreq Cave, Israel and their Correlation with Cultural Changes," *The Holocene* 21 (2011): 163–171. doi:10.1177/0959683610384165; Bar-Matthews, Miryam et al., "Sea–land Oxygen Isotopic Relationships from Planktonic Foraminifera and Speleothems in the Eastern Mediterranean Region and their Implication for Paleorainfall during Interglacial Intervals," *Geochimica et Cosmochimica Acta* 67 (2003): 3181–3199. doi:10.1016/S0016-7037(02)01031-1; Verheyden, Sophie et al., "Paleoclimate Reconstruction in the Levant Region from the Geochemistry of a Holocene Stalagmite from the Jeita Cave, Lebanon," *Quaternary Research* 70 (2008): 368–381. doi:10.1016/j.yqres.2008.05.004.

[43] Rossignol-Strick, Martine. "The Holocene Climatic Optimum and Pollen Records of Sapropel 1 in the Eastern Mediterranean, 9000–6000 BP," *Quaternary Science Reviews* 18 (1999): 515–530. doi: 10.1016/S0277-3791(98)00093-6; Emeis, Kay-Christian et al., "Temperature and Salinity Variations of Mediterranean Sea Surface Waters over the Last 16,000 Years from Records of Planktonic Stable Oxygen Isotopes and Alkenone Unsaturation Ratios," *Palaeogeography, Palaeoclimatology, Palaoecology* 158 (2000): 259–280. doi: 10.1016/S0031-0182(00)00053-5.

[44] Arz, Helge et al., "Mediterranean Moisture Source for an Early-Holocene Humid Period in the Northern Red Sea," *Science* 300 (2003): 118–121. doi:10.1126/science.1080325; Arz, Helge W., Frank Lamy, and Jürgen Pätzold, "A Pronounced Dry Event Recorded around 4.2 ka in Brine Sediments from the Northern Red Sea," *Quaternary Research* 66 (2006): 432–441. doi:10.1016/j.yqres.2006.05.006.

the 'classical' Mediterranean climate with typical winter precipitation during the Mid-Holocene.[45]

[45] Stevens, Lora A. et al., "Timing of Atmospheric Precipitation in the Zagros Mountains Inferred from a Multi-proxy Record from Lake Mirabad, Iran," *Quaternary Research* 66 (2006): 498–499. doi:10.1016/j.yqres.2006.06.008.

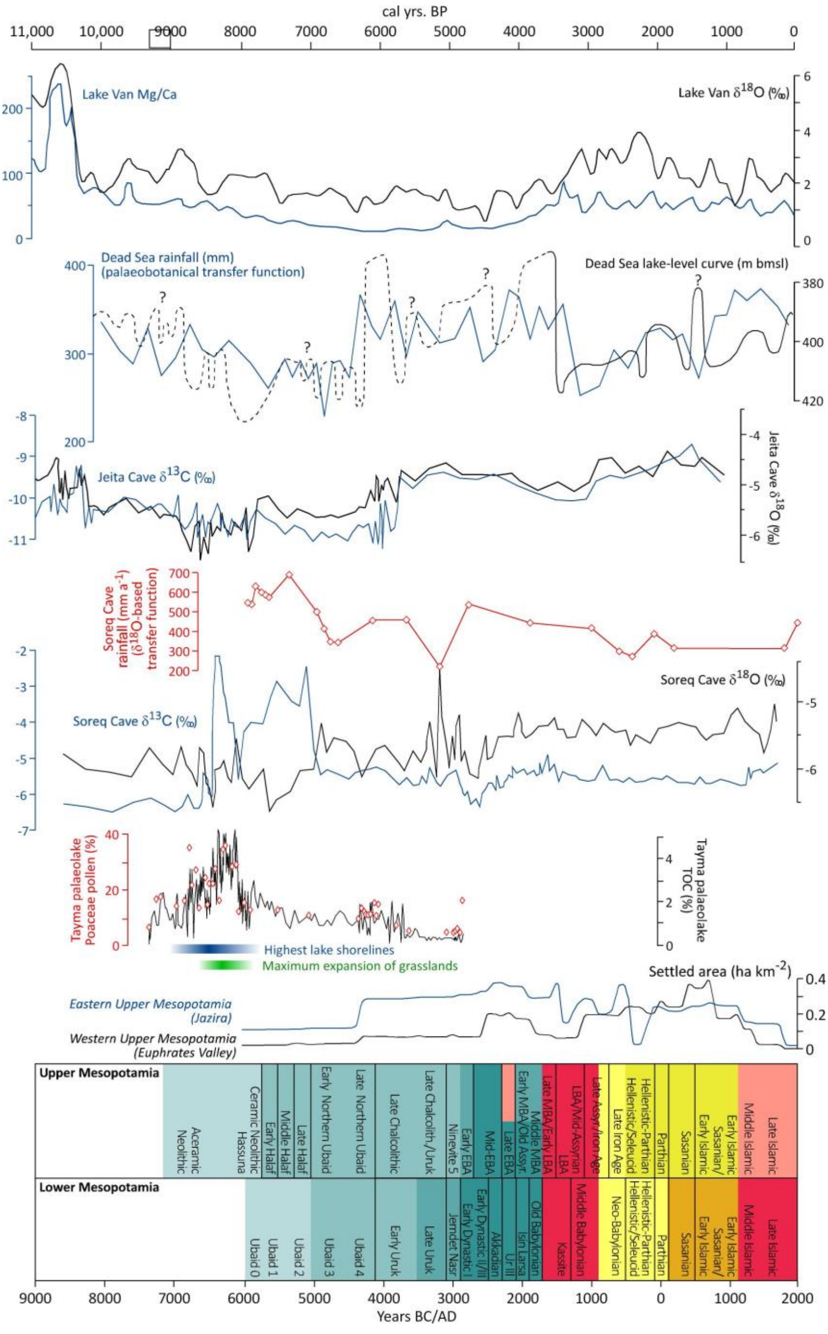
cal yrs. BP
11,000
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Lake Van Mg/Ca
Lake Van δ18O (‰)
Dead Sea rainfall (mm)
(palaeobotanical transfer function)
Dead Sea lake-level curve (m bmsl)
Jeita Cave δ13C (‰)
Jeita Cave δ18O (‰)
Soreq Cave rainfall (mm a-1) (δ18O-based transfer function)
Soreq Cave δ18O (‰)
Soreq Cave δ13C (‰)
Tayma palaeolake Poaceae pollen (%)
Tayma palaeolake TOC (%)
Highest lake shorelines
Maximum expansion of grasslands
Settled area (ha km-2)
Eastern Upper Mesopotamia (Jazira)
Western Upper Mesopotamia (Euphrates Valley)
Upper Mesopotamia
Aceramic Neolithic
Ceramic Neolithic Hassuna
Early Halaf
Middle Halaf
Late Halaf
Early Northern Ubaid
Late Northern Ubaid
Late Chalcolithic
Late Chalcolith./Uruk
Ninevite 5
Early EBA
Mid-EBA
Late EBA
Early MBA/Old Assyr.
Middle MBA
Late MBA/Early LBA
LBA
LBA/Mid-Assyrian
Late Assyr./Iron Age
Late Iron Age
Hellenistic-Parthian
Hellenistic/Seleucid
Parthian
Sasanian
Early Islamic
Early Islamic Sasanian/
Middle Islamic
Late Islamic
Lower Mesopotamia
Ubaid 0
Ubaid 1
Ubaid 2
Ubaid 3
Ubaid 4
Early Uruk
Late Uruk
Jemdet Nasr
Early Dynastic I
Early Dynastic II/III
Akkadian
Ur III
Isin Larsa
Old Babylonian
Kassite
Middle Babylonian
Neo-Babylonian
Hellenistic-Parthian
Hellenistic/Seleucid
Parthian
Sasanian
Early Islamic
Early Islamic Sasanian/
Middle Islamic
Late Islamic
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1000
2000
Years BC/AD

Figure 3. Holocene climate-related proxy records from sites around Mesopotamia (see Figure 1 for location of sites): A record of $\delta^{18}O$ and Mg/Ca ratios from Lake Van[46], a lake-level curve and a rainfall transfer function based on pollen spectra from lacustrine deposits of the Dead Sea (Ein Gedi)[47], $\delta^{18}O$ and $\delta^{13}C$ records of a stalagmite from Jeita Cave[48], $\delta^{18}O$ and $\delta^{13}C$ records and a $\delta^{18}O$-based transfer function for annual rainfall from Soreq Cave[49], and a TOC (total organic carbon) record and relative abundance of Poaceae pollen (grasses)[50] combined with phases of highest lake shorelines[51] and maximum grassland expansion[52] at Tayma. The records are synoptically displayed with estimates of settlement density[53] and urbanization trends during prehistorical and historical periods of Upper and Lower Mesopotamia[54]. A key to colours indicating settlement trends is shown in Figure 5.

One of the most common geochemical indicators used to infer past climatic changes is the ratio of oxygen isotopes ^{18}O and ^{16}O ($\delta^{18}O$), which is driven by fractionation processes during evaporation and, therefore, is an independent measure of relative humidity.[55] $\delta^{18}C$ mostly reflects changes in phytomass and the ratio between C3 (most plant taxa; lower values) and C4 (grasses, sedges; higher values) type plants in the vicinity of the climate archive.[56]

A key site of Quaternary climatic change in the eastern Mediterranean and Near East is Lake Van, located in the eastern Taurus Mountains of southeastern Turkey (Figure 1). It underlies a climatic regime comparable to Mesopotamia—apart from higher annual rainfall and a longer rain period from autumn to spring—but is very sensitive to climatic fluctuations controlled by shifts of the jet stream and the subtropical high-

46 Wick, Lemcke, and Sturm, "Sediments of Lake Van," 670.

47 Litt et al. "Dead Sea Pollen Record," 101.

48 Verheyden et al., "Stalagmite from Jeita Cave," 377.

49 Bar-Matthews et al. "Paleorainfall during Interglacial Intervals," 3195.

50 Dinies et al. "Holocene Vegetation in Northwestern Arabia," 6.

51 Engel et al. "Holocene Humid Period in NW Saudi Arabia," 135.

52 Dinies et al. "Grassland Expansion in Northwestern Arabia," 298

53 Lawrence, Dan et al., "Long Term Population, City Size and Climate Trends in the Fertile Crescent: A First Approximation," *PLOS ONE* 11 (2016): 8. doi:10.1371/journal.pone.0157863.

