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ORIGINAL PAPER

Empires and the acceleration of wealth inequality in the pre-Islamic Near East: an archaeological approach

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Abstract

We present an approach comparing wealth inequality between c. 3000 BCE and 224 CE in the Near East using house sizes and urban area from 1060 houses in 98 archaeological sites. We divide this dataset into two chronological phases, firstly c. 3000-800 BCE and secondly 800 BCE - 224 CE. The first phase is characterised by small, relatively weak states, while the second phase is characterised by major empires and large states, termed as the Age of Empire (AoE). For these two periods, inequality is measured using house size in relation to settlement scaling, and applying, in addition, the Gini and Atkinson indices on house sizes. Results demonstrate that pre-AoE houses have a lower scaling metric (β) that measures house size relative to site size (0.24), while for the AoE the value is higher (0.41). This indicates more rapid median house size expansion during the AoE as cities grew larger. For the pre-AoE, Gini and Atkinson inequality measures result in 0.45 and 0.16, respectively, while the AoE demonstrates 0.54 and 0.24 for the same measures, respectively. This demonstrates greater house size inequality in the AoE. Overall, we see that wealth inequality is not only greater in the AoE, but that increased wealth inequality has a likely power law relationship to increased settlement area. Alternative metrics to minimise data biases affecting results, including median house size and bootstrap sampling, are applied to strengthen these results and overall conclusions.

Keywords Wealth inequality · Age of Empire · House size · Ancient empires · Near East

Introduction

An increasing number of studies have been devoted to the ancient empires of the Near East and their role in shaping socio-economic and cultural expressions. This includes aspects of imperial rule and their effects on society, such as the role of elites, institutions and ideology (Barjamovic 2013; Lavan et al. 2016; Morris and Scheidel 2009), the relationship between imperial centre and peripheries (Areshian 2013; Boozer et al. 2020; Düring and Stek 2018), the definition of models of governance (Glatz 2009; Liverani 1988; Parker 2018; Parker 2020) and imperial infrastructural of power (Ando and Richardson 2017). Furthermore, other studies have highlighted the impact of population movement and migrations (Altaweel and Squitieri 2018) as well as the position of Near Eastern empires in the global history of empires, including both ancient and modern societies (Alcock et al. 2001; Bang 2021; Cline and Graham 2011). These studies have shown the heterogeneity of effects that empires had on ancient Near Eastern societies' socio-political and economic characteristics, though they have demonstrated that recurrent social patterns did emerge, such as in governance and imperial rule, despite historical contingencies.

While wealth and the economy have been major themes of studies on empires in the Near East, ways in which the specific organisational structures and socio-economic conditions of imperial scale polities shaped wealth inequality have been less studied. The study of wealth inequality trends and the related analysis of the unequal distribution of resources and assets in a given society has attracted much attention in socio-economic studies focusing on contemporary societies. This has also stimulated a number of studies on wealth inequality in ancient societies around the globe, intended to investigate how and when wealth inequality originated in human history, how it persisted and how variations could

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be accounted for (Kintigh et al. 2014; Kohler et al. 2017; Kohler and Smith 2018; Milanovic et al. 2007; Scheidel 2016). In archaeology, wealth can be observed through correlations with material forms, which often translates into correlations of wealth with physical parameters such as house size, land size and the variety of portable objects owned by individuals or households (Smith 1987), with the analysis approached by means of quantitative methods, such as Gini coefficient (Ames 2008; Smith et al. 2014; Windler and Thiele 2013; Wright 2014). This is a type of wealth that derives from accessibility to resources and services that would allow someone to accumulate specific forms of physical wealth (see also below). Wealth, archaeologically, is seen as a form of accumulated goods that are ascribed to individuals or social units and made evident through material culture. Consequently, wealth in the archaeological record is not equal to income, which is used in most studies focusing on contemporary societies as a measure of wealth; in archaeology, wealth represents the product of socio-economic and political forces that shaped the material world.

Previous archaeological studies on wealth inequality in the ancient Near East have used specific categories of items (Stone 2018; Wright 2014) or house size (Basri and Lawrence 2020; Stone 2018) as a proxy to analyse wealth inequality variations, and they have applied Lorenz curves and the Gini coefficient as methods to quantify wealth and make it comparable among different contexts. These studies have shown trends of wealth inequality in various periods in ancient Near East history. In the present study, however, we intend to focus the analysis on the large empires that dominated the Near East during the period that has been defined as the Age of Empire (hereafter AoE) by previous work (Altaweel and Squitieri 2018). This is a period characterised by a succession of large empires, starting at around 800 BCE (Cline and Graham 2011), that followed one another in the control of vast portions of the Near East, putting an end to a long period of political fragmentation, only punctuated by short-lived large states, that started around 3000 BCE. This work intends to assess the effect of large empires on wealth inequality by comparing the AoE (here chronologically defined between c. 800 BCE and 224 CE, see below) with the pre-AoE (c. 3000 - c. 800 BCE). Similarly to previous studies on wealth inequality, we use house sizes as a proxy. Though there are hints that the AoE's empires promoted a greater skew of wealth distribution (Baker 2014; Stone 2018), this has never been properly tested using a large dataset of archaeological data covering a long period. Moreover, in addition to using the Gini coefficient, as previous studies have done (Basri and Lawrence 2020; Smith et al. 2014; Stone 2018), we also used the Atkinson index and we measured, for the first time, wealth inequality through house sizes in comparison with urban area, using an urban scaling method. Since empires had a profound effect on cities and their social fabric (Altaweel and Squitieri 2018; Lawrence et al. 2016), urban scaling applied here allows us to investigate the relationship between urbanism and a proxy for wealth. Previous work on contemporary societies has shown that larger cities generally attract greater wealth and income, where the relationship is demonstrated to have power-law qualities (Bettencourt et al. 2007; Bettencourt and Lobo 2016). Unlike other studies, particularly on modern systems, using population directly, we use site area as our proxy for population. House size can be used as a proxy for wealth, where we posit house size should have a scaling relationship to settlements, where larger settlements potentially also enabled greater inequality in wealth. We do not claim that only large houses will be found in larger settlements; however, we attempt to demonstrate that larger settlements do generally have larger houses given their ability to attract greater wealth. The goal is to offer a more comprehensive analysis of wealth variations, accounting for urban factors affecting wealth, before and under the Near Eastern empires and discuss below the possible causes behind these results.

Definition of the Age of Empire (AoE)

Before presenting the methods and results of this work, it is worth giving a definition of the AoE and clarifying what distinguishes it from the previous historical period (pre-AoE). The study area, shown in Fig. 1, encompasses the Levant, Mesopotamia and south-west Iran. This is the area where we observe the emergence of the first urban societies in the 4th millennium BCE and their spread across the region by the Bronze Age (c. 3000 - 1200 BCE). Moreover, this is the core area of the large territorial empires that developed in the AoE.

