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Agricultural Production and Stability of Settlement Systems In Upper Mesopotamia during the Early Bronze Age (Third Millennium BCE)

Tuna Kalayci
University of Arkansas, Fayetteville

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AGRICULTURAL PRODUCTION AND STABILITY OF SETTLEMENT SYSTEMS IN UPPER MESOPOTAMIA DURING THE EARLY BRONZE AGE (THIRD MILLENNIUM BCE)

AGRICULTURAL PRODUCTION AND STABILITY OF SETTLEMENT SYSTEMS IN UPPER MESOPOTAMIA DURING THE EARLY BRONZE AGE (THIRD MILLENNIUM BCE)

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Anthropology

By

Tuna Kalaycı
Middle East Technical University
Bachelor of Science in Statistics, 2003
Middle East Technical University
Master of Science in Settlement Archaeology, 2006

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University of Arkansas

ABSTRACT

This study investigates the relationship between rainfall variation and rain-fed agricultural production in Upper Mesopotamia with a specific focus on Early Bronze Age urban settlements. In return, the variation in production is used to explore stability of urban settlement systems. The organization of the flow of agricultural goods is the key to sustaining the total settlement system.

The vulnerability of a settlement system increases due to the increased demand for more output from agricultural lands. This demand is the key for the success of urbanization project. However, without estimating how many foodstuffs were available at the end of a production cycle, further discussions on the forces that shaped and sustained urban settlement systems will be lacking. While large scale fluctuations in the flow of agricultural products between settlements are not the only determinants of hierarchical structures, the total available agricultural yield for each urban settlement in a hierarchy must have influenced settlement relations.

As for the methodology, first, Early Bronze Age precipitation levels are estimated by using modern day associations between the eastern Mediterranean coastal areas and the inner regions of Upper Mesopotamia. Next, these levels are integrated into a remote-sensing based biological growth model. Also, a CORONA satellite imagery based archaeological survey is conducted in order to map the Early Bronze Age settlement system in its entirety as well as the ancient markers of agricultural intensification. Finally, ancient agricultural production landscapes are modeled in a GIS.

The study takes a critical position towards the traditionally held assumption that large urban settlements (cities) in Upper Mesopotamia were in a state of constant demand for food. The results from this study also suggest that when variations in ancient precipitation levels are translated into the variations in production levels, the impact of climatic aridification on ancient settlement systems becomes less visible in the archaeological record.

This dissertation is approved for recommendation
to the Graduate Council.

Dissertation Director:

Dr. Jesse Casana

Dissertation Committee:

Dr. Jackson Cothren

Dr. Fredrick Limp

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CHAPTER 1: Introduction

The temporal and spatial variability of precipitation levels accounts for large production fluctuations in rain-fed agricultural systems (Wang et al. 2008). Under ever-changing climatic conditions, agricultural production requires risk minimization (Marston 2011), which also implies settling for lower, but more stable agricultural yields (Phillips, Cane, and Rosenzweig 1998). However, when the need for stability is accompanied by the need for high yields, the total vulnerability of a productive system becomes more pronounced.

The need for socio-political and economic stability immediately increases during times of social change (Inglehart 1997; Kay and Friesen 2011). A form of stability may eventually emerge if the system stagnates or if it creates new norms and conditions for the new social order. Changes in norms and conditions can be observed in every aspect of everyday life, including the production of commodities, labor relations, and gender roles (J. McCorriston 1997). Ancient urbanism, as an example of a social change, not only puts pressure on production by demanding more staples from the hinterland to feed emerging urban populations, but also rearranges the conditions of socially necessary agricultural labor time. Within this framework, the path to urbanism might concurrently undermine the success and sustainability of incipient urban projects.

This dissertation investigates the relationship between rainfall variation and rain-fed agricultural production in Upper Mesopotamia with a specific focus on Early Bronze Age urban settlements. In return, the variation in production is used to explore stability of urban settlement systems. Briefly, if production variation among settlements can be estimated, then resulting fluctuations in the flow of goods between communities can be further examined in an urban system. In this framework, the organization of the flow of goods is the key to sustaining the total settlement system.

1.1. Statement of the Problem

Archaeologists consider settlement patterns as physical manifestations of social, political, and economic practices of a society. In this respect, archaeological settlement patterns provide a research arena to understand how ancient societies were organized in various parts of the world (Willey 1953; Adams 1981; Church and Bell 1988; Kenoyer 1991; Underhill et al. 2008). Scholars also analyze settlement patterns with mathematical and statistical tools (Johnson 1980; Pearson 1980; Lewis and Patil 2003; Drennan and Peterson 2004). The results of quantitative analyses are usually employed to construct models —e.g., Central Place Theory (Crumley 1976), or rank-size distributions (Drennan and Peterson 2004) —with the purpose of understanding the structure of settlement patterns as well as their spatial variations.

Settlement ranking is a basic tool for studying the organization and variation of settlements within a system. Rankings are typically constructed by using settlement sizes, then rearranging these sizes on a predefined hierarchical scale. A hierarchical ranking arrangement in a settlement pattern indicates a settlement hierarchy (e.g., Wilkinson and Tucker 1995). Furthermore, a common postulate in settlement studies is that complex hierarchical patterns signify complex set of relations between settlements, and thus, the society which produces these relations is complex (Albarracin-Jordan 1996; Bauer and Covey 2002; Stein 2004).

Concurrently, in archaeological theory a complex society refers to a social organization with hierarchical relations (Yoffee 1995; Stanish 2003) analogous to hierarchical settlement patterns. In such a society, relations may have been constructed by a king-like figure with absolute power, where this power is shared between lesser offices for operational purposes. As another possibility, these relations may have been loosely formed between socio-political entities (such as households) where their shared power was used to organize everyday life.

Regardless of the level of rigidity in a hierarchy, some systems can only function when there is a socio-political arrangement securing the movement of agricultural yields in order to support administrative operations (Earle 1997, 71). Within this schema, the administrative apparatus is located at the top of a settlement hierarchy and foodstuffs are provided by the settlements at lower tiers, if and when necessary. Therefore, keeping the settlement system intact depends on the successful flow of excess production from outer settlements to central settlements as these central places are the most dependent to a secure and stable flow. For political regimes of ancient Mesopotamia, Adams (1981, 133) suggests, this was in part an effort to keep stability of the overall system. Nevertheless, flux was the prevailing outcome (*ibid.*)

Flux is the most susceptible to fluctuations when social, political and economic hierarchies reach a point where internal and external organizations of a society depend on a complex balance among settlements. Urbanization, a social process must have increased complexity of Early Bronze Age society, reformulates food production in such a way that the relationship between production and consumption become more responsive to internal and external variations. This discussion makes two critical assumptions concerning urbanization. First, it is assumed that urbanization detaches some portions of the population from traditional agricultural production. Second, an urban system requires high and stable production sources in order to arrange its complex relations. In complex systems, correct decision making requires predictability, and predictability is possible after stability. However, increased production accompanied with the need of stability comes at the expense of increased vulnerability.

In this generic urbanization model, the vulnerability of a settlement system increases due to the increased demand for more output from agricultural lands. This demand is the key for the success of urbanization project. However, without estimating how many foodstuffs were available at the end of a production cycle, further discussions on the forces that shaped and sustained urban settlement systems will be lacking. While large scale fluctuations in the flow of agricultural products between settlements are not the only determinants of hierarchical structures, the total available agricultural yield for each urban settlement in a hierarchy must have influenced settlement relations.

Documenting production capacities and estimating the flow of goods is not sufficient to fully understand the processes which create settlement patterns since these processes are also affected by production relations of any form as well as ideological and hegemonic practices in a society. Furthermore, production in and of itself, is only one, but a major element of the many aspects of socio-political complexity. Pastoralism (e.g., Zeder 1998) as well as regional exchange (e.g., Stein 1999) must also have been always been a part of ancient complex economies in Upper Mesopotamia. However, certain considerations make integrating non-agricultural components into the production schema a complex task. First, the material culture of a pastoral economy is less visible in ancient contexts. Likewise, the exchange of material goods is not always documented by literary and archaeological evidence. Second, a holistic approach towards ancient economies gets significantly more challenging as more economic components are integrated into the study. Acknowledging this complexity, this dissertation is based on the foundational importance of cereal cultivation as an essential staple for subsistence and the basis of the productive economy.

The Early Bronze Age in Upper Mesopotamia is selected to study the effect of agricultural production stability on the ability to sustain an urban settlement system for two main reasons. First, the lack of prominent topographical features and minimal geological constraints in the area provide a better control over environmental factors which might have affected the development of urbanization. The friction of movement in the flow of goods was not compensated by the use of other technologies, such as the case in irrigated plains of southern Mesopotamia (Adams 1981). Therefore, political relations between settlements must have been the most significant determinant in the flow of goods as bulk agricultural transportation was difficult from far settlements when local relations were under stress. The differential growth of settlements was not contingent on being in an environmentally advantageous position, although as this dissertation argues that differences in local productivity must have altered settlement relations in favor of certain Early Bronze Age settlements. Secondly, the relatively homogenous topography in this region and the morphology of Early Bronze Age settlements makes it possible to conduct a nearly complete remote sensing based archaeological survey of the area (Wilkinson 2000). This approach generates a close-to-complete settlement inventory of the study area. Such an inventory is crucial for understanding the flow of excessive agricultural production between settlements since modeling this flow requires a closed system where any possible input from outside of the system would distort the internal conditions. Bounding the Early Bronze Age settlement system eliminates potential agricultural flow from external areas. Also, this dissertation has the agenda to critically evaluate the theories of abandonment/collapse in the late third millennium BCE (e.g., Weiss et al. 1993). While doing so, the intention is to explore sustainability of traditional rain-fed agricultural systems in semi-arid regions of the world during the times of climatic stress. It is the hope that insights of this work will contribute to the discussions on modern day society and environment relations.

1.2. Outline of the Study

The dissertation is composed of 9 chapters. Chapter 2 is an introduction to Upper Mesopotamian geography and mid-to-late Early Bronze Age archaeology. Chapter 3 investigates urbanization as a socio-historical phenomenon, with a focus on urban-rural relations as well as the stability of urban settlement systems in relation to the Upper Mesopotamian urban landscape. This chapter also lays the groundwork for the archaeological model, used in this dissertation. Chapter 4 further investigates the stability of urban systems by concentrating on the incentives and processes behind agricultural intensification. Intensification during the urbanization phase is studied by using archaeological markers of urban Upper Mesopotamia. Chapter 5 discusses the relations between precipitation regimes and agricultural production. By using modern day associations between the eastern Mediterranean coastal areas and the inner regions of Upper Mesopotamia, Early Bronze Age precipitation levels are estimated. Next, these levels are integrated into a remote-sensing based biological growth model. Chapter 6 documents Early Bronze Age settlement pattern and off-site archaeological features, including ancient routeways using CORONA satellite imagery. As a result of this process, a near-complete inventory of Early Bronze Age settlements is provided. In Chapter 7, the settlement pattern is analyzed in order to approximate the largest settlement system boundary. Also in this chapter, the extents of agricultural production are modeled using documented off-site features. Chapter 8 is dedicated to calculating gross agricultural output per settlement in the study area. By using these calculations, the stability of Early Bronze Age settlement systems is investigated throughout the urbanization phase until its terminal stages. Chapter 9 summarizes the results of this dissertation, reiterates limitations of conducted research, and discusses future work.

CHAPTER 2: Upper Mesopotamia: Geography and Archaeology

2.1. Study Area

Recent decades have witnessed an increased focus of archaeological research in Upper Mesopotamia. Due in part to political conditions in Iran and Iraq as well as to the construction of massive scale structures such as Tabqa and Tishrin Dams in northern Syria and Ataturk Dam in southern Turkey, research has shifted geographically from southern to northern Mesopotamia providing an increase in archaeological knowledge of the region (e.g., Freedman 1979; Algaze 1989). However, current political upheavals in the Middle East will probably change this course once again. In modern day Syria, which comprises a substantial portion of Upper Mesopotamia, archaeological work might slow down or even stop while new research possibilities emerge in the Iraqi Kurdistan. Currently, archaeological work is moving towards the Tigris River. The consequences of this change are yet to be observed.

Upper Mesopotamia has been investigated via archaeological surveys (e.g., Davidson and McKerrell 1976; Monchambert 1983; Meijer 1986; Stein and Wattenmaker 1990; Wilkinson and Tucker 1995; Eidem and Warburton 1996; Lyonnet 1996; Ur 2002). These surveys provide information about the size and extents of settlements as well as the chronology, albeit with somewhat coarse temporal resolution. Cuneiform texts expand understanding of the formation of settlement relations, as the case in Tell Beydar (Sallaberger and Ur 2004). Land use studies (e.g., Ur 2003) offer new grounds for both reconstructing economic systems and determining how they might have affected settlement patterns. Excavations in the area produce archeological information about how settlement relations might have been structured (e.g., Curvers and Schwartz 1990). These scholarly endeavors in the area create a unique setting and make Upper

Mesopotamia suitable for conducting regional studies at multiple scales, ranging from local to regional landscapes.

2.1.1. Geography

Upper Mesopotamia is the area between the banks of the Tigris River in the east and the Euphrates River in the west. Further to the west, semi-arid conditions stand between the study area and the Mediterranean-type climate conditions. To the north, the area is bounded by high altitude Taurus-Zagros Mountains. To the south, the desert conditions forms an impermeable boundary where precipitation levels critically drop under 200-300mm/year. The elevation in this region varies between 300 and 450 meters above sea level, and the plate slopes down, towards the east (Figure. 2.1).

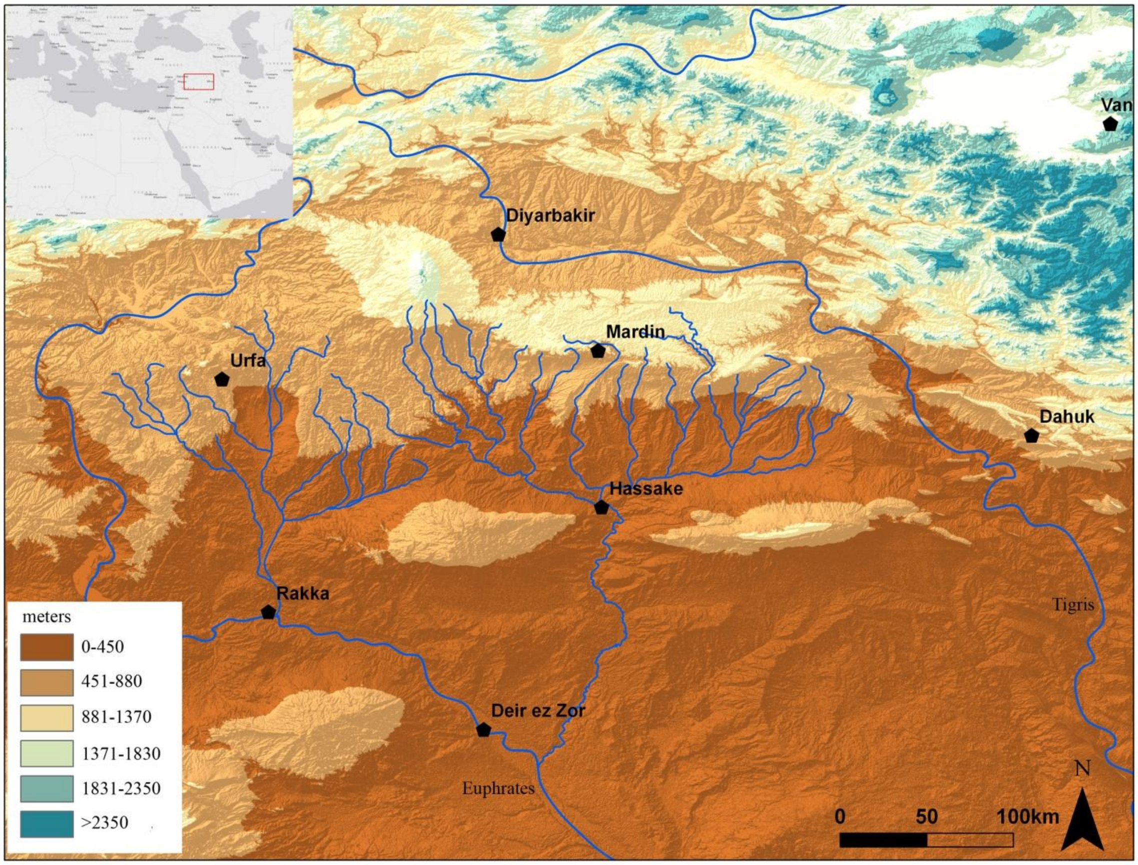

Figure 2.1. Upper Mesopotamia spans the area between Tigris and Euphrates Rivers

River systems dissect the flat landscape of Upper Mesopotamia. In the north, rivers cut the land deeply due to high gradient, and create narrow floodplains. Further to the south the river system loses its energy, forms wide alluvial deposits, and creates the signature southern Mesopotamian landscapes (Adams 1981). The tributaries of these rivers also contribute to sedimentation. While the sedimentation rate has varied throughout the Holocene, this rate was especially high at the end of the Early Bronze Age (Courty 1994).

Rivers also form large basins in Upper Mesopotamia. Among these, Khabur and Balikh Basins are the most prominent. The Khabur River is mainly fed by the karstic springs of Ras al-Ain ($40m^3$/sec) while Balikh River gets most of its water from the spring at Ain al-Arus ($6m^3$/sec) (Llamas and Custodio 2003, 361). Tributaries of these rivers also fill various wadis seasonally, creating zones of habitation in the semi-arid region. Other major wadis are fed by springs located in the foothills of Tur-Abidin and elsewhere in the basaltic landscape. Other than large ancient settlement mounds and two major anticlines, called Jebel Sinjar (920 meters) and Jebel Abd al-Aziz (1480 meters) (Brew, Litak, and Barazangi 1999), there are no significantly obtrusive features in the physical landscape. Basaltic plateaus in the area (Ur and Wilkinson 2008) are only slight modifications in the gentle geomorphology.

2.1.2. Climate

Modern-day Upper Mesopotamia is under the influence of continental climate. Summers are dry and hot, and winters are cool and wet. Local implications of this climate regime, however, are complex due to the geographical setting of the area. This is especially true for the precipitation levels. Average rainfall ranges from 100 mm to 600 mm per year; heavier precipitation in the areas closer to the northern mountain ranges and lower towards steppe and desert conditions.

Rainfall decreases from west to east due to north-south running Mediterranean mountains which create rain shadows for the inner sections of Upper Mesopotamia. A similar orographic effect is due to east-west running Taurus Mountains. Precipitation trends in Upper Mesopotamia are paralleled in the Mediterranean coastal areas as well as different parts of Upper Mesopotamia itself. For example, low rainfall in one part of Upper Mesopotamia indicates low rainfall in another area, and vice versa (Wilkinson 1994, 501; Wilkinson 2004, 1:44). The precipitation regime also indicates that dry and wet years usually occur in consecutive years, creating temporal clusters of aridification or amelioration. However, isohyets still shift during these clusters, creating a dynamic hydrological and agricultural production setting (Wirth 1971).

Precipitation in Upper Mesopotamia and around its proper is under the influence of the middle latitude westerlies (de Brichambaut and Wallen 1963). The main precipitation falls between October-November and April-June. This is due to due to moving cyclones which are formed either in the Atlantic or the Mediterranean. During March and April another climatic system is in effect, called the khamsin type. This is of northern Saharan origin, and after crossing North Africa, the system enters the region from the south, and provide some precipitation (*ibid.*).

2.1.3. Vegetation

Sub-Mediterranean trees, shrubs, and arboreal species are located close to Taurids, while vegetation on the southern steppes is characterized by Irano-Turanian sub-continental low scrubs (McCorriston and Weisberg 2002). However, vegetation in the area has been heavily impacted by human occupation over many millennia. With these considerations, Moore et al. (2000) reconstruct the potential vegetation of the region, providing a better historic representation of the climate. According to their reconstruction, forests are located along the northern mountain ranges and along the Mediterranean. In the south, the zone including the heart of the Khabur Basin is characterized by open woodlands. As the climate gets drier to the south, woodland steppe, medium-dry steppe and desert-steppe take over the landscape. In this north-south alignment of vegetation zones, wadis break the monotony of land cover by providing a more humid micro-climate during consecutive arid years so that drought intolerant vegetation can survive in small packets. However, modern day 200-300mm isohyet is the marker for the combination of true steppe and eventually desert conditions further to the south (Figure 2.2.).

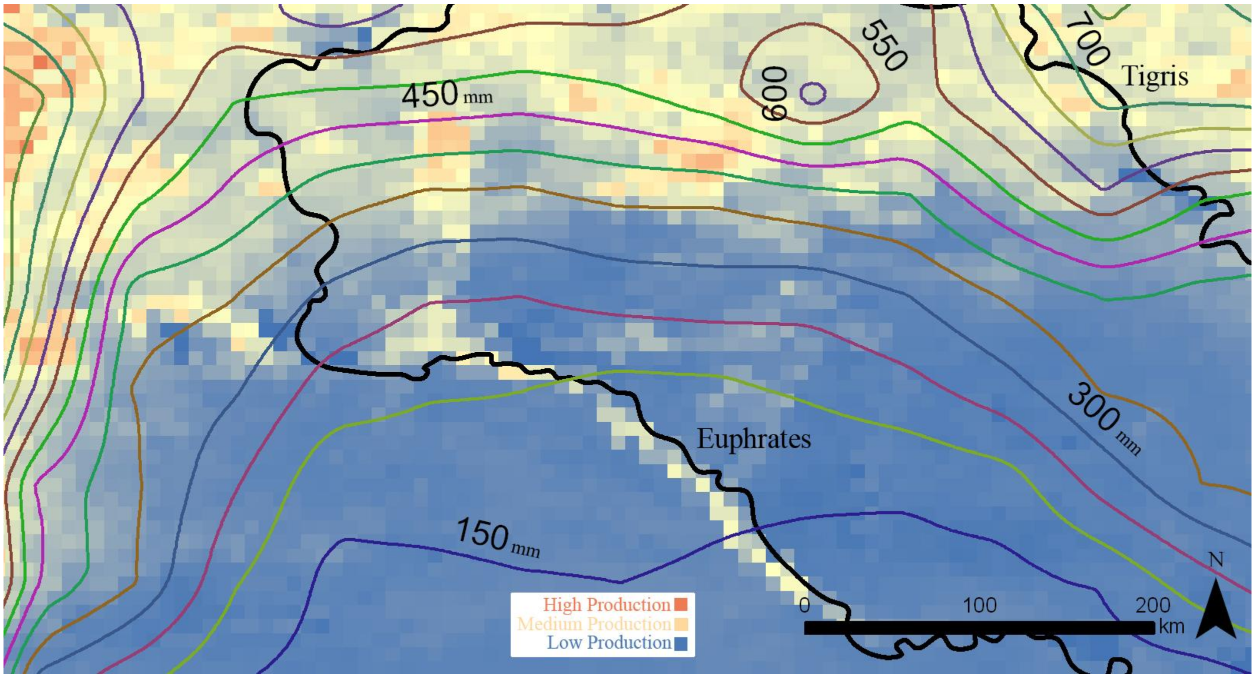

Figure 2.2. Spatial distribution of production areas with different productivity levels (NDVI data)

A similar geographic division is also observed in soil types. The northern section of Upper Mesopotamia is characterized by calcareous soils, whereas the soil to the south is gypsiferous which corresponds to a different agricultural potential. More to the northeast, reddish-brown loams dominate. In relation to climate and soil cover, Wilkinson (1997, 72) divides the area into five agro-ecological zones. In the north, the production of staples is possible as well as the growth of vineyards. To the south, due to the decrease in precipitation levels, drought resistant crops are preferred with an apparent increase in pastoral economy. The boundaries of these agro-ecological zones tend to correspond to precipitation levels as documented in this study. This is a significant observation since it highlights the importance of precipitation in the levels of production at different agro-ecological zones. Without such connection, translation of ancient precipitation levels into actual estimations of production levels would not be possible.

2.1.4. Past Climate

Scholars of Upper Mesopotamia use climate proxy records at various resolutions to reconstruct the paleoclimate of the region. These records include pollens and lake sediments (e.g., Bottema 1997; Wick, Lemcke, and Sturm 2003), sediments from the Red Sea (Arz, Lamy, and Patzold 2006), variations in Dead Sea levels (Enzel et al. 2003), marine-cores (e.g., Rossignol-Strick 1999), isotope composition of speleothems (Bar-Matthews, Ayalon, and Kaufman 1997), stream discharge (Cullen and deMenocal 2000), pedogenic carbonate coatings (Pustovoytov, Schmidt, and Taubald 2007). Geoarchaeological investigations also contribute to these reconstructions, and in some cases provide a measure of chronological control (e.g., Rosen 1997). These proxy data are synthesized in various studies (e.g., Wilkinson 1999; Casana 2008; Wossink 2009; Riehl and Deckers 2012).

For Upper Mesopotamia, speleothem records from Soreq Cave suggest slightly wet conditions from ca.2600 BCE onwards. Following this phase, there was the increased aridity by the end of the third millennium BCE (Bar-Matthews, Ayalon, and Kaufman 1997). The climate stabilized by ca.1800 BCE, though remained arid. Lake Van proxy data suggest optimum climatic conditions up until ca.2500 BCE, and drier conditions between ca.2500 BCE and ca.2200 BCE. Around ca.2100 BCE there is a reversal towards wetter conditions, but this was short lived and more arid conditions prevailed, lasting for several centuries (Lemcke and Sturm 1997). Investigations on the carbon-coatings of stones at Gobekli Tepe suggest high humidity and high temperatures for between ca. 4000 BCE and 2000 BCE. After 2000 BCE, lower humidity is detected (Pustovoytov, Schmidt, and Taubald 2007). Courty (1994) identifies several climatic phases in the history of Khabur Basin. Related to the Early Bronze Age of Upper Mesopotamia, phase 4 (ca. 3800-2250 BCE) was characterized with irregular water flow in contrast to more stable conditions in earlier phases. Phase 5 (ca. 2250-1850 BCE) indicates further deterioration in climatic conditions. In their geomorphological investigations on the Wadi Jaghjagh and Wasi Khanzir of Khabur Basin, Deckers and Riehl (2008) show favorable conditions conducive to woodland vegetation until ca. 2500 BCE. After ca.2500 BCE water flow in the wadis drop as conditions become more arid. One influential study, the Leilan Climate Change Model is based on a synthesis of archaeological and geomorphological data from Tell Leilan and Abu Hgeria (Weiss et al. 1993). In this model, during stage 3 (ca. 2300-2200 BCE) there is a significant trend towards arid conditions, and stage 4 represents a hiatus in the archaeological record, while this hiatus is considered to be an indication of an inhospitable environment.

In their summary of the Upper Mesopotamian palaeoclimate, Riehl and Deckers (2012) eloquently explains the conditions of human-environment interactions. They observe a trend towards arid conditions 4000BP and onwards. Due to this trend, southern fringes of Upper Mesopotamia became more inhospitable, and thus, differences in the river systems of Khabur and Euphrates Rivers became a more determinant factor in the changes of agricultural technology. In this paleoenvironmental timeline, “the 4200 ka event”, attracted most of the attention (e.g., Tao et al. 2004; Booth et al. 2005; Arz, Lamy, and Patzold 2006).

For the second half of the third millennium, a hypothesis suggests rapid increase in aridity in Upper Mesopotamia and elsewhere at approximately 2200 BCE (Weiss et al. 1993). This hypothesis, if it is true, has significant implications for the intensification of agricultural production. Usually called as the 4.2 ka event, the hypothesis claims climatic aridity was synchronous with the changes among Early Bronze Age societies. These changes were towards the "collapse of the politico-economic superstructures dependent upon cereal culture" (Staubwasser and Weiss 2006, 372). Weiss et al. (1993) initially proposed a volcanic eruption as the causal mechanism of this aridity. In a follow up study, this was refuted (Courty and Weiss 1997). Later on, Courty (1998) suggested meteor impact related aridity, but other discussions also raise an issue for the limited potential of this impact in creating extreme arid condition in wide areas (Courty 1999). Finally, Staubwasser and Weiss (2006) suggests changes in atmospheric circulation patterns as the prime cause of aridification.

4.2. ka event has also been proposed and studied globally. Discussions on 4.2 ka aridity include examples from Iran (Stevens et al. 2006), North America (Booth et al. 2005), China (Huang et al. 2011), Spain (Jimenez-Moreno and Anderson 2012), Africa (Gasse 2000), and Indus Valley (Staubwasser et al. 2003). There is, however, no complete agreement on the paleoenvironmental records for the proposed aridity at around 4.2 kBP (Staubwasser and Weiss 2006; Kaniewski, Van Campo, and Weiss 2012). For instance, proxy records from the Late Mirabad, Iran, suggest no evident drought at around 4.2kBP (Stevens et al. 2006). Similarly, in Spain Jimenez-Moreno and Anderson (2012) pushes the aridity event to 4.0kBP.

Even though most paleoenvironmental data suggest some trend towards aridity, the data are still too coarse for making certain arguments. Furthermore, when available, data also suggest disagreement on the temporal range and magnitude of this aridity. It is yet to be proven when exactly the rapid climatic aridity peaked between 4.2kBP and 4.0kBP. This two centuries range puts climate change induced collapse theories under critical spotlight. Finally, data sources are sparse, and extrapolations based on these sources only provide tentative studies. For instance, climate records from the Qunf Cave, Oman provide inconclusive evidence to isolate 4.2kBP event from the long term aridity trend (Fleitmann et al. 2003). Therefore, even if an arid phase at around 4.2kBP had occurred in Upper Mesopotamia, the intensity of this aridity is yet to be determined in an accurate model. The complexity of climate and the lack of robust data adversely affect environmental reconstructions in the region (Riehl and Deckers 2012).

Nevertheless, following Riehl and Deckers (2012) a brief synthesis can be provided for the sake of providing an overall picture. Climate data for the third millennium suggest progressively drier conditions starting in the middle-Early Bronze Age (ca. 2500 BCE) and extending well into the Middle Bronze Age (ca. 2000-1500 BCE). Specifically, the period between ~2600-2200 BCE was still relatively wet, but ~2200-1800 BCE is marked by a trend towards aridity. At the global scale, sea cores from the North Atlantic show two cold periods around 2600 BCE and ~2200-2050 BCE (Kuzucuoglu 2007b, 463). These cold periods are well correlated with aridity in lower altitudes, generally supporting Middle Eastern climate proxy data.

This synthesis, however, global in character and it is far from providing details for the local conditions of the environment. In this constantly shifting climatic setting, local variations must have been influential on the dynamics of agricultural production. Even though regional reconstructions provide invaluable information for the physical background of production, long term trends observed in these generalizations obscure details at local levels, impairing the ability to investigate production at the level of single settlements.

Differences in precipitation regimes, both in east-west and north south gradients, must have created variations in rain-fed agricultural production. Considering that low and high precipitation levels cluster together temporally, the effect of dry seasons on agricultural production may have been drastic. The ways in which societies were able to buffer against these low precipitation years, even consecutive drought seasons, must have been reflected in their production economies. This especially becomes evident when crop assemblages are investigated in different areas of Upper Mesopotamia (Riehl 2012, 117). However, it is important to note that vegetation also depends on local soil and hydro-geological conditions (e.g., Moore, Hillman, and Legge 2000).

2.2. Archaeology: Upper Mesopotamian Urbanism during mid-to-late Early Bronze Age

Agricultural intensification in Upper Mesopotamia during the mid-to-late Early Bronze Age happened along with other complex developments, many of which might have influenced agricultural decision makers towards intensification. In this section, the aim is to explore such developments in their archaeological trajectories. First, urbanization in the area is discussed as the most likely driver of agricultural intensification. Large urban centers in Upper Mesopotamia had their roles in the mid-to-late Early Bronze Age political landscape. These roles must have left their imprints on agricultural production landscapes as well. The Akkadian presence in Upper Mesopotamia is visible, following the initial urbanization phase. As an imperial power, Akkad might have had strong pressure on production landscapes, but the validity of this argument depends on the character of the relationship between the Akkadian and already established political life (McMahon 2012). By the end of the third millennium BCE, the urban system experienced a rapid transition towards less urban conditions. Some settlements were abandoned, and some reduced in size. Understanding the relationship between urban dissolution and agricultural intensification may provide clues on the nature of this dissolution, which also culturally marks the end of Early Bronze Age.

2.2.1. Early Bronze Age Urbanization

The earliest accounts of urbanism in Upper Mesopotamia come from Tell Brak (J. Oates et al. 2007). Monumental architecture, industrial workshops and prestige goods from fifth and fourth millennium levels suggest the site was already becoming an urban settlement (*ibid.*:586). Ur (2010, 400) suggests northern urbanism may even predate developments in the south. Towards the end of the fourth millennium BCE, the Southern Mesopotamian way of life was also urban where large settlements vacuumed up populations from rural areas (Adams and Nissen 1972), and grew as large as 250 hectares in the case of the city Uruk (Nissen and Heine 2009, 23).

A second wave of urbanism in Upper Mesopotamia arrived in the third millennium BCE (Akkermans and Schwartz 2003). Following the end of the Ninevite 5 period (ca. 2600 BCE), settlements in Upper Mesopotamia grew significantly larger, which is regarded as one of the main indications of urbanism (Weiss 1983; Stein and Wattenmaker 1990; Wilkinson 1994; McClellan 1999; Schwartz et al. 2000; Algaze et al. 2001; Cooper 2006; Castel and Peltenburg 2007). Changes in the structure of settlement patterns (Stein and Wattenmaker 1990; Wilkinson 1994; Matney and Algaze 1995; Wilkinson and Tucker 1995; Lebeau 1997; Emberling et al. 1999; Schwartz et al. 2000; Ur 2002), construction of monumental architecture, displays of status and other developments in economic and political organization of settlements also changed the daily life in Upper Mesopotamia (Akkermans and Schwartz 2003, 233; Stein 2004; Cooper 2010; Ur 2010a).

By the second half of the third millennium, some settlements concurrently grew significantly larger in size, but most in and around the Khabur Basin. When compared with the first half of the same millennium, settlement sizes increased several fold. Tell Leilan grew from 15 hectares to 90-100 hectares (Weiss 1983). Tell Mohammed Diab, a contemporary neighboring settlement of Tell Leilan reached to 43 hectares (Stein and Wattenmaker 2003, 361). Tell Brak was as big as 65 hectares (Emberling et al. 1999). Hamoukar, a prominent mounded site in eastern Upper Mesopotamia, extended as much as 105 hectares (Ur 2002). In the Iraqi Jazira, Taya, and Tell al-Hawa were ca. 60 hectares each (Wilkinson 1994).

This phenomenon is not a localized development; urban expansion is observed throughout the Fertile Crescent during the Early Bronze Age. Across the region, Titriş Höyük (Algaze et al. 2001), Tell es-Sweyhat (Wilkinson 1994), and Umm el-Marra (Schwartz et al. 2000) witness expansion to considerable sizes (Figure 2.3).

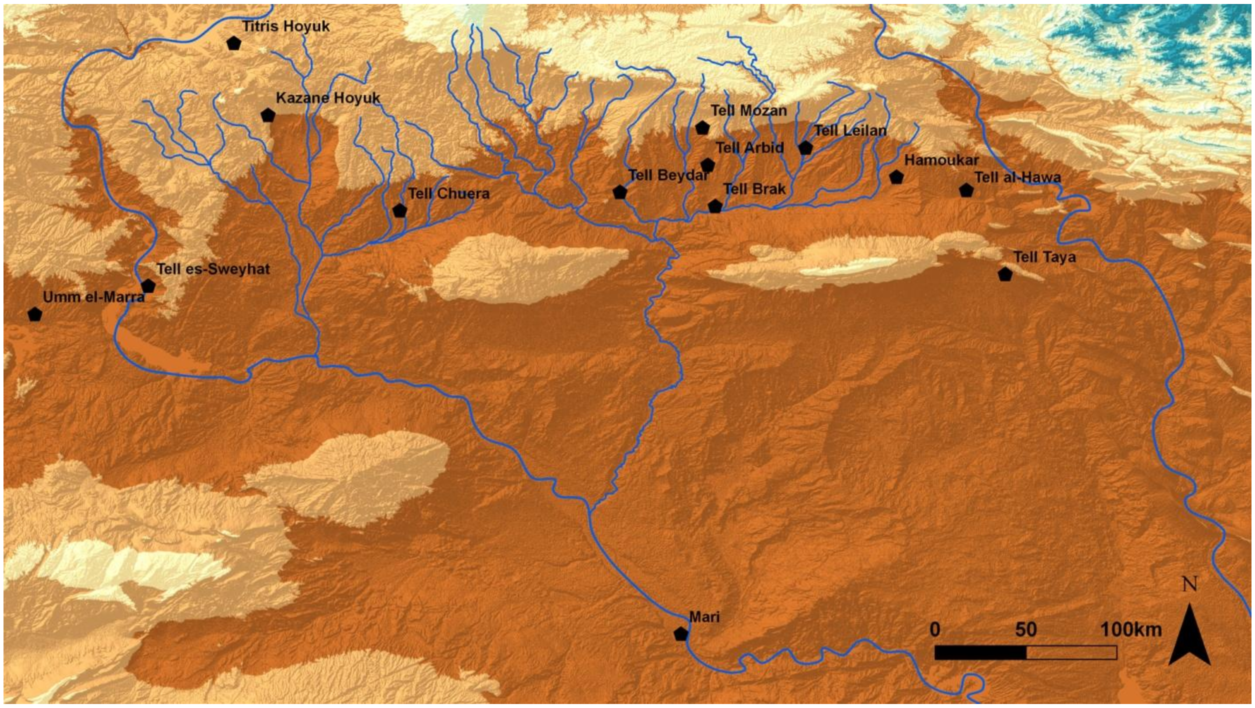

Figure 2.3. Large Early Bronze Age centers during the third millennium BCE

An increase in the number of settlements as well as their differential growth produced a distinctive settlement pattern. The relatively homogenous settlement pattern of the first half of the third millennium obtained a hierarchical form at the peak of this urban phase (Wilkinson 1994, 487).

While these developments were transforming the Upper Mesopotamian landscape, settlements were also obtaining new forms and layouts. Urbanism must have introduced a new structure of the organization of space. This reorganization was due to the socio-urban conditions that generated, utilized, and segregated these spaces. Closely spaced architectural structures around the existing settlement mounds created a new style of habitation. These lower town sections were compact and separated by streets. Kurban Höyük, located in the north of Balikh Basin, may represent this general layout of urban agglomeration (Creekmore 2010). Geophysical data collected from this settlement suggests neighborhoods and other urban elements in the lower town, and these neighborhoods further indicate multiple elite or administrative areas (*ibid.*). In another case, there is evidence not only for lower, but also for an outer town. At Titriş Höyük an outer town grew rapidly, making the settlement reach its largest extent in its occupational history (Wilkinson 1994, 486). In contrast to the more domestic lower and outer towns, the high mound was a place for monumental architecture most likely indicative of a supreme elite (or the head of the royal household). These monumental structures are usually interpreted as palaces or temples. Palaces were made out of thick walls, with an inner structure sometimes arranged around a courtyard (Ur 2010a, 40). The layout of the temples (or divine households) however, was variable across Upper Mesopotamia.

2.2.1.1. Major Players of the Political Landscape

The political landscape is shaped by active central powers (Sallaberger 2007; Cooper 2010). However, conflict between settlements is also visible at the local scale (Algaze et al. 2001, 68). These urban centers must have controlled and influenced geographical areas in different forms while at the same time competing and cooperating with each other in multiple domains. A brief introduction to some of these powerful urban centers is necessary to understand the political landscape of the region.

Even though it is located beyond the study area, west of the Euphrates River, Ebla (Tell Mardikh) provides enough archaeological evidence to examine the political structure at the core of Upper Mesopotamia. Specifically, Ebla Tablets, dated to a period between 2500BCE to 2250BCE, are used to formulate the dense network of relations between Ebla and other settlements in and around Upper Mesopotamia. These relations include direct control (e.g., Carchemish), loose connection (e.g., Tell Sweyhat), or economic competition even in militaristic forms at times (e.g., Mari). Textual evidence suggests that Ebla increased its inter-regional influence by 2400 BCE. Texts also indicate the existence of tribal confederations between their medium-sized urban settlements located in marginal lands (Bonechi 1993, 186). In terms of its management, Akkermans and Schwartz (2003, 239) propose the concurrence of kin-based and class-based power relations structuring political life (though the effect of the nature of Ebla’s management in its relation with other regional centers in Upper Mesopotamia has yet to be established).

Tell Brak, perhaps the most influential settlement in Upper Mesopotamia, was the urban capital (Ur, Karsgaard, and Oates 2011, 10). Its size was large enough to make it the most prominent settlement in the Khabur Basin. Palace G at Ebla archives provide details of the relations between Ebla and Brak (D. Oates and Oates 2001a). Evidence for the exchange of luxury goods and animals, visits by the city representatives from each side (Archi 1998), as well as some military conflict (Eidem, Finkel, and Bonechi 2001) indicate the eminent role that Tell Brak played in the region.

Evidence from Ebla also shed light on the settlement pattern around Tell Brak. Archi (1998, 7–8) proposes that 17 settlements documented in Ebla archives were all integrated into the Nagar Kingdom. The layout of the pattern as mentioned in texts and documented in archaeological surveys suggests that Tell Beydar was also in this system as a notable settlement. However, one has to consider the bias towards large settlements in ancient texts. Using settlement density calculations suggested by Wilkinson and Tucker (Wilkinson and Tucker 1995) for the Iraqi Jazira, the actual number of settlements in the Kingdom of Nagar is estimated in between 234 and 396 (Ur 2004, 272). This calculation assumes a circular boundary for Brak with a radius between 40 and 50 km which tangents other large settlements in the area such as Tell Leilan and Tell Mozan (*ibid.*).

Tell Leilan (Shubat-Enlil) is another important large urban center in Upper Mesopotamia, located more in north of the region. The settlement expands from 15ha to 100ha in the mid-late third millennium BCE. Dated to this phase, in a large building which includes grain storage area with Southern Mesopotamian style cylinder seals are found on the floor suggesting some connections with the south (Akkermans and Schwartz 2003, 261–262). In addition, texts from Naram-Sin Palace, a later building at Tell Brak, provide information on the number of towns, most likely sub-ordinate to Tell Leilan (Eidem, Finkel, and Bonechi 2001, 106).

In Upper Mesopotamia, Tell Beydar (Nabada) is well-known for its tablets found in the central mound (Ismail et al. 1996). These tablets provide valuable information about livestock (Van Lerberghe 1996), grain accounts (Sallaberger 1996) and land-use characteristics when complimented with survey data (Ur and Wilkinson 2008). Ur (2004) synthesizes archaeological data to propose a reconstruction of the Kingdom of Nagar during the third millennium which fits well with the structure of dry-farming states suggested by Wilkinson (1994).

Finally, current archaeological research in the marginal zones of Syria complicates the problem between settlement location, agricultural intensification and its possible environmental determinants. A large urban settlement, called Al-Rawda, was founded around 2400 BCE with a pre-formulated urban plan. The site is located in a very arid zone immediately suggesting that the urbanization process is a more complex phenomenon than previously anticipated. Even though the site is located far below the dry-farming belt, the site had eventually flourished. The inhabitants must have exploited the wadis which still capture water from the mountains located to the north of Palmyra in order to sustain agricultural practices (Castel and Peltenburg 2007). The deficit in rainfall was most probably eliminated by this water harvesting strategy, or one may call it irrigation, along with the help of a pastoral economy (*ibid.* 611). The location of Al-Rawda might also be explained by wetter climate in the past when the environmental conditions were better than modern day so that current limit of dry-farming belt is misleading. The spatial dynamics of this dry-farming belt is also the subject of this dissertation.

An alternative non-environmental model has also been proposed. Al-Rawda was a *Kranzhügel*, a mound type with a particular morphological structure. *Kranzhügels* are concentric settlements with also another circular inner core. They tend to appear in dry areas of Upper Mesopotamia where rain-fed agricultural productivity are relatively low. Tell Beydar and Tell Chuera are other examples of *Kranzhügels*. Usually high density occupation indicates these characteristic settlements hosted high populations surrounded by defense lines (Castel and

Peltenburg 2007, 605). *Kranzhügel* is an Early Bronze Age phenomenon (Akkermans and Schwartz 2003, 256).