54 Wilkinson, "Regional Approaches to Mesopotamian Archaeology," 243.

55 Wick, Lemcke, and Sturm, "Sediments of Lake Van," 667.

56 Bar-Matthews et al., "Paleorainfall during Interglacial Intervals," 3181.

pressure belt.[57] High $\delta^{18}O$ values from Lake Van strongly correlating with the Mg/Ca ratio—a measure of lake salinity—indicate very arid conditions during the Younger Dryas and the earliest Holocene, followed by a sudden shift to increased winter precipitation at around 10,500 cal. BP (Figure 3).[58] $\delta^{18}O$ records from speleothems of the karstic caves of Soreq (Israel)[59] and Jeita (Lebanon)[60], both subject to a genuine Mediterranean climate, show a more gradual increase in rainfall at that time. The Early Holocene shows a gradual increase in moisture availability over the entire Near East, as inferred from a rising lake level[61] and internal lake productivity reflected by total organic carbon (TOC), as well as a rise in grass pollen at Tayma (after 9,300 cal BP)[62] on the northern Arabian Peninsula. While generally the moisture pattern over time is similar to the classic Mediterranean climate sites, it is not yet entirely clear whether enhanced rainfall in northern Arabia is related to the African Summer Monsoon penetrating further eastward[63], winter–spring tropical plumes crossing the Red Sea,[64] and/or Meditteranean winter rains[65]. Likewise, salinity decreased with the onset of the Holocene in the eastern

[57] Wick, Lemcke, and Sturm, "Sediments of Lake Van," 666.

[58] Ibid., 673.

[59] Bar-Matthews et al., "Paleorainfall during Interglacial Intervals," 3190.

[60] Verheyden et al., "Stalagmite from Jeita Cave," 378.

[61] Engel et al., "Holocene Humid period in NW Saudi Arabia," 136; Pint, Anna, et al., "How to Discriminate Athalassic and Marginal Marine Microfaunas? Foraminifera and other Fossils from an Early Holocene Continental Lake in Northern Saudi Arabia," *Journal of Foraminiferal Research* 47 (2017): 179. doi:10.2113/gsjfr.47.2.175. The age model used in both papers is biased by the hard water effect; calibrated ^{14}C data are ~1000–1500 years too old based on the new age model from Tayma in Dinies et al. "Holocene Vegetation in Northwestern Arabia," 8.

[62] Dinies et al., "Grassland Expansion in Northwestern Arabia," 297; Dinies et al., "Holocene Vegetation in Northwestern Arabia," 6.

[63] Guagnin, Maria, et al., "Rock Art Imagery as Aproxy for Holocene Environmental Change: A View from Shuwaymis, NW Saudi Arabia," *The Holocene* 26 (2016): 1829. doi:10.1177/0959683616645949; Engel, Max, et al., "Lakes or Wetlands? A Comment on 'The Middle Holocene Climatic Records from Arabia: Reassessing Lacustrine Environments, Shift of ITCZ in Arabian Sea, and Impacts of the Southwest Indian and African Monsoons' by Enzel et al.," *Global and Planetary Change* 148 (2017): 265. doi:10.1016/j.gloplacha.2016.11.001.

[64] Enzel, Yehouda, Yochanan Kushnir, and Jay Quade. "The Middle Holocene Climatic Records from Arabia: Reassessing Lacustrine Environments, Shift of ITCZ in Arabian Sea, and Impacts of the Southwest Indian and African Monsoons," *Global and Planetary Change* 129 (2015): 71. doi:10.1016/j.gloplacha.2015.03.004.

[65] Arz et al., "Early-Holocene Humid Period in the Northern Red Sea," 121.

Mediterranean Basin[66]. Conflicting evidence, however, arises from the Dead Sea record, where Litt et al. established a rainfall transfer function based on the pollen record correlating with reconstructed Dead Sea lake levels. The authors infer warm and dry conditions from 10,000 to 6,500 cal.BP and explain disparities by processes other than climate-driven isotope fractionation that may influence isotopic source-water composition in the eastern Mediterranen Sea.[67]

The Early to Mid-Holocene transition is associated with a period of more humid conditions in nearly any palaeoclimate record from the Near East, even though its beginning and end varies. North of Upper Mesopotamia, Lake Van experienced relatively humid conditions until 4,000 cal. BP with a climatic optimum around 6,200–4,000 cal. BP. At Soreq Cave, high precipitation ocurred 8,500–7,000 years ago[68], while the Jeita Cave stalagmite shows lowest $\delta^{18}O$ and $\delta^{13}C$ values, highest growth rates, and, therefore, most humid conditions between 9,200–6,500 years ago. Northern Arabia experienced the peak of the humid phase at 8,700–8,000 cal. BP, followed by an abrupt shift to drier conditions indicated by both a decline in TOC related to lower lake-internal bioproductivity[69] and a fall of the lake level. A short window of slightly enhanced moisture availability at Tayma appears to have occurred 6,300–5,900 cal. BP.[70] Overlapping with this latter phase, the Dead Sea pollen record suggests highest Holocene rainfall amounts lasting for more than 3,000 years from 6,500 to 3,300 cal. BP, before more arid conditions set in again. Both, the humid phase and a long-term increase in rainfall during the subsequent drier phase strongly correlate with Dead Sea lake levels.[71]

The onset of significantly drier conditions during the Mid- and Late Holocene occured around 4,200–4,000 cal. BP at Lake Van, when the Mediterranean winter rains decreased and a more continental climate gained influence.[72] At Jeita, rainfall decreased markedly from 6,500 to 5,800 BP and then more gradually until the end of the record (1,100 years ago), with a temporary change to a somewhat more humid climate in the

[66] Emeis et al., “Temperature and Salinity Variations,” 259–280.
[67] Litt et al., “Dead Sea Pollen Record,” 102–103.
[68] Bar-Matthews et al., “Paleorainfall During Interglacial Intervals,” 3195.
[69] Dinies et al., “Holocene Vegetation in Northwestern Arabia,” 11.
[70] Engel et al., “Holocene Humid Period in NW Saudi Arabia,” 135.
[71] Litt et al., “Dead Sea Pollen Record,” 102–103.
[72] Wick, Lemcke, and Sturm, “Sediments of Lake Van,” 673.

4th millennium BP.[73] The long-term trend inferred from Soreq Cave shows increasing aridity during the last 7,000 years,[74] corroborated by the high-resolution record for the last 2,400 years from Geijkar Cave.[75] More recent insights into speleothem records at higher resolution from Soreq Cave, however, reveal considerable millennial- as well as superimposed centennial to decadal-scale fluctuations within these long-term trends.[76] This reflects a highly sensitive and unstable climate regime[77]. While the cyclicity of 1,500 years is related to Bond cycles driven by North Atlantic Oscillations (NAO),[78] decadal climatic changes, so-called Rapid Climate Change events (RCC) are associated with high-latitude cooling, low-latitude aridity, and major atmospheric circulation changes[79].

2.2. *Rapid Climate Change Events (RCC)*

Compared to gradual climatic trends, short-term changes or climatic events, respectively, have often triggered strong responses in ancient societies. The 8,200 BP global Rapid Climate Change event (RCC), a climatic deterioration with clear imprints in Greenland ice core records,[80] seems to have coincided with an abrupt increase of higher moisture availability in the growing season based on the Lake Van record.[81] Bar-Matthews et al. inferred opposed conditions, i.e. sudden cooling and drying 8,200–8,000 years ago at Soreq Cave based on a slight increase in $\delta^{18}O$ and sharp decrease in $\delta^{13}C$ (Figure 3).[82] This discrepancy, however, was attributed to local soil denudation and considered not representative for regional climate variability by Verheyden et al, who observed no such drying and cooling signal at Jeita Cave. [83] A later higher-resolution

[73] Verheyden et al., “Stalagmite from Jeita Cave,” 378–380.

[74] Bar-Matthews et al., “Paleorainfall during Interglacial Intervals,” 3195.

[75] Flohr et al., “Late Holocene Droughts in the Fertile Crescent,” 1532.

[76] Bar-Matthews, and Ayalon, “Mid-Holocene Climate from Soreq Cave,” 168.

[77] Bar-Matthews et al. “Regional Events at Soreq Cave,” 91.

[78] Bond, Gerald, et al., “A Pervasive Millennial-scale Cycle in North Atlantic Holocene and Glacial Climates,” *Science* 278 (1997): 1263. doi:10.1126/science.278.5341.1257.

[79] Mayewski, Paul A. et al., “Holocene Climate Variability,” *Quaternary Research* 62 (2004): 251. doi: 10.1016/j.yqres.2004.07.001;

[80] Thomas, Elizabeth R. et al., “The 8.2 ka Event from Greenland Ice Cores,” *Quaternary Science Reviews* 26 (2007): 72. doi:10.1016/j.quascirev.2006.07.017.

[81] Wick, Lemcke, and Sturm, “Sediments of Lake Van,” 673.

[82] Bar-Matthews et al., “Regional Events at Soreq Cave,” 91.

[83] Verheyden et al., “Stalagmite from Jeita Cave,” 379.

speleothem analysis at Soreq Cave by Bar-Matthews and Ayalon [84] correlates the first stepdown in rainfall inferred at Jeita (6,500–5,800 BP)[85] with distinct decadal-scale arid events 6,650–6,600 and 6,250–6,180 years ago (Figure 5).