During the Bronze Age, the historical data reveal a fragmented political landscape where city-states and regional states were the most common political entities across the Near East (Van de Mieroop 2004: 41-189). During the Early and Middle Bronze Ages (c. 3000 - c. 1550 BCE), some states grew larger in Mesopotamia and succeeded in imposing political control and sovereignty over previously independent states. These early large states included Akkad, Ur III and Hammurabi's Babylon; because of their political structure, debates have arisen whether they can be described as empires (Heinz 2012; McMahon 2012). Regardless of their definition, these large states mostly did not reach a considerable size, and they were often relatively weak in administering their authority (Richardson 2017). Additionally, many of the early large states lasted only a few generations and were replaced, after their collapse, by multiple small political entities. With the Late Bronze Age (c. 1550 - 1200 BCE), large territorial states developed once again and this time they managed to control vast portions of the

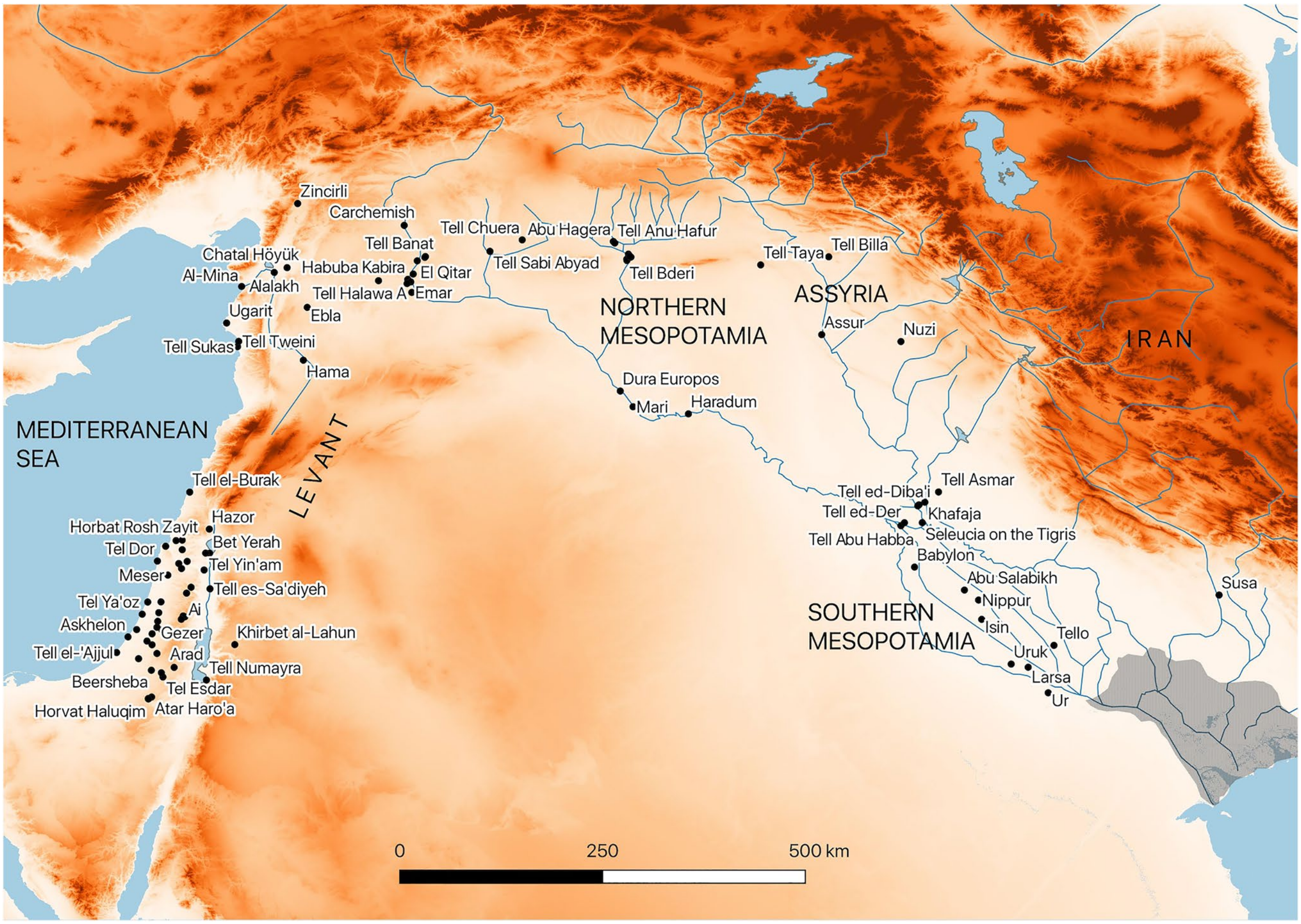

Fig. 1 The study area and the sites (black dots) used in this work. Only the main sites are labelled in the figure. For the complete site list, see S2 Table

Near East (Liverani 2001); however, none of them succeeded in controlling the entire Near East. Similar to the earlier periods in the Bronze Age, after their collapse at around 1200 BCE, they left behind a fragmented political landscape (Drews 1995). During this period, which spanned from c. 1200 to about 900 BCE, the Near East was populated by many regional kingdoms and city states (Van de Mieroop 2004: 190-206). Political rivalry, warfare and alternating alliances characterised the relations among states. Only one of these Iron Age states, Assyria, succeeded in establishing a territorial control over most of the Near East by promoting an aggressive expansionist policy that started in the ninth century BCE (Frahm 2017). The resulting Neo-Assyrian Empire is the first of a long succession of empires that followed and succeeded in controlling most of the Near East (Barjamovic 2021; Cline and Graham 2011; Turchin 2009); hence, it is the first empire of the period designated as the AoE.

The definition of empire used in this work is comparable to definitions provided by M. Doyle and M. Liverani. The former defined empires as political entities able to exert sovereignty over previously independent states, which thus become the subordinate periphery (Doyle 1986). Similar definitions, though more enlarged to include ethnic relations, territorial extension and coercive power, can be found in MacKenzie (2016), Morris (2021) and Bang et al. (2021). Liverani (2017) adds the concept of "imperial mission" characterising empires in their goal to extend their control over the "known world". The AoE's empires match these definitions. The empires of this period were able to extend their territorial control over vast areas of the Near East by far surpassing in size the pre-AoE large states (Fig. 2).

Such empires were able to develop large-scale infrastructure projects, particularly near and within their imperial core regions, affecting a variety of landscape features such as settlements, waterworks and agricultural production (Düring 2020; Düring and Stek 2018; Wilkinson and Rayne 2010). Another characteristic of AoE empires is resilience and continuity. Not only did they last longer than large pre-AoE states, but they also succeeded one another so that when an empire collapsed it was quickly replaced by another, without long periods of political fragmentation in between, as was

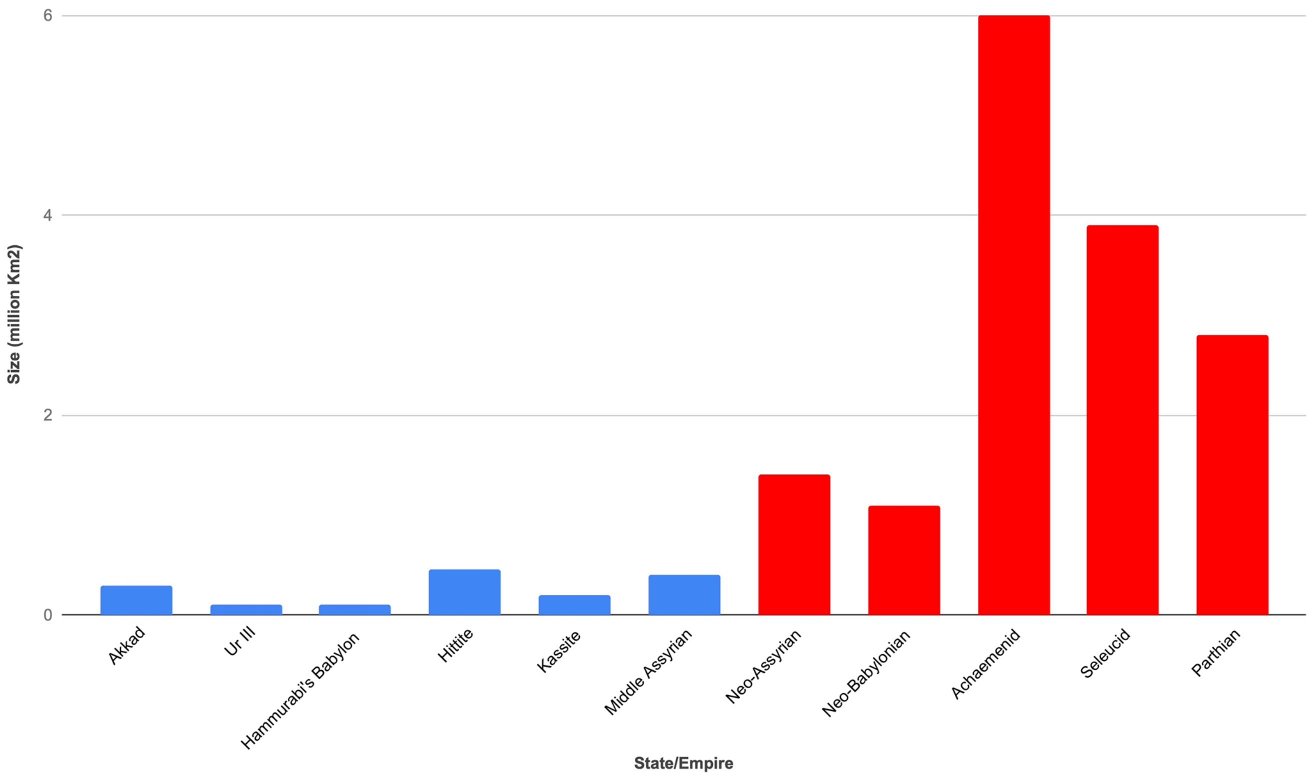

Fig. 2 Size (expressed in km^2) of the main pre-AoE states (blue) in comparison with the AoE empires (red). The measurements refer to the maximum expansion of the states/empires. Data sources, see Altaweel and Squitieri (2018) and Scheidel (2021)