According to Kouchoukos (1998), societies living in *Kranzhügel* were in constant relation with pastoral communities for the purposes of textile production. In their dry geographical settings the integration of pastoral and agricultural economies must have provided the means of life. Low production due to precipitation deficit must have partially compensated by the large amount of manure dropped by flocks to intensify production. This may also indicate a collaboration between sedentary and steppe communities where the mobility between these communities opened up opportunities for the integration of economies (Porter 2012), supplementing agro-production economies. Wilkinson (2005, 11) iterates this model and further suggests that trade routes across the steppe land were also important in the growth of these settlements so that possible intensification process has more complex incentives than Kouchoukos would have anticipated. Independent of the accuracy of these proposed models, agricultural intensification in these *Kranzhügel* settlements must have had a unique combination of production incentives, operating concurrently.

2.2.2. Akkadian Presence

Archaeological evidence from Upper Mesopotamia suggests Akkadian presence in the area during the urban phase. Sargon (2334-2279 BCE, Middle Chronology) marks the Akkadian in the archaeological record. The capital, though not specifically located yet, must have been located somewhere along the Tigris River (Wall-Romana 1990), but close to Kish (Yoffee 2009, 182). Royal inscriptions of the time describe Sargon’s “ownership” of the Mediterranean, Persian Gulf, Lebanon, and Taurus Mountains. Later in the history of the empire, Naram-Sin, grand-son of Sargon claims the title of “king of the four quarters”. This imperialistic mood, fictive or real, must have been felt directly (or indirectly) in various parts of the region.

But in fact, Sargon and Naram-Sin clearly exerted their influence in Upper Mesopotamia. Mudbricks from Naram-Sin Palace at Tell Brak were stamped with his name. At Tell Mozan, sealings in the name of the daughter of Naram-Sin, Tar’am Agade, also provide evidence for Akkadian political presence (Buccellati and Kelly-Buccellati 1997). Sargon and Naram-Sin both claimed to have subjugated Ebla, as attested to by inscriptions (Akkermans and Schwartz 2003, 243). Frayne (1993) also reports the activities of Naram-Sin in the Khabur Region.

Discussions of the Akkadian Empire in Upper Mesopotamia usually revolve around imperial domination. At Tell Brak, Level 6 ‘ED III destruction level’ was probably followed by early Akkadian (D. Oates and Oates 2001b). The character of this influence is now open to dispute. Weiss et al. (1993) suggest that increasing subsistence needs at the core of Akkad pushed the empire north in order to exploit the already established, stable agricultural production of the region. This proposition assumes that Akkadian imperial power was stronger than that of local polities and that imperial domination was strong enough to divert excess production without substantial resistance (Ur 2004, 277).

Found in the cultic section of the acropolis at Tell Leilan, Weiss (1997) interprets a tablet written in Old Akkadian as evidence for Akkadian conquest. Furthermore, rampart and the defensive structure around Tell Leian are attributed to Akkadian domination. Also, standardized and mass produced bowls are interpreted as vessels for distributing food rations, managed by the Akkadian administration.

Oates and Oates (2001a) interpret the bent-axis temple plan from Tell Brak as direct indication of Akkadian presence. Furthermore, administrative cuneiform tablets from the

Akkadian period buildings describe forms of bureaucratic management which can be considered as an indication of economic control (Akkermans and Schwartz 2003, 280). However, this textual evidence does not indicate how long the Akkadians were functionally effective at Tell Brak or when they arrived there (D. Oates and Oates 2001a, 384).

On the other side of the discussion, Ur (2010) interprets the same evidence in a different way, finding no clues to indicate a strict imperial occupation. For instance, sealings from Tell Mozan could be an indication of diplomatic connections reinforced by royal marriage (Ur 2004, 65). As another example, the evidence provided at Tell Brak indicating a more direct presence of the Akkadian, may have been an indication of a propagandistic device, so the presence of Akkadian may not have been in the form of direct conquest (Ur 2010a, 401). Furthermore, Stein and Blackman (1993) demonstrate that sila bowls at Tell Leilan, usually interpreted as rationing jars under a strict state controlled economy, were produced by different households within the city, which indicates the limits of state power in the society, and thereby questions Akkadian domination.

Architecture and settlement patterns only provides inconclusive evidence for the imperial nature of the Akkadian in Upper Mesopotamia (McMahon 2012). At Tell Brak, two religious centers and the building complex interpreted as a palace by Mallowan (1947) require further considerations. A scribal school, in the Akkadian “sections” of Tell Brak, must have introduced the Akkadian script into the economic activities at Tell Brak. This is a clear evidence for the connections between Upper Mesopotamian and Akkadian political economies, but to what extent this new script was introduced to the local political economy of Tell Brak has yet to be shown. Akkadian officials had their own sealings, but distinctive local variants of sealings are also found in Akkadian religious-administrative centers which again indicates the complexity of relationship between local presence at Tell Brak and the Akkadian Empire (McMahon 2012, 655).

The study of settlement patterns to understand the Akkadian presence in Upper Mesopotamia already suffers from the problems related to ceramic assemblages. Surveyed sites in the area cannot be always securely dated because the transition of material culture from pre-Akkadian to post Akkadian phases has yet to be fully understood. Using the dates from Early Bronze Age ceramic assemblages of Southern Mesopotamia only creates "artificial cultural divide" between the North and the South (McMahon 2012, 654).

2.2.3. Urban Dissolution

At the end of the Early Bronze Age, urbanized settlement patterns were dissolved in a considerably short amount of time. However, this change was by no means a uniform process. For example, while almost all of the small settlements in the Khabur Basin were abandoned (Weiss et al. 1993), habitation continued in some large settlements, albeit at a reduced scale (e.g., Tell Brak- D. Oates and Oates 2001, 393; Tell Mozan- Buccellati and Kelly-Buccellati 1988). In western Syria, Ebla, Tell es-Sweyhat and Selenkahiye provide evidence of destruction (Akkermans and Schwartz 2003, 283). Similarly, either complete or partial abandonment is observed in Umm el-Marra, Hammam et-Turkman and Tell Hadidi (*ibid.*). Parallel dissolution of settlements is observed in Southern Mesopotamia, as well as in the Aegean, Egypt, Palestine, and the Indus (Yoffee and Cowgill 1991). The reason behind this transformation towards less urban conditions is subject to debate. Stress on urban life is explained by environmental (Weiss et al. 1993) as well as social factors (Butzer 1997), and in some cases by a combination of these (Wilkinson 1997).

The hypothesis that environmental change caused the collapse of the urban system, proposed by Weiss and his colleagues, dominates scholarly discussions (e.g., Courty and Weiss 1997; Cullen and deMenocal 2000; Arz, Lamy, and Patzold 2006; Staubwasser and Weiss 2006; Pfälzner 2012; Riehl and Deckers 2012) and similar examples of the effect of climate change are suggested across the globe around 4.2 kaBP (e.g., Booth et al. 2005; Magny et al. 2009; Huang et al. 2011). Briefly, abrupt aridification in the climate at the end of the Early Bronze Age is hypothesized (Weiss et al. 1993). The evidence for aridification comes from a tephra layer at Tell Leilan dating to its IIb hiatus phase. Based on soil micromorphological analysis of this layer, Courty suggests a sharp increase in wind circulation, atmospheric dust and low precipitation levels. In this arid environmental setting, sharply decreasing agricultural production put substantial pressure on Akkadian imperialism since the subsistence base supporting the imperial core was obliterated. In later studies, the hypothesis of a volcanic eruption was replaced by an extra-terrestrial impact (Courty 2001). A similar "tephra" layer is also detected at Tell Brak (*ibid.*) suggesting a triggering event for aridification. However, C14 samples from this layer show that this event predates the end of Akkadian presence (Kolinski 2007, 8). In support of this argument, Oates and Oates (2001, 393) accept the possibility of some unusual climatic event, but also argue that this event was of relatively short duration, and that it didn't cause an end of the Akkadian presence. In addition, paleobotanical data from Tell Brak suggests no observable climatic variation between Akkadian and post-Akkadian phases in the settlement (Charles and Bogaard 2001, 325). Similarly, Bryson and Bryson (1997) reconstructed ancient precipitation in the region, suggesting that rainfall levels reached its minimum level around 4350 BP, predating the suggested 4.2 kBP event by more than a century. In another study, Wilkinson (1997) explains the end of urbanism as the expected result of frequent droughts imposed over specialized urban settlement systems. In this model, it wasn’t the environment which determined the faith of urban offices, but pressure on production increased the vulnerability of the overall system. Episodic droughts within the context of already brittle economy contributed to the dissolution of the system. In other words, the ability of the society to absorb regular shocks coming from the environment was reduced, and eventually the system had to forcefully transform into something new.

2.2.4. Archaeological Implications of Intensification in Upper Mesopotamia

Scholars generally agree that urbanism was possible in regions where dry-farming was practiced. Relatively high and reliable precipitation was needed for high and stable levels of agricultural production to support the urban system. Unlike Southern Mesopotamia, there is little evidence for irrigation outside narrow river valleys. Therefore, the limits of dry-farming set at the 250-300mm annual precipitation level determined the geographic limit of urbanization. However, even these precipitation values do not guarantee reliable agricultural production (Wilkinson 2000). Therefore, the density of settlements around these low precipitation areas is lower than in areas with higher precipitation.

Extended political landscape and its complex social elements provide clues for the possible intensification of agriculture. Moving from broader landscape perspective to local household level, intensification possibly happened due to a combination socio-political and economic action. Few of these actions must have been deliberate attempts to intensify production, but in most cases these actions might have contributed to the agricultural decision or affected from it.

Existence of luxury goods suggests a necessary mechanism where the production, acquisition, and exchange of goods required differentiation in some portions of the economy, including agriculture. This might suggest some intensification of production, at least in parts of the production landscape. Second, production of these goods must have required skilled craftsmanship. Furthermore, the wealth economy must have also required fluctuating levels of labor from other sectors of the society, including the agricultural sector. This pull from the labor pool might have been compensated by the intensification of production.

2.2.5. Conclusions

Upper Mesopotamia, due to its geographical integrity and rich history, provides a productive research arena. Despite the lack of systematic paleoenvironmental studies, current data still provide a course picture of the conditions of past climate. As the number of such studies increase, more information on local conditions will be available and paleoenvironmental reconstructions will be more reliable. However, in its current status, data rarely permits for in-depth analysis. Yet, this dissertation is an effort to fully exploit existing data to the extent that accurate inferences can be made for local climatic conditions. Soreq Cave speleothem data is the main paleoenvironmental record in this respect.

One of the main criticisms of the Central Place Theory (Christaller 1933) is on the homogenous flat landscapes in which modeled settlements reside in. Central places, in relation to their peripheral settlements mimic ideal systems of production, transportation, and administration. Curiously enough, Upper Mesopotamian landscapes create close-to-ideal conditions of the models of central places. Despite localized geographical and geomorphological variations, at the regional level the study area remains as a source of testing models. In the area, large central settlements of the Early Bronze Age were separated from each other with relatively similar distances. In this regard, locations of ancient settlements must have been affected by (i) locations of earlier settlements and (ii) the contemporary political landscape, but not differential access to various resources, goods, and services. Therefore, conditions of centralization and the formation of relations between central places and their peripheral settlements can be explored in a controlled setting.

Both centralization and urbanization in Upper Mesopotamia during the Early Bronze Age must have enforced a large set of incentives of intensification. To overview, (i) higher agricultural surplus levels from a unit area, (ii) amalgamation of various economies into the Early Bronze Age political economy, (iii) potential separation of agricultural labor from urban sphere, (iv) trend towards aridity, and (v) external pressures of local agricultural production (population increase, land scarcity, exploitative ideologies, etc.). These set of conditions for the intensification of production suggest a complex picture.

CHAPTER 3: Theoretical Background

Ancient urban settlements, as they are considered in this study, were “not structurally or functionally distinct entities” (Trigger 2003, 120), but performed functions in a wider spectrum than town, villages, hamlets, etc. so that they stand structurally tall at an arbitrarily selected size and function continuum (*ibid.*). This definition of the ancient city immediately suggests that urban central places were also fully agriculturalists in order to feed their populations as well as to support urban offices and related politico-economic activities. But since these cities had a wider spectrum of services, and thus, more internal demand than supply, the amount of locally produced staples was not sufficient at times. Cities in Upper Mesopotamia at the second half of the third millennium BCE must have relied on their hinterlands for surplus production. The character of the relationship between the city and peripheral settlements (in the forms of conflict, compromise, cooperation, or subordination) must have determined the stability of the urban system. To further investigate this proposal, two topics, namely the stability of urban systems and urban-rural relations are discussed in the light of ancient agricultural production.

3.1. Urban-Rural Interdependency

As more empirical data are gathered across the globe, the models of interaction between ancient cities and their immediate hinterlands provide means to understand the developmental trajectories of settlement systems. These trajectories usually encompass both urban and non-urban development. It is a common understanding that urban areas require non-urban areas for resource extraction and agricultural production. During the formation of state and the creation of bureaucratic institutes, the central power expands territorially. This expansion might have required creation of authoritarian or cooperative relations with communities along the way (Spencer 2010). Expansion requires positive growth through the extraction of resources, including products of agriculture. For instance, by the Middle Uruk period in Southern Mesopotamia, urbanized Uruk and Susa was at the upper part of a four-tiered hierarchical settlement pattern where this territorial expansion from these urban centers must have required considerable need of resources. Likewise, in Egypt, Hierakonpolis was the urban capital of the Egyptian state in which the process included the increase of influence and dominance at other areas (Hoffman, Hamroush, and Allen 1986). In this process, the urban capital must have been in constant need of sustaining the bureaucracy related to this growth, and the need must have required a stable flow of goods and services to Hierakonpolis from outer communities. Similarly, the state might have been built around groups, actors and factions might have been the agents of the political life (Brumfiel and Fox 1994). These dichotomies, though lead into different directions, all require a solution for the necessities of integration into larger political landscapes. The management of this integration must have always required some amount of surplus production and its distribution.

These examples suggest that for an urban settlement system total agricultural production must be above a certain level, enabling members of the urban community to engage in non-agricultural activities. Another assumption regarding urban settlements is that relations between the urban and the rural are structured in such a way that either a central urban place provides economic potential to the rural so that there exists a flow of agricultural goods to the center, or that there exists hegemonic, ideological or religious relations between the urban and the rural, thus securing the flow of goods to the urban. Therefore, an urban settlement system denotes a set of interactions where there is a constant shift towards urban priorities in the allocation of resources both within the city and the village, as well as between them (Box 1980, 117). If these requirements and assumptions are valid, then a distinction should be made between the urban and the rural in order to understand the structure of the relationship.

Frey and Zimmer (2001) propose three basic elements which distinguish the urban from the rural. The first element is ecological, and it investigates the population and density levels of settlements. A large population or high density in comparison to neighboring settlements separates urban from rural settlements. The second element is economic, focusing on the distinct functions and activities of a settlement. In this respect, settlements characterized by continuous agricultural practices are considered rural, and settlements where the bulk of economic activities are structured around non-agricultural production are considered urban. The third element has a social character, and the urban is distinguished from the rural based on the ways people live, behave and communicate, although providing specific boundaries between these social elements is always challenging.

In the urban-rural dichotomy, the markers of social complexity such as heterogeneity, inequality and long distance trade are considered to be urban attributes, and rural settlements are regarded as food sources even though some rural settlements were also actively engaged in activities of social complexity (M. E. Smith 1994, 144). Assumptions and methods built around this dichotomy distract focus from the hinterland, and homogenize the rural (*ibid. 145*).

Since the early 1990s there has been an effort to incorporate the (ancient) city into its hinterland (M. L. Smith 2003). This is a significant shift in how archaeologists study relations between the different components of a settlement system, although as more data is collected on ancient urbanism it becomes clear that when cities changed, their surroundings were also reconfigured (Yoffee 1995). Therefore, studies on or making use of the urban-rural dichotomy should have high temporal control over these structural changes in order to limit the amount of necessary generalizations and assumptions. Another difficulty in dissolving the urban rural dichotomy is that there has not always been a clear historical distinction between a city and its hinterland. In sixteenth century Mesoamerica, for example, there is no legal or terminological difference between cities and their hinterlands. In ancient Greece, a polis could indicate either a settlement or the polity associated with it (Cowgill 2004, 539). Even if urban settlements were surrounded by walls and embankments, the separation of the urban from the rural remained arbitrary (M. L. Smith 2003, 4).

Cowgill (2004, 526) offers an alternative method of dealing with the urban-rural dichotomy by defining the city as

> "a permanent settlement within the larger territory occupied by a society considered home by a significant number of residents whose activities, roles, practices, experiences, identities, and attitudes differ significantly from those of other members of the society who identify most closely with 'rural' lands outside such settlements".

In this regard, a society without a city can be called non-urban, but not rural, since rural can only exist in relation to an urban sector (*ibid.*).

Although Cowgill's definition is inherently broad, it also provides an opportunity to more fully integrate rural lands more into the picture. In fact, the definition can be extended to encompass urban settlement systems once the definition also includes the function of that particular settlement system. "Experience, identity, and attitudes" of the inhabitants of a settlement system, living either in urban central places or their peripheral settlements, continuously cross-cut each other, but their everyday life is affected by the relations between the settlements of the urban system. Overall, a settlement system is both producer as well as consumer such that the flow of necessary staples between settlements is the result of local activities, roles, practices, experiences, identities, and attitudes as well as inter-site relations affecting and affected by local conditions specific to each settlement.

Specific to an Upper Mesopotamian urban settlement during the mid-to-late Early Bronze Age, the difference between staple production and consumption in that settlement determined food deficit/surplus levels which fluctuated annually. A rural settlement didn't have a distinctly different functional form than an urban settlement when investigated in its production landscape. Following this argument, no apparent dichotomy is suggested between means and levels of production of the urban and the rural in this dissertation.

3.2. Stability of Urban Systems

Another clear dichotomy in urbanism studies lies between scholars who regard the royal family and its officers as the sole authority in the formation of cities, and those who consider the power of commoners during the city building process, spreading the decision making mechanism more horizontally (Marcus and Sabloff 2008, 10). Thus, a common theme in urbanism studies is the association between cities and state formation. In current archaeological research, urbanism is investigated within the domain of increased complexity of societies and state formation as a higher theoretical level (e.g., Bard 1997; Marcus and Sabloff 2008).

Hansen (2000, 12) argues that as the functions of a city become institutionalized, the city also becomes a political center, and "urbanization goes hand in hand with state formation" (but also see M. L. Smith 2003, 12–15). However, the classical understandings that *no states had existed without cities and that city could exist without a state* is currently being challenged, and some counter examples are provided in the archaeological literature (e.g., McIntosh 2005). Hansen's argument still remains valid for Upper Mesopotamia during the Early Bronze Age – a time of increased social complexity and state formation.

Since the urbanization process is considered to be closely knitted to the formation of states, it is not surprising to observe that scholarship focuses on the urbanization process alongside the factors and motivations of state formation (M. L. Smith 2003). The ways in which a society was organized is an important distinction to make if one wants to explore the stability of an ancient urban settlement system. But still, whether built by the elite or the commoners, an ancient urban settlement must have required a flow of agricultural goods at times when production in the urban settlement could not supply enough input for the inhabitants of that settlement. If a large urban settlement was occupied more densely than a small settlement within the same settlement system, it can be hypothesized that further along in the urbanization process, as more time and energy was dedicated to non-agricultural activities, less time was spent for agricultural production. This shift in focus would have likely created calorific problems unless the food deficit was compensated for other economies and/or acquired from other settlements. Furthermore, if this hypothesis is valid, the success of an urbanization process depends on the stability of a hierarchical settlement system as a complex adaptive system.

A complex adaptive system may be a useful concept in describing the stability of ancient urban settlement systems (Christiansen and Altaweel 2005). The characteristics of complex adaptive systems are component diversity, localized interactions between components, and an independent process which selectively uses these interactions for the improvement of the system (Holling 2001, 391). A complex adaptive system approach shifts the focus from individual elements to the system as a whole, at the expense of potentially losing an understanding of the causal mechanisms at local individual levels (J. S. Lansing 2003, 185). Characteristics of a complex adaptive system partly explain the structure of ancient urban settlement systems in Upper Mesopotamia during the Early Bronze Age. An agriculturally productive urban system was made up of diverse settlement components (urban agglomerations, towns, villages, etc.), locally interacting with each other for the common good.

Another intrinsic property of complex adaptive systems relaxes the requirements of strict top-down approaches and suggests diverse individual components of a system may create complexity without a deliberate attempt to create an optimal configuration (S. J. Lansing 2000, 313). On the other hand, the system is also adaptive so that the tendency is towards stability rather than chaos. Despite these possible tendencies towards stability, it is the chaotic conditions when the relations between the components of the settlement system become optimized (Langton 1990). In an archaeological context, this optimization can be interpreted as the continuous tendency of the settlement system to adopt new stable conditions during the urbanization process. A break in stability may indicate a phase change in the adaptive cycle (Holling 2001). Following this phase change, the character of the settlement system might change accordingly, and thus, a new definition for the new settlement system might be needed.

Stability is the ability of a system to return to equilibrium conditions after disturbance (Holling 1973), yet this return might be to new equilibrium conditions. Specifically for an ancient urban system, stability might have been required since cities would have tended to maintain their top-level positions since considerable capital had already been invested in them (C. A. Smith 1995, 29). Even though this claim is mostly valid for mature urban systems, the same tendency towards stabilization might be observed in systems at a variety of stages of urbanization. Furthermore, stability may only be possible with maximization (Adams 1978, 330). For an ancient urban system, this maximization would include agricultural production, though as Holling suggests (1973, 21) “effective and responsible effort to provide a maximum sustained yield…might paradoxically increases the chance for extinctions”.

To summarize, an ancient settlement with some degree of urban configuration was dependent on other settlements for their excess agricultural production in order to sustain its urban character. However, this dependency might not have been necessarily in a consumer-parasitic style, but characterized by a more dynamic set of interactions between settlements at various levels of hierarchies. The structure of these interactions was determined by the activities, roles, practices, experiences, identities, and attitudes embedded in the social, political, and economic domains of urban life. Keeping these interactions active was only possible if urban system was stable. This stability was provided by maximizing production in order to cope with fluctuations in the system, but at the expense of potential future breakdowns —as may have been the case for the urban settlements of Upper Mesopotamia at the end of the Early Bronze Age. Furthermore, this process might not have required a forceful external impetus (Wilkinson 1997), such as climatic aridity or changes in production relations due to an outer hegemonic entity (i.e. the Akkadian Empire) (Weiss et al. 1993).

3.3. An Archaeological Model for Upper Mesopotamia

Many archaeological studies related to Early Bronze Age settlement systems implicitly or explicitly make use of a model proposed by T.J. Wilkinson (1994) in his seminal paper "[T]he Structure and Dynamics of Dry-Farming States in Upper Mesopotamia". This study provides a solid representation of both production and territory relations. Follow up studies of this model integrate a social and dynamic ecological approach to this problem (Wilkinson et al. 2007; Altaweel 2008).

According to Wilkinson's model, inhabitants of Early Bronze Age urban and rural settlements had areas of intensive farming surrounding the settlements. Rural tributary communities supported the extensive populations of large, central settlements by sending them their excess agricultural output (Ur and Wilkinson 2008, 312–314). This flow of agricultural production also made it possible for early centers to expand and create a variety of economies (Wilkinson 1994, 484). In other words, a set of interactions between settlement hierarchies involving the flow of goods from lower order secondary and satellite settlements to central places of the highest order was the means by which such urban settlement systems sustained themselves.

Wilkinson also suggests that rain-fed agricultural production output sets an upper limit of 100 hectares surface area for Early Bronze Age settlements since production cannot be the sole support of urban populations above a certain value. Based on population density estimates of 100 to 200 person per hectare, a settlement of 100 hectares in extent indicates a population 10,000 to 20,000 people (Wilkinson 1994). However, considering productivity levels, labor requirements and the cost of bulk transportation, the maximum population that an urban Early Bronze Age settlement would have attained was more likely less than 15,000 persons at a 100ha site (Ur 2004, 80).

Assuming a closed system, Wilkinson’s model (Wilkinson 1994, 495) for dry-farming is based on three basic variables: the size of the production territory, mean crop yield, and available labor. Territory is estimated by off-site archaeological features, crop yield is assumed to fluctuate due to different environmental conditions while available labor is based on population estimations calculated in proportion to settlement sizes.

The first variable, the size of the production territory around an Early Bronze Age settlement, is estimated by calculating the extent of surrounding off-site archaeological features, namely the radial routeways constraining movement around settlements and extensive sherd scatters. The relationship between these archaeological features and agricultural production is subject to debate (e.g., Wilkinson 1994; Weiss and Courty in Wilkinson 1994, 512-514), but there is ample evidence demonstrating this relationship. These off-site features are discussed in detail in Chapter 5.

The second variable, mean crop yield is another important factor in understanding the structure and dynamics of dry-farming states in Upper Mesopotamia. In his initial model, Wilkinson estimates mean available yield by integrating population density, consumption per person, production per person, and production per unit area (Wilkinson 1994, 495). In this framework, production decreases as the distance from a settlement increases (*ibid.* 497). In order to provide a more dynamic and representative model of mean crop yield, Wilkinson and his team have more recently developed complex agent-based simulation models testing different environmental and production scenarios (Wilkinson et al. 2007). These simulation models provide a rich dataset which can be compared against archaeological and epigraphical evidence. These comparisons, in turn, enable researchers to iterate and improve simulations. However, despite their powerful methodologies, simulations provide a limited holistic approach since tested scenarios focus on isolated settlements rather than the economic interaction between settlements and may underestimate the role of pastoral economies in the region (Casana 2012; Porter, 2012) .

The third variable in understanding the Early Bronze Age agricultural production is available labor. This variable is modeled by using hypothesized Bronze Age populations where the estimator is the size of the settlement (Carothers and McDonald 1979). If one considers discrepancies in identifying settlement sizes in conjunction with the problems inherent in estimating ancient populations (Uerkvitz 1993), determination of the size of available agricultural labor remains problematic. Furthermore, the lack of robust archaeological evidence in Early Bronze Age land-labor-ownership relations as well as the inherent error in productive labor models makes it challenging to estimate how much labor was available for ancient agricultural practices.

To summarize, Wilkinson's model suggests that an Early Bronze Age central place was able to sustain its population up to a certain level, but when the population passed this critical threshold it became necessary to increase the foodstuffs incoming to the settlement. However, the first and third variables of the model (territory and labor) dictate that it wasn't always possible for a settlement to extend its production area or supply the labor necessary to increase agricultural production (e.g., Titriş Höyük (Wilkinson 1994, 498)). And, as the second variable suggests, the drop in mean crop yield during consecutive dry years must have had more impact on large urban centers than on settlements at second or lower tiers in the same settlement since the flow towards urban centers were cumulative in nature.

3.3.1. Implications of the Archaeological model

Following Wilkinson's work, this dissertation aims to investigate whether societies in Upper Mesopotamia were living in stable urban settlement systems or whether variations in agricultural production were always a concern for the Early Bronze Age decision makers during the second half of the third millennium BCE. Given a need for responding to such fluctuations, their decision-making mechanisms would have determined such a response.

In archaeological literature, top-down approaches for studying the structure of decision making bodies hypothesize a centrally planned administration in charge of the political sphere, managing various organizational aspects in society, including the urbanization process (Weiss 1990; Matney and Algaze 1995; Meyer 2007). The political organization would have maintained control of the economy by a number of actions, for example by creating and controlling the storage of agricultural surplus (Weiss et al. 1993, 997). Large granaries and silos (J. McCorriston 1995; Wetterstrom 2003) are usually regarded as an indication of a redistribution economy (e.g., Hald 2010), and following this economic structure. In this theoretical framework, scholars often envision the separation of the elite from the commoner. At the other end of the continuum, bottom-up approaches dominate (e.g., Schloen 2001; Ur 2004). Lack of evidence for direct state control of centralized storage, alternative interpretations for product specialization, and reassessment of specialized production create an alternative explanation for the political economies of third millennium polities in Upper Mesopotamia. Households, as politico-economic units, were connected to each other through a dense network of relations at different scales, managing the network via social actions (Schloen 2001). The bottom-up approach also implies that there were no strict territorial boundaries (Cooper 2010) as there was no consolidated body in charge of boundary making. Furthermore, due to constantly changing relations between political units, the legitimacy of operating powers was under constant negotiation and renegotiations (Ur 2010a).

Explanations for the structure of Upper Mesopotamian society during the second half of the third millennium BCE also determines the ways in which agricultural production is investigated. For instance, if a society is thought to be centralized, then surplus would be gathered in state controlled storage spaces, where these spaces are the physical manifestations of the centralized authority. On the other hand, if the society is considered to be emergent, then excess production is an end product of other social necessities (Ur and Colantoni 2010).

This dichotomy, if imagined in strict directional sense, can be limited at times. However, it is still open to suggest more amorphous models. For instance, socio-political control might have been in effect, but limited to the collection, storage, and redistribution of final agricultural products. The means of production, however, might have been fully belonged to the households. This makes state control irrelevant to agricultural labor organization, and thus, has wider implications.

Approaching from a bottom-up perspective, politico-economic households might have been densely organized for decisions regarding agricultural production. The reasons to intensify production, however, might have been still external to households—despite the dense network of household relations, managing the socio-political and economic life at different scales (Schloen 2001). The emergence of an urban sector (Stein 2004) might have been related to specialized production. It is also likely that the urban sector was getting separated from agricultural production at increasing levels during the course of urbanization.

What makes a city, however, is not solely based on the results of economic decisions and production mechanisms. The ancient urban sector might have included members of different households, cross-cutting normative household boundaries. Collaboration between the members of households due to socio-economic reasons might have eventually motivated the bourgeoisie, not in political Marxist, but in literal sense — "an inhabitant of a town" (*burgeis* in old French). The role of this sector in the political economy is yet to be established. But if indeed this sector was influential in the city life then it will not be surprising to observe that “the development of cities was strongly promoted by the upper classes, who used them to pursue their personal and collective goals” (Trigger 2003, 121).

A better understanding of agricultural production may therefore illuminate the structure of mid-to-late Early Bronze Age societies since agricultural production is a “fundamental and visible axis of political and economic action” (Hastorf 2001). Intensification is a form of production where the axis is the most visible. However, as Wilkinson (1994, 503) succinctly put it: “[w]hatever the cause of urbanization, the social/administrative entity, be it a chiefdom, state bureaucrats, or semiprivate system, would have had to deal with the problems of production and supply”. This dissertation has the aim to accurately model this production and supply.

CHAPTER 4: An Agricultural Intensification Paradigm for an Urban Context

A farmer's role as the productive agent and production relations, which are constantly negotiated between individuals as well as the individual and societal organizations, have material and social bases. Agriculture —as a form of production— also shares these bases. Biological, climatic, and geographical conditions influence the decisions of agriculturalists. Amount of precipitation, soil conditions, rapid temperature changes and others contribute to the complex agricultural decision making process. This process is also determined by the political economy of the intensifier society. Land ownership and use rights, labor division, gender relations contribute to the ways in which agriculture is practiced at a particular time. Thus, agricultural production is a physical manifestation of how a society is organized, but interpreting the spatiality of this complex process is never straightforward, and Early Bronze Age agricultural production in Upper Mesopotamia is not an exception.

In this chapter, the first aim is to review theoretical perspectives on the intensification of agricultural production, highlighting the causal relations of intensification, and intensification as a process. For causal relations, population and other incentives of intensification are explored through cross-cultural comparisons. Understanding agricultural intensification as a process is a more challenging task because it requires constant evaluation and reevaluation of social and productive systems. To establish a theoretical framework, intensification process is explored by focusing on working and landesque capitals. At every stage of intensification, capital enters production, and thus, it provides proxy or direct information for the intensification process. Building on these discussions, the chapter explores for the ways in which intensification is spatially manifested in the landscape, and thus, becomes observable to the modern researcher.

The second part of the chapter investigates agricultural intensification during the second half of the third millennium in Upper Mesopotamia. First, the chapter provides information on the productive setting of Upper Mesopotamia as well as the late third millennium BCE crop preferences. Second, possible incentives of Early Bronze Age intensification are explored. Third, intensification —as a process— is investigated through the analysis of working and landesque capitals going into the agricultural production in Upper Mesopotamia.

4.1. Agricultural Intensification

Agricultural intensification is generally characterized by higher capital input to obtain higher output characterizes intensification. The ultimate aim in intensification is to obtain high yields —regardless of the cost of the input. This production strategy comes with a distinct set of incentives, ranging from securing vital calorific requirements for an increasing population to satisfying the conditions of a social action (Brookfield 1972). Intensification also follows a multilinear path where its repercussions may be observed in new forms of labor organization (Stone, Netting, and Stone 1990), product specialization and territorial expansion (Allen 2004), the transformation of the landscape (Stanish 2007) or a possible combination of these. Intensification —as a strategy— and as a process introduces new conditions into the socio-political sphere, such as increased productivity and enhanced stability, as well as some which might be undesired or unexpected like agronomic failure.

Intensification involves the possibility of production decline in the long run due to the depletion of soil nutrients and the increased susceptibility to environmental variations due to crop specialization. Intensification also implies a decrease in the efficiency of work (Stone 2001a, but also see (Erickson 2006)). Hence, for the agriculturalist the decision for intensification is critical and its implications for the organization of society are significant.

The work of Boserup (1965) plays a pivotal role in the studies of agricultural intensification. “The Conditions of Agricultural Growth” explores the relationship between population pressure and agricultural production. A (neo) Malthusian understanding suggests that food availability cross-culturally determines the level of populations, and thus, human populations are inactive agents of the conditions of the agricultural growth. Boserup flips this demographic argument on top of its head. In complete disagreement with a Malthusian understanding of population dynamics she claims population pressure introduces changes in agricultural production so that new population levels can be supported based on the available agricultural technologies and methodologies. To put this into perspective, a Malthusian approach suggests that agricultural practice is determined by the available technology, and that accordingly production is always maximized on land. Boserup, however, shows how agricultural practices can maximize production through labor intensification without maximizing the amount of land in use.

Under pressure, farmers overcome the scarcity of land or the cost of use to farther productive plots through a dynamic land utilization system. Forrest-fallow cultivation, bush-fallow cultivation, short fallow cultivation, annual cropping, and multi-cropping is the main linear template of production in which Boserup (1965, 15–22) claims to be a solution for problems, external to production. In this regard, intensification implies shortened fallow lengths and increasing applications of manure in order to get more “output per man-hour”.

4.2. Approaches to Ancient Agricultural Intensification

Morrison (1996) argues that most archaeological studies related to agricultural intensification are built over cause and effect relationships —an artifact of the Boserupian thinking. However, “[c]auses are often multiple and cascading, and no doubt vary somewhat from case to case” (Morrison 2006, 237). These causal relationships are based on biological and cultural motivations, aspirations, or limitations which determine the character of agricultural intensification. For instance, increase in population levels, changes in production relations, environmental deterioration, or an external pressure to the society might create the incentives of intensification. Without such increase in agricultural production, it may not be possible to feed high populations, stabilize the political economy, compensate for the effect of low rainfall, or pay agricultural tribute (or contribute) as subject of a larger central system.

In reaction to studies which based on this causal organization, Morrison (2006, 235) suggests studying agricultural intensification as a process. There is a need to understand intensification momentarily and explore context and contingency of this process (Morrison 1996). Normative definitions usually suggest that “the measure of agricultural intensification has taken on a rather precise meaning as the total production per unit of area and time (typically per hectare and year). Its obvious measure, therefore, should be that of total output.” (Kates, Hyden and Turner in Morrison (Morrison 2006, 236)). In opposing to this argument, Morrison (2006) claims such explanations only define productivity, but not intensification. She further claims that using output levels to measure agricultural intensification obliterates the view on process. In fact, it is the process which generates the output in the first place (*ibid.*).

This theoretical conflict within agricultural intensification studies originate from a lack of consensus on what actually intensification means and represents. Causal explanations of intensification can be regarded as scholarly efforts to provide a universal definition of the process. But as many will agree, each cause is context specific, and thus, these efforts eventually fail to create a cross-cultural theory of intensification. Yet, without such theory, any empirical study on agricultural intensification will remain problematic.

Another difficulty in studying intensification is the limited availability of data. Investigating ancient agricultural intensification maybe sharply contrasts with studies of modern intensification strategies. In contemporary economic or anthropological research, the necessity for tight temporal control over a well defined spatial extent is usually satisfied when studying agricultural production systems (e.g., Stone, Netting, and Stone 1990). In addition, modern day intensification efforts in relation to market economy principles and neo-liberal policies (e.g., Cour 2001) can be thoroughly investigated using mathematical and statistical modeling (Shively and Pagiola 2004) since there is sufficient data for such global scale analysis. When investigating ancient agricultural production and its intensification, on the other hand, archaeological analysis relies on proxy variables. Such variables could include storage unit sizes (Curvers and Schwartz 1990), the number of draft animals attested to in the textual record (Van Lerberghe 1996, 114-117), botanical measurements in animal fodder (Marston 2011), changes in the diet as documented in bone minerals (Schurr and Schoeninger 1995), soil chemistry values (Berlin et al. 1977), and landscape signatures of intensification (Wilkinson 2005b; Stanish 2007). To what extent these and other variables can accurately represent agricultural intensification remains as a challenge to the discipline.

4.2.1. Incentives of Intensification

In anthropological theory, efforts to understand causal relations of agricultural intensification have mainly followed two distinct paths: following either demographic or non-demographic factors. Methodologies are often built on a perception of whether the biological needs of a population play an important role in agricultural intensification or not. However, as there is no simple dichotomy in agricultural practices (Brookfield 1972, 32) strict categorization of causality only highlights one incentive at the expense of the others, thus the proposed incentive remain limited in its explanatory power.

4.2.1.1. Population

The main idea behind population as a cause of intensification is that an increasing population requires an increase in the level of food production, in order to provide the calorific needs of an expanding population. The increase in foodstuffs may be provided by altering the method of agricultural production. In other words, if there is an increase in the population, this increase is a stimulus for change in production strategies (Boserup 1965).

Even though an increase in total population numbers may indeed require more food, immediately associating agricultural intensification with population pressure is problematic. First, depending on the socio-political and economic conditions of the expanding society, an increase in population density may not necessarily require local production intensification. Instead, food may be imported from other regions (e.g., Curvers and Schwartz 1990, but also Hole 1991). Extracting foodstuffs through political relationships (Hastorf 2001, 160) or exchanging locally produced crafts for food (e.g., Blanton et al. 1993; Feinman, Nicholas, and Middleton 2001; but also Feinman et al. 2007) are other documented possibilities for feeding populations. Second, local production strategies other than intensification are also possible methods of coping with an increasing number of people. If there is no constraint around the settlement, extending production areas is a plausible method. Expanding into new territories with agricultural potential (Cooper 2010, 91) is another option for increasing production while keeping existing production relations intact. Third, calorific consumptions vary drastically in space and time so that no universal schema exists to link in a population increase to agricultural intensification. For example, Bennett (1967) documents low level food consumption for

Canadian Hutterites when compared to their neighbors due to religious preferences. This basic observation suggests that there is no single calorific formula that is universally applicable to human populations. Finally, the association between agricultural intensification and changes in population dynamics are usually more complex than anticipated. In a representative example, Thurston (2007: 181) reports that during Danish state formation, demographic reconfiguration, rather than the observed increase in population, ignited the intensification of production.

4.2.1.2. Non-Demographic (The "Other") Incentives of Intensification

Agricultural intensification might not be simply a societal response to satisfy calorific needs of a population; socially motivated production might also initiate intensification (Brookfield 1972). Intensification may be practiced following uneconomic decisions, in order to obtain high social returns (*ibid.*). Social rules and practices of an ancient intensifier society might have led to a deliberately excessive production strategy. This excess was most probably used by chiefs and kings in order to support their elite activities (Earle 1997, but also Erickson 2006, 343), or to attain individual or group status and prestige. Ceremonies, ritual activities, and feasts must also have extracted significant amounts of agricultural product from the ancient production (Hayden in Jennings et al. 2005, 291), so that an intensification strategy was (or had to be) adopted.

Intensification may have also occurred as a result of political or militaristic pressure. An external hegemonic or conquering power might have forced intensification on production, thus changing the dynamics of local production relations. In this case, an external demand with any form of incentive, including population pressure at home, could be a determinant of intensification. However, such an impact probably didn't follow a uniform process, but rather intensification depended on both local socio-environmental conditions as well as the degree of hegemony asserted by the external entity. The form of conquest, the political structure of the conquered polity, the size of the conquered polity, and the geographical location (Hastorf 2001) must have been influential upon the decision to intensify agricultural production. For instance, under the Abbasid Caliphate (750-1258 CE), fixed tax rates were imposed by the state regardless of the quality and quantity of each harvest so that peasants were forced to cultivate intensively in addition to finding other supplemental forms of payments (Tainter 2006a, 62). Under such a forceful system, why and how these regimes were undermining the ways in which agriculture was practiced remains as a question. Possible answers to this problem may shed light on the incentives of intensification. Along these lines, Wittfogel (1957) investigates the overexploitation of production by unproductive elites resulting in custom shifts in the system equilibrium and even socio-political collapse.

Urbanism would have been another incentive for intensification. Depending on the path that urbanism followed, intensification might have also occurred in different forms. An ancient city with established urban offices and elites might have required excessive production as the urban system pulled labor and time from agricultural production. Or, following the loose organizational definition of the city, the pressure on production might have been to a lesser degree, and intensification might have been limited.

The discussion above, which explores population pressure, environmental deterioration, hegemonic relations, and urbanization as the incentives of agricultural intensification, is not complete. Unique historical trajectories create unique processes which may create (dis)similar intensification strategies. This list of incentives, however, is selective and provides theoretical background for the analysis of Early Bronze Age intensification in Upper Mesopotamia.

4.2.2. Intensification as a Process

Intensification may be explored by studying the underlying processes of production (Morrison 1994; Morrison 1996). Understanding the process may be achieved by focusing on two capital types: working and landesque (Brookfield 2001; Hakansson and Widgren 2007). "Landesque capital allows labor to be environmentally banked through stone walls, terraces, drainage and irrigation systems, raised fields, or other landscape infrastructure" (Fisher and Feinman 2005, 64). Working capital includes buildings, tools, vehicles and working livestock, but upmost the human labour force, greatly varying according to the structure of the political economy (Brookfield 2001, 183). This major division cannot be immediately applicable to every economy cross-culturally, but forcing such a division is a useful exercise in understanding the variables of a intensification process. Overall, the Capital —of any kind— entering into agricultural production, the production of this capital as well as capital produced at any interim stage of intensification forms the structure of this production strategy.

4.2.2.1. Working Capital

Working capital is made of both material and non-material capital types, including the labor used in agricultural buildings, production of tools, livestock, and agricultural labor (Brookfield 2001, 183). Ancient working capital was always in motion and dialectically related to each other in particular ways so that production could be intensified. Thus, understanding the ways in which the working capital was organized and used in agricultural production is a first step in exploring ancient intensification processes. This argument is evaluated below through an example of agricultural technology as a form of capital.

The complexity of agricultural hardware used in the production of staples may be related to the intensification process. Inherited or learned knowledge of tool making, changes and adaptations in the agricultural toolbox, technology and the style of tools affect and are affected by agricultural production. In the Titicaca Basin, the agricultural landscape was modified with agricultural terraces and raised fields through the use of basic wooden tools, creating means for intensification (Erickson 2000, 322). However, in other cases such as at Tell Beydar in Upper Mesopotamia, Early Bronze Age farmers were using animal traction and composite agricultural tools in a geomorphologically homogeneous landscape. These examples together suggest that there is no immediate connection between the complexity of working capital, and the tools creating this capital.

Approaching problem from another angle, the production of tools used in agriculture and the availability and access to these tools must have created a dynamic social setting which must have been reflected in the intensification process. Similar discussions can be made for the use of draft animals, cultivation of fodder to feed these animals, production of storage spaces, silos and the economies revolving around these types of working capital.

As the main non-material form of working capital, agricultural labor was a primary variable of the intensification process. The organization of agricultural labor impacts the cultivation of landscapes in various intensities at multiple scales (Erickson 2000, 325). The mobilization of labor in Andean civilizations (*ibid.*), Southern Mesopotamia (Adams 1981), and China (Chan 1992) was related to the intensification process. Nevertheless, it is essential to acknowledge that the organization of labor might have been more important than the amount of available labor.

Working capital is difficult to detect in archaeological contexts. Material forms of working capital going into agricultural production were constantly modified or recycled. Likewise, agricultural buildings might have assigned different functions as needed, or leveled for other uses of space. In some exemplary cases, storage units for production provide evidence for intensification (e.g., Curvers and Schwartz 1990, but also Hole 1991). Agricultural labor is even harder to detect in the archaeological record. Ancient labor, in its literal sense, is only visible through material culture, or when it was documented in written forms. The sparse evidence is useful only when working capital is investigated in a holistic manner, enveloping a large set of variables. However, in most cases, evidences for only a few variables are manifested in the archaeological record. Landesque capital, the other form of capital, though still challenging to discern archaeologically, provides a better medium for understanding the intensification process.