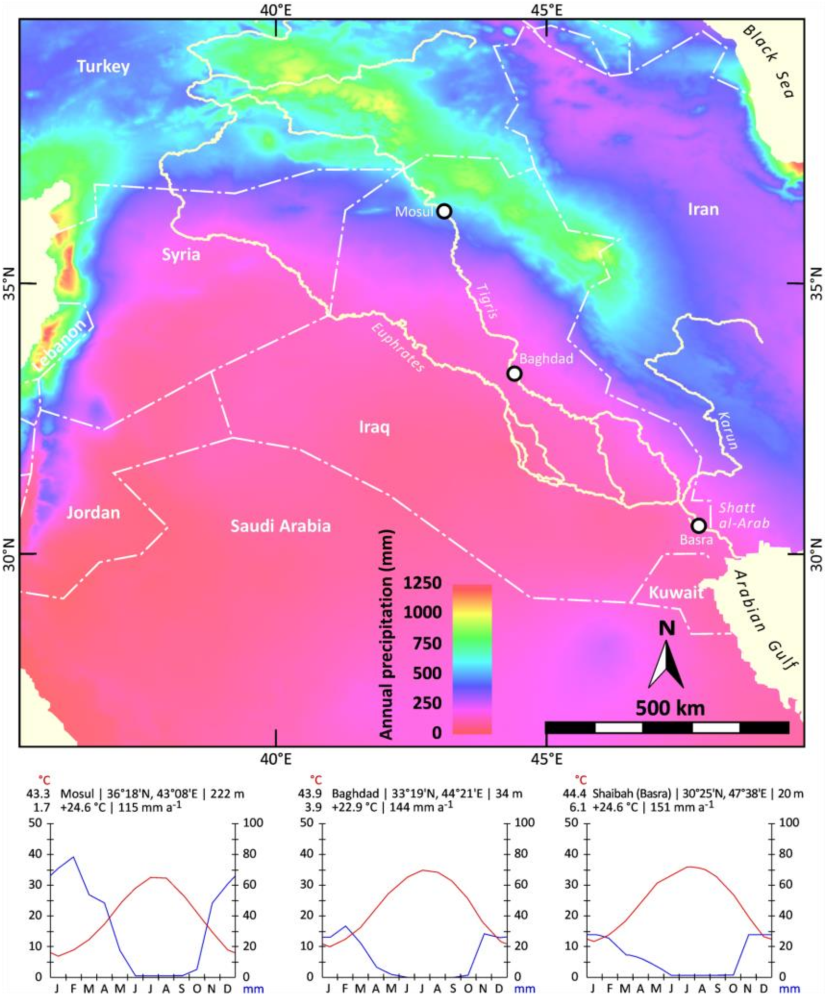

Figure 4: Distribution of annual precipitation in the Near East based on high-resolution, spatially interpolated monthly rainfall data of the

84 Bar-Matthews, and Ayalon, “Mid-Holocene Climate from Soreq Cave,” 168.
85 Verheyden et al., “Stalagmite from Jeita Cave,” 379.

WorldClim database (2.5 min. resolution)[86]. Climate diagrams of Mosul, Baghdad and Basra were adapted from the Worldwide Bioclimatic Classification System.[87]

An abrupt drought event around 5,200–5,100 years ago was identified in the Late Pleistocene–Holocene record of Soreq Cave[88] and is corroborated by Bar-Matthews and Ayalon (slightly shifted: 5,250–5,170 BP)[89] as well as the $\delta^{13}C$ record of barley grains from 33 ancient Mesopotamian sites (5,200 cal. BP)[90]. Bar-Matthews and Ayalon[91] argue that this RCC is part of the widespread dry period recognised all over southeastern Europe and the Mediterranean around 6,000–5,000 years ago[92] and that the peak drought during this phase coincides with the broader peak in $\delta^{13}C$ and $\delta^{18}O$ dated to 5,700–5,600 years ago.

The RCC at around 4,200 BP, with cross-continental recognition in Africa, West Asia and the North Atlantic area, was identified in sediments from the northern Red Sea as a distinct dry phase of short duration[93]. Its imprint, however, at Lake Van[94] and Soreq Cave[95] marks a long-term shift to drier conditions rather than representing a punctuated event[96].

[86] Fick, Stephen E., and Robert J. Hijmans, "WorldClim 2: New 1-km Spatial Resolution Climate Surfaces for Global Land Areas," *International Journal of Climatology* (2017). doi:10.1002/joc.5086.

[87] Rivas-Martinez, Salvador, and Salvador Rivas-Saenz, "Worldwide Bioclimatic Classification System, 1996–2017. Phytosociological Research Center, University Complutense of Madrid, Spain," Last modified January, 2017. Accessed July 14, 2017. http://www.pendientemigracion.ucm.es/info/cif/plot/diagram.htm.

[88] Bar-Matthews et al., "Regional Events at Soreq Cave," 89; Bar-Matthews et al., "Paleorainfall during Interglacial Intervals," 3195.

[89] Bar-Matthews, and Ayalon, "Mid-Holocene Climate from Soreq Cave," 168.

[90] Riehl et al., "Drought Stress Evidenced by $\delta^{13}C$ in Barley Grain," 12349.

[91] Bar-Matthews, and Ayalon, "Mid-Holocene Climate from Soreq Cave," 168.

[92] Mayewski et al., "Holocene Climate Variability," 250; Weninger, Bernhard, et al., "The Impact of Rapid Climate Change on Prehistoric Societies during the Holocene in the Eastern Mediterranean," *Documenta Praehistorica* XXXVI (2009): 34–44. doi:10.4312/dp.36.2.

[93] Arz, Lamy, and Pätzold, "A Dry Event Recorded Around 4.2 ka," 436.

[94] Wick, Lemcke, and Sturm, "Sediments of Lake Van," 673.

[95] Bar-Matthews et al., "Paleorainfall during Interglacial Intervals," 3196; Bar-Matthews, and Ayalon, "Mid-Holocene Climate from Soreq Cave," 169.

[96] Riehl, Simone et al., "Mid-to-Late Holocene Agricultural System Transformations in the Northern Fertile Crescent: A Review of the Archaeobotanical, Geoarchaeological, and Philological Evidence," in *Climates, Landscapes, and Civilizations*, ed. Liviu Giosan, et al., 119. Washington: American Geophysical Union, 2012. doi:10.1029/2012GM001221.

Another supraregional, Bond cycle-related arid event around 3,200–2,700 BP has been previously linked with impacts on the Upper Mesopotamian civilisation[97] and may correlate with the abrupt decrease in rainfall and lake-level fall observed at Ein Gedi, Dead Sea.[98] Other regional records, however, fail to reflect this event.

Significant events of increased humidity have been inferred form the high-resolution speleothem analysis at Soreq Cave 6,550–6,450 and 4,800–4,700 years ago. Shorter, less intense humid events were identified at 6,700–6,680 BP, 6,170–6,100 BP, 5,760–5,740 BP, and 5,500–5,450 BP.[99]

3. *Holocene Landscape Changes*

3.1. *Vegetation Changes*

Changes in Holocene vegetation, a pivotal resource for ancient societies, are driven by climate variability and, in particular since the Mid-Holocene, by anthropogenic impact. The state of knowledge for the Near East is mainly based on pollen analyses from lake[100] or marine[101] records and archaeobotanical studies[102].

During the Early to Mid-Holocene, it has been observed that vegetation response to climatic changes lags behind up to three millennia.[103] As there are no robust and well-dated Holocene pollen spectra from the Mesopotamian heartlands, again Lake Van, with its wide pollen catchment

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[97] Riehl et al., "Holocene Agricultural System Transformations," 119–120.

[98] Litt et al. "Dead Sea Pollen Record," 102–103.

[99] Bar-Matthews, and Ayalon, "Mid-Holocene Climate from Soreq Cave," 169.

[100] Wick, Lemcke, and Sturm, "Sediments of Lake Van," 670–672; Schwab, Markus J. et al., "Holocene Palaeoecology of the Golan Heights (Near East): Investigation of Lacustrine Sediments from Birkat Ram Crater Lake," *Quaternary Science Reviews* 23 (2004): 1726–1727. doi:10.1016/j.quascirev.2004.05.001; Roberts, Neil et al., "Climatic, Vegetation and Cultural Change in the Eastern Mediterranean during the Mid-Holocene Environmental Transition," *The Holocene* 21 (2011): 154–158. doi:10.1177/0959683610386819; Litt et al., "Dead Sea Pollen Record," 99–102.

[101] Rossignol-Strick, "Pollen Records of Sapropel 1," 517–521.

[102] Miller, Naomi F., "The Macrobotanical Evidence for Vegetation in the Near East, c. 18000/16000 BC to 4000 BC," *Paléorient* 23 (1997): 197–207. doi:10.3406/paleo.1997.4661; Riehl et al., "Holocene Agricultural System Transformations," 122–123.

[103] Miller, "Macrobotanical Evidence for Vegetation in the Near East," 198; Wick, Lemcke, and Sturm, "Sediments of Lake Van," 671.

at the crossroads between the Indo-Turanian steppe and desert in the north and the Kurdo-Zagrosian oak and pistachio-almond steppe forest in the south, provides a relevant reference for the northern basin.[104] Based on the Van record, the Early Holocene witnessed a dominance of non arboreal pollen (NAP), such as of *Gramineae* and other steppe to desert-steppe herbs, in combination with *Pistacia*, typically indicating summer drought and mild winters without frost. The shift towards deciduous oak forest seems to have gradually reached a maximum in arboreal pollen (AP) only around 6,500 cal. BP lagging behind the much earlier onset of a more humid climate.[105] This lag could partially be explained by the underrepresentation of AP in the pollen rain, cooler summer months[106], and changes in the seasonality of precipitation, which increased during winter but not in the growing season.[107] At around the same time, human clearing of deciduous oak in the Near East gave space to heliophilous taxa and led to increased soil erosion at Birkat Ram in the Golan Heights.[108] The maximum expansion of oak-dominated forest-steppe vegetation lasted until the onset of the 4th millennium BP, when deciduous oak gradually declined and synanthropic taxa such as *Plantago lanceolata* set in.[109]

The archaeobotanical record of sites in the Zagros foothills, Upper Mesopotamia, and the Levant, mostly consisting of seeds and charcoal, also points to *Pistacia* being the only widespread tree taxon during the Younger Dryas, while steppe herbs dominated. Eastward expansion of woodland including oak, almond, and pistachio during the early Holocene is reflected by seeds and charcoal from various sites. Significant human impact due to pastoralism is inferred only after 6,000 BP,[110] while potential signs of overgrazing inferred from a meta-study of seed/grain, charcoal and isotope data occurred during the Early Bronze Age.[111]

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[104] Roberts et al., "Climatic, Vegetation and Cultural Change," 155.

[105] Wick, Lemcke, and Sturm, "Sediments of Lake Van," 670–672.