more common in the pre-AoE. Potentially, the presence of stronger governing institutions in the AoE enabled this, as empires appear to have built on successes from previous states. Although the succession of large and long-lasting empires can be observed in the Near East up to the fall of the Ottoman Empire in modern times (Turchin 2009), in this paper the focus is purposely limited to the following empires: Neo-Assyrian (c. 900 - 612 BCE), Neo-Babylonian (612 - 539 BCE), Achaemenid (539 - 331 BCE), Seleucid (305 - 141/63 BCE) and Parthian (141 BCE - 224 CE). These empires, representing the incipient period of the AoE, despite having their own geopolitical and social specificities, show strategic regularities and recurrent patterns in how they approached territorial and population control, which contributed to irrevocably transforming Near Eastern societies (Altaweel and Squitieri 2018; Bang 2021). While politically these changes are evident from historical and other records, the intent in this work is to determine the effects of long-lasting imperial control over Near Eastern societies' wealth distribution. We postulate that long and persistent political control of the Near East by large territorial entities would have transformed and reoriented wealth inequality relative to what was evident in earlier periods such that wealth inequality became more exacerbated. In large part, we believe this was likely because empires afforded the opportunity for some individuals and private families to accrue greater resources and maintain them through time, a topic we will return to in the discussion.

Wealth inequality, house size and urban scaling

The study of wealth inequality trends in ancient societies has been the focus of much archaeological research in recent years, covering different cultural milieus across the globe and implementing both qualitative and quantitative methods (Basri and Lawrence 2020; Flannery and Joyce 2012; Kohler et al. 2017; Kohler and Smith 2018; Mattison et al. 2016; Scheidel 2016; Smith et al. 2014). As mentioned above, since archaeology is mainly concerned with material culture remains, wealth is seen as the abundance of material possessions accumulated by an individual or a group. Such wealth can materialise and become available for investigation in various categories of archaeological contexts such as burials, royal palaces, public buildings, religious buildings, or private houses (Kohler and Smith 2018). Here, we focus on private houses, or dwellings, as these contexts pose certain advantages to the study of wealth distribution. As pointed out by Smith (1987), in ancient agrarian societies, such as those concerned here, houses are the basic cells for economic production and consumption; they are impacted by socio-economic and political decisions taken by state administrations and they can reflect various economic groups across society. This gives the researcher the possibility to measure wealth accumulation across a large portion of the population. Furthermore, houses offer the possibility of a quantitative approach to material wealth analysis since some of their properties can be effectively measured, such as size as in this paper. Smith (1987) further indicates that house size has a positive relation to wealth for two main reasons: the larger the house the more material and labour is needed for construction and maintenance, thus reflecting the capability of the dwellers to mobilise increasing human and material resources; moreover, a larger house can be used to display and broadcast wealth. Although house architecture can be affected by several factors, such as the availability of resources, terrain morphology, cultural traditions and family structure, house size can broadly reflect levels of wealth accumulated by the dwellers. This connection between house size and accumulated wealth allows us to quantitatively investigate wealth distribution trends during the pre-AoE period and compare with the AoE.

Two more considerations need to be mentioned. First, we are not concerned with tracing a direct connection between houses and households. While the former can be identified in the archaeological record as coherent architectural units intended for dwelling and all connected activities, the latter are concerned not only with the material space but also with the family structure, the number of people living in a house and their biological and economic connections (Wilk and Rathje 1982). Even though there are connections between house materiality, including size, and household structure, the investigation of such a connection needs to be tested in detail, case by case, using textual evidence in addition to archaeological remains (Baker 2014). House size could relate to the number of individuals living in the unit, but as we compare house sizes through time, we are making the assumption that the number of household dwellers should stay somewhat constant, given that we see no socio-historical reason to believe the number of individuals found in ancient houses should change markedly. Provided this, the focus on the material evidence for wealth as expressed by house size is justifiable. Secondly, in this study we targeted buildings interpreted by the excavators as private houses, which are structures not intended for administrative and representative purposes connected to the state or empire (see also below). This helps us to distinguish broader societal wealth, where houses of private individuals are likely to be more representative of this measure.

For the periods and areas focused on here, there have been a limited number of studies that have used house size to analyse wealth trends across the Near East. Stone's (2018) and Baker's (2014) studies have shown higher levels of wealth being accumulated in households of the 1st millennium BCE, when compared to previous periods, particularly visible in the Neo-Babylonian period sites of southern Mesopotamia (c. sixth century BCE). The more recent Basri and Lawrence's study (Basri and Lawrence 2020) has shown increasing levels of wealth inequality from the prehistoric periods into the Iron Age (till about 800 BCE) across most sites of the Near East. Additionally, it has shown that while urban and countryside sites give similar results for pre-Iron Age periods (after removing royal palaces from the equation), during the Iron Age countryside sites become more equal, while urban settings display more inequality (Basri and Lawrence 2020). Compared to these studies, we have applied the analysis on a broader set of houses (see below) covering a long period, that is roughly from c. 3000 BCE to 224 CE. By increasing the number of houses, we have attempted to incorporate wider population samples across Near East societies, and, by covering a longer period, we have made the comparison between the pre-AoE and the AoE periods more robust in order to better reveal the long-term effects of empires on wealth. Furthermore, unlike previous studies which have solely relied on Gini coefficients, we have applied urban scaling in addition to Gini and Atkinson inequality indices.

Urban scaling analysis attempts to understand how non-linear properties found in cities, as demonstrated through infrastructure or wealth, adjust relative to urban size or population, where change in urban features develop in a sub-linear, linear or superlinear manner relative to population (Bettencourt et al. 2020). Growth and relationships between urban features and size could be irregular, but often power law relationships could be evident across wider urban systems. As explained in detail below, urban scaling offers certain advantages compared to the use of house size alone. This method is based on numerous observations conducted by urban geographers on modern cities which have allowed researchers to establish formal mathematical relationships between urban parameters such as area, population, infrastructure features and socio-economic phenomena, such as economic growth, innovation, health care and social inequality (Bettencourt et al. 2007; Bettencourt et al. 2020; Lobo et al. 2013). In fact, Bettencourt et al. (2007) demonstrate a power law, superlinear relationship between many larger cities and multiple wealth and/or income indicators; this aspect can be tested here for the pre-AoE and AoE. In the application of this method to ancient settlements in the Americas, the Mediterranean and the Near East, power law relationships between infrastructure and urban population have been demonstrated (Altaweel and Palmisano 2019; Hanson et al. 2019; Lobo et al. 2020), though more work is needed to ascertain to what extent modern and ancient cities behave similarly. Nevertheless, previous urban scaling work, with more details given below, has shown not only that a formal relationship can be expected between a city's infrastructure and the total urban area, but it has also shown that this relationship can be ultimately connected to broader socio-economic phenomena, including wealth distribution (Ortman et al. 2015; Ortman et al. 2016). Larger cities may, for instance, enable and sustain a larger number of social interactions, where these interactions grow in given measured time. The AoE empires concerned in this paper greatly affected the Near Eastern urban landscape. Some areas experienced the emergence of very large cities such as Nineveh, Babylon, Seleucia on the Tigris, while other areas became populated by relatively small sites dispersed across the landscape (Altaweel and Squitieri 2018; Lawrence et al. 2016; Wilkinson et al. 2005). By using urban or settlement scaling, we will test the expected relationship between site size and house size, and, by comparing the pre-AoE with the AoE, we will offer results that take into account changes to both house size and site size together, providing a more robust and complete picture of the changes in wealth inequality across time. Our expected relationship is that house size, as a proxy for wealth, should have a power law relationship to site size, as demonstrated for more recent societies (Bettencourt et al. 2007; Bettencourt and Lobo 2016). The use of scaling will demonstrate if house size has a relationship to the site area and what that relationship is. As this paper covers a broad area and a long period, we are mainly interested in overall statistical trends that emerge in the analysis. As mentioned above, the imperial legacy that empires in the analysis inherited and transmitted from one to another and which emerged in recurrent imperial strategies strengthens the validity of this approach.