The accuracy of these inferences based on working capital surely depends on the actual political structure of the intensifying society. A top-down management model would disregard any differential access to production of goods and services as the state is the ultimate power controlling them. From a bottom-up perspective, the economy is more internally organized, where the amounts of working capital might be reflected in the size of each household, as one household might employ intensification more strategically to provide advantage to itself over others, creating a dynamic, but uneven course of development.

4.2.2.2. Landesque Capital

Creating landesque capital is the deliberate alteration of a landscape in a way that the newly formed or transformed landscape allows for various levels production (Brookfield 2001; Hakansson and Widgren 2007). This alteration may aim to remove constraints on the landscape or simply to enhance productivity so that production increases (Stone 2001a). Landesque capital types include, irrigation systems (Adams 1981), terraces (M. E. Smith and Price 1994; Morrison 1996; Erickson 2000; Denevan 2001), raised fields (Graffam 1992; Erickson 2000) and others.

Thus, landesque capital may be interpreted as an investment in the land with an expected high return.

Landscape transformation, however, is not restricted to the direct manipulation of the environment. Creating boundaries across the landscape is another possible means of increasing output after restricting the movement of people and animals via pathways and fences. This restriction or regulation of movement helps minimize disturbance during production and harvesting. Restrictions may be forcefully or socially imposed (Dovey 1999) so that control over movement can be satisfied without necessarily creating physical markers over the landscape, and thus, without an input of working capital. Therefore, there also exists means to increase production without spending capital, yet still creating landesque capital. It is therefore possible to argue that landesque and working capital forms of intensification conform to each other in some respects and diverge in other ways.

For example, manuring is a form of capital that has both working and landesque connotations. The practice may be defined as deliberately transforming the soil by adding organic matter in order to produce a higher agricultural output. Archaeological evidence suggests that this practice was performed in various parts of the world with considerable success (Wilkinson 1989; Bintliff and Snodgrass 1988; Wilkinson 1994; Bintliff 2005; Jones 2005). The ways organic material is collected for manuring, the spaces where manure was stored, and the labor used for applying manure to the soil can all be regarded as working capital for agricultural intensification, and treatment of soil with manure creates landesque capital. Agricultural soil, enhanced for production via manuring, is constantly being worked and produced (Widgren 2007); it is not a static entity (Brookfield 1972, 43). In fact, soil is manufactured and it is the main form of landesque capital, making the core of agricultural landscape.

From a theoretical perspective, it can be argued that working capital is fixed in time, but fluid in space. Following an opposite path, landesque capital is fixed in space, but fluid in time (Widgren 2007). The spatial fluidity of working capital indicates that as production becomes more reliant on input, the variation of capital becomes a crucially determinant factor in agricultural production. Temporal fluidity of landesque capital suggests that intensification decisions made at a given point in time influence future agricultural decisions. For instance, a forced increase in the production capacity of the soil may last longer than it was intended, while over-production through manuring depletes soil fertility, and thus, future agricultural decisions are affected by it. Thus, manuring as working capital also constantly acts to create landesque capital.

4.2.3. Measuring Intensification

Considering the complexity of interaction between intensification incentives, multiple paths that ancient intensification might have followed, and the multiplicity of capital forms, developing methodologies for measuring intensification is a challenging endeavor. Studies of ancient intensification have at least two inherent problems. First, the intensification of agricultural production must have contained a heterogeneous set of strategies so that no single measure by itself can accurately isolate a specific intensification strategy. Second, what archaeologists observe today is a palimpsest of past intensification efforts so that tight chronological control is required. Considering the difficulties in absolute dating of landscape features, this need for high temporal resolution will rarely be satisfied.

Brookfield (2001, 182) measures intensification by fallow length, working hours, and the amount of off-farm work. Leaf (1987) explores intensification via spatial measurements such as the area under irrigation, deviations from carrying capacity, calorific measurements such as population density and consumption per area, and economic measurements such as input-output ratios per area. Marston (2011) suggests that two main markers of intensification are visible in the archaeological record. The first marker is the size of space both for storage vessels and buildings. Larger use of space for keeping excess production is considered as a proxy for overproduction. These features are detectable in the archaeological record unless composed of perishable material. The second marker is animal fodder, regarded as the transformation of overproduced perishable material into meat, which can be consumed at will. Schurr and Schoeninger (1995, 323) contribute to the discussion by suggesting that technological advances, forest clearance, variations in phenotypic diversity of cultigens, and studies on the contents of human bone collagen can also be used for measuring agricultural intensification. Morrison (1996) uses regional settlement data, pollen and charcoal analysis, and historical records to understand the levels of agricultural production in Vijayanagara of southern India. Her study emphasizes the complexity of production when the intensification process followed multiple cross-cutting paths resulting in a diverse agricultural system.

The spatial configuration of a settlement pattern in relation to the economy may also be used to understand the level of intensification. Under labor reciprocity, intensive agriculture may require a pattern favoring an agglomeration of households (Stone 1992), resulting in a clustering of settlements (Erickson 2000, 326). However, Netting (1993) suggests that household level intensive agriculture produces a dispersed settlement pattern with a high regional population. Similar arguments have been made for Mesoamerican landscapes (Drennan 1988).

A critical understanding of ancient agricultural intensification relies on the accuracy of archaeological evidence, and this evidence is usually scarce. When available, to what extent it can be translated into intensification measures such as fallow length or working hours remains problematic. In acknowledging this problem, studies of ancient intensification usually involve exploring spatial manifestations of agricultural production. Through the analysis of irrigation channels, cisterns, field boundaries, terraces, water-harvesting systems, and other related elements of the landscape, scholars explore ancient agricultural production systems. These elements all constitute working and landesque capital. If one can understand the relationship between these capital investments and the context of capital production, then intensification can be approached as a process, and may in fact, be visible in ancient productive landscapes.

4.3. Early Bronze Age Agricultural Intensification in Upper Mesopotamia

4.3.1. Settings of Agricultural Production

Agricultural production in Upper Mesopotamia during the second half of the third millennium was composed of environmental, social, political and economic relationships. It is not possible to reveal these complex relationships in their entirety in a single study, but a brief summary of productive settings helps to put intensification in context.

During the Early Bronze Age, agricultural production in Upper Mesopotamia was primarily rain-fed (Wilkinson 1994). Archaeobotanical evidence suggests that the main staple group was wheat and barley, although barley was dominating production (Miller 1997; Van Zeist 2003; Hald and Charles 2008). Agricultural economy interacted with other productive economies including pastoralism (Szuchman 2009) and textile manufacture (Biga 2010). The ingenuity in agricultural decision making and practice made it possible for the inhabitants of Upper Mesopotamia to establish large settlements, even with the limitations of rain-fed agriculture. Wilkinson (1997) proposes four different methods of dry-farming in this area. These are annual planting, planting with fallowing, annual planting with manuring, planting with manuring and fallowing. Each strategy provides a different amount of output at the end of a production cycle (*ibid.*).

According to Weiss (1986), dry-farming in Upper Mesopotamia had the potential to produce considerably higher aggregate yields when compared to Southern Mesopotamia, even though agricultural output per unit area was historically higher in the south. This is due to access to large extents of land around Upper Mesopotamian settlements. In Southern Mesopotamia, access was constrained by the limits of irrigation. Conversely, in Upper Mesopotamia the transportation of staples was crippled due to a lack of efficient modes of movement, which must have increased the cost of transportation drastically (see Wilkinson 1994, 501 for a possible exceptional case for Tell es-Sweyhat). In the south, however, river systems and associated man-made canals must have made the use of boats possible thus bulk transportation easier (Algaze 2008, 126)

Land ownership and tenure are also highly relevant to agricultural production. Evidence of these practices for Upper Mesopotamian mid-to-late Early Bronze Age is scarce, whereas for the same time period, Southern Mesopotamia provides extensive information about forms of possession of arable land and its related economic dynamics (Renger 1995; Van Driel 2000). Agricultural production in the Sassanid Empire (4th – 7th centuries CE) also provides significant insights for intensification strategies, landesque capital and the logic of an empire. These examples are further discussed later in this chapter, but for the moment, the focus is on the most common unit of agricultural production: the crop.

4.3.1.1. The Crop

Barley was the main cereal product throughout the Early and Middle Bronze Ages in Upper Mesopotamia (Riehl and Deckers 2012a, 15). Barley requires less water when compared to other crop types (Choi and Min 1982), is more resistant to salinity, and has a higher tolerance for poor soils. Furthermore, it completes its growing cycle earlier than wheat so that it is less prone to damage due to water-deficit conditions of summer months (Riehl, Bryson, and Pustovoytov 2008, 1012). There are other examples of barley dominating agricultural taxa in similar environmental conditions in other parts of the world. For instance, barley production was also higher in southern Greece during the later Neolithic when the soil was thin and edaphic conditions may not have been as favorable for more demanding wheat crops (J. M. Hansen 1988, 43). In other studies, barley has been introduced as a drought tolerant species, suitable for arid environments (e.g., Shakhatreh et al. 2001; Bekele, Alemayehu, and Lakew 2005).

The domination of barley is attested at various settlements spanning a large area (e.g., Tell es-Sweyhat: Miller 1997; Tell Brak: Hald and Charles 2008; Bderi: Van Zeist 2003) albeit in different ratios. In their analysis, McCorriston and Weisberg (2002) show an increase in the barley-processing debris as the climate became drier during the late 3rd and early 2nd millennia BCE. Their study also reveals a spatial trend where settlements to the south of Upper Mesopotamia had a larger ratio of barley with respect to other staples, suggesting the choice for barley production is not accidental, but an attempt to farm in a drier climate. However, establishing a causal relationship between climate and production is again problematic. One should always consider the possibility of changes in economy, social structure, or even a simple shift in the diet as determinants of production (e.g., D. Oates and Oates 2001a, 394). The transition to barley as a staple might have been due to a cultural transition in the eating habits of the urban Bronze Age inhabitants. Or, changing emergent conditions in society might have necessitated the production of other foodstuffs such as beer, barley being the main ingredient. Beer as a commodity might have been used as an incentive for the mobilization of labor. At

Ebla, beer production and distribution as a commodity is well-documented (Archi 2002, 6). The relation between agricultural production and a pastoral economy suggests that barley might have also been used as animal fodder (Porter 2012). Agricultural product, stored as meat, might have been consumed during gatherings, feasts, and other significant events. The importance of such gatherings for community organization is well attested, especially when the community is emergent rather than centralized. In another study, McCorriston (1997) relates the increase in barley production to the textiles. The transition from textile fiber to wool must have opened up more space for agricultural production since flax production was no longer required (J. McCorriston 1997). McCorriston also suggests that following this transition, production was extensified to exploit more land. This proposed extensificiation model must have had drastic impacts on the political economies of Early Bronze Age societies (*ibid.*).

4.3.2. Intensification of Production

In the Middle East, agricultural intensification is observed in different agro-ecological zones as well as for different time periods. Both working and landesque capitals had their roles in the intensification process and created their many marks on the landscape in the form of sherd scatters, hollow ways, terraces, cisterns, cairns, and alike.

Bronze Age Southern Mesopotamia is exemplary for its extensive network of irrigation channels, providing a production increase in an area with limited arable land (Adams 1981) (Algaze 2008). The Third Dynasty of Ur (21st to 20th centuries BCE) in Southern Mesopotamia was characterized by centralization and hierarchical authority with bureaucratic state regulated irrigation agriculture, harvesting, and sowing. Furthermore, state-run textile production constituted an important part of the economy which must have required a constant upkeep of herds in massive numbers —or at least access to the commodities of pastoral economy was possible to sustain textile production. Settlement pattern data from the area suggests a large number of people were living in the alluvial plains of Southern Mesopotamia. The necessity of feeding human and animal populations put immense pressure on the agricultural landscape.

Yet in fact, the biggest problem Third Dynasty of Ur faced was continuous environmental deterioration due to irrigation (Redman 1999, 136) —the marker of agricultural intensification. To sustain the operations of the extremely bureaucratic system, stable production was necessary. Unpredictable variation in the flow of Euphrates River led to excessive watering whenever possible in order to cope with the uncertainty of agricultural production. This practice greatly aggravated salinization due low permeability of soils in the area (Jacobsen and Adams 1958). Before the advent of Ur III state in the third millennium BCE, soil was able to produce crops as high as ~2000 liters per hectare. Production was reduced to ~1100 liters per hectare at the end of the millennium (Tainter 2000, 12). To compensate for this reduction as well as to support the bureaucratic apparatus of the state, production was further intensified, resulting in the eventual collapse of production. When the bureaucratic apparatus itself finally collapsed, production potential was reduced to ~700 liters per hectare. Thus, the means of production which enabled a large bureaucratic system to prosper simultaneously undermined the system itself.

Another example of agricultural intensification in the region comes from the Sassanid Period in Iran (224-642) (Alizadeh, Pahlavani, and Sadrnia 2002) . High agricultural output was the main source of the Sassanid Empire’s own prosperity. In a cyclical process, more revenue was required for imperial expansion, and as it expanded more, the Empire had to be sustained with more production. The necessity for constant increases in production required building large-scale infrastructure, including dams, wells, and massive canal systems (Adams 1978). Significantly, there was a dedicated sector in the Empire, overseeing constructions and maintenance of irrigation projects. For example, the massive Nahrawan Canal built in the 6th century CE by the Sassanid was in constant use up until the Abbasid 10th century (Morony 1997)

The fall of the Sassanid Empire is due to a complex set of factors. Certainly however, the necessary labor for maintaining and operating the complex agricultural system ceased to exist as expansion of the Empire slowed. In this case, it was neither the human induced environmental degradation nor climate change that shook the foundations of the Empire. The political system had to grow constantly, conforming to the internal logic of an empire. Thus, it had to produce more and more through intensification. But eventually, the high operational cost of this complex production schema made imperial operations unmanageable, and the Empire fell (Adams 1978, 333).

These two examples reveal the complexity behind the intensification process and show its ties to the political economy. Any discussion on agricultural intensification, therefore, should provide an attempt to expose this dynamic setting within the context of socio-political and economic conditions. For archaeological case studies, the investigation includes the study of possible incentives of intensification, archaeological evidences of these incentives and historical processes which must have created these evidences.

4.3.3. Incentives of Intensification during the mid-to-late Early Bronze Age

There are at least four possible processes related to the intensification of production by the second half of the third millennium BCE. First and the foremost is urbanization which changed settlement relations and many other aspects of daily life. A second, external pressure must have been due to the presence of the Akkadian Empire in the area. Third, the trend towards climatic aridity that peaked towards the end of the millennium may have driven decisions to intensify production. Finally, changes in the socio-political structure of Early Bronze Age communities might have created economies around intensified barley production.

As an overarching process, urbanization must have had a key role in the decision to intensify agricultural production during the second half of the third millennium. If strict urban-rural dichotomy is a valid theoretical framework for the Early Bronze Age, then there must have existed settlements with many inhabitants who did not participate in agricultural production (Rosen 1997, 94). Production was intensified either due to an increasing population at specific settlements or due to the need to support emerging elites and bureaucrats. Furthermore, considering the difficulty of bulk transportation between settlements in Upper Mesopotamia, one can easily assume that production was local, or at least that foodstuffs were imported only from immediate urban hinterland, when and if needed.

Following Wilkinson (1994), it can be suggested that urbanized Early Bronze Age settlements with production territories larger than hypothetically necessary to support their populations were surplus generators, and conversely, settlements with agricultural extents less than hypothetically necessary required inflow. In this framework, settlements at the top of their hierarchy were usually in need of excess foodstuffs. To obtain increased output, either more land would have been exploited or production would be intensified. In a dense and nucleated settlement pattern, as was the case for the mid-to-late Early Bronze Age, land availability must have been problematic. For example, Stein and Wattenmaker (2003, 365) show significant overlaps between sustaining areas for settlements in the Tell Leilan hinterland, suggesting that space was a constraining agent in production. In order to sustain the urban settlement system, production might have been intensified to cope with the limiting factors of the dense settlement pattern. (In support of this argument, see Chapter 6: The Boundary Problem).

Another incentive for intensification of production could have been political. Regional powers or powerful centers might have imposed or requested tribute payments in the form of staple crops from other settlements (Cooper 2010). In return, these communities, under the hegemony of the central power, might have intensified production without any internal population pressure of their own. In this respect, regional Akkadian presence in Upper Mesopotamia or Ebla as a player in the region might have provided an impetus for intensification.

However, the nature of foreign political domination determines whether that power exploited the region for its agricultural productivity. The character of the Akkadian presence in Upper Mesopotamia is problematic. Hegemonic Akkadian influence is yet to be shown (See Chapter 2), while to what extent other powerful centers, such as Ebla, had direct or indirect influence on Upper Mesopotamian productive landscapes has to be elaborated. Specifically, Ebla and Nagar communities, settled in two prolific mounded settlements, were in relation. It is archaeologically well attested that Nagar sent diplomatic gifts to Ebla (Archi 1998). High quality textiles were luxury items and they were exchanged as marriage gifts between two households of Ebla and Nagar (*ibid.*). To maintain this relationship, production in Tell Brak as well as in Ebla might have intensified, resulting in changes in agricultural production strategies. More barley might have produced in order to support of wool production and textile extensificiation (J. McCorriston 1997).

Another possible incentive for intensification in Upper Mesopotamia is related to changing climate. Climate controls the success of rain-fed agriculture, and variations in climate may therefore result in changes or adjustments in production strategies. A trend towards more arid conditions is evident during the mid-to-late Early Bronze Age. Furthermore, coupled with limited arable land and the increasing population/labor specialization which might have accompanied urbanization, the impact of aridification might have been amplified. Even though production responses to climate change must have been spatially diverse, the general trend towards drier conditions must have had an effect on production strategies. A consumer city would have considerable difficulty absorbing production fluctuations occurring in its countryside, as it was dependent on agricultural surplus, produced externally.

Changes in the political economy could have been an incentive for intensification. In this respect, (J. McCorriston 1997) provides an illuminating example from southern Mesopotamia. She suggests changes in textile production might have influenced or even initiated agricultural intensification. Once textile production had shifted from linen to wool, more agricultural space opened for production of other agricultural staples. In using this open space, some households might have intensified their production of cereals (*ibid.:525*).

The relationship between textile production and agricultural production is evident in epigraphical data. Akkadian texts from Tell Beydar suggest grain was used as animal fodder (Van Lerberghe 1996). It is possible that this practice was necessary to sustain wool processing for the production of textiles. With this change, more land was dedicated for staples with the purpose of feeding animals and less land for feeding people. Thus, production must have been intensified to cope with the calorific needs of human populations and to sustain the relations of political economy.

Finally, Porter (2012) extends the role of pastoral economy into a larger domain and creates a wider connection between sedentary and mobile communities of Early Bronze Age. In doing so, Porter (2012) attaches a pivotal role to pastoralism in general, and thus, the current understanding on agricultural production and its related economies require reevaluations through her model. Furthermore, Casana (2012) reminds scholars for the large flock sizes creating hollow ways around nucleated tell settlements. This fully integrated political economy might have included more variables and determinants than select economies, such as textile production. Thus, intensification of agricultural production might have also had more variables and incentives, if pastoral economy was also an important component of the regional political economy. Overall, cooperation, compromise and conflict built around multiple production relations as well as the separation and integration of society based on gender, household and community identity, divisions must have resulted in a complex set of incentives of intensification.

4.3.4. Agricultural Evidence for Intensification in Upper Mesopotamia

4.3.4.1. Sherd Scatters

Land use intensity determines the level of modification in soil structure (Plue et al. 2009). Differential treatment of soil based on different land use strategies results in local structural and chemical variations. As part of this treatment, organic material which is added to soil as manure eventually mineralizes into carbon, nitrogen and phosphate, and results in the enrichment of total phosphate levels as organic material decays (Schlezinger and Howes 2000, 479; Holliday and Gartner 2007). To measure this enhancement and thus to determine the intensity of land use geochemical-phosphate analysis can be employed (Eidt 1977; Entwistle, Abrahams, and Dodgshon 2000). In this analysis, high phosphate concentration may indicate intensification. Nevertheless, modern land use practices and variable aeolian deposition over ancient soil conceal useful archaeological data so that measuring Early Bronze Age phosphate levels remains a challenge. As such, a substantial coring methodology along with an extensive knowledge of geomorphological processes may be required to accurately interpret land use characteristics. In the absence of such geoarchaeological data other archaeological proxies for intensification may be used.

Off-site surveys around Tell es-Sweyhat (Wilkinson 2004, 55–81), Tell Beydar (Wilkinson 2002), Hamoukar (Ur 2008) and Tell al-Hawa (Wilkinson and Tucker 1995) have revealed dense sherd scatters surrounding these Early Bronze Age settlement mounds. Scatters, forming halos around the settlements have various densities and extents. Despite alternative interpretations (Alcock, Cherry, and Davis 1994; Weiss and Courty in Wilkinson 1994, 512-514), Wilkinson (1989; 1994) strongly argues that these scatters provide evidence of ancient manuring. In this proposed land use model, ancient agricultural producers applied manure to the fields in order to intensify production, where the manure as composed of night soil as well as discarded broken sherds coming from dumps in the settlement. Since this was a continuous process, the amount of sherds increased over time around settlements, and after the organic matter was depleted, sherds still remained in the fields.

There are other possible models for explaining the sherd scatter phenomenon (Bintliff and Snodgrass 1988). First model blames a “mythical donkey” randomly dropping sherd pieces along its trail and eventually forming random scatters of sherds in the landscape. Second, based on the results of the archaeological surveys in North America, sherd scatters might indicate ancient activity areas. Third model is based on the taphonomic processes which suggest that continuous cultural and natural disturbances might have caused the spread of discrete concentrations and eventually created sherd scatters around the source. In Upper Mesopotamia, first and second models have little explanatory power since observed scatters around mounded settlements has considerably high densities which exceed the potential of random occurrences and low level domestic and non-domestic activities. Taphonomic model might explain sherd scatters to some degree, but differential densities in relatively homogenous geomorphology rather indicates preferential deposition practices. This suggests the majority of variation in scatter densities is due to anthropomorphic process. Like Wilkinson (1994), Bintliff and Snodgrass (1988) suggests this anthropomorphic process is mainly based on spreading animal and human excrement together with the household refuse for manuring purposes.

Lack of diagnostic pieces in scatter assemblages makes it difficult to assign a date to these scatters. In the absence of diagnostics, association with other features may be used for archaeological dating. In this regard, nucleated tell-based settlements provide this association, suggesting that most sherd scatters are an Early Bronze Age phenomenon. Or at the very least, it can be suggested that manuring was also practiced during the Early Bronze Age since most of the mounds with scatters around them had an Early Bronze Age occupation on them. To further complicate the matter, the millennium-long Early Bronze Age provides a coarse setting for the analysis. However, there is no clear indication for intensifying agricultural production during the first half of the Early Bronze Age. In contrast, urbanization, climate change, the Akkadian influence, and changes in the political economies are all potentially incentives for intensification at the second half of the third millennium BCE. Therefore, if the scatters are dated to the Early Bronze Age, they likely belong to mid-to-late Early Bronze Age.

4.3.4.2. Hollow Ways

The other landscape signature in Upper Mesopotamia which is related to agricultural intensification is so-called the hollow way. Hollow ways are recess linear features in the region crosscutting the landscape at different lengths and angles. In some cases, they radiate from settlements, and bifurcate after a distance, averaging 2.5 to 3 kilometers. In other cases, they extend further into the landscape, connecting settlements to one another. They can also be documented running across the landscape with no association to identified settlements, suggesting differential preservation conditions (Figure 4.1.).

Figure 4.1. Hollow ways radiating from Tell Brak

Wilkinson (1994) suggests that hollow ways were used for controlled transportation of flocks from settlements to open pasture land. While moving, livestock was kept in groups to minimize crop damage, and when the agricultural production boundary was passed, flocks were dispersed in open pasture land. As a result of continuous use by animals and humans, linear depressions around settlements were formed, and the evidence for ancient movement still survives today (Ur 2003). Some scholars argue that a hollow way is the result of a hydro-compaction process where the rupturing of fine soil material initiates the formation of shallow gully (Tsoar and Yekutieli 1993). Others argue that these depressions were components of man-made drainage systems (McClellan, Grayson, and Oglesby 2000). However, geoarchaeological (Wilkinson et al. 2010), environmental (Deckers and Riehl 2008), and landscape studies (Ur and Wilkinson 2008; Casana 2012) in Upper Mesopotamia suggests that these radial and linear systems were indeed the artifacts of past movement.

As in the case for sherd scatters, dating hollow ways is problematic. There is no secure absolute dating method for landscape features, and thus only relative dating is used for these features. In this respect, yet another relationship can be established between tells and hollow ways. There are very few examples of hollow ways radiating from settlement types other than mounds, and again, in only very few cases they connect non-mounded settlements. Thus, hollow ways were products of socio-economic activities of societies, living on tells (Casana 2012). Furthermore, some hollow ways are documented around mounded settlements with no occupation after Early Bronze Age. Therefore, these hollow ways were in use —at least as early as Early Bronze Age.

However, a recent study reveals a much more complex picture of the use of hollow ways in different time periods. Casana (2012) provide clues for the association between hollow ways and archaeological sites dated to the Iron Age, Roman and early Medieval periods across a larger region than Upper Mesopotamia. According to him, different economical systems as well as the structure of sedentary life style determines the formation of hollow ways, but taphonomic processes in various parts of the Near East also affects these off-site features appear in different morphological forms (*ibid.*).

Despite this complexity, dating hollow ways to the mid-to-late Early Bronze Age remains as a plausible hypothesis for Upper Mesopotamia. First, and the most, urban Early Bronze Age populations, concentrated in tell settlements must have had the capacity to provide the volume to generate hollow ways. In later times, settlements were morphologically more dispersed on the landscape, forming complex low mounds (e.g., Wilkinson and Tucker 1995; Wilkinson 2002). Such urban morphology is less likely to be responsible for the formation of hollow ways. Non-mounded settlements also dominated later occupational styles (Wilkinson, Ur, and Casana 2004, 191). Following these observations, it can be suggested that later settlements had morphologies which would have supported lower population densities, and thus, lacked of the sources for large concentrated movements across the landscape. Without such volume of traffic, concentrated in nucleated settlements, no such hollow way could have formed (Casana 2012).

4.3.5. Implications

Both ancient manuring and movement along the hollow ways lasted throughout the second half of the third millennium BCE up until the end of the same millennium. In this long duration, intensification created distinct signatures on the landscape, and they can be considered as the material evidence of the landesque capital that went into production. Signatures have been investigated via archaeological surveys (Wilkinson and Tucker 1995), remote sensing (Ur 2003; Casana 2012) as well as geoarchaeological studies (Wilkinson et al. 2010). These archaeological studies provide a comprehensive understanding on spatial aspects of intensification.

Sherd scatters and hollow ways are important landscape elements since they also provide possibilities to understand intensification as a process. Both sherd scatters and hollow ways are the results of individuals' constant action with specific aims. Sherd scatters are the result of frequent manuring and hollow ways are formed out of constant, but controlled movement to and from settlements.

Perimetrics is a term which is used to define a geometric property of a plane. It denotes boundary properties of a feature and measures how clearly one area is separated from another. Following this definition, Stone (1994, 317) identifies two types of perimetrics for intensive agriculture. Pure perimetrics are physically constructed markers informing people about the boundaries of access and movement. Latent perimetrics, on the other hand are also markers, but do not carry the purpose of a marker. Yet, they still contain embedded information on the location of boundaries. Cultural features such as agricultural terraces or natural features like rivers help or dictate movement in the landscape. In this regard, hollow ways can be considered as latent perimetrics, and thus, they hold implications with respect to intensification strategies.

If the extent of hollow ways are considered to be latent perimetrics, and assuming a circular production area around each settlement with an average radius of 3km, then it can be determined that ca.2800 ha was dedicated to agricultural production minus the area of the actual settlement and hollow ways. Sherd scatters around settlements are generally limited to the first few kilometers beyond the settlement boundary (Wilkinson 1994).

The amount of manure required per unit area is based on the chemical content of the manure, the type of animal which produces dung, soil type, crop type and fallowing/rotation strategy. As a specific example for a wheat crop, Araji, Abdo, and Joyce (2001) suggests an optimum manure rate application between 4 and 72 metric tons of cow manure per hectare depending on soil and rotation type. To continue with a conservative estimate, 4 metric tons/ha of manure can be taken as an estimator. To make the estimation even more conservative; if dung only makes only half of the organic additives and the rest being composed of night soils and domestic garbage, then the total amount of dung required for intensive agriculture for an average settlement (with 1km radius of manuring) was 730 metric tons. Considering that manure was only applied to soil at specific times during the growing season, collecting and storing 730 metric tons of manure must have constituted a managerial problem.

This argument excludes the possibility of manure coming from different sources. A pastoral nomadic economy coexisted with the urban settlements in Upper Mesopotamia. It is possible that through economic arrangements, settlements might have opened their fields for grazing and in doing so manuring might have established (J. McCorriston 1997, 525). Giving use rights might also have opened up other possibilities of interaction in social settings, bolstering the model proposed by Porter (2012).

If Early Bronze Age societies were organized around a strictly centralized hierarchical system where agricultural products were redistributed by that system then it is also likely that manuring, as a service, was also managed by the same system. However, not only there is no direct archaeological evidence for the existence of mid-to-late Early Bronze Age centralized agricultural storage facilities, but studies have not revealed any manure storage spaces. Therefore, it can be argued that either the central power was not interested in managing this commodity despite its high use-value, or that the political economy was not organized in a strictly hierarchical way such that no public storage was necessary. Ur and Colantoni (2010) argue that animal wastes were probably collected in domestic courtyards so that manuring was a practice organized at the household level. However, manure odor and manuring-related pathogens must have been a problem just as they are today. If there was a central authority, it might have arranged storage away from settlements for sanitary reasons. In other words, absence of evidence for storage cannot be immediately taken as an evidence for absence so that the “redistribution of manure as a commodity” under a central authority cannot be refuted immediately.

Independent of which incentive or incentives were in effect for Upper Mesopotamian intensification or in whichever ways working and landesque capital were included in the intensification process, inferences to be made depends on the structure of political economies. Assuming a political organization which was lacking centralized power, Early Bronze Age households, as basic socio-political units in the society, might have been competing and cooperating with each other for prestige, status, and wealth. In turn, these competition and cooperation relations might have been influenced by the social sphere of their community while creating the very conditions of the political economy for agricultural production. In other words, these households might have determined their own levels of intensification regardless of the complexity of the society on which they existed (Netting, 1993). However, it is unlikely that households would have made these decisions independently of each other (Johnson, 1980). Animal sacrifices for status gain, excessive production for festivities, and commodity exchange between the households residing in the same or different settlements were all partial incentives for intensification.

If a central authoritarian power (local or external) was in charge of regulating agricultural practices, then it wouldn’t be surprising to observe agricultural intensification as well. Local authorities must have acquired significant amounts of agricultural input from non-urban settlements. Or, if the Akkadian presence in Upper Mesopotamia was indeed authoritarian in nature, then economic pressure must have been an involuntary incentive for intensification for central authorities in Upper Mesopotamia and for their domains.

Regardless of the direction of the power, hierarchical or household level, or even a combination of those, urbanization must have introduced segregation into different spheres of the economy. Either a forced or organic division of labor must have been necessary to sustain urbanism at its peak. And, intensification of production might have provided the stimulus for divisions in labor and gender (J. McCorriston 1997). Nevertheless, economic coherence must have been the goal since stability and predictability were required to sustain an urban system, as argued in the proceeding chapters. Regarding the intensification of agricultural production, urbanization would have increased the amount of delayed return which was embedded into the economy, necessitating improvements in storage technologies as well as various forms of redistribution, particularly when staples were scarce. Furthermore, the need to keep manure usable and accessible as well as distribution restrictions forced or socially-emerging movement constrictions must have had immediate and long term impacts on mid-to-late Early Bronze Age societies. The character of these impacts is yet to be determined.

As the discussion above suggests, incentives of intensification during Early Bronze Age were tightly knitted to each other, creating complex conditions of ancient fallowing, manuring, and land use. In studying these conditions, available environmental and archaeological data is still limited, despite the long research history in Upper Mesopotamia. Scholarly discussions which are related to the overarching theories of socio-political structure (e.g., authoritarian state vs. emergent household models), urbanism (e.g., distinct urban and rural settlements vs. ancient city as an extended village), and environment (e.g., 4.2kBP as a causal event vs. non-determinist models) dictate the ways in which intensification is theorized.

There is one substantial problem in studying agricultural intensification for ancient societies. The product itself remains unknown. Therefore, discussions on surplus production and its distribution among settlements come without empirical models. Without knowing how much staples were available at a settlement in a given year, structure of ancient dry-farming economies will be limited for testing its theories. Upper Mesopotamia during Early Bronze Age provides clear evidence for ancient intensification efforts. Sherd scatters and hollow ways indicate spatial extents of intensification. Thus, it is possible to model ancient production territories accurately. If this spatial model can be coupled with precipitation data, estimating ancient production levels becomes a possibility. Paleoclimatic studies in and around Upper Mesopotamia provide means for a reconstruction of paleoprecipitation. Proceeding chapters now will explain this methodology in detail.

CHAPTER 5: Precipitation as the Agent of Rain-Fed Agricultural Production Systems

5.1. (Paleo)environmental Data

Understanding immediate effects of climate variability on human societies requires high resolution data. Variability at seasonal, annual, inter-annual, and decadal scales has the most impact on the decisions of everyday life when compared with variability at longer temporal cycles. If there is an element of causality in human-environment relationship then it is the climate shifts at smaller scales that humans respond to. As the scale gets larger, the role of human agency in adapting climate variability becomes less visible in the archaeological record.

For instance, drought, as an active agent of production, is due to a combination of small scale climate variability and catchment properties of the region, but also operates under larger climate cycles, determining the spatial and temporal characteristics of drought (Tallaksen and Stahl 2012). Depending on the magnitude of drought as well as the structure of a political economy for its coping mechanisms with drought, ancient societies must have rearranged their agricultural production and production relations under new socio-environmental conditions.

Wilkinson (1997, 75) suggests that during the third millennium BCE in Upper Mesopotamia five or ten major droughts might have hit agricultural production. It is also widely accepted that the sharp transition from wheat to drought tolerant barley (Miller 1997; Van Zeist 2003; Hald and Charles 2008) was part of the coping process with drying conditions of the second half of the third millennium BCE (Wilkinson 1997; Riehl and Deckers 2012).

Seasonal, annual, inter-annual, and decadal climatic events become part of the archaeological record, and provide broad information for the paleoenvironmental conditions. However, the ability to detect small scale variation in the environmental record, for instance episodic droughts in Upper Mesopotamia during the third millennium BCE, mostly depends on the power of instrumentation, sampling strategy, and a robust model of proxy environmental data. Such data with high temporal resolution is rarely available for archaeologists; only in exceptional cases, rich paleoclimatic data support accurate annual reconstructions of climate in relation to archaeological record (e.g., Gumerman et al. 2003).

Estimating agricultural production requires the knowledge of local climatic and geographic conditions at a given time as well as the ways in which production is performed. In Upper Mesopotamia, archaeological (Wilkinson 1994) and epigraphical studies (e.g., Widell 2004) provide invaluable information on ancient agricultural practice during the third millennium BCE. However, most paleoenvironmental data in the region offer only coarse reconstructions of the ancient climate (e.g., Lemcke and Sturm 1997; Deckers and Riehl 2008). The shift in climate is usually documented at a centurial scale, if not multiple centuries. But, this large scale does not permit an in-depth temporal analysis of events, such as decadal droughts.

Another problem with a low resolution environmental dataset is its inability to separate local climatic highs and lows from the general trend. When plotted on a timeline, climatic data may show significant shifts from earlier centuries, yet the processes which generated these main trends remain hidden in short-scale shifts. Without an understanding of short-scale shifts, environmental explanations of social change will always remain speculative since the intensity of environmental impact may always be absorbed by social systems, and thus, become invisible in the archaeological record.

Despite the gloomy picture drawn above, there are ways to overcome the inefficiency of paleoenvironmental reconstructions in explaining climatic variability in short-scales. In support of this claim, this dissertation is based on a methodology which uses modern climatic data in collaboration with paleoclimatic data. The first aim is to understand physical conditions of current day agricultural production with the help of high resolution modern environmental data. The second aim is to project this understanding back to the Early Bronze Age production conditions. Such projection requires making two main assumptions. First, ancient and modern day climate patterns does not significantly diverge from each other. Second, the relationship between climate and the amount of production can be comparable for different time periods.

Upper Mesopotamian climate is determined by the interactions among Asian monsoon systems (Gupta, Anderson, and Overpeck 2003), the North Atlantic Oscillation (Cullen and deMenocal 2000) and Caspian-Black Sea westerlies (Alpert, Neemn, and Shay-El 1990). The dynamic character of this interaction is constantly under motion in centurial and millennial cycles and so does the track of cyclone paths change which is the main responsible system for the rain-fall in the area. Without long term high precision instrumental data, the complexity of climate systems prohibits constructing accurate climate models, but they mostly rely on simulations. Thus, in the current stage of climate science, the assumption on the relevance of past and modern climate remains untestable.

The picture looks more promising for the second assumption which states that the relationship between climate and the amount of production is comparable for different time periods. Wheat and barley is widely documented in the archaeological taxa, and these staples still form the bulk of agricultural production in modern Upper Mesopotamia (NAPC 2006: Syrian Agricultural Database (SAD)). Despite this similarity of the output, the production processes are significantly distinct from each other. Large scale irrigation projects, extensive use of pumps for extracting ground water, and the introduction of chemical fertilizers create a unique modern production schema when compared with dry-farming economies of the Early Bronze Age. The level of production today is determined by a combination of socio-political and economic factors, such as the producer’s access to fertilizers, diesel-fuel, and modern machinery. The capacity of a state to maintain and extend irrigation projects or to subsidize agricultural production is yet another determinant of production. However, this distinction between ancient and modern production should not be assumed, but shown.

According to the World Bank report 22602-SYR (2001) for Syria, irrigation increased from 660,000 to 1,121,300 hectares between 1988 and 1998. This sharp increase in the extent of irrigated land is due to the efforts and development policies of Syrian Arab Republic. However, this statistic is an aggregate value from the whole country, but in fact composed of different agro-climatic zones. Furthermore, the statistic does not give information for specific crop types, and their possible production fluctuations due to irrigation. Syrian Agricultural Database (SAD-GCP/SYR/006/ITA), a joint effort among Food and Agricultural Organization of the United Nations (FAO), *Cooperazione Italiana*, and Ministry of Agricultural and Agrarian Reform of Syrian Arab Republic (NAPC 2006), provide a rich dataset at sub-regional levels. According to SAD, despite the increase in the extents of irrigation agriculture, total barley production statistics reveal interesting results. Data from Al-Hassakeh and Al-Rakka (two Syrian governorates, whose political boundaries fall in rain-fed agro-ecological zone of Upper Mesopotamia) suggest that despite an increase in irrigation practices, rain-fed strategy provided most if not all of barley production (Figure 5.1).

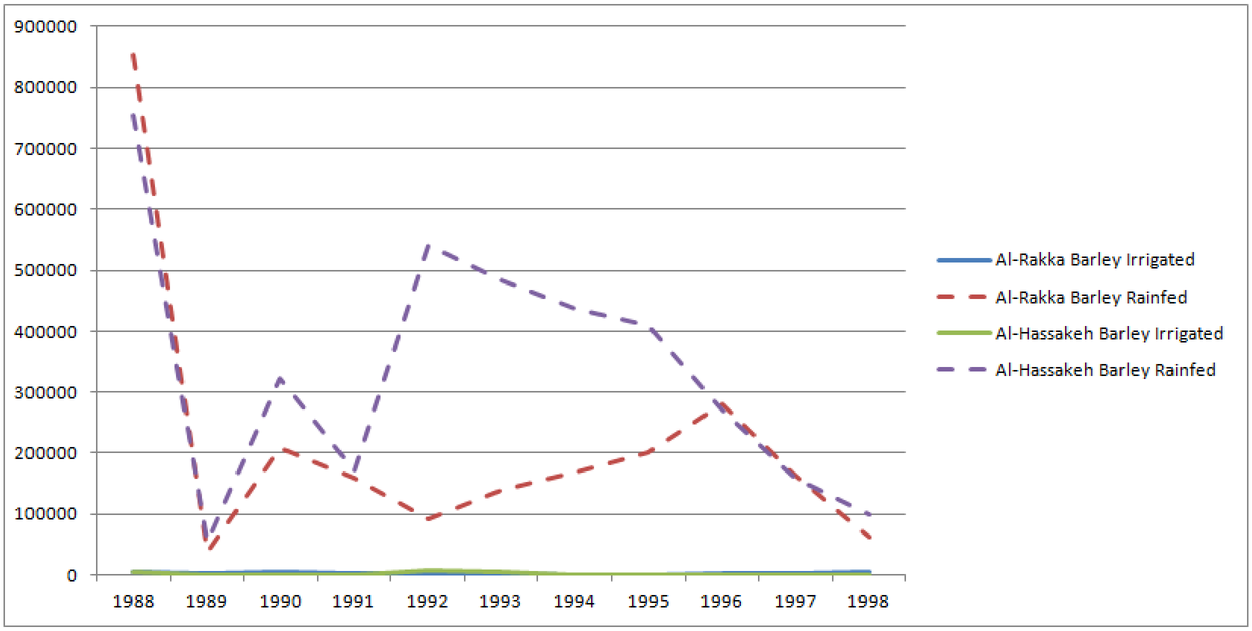

Figure 5.1. Irrigated vs. Rain-fed Barley Production in Upper Mesopotamia (1988-1998)

This observation suggests that despite the initiatives of the Syrian State to increase irrigation agriculture, the bulk of production was still rain-fed in Upper Mesopotamia for the years between 1988 and 1998. It is likely that further developments in the area has already changed this picture (see section 5.5. for an analysis with longer temporal range), but in its current stage of analysis, precipitation is the main variable of production.

5.2. Precipitation as a Climatic Agent and its Role in Human Societies

Precipitation, as one of the main variables of a climate system, is directly relevant to rain-fed agricultural production. It is a complex natural phenomenon which also has multiple scales of variability. Annual and inter-annual shifts in rainfall drastically alter the potential of agricultural production, especially in arid and semi-arid areas (Rosen 2007, 7). If there is no other means to compensate for the loss in production, consecutive years with rainfall levels below the average increase the vulnerability of staple economies.

On the other hand, it is also important to note that ancient societies must also have reacted to larger, decadal scale precipitation variations at institutional levels. For instance, based on historical records, Feliks (1971) and Sperber (1978) report high crop yields in Palestine during the late antiquity. Even though intensification of production must have played an important role in this increase, an intensification strategy would have been challenging in the absence of high precipitation levels. However, archaeological examples from Jordan also show the ingenuity of human societies in developing strategies in the absence of high precipitation (AbdelKhaleq and Ahmed 2007). Deflection dams during the Bronze Age, complex hydraulic systems feeding the town and agricultural fields during the Late Roman period, and large number of cisterns at the Nabataean Humeina made human life possible and flourish under dry climatic conditions (*ibid.*). However, to what extent such water collection efforts can be sufficient for large scale intensification projects remain to be shown.

5.3. Assessment of Precipitation Datasets

Investigating the impact of precipitation variations on agricultural decision making requires a high resolution rainfall dataset. This data resolution is possible after daily, or even hourly, instrumental analysis with a dense sampling pattern. However, instrumental analysis is a modern method, and it is usually far from providing data for the analysis of long-term changes; let alone no instrumental data exists for ancient times. Furthermore, some regions in the world have a sparse distribution of meteorological stations so that precipitation data rarely presents its regime over large geographical areas. But, in order to obtain an accurate representation of precipitation a reliable rainfall data set is required. This dataset should have minimum number of missing values and low measurement errors. Moreover, it is the best if each ecological and geographical unit is represented by a weather station. Unfortunately, not many regions in the Middle East satisfy these conditions.

In order to overcome the insufficiency of available precipitation data, some scholars adopt a remote sensing approach. With satellite data, it is possible to reconstruct high resolution (~1.0 degree) precipitation grids (e.g., Huffman et al. 2001). Despite the power of this new approach, precipitation estimations in arid and semi-arid regions still have basic estimation problems, and Upper Mesopotamia is no exception. Furthermore, a remote sensing approach currently is not able to compensate for orographic effects on precipitation regimes, while the short duration of the temporal dataset does not permit for long term analysis.