[106] Roberts et al., "Climatic, Vegetation and Cultural Change," 156–157.

[107] Wick, Lemcke, and Sturm, "Sediments of Lake Van," 673.

[108] Schwab et al., "Holocene Palaeoecology of the Golan Heights,"1730.

[109] Wick, Lemcke, and Sturm, "Sediments of Lake Van," 673.

[110] Miller, "Macrobotanical Evidence for Vegetation in the Near East," 198;

[111] de Gruchy, Michelle, Katleen Deckers, and Simone Riehl, "A diachronic reconstruction of the Northern Mesopotamian landscape (4th to 2nd millennia BCE) from three separate sources of evidence,“ *Journal of Archaeological Science: Reports* 8 (2016): 265. doi:10.1016/j.jasrep.2016.05.047.

3.2. *Hydrological Variability of the Tigris and Euphrates Rivers and the Geomorphic Response*

Streamflow of the Tigris and Euphrates rivers is strongly controlled by activity of the North Atlantic Oscillation (NAO)[112], referring to the air mass transfer between the Arctic and subtropical Atlantic which drives to a large extent climate fluctuations in the Northern Hemisphere, including the eastern Mediterranean region[113] (Figure 3b,c). Accordingly, Kay and Johnson present a Mid- to Late Holocene curve of Euphrates-Tigris streamflow strongly correlating with the oxygen isotope curve of Lake Van that is similarily tied to NAO-driven Mediterranean rainfall.[114]

Streamflow in combination with relative sea-level fluctuations of the Arabian Gulf are the main drivers of fluvial landscape formation on the Mesopotamian Plain.[115] High streamflow is generally associated with the formation of long, high-amplitude meanders, initial channel braiding and periods of aggradation or incision, whereas low streamflow is linked to a shift from braiding to meandering and dominant incision. While the *Jazīra* region of Upper Mesopotamia, dominated by broad terraces, gullies, large-scale gypsum crusts, endhoreic depressions, alluvial fans, and gravel-covered floodplains, is the result of relict depositional and erosional activity during the Pleistocene, Lower Mesopotamia comprising the meandering and anastomosing floodplains of the Euphrates, the meandering floodplain of the Tigris, the abandoned, inactive floodplains of the central plain, as well as the fluvio-lacustrine deltaic complex of the Euphrates-Tigris-Karun system is characterised by high morphodynamic activity over most of the Holocene until today. Dominating processes comprise vertical floodplain accretion, levee migration, and alluvial fan development along the margins of the plain directed perpendicular to its longitudinal axis. On the largest spatial scale, the most important evolution is the change from a Late Quaternary braided river system to an anastomosing one and, related to the Mid-Holocene sea-level or base-level

112 Cullen, and deMenocal, “Influence on Tigris–Euphrates Streamflow,” 862.

113 Brandimarte, Luigia, et al. “Relation Between the North-Atlantic Oscillation and Hydroclimatic Conditions in Mediterranean Areas,” *Water Resources Management* 25 (2011): 1270. doi: 10.1007/s11269-010-9742-5.

114 Kay, Paul A., and Douglas L. Johnson, “Estimation of Tigris-Euphrates Streamflow from Regional Paleoenvironmental Proxy Data,” *Climatic Change* 3 (1981): 258. doi: 10.1007/BF02423218.

115 Verhoeven, “Changing Watercourses in Babylonia,” 181, 192; Morozova, “Holocene Avulsions,” 412.

highstand, respectively, predominantly single-channel meandering system. The main active channels benefitted from gradual siltation of the parallel, anastomosing watercourses.[116]

Riehl et al. compile sites within and around Mesopotamia, where significant changes in streamflow and morphodynamic response associated with a pan-Mesopotamian aridisation trend after 4,200 years ago were identified. A regime of predictable, steady streamflow seems to have changed to a lower total flow and more erratic pattern resulting in a shift from valley aggradation and floodplain stability to incision and the disappearance of wetland environments,[117] as, e.g., in the upper Khabur basin, a tributary of the Euphrates in northeastern Syria.[118] Further to the west, in the upper Middle Euphrates Valley of the Turkey-Syria border region, where the river enters the Syrian Plateau, the Early Holocene braided river pattern led to the deposition of a predominantly silty terrace during high floods. After 6,000 BC, streamflow concentrated in very few main channels incising these deposits, which then formed terraces where soils developed. A shift to more instable conditions and erratic floods over the Middle Euphrates Valley occurred asynchronously depending on site characteristics (e.g. catchment order of tributaries, historical land use, etc.) and the general lag between climate shifts and fluvial response.[119]

[116] Verhoeven, "Changing Watercourses in Babylonia," 181

[117] Riehl et al., "Holocene Agricultural System Transformations," 124.

[118] Deckers, Katleen, and Simone Riehl, "Fluvial Environmental Contexts for Archaeological Sites in the Upper Khabur Basin (Northeastern Syria)," *Quaternary Research* 67 (2007): 347. doi:10.1016/j.yqres.2006.11.005.

[119] Kuzucuoglu, Catherine, Michel Fontugne, and Damase Mouralis, "Holocene Terraces in the Middle Euphrates Valley, between Halfeti and Karkemish (Gaziantep, Turkey)," *Quaternaire* 15 (2004): 195–206. doi:10.3406/quate.2004.1767.

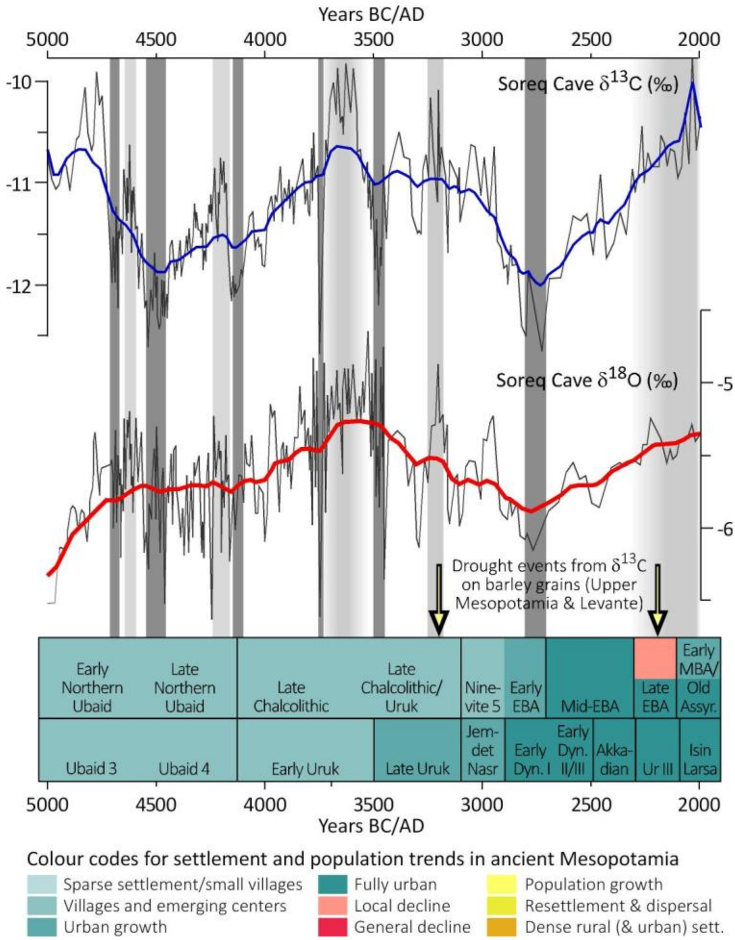

Figure 5: High-resolution $\delta^{18}O$ and $\delta^{13}C$ data from Soreq Cave, Israel (Figure 1), shown in combination with smoothed curves, inferred short-term dry (light grey) and humid (dark grey) periods[120], cultural periods, and urbanisation trends[121]. Droughts reflected by $\delta^{13}C$ of barley grains from 33 archaeological site of Upper Mesopotamia and the Levant are indicated by vertical arrows.[122] Colour codes for settlement and population trends also apply to Figure 3.

[120] Bar-Matthews, and Ayalon, "Mid-Holocene climate from Soreq Cave," 167–168.

[121] Wilkinson, "Regional Approaches to Mesopotamian Archaeology," 243.

[122] Riehl, Simone, et al., "Drought Stress Variability in Ancient Near Eastern Agricultural Systems Evidenced by $\delta^{13}C$ in Barley Grain," *Proceedings of the National Academy of Sciences of the USA* 111 (2014): 12350. doi: 10.1073/pnas.1409516111.

Besides these gradual, longer-term changes driven by external factors, there are numerous short-term, intrinsic morphodynamic changes active on a more local scale. These include meander cut-offs where cut banks at the neck converge due to continuous erosion, downstream migration of meanders, or sudden avulsion processes.[123] Avulsion describes the diversion of a major river channel framed by levees to the lower-lying floodplain and initiation of a new channel, and can occur through abrupt reoccupation of a pre-existing channel or long-term channeling of a flooded plain, mostly in an anastomosing pattern, after a levee break.[124] Large-scale flooding associated with levee breaks represented a constant hazard to settlements in the floodplain throughout history.[125]

The oldest abandoned channels associated with avulsion processes are dated to the 4th millennium BC (Uruk period), when Euphrates and Tigris coalesced near Sippar. After the 4th millennium BC, the rivers separated as the Tigris shifted eastward, still exhibiting a multiple channel network. From the middle of the 2nd millennium BC, with the onset of the two-channel system, these networks were abandoned.[126]

3.3. *Coastal Changes and Noah's Flood Hypothesis*

Until the end of the Pleistocene, the Arabian Gulf was dry and formed the extension of the Euphrates-Tigris drainage system. Initial marine incursions into the Gulf date to c. 12,500 BP, whereas the current sea level was first reached c. 7,000 to 6,500 years ago, followed by the Mid-Holocene relative sea-level highstand of at least two metres higher at around 6,000–4,500 years ago.[127]

The rapid flooding of the c. 1,000 kilometres long and up to 350 kilometres wide Gulf is explained by high rates of the global eustatic sea-level rise until 7,000–6,000 BP and its shallow and for most parts very gentle bathymetry. Extremely rapid lateral shifts of the Gulf coastline northward

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123 Verhoeven, "Changing Watercourses in Babylonia," 192–195.

