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MILLENNIAL AND CONTEMPORARY CHANGES OF MIDDLE EAST CLIMATE

INTRODUCTION

Near East is one of global cradle of the human civilization where the first mature civilizations appeared represented by Sumerian, Akkadian, Babylonian, and Assyrian ones. The economic basis of these civilizations was agricultural production depended mostly on the rain-fed water supply. That is why any change in precipitation and air temperature had a direct impact on food production and consequently on the functioning of political, social and economic systems. Several studies have been performed to document the causal links between climate change and the socioeconomic and political fluctuations that have accompanied environmental change in the Middle East, particularly Mesopotamia (MUSLIH 2015).

The Middle East region is a transition area that is influenced by different air masses. There, the oceanic air masses of the northwest meet here the tropical air masses that come from North Africa and the Arabian Peninsula. In addition, masses of air reach there, the source areas of which are located above the subtropical and northwestern highlands. This leads to temporal and spatial differentiation of the climate. It also means that any imbalance in the atmospheric system, which is often the result of global changes in the solar radiation, has led and is currently leading to disturbances in the climate system, and ultimately – to significant climate changes in this region

(NEUMANN and PARPOLA 1987, WEISS *et al.* 1993, CULLEN *et al.* 2000, DEMENOCAL 2001, ISSAR 2003, STAUBWASSER and WEISS 2006, WOSSINK 2009, KANIEWSKI *et al.* 2010).

There are numerous studies documenting that the modern climate regime in the Middle East (which is characterized by hot, dry summers and mild, wet winters) dates back to nearly 3,000 BC (EL MOSLIMANY 1983, FLEITMANN *et al.* 2007, THAMBAN *et al.* 2007, ROBERTS *et al.* 2011). Due to the location of the region between the subtropical highlands and the Mediterranean areas, following the southern movement of the Intertropical Convergence Zone (ITCZ), there is a southern shift of the influences of the Mediterranean climate. This makes it easier to enter the Atlantic lows to the region. This results in increased moisture transport and regionally enhanced cyclogenesis (CULLEN *et al.* 2002).

Climate change is one of the most serious environmental problems in recent decades due to its direct or indirect consequences for communities and people's well-being, as well as for many aspects of human life (IPCC 2007, 2021). According to the estimates of the Intergovernmental Panel on Climate Change (IPCC), the average surface temperature in the second half of the last century increased significantly on a global scale. The latest IPCC report (IPCC 2021) suggested that the mean global surface temperature increased by about 0.99°C in the period 2001-2020 compared to its level in

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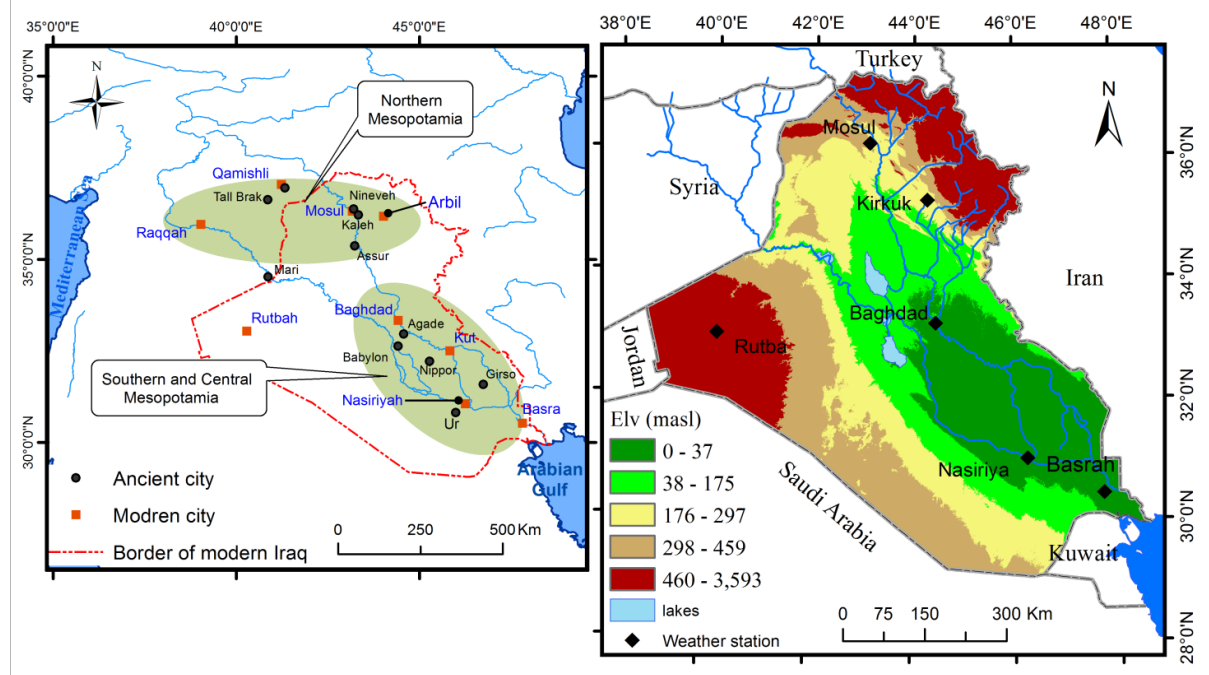


Fig. 1. Regional and geographical setting of Mesopotamia and Iraq (adapted from PAULETTE 2012 – left panel, own elaboration – right panel).

the period 1850-1900, and that more than half of this increase is due to human activity. And the range of total man-made growth from 1850-1900 to 2010-2019 is 0.8°C to 1.3°C.

In the case of Iraq, several studies have focused on the analysis of temperature variability. ROBAA and AL-BARAZANJI (2013) studied the spatial variability of the mean annual air temperature from 11 stations in Iraq, with different length time ranges depending on the station records. The study confirmed the warming trend in all stations at the rate of 0.5°C/decade, and that the highest warming trend occurred after 1995. MUSLIH and BŁAŻEJCZYK (2017) also documented air temperature trends in Iraq in 1941-2013. The highest increase in T_{mean} and T_{max} values was observed in July at the Basrah station (approx. 0.89°C/10 years and 1.28°C/10 years, respectively) and at the Nasiriyah station for T_{min} in August at approx. 0.8°C/10 years. SALMANA *et al.* (2017) assessed the mean and extreme temperature trends at 15 stations in Iraq between 1965 and 2015 using the normal and modified Mann-Kendall test. They found that the annual minimum and maximum temperatures increased at all stations in Iraq, with temperatures in Iraq rising about 2 to 7 times faster than indicated by the global temperature rise.