5.4. Modern Precipitation in Upper Mesopotamia

In analyzing and reconstructing the modern precipitation regime in Upper Mesopotamia, two precipitation datasets are used. The first dataset is obtained from Global Precipitation Climatology Center (GPCC) at the *Deutscher Wetterdienst*. Detailed analysis of fresh water assessment, agricultural production, surface runoff, climate change and many other subjects require long and reliable time-series data, covering extensive areas. GPCC was established with this motivation. GPCC products include precipitation data with 0.5, 1.0 and 2.5 degree grid-sizes, generated from ca. 67200 weather stations all over the world. The center hosts rainfall data from 1901 to 2010.

The second dataset comes from the National Climatic Data Center (NCDC), which is a part of the National Oceanographic and Atmospheric Agency (NOAA). NCDC data also include other climatic measurements from individual stations in and around Upper Mesopotamia. These data are used to check the accuracy of precipitation reconstructions and to select a suitable interpolation methodology for generating continuous precipitation surfaces.

5.4.1. Grid Data and Interpolation

GPCC employs a series of steps for creating gridded precipitation data. Climatic measurement from stations are used to predict precipitation values at imposed grid locations by a modified version of Spheremap interpolation method (Schneider et al. 2011, 2). This method follows Shepard's empirical weighting schema, and it relies on the availability of high number of observing stations. Therefore, any further analysis of a gridded data should consider the initial reliability of grid data, determined by the number and distribution of weather stations. To facilitate this, GPCC also distributes the number of stations used for estimating values at grid locations.

Distribution of stations used in creating GPCC grid data is uneven in Upper Mesopotamia and for the regions around it (Figure 5.2).

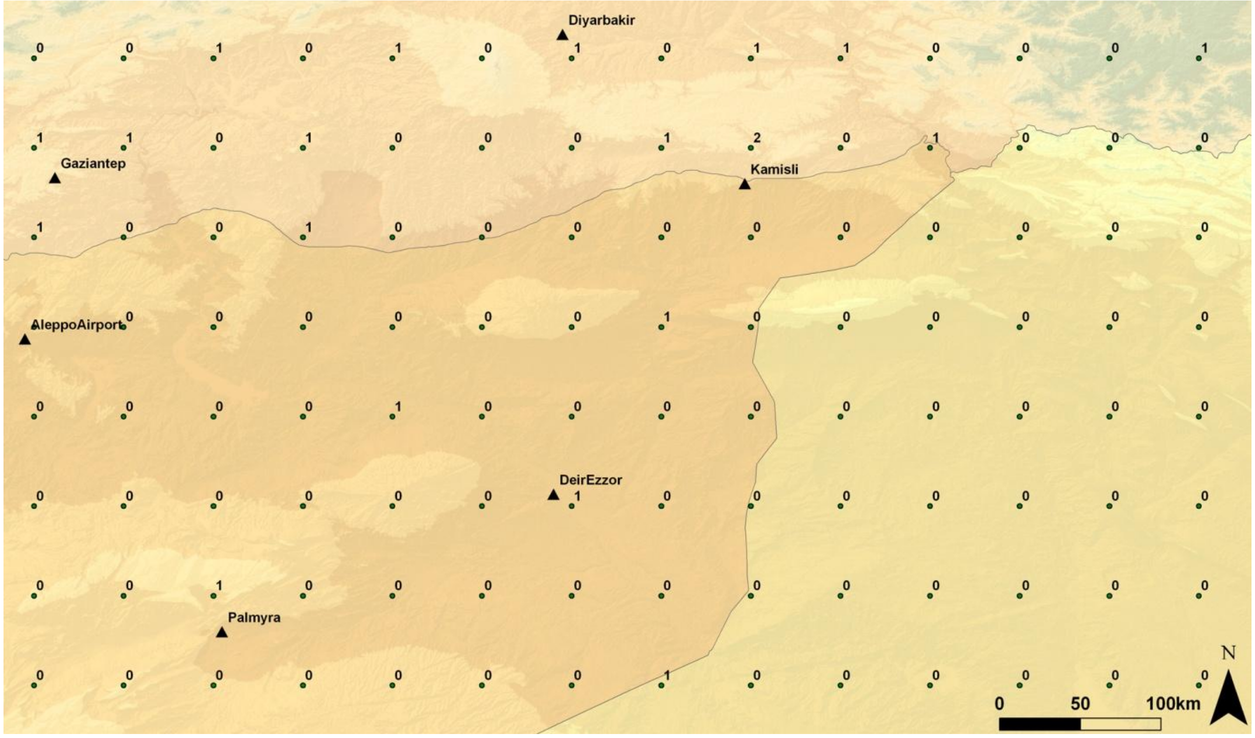

Figure 5.2. Number of stations used in GPCC interpolation

While there is considerable station control for the areas which are close to the Mediterranean, drier inland areas lack robust station coverage so that grid data in these regions are less reliable. This remains as a significant problem since the geographical focus of this study is also on this area. Therefore, an accuracy analysis is needed after the generation of precipitation surfaces with various interpolation methods for the years between 1981 and 2010, and this is where NCDC data provides the most help.

5.4.2. Interpolation of Monthly Precipitation Surfaces

Creating continuous climatic surfaces from location data and accuracy assessment of these models is a developing subject in environmental and meteorological studies (Tveito et al. 2006). A large array of climate data including temperature, wind speed, and humidity can all be treated with various statistical interpolation tools, enabling values at unknown locations to be estimated.

There are a large number of interpolation methodologies with various properties and prediction power. These can be investigated under three main categories: deterministic, probabilistic and deterministic-probabilistic methods. In precipitation studies, deterministic methods include Thiessen polygons (Abtew, Obeysekera, and Shih 1993; Ruelland et al. 2008; Vicente-Serrano, Saz-Sánchez, and Cuadrat 2003), neighbor interpolation (Hofstra et al. 2008; X. Zhang and Srinivasan 2009), inverse-distance weighting (Abtew, Obeysekera, and Shih 1993; Apaydin, Sonmez, and Yildirim 2004; Eischeid et al. 2000; Lloyd 2005; Ruelland et al. 2008; Vicente-Serrano, Saz-Sánchez, and Cuadrat 2003; X. Zhang and Srinivasan 2009), and splines (Abtew, Obeysekera, and Shih 1993; Apaydin, Sonmez, and Yildirim 2004; Hofierka et al. 2002; Ruelland et al. 2008; Vicente-Serrano, Saz-Sánchez, and Cuadrat 2003). In this family, the use of artificial neural networks and genetic algorithms are increasing (e.g., Chang, Lo, and Yu 2005).

Probabilistic methods include optimum interpolation (e.g., Abtew, Obeysekera, and Shih 1993; Eischeid et al. 2000), and a suite of geostatistical tools, called kriging. Various types of kriging are extensively used in creating precipitation surfaces (e.g., Apaydin, Sonmez, and Yildirim 2004; Atkinson and Lloyd 1998; Borga and Vizzaccaro 1997; Carrera-Hernandez and Gaskin 2007; Goovaerts 2000; Haberlandt 2007; Kastelec and Kosmelj 2002; Lloyd 2005; Ruelland et al. 2008; Vicente-Serrano, Saz-Sánchez, and Cuadrat 2003; X. Zhang and Srinivasan 2009). In deterministic-probabilistic methods, climate data are investigated in its time-series form, and trends are analyzed stochastically (e.g., MISH method by Szentimrey, Bihari, and Szalai 2007). Another method in this family, called PRISM, is particularly developed as a knowledge-based global system to produce continuous climate data coverage for the entire world (Di Luzio et al. 2008).

In this dissertation, two deterministic methods (inverse-distance weighting, and natural-neighbor interpolation), and a probabilistic method (ordinary kriging) is used to produce monthly precipitation surfaces for the years between 1981 and 2010 by using GPCC data. Next, processed NOAA precipitation data is used to explore accuracy levels of these interpolations.

5.4.2.1. Inverse-Distance Weighting

Inverse-distance weighting is an efficient interpolation method with some prediction capability. This method’s main premise is based on the similarity of features in close spatial proximities. To put it differently, features spatially close to each other are more similar than features further apart. Therefore, it is possible that a location with an unknown value can be estimated by using locations with known values. Furthermore, as known locations get farther away from the unknown location, they contribute less in calculations, facilitated by using a weighting system. The effect of the distance between known and unknown locations can be adjusted in a way that the distance becomes less or more influential in the interpolation. To define the process mathematically:

$$Z(u) = \frac{1}{\sum_{i=1}^{N} w_i(x)} \sum_{i=1}^{N} w_i(x).Z(x)_i \quad where\ w_i(x) = \frac{1}{d(x, x_i)^p}$$

How much the predictor contributes in calculations is determined by the weight w. Weight w is based on the power p of the Euclidean distance between the points. Thus, according to the formula, as the power of distance increases, the weight on estimation decreases.

Inverse distance weighting interpolation is conducted in ArcGIS 10.0 in batch processing mode, and 360 monthly precipitation surfaces are generated for years between 1981 and 2010. The power p is selected as 0.5 in order to maintain the original values at grid locations as much as possible.

5.4.2.2. Natural Neighbor Interpolation

Natural neighbor interpolation (NNI) is a baseline method which has been widely used by climate researchers as part of their standard mathematical library. Similar to the inverse distance weighting algorithm, the information on the proximity of features is used to estimate locations for their unknown values. However, natural neighborhood interpolation takes account the areas spanned around locations rather than their Euclidean distances as the case in inverse distance weighting. Inverse distance weighting and natural neighborhood interpolation tend to produce similar climatic surfaces. This is especially true for regularly spaced grid data, which is the case for the GPCC precipitation inventory.

NNI uses Thiessen polygons, and polygon geometries to determine the number of interpolators that go into the analysis. NNI is an exact interpolator where it reproduces same values at observation locations. In mathematical terms:

$$G(x,y) = \sum_{i=1}^{n} w_i \,.\, f(x_i, y_i)$$

where G is the estimate at (x,y), and f is the estimator with a weight value of w.

Natural neighbor interpolation of precipitation surfaces are performed in Matlab 2010. GPCC grid data is interpolated for 360 surfaces for the years between 1981 and 2010.

5.4.2.3. Kriging

Kriging is a powerful geostatistical tool which is widely used in interpolation studies. The kriging estimator is a Best Linear Unbiased Estimator (BLUE). These conditions satisfy unbiasedness and minimum variance criteria of an interpolator so that the mean square of error is minimized. These conditions can be given as:

$$E[\hat{z}(x) - z(x)] = 0 \; (unbiased) \; and \; Var[\hat{z}(x) - z(x)] \; is \; minimum$$

In kriging, BLUE from neighboring known points are used to estimate the values at unknown locations. These weights are constrained by a semi-variogram model of the spatial variability of the entire dataset. Semi-variogram expresses variance as a function of distance, and it is defined as:

$$\gamma(h) = \frac{1}{2} . E\{\, [Z(x_i) - Z(x_i + h)]^2\}$$

and $\gamma(h)$ can be estimated by:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} . \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2$$

where N(h) is the number of pairs of observation separated by a lag vector h. Semi-variogram is the base of any kriging interpolator.

In this study, a special form of kriging which is called ordinary kriging is used. Ordinary kriging is more robust when compared to other kriging techniques and it performs better interpolation under non-normality conditions. Ordinary kriging estimates unknown location values by using a linear combination of neighboring locations:

$$Z(u) = \sum_{i=1}^{N} w_{ui}. Z(x_i)$$

The weights are calculated by solving a series of linear functions:

$$\sum_{j=1}^{N} w_{uj\gamma}\,(hij) + \mu(u) = \gamma(h_{ui})\,, i = 1,2, \dots, N$$

$$\sum_{j=1}^{N} w_{uj} = 1$$

where μ(u) is the Lagrange multiplier for the constraints and h is the separation distance between sample locations. Kriging is performed in ArcGIS 10 for monthly precipitation data, and a total of 360 surfaces are generated for the years between 1981 and 2010.

5.4.3. Station Precipitation Data

NCDC hosts climatic data, collected across the globe with different temporal resolutions. Data include daily measurements of temperature, pressure, wind speed, visibility as well as precipitation. Since there is no world-wide standard in climatic data gathering, NCDC also reports reliability of its data. Another problem in the data set is related to the collection times. In some stations, a series of daily values are missing so that monthly statistics created from these stations are not fully representative of climatic conditions. The distribution of stations also creates another problem in accurately representing regional climate. As in the GPCC data, NCDC stations cluster at the western portions of Upper Mesopotamia, and as one moves to the east, the number of stations drops significantly. Also, to the south of Upper Mesopotamia few stations provide reliable climatic information. These temporal and spatial problems make NCDC data not suitable for further analysis so that the dataset is rather used to check the accuracy of interpolated precipitation surfaces in order to select the most suitable method for the GPCC data.

A series of processes are followed to prepare NCDC data for accuracy assessment. First, precipitation data is investigated for possible errors. Double-mass curve analysis (Searcy, Hardison, and Langbein 1960) is used in this step. Briefly, this analysis involves investigating data in time-series, and detecting unexpected breaks in the series as an indication of error. Once these breaks are detected, they are replaced with corrected values. Correction is based on calculated average precipitation around the break. The second step in the process is to determine months with less than 5 missing observation and extract reliable values reported by the NCDC. This increases the value of NCDC data in accuracy checking. Once these months are detected, monthly precipitation averages are calculated from daily values and time-series data are regenerated.

One of the constraints in using gauge data is the need for a homogenous precipitation dataset. Homogeneity of gauge data can be tested by employing the standard normal homogeneity test, the Buishand range test, the Pettit test, or the Von Neumann ratio test (Wijngaard, Klien Tank, and Konnen, 2003). However, homogeneity tests are not performed and Upper Mesopotamian rainfall data are assumed to be homogenous.

5.4.4. Comparison of Interpolated Surfaces

Inverse Distance Weighting, Natural Neighborhood interpolation, and ordinary kriging are used to create monthly precipitation surfaces for the years between 1981 and 2010. For the same time period, NCDC station precipitation data is plotted against three types of interpolation and deviations between interpolated and measured data are investigated.

Visual comparison of root-mean square error between interpolated GPCC surfaces and station data shows little difference between selected interpolation methodologies in comparison to NCDC data (Figure 5.3).

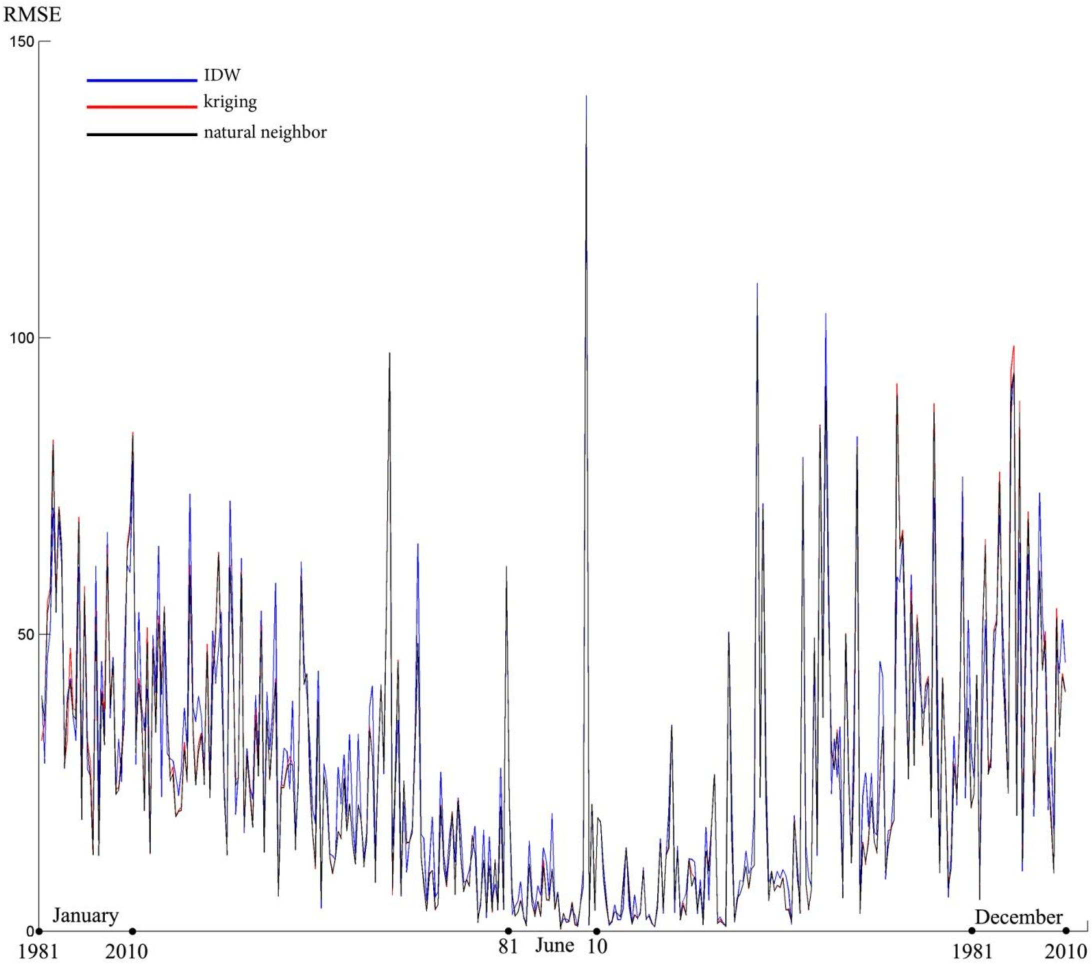

Figure 5.3. Interpolation RMSE values against NCDC data

For months with high precipitation, the difference between GPCC and NCDC data increases, and in the summer time when the precipitation is minimum deviation is at the minimum. This observation raises an issue with current interpolations since the growing season in Upper Mesopotamia overlaps with the high-deviation periods in data. Moreover, it is the growing season precipitation which requires the most accuracy for a good agricultural production model.

On the other hand, some of the high variability between interpolation and station measurements can also be attributed to the errors in station measurements even though they are pre-processed before comparisons. For instance, the highest discrepancy occurs in June 1992 where all of the other summer precipitation interpolations produce extremely low errors. This is most likely due to an error in the NCDC data despite double-mass curve correction and the elimination of unreliable data.

Overall, the averages for root-mean square values are 27.38, 27.12, and 25.80 for inverse distance weighting, ordinary kriging and natural neighbor interpolation. These similar statistics indicate that even though spatial distance between known data points in spatial interpolation is important (Ahrens 2006), the choice of the interpolation method may remain arbitrary in terms of its accuracy when grid data is used. In this study, Matlab 2010 is extensively used for the statistical analysis. Therefore, the select interpolation methodology is the natural neighbor which is efficiently performed in the Matlab. In doing so, no conversion between geographical information systems (GIS) and Matlab is required, and fast data processing is achieved.

5.4.5. Observations on Modern Precipitation

When precipitation values of Upper Mesopotamia and its surrounding regions are averaged and investigated in a time-series between 1981 and 2010, a trend towards arid years is apparent (Figure 5.4). This also conforms to the findings of Zhang et al. (2001) in their analysis of climatic trends from 1950 to 2003. Even though the 1981-2010 time range is not wide enough to argue that the downwards trend will bring extreme arid conditions in the near future, it can be still taken as an indicator. Recent climate models suggests that eastern Mediterranean landscapes and the Middle East will see less precipitation and lower hydrological discharge (Milly, Dunne, and Vecchia 2005).

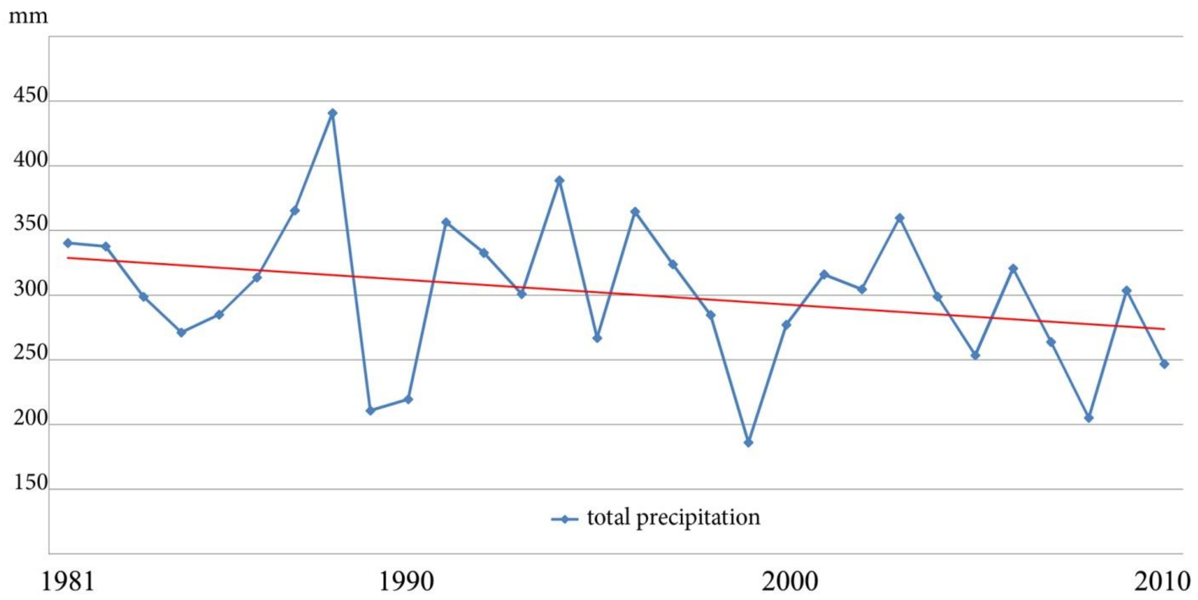

Figure 5.4. Average rainfall between 1981 and 2010 in and around Khabur Basin

Simulation models reported by Kitoh (2007) and Kitoh et al. (2008) also claim that total precipitation and precipitation frequency will decrease, but precipitation intensity will increase. A decrease in the total precipitation is explained by a smaller number of rainy days in the future. It has been also argued that evaporation will increase in all seasons (Kitoh 2007). Milly et al. (2005) shows a 30% decrease in surface runoff by 2050 in the Middle East, and Nohara et al. (2006) projects a 40% reduction in the flow of Euphrates River. Considering population increase, excessive water usage for food production, and the contamination of water sources the impact of climate change on food production will be dramatic.

Reconstructed precipitation shows the anticipated north-south rainfall gradient which follows orographic patterns as well as the coastal maximums (Figure 5.5). Most of the Khabur Basin falls between the 350-500mm isohyets. Isohyets in this region get close to each other as they pass between two anticlines in the south, and high range mountains in the north. Once this zone is passed, 350mm isohyet moves to the south, expanding the area for rain-fed agriculture.

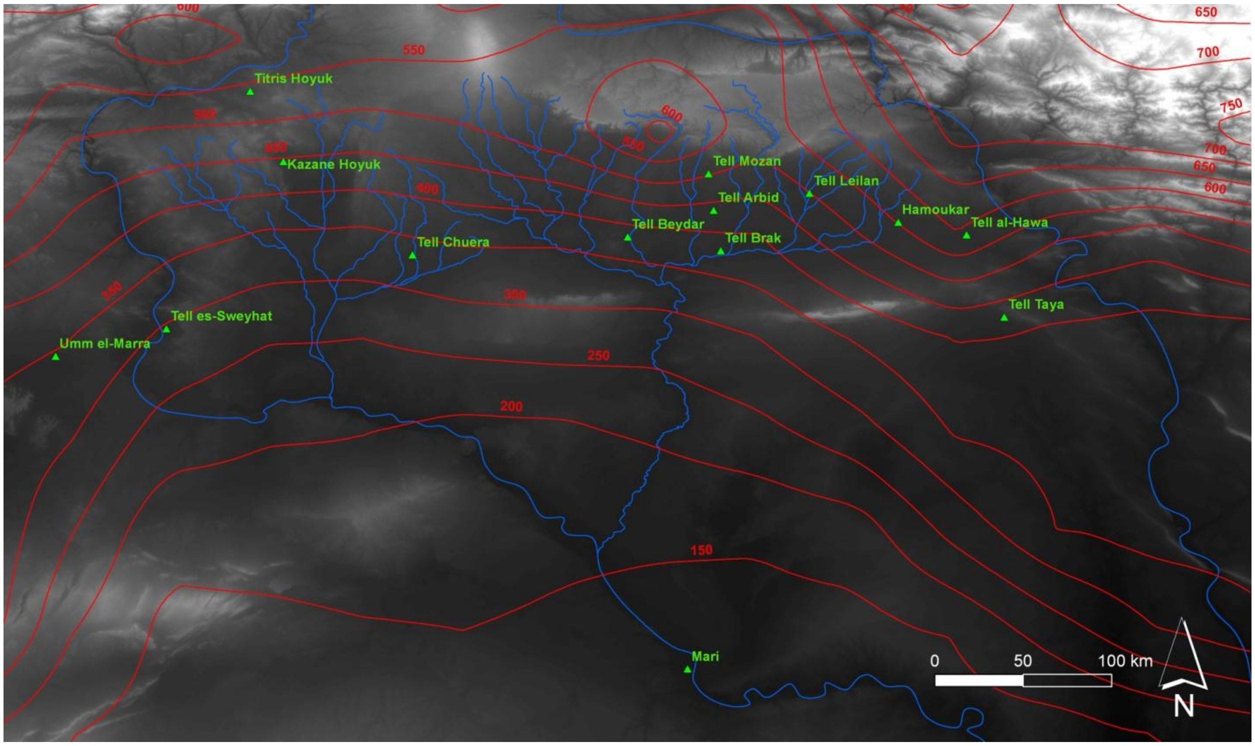

Figure 5.5. Isohyets from normalized precipitation data for between 1981 and 2010

When investigated under modern precipitation values, all large Upper Mesopotamian Early Bronze Age settlements fall above the 200mm/yr dry farming limit (Figure 5.5.). This observation supports Wilkinson's (1994) initial claims on dry-farming as a limiting agent of settlement growth.

Reconstructed precipitation in the area also suggests high variation. To illustrate this, moving averages in 5 year brackets are calculated, and variations from these averages are plotted for each year. Downward precipitation trends are still apparent in the variations plot. The range of deviation is around 100mm, and goes as high as 150mm (Figure 5.6.).

Modern precipitation data has the range of 30 years. Annually available data makes it possible to investigate precipitation regime in this short range. Both local and global minimum and maximum values indicate a fluctuating environment.

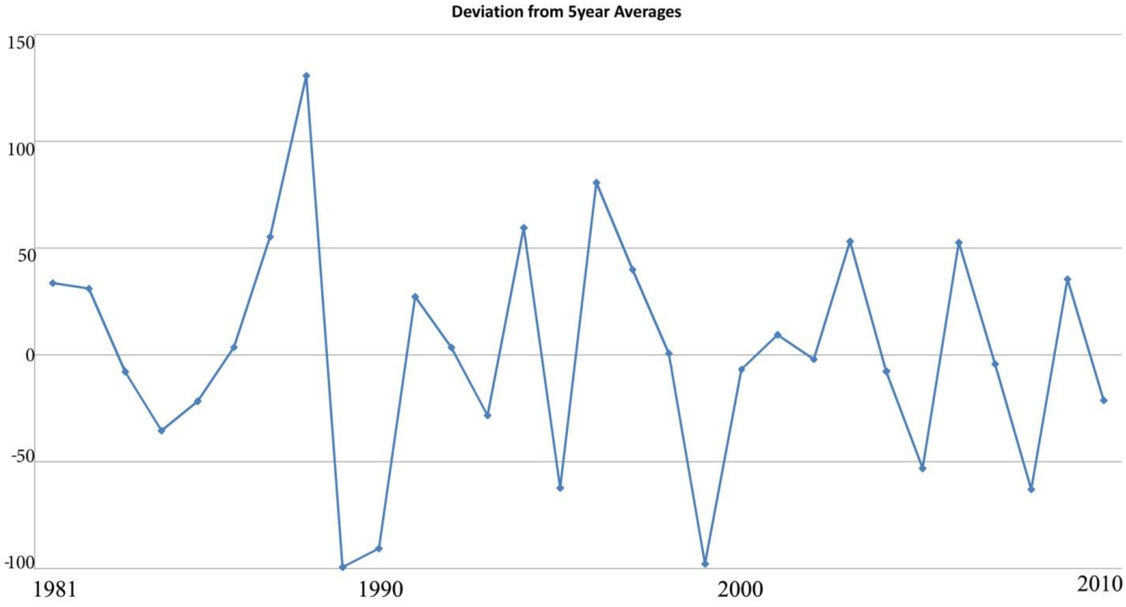

Figure 5.6 Precipitation value deviations from 5 year averages

But most significantly, a decadal drought is visible in the dataset. Conditions created by the high precipitation values in 1988 are reversed by low precipitation values in 1999. This sets a trend in the precipitation dataset towards more arid conditions. This decadal variation, if not an artifact of a short temporal range, is akin to Wilkinson's proposal where he states decadal droughts are one of the characteristics of the Middle Eastern climate.

Modern precipitation gradients mimic the Fertile Crescent belt. This spatial layout must have influenced the decisions of agricultural human occupation of landscape under various climatic conditions. Up until the introduction of large scale irrigation agriculture, the practice was mostly rain-fed farming. In fact, SAD shows the production in most of the Khabur Basin is still rain-fed. This provides unique opportunities to understand ancient production variations based on the observations gathered from modern environmental data.

5.4.6. Ancient Precipitation

Early Bronze Age precipitation values in Upper Mesopotamia are estimated using paleoclimatic data from Soreq Cave since it provides a relatively high temporal resolution. The cave is approximately 40km inland from the Mediterranean coast, and located 400m above sea level (Figure 5.7.).

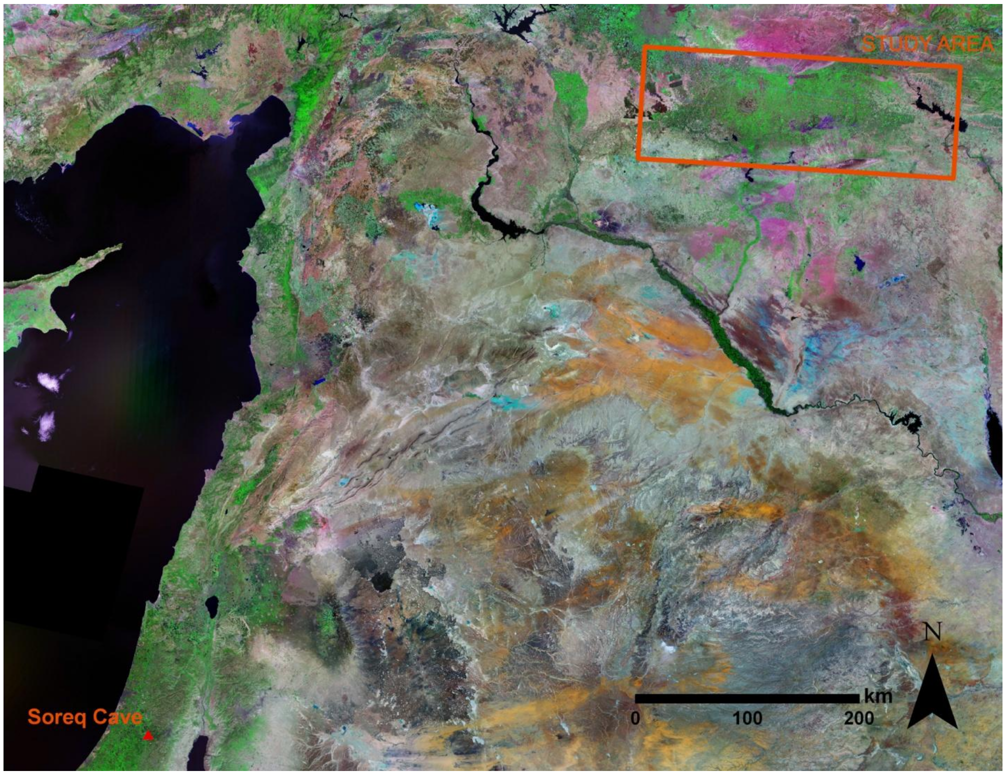

Figure 5.7. Soreq Cave's location in relation to study area

It is 10 to 50 meters below the surface. The cave was formed in the Jibal al-Khalil (Judean Mountains) in the Cenomanian dolomite Weradim type host rock. Plants around the cave are in Mediterranean C3 class(Bar-Matthews et al. 2003, 3182; Bar-Matthews et al. 1999, 86).

Simply put, as water travels through the cave, it dissolves chemical compounds. Once exposed to proper micro-climatic conditions in the cave, compounds precipitate. Released chemical compounds accumulate over time, creating physical formations in the cave. These cave deposits, or speleothems, contain information about the macro-climate of time during the deposition. However, obtaining this information is not an easy process since a cave environment is a complex system where micro and local climatic conditions operate at the same time. Despite this complexity minimal erosion in the cave and stable cave air temperature with very low variation attract researchers for paleoclimatic analysis of speleothem data (McDermott 2004).

Speleothem growth rates are variable, but they usually range between 0.01 to 1mm/year depending on climatic factors like temperature and ion concentrations (Genty, Baker, and Vokal 2001). The accumulation rate of deposits determines whether short term climatic events can be detected in the paleorecord. The accumulation rate is also a factor for the temporal resolution of the paleoclimatic data. However, creating a high temporal resolution data also depends on the spatial resolution of samples taken from the speleothem. Samples with 0.5mm separation may provide a resolution of years or decades. Newer techniques such as laser-thermal releasing provide finer spatial resolutions as high as 250µm, creating significant advantages over traditional sampling methods (McDermott, Mattey, and Hawkesworth 2001). Once samples are obtained, a range of methods are used for dating the samples. Alpha-spectrometric U-series dating (Thompson, Schwarcz, and Ford 1974), thermal ionization mass-spectrometry (TIMS) (W. Li et al. 1989), and a new generation plasma-ionization magnetic-sector mass spectrometry (PIMMS) (Shen et al. 2002) provide dating in various accuracies and resolutions.

Speleothem data is investigated for their growth periods (Vaks et al. 2007), petrography (Ayalon, Bar-Matthews, and Kaufman 1999), trace elements (Frumkin and Stein 2004), and clumped isotopes for paleotemperature reconstructions (Affek et al. 2008). In this dissertation, published stable oxygen and carbon isotopes data from Soreq Cave speleothems (Ayalon, Bar-

Matthews, and Schilman 2004; Bar-Matthews, Ayalon, and Kaufman 1997) are used as proxy paleoclimatic records.

A speleothem oxygen isotope value is a proxy variable for temperature and precipitation during the time of growth of laminates. Under specific conditions, $\delta^{18}O$ in freshly precipitated calcite reflects both the $\delta^{18}O$ of drip water and temperature at the time of separation of drip water and calcite deposition (McDermott 2004). The main requirement in these relations is that calcite should be under isotopic equilibrium conditions (Bar-Matthews et al. 2003). This requirement is validated when $\delta^{18}O$ is relatively constant along a growth layer while $\delta^{13}C$ fluctuates. Also there must be no correlation between $\delta^{18}O$ and $\delta^{13}C$. If these requirements are satisfied then there exists a relation between precipitation and the $\delta^{18}O$ record of a speleothem so that cave data can be used to investigate paleoprecipitation levels (Ayalon, Bar-Matthews, and Schilman 2004, 3). In the paleoclimatic dataset, low $\delta^{18}O$ values correspond to high precipitation values, and vice versa (*ibid.*).

In the speleothem record, variation in $\delta^{13}C$ values reflects vegetation changes around the caves. Increased C13 usually indicates an increase in the soil CO_2 due to activity of C4 based plants. In water deficient environments, C4 plants are photosynthetically more efficient than C3 plants so that any increase in the $\delta^{13}C$ record is a proxy for drier conditions. On the other hand, in arid environments C3 plants have more positive values compared to those under less stressed environments. This complex interaction between plant structures and the record they leave on calcite speleothems makes it challenging to analyze and interpret this invaluable paleoclimatic record. Acknowledging this difficulty, only oxygen isotopes are employed in reconstructing paleoprecipitation.

Isotope analysis of speleothems from Soreq Cave provides invaluable information on climatic conditions extending as back as 250 kyr (Ayalon, Bar-Matthews, and Schilman 2004; Bar-Matthews, Ayalon, and Kaufman 1997; Bar-Matthews, Ayalon, and Kaufman 2000; Bar-Matthews et al. 2003). Other caves in the Eastern Mediterranean, Peq'in (Bar-Matthews et al. 2003) and Jerusalem West Cave (Frumkin, Ford, and Schwarcz 2000) also provide complimentary information (Bar-Matthews et al. 2003), but the sampling resolution of Soreq Cave data for the mid-to-late Early Bronze Age is superior to other cave deposit data so that only Soreq oxygen isotopes are explored.

The dataset includes carbon and oxygen isotope values dating from -246250 BP 1950 BP, and provide a synopsis of the Eastern Mediterranean climatic conditions. Sampling resolution increases as paleoclimatic data gets closer to modern day. Specifically for the Early Bronze Age, i.e. third millennium BCE, there is a speleothem record for every ~20 years, and thus, Soreq cave data provide good conditions to investigate climate at the decadal cycle. In explaining the urban collapse, Wilkinson (1997) emphasizes the importance of frequent droughts occurring in the decadal cycle. Therefore, Soreq Cave speleothem data can be used to evaluate the relationship between aridity and the changes in the urban life by the end of Early Bronze Age.

The interpretations of $\delta^{18}O$ Soreq Cave data suggest decreasing rainfall from 7.5 kyr onwards (Figure 5.8.). This trend is also validated by more arid conditions in the Middle East and North Africa during the later part of the Holocene (deMenocal 2001). Drops in lake levels, and deteriorating vegetative conditions are also documented (Bar-Matthews et al. 1999). Specific to Early Bronze Age, Bar-Matthews et al. also suggest a systematic decrease in precipitation values between 4.5kyr to 2.5 kyr. Especially, the significant increase in $\delta^{13}O$ for between 4.1 and 4.0 kyrs (Bar-Matthews et al. 1999) may be linked to 4.2ka BP event.

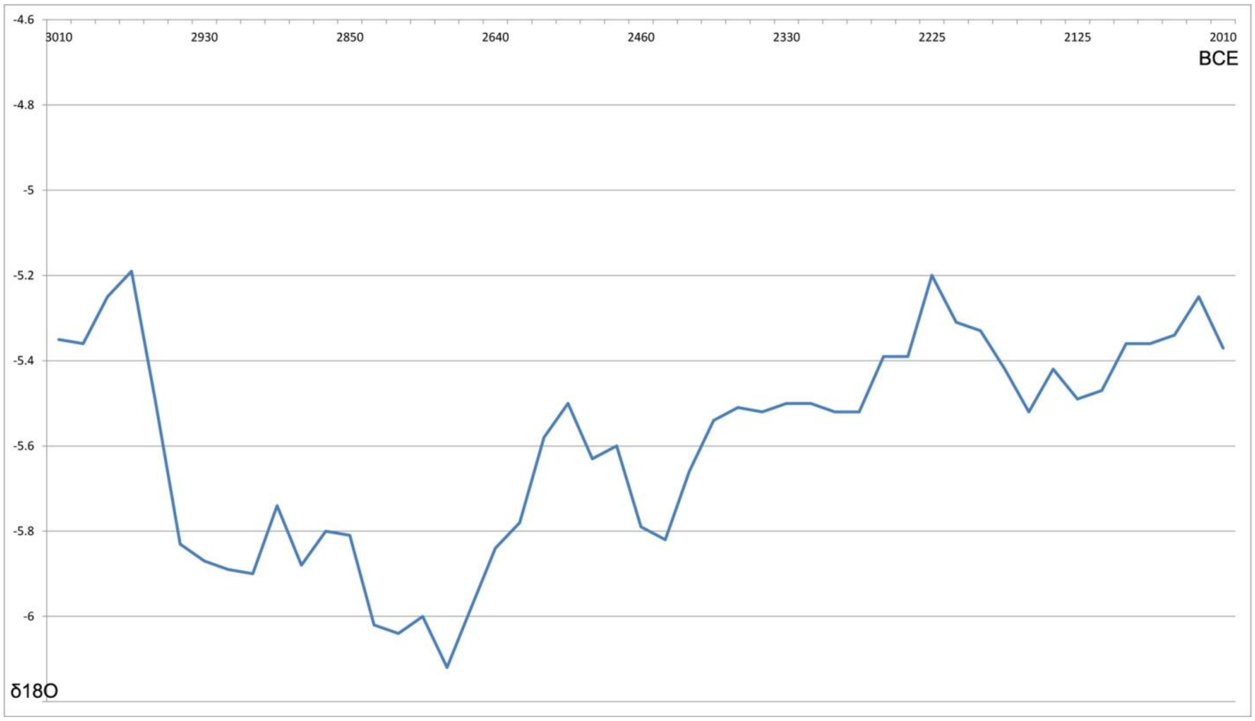

Figure 5.8 Oxygen Isotope values from Soreq Cave during the third millennium BCE

However, this temporal mismatch immediately raises some questions. First, what is visible in the Soreq Cave speleothem data may not be related to climatic aridity at 4.2ka BP. In fact, 4.2ka BP event is not detectable in some paleoclimatic records in the region (e.g., Stevens et al. 2006), and sometimes indicate contradictory humid conditions (Wick, Lemcke, and Sturm 2003) Second, Soreq Cave data questions the amplitude and duration of the 4.2ka BP event. The variation in the speleothem records for between 4.1 and 4.0 kyrs might not have the corresponding variation in precipitation levels which generates these paleorecords at the first place.

The average annual rainfall (500 to 600mm) in the area generates δ^{18}O values around 6.0%. Considering the δ^{18}O precipitation association any deviation from average δ^{18}O value can be used to construct precipitation values. Following this idea, Ayalon et al. (2004) performs a regression analysis between weighted annual δ^{18}O values and annual precipitation for the years between 1991 and 2003. This relationship is given as:

$$\delta^{18}O = -0.004 \,.\, annual\ rainfall - 3.7$$

Using this already established relation, it is possible to estimate ancient annual precipitation values around Soreq Cave for the years where δ^{18}O data exists. One of the strict assumptions in this process is that δ^{18}O and δ^{13}C variation during the Early Bronze Age was structured by the same conditions as today. Only under this assumption, it is possible to use the same modern precipitation-isotopic relation to reconstruct paleoprecipitation. This assumption has been validated by Bar-Matthews et al. (1997). Another issue associated to the speleothem record is that the lamination also continues in dry conditions (Orland et al., 2009). Thus, samples represent precipitation and natural growth at the same time. The spatial resolution of speleothem sampling strategy in Soreq Cave cannot solve for this issue, so only a coarse paleoprecipitation trend can investigated in the analysis. One last problem in the reconstruction of ancient rainfall regime is related to the development of δ^{18}O record. The Caves located in arid and semi-arid regions of the world, including the Soreq Cave, may face isotopic enrichment during the near-surface evaporation processes. Therefore, the reliability of the paleoprecipitation reconstructions is reduced in such environments. Despite these apparent problems, Soreq Cave still remains as the only reliable source for investigating mid-Holocene precipitation patterns in the Near East.

The Soreq Cave δ^{18}O dataset is available via the National Climatic Data Center (NCDC) paleoclimatology program. This dataset contains sample values for δ^{18}O and δ^{13}C, and their corresponding dates (Bar-Matthews et al. 2003). High precision TIMS dating on a dense sample provides isotopic information with an average of 20 years during the third millennium BCE.

For the analysis, Soreq Cave δ^{18}O values for the third millennium BCE is extracted from the dataset, and following Ayalon et al. (2004), linear regression formula is applied to δ^{18}O values. After rewriting the formula as:

$$(-250).(\delta^{18}O + 3.7) = annual\ rainfall$$

50 precipitation values are calculated for the years between 3005 and 1990 BCEs. Using estimated precipitation values, a linear interpolation is used to approximate yearly precipitation values for the third millennium BCE (Figure 5.9).