124 Morozova, "Holocene Avulsions," 407–410. Jotheri et al., "Avulsions of the Euphrates River," 188.

125 Brückner, Helmut, "Wasserstraßen im Wüstensand," *Antike Welt* 44.3 (2013): 11.

126 Morozova, "Holocene Avulsions," 407–410.

127 Cooke, Gary A., "Reconstruction of the Holocene coastline of Mesopotamia," Geoarchaeology 2 (1987): 19–20. doi:10.1002/gea.3340020102; Lambeck, "Shoreline Reconstructions for the Persian Gulf," 47; Engel, and Brückner, "SQSP—Holocene Coastal Changes," 299.

of up to one kilometre yr^{-1}[128] led to flooding of the Shatt al-Arab region at c. 9,000–8,000 BP, reflected by a thick sequence of brackish marine deposits[129]. Marginal marine sedimentary environments were reconstructed around 9,000 BP along the current coastline near Fao, at around 8,000 BP near Basra and at around 6,000 BP during the Mid-Holocene highstand at least as far as the ancient city of Ur in the west and modern Amara in the east (Fig. 1), overriding pre-transgressive fluvial to wetland deposits in the east and evaporate-rich *sabkha* (salt flat) deposits towards the west.[130] After 5,000 BP, during the highstand plateau and subsequent relative sea-level fall, hypersaline coastal *sabkhas* developed from salt marshes along the inland coastline under an increasingly arid climate. The subsequent initiation of delta formation can be inferred by the capping of the transgressive parasequence by coastal marsh facies, evaporates dominated by gypsum, dolomite and palygorskite, as well as fluvial silts and clays.[131] The latter terrestrial facies is associated with rapid post-highstand delta progradation controlled by river sediment loads, eustasy and isostasy, while the role of vertical tectonic activity seems to be of minor importance.[132]

The most detailed palaeogeographic scenarios for the local extent of the mid-Holocene transgression were created by Pournelle[133] based on a synthesis of published borehole data of the Geological Survey of Iraq[134] and those compiled by Larsen and Sanlaville[135], archaeological findings

[128] Teller, Jim T. et al., "Calcareous Dunes of the United Arab Emirates and Noah's Flood: The Postglacial Reflooding of the Persian (Arabian) Gulf," *Quaternary International* 68–71 (2000): 303. doi:10.1016/S1040-6182(00)00052-5.

[129] Aqrawi, Adnan A.M. "Stratigraphic Signatures of Climatic Change during the Holocene Evolution of the Tigris–Euphrates Delta, Lower Mesopotamia," *Global and Planetary Change* 28 (2001): 273–275. doi:10.1016/S0921-8181(00)00078-3.

[130] Sanlaville, Paul, "Considérations sur l'évolution de la Basse Mésopotamie au cours des derniers millénaires," *Paléorient* 15 (1989): 21. doi:10.3406/paleo.1989.4506; Aqrawi, "Holocene Evolution of the Tigris–Euphrates Delta," 275–276; Heyvaert, Baeteman, "Palaeocoastlines of the Lower Khuzestan Plain," 101–105.

[131] Cooke, "Holocene coastline of Mesopotamia," 21; Aqrawi, "Holocene Evolution of the Tigris–Euphrates Delta," 275–276.

[132] Sanlaville, "L'évolution de la Basse Mésopotamie," 11–14; Aqrawi, "Holocene Evolution of the Tigris–Euphrates Delta," 275–276; Pournelle, "Deltaic Landscapes," 112; Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 240–241.

[133] Pournelle, "Deltaic Landscapes," 114–124.

[134] Aqrawi, "Holocene Evolution of the Tigris–Euphrates Delta," 269.

[135] Larsen, Curtis E., "The Mesopotamian Delta Region: A Reconsideration of Lees and Falcon," *Journal of the American Oriental Society* 95 (1975): 54. doi:10.2307/599157; Sanlaville, "L'évolution de la Basse Mésopotamie," 15.

from the ancient cities of Lower Mesopotamia, and multispectral satellite image analysis. In these scenarios, the maximum transgression reached even further up the two rivers mainly covering an area which is now occupied by wetlands (*ahwar*)[136] (Figure 1). The massive extent of the Mid-Holocene transgression is corroborated by cuneiform texts indicating that the inland sites of Lagash and Ur were port cities in the 3rd millennium BC,[137] and by Classical texts, which inspired J. DeMorgan as early as in 1900 to draw a 1st millennium BC shoreline just south of Amara and Ahwaz[138]. Excavations at the Ubaid sites of Eridu and Tell Oueili suggest an economy strongly adapted to coastal wetland environments, mostly based on fishing and cattle breeding,[139] while the archaeobotanical record of Oueili reflects marshy conditions around the tell as well[140].

The high rates of lateral transgression until the Early to Mid-Holocene inferred from the sedimentary record in combination with probably increased rainfall at that time (see Chapter 2.1 and Figure 3) triggered associations with the great deluge of the Epic of Atrahasis, the Akkadian Epic of Gilgamesh and the Genesis flood narrative[141] all of which are believed to have a common oral tradition.[142] Teller et al. draw a scenario of a Neolithic community settling on a gentle rise of the pre-transgressive exposed floor of the Gulf, which may have become isolated by the rapidly encroaching sea, a situation exacerbated by cataclysmic rainfall and runoff both by the Euphrates-Tigris system and from the nearby Zagros

[136] Pournelle, "Deltaic Landscapes," 123; Pournelle, "Physical Geography," 19.

[137] Jacobsen, Thorkild, "The Waters of Ur," *Iraq* 22 (1960): 184–185. doi:10.2307/4199683; Pollock, Susan, *Ancient Mesopotamia* (Cambridge: Cambridge University Press, 1999), 34.

[138] Larsen, "The Mesopotamian Delta Region," 44.

[139] Huot, Jean-Louis, "Ubaidian Villages of Lower Mesopotamia," in *Upon these Foundations: The 'Ubaid Reconsidered, Proceedings from the 'Ubaid Symposium, Elisnore*, ed. Elizabeth F. Henrickson and Ingolf Thuesen (Copenhagen: Museum Tusculanum Press, 1989), 39; Pollock, *Ancient Mesopotamia*, 81–83.

[140] Neef, Reinder, "Plant Remains from Archaeological Sites in Lowland Iraq: Tell El 'Oueili," in *'Oueili—Travaux de 1985*, ed. Jean-Louis Huot (Paris: Éditions Recherche sur les Civilisations, 1991), 324.

[141] Teller et al., "Postglacial Reflooding of the Persian (Arabian) Gulf," 304; Brückner, "Uruk—A Geographic and Palaeo-Ecologic Perspective," 246.

[142] George, Andrew R., *The Babylonian Gilgamesh Epic: Introduction, Critical Edition and Cuneiform Texts vol. 1* (Oxford: Oxford University Press, 2003), 70.

Mountains.[143] However, despite of the high rate of lateral transgression it is highly unlikely that communities were surprised in a way not permitting to shift their dwelling places accordingly. The origin of the flood narrative probably lies in a phase of an extreme amount of rainfall and flooding events related to avulsions in the alluvium of Lower Mesopotamia rather than a single, unique event,[144] which is corroborated by thick and sterile alluvial muds in several tells burying archaeological layers of pre-Ubaid civilisations.[145]

4. *Social Response to Holocene Landscape Dynamics*

The relevance of environmental changes for ancient social systems of Mesopotamia stems from a strong dependence on locally available resources. While the range of activities and animals exploited were similar along the two rivers, subsistence techniques and specialisations strongly diverge from the headwaters to the Gulf shores.[146] We sum up how larger-scale environmental conditions and their changes over millennial time scales have influenced socio-economic, cultural, and political changes in different parts of Mesopotamia and how they help to explain the emergence of the first hierarchical, complex urban-type societies. Thereby, it is obvious that—apart from the Uruk case study—an emphasis has to be set on larger-scale dynamics and changes, as local developments may have varied significantly and may even have opposed broader trends, adding enormous complexity as we try to analyse the man-environment relationships in Mesopotamia over time in detail.[147]

[143] Teller et al., "Postglacial Reflooding of the Persian (Arabian) Gulf," 304; Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 243.

[144] Brückner, Helmut and Max Engel, "Noah's Flood – probing an ancient narrative using geoscience," in *Palaeohydrology – traces, tracks and trails of extreme events*, ed. Jürgen Herget and Alessandro Fontana, A. (Cham: SpringerNature, 2019), 14–15. doi:10.1007/978-3-030-23315-0_7.

[145] Woolley, C. Leonard, "Excavations at Ur of the Chaldees," *The Antiquaries Journal* 3 (1923): 315. doi:10.1017/S0003581500014980; Raikes, R.L., "The Physical Evidence for Noah's Flood," *Iraq* 28 (1966): 54. doi:10.2307/4199795; Morozova, "Holocene Avulsions," 416.

[146] Pollock, *Ancient Mesopotamia*, 78–81.

[147] Riehl et al., "Holocene Agricultural System Transformations," 129.

4.1. *Upper Mesopotamia*

From the Neolithic until the Ubaid period, agricultural and agro-pastoral subsistence in Upper Mesopotamia benefitted from a relatively stable climate with humid winters and reliable water availability, best reflected by the Lake Van record (Figure 3),[148] facilitating the emergence of agricultural practices and technology since the Early Neolithic, which relied mostly on different wheat, barley and pulse varieties.[149] Apart from reduced functionality and even partial abandonment of Upper Mesopotamian sites as a response to the 8.2 ka RCC[150], a stable climate and long-term development of rain-fed agriculture facilitated cultural continuity until the Late Chalcolithic.[151] Later RCCs as reflected by the high-resolution speleothem record of Bar-Matthews and Ayalon[152] in Figure 5, in particular the shift to a more continental climate with higher rainfall variability after the humid event around 4,500 BC, can also tentatively be linked with socio-political and agricultural adaptations. While during the 5th millennium BC only the disappearance of the Ubaid culture from the north seems to be worth mentioning in this context,[153] the first signs of urbanisation appearing during the late 5th to 4th millennium BC, parallel to the development of a dense network of rural settlements,[154] seem to be related to intensified land use.[155] Ongoing population increase in Upper Mesopotamia between 4,400 and 3,400 BC may be linked to production surpluses during phases of enhanced rainfall,[156] and as yet stable perennial streamflows and fluvial wetlands, which can be inferred, from the geomorphic record in the Upper Khabur basin of easternmost

[148] Roberts et al., "Climatic, Vegetation and Cultural Change," 151; Riehl et al., "Drought Stress Evidenced by $\delta^{13}C$ in Barley Grain," 12349.