Contemporary climate changes in the Middle East are related to its location in the

transitional zone, which gave it a climatic differentiation between the Mediterranean climate in the north and dry and semi-dry climates in the central and southern parts (EVANS 2009, MUSLIH and BŁAŻEJCZYK 2017). Despite the lack of sufficiently long observation sequences, long-term changes in temperature in the Middle East region, studies have appeared in recent years that focused on the analysis and spatial variability of temperature in many places in this region on the basis of proxy data (KADIOĞLU 1997, GHAHRAMAN 2006, KARABULUT *et al.* 2008, ELNESR *et al.* 2010, TABARI and TALAEI 2011, ALMAZROUI 2020, MIRI *et al.* 2021).

The aim of the study is to: a) identify the climatic sub-periods that prevailed in the period from 3000 to 0 BC and b) contemporary changes in precipitation and air temperature. To achieve these goals, several data sources were used: 1) information from a large number of archaeological, historical and geological records and documents, 2) winter precipitation totals (DJFM) for three Iraqi stations and the NAO index for 1890-2020, and 3) the average monthly air temperature in the period 1941-2020 for six stations located in the region.

GEOGRAPHICAL SETTING

The region of the Middle East includes the area of historic Mesopotamia, lying in

the valleys of the Tigris and Euphrates rivers, and the surrounding desert areas of the Arab homeland (Western Iran, Syria, Jordan, Saudi Arabia and Kuwait). More or less the area of historic Mesopotamia is now identical to Iraq (Fig. 1).

Due to the geographical location, the climate of the studied area is continental, subtropical and semi-arid. In summer, the strong anticyclonic circulation associated with the Azores high dominates, while in winter this high-pressure system collapses and is replaced by periodic low-pressure systems that move from west to east, bringing winter rainfall, and in the mountain region of the north also snow (KOSTOPOULOU and JONES 2007).

These seasonal migrations of subtropical high pressure and low pressure at mid-latitudes allow the study region to be divided into three separate climatic zones according to the Köppen climate classification (MALINOWSKI 2003): Mediterranean climate (Csa) in the north (represented by Mosul station), subtropical steppe climate (BSH) in the upland region south of the first (Kirkuk station) and subtropical desert (BWh) in the west, middle, south and eastern parts of the area (Rutba stations, Baghdad, Nasiriya and Basrah).

Overall, the climate is characterized by hot and dry summers, with maximum temperatures of over 48°C in the hottest months, especially in the center and south of the region. Winter is cold or frosty, the minimum temperature drops to almost freezing in the north and to 5°C in the south. Annual rainfall in the northern mountains reaches 1000 mm and tends to be less than 100 mm in the south and southwest. 90% of the annual rainfall occurs between November and April. The increase in rainfall in the north is due to frequent advection of low pressure systems from the Mediterranean (from 75-100 cyclones per year) (WALKER 2005).

MATERIAL AND METHODS

As mentioned earlier, this article deals, among others, with identifying intervals of climate change in the Middle East in the period from 3000 to 0 BC. The reason for determining this period is that the major ancient civilizations in Mesopotamia (Sumerian “early dynastic period”, Akkadian, Babylonian and Assyrian civilizations) arose during these years. Therefore, it is possible to study the relationship between climate change and changes in the social, economic and political structures of human societies in Mesopotamia. For the modern

period (1890-2020), the data comes from direct observations at major Iraqi meteorological stations. Time series with sufficient quality data are available, which provides a good opportunity to obtain reliable results on contemporary climate change and its variability in the Middle East. This made it possible to compare the nature of contemporary and millennium changes in Iraq's climate.

Therefore, the relationship between the NAO index and winter rainfall (DJFM) for four selected stations (Basra, Rutba, Mosul, Baghdad) was investigated. This allowed for a deeper understanding of the nature of atmospheric circulation patterns and sea surface temperature (SST) anomalies associated with high and low NAO values in both the North Atlantic (NA) and Mediterranean regions. Several recent studies (eg. RIMBU *et al.* 2003, KWIECIEN *et al.* 2009) examining the relationship between SST and NAO have found a strong relationship between them. Finally, the above relationships were used to identify the millennial climate change represented by Draft Ice Indices (Fig. 2). A number of regional millennium-wide climate change studies conducted in the Mediterranean (eg RIMBU *et al.* 2003) used this type of extrapolation and indicated that the Eastern Mediterranean was very sensitive to climate and oceanographic change in NA. Moreover, many other studies (e.g. LAMY *et al.* 2006, FAUST *et al.* 2016) have found clear evidence of a link between the Northern Hemisphere climate history and the regional impact of NAO, and persistent negative or positive NAO phases are consistent with warmer and cooler climatic ranges in the Late Holocene. Therefore, this article uses three following datasets.

MILLENNIAL DATA

Several sources of proxy data were used to reconstruct the millennial fluctuations of the Mesopotamian climate (MUSLIH 2015). These include pollen analysis (AL-JUBOWRI 1997), historical and archaeological records (NEUMANN and SIGRIST 1978, NEUMANN and PARPOLA 1987, WEISS *et al.* 1993, ALI 2005), C14 dating for the Gulf of Oman (CULLEN *et al.* 2000), Lake Zeribar and Lake Mirabar (STEVENS *et al.* 2006), geomorphological records (WEISS *et al.* 1993) and others (see MUSLIH 2015). The data was critically analyzed to identify possible intervals of change in climate features.