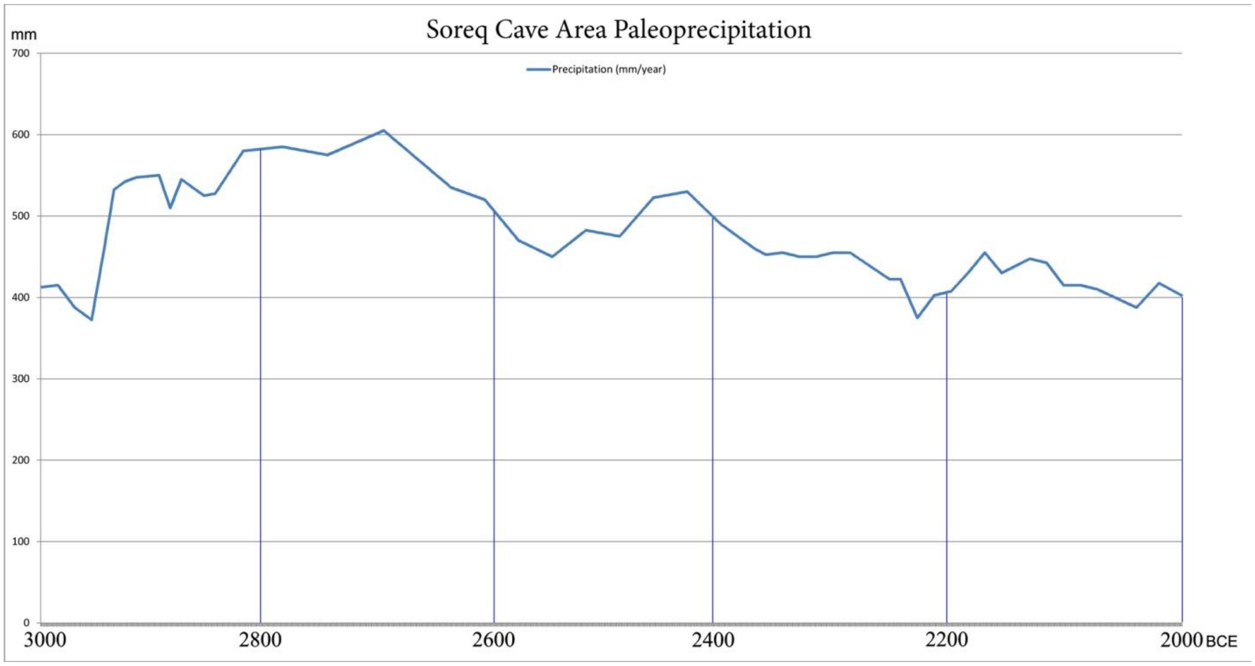

Figure 5.9 Precipitation reconstruction for the Soreq Cave area

Linear interpolation is a deterministic method and it ignores likely variation between sample years. Nevertheless, it also provides information on the precipitation trend throughout the millennium.

The trend is towards more arid conditions during the millennium. The wettest years are detected in between the 28th and 27th centuries. Following these centuries, precipitation follows a stable pattern. Total precipitation reaches a minimum slightly before 2200 BCE, and stabilizes for two more centuries.

5.4.7. Relations between Soreq Area and Upper Mesopotamia – Modern and Ancient

If the meteorological relationship between Soreq Area and Upper Mesopotamia can be established then precipitation reconstructions for the Soreq Cave can be used to estimate third millennium BCE precipitation in Upper Mesopotamia. Located closer to the Mediterranean Sea, Soreq Cave gets more rain throughout the year and north-south running mountains act like a barrier when weather system moves inland and creates a truly complex climatic system. Therefore, there is no straightforward methodology to reveal climatic relation between the Soreq Cave area and Upper Mesopotamia. For instance the northward transgression of the monsoon system affecting Upper Mesopotamia might have only had minimal influence in and around Palestine, reducing the amount of correlation between Soreq Cave area and Upper Mesopotamian precipitation

Despite this complexity, there is some correlation between the amount of rain in Soreq Cave area and Upper Mesopotamia where this relation is used to reconstruct Early Bronze Age precipitation levels. In order to accomplish this, first modern-day regional meteorological relationships are constructed, and second, Early Bronze Age precipitation levels in Upper Mesopotamia are estimated using Soreq Cave precipitation levels under the assumption that modern-day regional meteorological relation can be projected backwards in time.

To explore modern-day meteorological relationships between regions, GPCC grid data for the years between 1981 and 2010 are analyzed in order to represent this meteorological relationship (Figure 5.10).

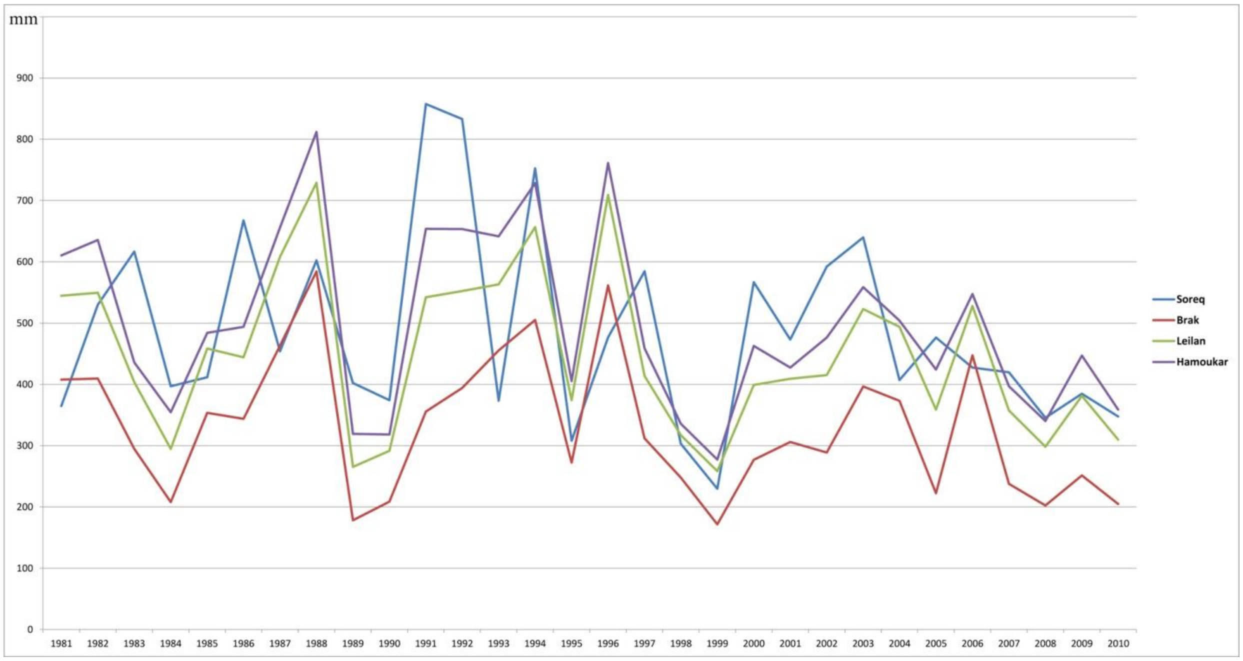

Figure 5.10. Comparison of modern day Soreq Cave precipitation values (Blue) against Tell Brak (Red), Tell Leilan (Greed) and Hamoukar (Violet) in Upper Mesopotamia

To formalize a model, Pearson product-moment correlation coefficients are calculated between grid locations at Upper Mesopotamia and Soreq Cave. Resulting coefficients suggest a weak correlation. For the Khabur region and its eastern proper, the coefficients range between 0.4 and 0.6 (Figure 5.11). To understand the structure of association, scatter plots between Soreq Cave and select archaeological sites are investigated (Figure 5.12).

These scatter plots show a non-linear data fitting method can be used to predict precipitation values in Upper Mesopotamia. Even though the power of exponential model drops significantly for higher precipitation values, a second order polynomial data fitting in least squares sense is performed between grid locations.

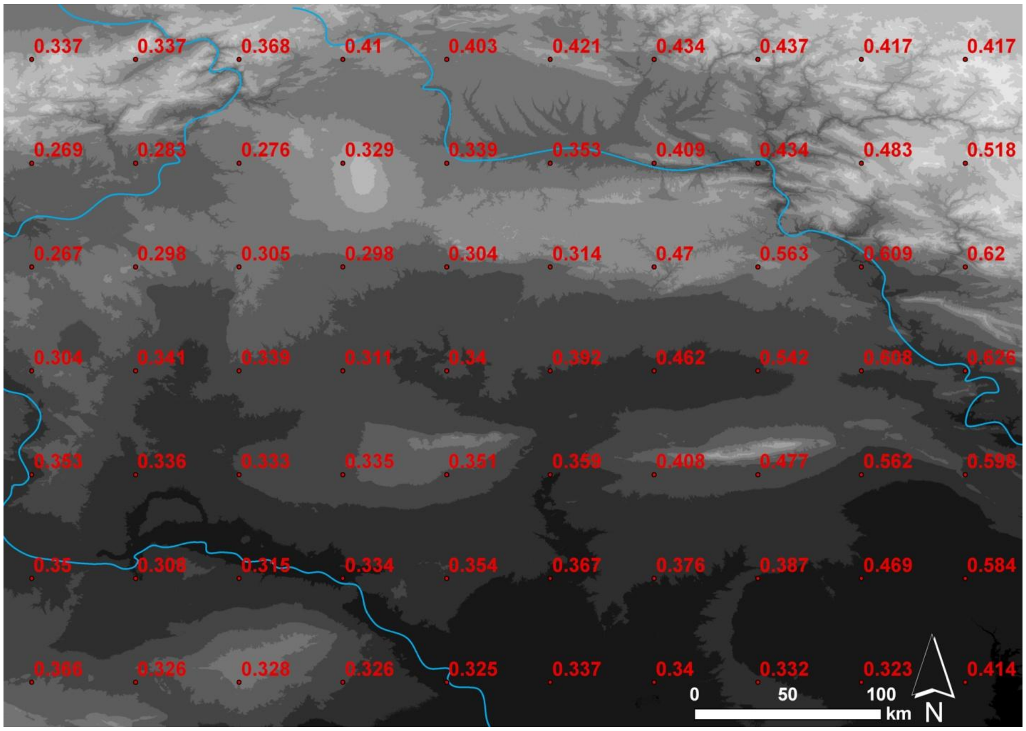

Figure 5.11. Pearson correlation coefficients between Soreq Cave and grid precipitation values

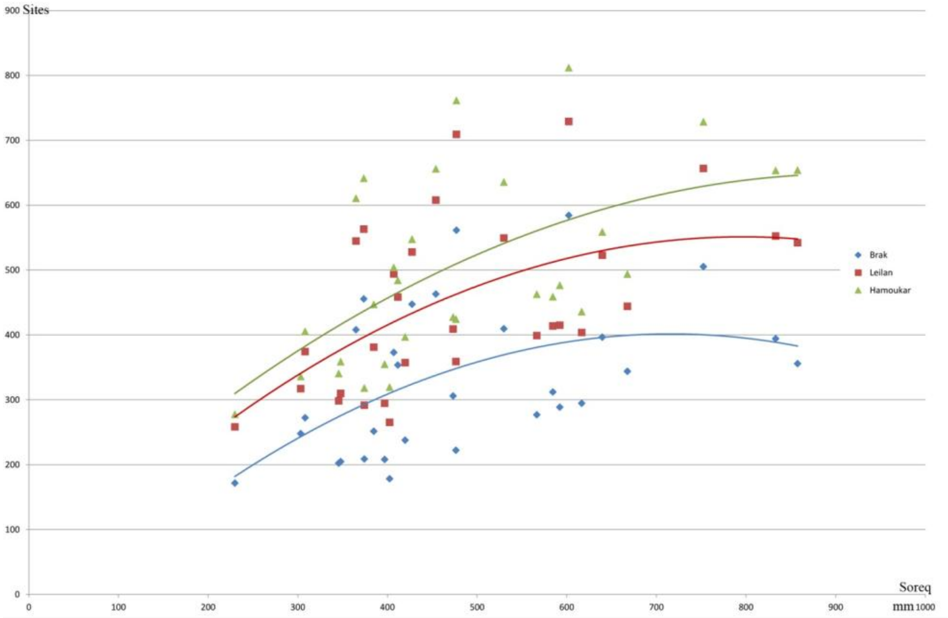

Figure 5.12. Scatter plot for Soreq Cave precipitation values against Tell Brak (Brak), Tell Leilan (Red) and Hamoukar (Green) in Upper Mesopotamia

To examine the predictive power of the model, the difference between observed and estimated precipitation values in Upper Mesopotamia is investigated. Soreq Cave area precipitation values are used to predict precipitation in the study area and error is calculated. Mean absolute errors of each grid location suggest that models behave rather poorly in mountainous areas, and discrepancies between observed and estimated values are as high as 100mm/yr. Further to the south, the predictive power of the model increases and the error drops as low as 50mm/yr (Figure 5.13).

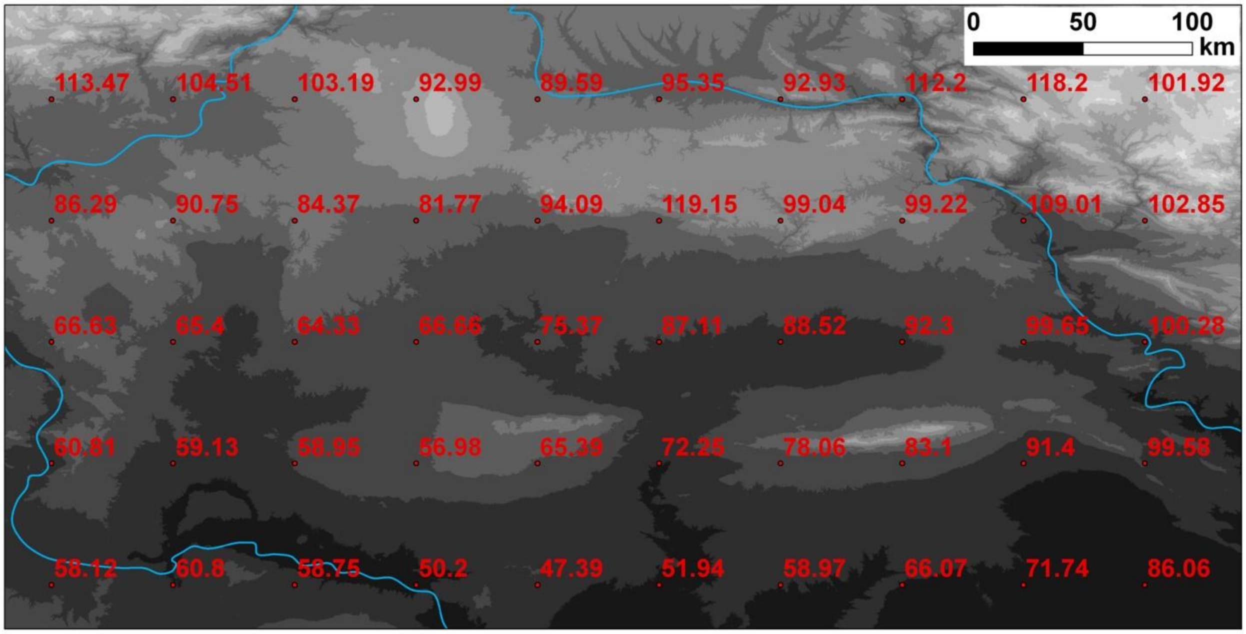

Figure 5.13. Absolute error of precipitation model based on Soreq Cave data

Using constructed meteorological relationships between regions, Early Bronze Age precipitation values are estimated for years between 3000 and 2000 BCE. Ancient isohyets for 200mm and 500mm at each 200th year are calculated and mapped for comparative purposes (Figure 5.14).

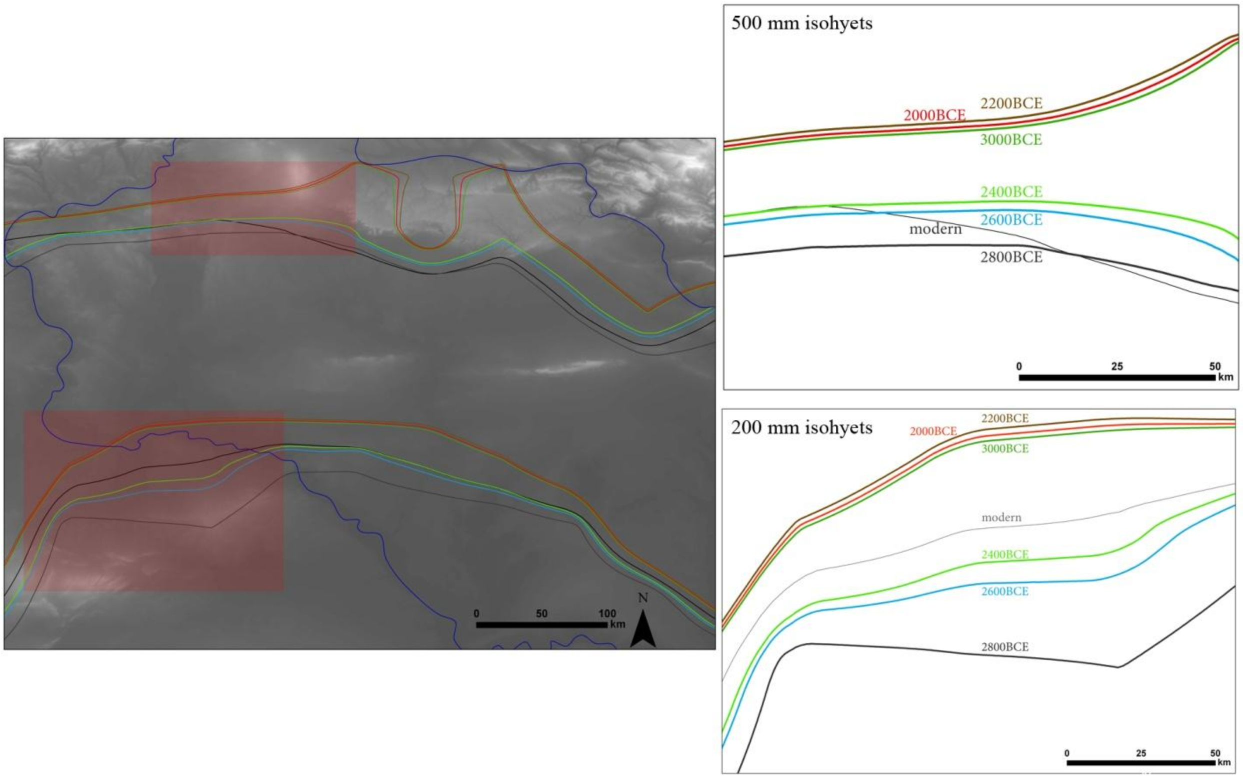

Figure 5.14. Early Bronze Age isohyet reconstruction with 200 years interval

According to the model, the amount of precipitation increased significantly between 3000 BCE and 2800BCE as suggested by the sharp southerly movement in isohyets. From the 2800 BCE onwards, 200mm/yr critical line moved north, indicating progressively drier conditions in the region. This critical line reaches its northernmost position between 4.2kBP and 4.1kBP. The 500mm/yr line also had a northerly movement even though the amount of shift is not as drastic as the southern portions of the region. The ancient 500mm/yr isohyet also shows a pocket like anomalous region where a sharp drop in precipitation values is observed for dry centuries of the third millennium. Considering the low predictive power of the model at mountainous regions, this might be an artifact of calculations.

Specific to the core of the study area which spans large portions of the Khabur Basin as well as its eastern periphery, the maximum deviation between precipitation values is observed between 2800 and 2200 BCE which also fits the paleoprecipitation reconstruction of the Soreq Cave area (Figure 5.15).

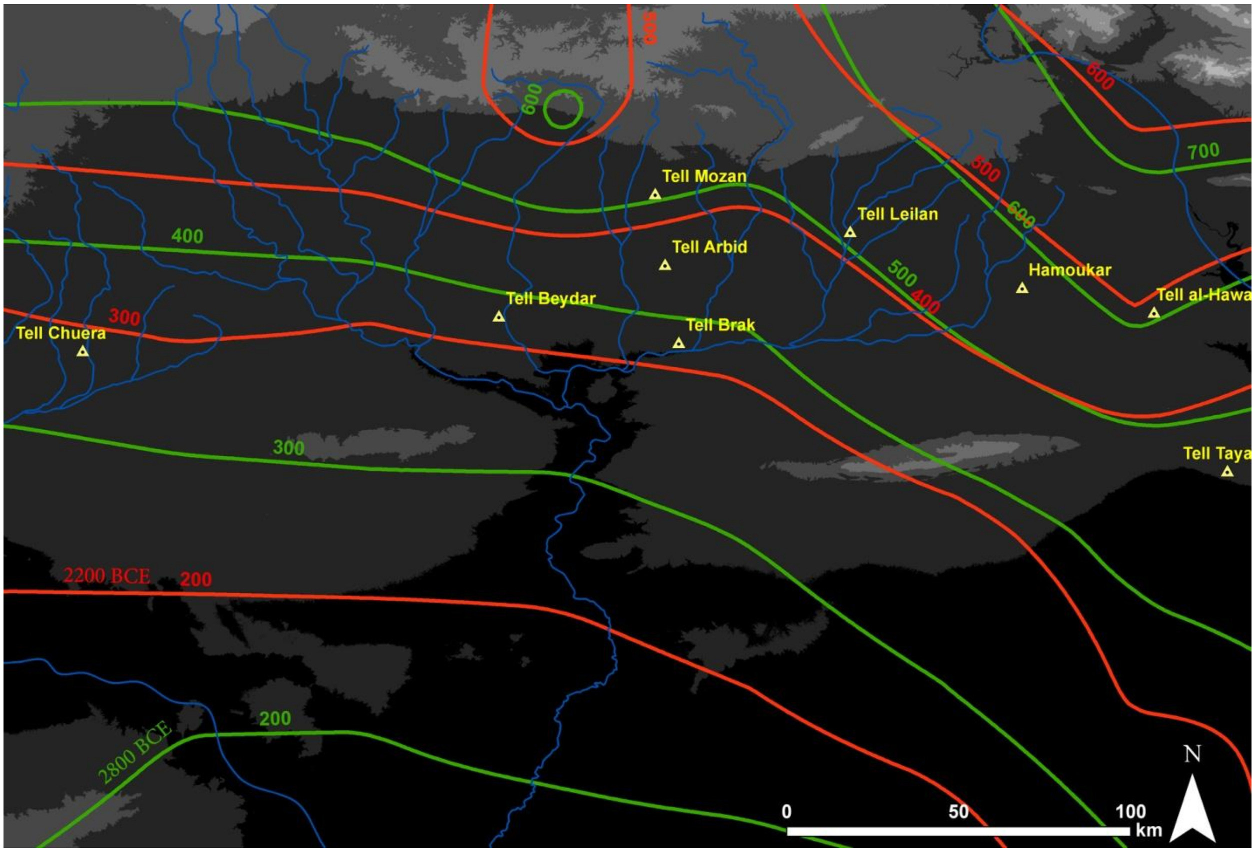

Figure 5.15. The maximum deviation between precipitation values is observed between 2800 and 2200 BCE

To the north of the Jebel Sinjar and Jebel Abd-al Aziz anticlines, 550 mm/yr was the maximum amount of rainfall during the third millennium BCE. During the mid-to-late Early Bronze Age, average rainfall in the area ranged from 350mm/year to 450mm/year which is above the theoretical dry-farming limit, but still not high enough to have stable agricultural production (Figure 5.16).

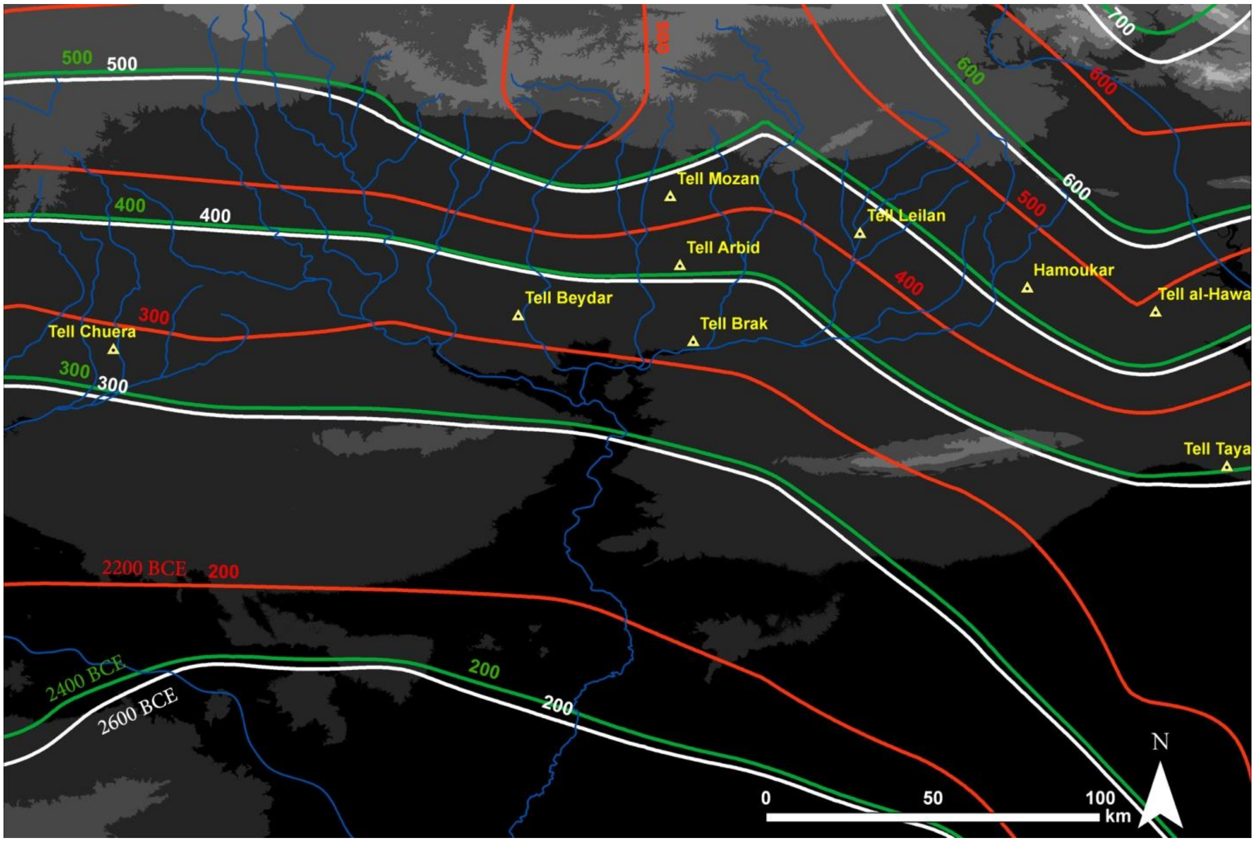

Figure 5.16. A close up for isohyets at 2600, 2400, and 2200 BCEs

5.5. Precipitation and Agricultural Production in Upper Mesopotamia

Under no cultural modification, ecosystems naturally emerge in various climatic conditions, albeit in very complex ways. Intensive agricultural systems, on the other hand, represent drastic human induced changes imposed over natural background so that production becomes less flexible, and thus, more vulnerable to climatic changes. To make the picture more complicated, juxtaposition of natural and cultural systems create a production phenomenon in which the response of agricultural production to climatic shifts varies greatly, even in a single agro-climatic region. Therefore, reconstructing a complete picture of possible production variation under ever changing climatic conditions is a daunting task, and the analysis of these systems require making strict assumptions as well as fixation of many of the climatic variables in the analysis. Nonetheless, reconstructions in paleoprecipitation presented above enable a quantitative, if still inconclusive, investigation into the relationship between climatic variability and agricultural production in Upper Mesopotamia.

A precipitation based classification of bioclimatic zones in the Middle East shows that most of Upper Mesopotamia is a semi-arid region:

Zone-Type	Annual Rainfall (mm)	Percent of Arable Area
Super-arid	<200	0
Semi-arid 1	200-400	74
Semi-arid 2	400-600	14
Sub-humid	600-800	10
Humid	800-1200	1
Super-humid	>1200	1
Table 1: Adapted from Hazell, Oram, and Chaherli 2001, 2)		

A similar agro-ecological classification in modern Syrian Arab Republic mimics annual rainfall pattern in the country (Figure 5.17). These boundaries encompass semi-arid 1, and semi-arid 2 regions suggested by Hazell et al (2001) (Figure 5.18). Geographically, dry-farming extends to the south of modern Turkey and covers extensive areas in northern Syria, makes a sharp turn around the Jebel Sinjar, and reaches into Iraq (*ibid.*). The limits of dry-farming in Upper Mesopotamia are also documented by de Brichambaut and Wallen (1963). It should be also noted that these limits are based on long term trends and averages of precipitation values. In other words, precipitation boundaries are set by the normalized values of a large dataset. Considering the erratic nature of rainfall regime in the Middle East, there are individual years which significantly deviate from the normal. Evaluating these variations, Pratt et al. (1997) suggest that drought occurs in a given year if precipitation falls below half of the long term average or when rainfall in two or more successive years is below 75 percent of the average.

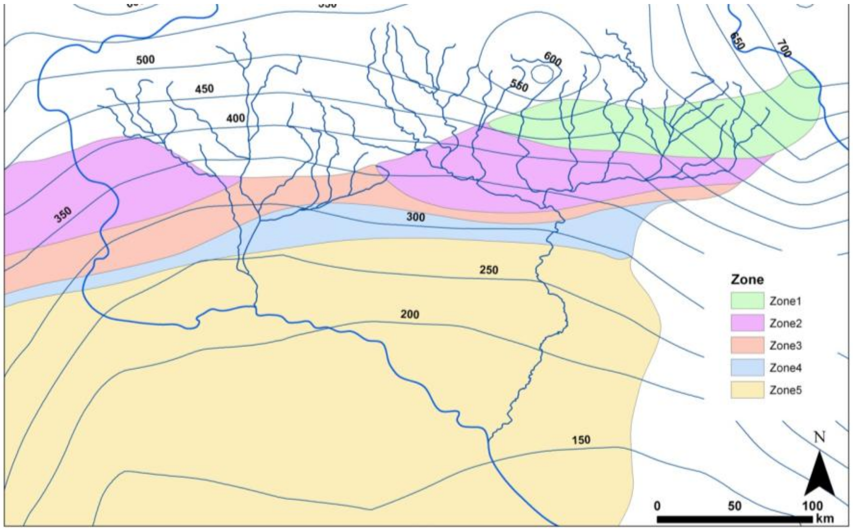

Figure 5.17. Agro-ecological zones reported in Syrian Agricultural Database (SAD)

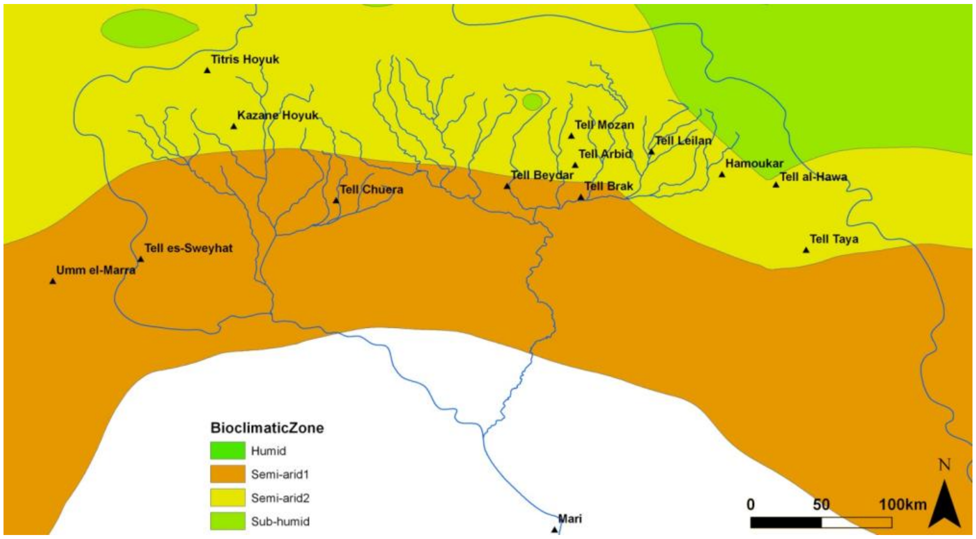

Figure 5.18. Bioclimatic zones reported in Hazell et al., 2001

The Syrian Agricultural Database (SAD), hosted by the National Agricultural Policy Center (NAPC) of the Ministry of Agriculture and Agrarian Reform, Syrian Arab Republic, provides a rich dataset for the years between 1985 and 2010. The SAD is divided into provincial data as well as agro-ecological zones. Agro-ecological zones overlap with Upper Mesopotamia, but also extend into the Ghab Basin and the Mediterranean (These western zones fall outside the study area). Provincial data for Al-Hassakeh, Al-Raqqa, Deir-ez Zor provide a valid representation of Upper Mesopotamian socio-environmental conditions.

In the SAD, land-use data are divided into three main categories: irrigation, fallow, and rain-fed. These categories are investigated for land-use changes in percentages for the years between 1985 and 2010. Al-Hassakeh (Figure 5.19a) in the Khabur Basin and Al-Raqqa (Figure 5.19b) has similar land-use change characteristics.

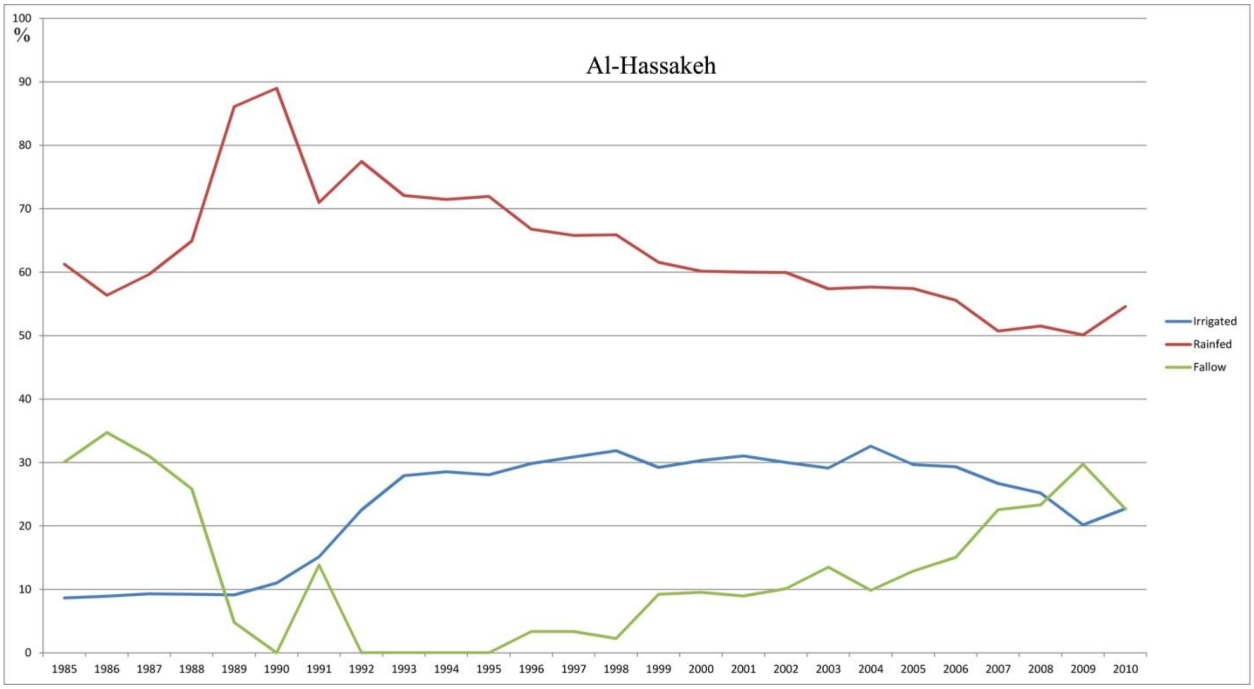

Figure 5.19a. Area land-use percentages in al-Hassakeh

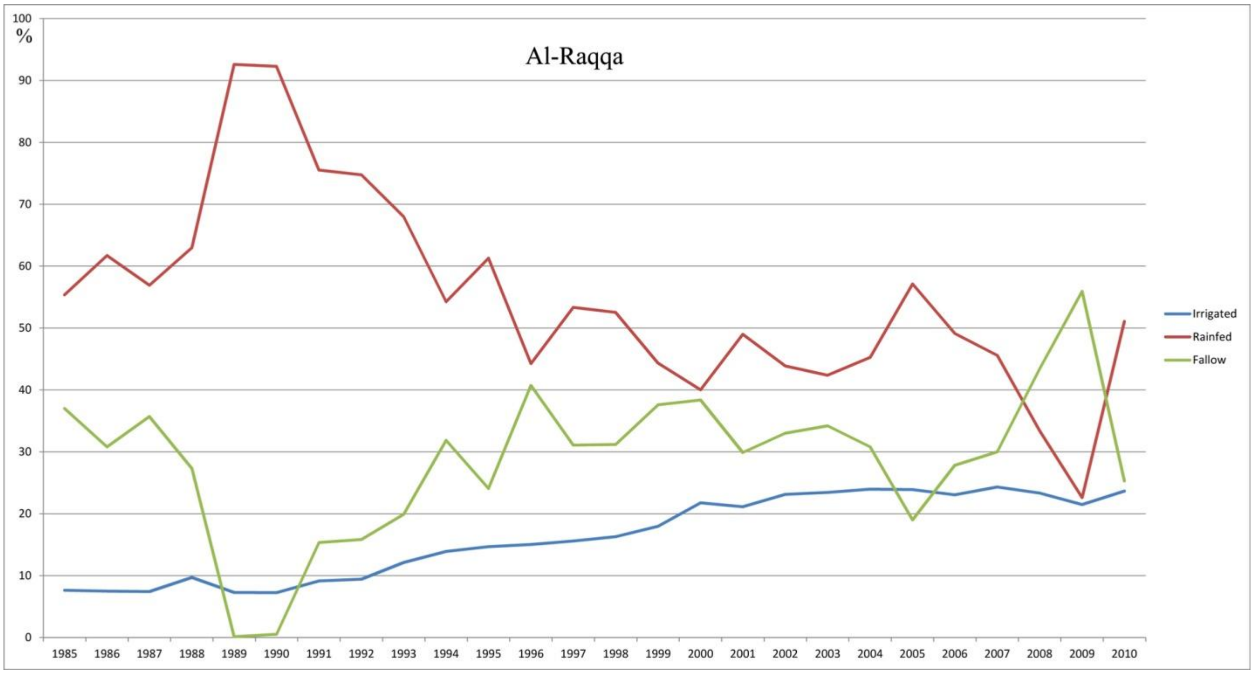

Figure 5.19b. Area land-use percentages in al-Raqqa

Both provinces are characterized by rain-fed agriculture until the early 1990s. By the second half of the same decade, land dedicated to rain-fed agriculture started to decline. This decline is more dramatic for Al-Raqqa than Al-Hassakeh. In Hassakeh, irrigation agriculture makes a sharp increase by 1990, but no significant change is observed after 1993. The ratio of the land dedicated to irrigation agriculture to the total agricultural land remains around 30 percent with a slight decrease after 2006. In Al-Raqqa, the ratio of irrigation agriculture never reaches to 30 percent, but a steady, slow increase is observed after 1993. The Deir-ez Zor province in the south has significantly different land-use characteristics than Al-Raqqa and Al-Hassakeh (Figure 5.19c).

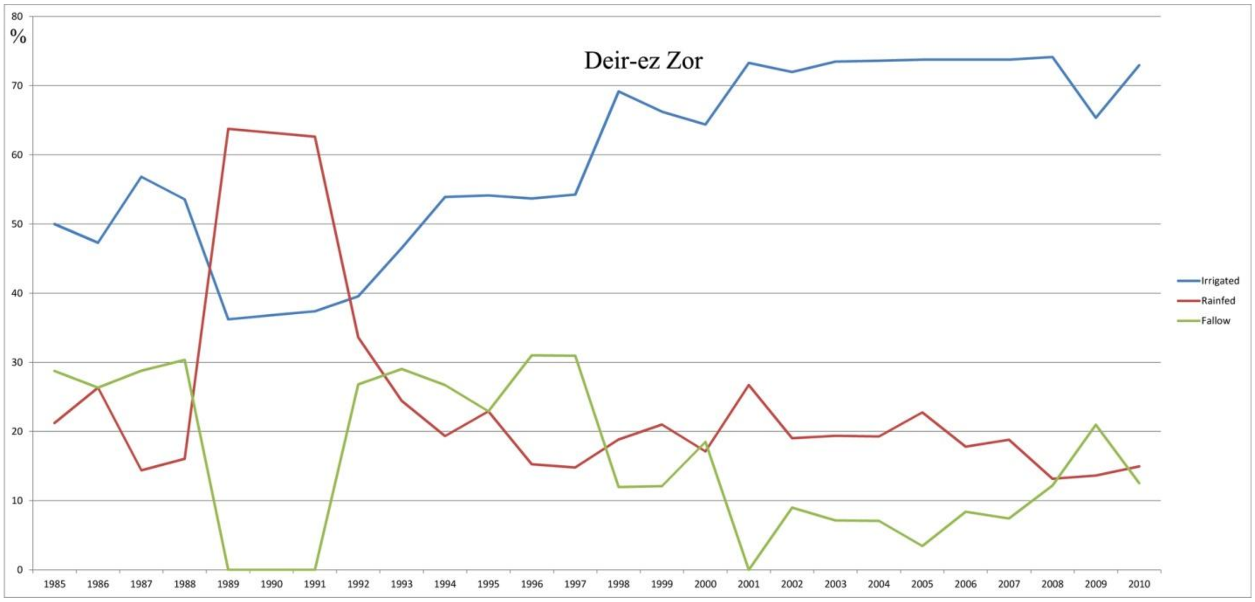

Figure 5.19c. Area land-use percentages in Deir-ez Zor

Irrigation agriculture has been heavily employed in the area because the province is located at the very margins of rain-fed agriculture, but still some dry farming is practiced. Between 1989 and 1991, rain-fed agriculture jumps from 15 percent to 60 percent, due to abandonment of fallowing. This is a significant observation since 1989 is also marked as a very dry year. This example supports the idea that climatic pressure over production may result in changes in agricultural strategies. In order to keep the production in the same levels as previous years, statistics show that fallowing was abandoned, and production was increased by increasing the spatial extent of cultivation. Furthermore, even though 1990 and 1991 were relatively wet, fallowing was still at the minimum, most probably to recover from the effects of 1989 drought.

A similar inquiry can be made by comparing barley and wheat total yields with respect to different land-use practices in three provinces. This will show how much change in total production can be attributed to the amount of change in land-use strategies. In terms of output, Al-Hassakeh (Figure 5.20a) and Al-Raqqa (Figure 5.20b) have similar production values.