Data

Site size

The dataset incorporates 98 sites scattered throughout the Levant, Mesopotamia and South-West Iran (Fig. 1, see also S1 Table). They range from small sites of about 1-2 ha to larger sites exceeding 500 ha, thus providing a representative section of the different site categories present in the area. For this study, we relied on estimates based on other scholars' works or what has been previously published about these sites. The references shown in S1 Table also report information on site size. For sites which are known to have changed size of occupation during the long time spans covered by this study, we used the respective sizes for the pre-AoE and AoE, each divided into sub-periods (e.g. pre-AoE into Early Bronze Age, Middle Bronze Age, Late Bronze Age and Early Iron Age) so as to better represent the size changes of a given site for measured individual houses that relate to that period. In some cases, we relied on site size estimates taken as valid for all the occupation periods of a given site.

House size

A total of 1060 houses, for both the pre-AoE and AoE, are included in the dataset (S1 Table). By houses, we mean domestic dwellings in which no evidence was found of administrative and representative functions as being primary functions. As for the identifications of specific buildings as domestic dwellings, we mostly relied on the excavators' interpretations as well as on comprehensive studies dealing with domestic architecture from various periods. We had deliberately excluded royal palaces, defined as buildings hosting various functions connected to state administration including official, representative and ceremonial activities, and we excluded governors' houses in which officials appointed by the state organisation resided. In this case, institutional or government structures, including government buildings such as palaces, are excluded because they represent clear state-level wealth, which is not the focus. Rather, our work focuses on private individuals and attempts to better measure the breadth of wealth across society using private houses as a proxy for measurement. The built area we used refers to the total built-up area of houses at the ground floor, including walls. In this study, we assume that houses mostly developed only on the ground floor, since the existence of upper floors cannot be established with certainty in the majority of cases. Certainly, additional storeys are possible, but they neither can be easily measured nor assumed, noting that the lack of preserved additional floors above a ground floor is equal across all periods. We used buildings with complete plans or buildings which have been excavated for at least 90% of their original plan, which, therefore, can be reconstructed with high certainty. Based on this, the method applied to measure house size used the criterion for measurement as defined in Basri and Lawrence (2020).

As the dataset includes houses from various sites across the Near East, problems related to the unevenness of the archaeological data recovery are inevitable. The first problem concerns the unevenness of the number of observations (that is houses) available from publications. For the pre-AoE, 823 observations have been collected, while for the AoE the number decreases to 237. This is mainly due to the fact that in many sites archaeological explorations have mainly focused on large royal palaces, administrative or religious buildings, rather than private houses. This is particularly true for the AoE, as many imperial cities and provincial capital cities are almost only known for their royal and official settings, while domestic quarters, if they existed, have been left largely unexplored. There is also a likely bias, purposeful or not, towards earlier periods. Since the discrepancy in observations between the pre-AoE and the AoE can statistically affect the results, we implemented a bootstrap sampling method by averaging estimates from multiple randomised sub-samples drawn from the total dataset in order to reduce sample size biases and make the pre-AoE and the AoE results more comparable (see below). In addition to this, it is also worth mentioning that some areas and sites are more represented in our dataset than others, depending on the period of analysis. For instance, data on domestic buildings of the Neo-Babylonian period are more represented in Mesopotamia (N=35) rather than in the Levant (N=2). However, by using a large number of sites and houses across a vast area and long periods, these discrepancies in the dataset are better balanced and emerging trends can be more easily highlighted.

Periodisation

We used data pertaining to the period spanning from c. 3000 BCE, that is the beginning of the Early Bronze Age, through the Parthian period, with its ending fixed to 224 CE, that is when the Parthian (Arsacid) Empire was taken over by the Sasanian Empire. As mentioned above, we are interested in comparing the pre-AoE with the AoE. The latter started around 800 BCE, that is when the Neo-Assyrian Empire expanded in all directions and started to implement territorial control over conquered areas and populations (Frahm 2017), marking the start of the empire succession characterising the AoE (Altaweel and Squitieri 2018). Because the Neo-Assyrian Empire's expansion occurred in a temporal succession of several victorious battles, the precise cut-off date for when a given site's layer can be included in the AoE depends on when that given site was conquered by the Assyrians or was highly affected by their rule. This means that the layers of most Iron Age sites, dated to 1200 - 600 BCE, are assigned to the pre-AoE period or to the AoE period depending on when that specific site was included into the Neo-Assyrian Empire. To establish the chronologies of the archaeological layers, and, consequently, of the buildings unearthed in these layers, we relied on the excavators' insights. Data on house size and layers' chronologies are given in S1 Table. We should state that data from individual houses derive from specific periods within the pre-AoE or AoE, rather than covering the entirety of any given period provided. In other words, the life history of houses is generally shorter than the periods indicated for houses.

Methods

Urban scaling

Urban scaling has been deployed in urban geography and related disciplines to analyse different built environments and social components found in cities and towns, including in the past and contemporary societies. In urban settings, scholars have analysed a broad range of social, cultural and economic phenomena (Altaweel and Palmisano 2019; Bettencourt et al. 2007; Lobo et al. 2013; Lobo et al. 2020; Schläpfer et al. 2014). These studies, conducted on both ancient and modern settings, have shown empirical power law relationships between infrastructures and urban sizes across a variety of temporal and geographic settings, with sometimes recurrent and somewhat regular patterns. Urban scaling draws from broader scaling studies applied to various systems (e.g. biological systems) to understand how parts of a system change in relation to the system's overall size (Bettencourt 2013). Settlements can be thought of as systems in which their parts (such as houses, as in our case) relate to the settlement following an expressed mathematical relationship, often indicated via regression models. Often, power law relationships are evident between the size of an urban system and given parts measured, with changes in urban size corresponding to a demonstrable effect on given qualities. Different reasons could cause these changes, but urban size is a convenient proxy to demonstrate if population demonstrates some overall change or relationship to measured qualities in an urban landscape.

Although ancient cities do not always offer the possibility to quantify specific parameters as modern cities do (e.g. population), other parameters (e.g. settlement and building area) do offer the possibility for a quantitative approach. In the absence of population data for ancient cities, we, therefore, used settlement size. Previous studies that have applied urban scaling theory to ancient cities have successfully revealed the existence of empirical regularities that can be described in terms of scaling relationships, particularly between site size and different forms of urban infrastructure (Bettencourt et al. 2020; Ortman et al. 2015). Previous work on modern cities has also demonstrated that as cities become larger, they are also able to absorb greater economic and/or social resources or enable the building of larger infrastructure (Bettencourt et al. 2007; Hanson et al. 2019). In these works, effects on wealth, infrastructure, or other urban characteristics are not even in relation to urban population. Some qualities, such as infrastructure, show a sublinear relationship in the change of infrastructure relative to population, while qualities such as wealth show a superlinear relationship in wealth change relative to population. Overall, these works demonstrate that resources do generally have a power law relationship to urban populations. House size in ancient cities could be thought of as another form of resource or infrastructure where we might expect a power law relationship to urban size.