PRECIPITATION CHANGES

In order to investigate changes in precipitation, their totals for the months from December to March (DJFM) were analyzed. The

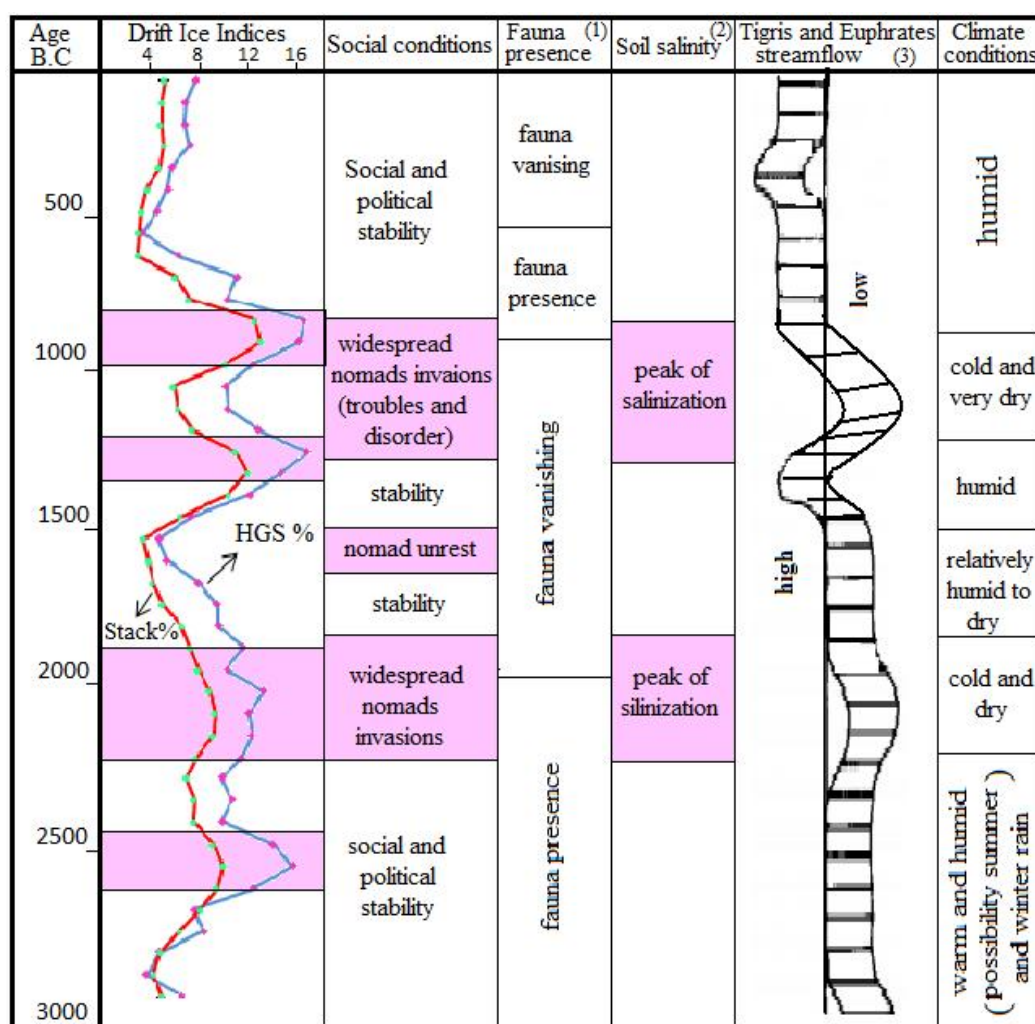


Fig. 2. The general climate conditions in Mesopotamia during the study period [sources: the given figure was synthesized by MUSLIH 2015. Note that: 1. The fauna species that surveyed at this study (elephant, monkey, lion, wild bull bison and ostrich); 2. JACOBSEN and ADAMS 1958; 3. KAY and JOHNSON 1981; Drift ice indices from BOND *et al.* 2008].

changes in precipitation were compared with the fluctuations in the winter NAO index. For this purpose, two data sets were used: 1) monthly rainfall data for Mosul (1923-2014), Rutba (1928-2014), Baghdad (1889-2020) and Basrah (1900-2020) stations. Rainfall data for all stations was provided by the Iraqi Meteorological and Seismology Organization. It should be added that the database on precipitation and temperatures for Mosul and Rutba stations was broken in 2014 as a result of the then terrorist occupation of these cities by ISIS. 2) Standardized difference of sea level pressure for winter months (DJFM) between Lisbon (Portugal) and Stykkisholmur (Iceland) from 1889 to 2020 obtained from the Climate Data Guide.

Simple regression and linear correlation were used to investigate the statistical relationship between the winter NAO index and the totals of DJFM rainfall.

AIR TEMPERATURE CHANGES

The database for this study consists of the monthly mean air temperature (T_{mean}) for six stations in Iraq (Mosul, Kirkuk, Baghdad, Rutba, Nasiriya, and Basrah) which were obtained from the Iraqi Meteorological and Seismology Organization (Fig. 1). The data covers the 80-year period from 1941 to 2020. The completeness of the data varies from 97% to 100%. In the study, a linear regression model was used to detect statistical trends in annual and monthly T_{mean} values.

RESULTS AND DISCUSSION

MILLENNIAL FLUCTUATIONS OF CLIMATE

The research results suggest that the climatic conditions in the considered millenni-

ums underwent significant changes. The defined climatic sub-periods are the result of combining evidence from different data. The analyzed historical and archaeological data and information on fauna species presented in the art and literature of ancient Mesopotamia provided important information on climatic conditions due to the different environmental requirements for each fauna species. Climate instability in the period 3000–0 BC also gives an in-depth overview of the invasions by nomads of the inhabited areas in the south of Mesopotamia, which usually coincide with periods of drought and famine (Fig. 2).

Beginning of the third millennium BC was characterized by a humid, warm climate with increased rainfall, especially in southern Mesopotamia. During this period, there was an increase in the number of all species of fauna that in ancient Mesopotamian literature were the subject of research as exotic to the Mesopotamian environment.

The widespread social and political stability of Mesopotamia over the course of the three millennia, both in sedentary regions and in remote nomadic habitats, is due to sufficient rainfall for agriculture and livestock farming in the steppes upon which the nomads depend (ISSAR and ZOHAR 2007).

The first textual evidence of soil salinity dates back to 2400 BC (JACOBSEN and ADAMS 1958). Reconstruction of historical Euphrates and Tigris floods shows peak flow between 2900 and 2500 BC (SUSA 1963, KAY and JOHNSON 1981). Favorable climatic conditions continued until the beginning of the 24th century BC, when at the end of the third millennium the climate began to gradually change to dry and cold. Numerous historical and archaeological evidence confirms that between 2200 and 1900 BC, there was a brief wet period of at least one hundred years, during the Third Dynasty of Ur, when rainfall increased.