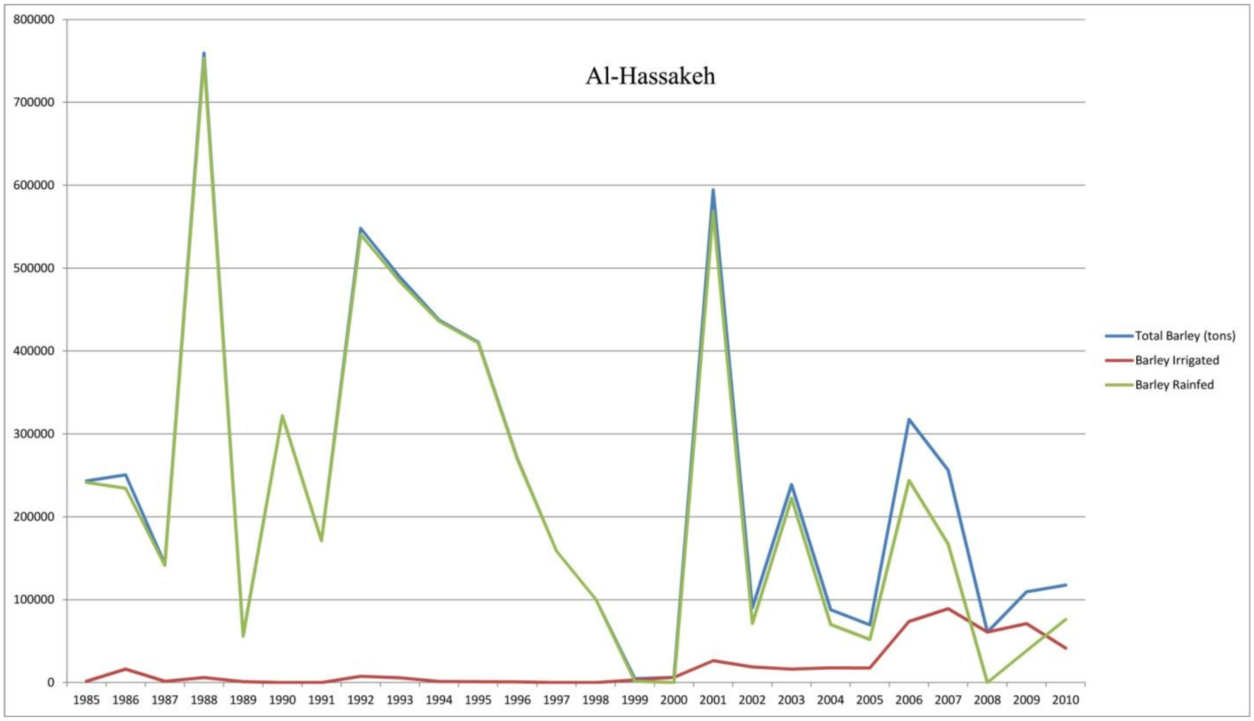

Figure 5.20a Production percentages based on land-use practices in al-Hassakeh

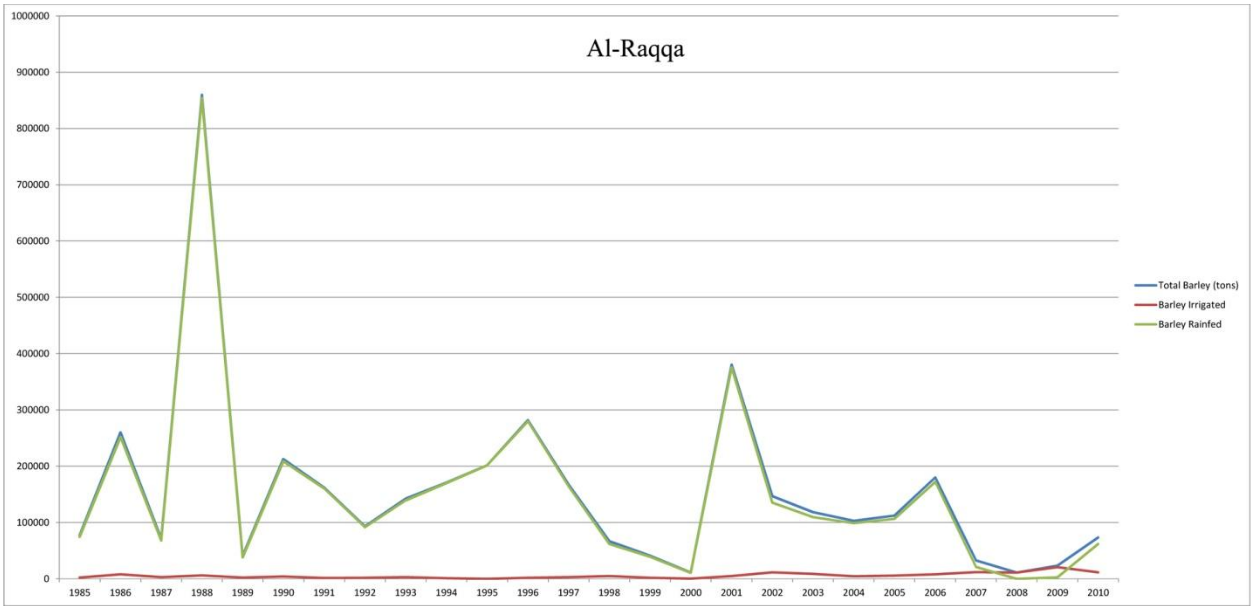

Figure 5.20b. Production percentages based on land-use practices in al-Rakka

In comparison to land-use strategies, when the total amount of production is investigated, irrigation agriculture doesn't contribute to the sum as much as rain-fed agriculture. Only after 2005 more staples were produced by irrigation in Al-Hassakeh and Al-Raqqa. Extreme dry conditions in 1989 had major impacts in Al-Hassakeh and Al-Raqqa production. However, after this arid year Al-Raqqa did not recover as quickly as Hassakeh province, due to an increase in irrigation agriculture in Hassakeh immediately after 1989. Some interesting inferences can be made for Deir-ez Zor (Figure 5.20c). Irrigation agriculture is more widely practiced than rain-fed agriculture, but still rain-fed agriculture provides more yields until 2002. Overall, to diminish the effect of irrigation agriculture on total production levels, precipitation data 2005 onwards are omitted from the analysis.

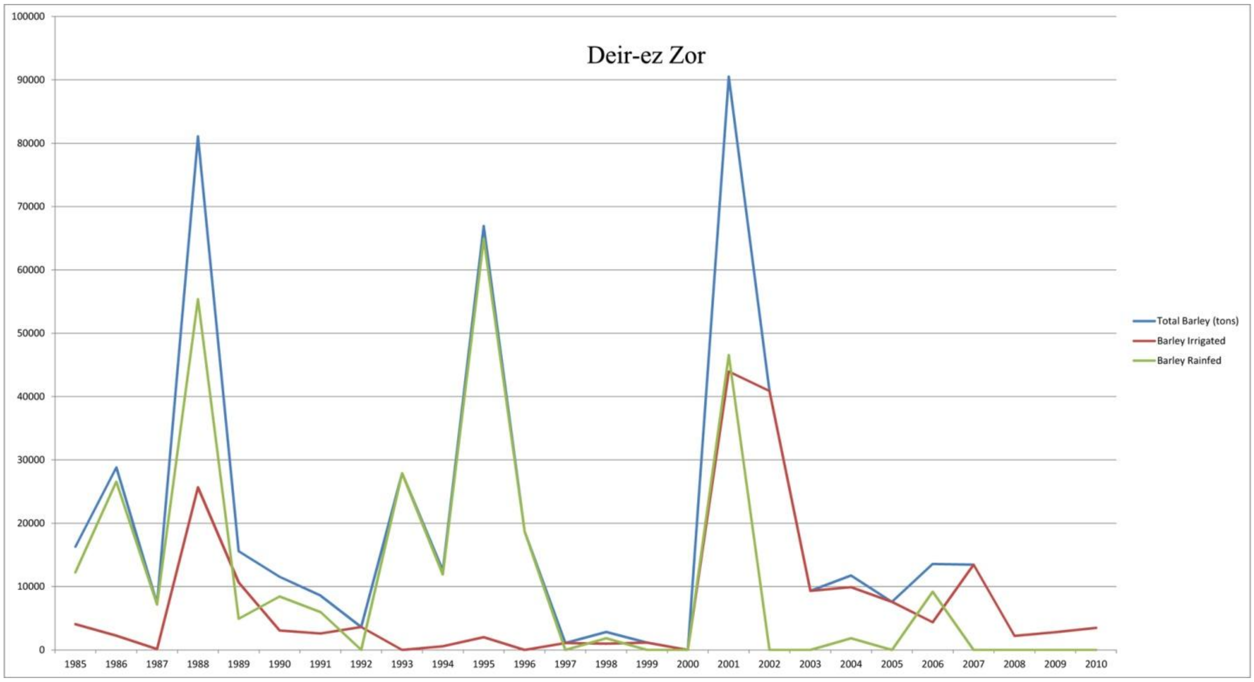

Figure 5.20c. Production percentages based on land-use practices in Deir ez-zor

5.5.1. Agricultural Yield Estimations based on Precipitation Values

Understanding the direct relationship between precipitation and agricultural production depends on minimizing the production contribution originating from practices with supplemental systems like irrigation. Basic comparisons among Syrian political provinces suggest that even though some irrigation is practiced, rain-fed agriculture still provides the bulk of products. Thus, in order to simplify the production model it is assumed that only rain-fed agriculture is practiced in the region. Another main assumption in yield estimations is that there is uniformity in other components of production. Differential access to chemical fertilizers, pesticides, modern machinery as well as labor differences all create major production variations, but no such variables are included in the analysis for the sake of simplicity.

Two distinct modes of production strategies are practiced in the area, conforming to the biotic conditions of agricultural species. Autumn sowing is possible in places where winter conditions are not hostile such as the Mediterranean littorals of Turkey and Syria. Under colder conditions the seed can be sown only after the winter frost passes (Oram 1985). Depending on local conditions and contemporary climate, two consecutive sowings can also occur. This strategy boosts the gross agricultural output significantly while putting a pressure on the agricultural soil. Throughout this dissertation only one sowing season will be considered with the dates suggested below. According to International Center for Agricultural Research in the Dry Areas (ICARDA), barley and wheat sowing is practiced sometime around November 15, and average harvest dates are June 23 for barley and July 13 for wheat in and around Upper Mesopotamia (Mauget and De Pauw 2004). Following these dates, the growing season is set for between December and May, and total precipitation during the growing season is used to estimate total agricultural output through a remote sensing-based statistical model.

5.6. Production Model

There are various methods for estimating agricultural output. One of the well established approaches in crop estimation studies is to document productivity by biological variables. A variable, net primary productivity (NPP) is defined as the total mass of photosynthate stored in organic dry matter. NPP can be estimated by parametric models based on incoming solar energy and transformation of this energy into the green body (Ruimy, Saugier, and Dedieu 1994). These models reflect local conditions that they were built in, so that their direct application remains problematic across the landscape. However, when supplemented with simulation studies these productivity-based measures can still provide accurate estimations of net agricultural yield if an appropriate biological model is selected (Baez-Gonzalez et al. 2002). Selection of this biological model is not a trivial task since this process requires establishing appropriate parameters, preferably with *in-situ* measurements. Considering the size of the study area, field work is not feasible. Thus, NPP approach is disregarded and biological production model based on remotely sensing data is constructed.

The biological model is based on precipitation-evapotranspiration relations. This model is further iterated with normalized difference vegetation index (NDVI) values to compensate for changing production strategies in the area (Zaitchik, Smith, and Hole 2002). Integration of NDVI data to the model is discussed later in the chapter.

Assuming a sustainable production strategy, the water balance can be given as:

$$Q = R + D = P - E$$

where Q is the water excess which is necessary for growth, R is runoff and D is the drainage below the plant root system. The same equation also holds for the difference between the precipitation (P) and evapotranspiration (E). Evapotranspiration can be estimated by:

$$E = P.\left(\frac{1 + w.\frac{E_M}{P}}{1 + w\frac{E_M}{P} + \left(\frac{E_M}{P}\right)^{-1}}\right)$$

where w is plant specific water coefficient, which also varies with seasonality. EM is the potential evapotranspiration, which can be parameterized and fixed to a value. Even though the parameters of evapotranspiration can be modeled and estimated for modern production (e.g., L. Zhang, Dawes, and Walker 2001), ancient production suffers from unknown evapotranspiration parameters. Therefore, throughout this study the water balance, which is necessary for Early Bronze Age agricultural production, is directly set to the precipitation amount as:

$$Q = P$$

In arid and semi-arid regions of the world, crop yield is mostly determined by the availability of water rather than by temperature and radiation conditions so that precipitation can be directly used to satisfy the water balance equation above. Under this assumption, Ehlers and Goss (2003) set the relation:

$$\frac{DM}{T_C} = \frac{k}{\Delta e}$$

where DM is the amount of biomass, Tc is the crop transpiration during the production period, k is the crop-specific constant, and Δe is the vapor pressure deficit, once the conditions for water excess (Q) is satisfied. Wang et al. (2008) re-writes this formulation as:

$$Yield\ =\ H\ .(Ec - Es).\frac{k}{\Delta e}$$

where H is the crop harvest index, Ec is the crop evapotranspiration, and Es is the evaporation from the soil surface. Es constitutes 30% of Ec (Angus and van Herwaarden 2001, 291) Considering wheat can only grow above the 110mm/year rainfall limit, the equation can be constricted to:

$$Yield = 0.7H.Ec\frac{k}{\Delta e}\ for\ Ec \geq 110\ mm$$

with harvest index (H), total precipitation (Ec), crop specific index (k), and vapor pressure deficit (Δe). k is usually set between 45 and 60 kPa (Ehlers and Goss 2003). Under rain-fed conditions, Ec can be replaced by total precipitation amount (Wang et al. 2008, 1962).

The vapor pressure deficit (Δe), or the drying power of air, is determined by the temperature and relative humidity of the environment at the time of measurement (Anderson 1936). The vapor pressure deficit can also be defined as the difference between the vapor pressure inside the leaf and the vapor pressure of the air; the higher the vapor pressure deficit, the more the air sucks moisture from the plant, creating more hydrologic stress on the plant. The vapor pressure deficit can be calculated in the field (Bassow and Bazzaz 1998), or a satellite remote sensing approach can be used to estimate Δe values (Hashimoto et al. 2008). Estimation of this value is beyond the scope of this study for the Early Bronze Age production levels, but, in order to provide a conservative estimate of production, Δe is fixed 3. This Δe value signifies high temperature with low relative humidity conditions, and thus, mimicking semi-arid regions of Upper Mesopotamia in general.

In this methodology, the only unknown remains as the harvest index (H). H usually requires ground observations to estimate its value. On the other hand, considering the large extents of the study area such a ground option is again not feasible. But, estimation of the harvest index is also possible by using satellite remote sensing product, called Normalized Difference Vegetation Index (NDVI).

5.7. AVHRR-NDVI

Studying vegetation spectral characteristics to determine vegetation type and other biophysical properties is one of the main focus areas of remote sensing. Vegetation health, growing conditions, and the amount of vegetation biomass can be modeled by exploring vegetation in the electromagnetic spectrum. Three regions in the spectrum are the most relevant for the analysis of vegetation reflectance. Information on chlorophyll absorption can be obtained from the visible portion of the spectrum, whereas sustained reflectance can be documented in near infra-red part. Water absorption levels can be investigated over the middle infra-red region (C.J. Tucker 1979; J. R. Jensen 2007, 372).

Vegetation characteristics and the ways in which these characteristics are reflected on the electromagnetic spectrum are variable. Optimum conditions for measuring vegetation characteristics via satellite sensors is distorted if vegetation is planted at different times in their growth cycles, which results in variations at canopy level. Also, even if the biological structure of the biomass is compatible in a given area, different crop management strategies, such as variable access to irrigation, manuring, weed control, row spacing and field orientation have an impact on the relations between the vegetation and how it is measured in the multispectral satellite sensor (J. R. Jensen 2007, 374).

5.7.1. Normalized Difference Vegetation Index (NDVI)

In order to normalize for external factors such as the incidence angle of the sun, to minimize internal effects such as topographic variations, and to maximize sensitivity to plant biophysical parameters, a set of vegetation indices are used in the remote sensing. These include Simple Ratio (SR), Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture or Water Index (NDMI or NDWI), Perpendicular Index (PVI), and Enhanced Vegetation Index (EVI). These indices are dimensionless radiometric measures to investigate leaf area, percentage of green cover, chlorophyll content, biomass, and absorbed photosynthetically active radiation (Purevdorj et al. 1998; J. R. Jensen 2007, 382). While some of these indices provide redundant data, they also complement each other in other respects (Gao et al. 2000).

Among these vegetation indices, Normalized Difference Vegetation Index (NDVI) is the most widely used. Seasonal and inter-annual changes in vegetation growth can be monitored with this index. The index is calculated simply by:

$$NDVI = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

where NIR is the measurement from the near-infra portion of the spectrum, and R is the measurement from the red band portion of the visible spectrum. Normalization reduces multiplicative noise (topographic variations, sun illumination differences) in the data. However, NDVI is prone to additive noise such as atmospheric path radiance, and moisture levels in the air (Hobbs 1995, 1290). It is also sensitive to variations in the canopy background (Purevdorj et al. 1998, 1998; Hobbs 1995, 1290).

Many multi-spectral sensors can be used to generate NDVI. However, there are some specialized sensors which are specifically optimized for NDVI data collection. The Advanced Very High Resolution Radiometer (AVHRR) is a series of sensors mounted on National Oceanic and Atmospheric Administration (NOAA) polar orbiting platforms (POES). Spectral data collected by these instruments have been processed to produce a historic NDVI dataset from 1981 onwards (Compton J. Tucker et al. 2005). The data set is processed by radiometric calibration, atmospheric correction, cloud screening, and solar zenith angle correction, and the final product has 8km spatial resolution (*ibid.*).

The Moderate Resolution Imaging Spectrometer (MODIS) sensors mounted on Terra and Aqua platforms were designed to improve on the AVHRR (Running et al. 1994) by increasing its spatial and spectral resolution. Currently, MODIS serves vegetation indices at 500meter and 1km spatial resolutions. There is also another index set with 250 meter resolution, albeit with a limited scope. NDVI values generated from the MODIS collection are directly comparable to AVHRR-based NDVI values. This is a significant contribution for the systematic collection of remotely sensed data. MODIS and AVHRR NDVI values are replaceable for the measurements from arid and semi-arid areas. However, during the wet growing season, discrepancies arise, most probably due to the influence of water vapor content in the atmosphere which pushes AVHRR near infra-red values to decrease (Huete et al. 2002, 208).

The final set for NDVI values comes from the SPOT-4 Vegetation instrument, collecting data from 1998 onwards. The vegetation sensor collects spectral data on blue, red, near infra-red and middle infra-red bands, with a ground resolution of 1165 meters. Daily and ten day synthesis products are available at full resolution as well as at 4km and 8km resolutions.

5.7.2. A Brief Evaluation of NDVI values (1982-2006) in Upper Mesopotamia

In this dissertation, AVHRR NDVI data provided by Tucker et al. (2005) is used in order to model agricultural productivity in the study area. Even though other platforms offer higher spatial resolution NDVI data for Upper Mesopotamia, the temporal coverage that AVHRR provides (1981-2006) is superior to other sensors. Tucker et al. (2005) provide NDVI data in Albers projection, and index values are scaled to range between -1000 and 1000. In order to convert these values into original NDVI and to extract flags two operations are performed:

$$\mathrm{flag} = \mathrm{raw} - \mathrm{floor}\left(\frac{\mathrm{float(raw)}}{10}\right) * 10\,; \mathrm{NDVI} = \mathrm{float(raw/1000)}$$

The NDVI dataset contains bimonthly values. Although these data provide a detailed time-series, corresponding precipitation data in the region do not have the same temporal resolution. Therefore, NDVI values are averaged to create a monthly series. In the next step, these monthly values are integrated into a Matlab structure. Finally, a natural neighbor interpolation is applied to NDVI grid data in order to generate a continuous index surface (Figure 5.21).

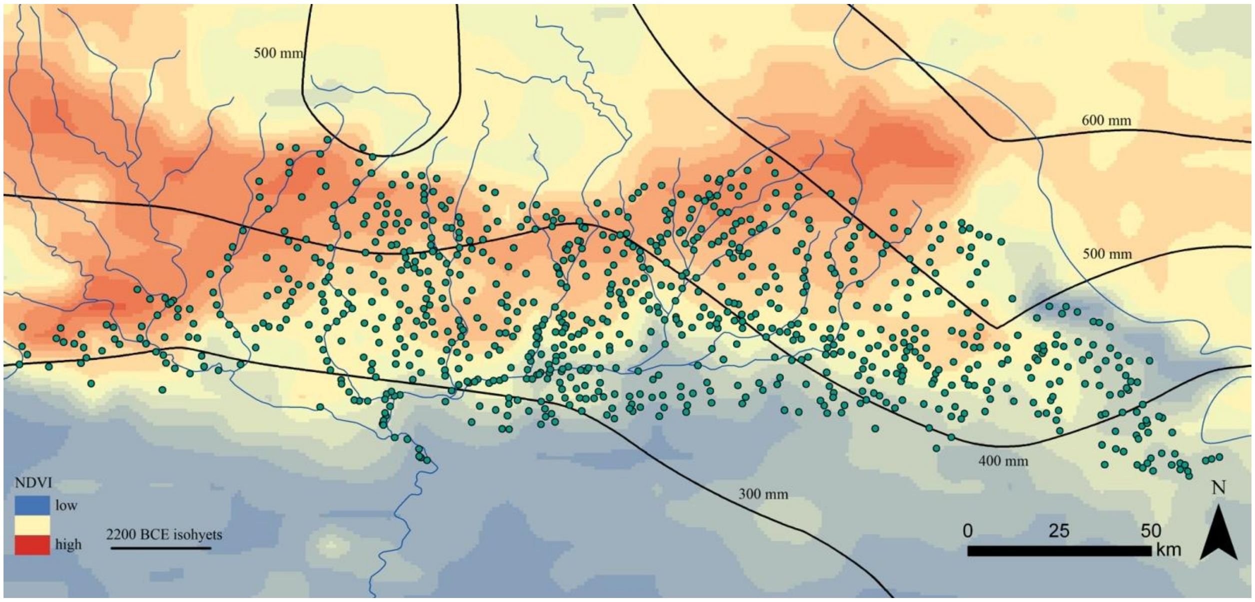

Figure 5.21 NDVI generation

Six geographically representative points in the study area are visually investigated for their NDVI time series. Specifically, the amplitude of the annual cycle and the annual maximum vegetation are studied in detail, thanks to the high temporal resolution provided by the AVHRR system. An analysis of these data reveals two significant observations. First, temporal data suggests that rain-fed agriculture is the main strategy in the study area. The high amplitude reflectance values occur in the late spring is an indication of the natural growing cycle of wheat and barley (e.g., Figure 5.22a). The late maturity of crops, represented in small local peaks (summer) to the right of main amplitudes (late spring), is an indication of irrigation. Irrigation extends the growth, even under unfavorable conditions so that some vegetation is detected even in the summer. However, considering the small amplitude of these local maximum values, the production area, supplemented by irrigation is limited.

Even though irrigation agriculture is evident at all sample locations, it is slightly more pronounced at the southern half of the study area. However, after the year 2000, irrigation becomes visible at the core and eastern sections of the Khabur Basin (Figure 5.22d, f). The clearest evidence for irrigation comes from the western section of the Khabur Basin (Figure 5.22c). This sample point is selected at the vicinity of one of the main tributaries in the Khabur where pump irrigation has been locally used since the early 1980s. But since pump irrigation is viable only in the vicinity of perennial and intermittent streams, it is likely that the irrigation zone constitutes a small portion of the whole study area.

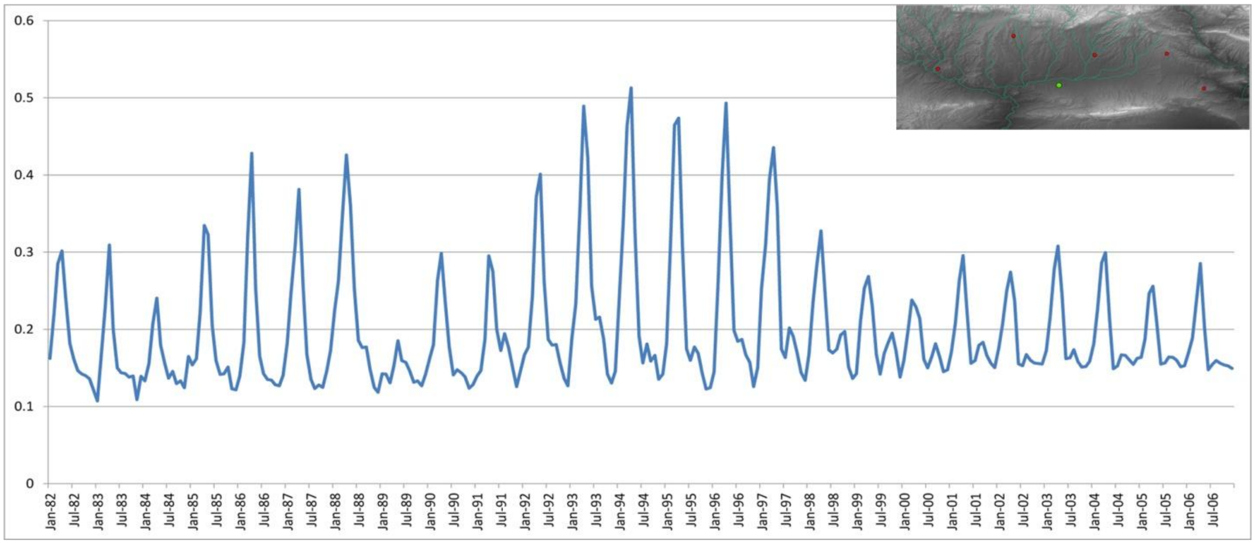

Figure 5.22a NDVI time series data from sample #1

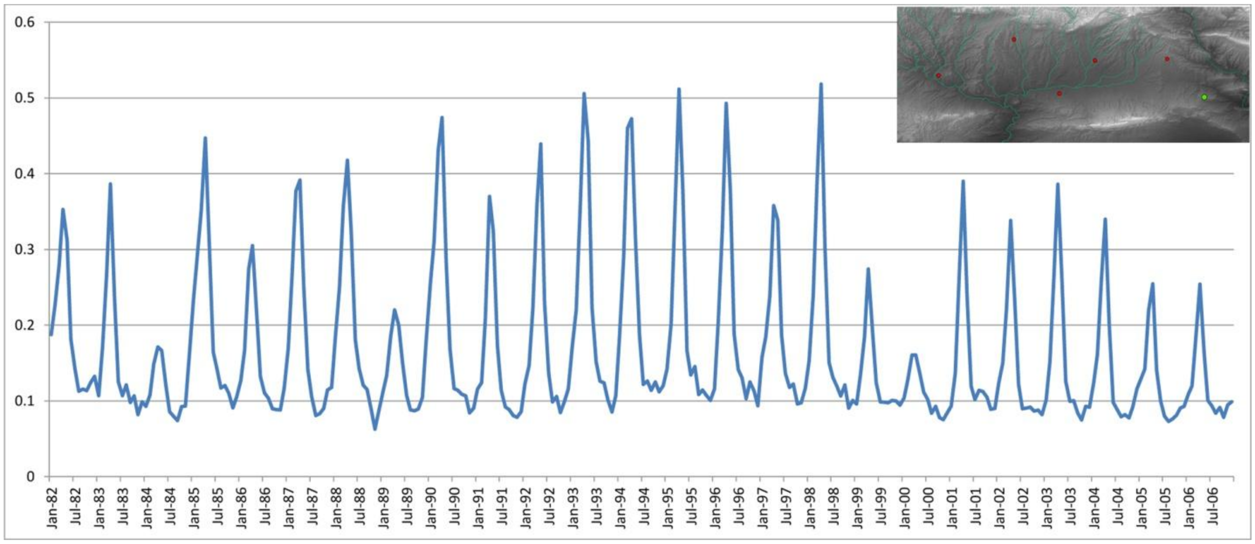

Figure 5.22b NDVI time series data from sample #2

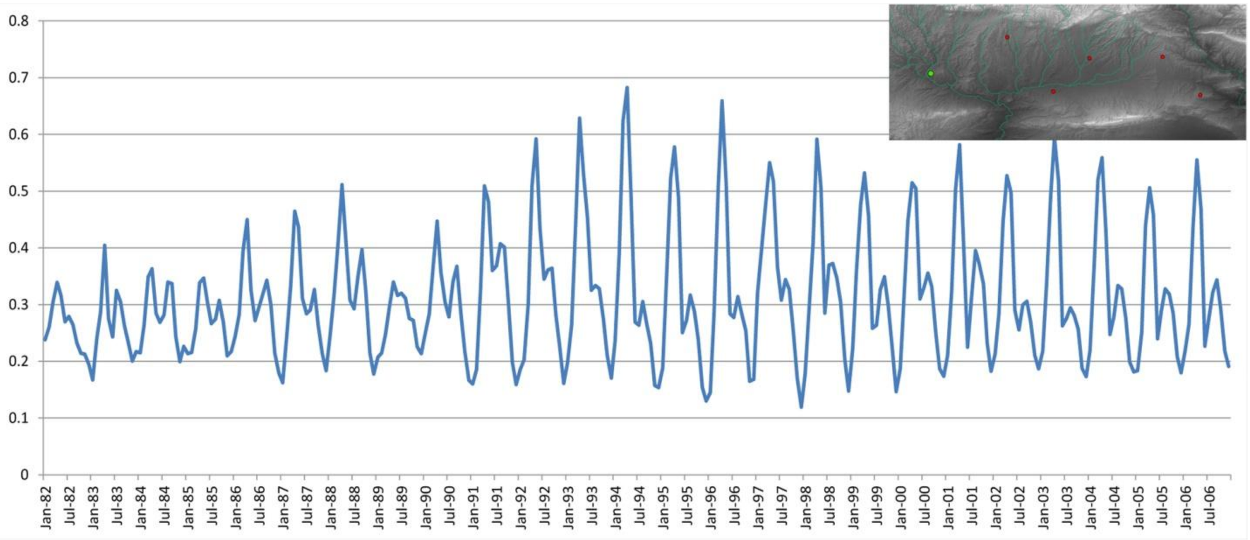

Figure 5.22c NDVI time series data from sample #3

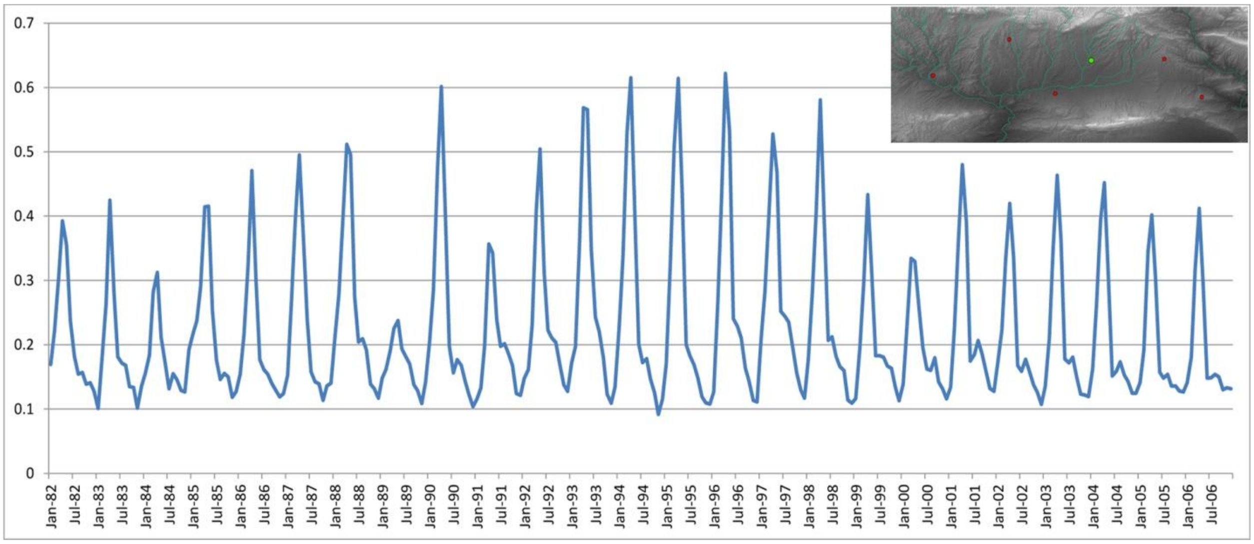

Figure 5.22d NDVI time series data from sample #4

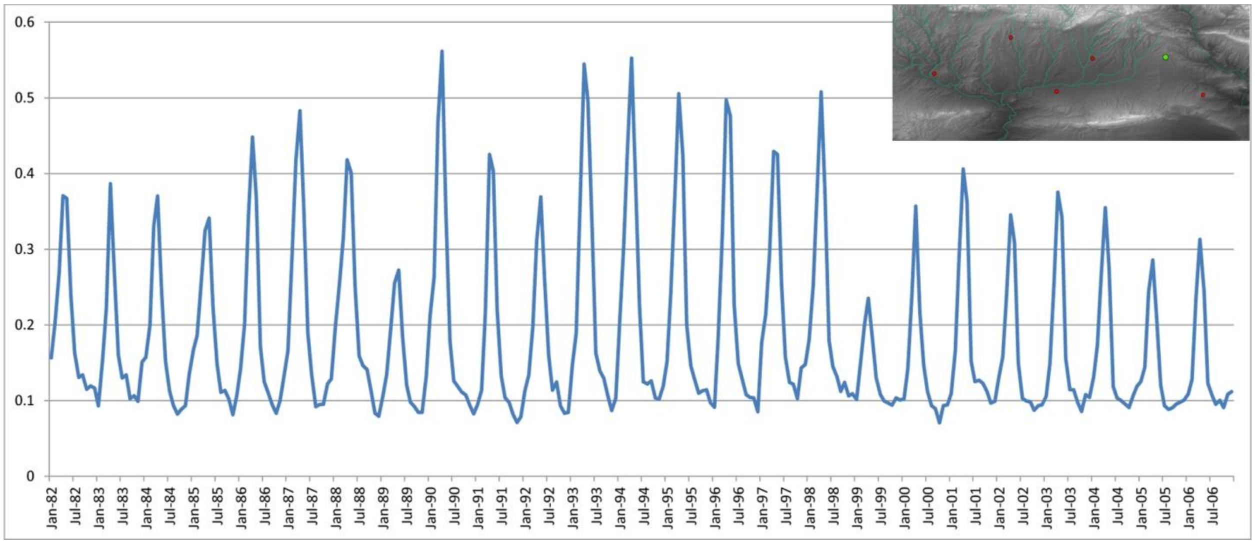

Figure 5.22e NDVI time series data from sample #5

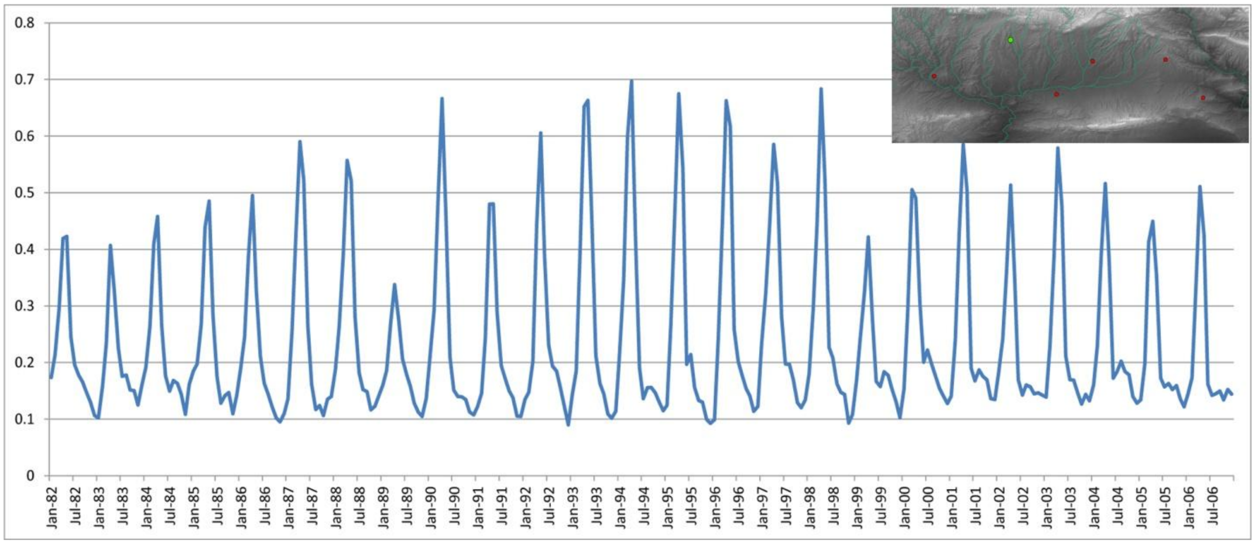

Figure 5.22f NDVI time series data from sample #6

A second observation is related to the variation within and between sample points. Sample locations reveal an increase in productivity between 1982 and 1994. A very sharp drop in 1989 can be attributed to the lack of precipitation in the area, which is also evident in rainfall data (Figure 5.4). Following 1994, the productivity trend decrease, with another sharp drop around 1999. Even though productivity trends are similar at sample locations, their amplitude varies greatly. While this can be attributed to variations between agro-ecological zones, it is also possible that different vegetation grown at sample locations contributes to the discrepancy.

5.7.3. NDVI and Yield Estimations

Estimating green biomass production is also possible using satellite sensors like AVHRR and MODIS. Three methodologies are generally used in this attempt: mixture models, cover-radiance relationships and vegetation index approaches (Purevdorj et al. 1998, 3520). Among these methods, vegetation index approaches are popular. In particular, green vegetation growth (P. J. Kennedy 1989; Diallo et al. 1991; Prince 1991a; Prince 1991b; Baez-Gonzalez et al. 2002; Sannier, Taylor, and Plessis 2002), and production level estimations (Hobbs 1995; Fuller 1998;

Funk and Budde 2009) are used in agricultural studies. These associations help researchers to develop strategies for studies such as wildfire management (Sannier, Taylor, and Plessis 2002) and drought analysis (Gouveia, Trigo, and DaCamara 2009).

There are multiple strategies for estimating crop yields via vegetation indices, especially the normalized difference vegetation index (NDVI). The first approach relies on ground data. Once an initial vegetation growth-reflectance relation is formulated through local ground measurements, this relation can be extrapolated to other areas with similar climatic and soil characteristics (Sannier, Taylor, and Plessis 2002). However, even if no ground information exists, among other indices NDVI still remains as a reliable estimator (Purevdorj et al. 1998, 3533).

Another method based on NDVI is the productivity index. The basic premise of a productivity index is to assess contemporary vegetation conditions by creating probability distribution functions of historic NDVIs. In building a productivity index, an integrated NDVI approach (Diallo et al. 1991) or a single NDVI approach (Kennedy 1989) is employed. Both of these approaches are based on a plausible assumption that rainfall is a direct determinant of vegetation health, which has been well-demonstrated.

An integrated NDVI approach involves using a combination of NDVI values (e.g., cumulative sum) from a portion of the time series. However, in order to transform single NDVI values into useable statistics, rainfall should be regular and uniformly distributed, which is rarely the case for arid and semi-arid regions of the world. The single NDVI approach, using values such as the mean or maximum NDVI, is also problematic because individual values may or may not accurately represent green biomass. Hobbs (1995, 1291) shows that maximum NDVI does not correspond to the peak growing season. Similarly, Funk and Budde (2009, 115) demonstrate that mid-to-late season NDVI values represent yields better than seasonal integrations or maximum NDVI values. Weak correlation between single NDVI and yield estimation is also reported by Daughtry et al (1983) and Malingreau (1986). In another study, Rasmussen (1992) suggests that early NDVI has no significance in documenting production, yet values from 30 days after the mid-season maxima are significant. In another study, Tao et al. (2004) reports significantly high correlation among NDVI values, crop variability, and precipitation variance. These studies all show that even though each vegetation type has a different behavior compared to its corresponding NDVI value, a temporal pattern exists. A single NDVI value selected immediately after the peak of the growing season may accurately estimate agricultural production. In this dissertation, however, a new NDVI approach is tested to model vegetation growth.

5.8. Remote Sensing Based Staples Production Formula

Crop yield estimation is provided by the formula:

$$Y = 0.7H.Ec\frac{k}{\Delta e} \; for \; Ec \geq 110\,mm$$

Above the annual 110mm precipitation line, the total amount of yield can be estimated by a combination of harvest index (H), total precipitation (Ec), crop specific index (k), and the vapor pressure deficit (Δe).

Simulation models such as CROPSYST (Stockle, Donatelli, and Nelson 2003) have been used in recent agronomic research to calculate the harvest index (H). Even though these simulations provide accurate estimations for H, they also require measurements collected in the field. In an alternative approach, H can also be estimated using NDVI data. The basic assumption in this process is that water and temperature stress affect the optimal final harvest index (HImax), and are related to the drop in NDVI from pre-anthesis to post-anthesis stages in the crop cycle (Moriondo, Maselli, and Bindi 2007, 270). This assumption can be formulated as:

$$HI_{NDVI} = HI_{MAX} - HI_{RANGE}(1 - \frac{NDVI_{post}}{NDVI_{pre}})$$

where HI_{NDVI} is the final harvest index. HI_{MAX} is the optimal value and set to 0.48, and HI_{RANGE} is set to 0.18. NDVIpre is the mean NDVI value from emergence to anthesis and NDVIpost is the average value from anthesis to maturity date, and thus, the ratio for post and pre-values usually ranges between 0 and 1. This ratio tends to generate harvest index values between 0.30 and 0.48 imposed by NDVI maximum and range values.

Merging the production formula-based precipitation value with the estimation of harvest index via NDVI values, the formula can be rewritten as:

$$Y \ = \ 0.7(HI_{MAX} - HI_{RANGE}\left(1 - \frac{NDVI_{post}}{NDVI_{pre}}\right)).Ec\,\frac{k}{\Delta e}$$

Finally, after plugging an estimated NDVI harvest index and Δe (=3) into the yield estimation formula suggested by Ehlers and Gros (2003), with k is set to 45kPa, total production (tons/ha) based on NDVI and precipitation values can be obtained by:

$$Y = 10.5\,.\,(\,Growing\ Season\ Precipitation).(0.48 - 0.18\left(1 - \frac{NDVI_{post}}{NDVI_{pre}}\right))$$

According to the formula, if growing season precipitation and NDVI time series data are available for a specific location, then it is possible to estimate total grain yield in tons per hectare. This provides information on local productivity rather than relying on statistics obtained from large region-based analyses, or agricultural databases (e.g., SAD). Therefore, proposed model is more powerful in capturing local variations.

This model establishes a one-to-one relationship between precipitation and total agricultural production, such that if growing season precipitation is available, the quantity of grain that can be obtained from a unit area can be calculated. This provides an opportunity to estimate ancient production. Paleoprecipitation data, like those reconstructed above makes it possible to estimate the amount of staples Early Bronze Age settlements were potentially able to produce. Therefore, a model of staples movement between settlements now have empirical basis.

Proposed production model is more realistic when compared against production estimations with fixed productivity values per unit area (e.g., Wilkinson, 1994). Rather than using fixed production values, the model is specific for each unit area so that possible production variation over extensive areas is observable. Understanding such variation is critical for studying how smaller settlements at the peripheries were constantly able to provide surplus food to urban central places during the Early Bronze Age and especially during the so-called 4.2kBP event.

The model has the hidden capacity to include other determinants of production. Not only precipitation, but also soil productivity, drainage, moisture retention capability and other factors are influential in crop growth, albeit in various degrees. These factors combined determine the total production amount in a given area. Even though precipitation levels explain much of the production variation, the proposed model corrects the precipitation - production relationship for each specific location since this relationship is based on NDVI data with 30 years range.

With this model, it is now possible to estimate how much food was produced in a given area. Therefore, total production can be calculated if the extent of production territory is known. Intensification of production in Upper Mesopotamia during Early Bronze Age left boundary markers of production territories in the form of hollow ways. Mapping these hollow ways in relation to the settlements which they were radiating from generates a rich inventory for the boundaries of ancient agricultural production.

CHAPTER 6: Remote Sensing of the Early Bronze Age

Tell (or mound, *höyük, hüyük, tepe*) is a particular settlement type in the Middle East, formed from the accumulation of generations of building materials (Rosen 1986). Many modern-day villages still occupy ancient mounds, adding to their material cultures. Tell-sites can be as high as 40 meters, and can attain a size of more than 100 hectares in Upper Mesopotamia (Wilkinson 1994). Consequently, mounds are easily distinguishable morphological features on the landscape. Tells cast shadows in different lengths depending on their height, and extents of these sites are usually circular in shapes. This distinctive topographical combination helps researchers to differentiate tells from other cultural and natural features. In Upper Mesopotamia, these settlements are almost invariable visible on CORONA images (Figure 6.1.).

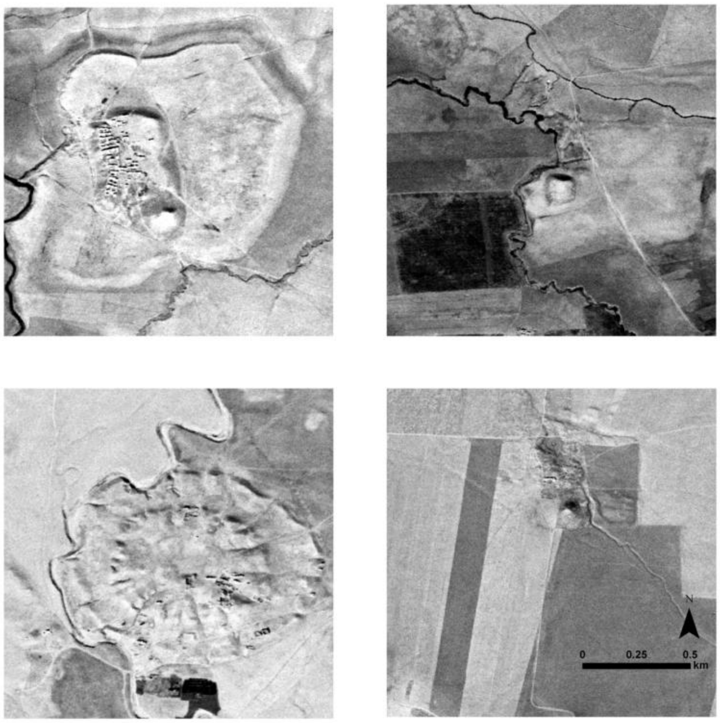

Figure 6.1. Mounds have unique geomorphological signatures

Tell-settlements left their physical marks on the landscape. In Iraqi Jazira, dispersed rural settlements during the 6th and 5th millennia were overshadowed by an urban center at Tell al-Hawa in the 4th millennium. These rural settlements were still occupied during the first half of the third millennium BCE, but by the second half of the same millennium more urban centers and a network of small towns dominated the landscape (Wilkinson 1989, 36). These urban centers and towns, when observed at a size scale, created hierarchical patterns. For the Tell al-Hawa region Wilkinson and Tucker (1995) builds 6 different classes for morphological characteristics of sites. Large and high mounds were mostly with 3rd or 2nd millennium BCE occupation. Groups of smaller and simpler mounds often had prehistoric occupation. Islamic habitation created topographically complex mounds, and geometric enclosures are dated to Sasanian or Islamic times.