[149] Miller, "Macrobotanical Evidence for Vegetation in the Near East," 202; Riehl, Simone, Mohsen Zeidi, and Nicholas J. Conard, "Emergence of Agriculture in the Foothills of the Zagros Mountains of Iran," *Science* 341 (2013): 65. doi:10.1126/science.1236743.

[150] Staubwasser, Michael, and Harvey Weiss, "Holocene Climate and Cultural Evolution in late Prehistoric–Early Historic West Asia," *Quaternary Research* 66 (2006): 378. doi:10.1016/j.yqres.2006.09.001.

[151] Clarke, Joanne, et al., "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 (2016): 114. doi:10.1016/j.quascirev.2015.10.003.

[152] Bar-Matthews, and Ayalon, "Mid-Holocene Climate from Soreq Cave," 168.

[153] Clarke et al., "Climatic Changes and Social Transformations," 114.

[154] Lawrence et al., "Long-term Population, City Size and Climate Trends," 11.

[155] Clarke et al., "Climatic Changes and Social Transformations," 114.

[156] Lawrence et al., "Long-term Population, City Size and Climate Trends," 11.

Syria.[157] A first larger-scale cultural break in Upper Mesopotamia, linked to a temporary population decline due to southward migration, has probably been triggered by precipitation levels too low to sustain rain-fed cereal cultivation. This change in conditions is related to the 5,200 BP drying and cooling event,[158] which left its stable isotopic signature in barley grains[159] and the Soreq speleothem record.[160] Significantly reduced and more variable streamflows after 2,500 BC, when both the Soreq and Lake Van records indicate the onset of a long-term drying trend (Figures 3, 5), in combination with population growth and intensification of land use resulted in increased erosion and correlating aggradation in subcatchments of the Euphrates Valley.[161]

The transition from the relatively humid Early Bronze Age to the Middle Bronze Age coincided with the 4,200 BP aridification event of unprecedented magnitude, expressed through reduced seasonal temperature, dust, and a decline in rainfall of c. twenty to thirty percent,[162] which had a substantial impact on agricultural production and the selection of crops. A general decline in the presence and abundance of water-demanding crops and those sensitive towards soil salinity was observed in the archaeobotanical record of Upper Mesopotamia after the EBA. While free-threshing wheat, garden pea, linseed and grape vine decrease, the cultivation of the much more stress-tolerant barley significantly increases all over Upper Mesopotamia, along with the resistant bitter vetch at least in some areas. Together this presents unequivocal evidence of a higher drought stress.[163] Furthermore, significantly lower number of Late EBA/Early MBA archaeological sites may relate to these challenges of

[157] Deckers, and Riehl, "Fluvial Environmental Contexts," 347.

[158] Staubwasser and Weiss, "Holocene Climate and Cultural Evolution," 379; Clarke et al., "Climatic Changes and Social Transformations," 97.

[159] Riehl et al., "Drought Stress Evidenced by $\delta^{13}C$ in Barley Grain," 12349.

[160] Bar-Matthews et al. "Regional Events at Soreq Cave," 89; Bar-Matthews, and Ayalon, "Mid-Holocene Climate from Soreq Cave," 168.

[161] Kuzucuoglu, Fontugne, and Mouralis, "Holocene Terraces," 204; Deckers, and Riehl, "Fluvial Environmental Contexts," 346.

[162] Weiss, Harvey, et al., "The Genesis and Collapse of 3rd Millennium North Mesopotamian Civilization," *Science* 261 (1993): 1002. doi:10.1126/science.261.5124.995; Cullen, Heidi M. et al., "Climate Change and the Collapse of the Akkadian Empire: Evidence from the Deep Sea," *Geology* 28 (2000): 382. doi:10.1130/0091-7613(2000)28<379:CCATCO>2.0.CO;2; Staubwasser and Weiss, "Holocene Climate and Cultural Evolution," 381.

[163] Riehl et al., "Holocene Agricultural System Transformations," 129–130.

extrinsic, environmental nature as well.[164] In the area of Tell Leilan in easternmost Syria, 73 percent of all sites experienced abandonment, while the total occupied area fell by 93 percent.[165] Correlation between climate deterioration and the collapse of the pan-Mesopotamian Akkad Empire around 2,200 BC has been vivdly discussed in light of strongly diverging resilience from site to site.[166] The high degree of political and economical centralisation and agricultural specialisation may have prevented appropriate adaption to the changing environments in the major cities leading to crisis, while more independent, peripheral regions, with less complex socio-political hierarchies and more flexible production processes, were able to adapt and kept thriving.[167]

Resettlement after the 4,200 BP RCC from c. 1,900 BC onwards occurred in the context of substantial socio-political reorganisation, where individual settlements had distinct functions within the region. The downfall of the Old Babylonian kingdom and onset of a Dark Age period with decreasing population densities in Upper Mesopotamia happened against the background of the aridisation trend continuing after the MBA, which fostered further emphasis on water stress-tolerant crop species, in particular barley. However, deurbanisation results from a complex interplay of different factors including social, political, economic, and ecological parameters, and the exact role of climatic changes is difficult to evaluate.[168] Lawrence et al., however, identify a decoupling of climatic changes and settlement patterns since 2,000 BC.[169]

The recovery phase of population and settlements during the Iron Age witnessed the emergence of new crop species, such as cotton, pomegranate or cucumber, whereas water demanding free-thrashing wheat and grape increase again. In combination with ongoing gradual drying and salinisation indicators in the palaeobotanical record, this pattern indicates agricultural intensification through the introduction of irrigation techniques.[170] From a demographic point of view, either cities grew to

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[164] Riehl et al., "Drought Stress Evidenced by $\delta^{13}C$ in Barley Grain," 12350; Lawrence et al., "Long-term Population, City Size and Climate Trends," 10.

[165] Staubwasser and Weiss, "Holocene Climate and Cultural Evolution," 382.

[166] Weiss, Harvey, et al., "Genesis and Collapse," 999; Rosen, Arlene M. *Civilizing Climate. Social Responses to Climate Change in the Ancient Near East* (Lanham: Altamira Press, 2007), 143.

[167] Roberts et al., "Climatic, Vegetation and Cultural Change," 152.

[168] Riehl et al., "Holocene Agricultural System Transformations," 119.

[169] Lawrence et al., "Long-term Population, City Size and Climate Trends," 11.

[170] Riehl et al., "Holocene Agricultural System Transformations," 130.

such a level in terms of size and power which could not have been sustained by rain-fed agriculture only,[171] but may have been sustained by pastoralism and the establishment of an agro-pastoralist buffering strategy.[172]

4.2. *Lower Mesopotamia*

Also in Lower Mesopotamia, ambiguities remain about the exact contribution of changes in climate, streamflow and landscape dynamics to the success and downfall of complex societies. Similar to today's conditions, differences from Upper to Lower Mesopotamia in, for example, the rainfall gradient must also be anticipated for ancient times. Moreover, the Saharo-Arabian climate with strengthened African and Indian monsoonal activity driven by orbital forcing during the Early Holocene,[173] as possibly reflected by the record from Tayma[174] (Figure 3), played a more important role and probably provided additional summer rainfall during the Neolithic. During this favourable pre-Ubaid and also pre-transgressive phase of enhanced moisture availability, smaller, dispersed communities may have practised a semi-nomadic subsistence along the Ur-Shatt River in Lower Mesopotamia. Close to the coast, they were forced to relocate or at least adjust their roaming area due to the rapid lateral marine transgression. However, all these scenarios are based on assumptions as archaeological traces of this period are buried under thick alluvium.[175]

The gradual decline of available water resources during summer triggered competition for natural resources at the beginning of the Ubaid Period, and led to population clustering, more intense agriculture, economic differentiation, and the establishment of new ideologies and socio-political structures. Growing communities emerged at sites such as Ur and Eridu,[176] which were influenced and shaped by transgressive

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[171] Lawrence et al., "Long-term Population, City Size and Climate Trends," 11.

[172] Wilkinson, "Contextualizing Early Urbanization," 96.

[173] Claussen, Martin et al., "Simulation of an Abrupt Change in Saharan Vegetation in the Mid-Holocene," *Geophysical Research Letters* 26 (1999): 2037. doi:10.1029/1999GL900494.

[174] Engel et al., "Holocene Humid Period in NW Saudi Arabia," 135;.Dinies et al. "Grassland Expansion in Northwestern Arabia," 298; Dinies et al., "Holocene Vegetation in Northwestern Arabia," 6.

[175] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 248.

[176] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 250.

wetlands and estuaries providing an important source of food as well as pathways for transportation.[177] Early Ubaid settlements show strong continuity in terms of their location, mostly covering river levees close to swamps and marshes. During Ubaid 3 and 4, new settlements were founded at elevated sites of remnant Pleistocene river terraces (turtlebacks) close to palaeo-shores,[178] which were high enough and protected from the ongoing transgression. The coastal and wetland resources provided resilience capacities countering a decrease in rainfall. Competition for resources increased during the Ubaid, magnified by migrating communities, who, after merging with local groups, formed the core of what were to become urban centres.[179] The environmentally driven demographic pressure in combination with the rise in seafaring, may have stimulated the spread of the Ubaid culture along the western margin of the Gulf.[180]

Post-Ubaid community aggregation at the most favourable sites culminated in the first complex, urban-type societies of the Late Uruk period.[181] The importance of Lower Mesopotamia's wetlands and the marginal marine environment as food resource and access gateway to transport and maritime trade is strongly reflected by the archaeological record[182] and by administrative texts reaching back to the earliest protoliterate lexical lists,[183] while longer-distance travel and exotic trading goods may have facilitated the exchange of ideas and the establishment of a clear social and political stratification. Natural watercourses were used and directed to make effective use of the surrounding amphibious environments in terms of large-scale irrigation (see also the example of Uruk in Chapter 4.3). Expanding floodplains after the onset of coastal regression provided fertile terrain for intensified irrigation agriculture,

[177] Pournelle, "Deltaic Landscapes," 252–253.