During this period, there was a cooling phase in the North Atlantic that allowed the cold polar waters to spread into the Mediterranean Sea. The cold air mass decreased the surface temperature gradient of the atmosphere and the sea surface, causing not only a drastic reduction in the strength and frequency of storms, but also a reduction in rainfall in the eastern Mediterranean, including Mesopotamia (KEIGWIN and BOYLE 2000). During this period, attacks by nomad groups on the inhabited areas of southern Mesopotamia intensified, related to the spread of drought, famine and the abandonment of farmland. These nomadic attacks coincided with the disappearance of faunal records from ancient art and lit-

erature. The exception is the few records from the Third Dynasty of Ur from 2111 to 2003 BC, which suggest that a brief wet phase occurred during a very dry period from 2200 to 1900 BC. Figure 2 shows that the major salinity episode combined with a sharp drop in the Tigris-Euphrates flow rate corresponds to the combined palaeoclimatic proxy records. Particular attention was paid to this period due to the numerous palaeoclimatic and archaeological records related to the decrease in precipitation and the collapse of the political and economic superstructures dependent on the cultivation of cereals in Mesopotamia (KAY and JOHNSON 1981, WEISS *et al.* 1993, CULLEN *et al.* 2000, DEMENOCAL 2001, STAUBWASSER and WEISS 2006).

This drought period has also been observed over a large area outside the Mesopotamian region, including the Indus Valley (POSSEHL 1997). It is therefore also related to the weakening of the monsoon in South Asia (HONG *et al.* 2003) and coincides with cool, dry conditions in many areas of the Northern Hemisphere (MAYEWSKI *et al.* 2004). After this cool and dry period, the climate in Mesopotamia improved quickly, especially in the northern part, although it did not reach the optimal conditions in the early third millennium BC. Melioration gradually revived the urban centers in the Levant that had been abandoned in the previous drought period, reducing attacks by nomads to the south of Mesopotamia (ISSAR and ZOHAR 2007). In contrast, rainfall was still insufficient in southern Mesopotamia, which explained the great interest in the irrigation channels dug by the inhabitants, especially during the kingdom of Hammurabi (1792–1750 BC).

NEUMANN and SIGRIST (1978) concluded that the period 1800–1650 BC was warmer and drier than it is today, and that the harvest began 10–20 days earlier than is now possible. The climate developed to conditions that were drier around 1600–1500 BC, leading to social and political instability represented by the Hittite and Kassite invasions, as already mentioned. This period was followed by a wet period accompanied by a sharp increase in the flows of the Tigris and Euphrates around 1450 BC, with a maximum peak dated around 1350–1250 BC (KAY and JOHNSON 1981). All the data show that the period 1200–900 BC was dry. This is evidenced by numerous epigraphic and archaeological data about the prevailing drought and famine during the minimum levels of the flow of the Tigris and Euphrates rivers, which correlates with one of the

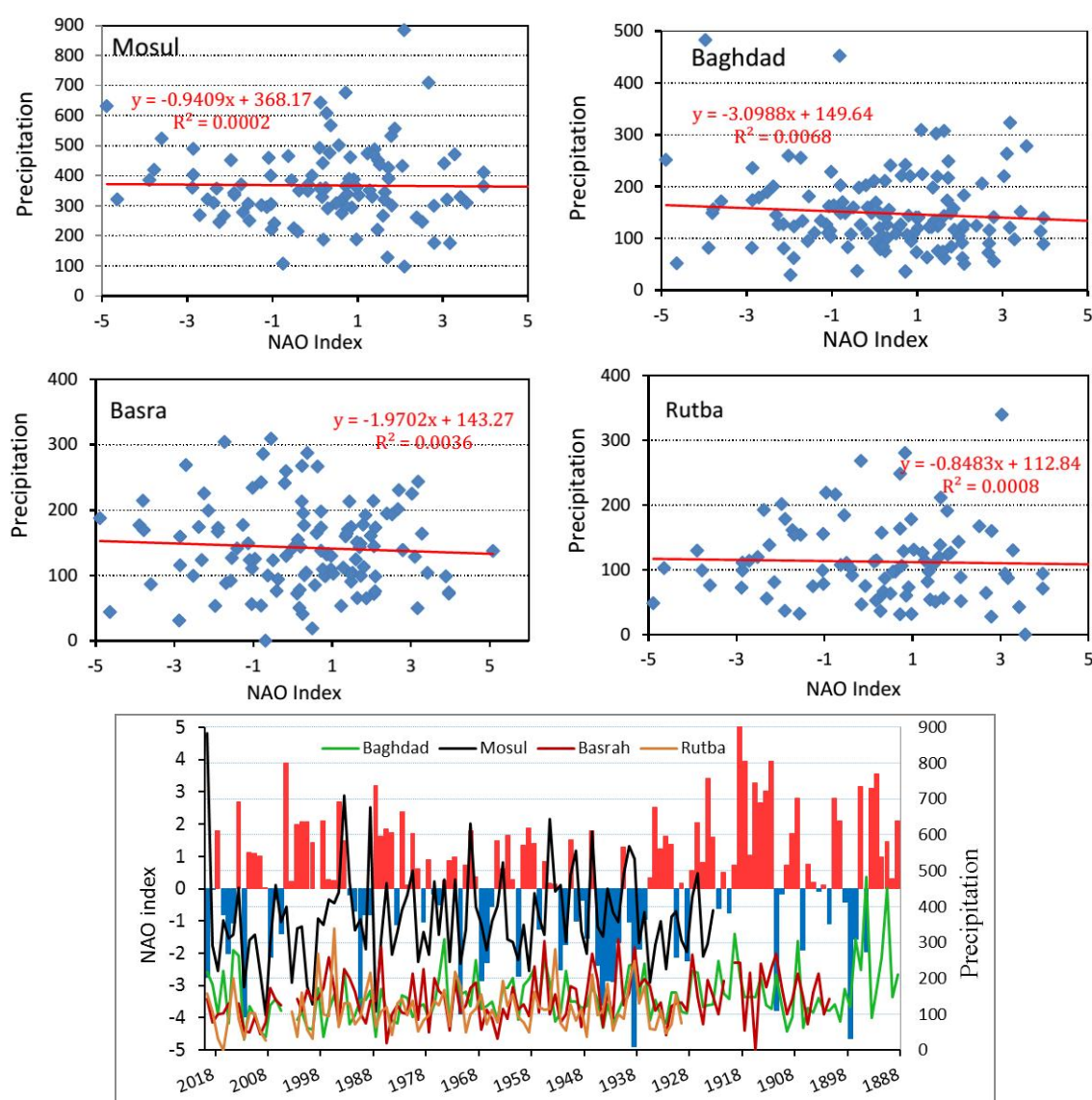


Fig. 3. Linear regression between the winter NAO and DJFM precipitation at selected Iraqi stations (upper panel) and multiannual changes in winter NAO (vertical bars) and DJFM precipitation (in mm) in selected stations in Iraq (lower panel) [source: The precipitation data from: Iraqi Meteorological Organization and Seismology (Unpublished data); The NAO data from (<https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based>)].

major episodes of salinity of Babylonian agricultural land.