In the Tell Beydar Survey, Wilkinson (2002) identifies three classes of site morphologies. Class 1 consists of small mounds which were primarily occupied during either early prehistoric times or during the Iron Age and later. Class 2 is a set of larger mounds than Class 1 sites, both in extent and height. These were mainly occupied during the Early Bronze Age. Some Late Chalcolithic and Ubaid mounds fell into this class, but they were still usually smaller than the mounds of Early Bronze Age. Class 3 is made of lower towns, characterized by extensive low mounds around higher tells. In the Tell Beydar region these sites are usually dated to Iron Age.

In a similar fashion, Ur (2008) classifies sedentary sites in Hamoukar region. In this schema, low mounds usually had prehistoric, Late Bronze Age or Iron Age occupations. High mounds in the area had initial prehistoric habitations, but later were covered by third millennium occupations. If on a high mound, Late Bronze Age occupations usually had lower towns. However, lower towns are not specific to the Late Bronze Age. In some large Early Bronze Age sites habitation was also spread to lower towns, creating extensive elevated areas around some major mounds. One another settlement type in the Hamoukar area is the complex mounded site. These were usually occupied during the Iron Age or later. Unmounded sites in the area were mostly occupied during the Late Chalcolothic period. Probably, these sites also once had topographic expression, but eventually were leveled.

The synthesis of these studies suggests that the dominant sedentary occupation type of the Early Bronze Age in Upper Mesopotamia was a nucleated tell-based settlement with some considerable size. Early Bronze Age settlements were usually larger and higher than other prehistoric or Iron Age mounds, and usually without a lower town. Lower towns were usually located only around prominent Early Bronze Age sites.

This morphological categorization is useful when viewing CORONA imagery for site types. Physical characteristics of Early Bronze Age sites are easily detectable on the imagery, and thus, it is possible to map the Early Bronze Age settlement pattern in its near entirety. Such dataset is invaluable for many respects. First, it is the most evident manifestation of the relationship between Early Bronze Age settlements and environmental dynamics. Extents of human sedentary occupation are the most visible when the settlement pattern data is complete and not restricted by artificially created archaeological survey boundaries. Second, this near-to-complete settlement inventory has the immense potential for investigating settlement relations (e.g., Menze and Ur 2012). Revealing these relationships is necessary to understand the ways in which settlement hierarchies are formed and sustained. Finally, this settlement inventory, coupled with production model can reveal settlements with food deficit and surplus. Investigating these settlements in a holistic manner can point at areas with food shortages or excessive production. In return, these minimal and maximal areas can be further studied for their vulnerabilities under ever-changing climatic conditions.

Remote sensing based archaeological mapping of extensive areas is possible when there is a reliable data source, covering extensive areas in an accurate manner. CORONA satellite imagery has the advantage over other systems for its spatial resolution, date of images, wide scan angle, etc. Mapping procedure heavily exploits CORONA imagery in a systematic manner, using the capabilities of the "CORONA Atlas of the Middle East" (Casana, Cothren, and Kalayci 2012).

6.1. CORONA

A very special form of high resolution satellite data pre-dates many of the sensors today. The CORONA spy-satellite system (1963 to 1972) was developed as part of the US intelligence program in the Cold War era (Day, Logsdon, and Latell 1999). In this time period, a large number of CORONA missions were run with different camera characteristics, with or without success.

Due to its high spatial resolution, temporal coverage, and stereoscopic capability, CORONA images are used in archaeological studies of the Middle East (D. Kennedy 1998; Challis et al. 2002; Philip et al. 2002; Ur 2003; Beck et al. 2007; Casana and Cothren 2008; Goossens et al. 2006; Fowler 2004; Casana, Cothren, and Kalayci 2012). However, this system is not only used by archaeologists. Studies in glacial geology (Bolch et al. 2008; Grosse et al. 2005; Stokes et al. 2006; Kim, Jezek, and Liu 2007; Surazakov et al. 2007), geology (Lorenz 2004; Murphy and Burgess 2006), land use (Kostka 2002; Maathuis and Van Genderen 2004; Birch-Thomsen et al. 2001; Sulzer and Zsilincsar 2002), change detection (Duran, Musaoglu, and Seker 2006; Franklin, Montgomery, and Stenhouse 2005), environmental monitoring

(Hamandawana, Eckardt, and Chanda 2005), forestry (Nyerges and Green 2000; Rigina 2003; Andersen 2006), agriculture (Elmqvist and Khatir 2007) employ CORONA imagery with considerable success.

CORONA images were obtained before the massive scale constructions, industrial agriculture, and urban expansion in the Middle East. The impact of such land-use land cover changes on the preservation of ancient material culture is immense, and in many cases, there is complete loss (Casana, Cothren, and Kalayci 2012). Considering the problems in obtaining historic aerial photographs in the Middle East, the value of CORONA imagery as a snapshot of the area before the drastic landscape transformation is beyond doubt. Furthermore, large spatial coverage enables researchers to document past landscape at a wider scale. CORONA also offers high temporal resolution. Areas of Upper Mesopotamia were usually visited by more than one CORONA mission at different times of year. Since the visibility of archaeological features depends on geometric, geographic and geological as well as local soil conditions, multiple images from different dates increase the detection probability of archaeological features. Another unique opportunity CORONA provides is the stereoscopic view in select missions. It is possible to create historic elevation models and to analyze CORONA in three dimensions using stereo-pairs (Casana and Cothren 2008). Through these topographic data, researchers can study site-taphonomies and landscape processes which might have affected site preservation and their destruction.

Within the CORONA program, the KH-4B series provides the highest spatial resolution with a dual panoramic camera system (but see KH-4A series, Ur in press). However, its advantage is diminished by extreme spatial distortions inherent in a panoramic scan (Figure 6.2). These distortions drastically lower the spatial accuracy of the data (Casana and Cothren 2008).

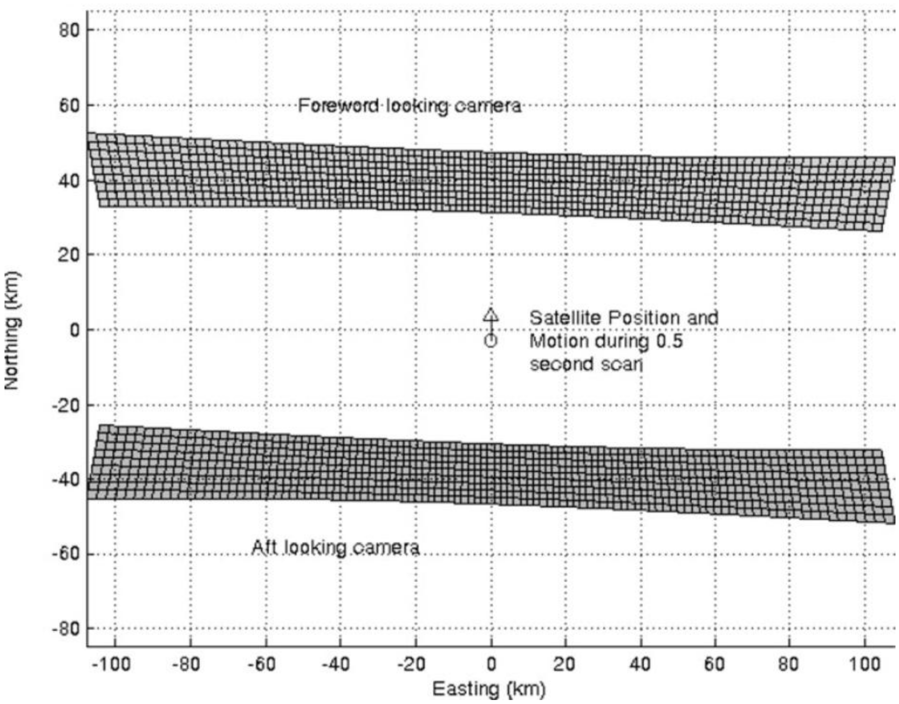

Figure 6.2. CORONA image distortions based on panoramic scan

Therefore, scholars either solely focus on visual interpretation of CORONA images without any geometric correction (e.g., Birch-Thomsen et al. 2001; Maathuis and Van Genderen 2004) or they work on image subsets where ground control points are used to correct distortions (e.g., Grosse et al. 2005). In few cases, these ground control points are used to estimate image parameters for a photogrammetrical solution (Bolch et al. 2008; Casana and Cothren 2008). Overall, the complexity in spatial distortions limits researchers to work on small areas.

6.2. Mapping the Early Bronze Age Settlement System

A NEH-funded recent project, the "CORONA Atlas of the Middle East", developed more efficient means of photogrammetric correction and now provides a large image database for spatially accurate orthorectified CORONA images. The project provides a unique opportunity to explore landscapes in a comprehensive manner at larger scales (Casana, Cothren, and Kalayci 2012) (Figure 6.3). In this dissertation, remote sensing based archaeological survey of Upper

Mesopotamia identified and mapped archeological settlements dated to the Early Bronze Age using the products of CORONA Atlas of the Middle East.

Figure 6.3. The coverage of the "CORONA Atlas of the Middle East"

6.2.1. Mapping Early Bronze Age Nucleated Tell-Settlements

6.2.1.1. Mapping Sites -Methodology

Mapping Early Bronze Age settlements in the study area is conducted in two phases. In the first phase, published survey reports from archaeological studies (Davidson and McKerrell 1976; Meijer 1986; Weiss 1986; Stein and Wattenmaker 1990; Wilkinson and Tucker 1995; Eidem and Warburton 1996; Kouchoukos 1998; Ur 2002; Wilkinson 2002; Wright et al. 2006) are selectively compiled. Next, site gazetteers and distribution maps are digitized. Using known site locations and other geographical elements, as they are provided in the report, distribution maps are spatially corrected in ArcGIS 10 (Figure 6.4). When overlaid on CORONA imagery, distribution maps reveal which sites appear in what forms on the imagery. This phase is necessary to create a morphological knowledgebase for mounds with the Bronze Age occupation, and to understand reconnaissance capabilities of the CORONA as well as its deficiencies.

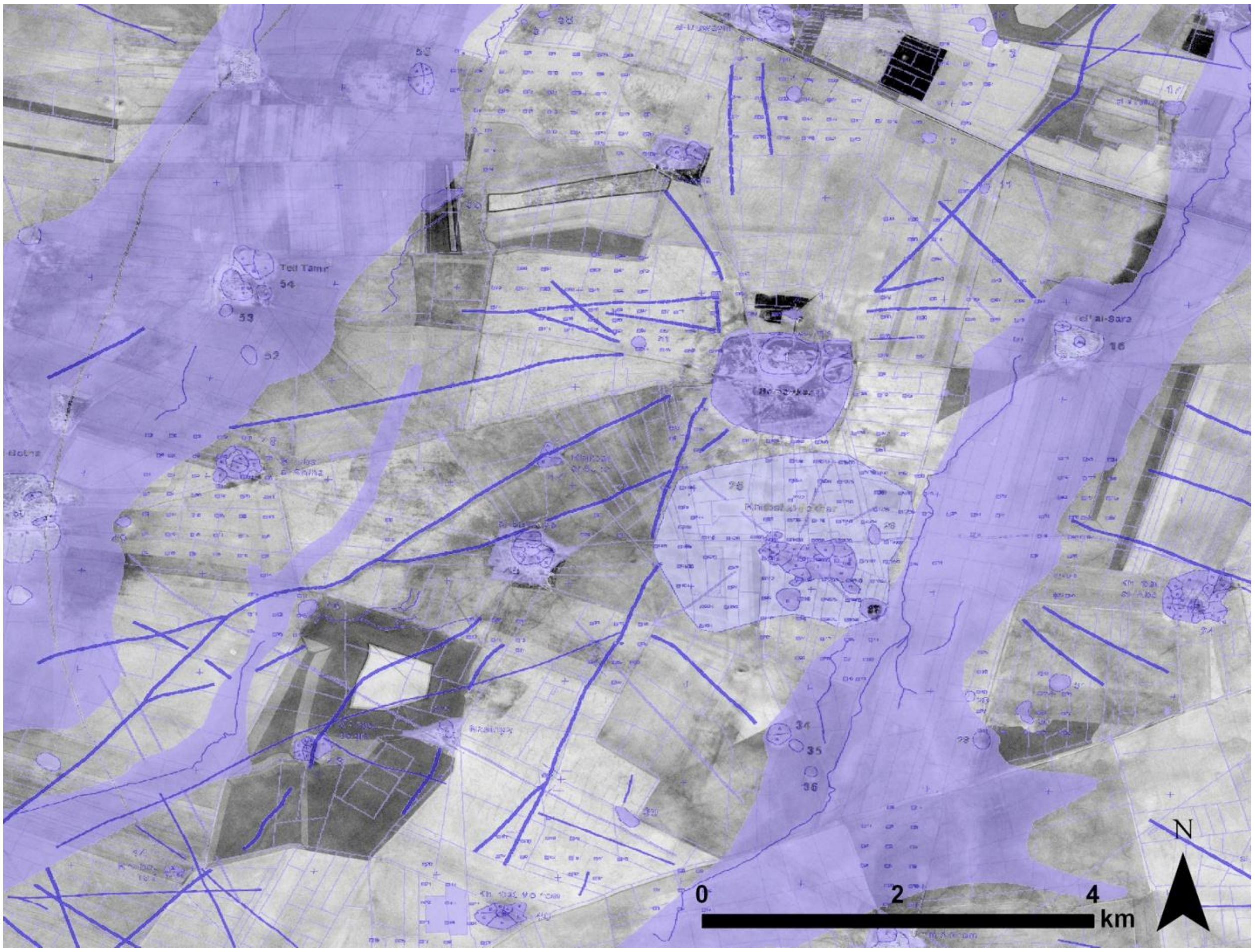

Figure 6.4. Hamoukar survey results (Ur 2008) on CORONA imagery

Published surveys are also used to gather information about reported morphological characteristics, and precise dating of sites. In some earlier surveys such information does not exist (e.g., Einwag 1993). However, in some cases detailed information on dates, shapes and height are available (e.g., Ristvet 2005). Using these attributes morphological knowledgebase is refined for the Early Bronze Age occupation.

The second phase in mapping involves inspecting previously non-surveyed areas for other mounds which are not documented by earlier studies. Despite the long history of archaeological research in the area, there are still large gaps between survey coverage. This is a limiting factor for archaeologists to work on complete pictures of settlement systems. Following a remote sensing approach, these gaps and previously surveyed areas are visually investigated on CORONA imagery, and a total number of 1099 sites have now been mapped (Figure 6.5) using images from 1102-1025D (12/11/1968) and 1105-1025D (11/05/1968) missions.

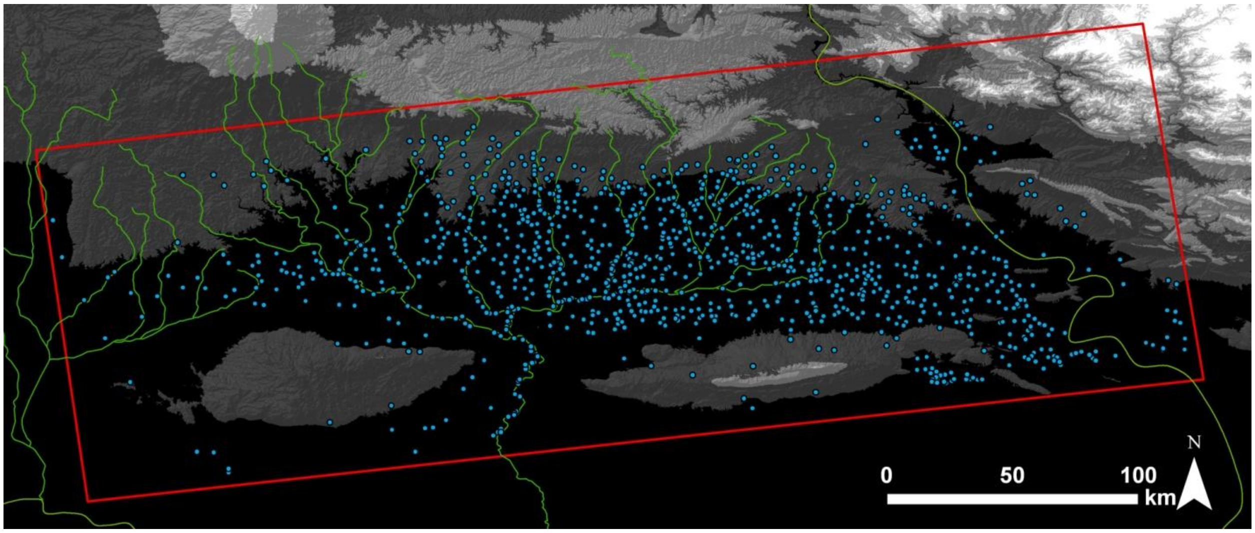

Figure 6.5. Distribution of settlement mounds in the study area

There are several sources of error in this morphology-based approach to documenting the Early Bronze Age landscape. The first source is mounded settlements which had no actual Early Bronze Age occupation. Considering these mounded sites in the Early Bronze Age settlement inventory would lead to erroneous inferences. Ground data, however, suggest that very few nucleated tell-based settlements are without Early Bronze Age occupation. Considering the taphonomic processes affecting the preservation conditions, it is also possible to suggest that at tell sites with no visible Early Bronze Age occupation had in fact this occupation phase, yet it is either badly damaged or buried under later occupations.

A second source of error comes from non-mounded settlements which had Early Bronze Age occupation. Without actual groundwork there is no secure way to date these settlements as Early Bronze Age so that they are excluded from the remote sensing based archaeological survey. This creates an immediate bias against such sites in the archaeological settlement record. On the other hand, survey results suggest such non-mounded settlements with Early Bronze Age occupation are very few in number. Ristvet (2005) reports more than 60 settlements which are dated to Phase 4 (2500-2300 BCE) and Phase 5 (2300-2200 BCE). Only 7 of these settlements are non-mounded, but rest of the settlements differs by their nucleated tell-based morphologies. Similarly, among 20+ Early Bronze Age sites reported by Wilkinson (2002), only one of them appears as a flat site on CORONA imagery. Though these surveys cannot fully represent the totality of Upper Mesopotamian Early Bronze Age occupation, they provide further support for the claim that nucleated tell-based settlements were the signature settlement type in the region.

Third, the model suffers from settlements buried under sedimentation. These settlements can hardly be detected on satellite imagery, unless some physical and/or chemical manifestation exists. Furthermore, these settlements are also likely to remain unrecorded, even surveyed with an intensive strategy. A classic example comes from Southern Mesopotamia where Adams and Nissen (1972) raise the question of alluvial sedimentation as an impediment for archaeological observations. However, such drastic geomorphological changes are not observed in Upper Mesopotamian landscapes. Homogenous surface conditions only accumulate limited aeolian deposits and alluvial deposition is also limited due to high energy of rivers creating deep trenches, rather than moving laterally. Since Early Bronze Age dwellers preferred nucleated tell-based settlements, it is unlikely that surface processes completely erased these settlements from the archaeological landscape. This argument cannot be made with the same confidence for earlier prehistoric and later Iron Age mounded sites as these sites were less prominent when compared with the Early Bronze Age occupation.

Finally, sites occupied by non-sedentary groups were ephemeral in character. Even though some seasonal campsites must have left some marks on the landscape (Ur 2008, 78), these are rather hard to detect. Therefore, non-sedentary dwelling during the Early Bronze Age are under-represented or even non-existent in settlement pattern studies. These settlements are either badly damaged by natural and cultural processes or their ephemerality drastically reduce their detection potentials.

6.2.1.2. Mapping Early Bronze Age Hollow Ways

CORONA imagery from Upper Mesopotamia is also used to document Early Bronze Age hollow ways. Due to their structural characteristics, these routeways are usually visible on the imagery (Figure 4.1). An initial inventory for hollow ways is kindly provided by Jason Ur, and more hollow ways are added to this inventory by visually investigating CORONA images of the study area.

Studies on hollow ways focus on Upper Mesopotamian landscapes, but mostly the areas in and around Khabur Basin are investigated (e.g., Wilkinson 1993; Ur 2003). Limited geomorphological processes in the area pose limited danger on the preservation conditions so that these route systems can be detected through satellite imagery. However, a recent study by Casana (2012) suggests that not only preservation conditions, but also the processes which generate these hollow ways are also determinant on how scholars observe these off-site features today. Furthermore, Casana (*ibid.*) extends the focus towards western Syria and northwestern

Iran and suggest that hollow way is a more widespread phenomenon than suggested before and they are reliable proxies to understand the relationship between sedentary and pastoral economies. This dissertation only considers hollow ways in Upper Mesopotamia. In this region, there are two basic categories of route systems: hollow ways radiating from a settlement mound-as a proxy for the extent of intensive agriculture practiced in that settlement and hollow ways which connect settlement mounds to one another.

In Upper Mesopotamia, hollow ways radiating from nucleated tell-based settlements appear on CORONA imagery in exclusive forms. The main form has various levels of visibility in the study area. Hollow ways, due to the differences for the ways in which they were used (and preserved), have differential water retention capabilities. Moist soil at the center is less reflective when compared with the edges of the hollow way, and thus, they appear darker. Drainage at the edges are more compared with the center and they appear in bright colors due to high reflectivity (Ur 2003, 106). A structural comparison of hollow ways and how they appear on CORONA imagery is given by (Casana 2012, 13). This is a key comparison to differentiate between hollow ways from Early Bronze Age and hollow ways from later periods.

Building on top of the already existing hollow ways inventory (Ur 2009), 5550 km of hollow ways made available for the analysis. Among 2296 hollow ways, 606 of them are inter-site, 1663 of them radiates from a mound, and 27 of them have no clear association with another archaeological feature (Figure 6.6). These ‘floating’ hollow ways are most probably disturbed in a way that their association with a settlement is lost. It is also possible that a mound associated with these hollow ways are completely erased from the landscape, though this is less likely be the case.

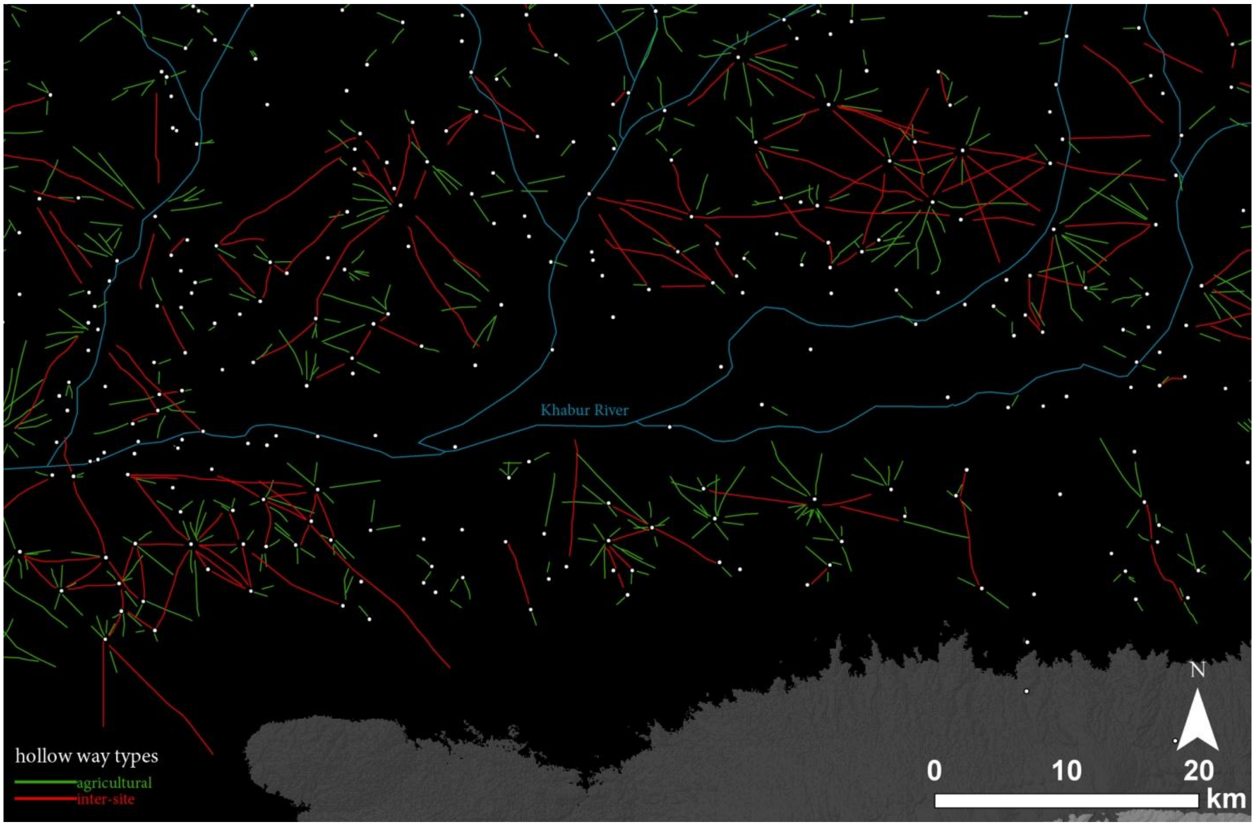

Figure 6.6. A sample of hollow way distribution in the area

The map of hollow ways in Upper Mesopotamia is useful for at least two reasons. First, this dataset makes it possible to calculate extents of intensive agriculture at a regional level. This understanding of agricultural production at a large scale is beneficial. Second, intra-site hollow ways suggest a connected network of settlements in constant interaction with each other. This high level of connectedness, as shown by the mapping project is a challenge to central place theory based models where the interaction between settlements is in two main directions; from center to the periphery or vice versa. This dissertation only makes use of hollow ways radiating from settlements. The methodology for defining the boundaries of intensification is discussed in the next chapter.

CHAPTER 7: The Boundary Problem

The total size of fields is one of the main determinants of how much agricultural yield can be produced in a given settlement. While many variables affect total production, including labor availability, labor relations, production strategies, and levels of agricultural intensification or extensificiation, production territory as a product of both working and landscape capitals, is one of the most important factors. Thus, success in modeling ancient agricultural production and estimating agricultural product flow among Early Bronze Age settlements depend on how accurately the extent of a production territory is approximated.

Fortunately, the intensification of agricultural production during the 3rd millennium BCE in Upper Mesopotamia left landscape evidence of ancient production territories, namely hollow ways, which can be used to estimate production territories surrounding individual sites. Terminal points of hollow ways indicate the extent of intensive production when roadways are well preserved. For settlements with no or fragmentary hollow ways around them, production territory can be estimated using spatial modeling techniques. The first section of this chapter (7.1) focuses on modeling production territories with well-preserved hollow ways surrounding them. The section also extends this spatial model to settlements with no associated hollow ways. By combining these models alongside settlement discussed in Chapter 6 a full picture of Early Bronze Age production territories can be reconstructed.

The theoretical model as used in this dissertation is heavily influenced from the pioneering studies of Vita-Finzi and Higgs (1970) related to Site Catchment Theory. According to this theory, the extent of the territory under use is determined by the ability of inhabitants of a settlement to travel at distances. Travel time on foot, based the principles of least effort, suggests a 10km radius from home for hunter gatherers, a 7.5km radius for pastoral herders, and a 5 km radius for farming communities (Bintliff 2000: 506). As travel time from a settlement increases, the level of intensity of land-use can be expected to drop. Furthermore, if exploited resources or reasons for travel around the settlement are isotropic, and if the topography around the settlement are flat, then the settlement territory is circular in shape and settlement tends to be central to its territory (*ibid.*: 522). This ideal model is only valid for a single settlement which stands in isolation from other settlements. Interaction with neighboring settlements and with the overall socio-political landscape, however, distorts this model. Other criticisms for a site-catchment based analysis of settlement territories argue that the land-use model is prone to environmental determinism, has superfluous assumptions about population densities and food consumption measurements do not allow for some fundamental features of ancient organization such as feasting, is based on homeostatic equilibrium conditions, and finally that the model does not allow for human agency (Wilkinson 2005a).

Despite these criticisms, Upper Mesopotamian site territories during the second half of the third millennium BCE may be represented through conditions of this ideal model. The topography of the Upper Mesopotamia is considerably flat, even over extensive territories. Moreover, the agricultural political economy indicates immediate exploitation of settlement vicinities through intensification of production (Wilkinson 1994). Therefore, some elements of Site Catchment Theory can be used to successfully model the extents of production territories (*ibid.*). The complete map of Early Bronze Age settlements and hollow ways also provides means for correcting this territory model for relative locations of settlements with respect to one other.

7.1. Defining the Agricultural Production Boundary

Hollow ways, radiating from a nucleated tell-based settlement, are an indication of constrained movement. This controlled movement is usually interpreted as an effort to minimize damage on agricultural soil, and thus, support the claims for intensive land use practices (Wilkinson 1994). Hollow ways radiate from these settlements in various angles and in all directions, and it is therefore, possible to define the geometric shape of agricultural boundaries in a statistical sense. The effort is to fit a shape to the end points of hollow ways, where they disappear in the landscape, and a quick exploration of the hollow ways indicates territories were roughly circular in shape.

7.1.1. Shape Fitting

There are various approaches to fit shapes to known data points. The process involves, first, determination of the end points of hollow ways in the landscape and second selecting an appropriate methodology for shape fitting depending on the number of available points. Six hollow ways (or more) around a settlement provide an accurate solution (Figure 7.1). However, only thirty-four settlements satisfy this condition (Figure 7.2) so that further manipulation is required for the remaining dataset. If the number of hollow ways is between 3 and 6, it is assumed that the symmetric position of the end point of a hollow way with respect to the settlement also represents the boundary of the production territory. To secure non-directionality, orthogonal vectors of known hollow ways are also calculated and included in the analysis. Following this assumption, it is possible to secure at least 6 points for the fitting problem. For these settlements, a 6 parameter algebraic circle fit following the equation:

$$0 = a(1)x^2 + a(2)xy + a(3)y^2 + a(4)x + a(5)y + a(6)$$

is performed where x and y denotes the end point coordinates of hollow ways in a settlement. The computation is based on solving an eigensystem of design (D)-constraint (C) matrices:

$$S = D'x\ D\ where\ D = [x.x, x.y, y.y, x, y, 1]\ and$$

$$C(1,3) = -2 \quad C(2,2) = 1 \quad C(3,1) = -2$$

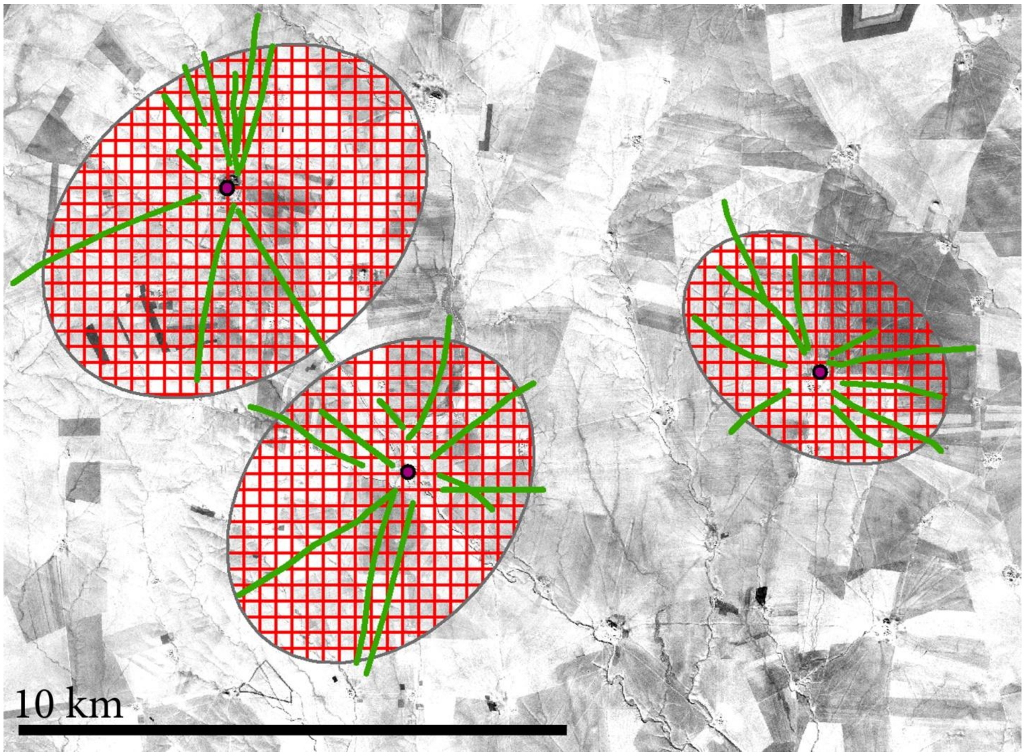

Figure 7.1. Shape fitting on hollow ways

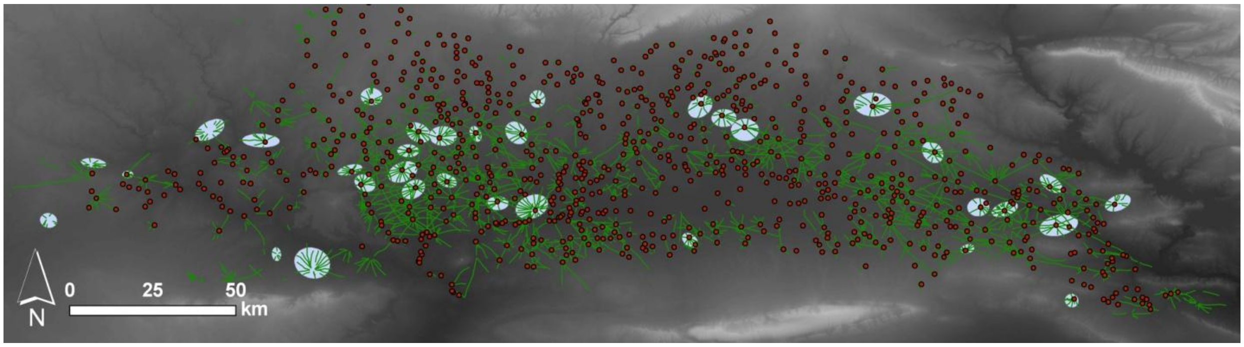

Figure 7.2. Settlements with more than 6 hollow ways

If the number of hollow ways in a settlement is less than two, a circle is drawn around a settlement in which the radius, the average of the hollow way lengths. After this process, 628 settlements are modeled for their agricultural production territories with the help of documented hollow ways on CORONA images.

Depending on the spatial layout and the length of the hollow ways, some overlap is observed between estimated agricultural production extents (Figure 7.3). Furthermore, in some cases the modeled production area of one settlement completely covers the production area of another settlement (Figure 7.4).

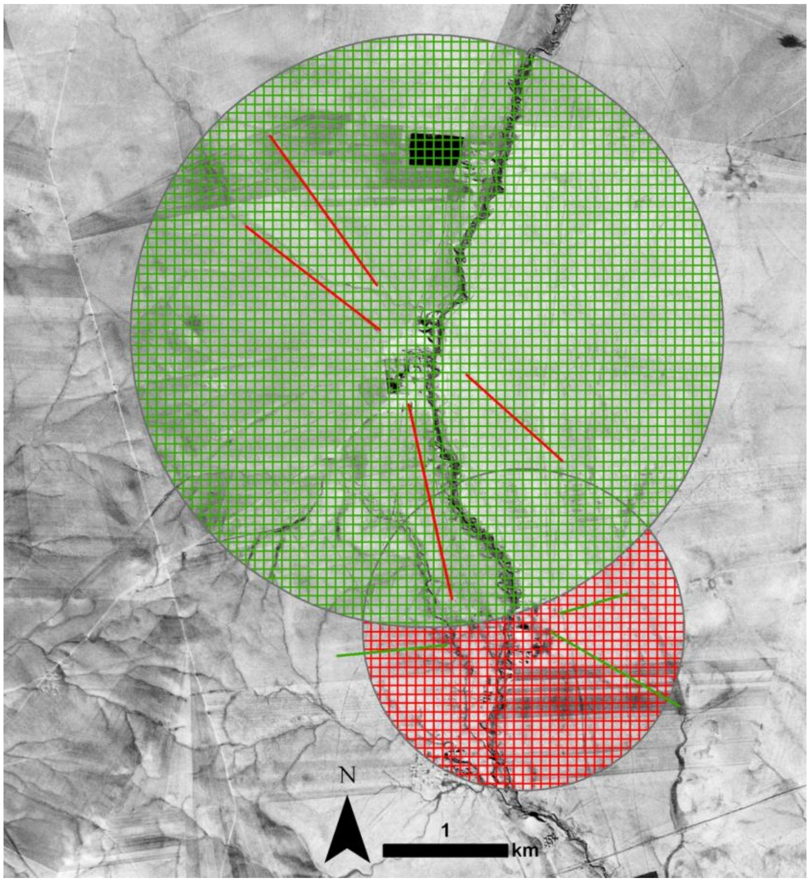

Figure 7.3. Overlapping zones based on hollow way modeling

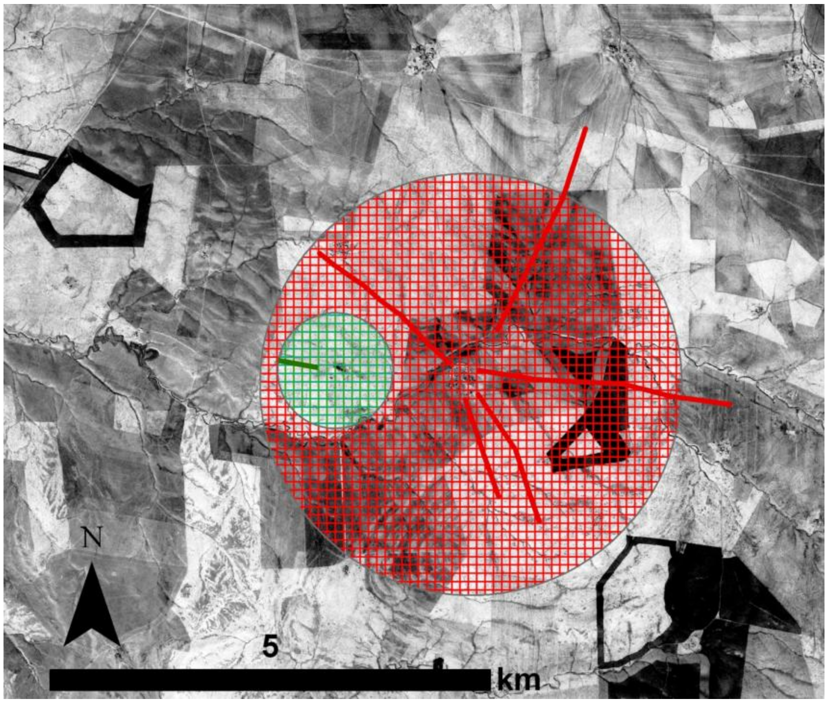

Figure 7.4. Complete coverage by a larger production zone

This is a significant observation in terms of how agricultural production was organized, and in which cases a settlement required establishing another small settlement nearby to supplement its own production. It is most likely that labor constraints in the parent settlement limited the amount of local production, even though there was enough agricultural land around it. In similar cases, a smaller settlement must have been established to increase the amount of agricultural labor at the expense of losing some portion of the production zone for establishing the daughter settlement. These arguments, however, are only valid under the assumption that settlements were occupied contemporaneously.

7.1.2. Spatial Modeling

Not every Early Bronze Age settlement mound has a documented hollow way associated with it. This creates a problem in determining the extents of agricultural production of a settlement as no empirical evidence exists for its production territory. Therefore, various spatial models are tested against settlements with documented hollow ways. Thirty-four settlement mounds in the study area have a large number of hollow ways radiating in multiple angles from the center. This leaves little room for ambiguity regarding the extent of production territories. Thus, this training set provides an opportunity to investigate the accuracy of spatial models used in estimating the extents of production throughout the region.

The correlation coefficient between settlement areas and production territories for the training set is 0.36. This relatively low number suggests that there is no immediate relationship between the size of a settlement and its production territory. A scatter plot for normalized values of settlement areas and estimated production zones visually supports this lack of association (Figure 7.5).

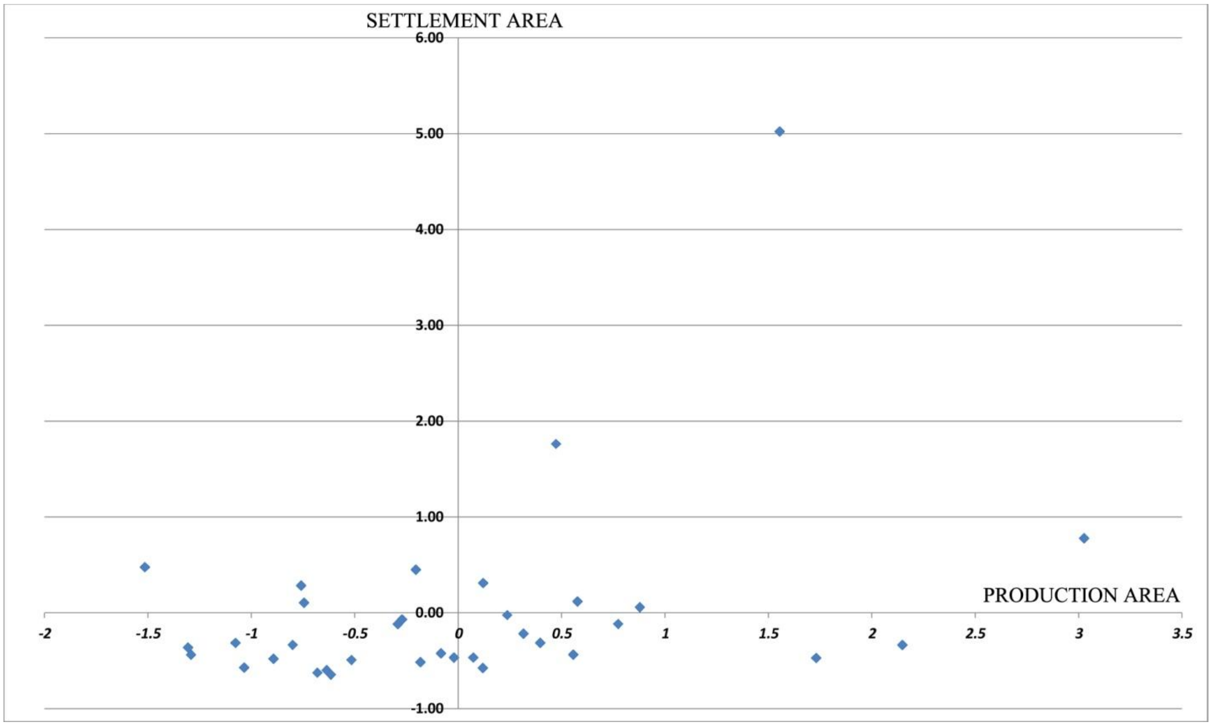

Figure 7.5. Comparison of settlement areas with their estimated production extents

Therefore, it is not directly possible to suggest a simple model based on settlement sizes to study production levels suggesting that many such models commonly employed in studies of Upper Mesopotamia (e.g., Ur 2010b, 153) may require modifications. This observation further complicates discussions of dry-farming economies, because population size is usually based on site size, and available agricultural labor is a function of population. According to Wilkinson's (1994) influential model, production area is expected to be correlated with the available agricultural labor (and thus, the site size) since more available labor makes it possible to expand the production area.