In the present study, we will plot house sizes against site sizes, comparing the pre-AoE and the AoE by applying a power law, scaling relationship formulated and explained in Lobo et al. (2013). This method effectively allows us to measure the rate at which one variable (house size) grows in comparison with the overall system size (site size), which is expressed by the beta value (β). The β value shows how much house sizes change in relation to site sizes. Positive values for β indicate that both variables (site size and house size) are positively related, meaning that as one variable grows the other also grows. Following Lobo et al. (2013), a normalisation constant is also applied, called Y_0, and reported in S3 Table.

With β = 1, each unit of change or growth in the site area has an equal change and growth in the building area (this is linear scaling). Values for β below and above 1 are referred to as sub- and superlinear scaling, respectively. A sublinear relationship indicates that each unit of change in the site size corresponds to a smaller unit of change in the house size, and vice versa for a superlinear relationship. Previous studies concerning city infrastructure have mostly shown sublinear relations between various categories of urban infrastructure and city size (Bettencourt et al. 2007; Hanson et al. 2019; Ortman et al. 2015), which may be expected as the growth of urban infrastructure has some efficiency relative to the urban population as existing infrastructure can absorb some of the population growth. Additionally, as the urban area becomes larger, comparable infrastructure growth may demand a level of resource that is not possible or limited by social or physical constraining factors. In this paper, in addition to the absolute value of β, we are interested in comparing the β values obtained for the pre-AoE with that obtained for the AoE. This comparison will allow us not only to establish whether houses of the AoE tend to be larger than those of the pre-AoE, but also whether they tend to be larger in the AoE in relation to site size.

The advantage of using urban scaling, instead of house size alone, is that it takes into account the effects of cities and in particular the emergence of very large cities during the AoE, which have no parallel in size in the pre-AoE (Altaweel and Squitieri 2018; Lawrence et al. 2016). This is the case for cities such as Babylon and Seleucia on the Tigris, which reached the impressive sizes of 900 ha and 550 ha, respectively. This method enables us to investigate whether cities were able to absorb more resources as they grew, which could have enabled them to build larger structures including domestic housing, such as seen in more recent urban environments (Bettencourt et al. 2007; Bettencourt et al. 2020). As empires tended to inflate some cities' area, one may expect to find at least some larger houses in the latter as more space is available and more resources are incorporated in such cities. Furthermore, by measuring inequality, we are measuring disparity of wealth, where cities could certainly have many small houses that are densely distributed, but greater wealth could mean greater discrepancy between the largest and smallest houses in the distribution, with inequality growing faster in larger sites. In contrast, if houses and cities grew proportionally or had a comparable power law relationship with one another from the pre-AoE into the AoE, we should expect similar β values for both periods. This scenario would mean that, despite some cities growing larger in the AoE, houses should tend to grow in a similar manner to the pre-AoE. On the other hand, if the AoE β value was higher than in the pre-AoE, it would mean that the growth of some cities during the AoE cannot account alone for emergence of larger houses, or, in other words, AoE houses tend to be larger than in the pre-AoE not only because there is more space available within cities. As an additional justification for the use of site size and house size together, we tested their statistical correlation by means of the Pearson correlation test (run in R, v. 3.6.1). The test gave a p-value < 2.2e-16, allowing us to reject the null hypothesis and suggest that a statistically significant correlation exists between house size and site size in the present dataset. We feel that this result allows us to justify the use of these two variables for the urban scaling method. The regression analysis used to determine the β values has followed the equation given in Lobo et al. (2013) and was applied in Python 3.8 with the scaling code available as supporting information (S1 File).

Gini and Atkinson indices

In addition to urban scaling, we applied the Gini and the Atkinson indices (Atkinson 1970; Cowell 2011) in order to measure inequality levels in the distributions of house sizes comparing the pre-AoE and the AoE periods. The Gini index is probably the most commonly used in archaeology for analysing various types of distributions, and it has been frequently used to determine wealth inequality in ancient societies (Ames 2008; Basri and Lawrence 2020; Kohler et al. 2017; Smith et al. 2014; Stone 2018; Windler and Thiele 2013; Wright 2014). The Gini index scores from 0 to 1, where 0 represents a perfectly equal distribution, while 1 a perfectly unequal distribution. Applying this index to house size means that the closer the Gini value is to 0 (= perfect equality) the more uniform house sizes are across the entire sample. On the other hand, the closer the Gini value approaches 1 (= perfect inequality), the more the house size distribution becomes unequal, meaning that very few houses tend to be large and many smaller houses are evident. If house size is then considered a proxy for accumulated wealth, as in this paper, then the higher the Gini index the more skewed wealth distribution is across society. Although the Gini index does not capture absolute wealth, it is a valuable method to make distributions comparable, and, in our case, it allows us to compare the pre-AoE with the AoE periods. The second index we applied is the Atkinson index, also used as a measure of inequality in contemporary societies. This index also ranges between 0 and 1, but applies a different formula than Gini. Despite being less commonly used in archaeology, it has the advantage over the Gini index in better representing the inequality distribution among the lowest values. While the Gini index gives equal weight to the entire distribution, the Atkinson index uses a so-called sensitivity parameter (Atkinson 1970), which allows us to give more weight to the lower end of the distribution, where the smaller houses are represented. In our case, the Atkinson index better captures the inequality among smaller houses; consequently, it "grows" slower towards 1 (that is to maximum inequality) than the Gini index if there are relatively more observations with low values. We used the Atkinson index in support of the Gini index results, which also helps to validate conclusions made if the two measures show comparable trends, with the Gini and Atkinson indices calculated using the package "ineq" in R software (v. 3.6.1).

Results

The total house size data are graphed (Fig. 3), with summary statistics of the distribution (Table 1), and results divided into pre-AoE and AoE. Generally, we can see that houses are, on average, smaller in the pre-AoE, with the distribution more positively skewed in the AoE and with both distributions having heavy tails.

Table 1 Mean, median, skewness and kurtosis values for the house size distributions

Data	Mean (m^2)	Median (m^2)	Skewness	Kurtosis
pre-AoE	111.75	78	4.04	28.36
AoE	248	155.5	3.34	16.38