Many Eastern Mediterranean proxy documents describe this dry state. These cold and dry periods coincided with the fall of Late Bronze Age civilization in Mesopotamia (KAY and JOHNSON 1981, NEUMANN and PARPOL 1987, KANIEWSKI *et al.* 2010) and in vast areas around the world (e.g., HAUG *et al.* 2001, MAYEWSKI *et al.* 2004, NIETO-MORENO *et al.* 2011). The climatic conditions improved towards a humid climate after 900 BC and lasted until 600 BC, as shown by studies related to fauna species. The fauna is not mentioned in later Babylonian texts and it can be assumed that the last animals

of Mesopotamia became extinct as a result of the spread of hunting (GILBERT 1995, 2002).

Mesopotamian climate in the early third millennium BC was humid and was influenced by two climatic regimes. The Mediterranean regime caused cyclonic rainfall in the winter period, while the monsoon regime with summer rainfall was associated with the advection of the air from the Indian Ocean. By the end of the third millennium, the summer monsoon had regressed to the region where it is today, and all parts of Mesopotamia were still hit by winter rainfall (as it is today). This means that the seasonality of the precipitation in Meso-

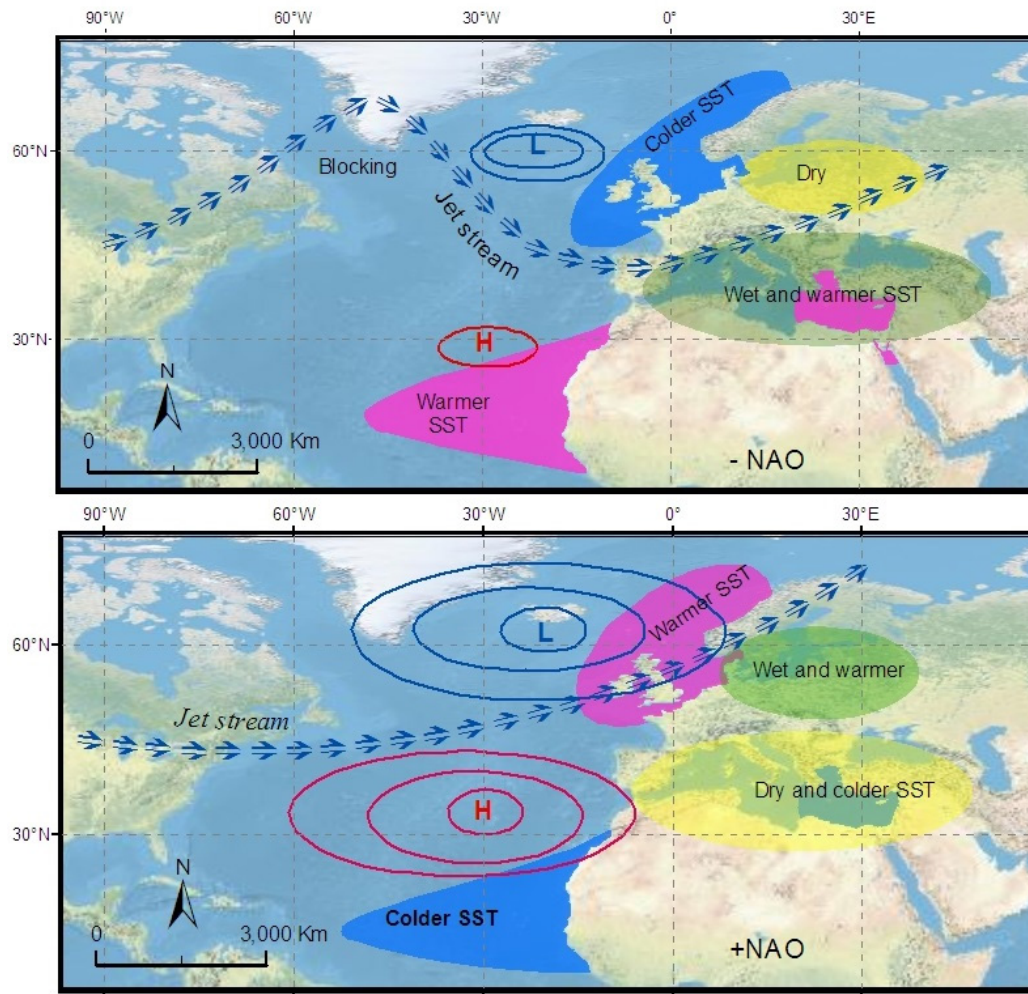


Fig. 4. The contemporary regional SST anomalies and atmospheric circulation associated with the negative (upper panel) and positive (lower panel) NAO index (extracted from HURRELL 1995, RIMBU *et al.* 2003, LAMY *et al.* 2006, HURRELL and DESER 2009).

potamia occurred from the end of the third millennium BC. The climatic conditions during the period 2200-900 BC were semi-dry to dry, especially in the center and south of Mesopotamia, while the period after 900 BC was characterized by a relatively humid climate with winter rainfall.

CONTEMPORARY CLIMATE CHANGES

PRECIPITATION AND NAO INDEX

The North Atlantic Oscillation (NAO) is a dominant mode of interannual-decadal atmospheric variability for the Atlantic sector, accounting for 20-60% of December through March (DJFM) temperature and rainfall variability in Northern Hemisphere including the Eastern Mediterranean (EM) region over the last 150 years (HURRELL 1995). Trend lines suggest a weak negative correlation between winter NAO values and DJFM pre-

cipitation. A high NAO is accompanied by a decline in rainfall in the region, while increased rainfall in Iraq is usually associated with a low NAO index. The Fig. 3 also show a weak and insignificant negative correlation between NAO and DJFM rainfall, especially southwards, such as in Basrah, even though the climate in Iraq is governed by the same mechanisms as the Mediterranean region. The absence of significant trends here reflects the highly variable rainfall distribution, perhaps due to the distance in the centers of the cyclone genesis over the Atlantic and Mediterranean Sea (MUSLIH 2014) (Fig. 3).