[178] Pournelle, "Physical Geography," 22.

[179] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 250–251.

[180] Carter, Robert A., "The Social and Environmental Context of Neolithic Seafaring in the Persian Gulf," in *The Global Origins (and Development) of Seafaring*, ed. Atholl Anderson, James H. Barrett, and Katherine V. Boyle (Cambridge: McDonald Institute of Archaeological Research, 2010), 198; Drechsler, Philipp, "The Arabian Peninsula," in *A Companion to the Archaeology of the Ancient Near East, vol. I*, ed. Daniel T. Potts (Hoboken: Wiley-Blackwell, 2012), 491. doi:10.1002/9781444360790.ch25.

[181] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 252.

[182] Huot, "Ubaidian Villages of Lower Mesopotamia," 39.

[183] Pournelle, "Physical Geography," 23.

which, in combination with fishing represented an important base for population growth.[184] The nuclei of early irrigation practices may be found on proximal crevasse splays resulting from levee breaks with their coarser texture being less susceptible to salinisation and flooding. Morozova regards the complex avulsion belts created by successions of levee breaks as "oases" of easy cultivation, high agricultural productivity, and, therefore, targets of migration, all representing critical factors for the emergence of the complex, urban-type societies.[185] Reduced streamflows of the two rivers related to the 5,200 BP RCC had severly affected irrigation agriculture in Lower Mesopotamia and may be regarded as a root cause for societal collapse.[186]

During the Early Dynastic Period, settlements decreased in numbers but increased in size, as wetlands slowly contracted with coastal regression and lower groundwater tables, and advancing fluvial fans from the valley margins potentially started to bury older sites. While the urban centres grew, smaller settlements followed the prograding coastline, still connected to the inland centres by waterways. Wetland resources such as reed and fish remained important throughout the Ur III period and beyond, while irrigation agriculture on elevated grounds protected from seasonal flooding became even more significant in a continuously drying climate.[187] The 4,200 BP RCC seems to have impacted Lower Mesopotamia and coincides with reduced crop yields, political deterioration and instability, as well as migration from the Upper Mesopotamian plains, as reflected by cuneiform inscriptions.[188] However, the population decrease since 2,100 BC is considered to be gradual over a time period of c. 1,500 years.[189]

4.3. *Case Study: Uruk*

Uruk (modern: Warka) is located c. 15 kilometres east of today's main course of the Euphrates River and rises c. 16 metres above the alluvial plain, which has an elevation of c. ten metres a.s.l.. The city was founded at the end of the 5th millennium BC and grew rapidly. Uruk played a pivotal role in the evolution of the world's first urban-type societies and

[184] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 252.
[185] Morozova, "Holocene Avulsions," 414–416.
[186] Staubwasser and Weiss, "Holocene Climate and Cultural Evolution," 379.
[187] Pournelle, "Physical Geography," 25–27.
[188] Weiss, Harvey et al., "Genesis and Collapse," 1002; Staubwasser, and Weiss, "Holocene Climate and Cultural Evolution," 382.
[189] Brinkman, "Mesopotamian Demography," 173.

is seen as a major origin of writing and bureaucracy during the 4th millennium BC.[190] By the beginning of the 3rd millennium BC, the city already covered c. 5.2 square kilometres[191], protected by a nine kilometres-long city wall (Figure 6), and kept its status as the largest city in Lower Mesopotamia until the 6th century BC. Sometime at the beginning of the 3rd millennium BC, Uruk lost its exceptional political position as other cities emerged in the region. Afterwards, the city persisted with fluctuating regional importance,[192] before the area became deserted around the 7th century AD.[193]

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190 Nissen, Hans J., "*The early history of the Ancient Near East, 9000-2000 B.C.*" Chicago/London: Chicago University Press, 1988, 85-90; Van Ess, "Uruk—Verortung in Raum und Zeit," 40.

191 Van Ess, Margarete, "Die topographische Entwicklung der Stadt Uruk im 4. und 3. Jt. v. Chr.," in: *Uruk. Altorientalische Metropole und Kulturzentrum (=Colloquien der Deutschen Orient-Gesellschaft Band 8)*, ed. Margarete van Ess (Wiesbaden: Harrassowitz-Verlag, in press).

192 Van Ess, "Die topographische Entwicklung der Stadt Uruk," 42–44.

193 Adams, Robert McC., and Hans J. Nissen, *The Uruk Countryside* (Chicago, London: The University of Chicago Press, 1972), 59.

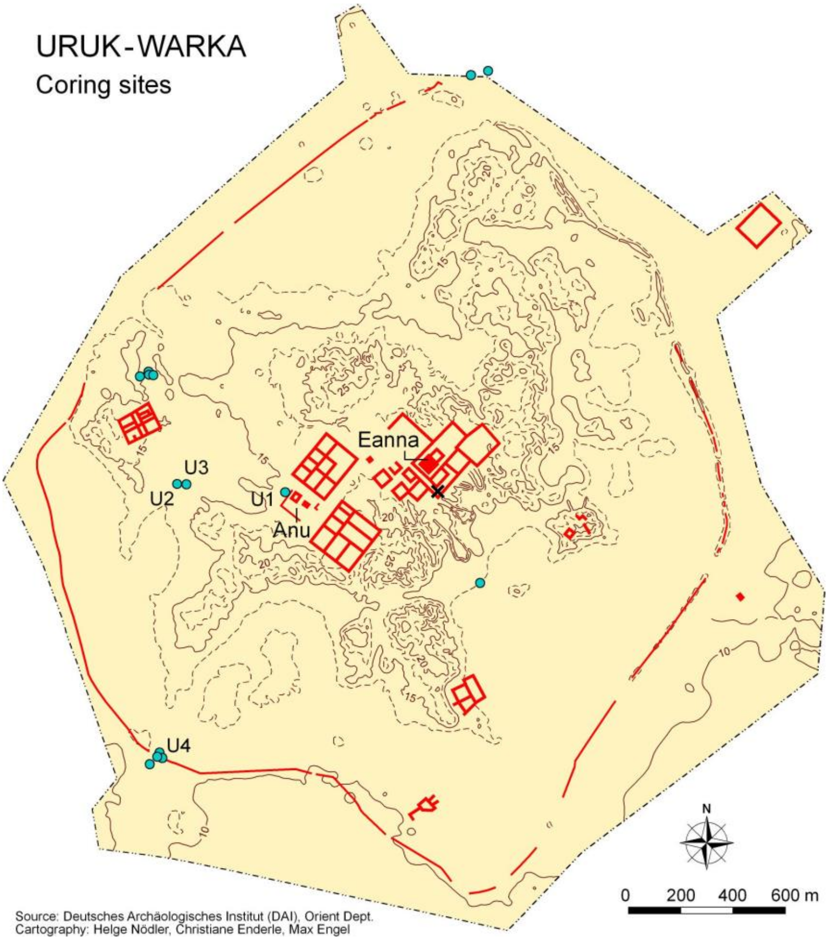

Figure 6: Topographic map of the archaeological zone of Uruk (modern Warka), with sediment cores (blue circles), city wall and main buildings (red structures). Altitudes in metres a.s.l.[194]

Considering present geomorphic and archaeological evidence, Uruk seems to have been founded on the proximal part of an interior delta, where the Euphrates River debouched into extensive wetlands during the

[194] Modified after Brückner, "Uruk—A Geographic and Palaeo-Ecologic Perspective," 243.

Late Ubaid.[195] Watercourses were systematically used since the mid-4th millennium BC[196] and networks of intramural canals for transportation and irrigation purposes identified by geomagnetic surveys [197] as well as sediment cores were established during the 3rd millennium BC.[198]

The role of environmental changes as a driver of cultural change inside the city and in the region has been vividly debated. It is anticipated that the presence of the Euphrates controlled the growth of the city[199] and that watercourses shifting away from the city contributed to its decline, in particular in the middle of the 2nd millennium BC.[200] Here, we present original geoarchaeological data from inside the city limits of Uruk providing clues to location factors for the city's foundation, i.e. evidence for changing morphodynamics and environments such as the 4th millennium BC canal networks or catastrophic floods.[201]

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[195] Ibid., 243.

[196] Van Ess, "Uruk—Verortung in Raum und Zeit," 42.

[197] Becker, Helmut, Margarete van Ess, and Jörg Fassbinder, "Uruk: Urbane Strukturen im Magnet- und Satellitenbild," in *Uruk. 5000 Jahre Megacity. Begleitband zur Ausstellung „Uruk – 5000 Jahre Megacity" im Pergamonmuseum. Curt-Engelhorn-Stiftung für die Reiss-Engelhorn-Museen Mannheim, dem Deutschen Archäologischen Institut – Orient-Abteilung, der Deutschen Orient-Gesellschaft e. V. und dem Vorderasiatischen Museum – Staatliche Museen zu Berlin,* ed. Nicole Crüsemann, et al., 357–358. Petersberg: Imhof Verlag, 2013.

[198] Brückner, "Wasserstraßen im Wüstensand," 14.

[199] Wilkinson, Tony J., "Early Channels and Landscape Development around Abu Salabikh, a Preliminary Report," *Iraq* 52 (1990): 75–83. doi:10.2307/4200320.

[200] Adams, and Hans J. Nissen, *The Uruk Countryside* (Chicago, London: The University of Chicago Press, 1972), 59.

[201] Brückner, "Uruk—A Geographic and Palaeo-Ecologic Perspective," 230.

Figure 7: a) The tell of Uruk with the preserved core of the Eanna-Ziggurat (21st century BC), the main sanctuary of the goddess of Inanna (Ishtar), in the Background. The foreground shows excavations of the Seleucid sanctuary of Ishtar (Irigal). b) View from Uruk towards two other former settlement mounds. The vegetated, marshy floodplain sourrounding Uruk during the late 5th millennium BC, is today replaced by a desert landscape with encroaching sand dunes in the background. The foreground shows colluvium which accumulated at the foot of the tell due to the decay of the air-dried bricks. c) Coring site U1 (Figure 6) in front of the limestone-built "Steingebäude". Mud-brick layers of Anu Ziqqurrat in the middleground. d) Former irrigation canals of Sumerian agriculture, today preserved as ’inverted channels’. Black ball pen for scale.