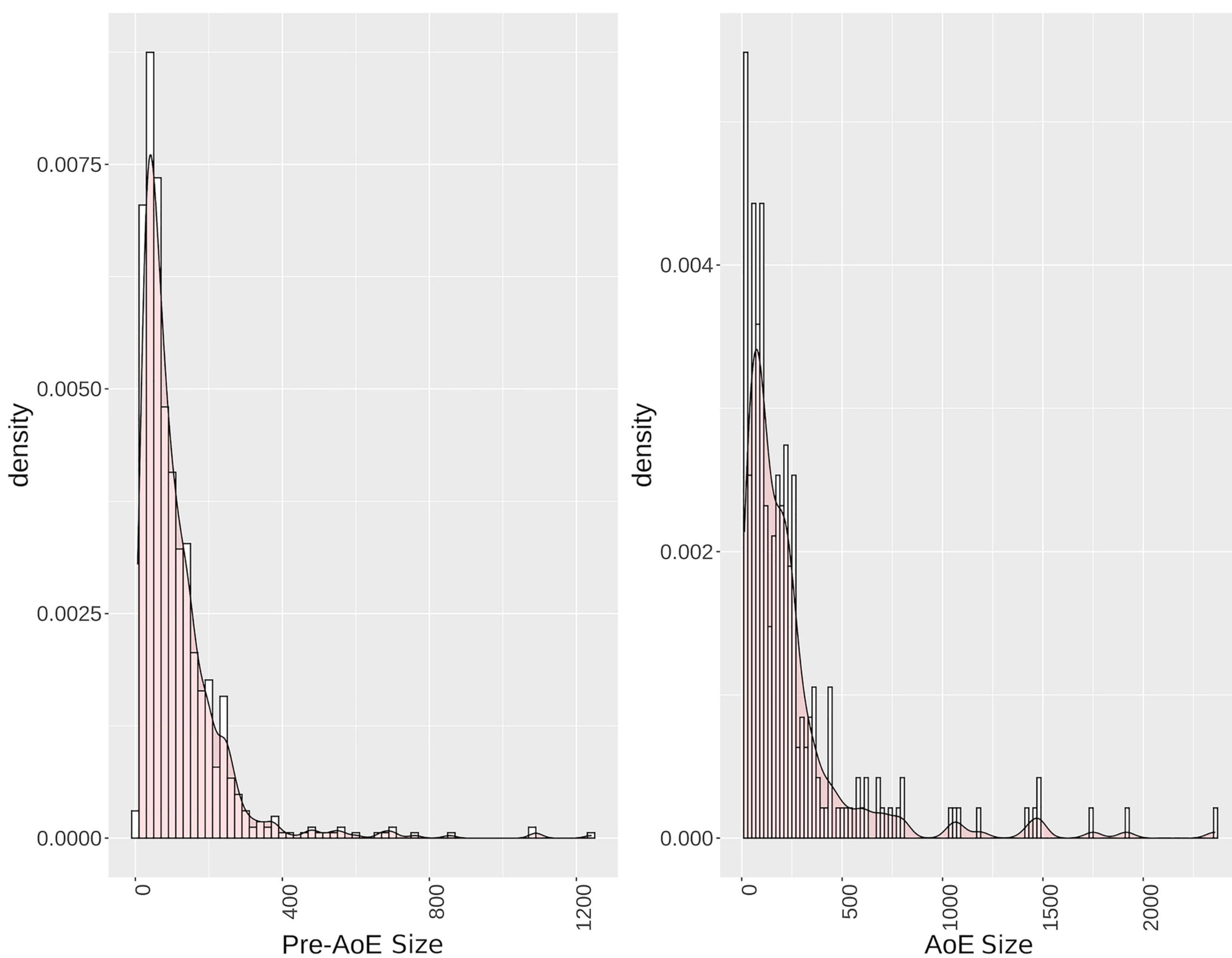

Fig. 3 House size distributions for the pre-AoE and AoE houses

Urban scaling

Results from the urban scaling analysis covering the pre-AoE and AoE are shown in Table 2. The correspondent graphs showing the scaling relationships for site areas and house sizes are shown in Fig. 4. S3 Table in supporting information contains additional results, including constant (Y_0), the mean absolute error (MAE) and the root-mean-squared error (RMSE) for the pre-AoE and AoE. Here, we focus on the β values and their implications.

The urban scaling analysis applied on the entire dataset, which comprises 1060 observations (that is houses), returns a β value of 0.28. This value indicates a sublinear relationship for houses in relation to site size, meaning the houses tend to increase at a β being close to $^{1}/_{3}$. Breaking down the entire dataset in pre-AoE and AoE periods, we obtain a β value of 0.24 for the pre-AoE, with 823 observations. For the AoE period, the analysis, based on 237 observations, returns a β value of 0.41. By comparing the two obtained β values, we can see that the AoE β value, though still indicating a sublinear positive change of houses compared to site sizes, is now higher than the pre-AoE β value. This means that during the AoE houses tend to demonstrate accelerated growth relative to the houses of the pre-AoE in relation to site size. The adjusted R^2 for house size and site size is not nearly as high as Bettencourt et al. (2007), but they show a significant relationship. Overall, site size is a better linear, power law predictor for house size in the AoE rather than in the pre-AoE. S3 Table in supporting information also shows a higher variation in the AoE data compared to pre-AoE (MAE and RMSE), meaning that a wider gap between the smaller and the larger houses is evident during the AoE than in the pre-AoE dataset.

Since the number of observations for the AoE period is lower than in the pre-AoE (237 vs. 823), we apply a sample randomisation in order to reduce the effects of sample size on the results. The analysis was applied on a subset of 237 observations randomly selected, using a bootstrapping sampling method, from the pre-AoE dataset to match the number of AoE observations. We iterated the analysis 100 times on randomly selected subsets for each iteration. The resulting β values have a mean of 0.23, with the most common value being 0.22 (Table 3).

This result shows that even randomising the pre-AoE dataset the β values for pre-AoE houses are consistently lower than the AoE value (= 0.41). In addition, we have also run a sample randomisation for the AoE dataset, so as to observe the effects of sample size on the β value. The results, shown in Table 4, indicate that the most frequent β value is 0.4, matching the previous results of 0.41, obtained with no randomisation.

The results from the sample randomisation of both the pre-AoE and the AoE datasets confirm the β values shown in Table 2. They show that the difference in sample size

Table 2 Power law scaling for urban and house sizes

Urban scaling results	β value	N. of observations	Adjusted R^2 for size
All dataset	0.28	1060	0.28
pre-AoE	0.24	823	0.21
AoE	0.41	237	0.44

Table 3 Sample randomisation of pre-AoE dataset

β value mean	β value STD	Most common β value	N. of observations	Iterations	Adjusted R^2 for size
0.23	0.024	0.22	237	100	0.38

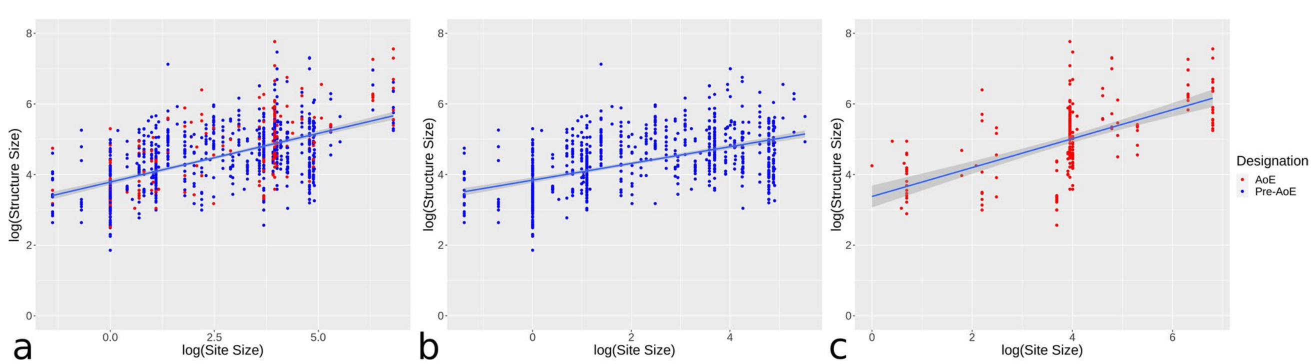

Fig. 4 Scaling relationship between site size (X-axis) and house size (Y-axis) covering **a** all of the dataset, **b** the pre-AoE period and (**c**) the AoE period. The adjusted R^2 value reflects coefficient of determination between house size and urban size for sites using a linear regression

Table 4 Sample randomisation results of the AoE dataset

β value mean	β value STD	Most common β value	N. of observations	Iterations
0.40	0.022	0.4	237	100

between the pre-AoE and the AoE does not seem to greatly affect the obtained β values, giving more confidence in the patterns observed.

We additionally carried out the analysis on both the pre-AoE and the AoE datasets by using median values for house sizes. The reason for this is that in some sites under analysis the house size range can oscillate greatly, an example being the city of Assur (AoE period) where house size ranges from 36 m^2 to 1750 m^2. By using median values, the intent is to reduce the effects of both very large and very small houses on the results. The results obtained are offered in Fig. 5 and Table 5, where the β value for the pre-AoE period is 0.25 and 0.35 for the AoE period. Once again, when using median house size, the AoE β value is clearly greater than the pre-AoE.

The results above consistently show β values for the AoE at a higher level than the pre-AoE. Despite all the obtained values being below 1, hence indicating a sub-linear relation between house size and site size, higher β values for the AoE demonstrate with some confidence that houses of the latter period are larger in relation to site size compared to the pre-AoE. The implications of these results will be discussed in the section below.