The correlations mentioned above support previous studies, which have reported links between EM climate and the NAO index. They demonstrate the far-field influence of the NAO on the Middle East climate and illustrate the distinct dipole relationship with the subtropical-subpolar NAO pressure

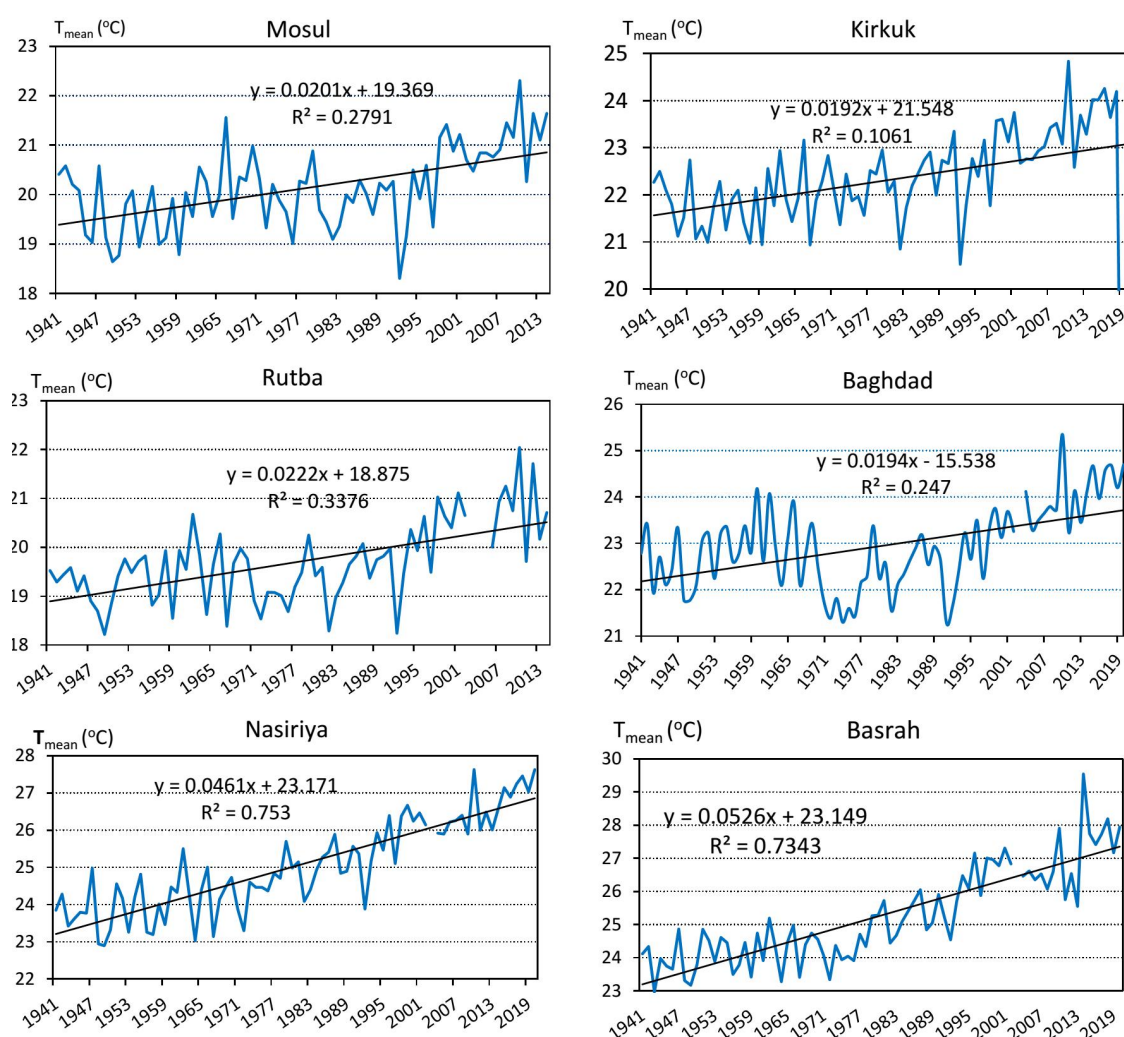


Fig. 5. Mean annual air temperature (T_{mean}) for selected meteorological stations in Iraq in the period 1941-2020 (source: own elaboration based on Iraqi Meteorological Organization and Seismology, unpublished data).

gradient (e.g. CULLEN et al. 2000a, 2002). In the high NAO phase, the Icelandic Low and the Azores High are well developed, with anomalously extreme air pressure values. This pressure configuration leads to strong pressure gradients and strengthens westerly winds across the North Atlantic accompanied by a more northern jet axis. They cause relatively mild and wet winters over northern Europe and the anomalously high pressure system covers a large part of the Mediterranean and Middle East regions, causing north winds in their eastern parts which cause an advection of dry and cold air (Fig. 4).

INTER-ANNUAL TEMPERATURE VARIATION

Figure 5 shows the mean annual air temperature for Kirkuk, Baghdad, Nasiriyah and Basrah stations in the period 1941-2020 and for Mosul and Rutba stations for the period 1941-2014. There has been a

general warming trend at all stations since the early 1970s and this trend seems to be correlated with the global warming trend that has started since then (IPCC 2013).

According to our database, the warmest year at all stations for considered period except Basrah station was the year of 2010, with temperature ranged between 22.0°C in Rutba to 27.6°C in Nasiriyah. This is similar to some of the studies that have indicated that the 2010 was one of the warmest year at the global scale (e.g. VOSE et al. 2012). In our opinion, the high temperature in 2010 is due to the significant decline in the North Atlantic Oscillation (NAO) as the most extreme negative NAO index since 1969 was recorded this year. The wind is then weaker than usual in northern Europe, and the jet currents move south from their normal position (Fig. 4), contributing to an increase in temperature in the Eastern Mediterranean (HURRELL 1995). However, the ex-

treme warmest year in Basrah station was observed in 2014 with temperature 29.6°C.

On the other hand, the records for the coldest year varied from station to station. At Baghdad station in central Iraq, the coldest year was 1991, at Kirkuk and Rutba stations – 1992. This temperature reduction was consistent with the results of numerous studies dealing with global time series analysis that attributed this cold episode to the Pinatubo volcano eruption in the Philippines (e.g. HANSEN *et al.* 2010, IPCC 2013). At the other stations, the coldest year was varying from one station to another.

Figure 5 also shows the spatial heterogeneity in the temperature variation pattern. It appears clearly that there are two patterns of annual temperature variation in the study region as follows:

1. The first pattern is represented by the stations in the north, west and center of the region (Mosul, Rutba and Baghdad), where the temperature curve begins to decline from the start of the time series to the beginning of the 1950s. The temperature then rose slightly, creating the first warm period that peaked in the early 1960s, followed by a halt for about 20 years. Warming up again was intense in the 1990s. In big cities, such as Baghdad, it coincided with intense urbanization and population growth.