Percussion cores were taken inside the city, e.g. right at the settlement core next to the “Steingebäude” (U1 in Figures 6,7), in the area of the canal networks (U2, U3), and inside the main canal outlet at the southern city gate (U4).[202] Well-sorted, sterile fine to medium sand is present at the base of all cores representing the undulating surface of Late Pleistocene to Early Holocene aeolian dunes, most likely connected to those identified at

[202] Brückner, “Uruk—A Geographic and Palaeo-Ecologic Perspective,” 234–242.

the bottom of the Arabian Gulf before it became flooded.[203] The rising sea level drowned lower river courses and triggered the deposition of alluvial mud, intercalated by episodic sandy flood deposits. The transgression of the Gulf shifted the shoreline and a belt of wetlands northeastwards. While during the peak of the transgression, coinciding with the relative sea-level highstand at around 6,000 BC, these wetlands reached Uruk, as indicated by cores U1 and U4 (upper boundary c. two metres a.s.l.), the coastline never did.[204] The inland extent of the marine incursion passing Uruk along the main course of the Euphrates at 4,000–3,300 BC as reconstructed by Pournelle[205] (Figure 1) definitely never reached the city proper. Slightly before the time of the maximum ingression, Uruk was founded, initiating the rich archaeological stratigraphy embedded into an alluvial matrix detected in cores U1 and U3, the former potentially covering even the earliest settlement period. At the fringes of the city (U4), increasing precipitation of gypsum crystals reflects the arid trend since the Late Ubaid[206] and possibly also increasing soil salinisation due to irrigation agriculture.[207] Preliminary examination of artifacts in the cores indicates that the Late Ubaid until at least the Early Dynastic I is covered in the central part of the city (U1), the assumed core of the initial settlement. At U2, a thick layer of sterile alluvium overlies the basal archaeological layer. Its origin is unclear, even though it shares similarities with the massive flooding deposits already identified at Ur and other tells, which were associated with Noah’s Flood hypothesis.[208] Sediment cores U2 and U4 verify the Uruk-age canal networks inside the city, as they comprise facies units of low-energy aquatic deposition, laminated and slightly coarser than the sterile alluvium, and numerous (sub-)rounded ceramic fragments. From the western-central part of the city (6.38 metres a.s.l.) to the southwestern outflow gate (5.57 metres a.s.l.), a clear gradient of the base of the canal can be inferred confirming flow direction and interconnection

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[203] Sarnthein, Michael, “Sediments and History of the Postglacial Transgression in the Persian Gulf and Northwest Gulf of Oman,” *Marine Geology* 12 (1972): 259. doi:10.1016/0025-3227(72)90002-3; Uchupi, “Stratigraphy, Paleoclimate and Neotectonism,” 9.

[204] Brückner, “Uruk—A Geographic and Palaeo-Ecologic Perspective,” 242.

[205] Pournelle, “Deltaic Landscapes,” 124.

[206] Brückner, “Uruk—A Geographic and Palaeo-Ecologic Perspective,” 242–245.

[207] Brückner, “Wasserstraßen im Wüstensand,” 11.

[208] Woolley, C. Leonard, “Excavations at Ur of the Chaldees,” *The Antiquaries Journal* 3 (1923): 315. doi:10.1017/S0003581500014980; Raikes, R.L., “The Physical Evidence for Noah's Flood,” *Iraq* 28 (1966): 54. doi:10.2307/4199795.

of the canal system.[209] The fauna, detected in U4 at the base of the former canal (Unio tigridis, Melanopsis nodosa, Theodoxus [Neritaea] doriae), indicates clear, running freshwater.[210]

The Sumerian irrigation canals are still well visible in today's landscape as 'inverted channels' (see fig. 7d). During their use, the canals had been cleaned regularly. After they were given up (probably due to the salinization of the fields), they were gradually filled with sediments which were then cemented as a consequence of the high evaporation and the reprecipitation of calcium carbonate. Thus, the canals became more resistant to wind erosion than the degraded soils of the former fields. This created the obvious relief inversion.

[209] Brückner, "Uruk—A Geographic and Palaeo-Ecologic Perspective," 242–245.
[210] Ibid.," 242.

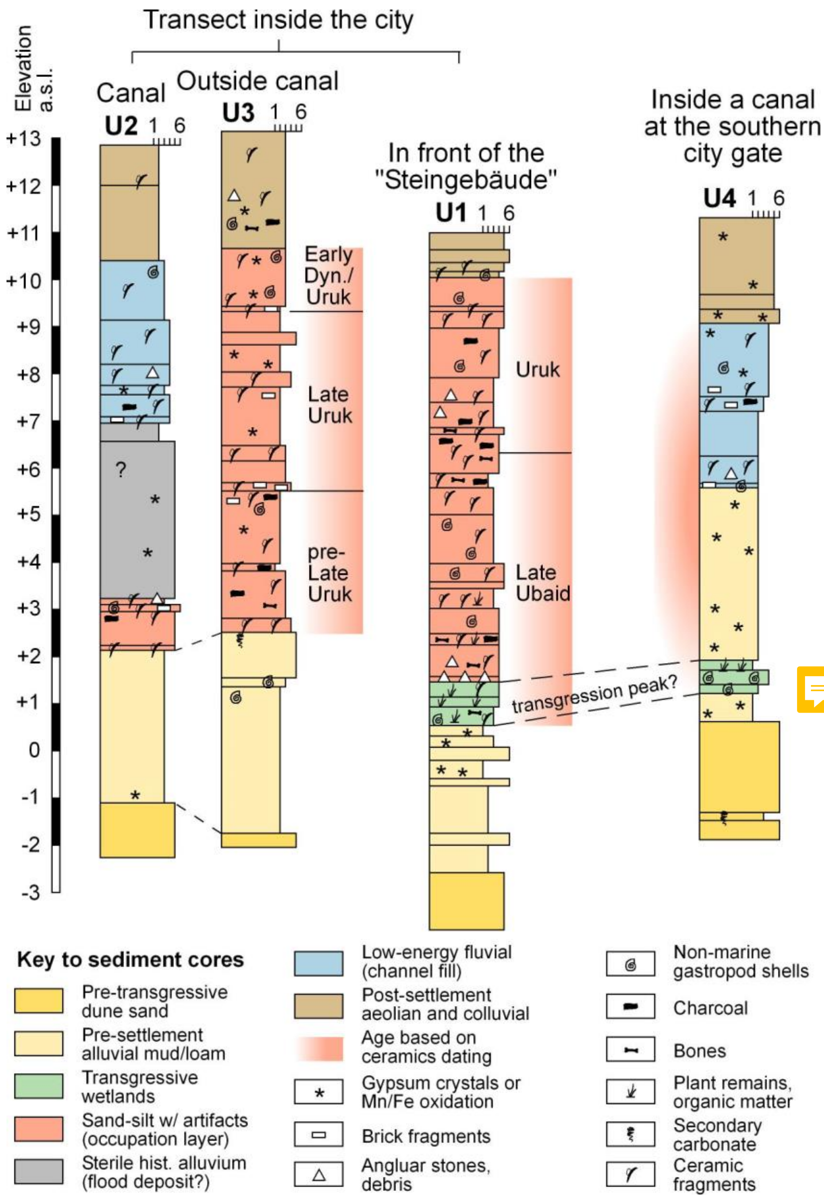

Figure 8: The stratigraphy from intramural Uruk based on sediment cores U1 to U4 (Figure 6) revealing local environmental changes from Early Holocene dune formation to the establishment of freshwater marshes, and the spread of the alluvial plain due to the Early to Mid-Holocene sea-level rise, followed by almost five thousand years of urban

history.[211] Width categories of the core log: 1=clay to silty clay; 2=clayey silt; 3=silt to clay-rich loam; 4=sandy silt to loam; 5=silty fine sand to silty sand; 6=fine to medium sand.

5. *Conclusion*

A number of links between changes in climate, landscape, and socio-technical adaption have been established based on a large body of interdisciplinary research. Many of the relationships presented above seem to be straightforward, especially where they are confirmed by cuneiform inscriptions, classical texts or archaeological evidence. However, a significant gap in chronological resolution between very precise information on socio-historical development and constraints on climatic changes with a much higher uncertainty exists.[212] Moreover, RCC impacts appear to have been complex and site-specific. The resilience towards RCCs such as the 4,200 BP event strongly depended both on physical sensitivity towards climatic changes and political governance. It appears that in semi-arid regions and in cities where political leadership failed to implement adaption strategies in the light of changing environments, negative responses occurred more rapidly and were more severe.[213] The role of environmental change in the emergence of complex urban-type societies of Mesopotamia—emphasised by some, downplayed by others—cannot be separate from other strongly interrelated cultural factors, such as population growth, environmental and social circumscription, increasing conflicts, development of irrigation agriculture, and the spread of trade in a clear and distinctive way.[214]

However, it was shown how the rainfall gradient between Upper and Lower Mesopotamia first benefitted rain-fed agriculture and settlement in Upper Mesopotamia, while the emergence of irrigation practices in combination the Mid-Holocene arid events and, later, long-term aridisation, represented a pull factor and motor of the development of complex societal structures. Shifting coastal and alluvial environments, such as river channels and wetlands, provided crucial resources for irrigation and fishing/hunting, respectively. First-hand sedimentary data

[211] Brückner, "Wasserstraßen im Wüstensand," 12; with modifications from Van Ess, "Die topographische Entwicklung der Stadt Uruk".

[212] Riehl et al., "Holocene Agricultural System Transformations," 129.

[213] Roberts et al., "Climatic, Vegetation and Cultural Change," 152.

[214] Kennett, and Kennett, "Holocene Marine Transgression and Climate Change," 248.

from Uruk provides direct evidence for the changing landscapes of Lower Mesopotamia and strategies for efficient use of resources and landforms to sustain large urban populations. These data also show how salinisation of the fields due to high evaporation and the lack of a proper drainage system may have forced the abandonment or shrinking of the southern settlements and their shift towards the north.

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