Gini and Atkinson indices

We now turn to the results for the Gini and Atkinson indices on house sizes for the pre-AoE and AoE, with results shown in Table 6.

Table 5 Results from the urban scaling method applied on median values for house sizes of the pre-AoE and the AoE

Urban scaling results (median values)	β value	N. of observations
pre-AoE	0.25	823
AoE	0.35	237

Table 6 Results of Gini and Atkinson inequality indices applied on the pre-AoE and AoE houses

Inequality indices results	Gini	Atkinson	N. of observations
pre-AoE	0.45	0.16	823
AoE	0.54	0.24	237
Neo-Assyrian/Neo-Babylonian Empires (excluding Assur, Babylonia and Zincirli)	0.57	0.27	40

The Gini indices score 0.45 vs 0.54 for the pre-AoE and AoE, respectively, while the Atkinson indices score 0.16 vs 0.24. This means that, overall, houses are closer to equality (Gini/Atkinson = 0) in the pre-AoE rather than in the AoE, hence showing a higher degree of uniformity in size in the pre-AoE. For the AoE period, a difference with the pre-AoE results is observable, although the number of AoE houses is lower than the pre-AoE. Both indices grow towards 1 during the AoE, indicating that houses of the AoE display a

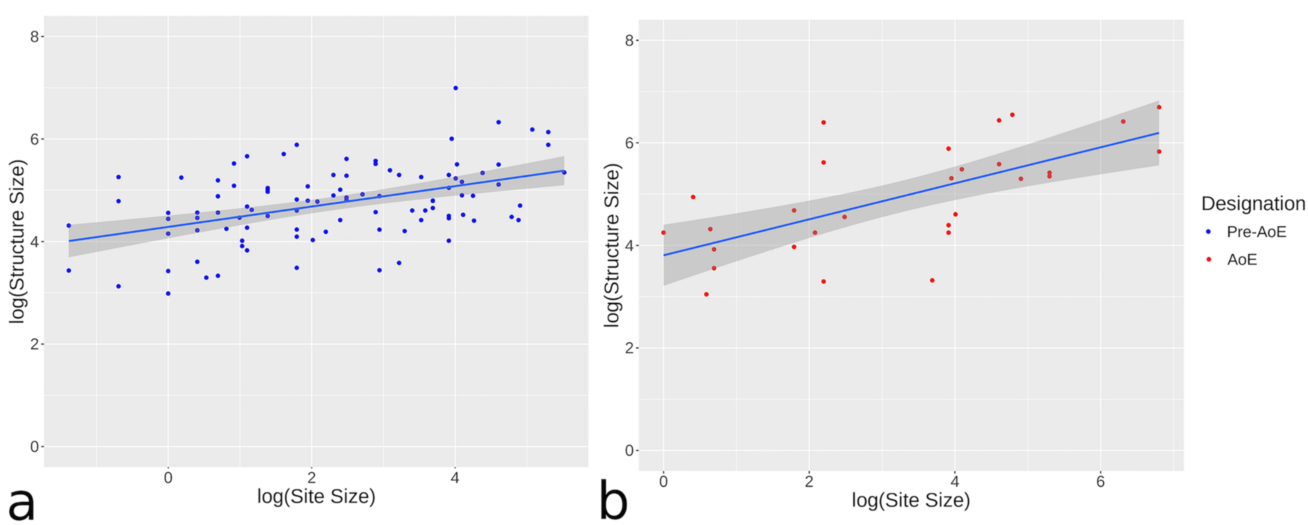

Fig. 5 Scaling relationship between site size (X-axis) and house size (Y-axis), using median values for house sizes. **a** pre-AoE period; **b** AoE period

higher degree of inequality. In other terms, a small number of AoE houses grew considerably larger than the rest, while during the pre-AoE houses were more equal in area. This suggests that private houses display a higher level of inequality in the AoE. Additionally, because the Atkinson index is much lower than the Gini in both periods, we can conclude that most of the observed houses fall in the lower end of the distribution tail, towards relatively smaller sizes. Since the Atkinson index increases during the AoE, we can also conclude that smaller houses located at a lower end of the distribution display higher inequality levels compared to the pre-AoE. Overall, wealth disparity increases in the AoE, as few houses grow much larger.

Finally, we tested the weight of imperial cities and major cities in the results. The Gini and Atkinson indices for houses of the Neo-Assyrian and Neo-Babylonian Empires were calculated by removing the observations from Assur and Babylonia, the two imperial cities of these respective empires, and from Zincirli, a major imperial provincial capital city of the Neo-Assyrian Empire, located in today's south Turkey. As a result, the Gini and Atkinson indices score 0.57 and 0.27, respectively. Comparing these results with the pre-AoE (0.45 and 0.16), we still observe an increase in inequality despite removing the observations from these major cities. This means that, although it is expected that wealth accumulated more in imperial cities and other major cities during the AoE (see below), a rise in inequality levels can also be seen outside the major imperial centres.

Discussion and conclusion

This work has presented an investigation of wealth inequality during the period spanning 3000 BCE to 224 CE by applying an urban scaling method as well as the Gini and Atkinson inequality indices. The goal was to compare the pre-AoE (c. 3000 - c. 800 BCE) with the AoE (c. 800 BCE - 224 CE) in order to observe the effects of large and long-lasting empires on house size in relation to site size, with the former being used as a proxy for accumulated material wealth across society. The urban scaling analysis has yielded β values of 0.28, 0.24 and 0.41 for the entire dataset, the pre-AoE and the AoE, respectively, with a higher variation for the AoE than pre-AoE. One clear result is that the obtained β values are below 1, which indicates a sub-linear relationship between house size and urban area, with values oscillating near $^1/_3$. Although we use area rather than population directly, interestingly comparable values have been observed in previous studies focusing on the ratio of power law growth for urban infrastructures to urban area or population, with previous studies comparing roads, gates and squares (Altaweel et al. 2021; Hanson et al. 2019; Hanson 2020). This suggests that certain physical infrastructures within cities, including gates or roads, change at a comparable, general level relative to urban size in a manner that is also similar to house size that was measured in this work. One possible interpretation is that population growth, and consequently urban area growth, could be having a comparable effect on the growth of a variety of infrastructural features, with that growth somewhat regular in some periods and regions. In the case of houses, a variety of factors are possible, including efficiency in house size growth relative to population or limitations to house size growth as the urban area grows due to limited resource, crowding or social constraints. While the above results are worth further investigating, it is not the primary focus of the present paper.

From our results, we observe that houses of the AoE tend to change at a greater, positive rate than in the pre-AoE when compared to site size, since the AoE β value is higher than the pre-AoE. Even after a sample randomisation and the use of median values for house size, the AoE β value is consistently higher than the pre-AoE. This means that house sizes in the AoE do not change in relation to site size with the same proportion as in the pre-AoE; however, they generally accelerate more positively in the AoE as cities become larger. Admittedly, the relationship between house sizes and urban area is not as strong as modern proxies for wealth, but we do find a strong statistical relationship. By applying Gini and Atkinson indices, it has emerged that the disparity between a few large houses against many small houses generally increases from the pre-AoE into the AoE. The Atkinson index alone points at a higher house size inequality during the AoE than in the pre-AoE among the lower end of the distribution, that is among smaller houses, which is confirmed by the inequality analysis conducted without taking into account major cities of the AoE (Assur, Babylon and Zincirli). We should note, however, there are only 40 houses when accounting for sites outside these major cities. Overall, what we see is an increase in inequality in house size from the pre-AoE into the AoE, a trend which is visible across all sites.