2. The second pattern of annual temperature variation is represented by the stations of Kirkuk, Nasiriya and Basrah. The temperature there was the lowest at the beginning of the time series and then it started to rise gradually. To year 1980 the temperature was lower than the long-term value, and after this year it is higher than that.

The general trend of warming in Iraq was already confirmed by ROBAA and AL-BARAZANJI (2013). However, while BILAL *et*

al. (2013) noted insignificant trend towards the cooling temperature of the Baghdad in 1-2 months for the period 1941-2000. The reason for Bilal's results was the shorter period (until 2000), while our study (until 2020) clearly shows the continuation of the air temperature increase after 2000 (Fig. 5).

Table 1 shows that all months indicate a warming trend. In November, there were no significant trends, neither positive nor negative, at all stations. However, the significance of temperature trends increases in December, January and February in Mosul, Kirkuk, Nasiriya and Basrah. For the period from March to July, the results show a clear, statistically significant warming tendency at all surveyed stations.

The highest values of the 10-year linear trend were recorded in July in southern Iraq, at Basrah (0.90°C) and Nasiriya (0.81°C) stations. In the center and in the west of the region, the highest trend was recorded in April (Kirkuk 0.4°C; Rutba 0.35°C; Baghdad 0.33°C). In the north of the region, represented by the Mosul station, the highest value of temperature trends was recorded in October (0.29°C).

The temperature values found in the current research are clearly higher than those indicated in the IPCC (IPCC 2021) estimates for the Middle East. The IPCC has assessed the warming trend in this region between 0.4°C-0.6°C/decade (based on the 1981 to 2020 time series). Moreover, for seven months of the year, warming trends higher than or equal to the Middle East trend value suggested by the IPCC (2021) were observed.

Looking at the spatial differentiation of trends, it can be seen that along with the moving from the Arabian Gulf region in the south to the north and west, the temperature trend values indicate a gradual decrease (Table 1).

Table 1. Monthly trends (°C/10 years) in mean air temperature over the period 1941-2020 at different significant levels.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mosul	0.09	0.12	0.22	0.27	0.25	0.25	0.23	0.22	0.21	0.29	0.01	0.18
Kirkuk	0.19	0.27	0.39	0.40	0.35	0.36	0.27	0.35	0.22	0.22	0.01	0.17
Rutba	0.08	0.12	0.27	0.35	0.23	0.24	0.29	0.30	0.32	0.22	-0.07	0.20
Baghdad	0.07	0.14	0.27	0.33	0.23	0.16	0.25	0.22	0.17	0.24	-0.008	0.12
Nasiriya	0.16	0.23	0.45	0.49	0.57	0.74	0.81	0.70	0.53	0.42	0.07	0.21
Basrah	0.10	0.20	0.32	0.53	0.66	0.82	0.90	0.87	0.72	0.48	0.08	0.16

Significant level 95% is marked by bold and significant level 99% is marked by bold-underlined.

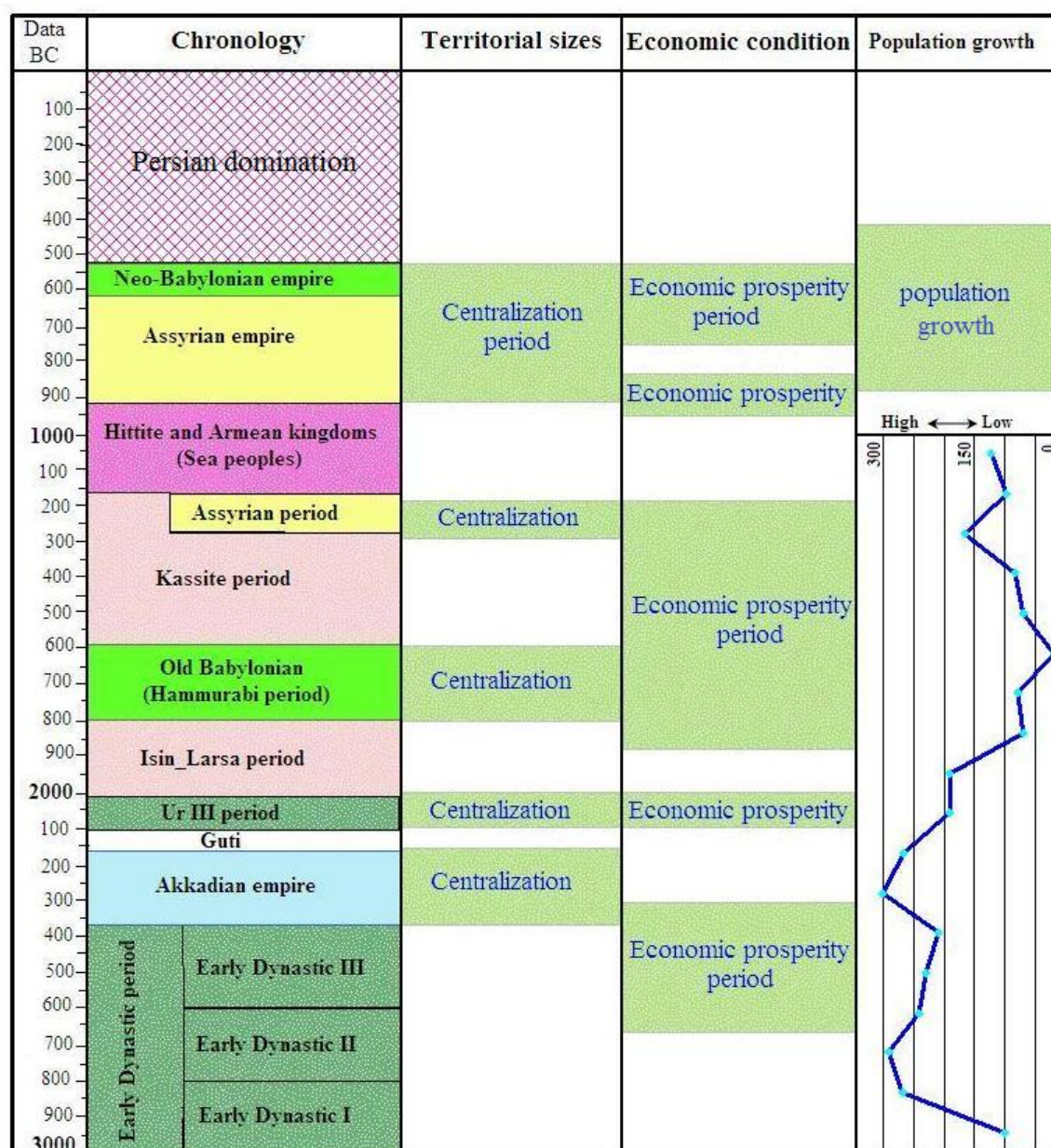


Fig. 6. The relations between climate conditions and civilizations in Mesopotamia during study period (source: own elaboration).