Empires, wealth generation and inequality

As we have seen above, we have used house size as a proxy for accumulated material wealth across society. Following this connection between house size and accumulated wealth, we can conclude, on the basis of our results, that wealth inequality increases under AoE empires, with a few houses having become much larger than the rest, relative to the pre-AoE. These results are in agreement with previous studies that have shown an increase in wealth disparity during the 1st millennium BCE in the Near East (Basri and Lawrence 2020; Baker 2014; Stone 2018), which roughly overlapped with the periods and regions considered in this work. As this work covers a longer period into the AoE, and uses a wider dataset, we support and provide a new perspective for urban sites in relation to previous studies. We demonstrated an emergent pattern for large empires of the Near East, at least within the present study's geographic and temporal limits, showing increased wealth disparity across society. As with other studies, we have not included royal palaces, official residences and temples, which are the archaeological manifestation of ruling classes. Nevertheless, wealth disparity seems to increase across populations outside the ruling classes. It seems, therefore, a generalised effect of empires on society, where results show greater and more unequal wealth accumulation is evident in the AoE. Urban scaling has shown that the increase in wealth inequality has a power law relationship to settlement areas, where larger sites tend to have larger houses. This is relevant as it allows us to connect cities and wealth or a form of housing infrastructure; as sites become larger during the AoE, they are able to draw even higher flows of resources than the pre-AoE and, therefore, they tend to display larger houses and ultimately greater inequality. While this may seem somewhat counterintuitive, as larger cities may be seen as more crowded with smaller and denser houses, the result agrees with what has been observed in modern cities, if we take houses as a proxy for wealth, where a positive power law relationship has been observed between increasing wealth flow and urban area (Bettencourt et al. 2007). However, we note that we did not achieve a superlinear relationship between urban area (proxy for population) and wealth, as demonstrated for modern cities, but our β results are more akin to those demonstrating infrastructure growth (e.g. see Hanson 2020; Altaweel et al. 2021), which have a sublinear relationship. This could suggest that houses, while affected and related to wealth, change comparably to urban infrastructure. Nevertheless, we can suggest that power law relationships between wealth and urban areas are evident in the past. The rate of growth measured here is different from modern cities, but this could be due to the use of different proxies for wealth (e.g. GDP vs. house size).

Overall, our work has demonstrated that not only did wealth inequality increase during the AoE, relative to the pre-AoE and likely due to the effects of large empires, but wealth increases somewhat comparably to modern societies in that wealth growth has a power law relationship to urbanism. It is, therefore, worth asking how empires considered here transformed wealth inequality trends as observed in this study. As stated, one of the main characteristics of the AoE is long-term and persistent imperial control over vast portions of the Near East, in striking contrast with the more politically fragmented landscape of the pre-AoE. A durable control over vast territories conferred to empires the ability to tap into wealth-generating resources to a level that was not possible for pre-AoE states. The strategies of population migration and management that empires implemented via deportation and large resettlement programmes gave them the possibility of increasing labour supply in key sectors of their economies, such as agriculture. In addition to this, volunteer movement of private individuals was also generally evident in the AoE, facilitating labour and wealth flows to cities (Zaccagnini 1983). Agricultural productivity was also favoured by extensive irrigation programmes that, although they can be traced back to the pre-AoE and even earlier, became increasingly important and intensive during the AoE (Wilkinson and Rayne 2010). Increasing agricultural productivity meant increasing the possibility for empires to expand their expenditures via tax revenues. AoE cities could afford growing larger as they could be supplied with high quantities of agricultural products being produced by populations, often deportees or descendants thereof, working in small farm sites surrounding the cities themselves. Examples of this are the large Neo-Assyrian citadels in Assyria (northern Iraq), fed by vast irrigation infrastructures, and Babylonia (southern Mesopotamia), which experienced incremental increases in urbanisation and cultivation during most of the AoE (Jursa 2014; Van Der Spek 2007). This increasing intensity in agriculture suggests a larger population to feed, which is further supported by broader survey settlement data indicating increased population (Adams 1981).

The increasing monetisation of the economy is another aspect to be taken into account. With the Achaemenid Empire (550-330 BCE), coin use became more widespread for economic transactions, and especially with the Seleucid Empire (312-63 BCE), coins became the main means for trade transactions as well as salary and tax payments (Aperghis 2004). Coins helped make the extraction of resources from the empires' provinces much easier, as these resources did not consist only of agricultural goods, human and material resources, whose transfer from the empires' peripheries to the centre could have a great cost, but also a mobile and more transferable type of wealth expressed by coins. Although in this paper we are concerned with a form of material wealth represented by houses, the examples listed above (agricultural productivity, infrastructure, labour management, coins) all point to a greater power for empires to generate wealth than was possible during the pre-AoE. To this, we have to add another key sector in the empires' economy that is long-distance trade. Though regions of the Near East have long been interconnected via trade routes, the scope and intensity of long-distance trade networks peaked during the AoE, reaching unprecedented levels. Following the expansion of trade routes that had started with the Neo-Assyrian Empire, by the Parthian period, all of Eurasia, from the Mediterranean shores to South Arabia, India and China, was interconnected via numerous trade routes that generally go under the names of the Silk Road, Incense Road and Indian Ocean route (Benjamin 2018). Such an extended trade network could generate much wealth from which the Near Eastern empires here concerned could benefit via tax extraction. This long-distance trade network was also an opportunity for private individuals (such as merchants) to accumulate wealth (Frye 1992).

As this study has focused on private houses, our results point to the existence of groups of private individuals or even households who could more easily accumulate wealth under empires, so that disparity in wealth had the possibility of increasing during the AoE. We note that during the AoE, and not unlike the pre-AoE, much of material wealth was generated and managed by state administration and temples. The latter still retained their economic power during most of the AoE, as temples owned lands and managed various aspects of the economy (Aperghis 2004; Van Der Spek 2007). We suggest, on the basis of our results, that wealth disparity became more prominent under empires, with these results evident among private houses. The mechanisms behind this observed phenomenon are complex. Certainly, some individuals working for temples or government institutions could have lived in private houses and, therefore, accumulate more wealth through their affiliation to wealth-generating institutions. In addition to this, private initiative in the economy of empires may have also helped drive greater overall wealth inequality. Although the evidence is not consistent for all the AoE and regions, in Southern Mesopotamia, private family-run businesses are known to have been involved in a wide range of economic activities (Jursa 2010). From sixth century BCE Babylonia, we also have information about private families of Judean background who were involved in tax collection on behalf of the state (as this was partially privatised) and other private economic activities (Pearce and Wunsch 2014). The incorporation of private initiative in the economy is not a novelty of the AoE, and the extent to which this initiative was able to affect the empires' economy as a whole is debatable (Jursa 2010). To interpret our results, we suggest that some private individuals and families in the AoE had greater opportunity to generate a level of wealth that would enable overall wealth disparity to increase. The latter, along with those above, is a tentative suggestion for understanding our results, as other strands of evidence, systematically measured, would be needed to clearly demonstrate what different factors could have affected the wealth inequality observed.

Limitations and future developments

The unevenness of data represents a limit of the present study, as houses are far better represented in the pre-AoE than in the AoE for various reasons. Though we tried to mitigate this issue using statistical methods, it is still important to bear in mind that our AoE dataset reflects a smaller portion of the sample population than the pre-AoE. We have used the size of private houses as a proxy for accumulated wealth, which has some justification in the previous literature, but house size is only one dimension in which wealth can be expressed. It is possible other wealth proxies could better demonstrate an urban size relationship; we note that our results are more similar to urban infrastructure measures rather than wealth proxies used in modern cities. Future studies could combine other sets of data that may cast light on other dimensions of wealth, such as burial goods and household objects. Although the use of various datasets poses comparability problems, it is still worth observing how different archaeological wealth markers distribute in the AoE compared to the pre-AoE, and what that may show regarding wealth inequality trends. Another further development would be to compare our results with other trends for the periods concerned in this paper, especially the AoE. Future studies may compare wealth distribution trends based on house size as in this paper with, for instance, demographic trends, population movement or price variations for goods. More study is needed that, combining different lines of evidence, may cast light on how Near Eastern empires affected societies structurally, in either planned or unplanned ways, and how the economic change they promoted led to the inequality trends observed. Finally, obtaining more regional and varied temporal data could allow for a more nuanced spatio-temporal understanding of inequality trends.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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