CONCLUSIONS

Over three millennia, Mesopotamia has witnessed the emergence of urban society, its decline and rebirth, and consecutive episodes of centralization and fragmentation. In Mesopotamian history, these changes occurred four times in less than three millennia, as can be clearly seen in Figure 6. The first began with the advent of the early dynasty (Sumerian civilization), peaking during the Akkadian empire. The second period referred to as Ur III (Sumerian Revival) marked another brief era of social complexity. The third period of civilization's heyday

falls in the time of old Babylon (the Hammurabi period) after 1800 BC, which lasted until the end of the Kassite period around 1150 BC. The fourth period was in 912-539 BC. and included the Assyrian and New Babylonian civilizations.

Climate played a fundamental role in the rise and development and subsequent decline of ancient civilizations in Mesopotamia. The impact is direct and more pronounced in northern Mesopotamia, where the economy depended on rain-fed agriculture. The indirect influence is more pronounced in southern Mesopotamia. Figure 6 also shows that in three periods the positive impact of

climate, associated with the increase in rainfall, accompanied by the increased complexity of the social and political structure of societies, even reached the level of a great empire. The negative side of climate-civilization relations is the emergence of two periods of extreme drought that coincided with the complete collapse of societies in Mesopotamia. The climate improvement and heyday that followed, followed by the harsh climate, coupled with the regression in the civilized system of societies in Mesopotamia, occur periodically and repeat in almost the same way over three millennia.

A comparison of the modern relationship between NAO and winter month rainfall (DJFM) provides a better understanding of the nature of atmospheric circulation patterns and SST anomalies associated with high and low NAO rates in the Middle East. The most important conclusions that can be drawn from the compilation and analysis of proxy data records are.

1. The modern Middle East climate is very sensitive to NAO and Sea Surface Temperature (SST) anomalies in the North Atlantic (NA), where low SST values in NA lead to a negative NAO.

2. A negative NAO index induces a southward shift of the Northern Hemisphere's Polar Front, accompanied by an enhanced airflow from the west towards the Mediterranean. These mid-latitude atmospheric conditions lead to frequent and intense cyclones that are normally fed by moisture drawn from the relatively warm Mediterranean surface waters that supply moisture to the eastern Middle East region.

3. Contemporary changes in air circulation patterns related to NAO also confirm the existence of significant dry and cool periods in the years 2650-2500, 2200-1900, 1300-1200 and 1000-850 BC. The period of 2200-1900 BC coincided with the collapse of the Akkadian empire, while the phases 1300-1200 and 1000-850 BC are accompanied by severe crop failures and the fall of the Assyrian and Babylonian empires.

4. Local and mesoscale factors have a clear impact on the spatial temperature distribution in the region, both in the inter-annual variation and in the general temperature trend. The stations most affected by these factors are Baghdad and Kirkuk. In Baghdad it is also due to the influence of the urban heat island, and in Kirkuk to the influence of topographic factors.

5. The results of inter-annual variability indicated a general trend towards warming, which at all stations from the mid-1970s was identical to the current trend of global warming. The similarity also pointed to the

hottest years observed in 2010 at all stations except Basrah, which recorded the hottest year in 2014.

6. A marked increase in air temperature is observed in the south of the region, while its northern part is less susceptible to warming.

7. The analysis of the temperature time series shows that the highest values of upward trends were observed at Basrah in July ($0.9^{\circ}\text{C}/10$ years). The trend values are clearly higher than those estimated by the IPCC (2021) for the Middle East, and amounting to $0.4\text{--}0.6^{\circ}\text{C}/10$ years

Summary

The article identifies the intervals of climate change in Middle East during the period of 3000–0 BC as well as its contemporary changes. For this purpose, various data sets were used: 1) information from numerous archaeological research and historical documents, 2) the NAO index and winter precipitation (DJFM) databases for the years 1890-2020, 3) average monthly and annual air temperature values (T_{mean}) for 6 stations in Iraq for the period 1941-2020. In the millennium perspective, four periods of significant cool and dry phases were identified (2650-2500, 2200-1900, 1300-1200 and 1000-850 BC). These phases were characterized by extreme climatic harshness, which resulted in significant socio-political changes in the Mesopotamian area. Studies of contemporary climate change suggest negative correlations between the winter NAO index and DJFM precipitation, and in the last 80 years - positive air temperature trends of up to $0.9^{\circ}\text{C}/10$ years.

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MILLENNIALNE I WSPÓŁCZESNE ZMIANY KLIMATU BLISKIEGO WSCHODU

Streszczenie

Artykuł identyfikuje fazy występowania zmian klimatu na obszarze Bliskiego Wschodu w dwóch perspektywach czasowych: 3000-0 BC oraz zmian współczesnych. W tym celu wykorzystano różne zbiory danych: 1) informacje zaczerpnięte z licznych badań i dokumentów archeologicznych i historycznych, 2) bazy indexu NAO i opadów atmosferycznych okresu zimowego (DJFM) za lata 1890-2020, 3) średnie miesięczne i roczne wartości temperatury powietrza (T_{mean}) dla 6 stacji w Iraku za okres 1941-2020. W perspektywie millennialnej zidentyfikowano 4 okresy znaczących faz chłodnych i suchych (2650-2500, 2200-1900, 1300-1200 i 1000-850 BC). Fazy te cechowały się dużą ostrością klimatu, co spowodowało znaczące zmiany społeczno-polityczne na obszarze Mezopotamii. Badania współczesnych zmian klimatu sugerują ujemne korelacje pomiędzy zimowym wskaźnikiem NAO i opadami, a w ostatnich 80 latach - dodatnie trendy temperatury powietrza wynoszące nawet 0,9°C/10 lat.

Słowa kluczowe: Bliski Wschód, Irak, millennialne okresy suszy, NAO, trendy temperatury powietrza