The correlation coefficient of 0.36, however, suggests this relation is not a direct one. It is still possible that population size and production amount was correlated, but each settlement had different productivity values. Or, the amount of total production was made sufficient to feed the populations through differential treatment of soil. Therefore, it would be more accurate to investigate not the relation between production areas with the site size, but use estimates of ancient production levels in relation to site size.

One of the implications regarding the spatial layout of hollow ways is that the terminal points of hollow ways usually fall in areas between two settlements. In other words, it is not the settlement area (or the size of the population) but the spatial configuration of the settlement pattern that is determinant of how much land is dedicated for production. In this regard, the Thiessen polygon (Aurenhammer 1991) is a simple, but effective spatial tool to estimate production areas in the absence of empirical data.

To suggest a model, Thiessen polygons are generated using ArcGIS 10.0 for the entire Early Bronze Age settlement dataset. Second, polygons at the periphery of the system are discarded since these polygons are heavily biased for their positions at the edge. Finally, Thiessen polygons for settlements with a well-preserved hollow way system are extracted for further analysis. Visual comparison of hollow ways and Thiessen polygons immediately suggests a relationship (Figure 7.6). On the other hand, this relationship is far from perfect. For settlements with very large production areas, such as Tell Brak, a Thiessen polygon is not able to represent the production area (Figure 7.7). At this large urban center, food requirements must have been high and spatial borders, as modeled by Thiessen polygons, were violated due to the power of Tell Brak in the political landscape.

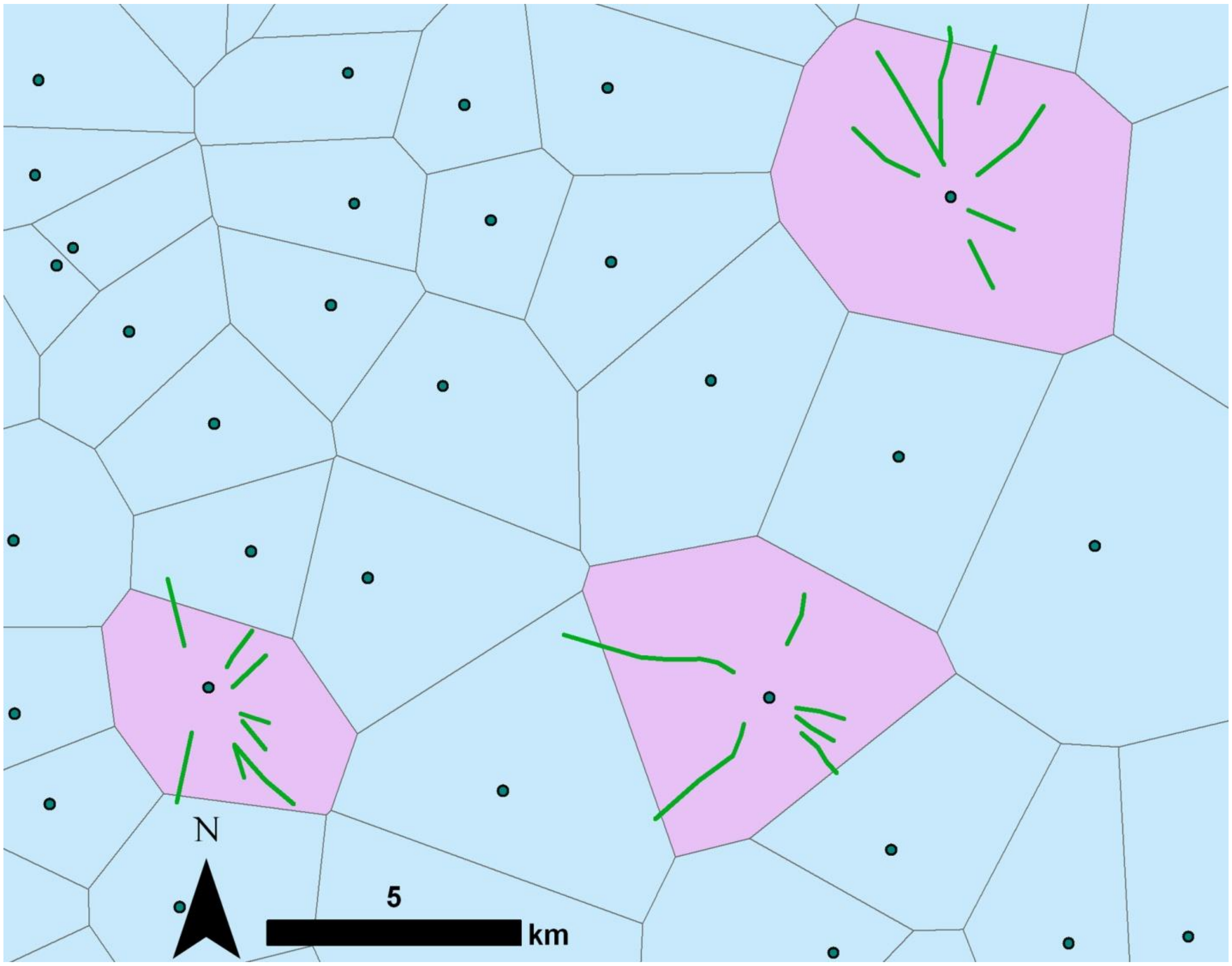

Figure 7.6. Spatial relations between hollow ways and Thiessen Polygons based on settlement locations

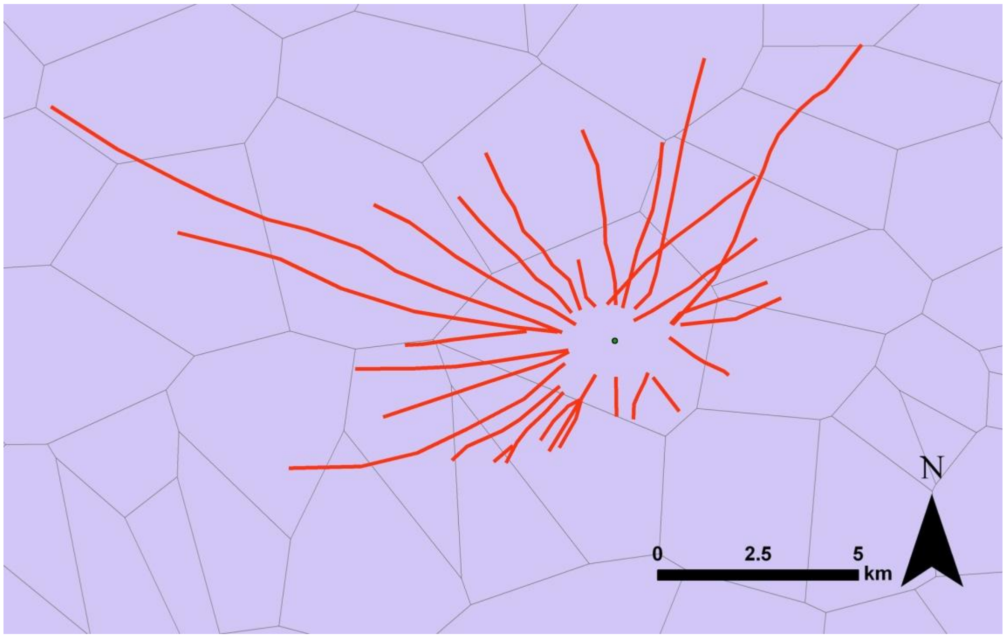

Figure 7.7. Tell Brak production extents violate Thiessen Polygon configuration.

Methodological problems also reduce the accuracy of Thiessen polygons in representing the Early Bronze Age productive landscape. The layout of polygons strictly depends on the locations of settlements, so that a missing settlement in the inventory or a settlement which is not contemporaneous with other settlements distorts the model. Nevertheless, for settlements with no documented hollow ways around them, spatial modeling remains a viable option for estimating site territories.

In using Thiessen polygons, first, the geometry of the polygons is imported to Matlab 2010. Under the assumption that the boundary of agricultural production coincides with the Thiessen polygon of a settlement, mid-points of the edges of polygons are located. Second, as described above, an algebraic circle fitting algorithm is used to model production areas. Finally, production areas which are modeled with Thiessen polygons and areas obtained from hollow ways are merged into a single ArcGIS layer (Figure 7.8).

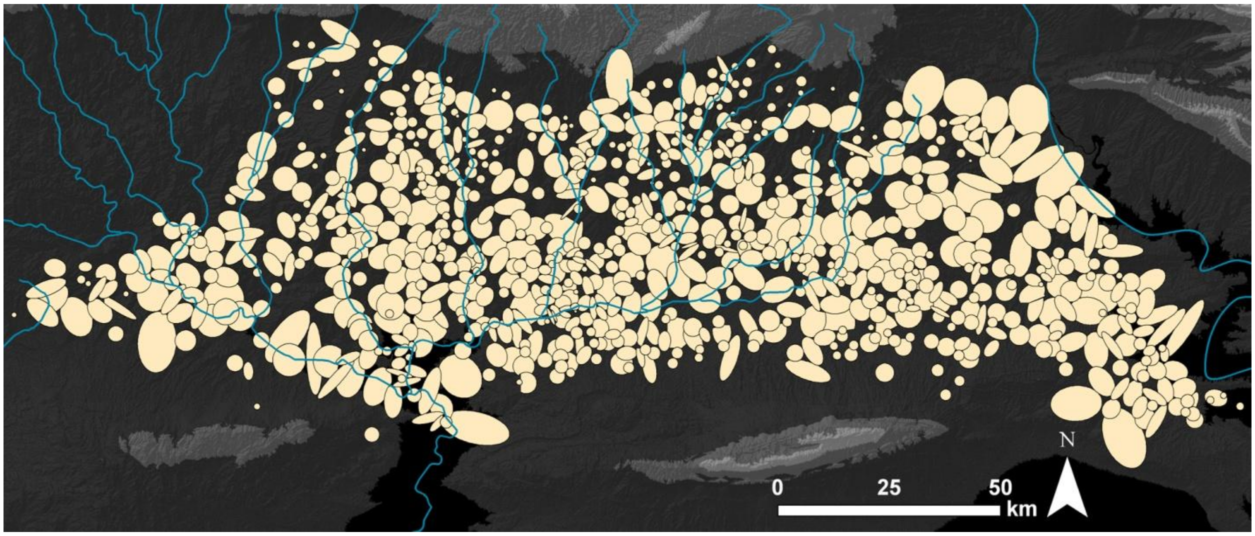

Figure 7.8. Final production extents model

7.2. Defining the Settlement System Boundary

Analysis of the close-to-complete inventory of Early Bronze Age settlements (see Chapter 6) clearly suggests some form of spatial boundary for the Early Bronze Age settlement systems. Overlying settlement location data with a LANDSAT image shows that the distribution of Early Bronze Age settlements had some relation with the environmental dynamics of the region (Figure 7.9). Settlement systems were preferably located at the core of highly productive areas, and the limits of productivity seemingly determined the extents of the Early Bronze Age settlement system. Yet, there is still a need to formalize this argument so that a boundary model can be built.

The Early Bronze Age settlement system boundary is defined in two steps. First, settlement mounds are visually investigated on CORONA imagery to explore the structure of the settlement pattern. Second, settlement sizes and locations are used to draw the settlement system boundary. This approach requires separating the notion of settlement patterns from settlement systems.

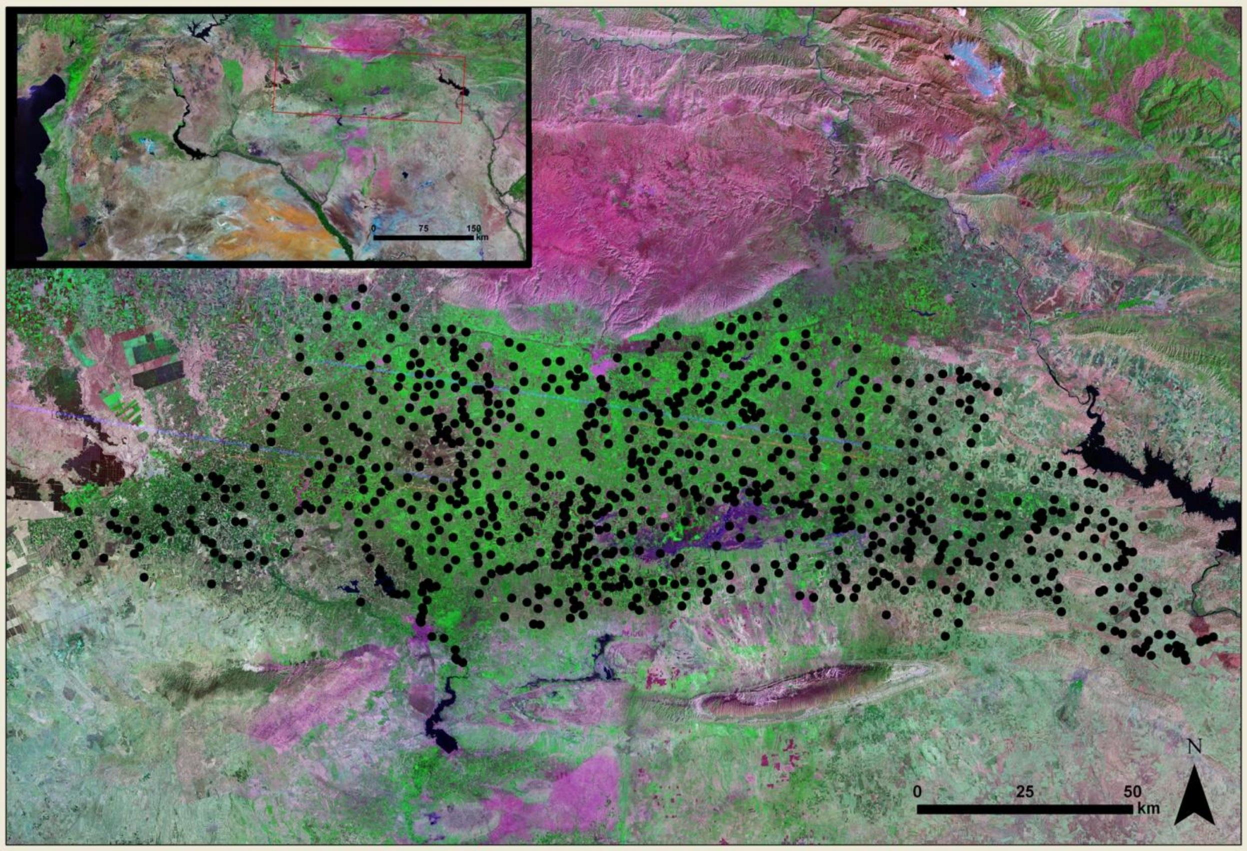

Figure 7.9. Settlement pattern on LANDSAT data

Definitions for settlement systems and settlement patterns crosscut each other, and they are often used interchangeably (e.g., Drennan and Peterson 2004). However, in this dissertation these concepts are treated differently. A settlement pattern is defined as the spatial layout of ancient settlements as observable today. On the other hand, a settlement system is considered to be the result of intentional (ancient) connectivity where the motivations and incentives for connectivity originate with the social, political, and economic practices of a society. In other words, the settlement pattern of a certain time period provides a generalized spatial structure in the landscape as a fossil of a system. The pattern is visible to the archaeologist as it is today. A settlement system provides information on how individual settlements might have functioned in the past. In this regard, settlement patterns may contain different settlement systems with different functions. For instance, in this dissertation a dry-farming settlement system is defined as having an urban settlement located at its center, with its providers located around it; other settlement systems operating are disregarded. Settlement systems composed of large urban centers structures the political landscape of the region while also capturing local settlement relations between central settlements and their satellites. These local political and economic relationships must have been affected by other actors in the political landscape, including more distant cities, pastoral nomads, or other elements. Thus, defining the boundary of a settlement system requires making a clear definition of which sites are under consideration and what type of boundary is being described.

7.2.1. Boundary Conditions

To begin with, when boundary conditions are considered, archaeological settlement systems are neither closed nor isolated. At the very least, one should assume that ancient communities were constantly relating with other communities resident at other settlements, transgressing social and physical boundaries in all domains and at all times. Even under the current day nation-state paradigm, which actually imposes physically visible and forcefully regulated boundaries, they still remain porous to the society (Mitchell 1991), and thus, prone to rapid reconfigurations and negotiations. Moreover, spatial manifestations of different ancient settlement systems were not mutually exclusive, i.e. multiple settlement systems might have existed within a given area, overlapping with other systems with other functionalities. Furthermore, it can be argued that larger settlement systems, structuring the geo-political landscape, were operational only when smaller settlement systems composed of regional centers and their peripheral settlements were also operational (A. T. Smith 2003). Consequently, settlement systems in a given ancient landscape may or may not have shared the same boundaries (Dziewonski 1978), further complicating the picture.

In order to estimate settlement system boundaries based on observed settlement patterns, at least two basic conditions must be satisfied. First, the archaeological settlement inventory of a region must be complete or near-to-complete, and second, settlements forming the pattern should be contemporaneous. A dataset satisfying these conditions may provide an empirical database necessary for evaluating the boundary conditions of settlement systems.

7.2.2. Initial Observations on the Early Bronze Age Boundary Conditions

The distribution of 1099 mounded settlements in Upper Mesopotamia suggests a unique settlement-environment relationship and provides considerable information on the structure of the productive settlement system. Nucleated, tell-based settlements generally exist when the topography is relatively flat and agricultural productive potential is high (Casana 2007). High range Anatolian mountains, for example, create an inhospitable landscape for tell-based settlements. In this rugged terrain, settlement mounds exist only in the alluvial floodplains of Tigris and Euphrates rivers, and flat areas in general. Visual inspection of site locations on a slope map of the study area supports this idea (Figure 7.10). Even though this is a simple observation, it is important for delineating an Early Bronze Age settlement system, because Taurus-Zagros Mountains can be regarded as a natural boundary for the settlement system with exceptional infiltrations only in the river floodplains. The settlement pattern also suggests that the number of mounds drop significantly once the environmental conditions no longer permit rain-fed farming, as has long been argued by Wilkinson (1994).

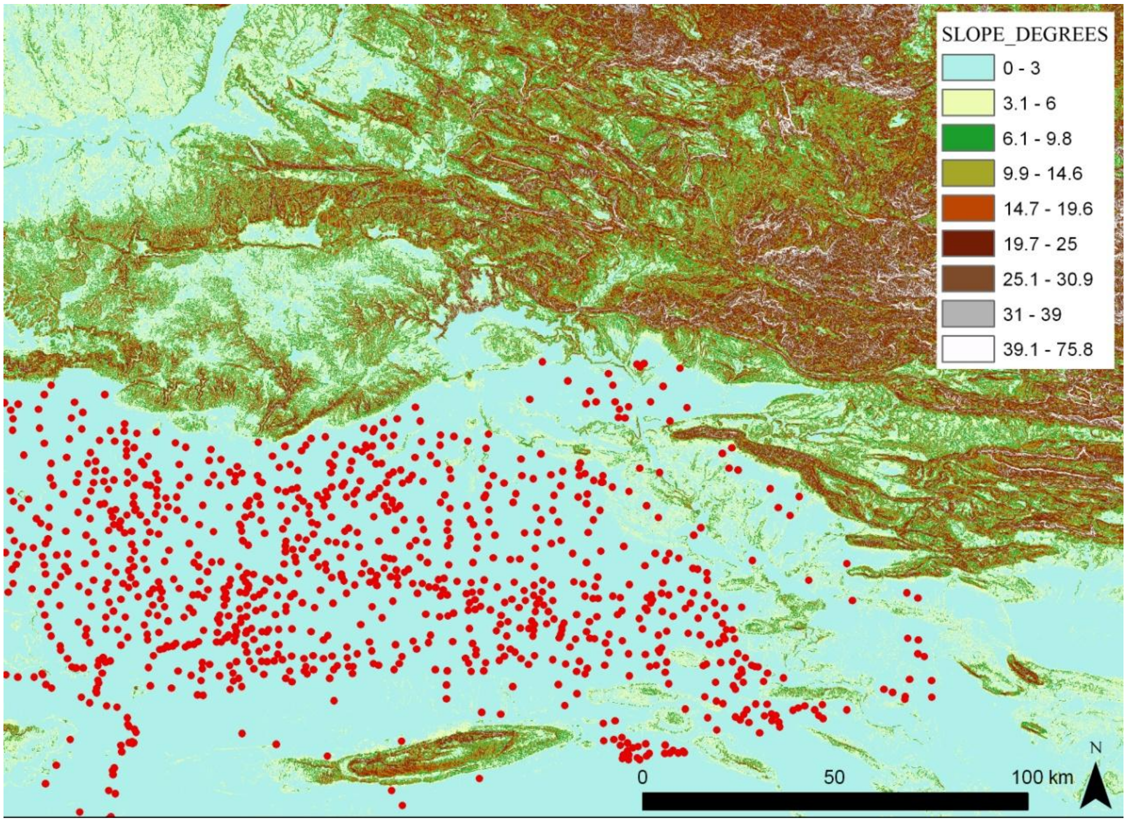

Figure 7.10.Site distribution on the slope map of the study area

As one moves further south in Upper Mesopotamia, below the modern day 200-250 mm isohyet, mounds cluster exclusively around major rivers forming linear patches, but otherwise settlements are sparsely distributed. To the west, there is also a decline in the number of nucleated tell-based settlements once the core of Khabur Basin is passed. To the east, there is a similar drop once the Tigris River is crossed. The eastern bank of the river was less favored when compared to its western bank. As one moves north towards the Zagros Mountains, the number of mounded settlements similarly declines. Following these arguments, a tentative boundary of the settlement system becomes visible based on observations of the changing density of occupation.

As expected, the mapping methodology undertaken herein suffers from edge effects as well. The available coverage of CORONA imagery creates false line at the western edge of the distribution map. Settlements running on this north-northwest by south-southeast line are artifacts of mapping and therefore not included in modeling the Early Bronze Age settlement system boundary. One method to overcome this edge effect would be to map settlements beyond the study area and observe settlement densities in areas larger than tentative boundary of the Early Bronze Age settlement system. Nonetheless, the drop in the density of settlement is sharp at the edges of the study area, enabling the estimation of a system boundary with some confidence.

7.2.3. A Model for the Settlement System Boundary

CORONA satellite imagery is an excellent source for mapping settlement mounds in Upper Mesopotamia, and a close visual inspection of these images provide a close-to-complete settlement inventory in the area once previous archaeological surveys are integrated into the mapping procedure. The contemporaneity of mounds can also be assumed as archaeological surveys in the area consistently report a few if any unmounded Early Bronze Age settlements, while all prominent mounds possess Early Bronze Age settlement (e.g., Algaze, Breuninger, and Knudstad 1994; Wilkinson and Tucker 1995). A detailed discussion on the contemporaneity of mounds is available in Chapter 6.

A key objective of this dissertation is to model production and movement of agricultural staples among settlements, and to use possible fluctuations in the flow of products to explore the sustainability of the Early Bronze Age settlement system under variable climatic conditions. The connectivity between settlements in relation to their relative sizes and locations is thus critical to understand. To put it differently, the settlement system is hypothesized as a group of settlements where the potential of staples movement is at the maximal at its core, while at the peripheries of that settlement system there is less movement. Thus, as settlements get closer to each other, and as they are larger in comparison to their neighbors, they are considered to be closer to the core of the settlement system. As settlements get farther apart and smaller, they are pushed to the edges of the settlement system. Thus, the dynamic interaction of settlement sizes and their relative locations help to draw the boundary of this settlement system.

7.2.3.1. Defining Connectivity as a Measure of Movement

Early Bronze Age of Upper Mesopotamia provides material evidence of movement (Ur 2009). Radial and inter-site hollow ways (Ur 2003; Casana 2012) succinctly preserves the ancient movement of humans, flocks, goods, services, etc. In return, they provide information on the political economies of urban settlements during the third millennium BCE (Ur 2009). This is especially evident in the discussion provided by Casana (2012) in integrating pastoral economy into the urban sphere.

While movement implies dynamism and transformation, it can be also self-restrictive, or else, it can be used for restriction. These may be socially or culturally imposed or adopted. Yet, at times, the duration of travel also becomes a restrictive agent. This was especially the case in Upper Mesopotamia where production intensification was concentrated around nucleated tell-settlements. Movement for production was concentrated for the first couple of kilometers after the settlement, and bulk transportation must have been costly and limited due to the high friction in the Upper Mesopotamian landscape. Unlike Southern Mesopotamia, where Tigris and Euphrates Rivers made it possible to move heavy loads, in the North the movement was on foot. Even though there is evidence for long distance movements of goods and services, these had political rather than subsistence connotations. In the Late Antiquity, however, "[l]arge scale animal trains were certainly involved in the overland of grain trade between pre-Islamic Arabia and Syria”(Decker 2009, 256). In this dissertation, however, the limit of feasible bulk transportation is set to 15km suggesting it is the maximum distance for a community to move agricultural staples for another settlement.

In modeling the potential movement of staples between settlements, minimum spanning trees and geostatistical tools are employed. A minimum spanning tree is used to document connectivity between settlements, and geostatistics is used to map this connectivity in order to determine the boundaries of the settlement system.

A minimum spanning tree is a part of the vocabulary of Graph Theory in which a graph is a set of nodes that are connected to each other. A path in the graph is a sequence of nodes and edges where each node and edge is unique. Thus, the sum of the length of the edges defines the length of the path. A minimum spanning tree is a unique path that joins all the nodes in a graph while minimizing total length of the path (Harary 1994). Following this theory, Early Bronze Age settlements are represented as nodes, and the minimum distance between settlements is taken as the edges. Since the topography of Upper Mesopotamia is considerably flat, Euclidian distances between settlements are assumed to represent actual distances. The sum of the edges of a minimum spanning tree represents the total amount of connectivity in a group of settlements. Increased connectivity between settlements is a step towards the aggregation of the settlement system, forming a core.

A similar methodology already provides a sophisticated map of connectivity among settlements in Upper Mesopotamia (Menze and Ur 2012). In this work, the volume of a tell-based settlement is taken as a proxy for ancient population levels. Using an exponential decay function they model the level of connectivity in direct relation with number of people living in settlements. Finally, Menze and Ur compare reconstructed inter-site exchange model results with inter-site hollow ways and suggest “a transportation network that is more complex than one solely arising from nearest-neighbor triangulations of settlement locations" (*ibid.* 9). This arises as a promising path, since the current methodology, which is described below, approaches to the same problem with a different outlook and provides similar results.

To define connectivity, each settlement is first investigated within multiple proximities of its neighboring settlements (i.e. buffer zones with different radii). At each proximity level, a group of settlements is clustered around a settlement (node), regardless of the size of this central node. These artificially created groups may be archaeologically meaningful, but rather are used as a unit of analysis in the study to represent settlement connectivity at different scales. It is assumed that a small cluster depicts local relations, and as the size of the cluster increases it represents interaction over longer distances. In this step, settlements are investigated for their neighbors from 10km to 15km buffers in 1km increments. This process creates 6 different groups for each settlement (Figure 7.11).

In the next step, edge values (distances) between nodes (settlements) and node sizes are used to calculate the connectivity between settlements. The calculated connectivity is called the flux of a group. First, initial edge values are calculated by measuring spatial distances between nodes. This creates a distance matrix for the whole dataset which shows all of the settlement distances in a group. In this matrix, longer distances indicate smaller flux between settlements, and vice versa. However, this relationship is not linear, but exponential, so that as one gets farther away from a settlement, the contribution of that settlement to the flux drops exponentially. To model this probabilistic behavior, a decay function is applied to the distance matrix to generate a distance-decay matrix:

$$P_{ij} = \exp\,(\theta \,.\, D_{ij})$$

where D_{ij} is the initial edge value, θ is the decay coefficient which characterizes the decay, and P_{ij} is the elements of the distance-decay matrix (Urban and Keitt 2001, 1207). This matrix is later normalized for the row sums to satisfy the conditions of probability theory.

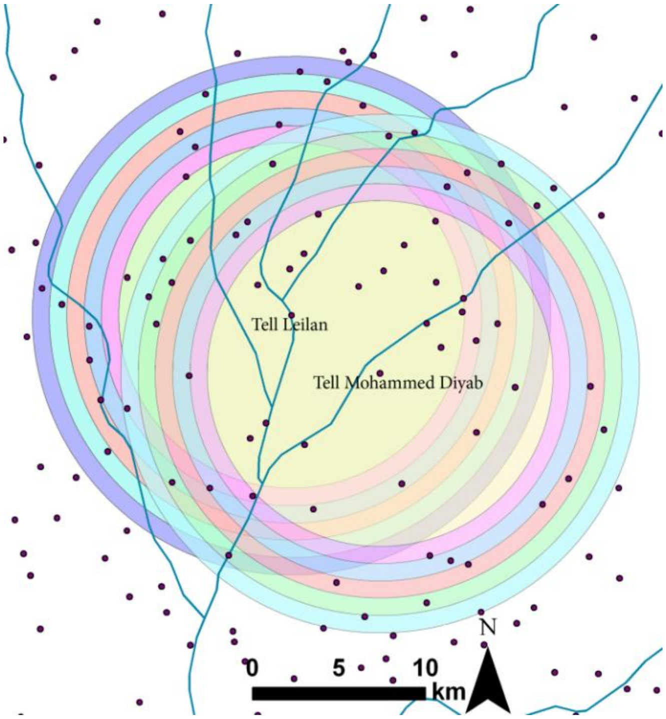

Figure 7.11. Creating 6 settlement clusters around each node based on spatial distance

The distance-decay matrix does not take into account node sizes. Therefore, the matrix is symmetrical since an edge value is the same between two specific nodes, regardless of the direction of travel. However, the volume of connectivity was likely different between two settlements, depending on the sizes of these settlements. In other words, even though the spatial distance is fixed between settlements, transportation from one settlement to another these settlements must have varied in direct relation to their sizes. To mimic this behaviour, two different flow rates are obtained for the same edge. This is represented in the equations:

$$F_{i.} = P_{i.} \,.\, A_i \; and \;\; F_{.j} = P_{.j} \,.\, A_j$$

where A is the area of settlement, connected to the neighboring settlement, and F is the flow rate for that settlement. Then the sum:

$$F_{i.} + F_{.j}$$

is the total flux between two settlements. Flux indexes are written to a now non-symmetrical matrix of the group, and the minimum spanning tree is computed for this matrix. It is hypothesized that this minimum spanning tree is an estimator of the connectivity of a group. The minimum spanning tree is the best layout where the cost of travel (i.e. the flow of goods) is at the minimum, but still connected. The sum of edge values of the spanning tree is assigned to the central node as an index for potential connectivity of that settlement in relation to its group at each proximity level (i.e. 10km to 15km buffers in 1km increments). It is this index which is mapped for defining the possible boundary of Early Bronze Age settlement system.

This proposed methodology has two basic problems which can be mathematically corrected. First, a minimum spanning tree does not differentiate between the sizes of root settlements of artificially created clusters. In other words, a cluster formed around a small settlement and another one formed around a large settlement is only different when the sizes of other settlements in these clusters differ. This creates a bias against large settlements in a group since it is more likely that these large settlements were more central within their groups than smaller settlements in relation to their own groups. To ensure that large settlements have more impact on the overall flow than smaller settlements in a pattern, a weight is assigned to a group by considering the sizes of all settlements in the group. Weights are determined by dividing settlement areas by the total occupation area in a sub settlement system. In this way, a large root settlement, and thus, its corresponding group, is assigned a larger weight, and a group formed around a small root settlement is assigned a smaller weight.

This cluster based settlement area-weighting framework is different from the area measurements which determine flow values (F_{ij}). The weight assigned to a cluster is a scaling measure for the overall settlement system whereas weights assigned to the flow (F_{ij}) are for modeling the structure of one-to-one relationships between settlements which form the system. The cluster weight indicates larger contributions from central places at localized sub-systems. However, as the extent of the sub-system approaches the extent of the hypothetical largest settlement system, large settlements (central places) contribute less to the calculations. In mathematical terms, this is also to say node settlement size remains the same while the total occupation area increases as the settlement groups get larger in size. Thus, it disregards the importance of some large settlements. To fix this, a cluster weight is applied to final flux indices in order to give more emphasis to large and presumably urban settlements in their immediate landscapes, but also to diminish this emphasis and treat settlements more equally at larger distances.

The second problem in creating fluxes is related to the edge effect (Griffith 1983). In the Early Bronze Age settlement pattern, the number of settlements in a group, located at the edge of the pattern, is expected to be lower than the number of settlements in a centrally positioned group. Therefore, numerical scaling is necessary for a more unbiased index. This is simply performed by dividing the calculated flux value of a group with the square of the number of settlements in that group so that a unit average flux value can be obtained, thereby overcoming the edge effect.

Finally, weighted and scaled indexes are normalized. This is required in order to compare clusters of different sizes. A large cluster generates higher flux and the same settlement will produce smaller indices in localized groups at smaller scales. Mapping and comparing groups of different scales is possible after this normalization.

7.2.3.2. Mapping Interactions

To provide a dynamic workflow towards a boundary solution of settlement systems of different scales, settlement interaction is spatially captured in statistical estimates of the flux between settlements. These estimates are mapped and prediction surfaces for connectivity are generated using natural neighbor interpolation. In the mapping process, it is hypothesized that the connectivity between Early Bronze Age settlements can be shown as continuous surfaces, and that as the level of connectivity diminishes for a given size of a group, a boundary starts to emerge for the settlement system.

Natural neighbor interpolation is performed in ESRI ArcGIS 10.0 software for 6 different settlement groups with sizes between 10 and 15kms with 1km increments. Not surprisingly, as the size of local settlement groups increase, the boundary of the settlement system gets larger. However, the incremental analysis also suggests that the boundary is considerably more stable for different group sizes, and thus, that the boundary of the Early Bronze Age settlement system did not fluctuate drastically for differently sized settlement groups, but only flux indices get smaller for larger groups.

Based on cumulative interaction of settlement groups, the boundary of the Early Bronze Age settlement system at its largest extent is given in Figure 7.12. In this figure, the settlement system boundary is between negative and positive flux indices. As expected, sparse patterning at the edges of the settlement distribution has less potential for interaction even though these areas are corrected for edge effects. Once these settlements with negative values are discarded from the pattern, the boundary is defined, and the settlement system is closed for further analysis.

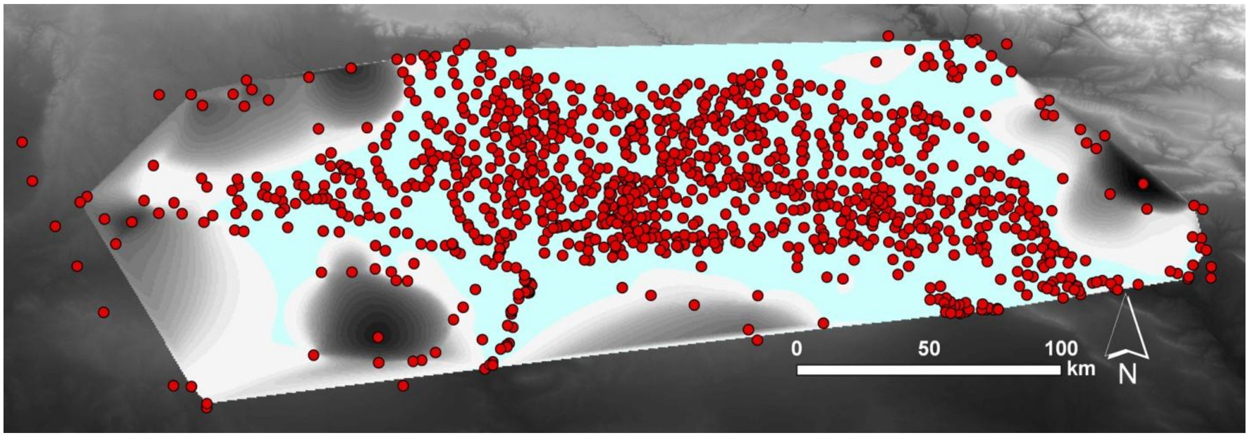

Figure 7.12. Proposed boundary of the largest settlement system depicted in blue

One of the parameters in the flux analysis requires further attention. θ value of the decay function determines the power of distance so that it influences the final flux indices significantly. Therefore, the results vary for different values of this parameter. In general, the value for this parameter is selected arbitrarily from the flat tail of the decay function (Urban and Keitt 2001). Alternative statistical distributions for decay and their related parameters also exist, and are widely discussed in ecological applications (e.g., Clark et al. 1999). It is beyond the scope of this dissertation to discuss a decay function methodology for archaeological settlement patterns, but the behavior of this parameter and its impact on the results is empirically investigated.

For testing the decay parameter, groups with sizes 11, 13 and 15kms are used against 10, 20 and 30kms flat tail distances with a probability value fixed to 0.05 (Figure 7.13). Next, flux indices are interpolated with a natural neighbor algorithm, and results are visually investigated (Figure 7.14). Interpolated surfaces reveal that there is no significant difference between 10km and 20km tail distances at small scales. Thus, it can be suggested that the tail distance doesn't impact the boundary analysis. Following this observation, 10km tail distance at a 0.05 probability value are chosen, which fixes the theta value to -0.29 for unit km.

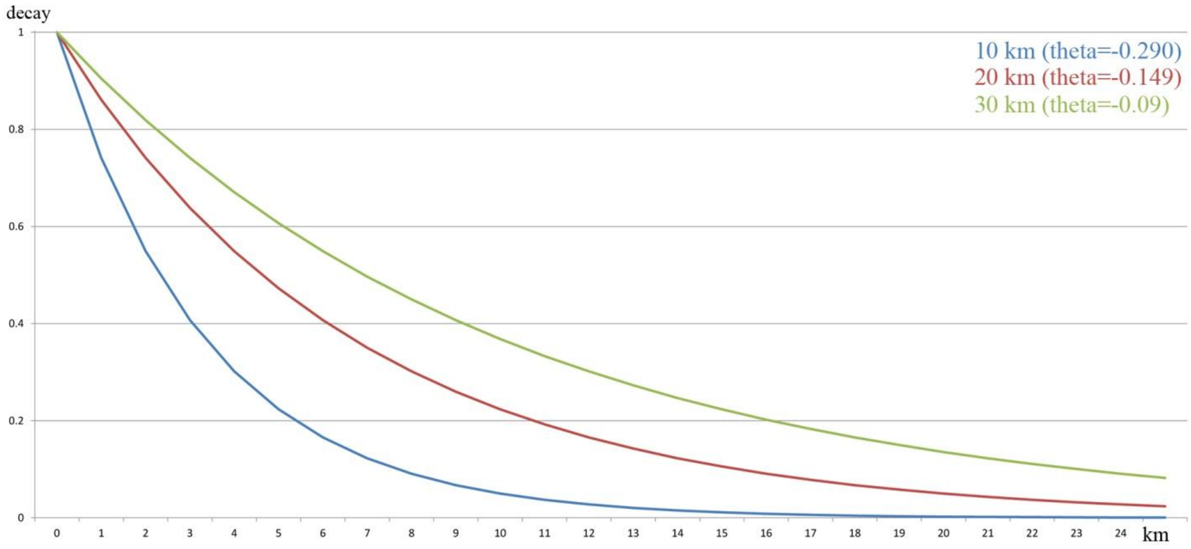

Figure 7.13: Theta values at 10, 20 and 30 km tail distances

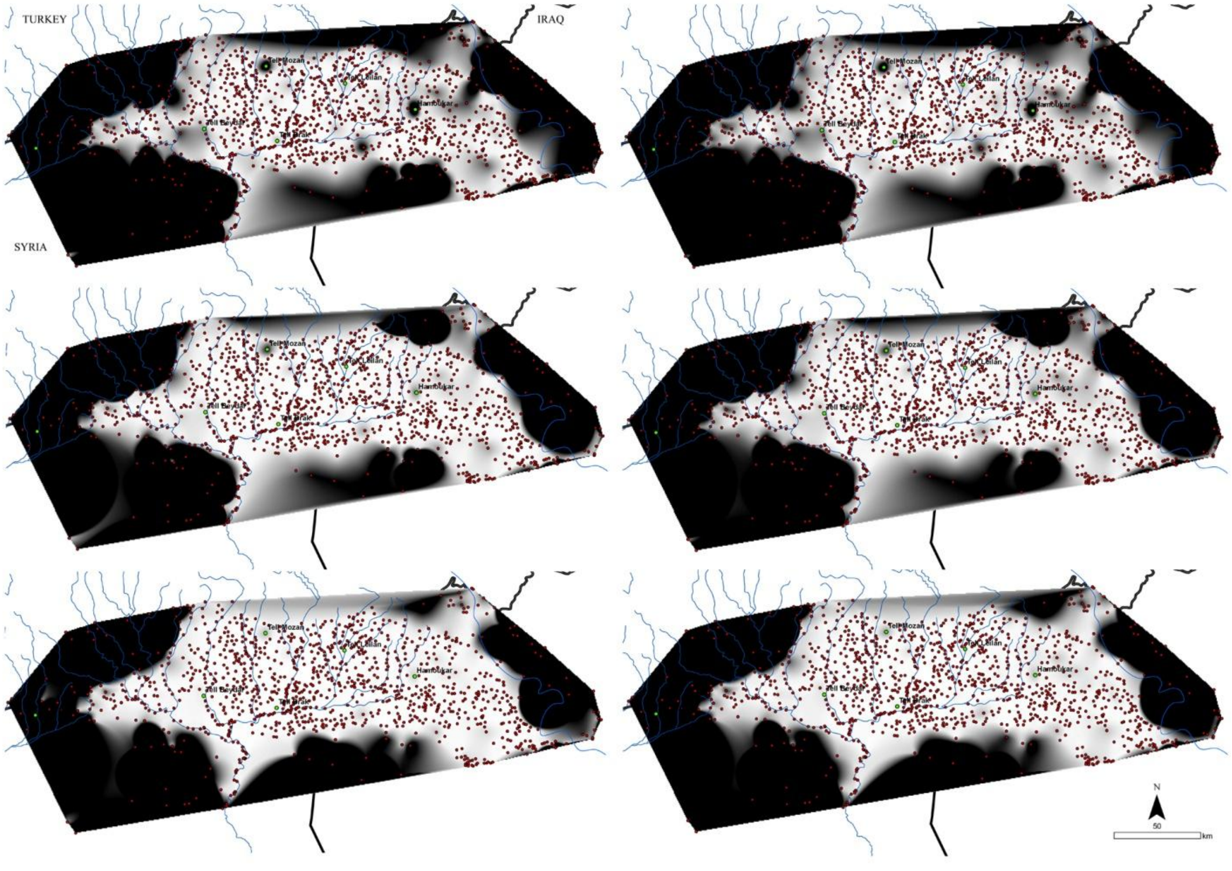

Figure 7.14. Visual comparison of interpolated surfaces with different theta values

Finally, after removing the settlements with negative flux values from the inventory, the total number reduces to 906. These settlements are assumed to be contemporary, and to represent the closed Early Bronze Age settlement system. Using these results, it is possible to model variations in agricultural surplus levels and to investigate whether this variability is a sustainable one for the system as a whole.

7.3. Early Bronze Age Settlement Inventory and Observations on the Settlement System

Evaluating Early Bronze Age agricultural extents within the light of the boundaries of the settlement system brings some further iteration in the final data set. In the absence of hollow ways, thiessen polygons were used for defining production boundaries. Thiessen polygons are prone to spatial configuration of settlements, especially at the edges, so that settlements located closer to the boundaries tend to create polygons which are unlikely to represent actual extents (Figure 7.15). For the integrity of this study, these polygons and their associated settlements are manually deleted from the inventory, resulting in a final distribution of 868 mounded sites (Figure 7.16).

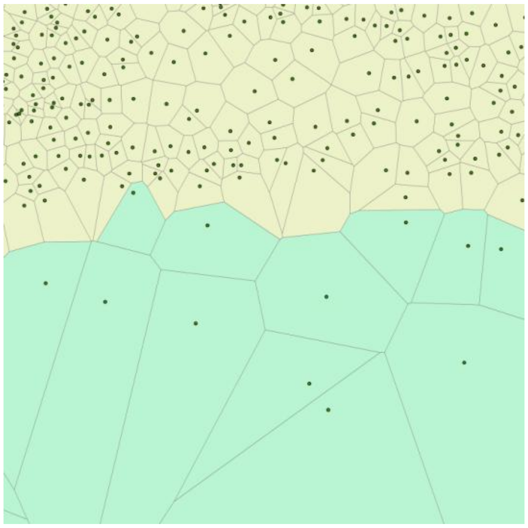

Figure 7.15: Unrepresentative Thiessen Polygons at the edges of settlement pattern

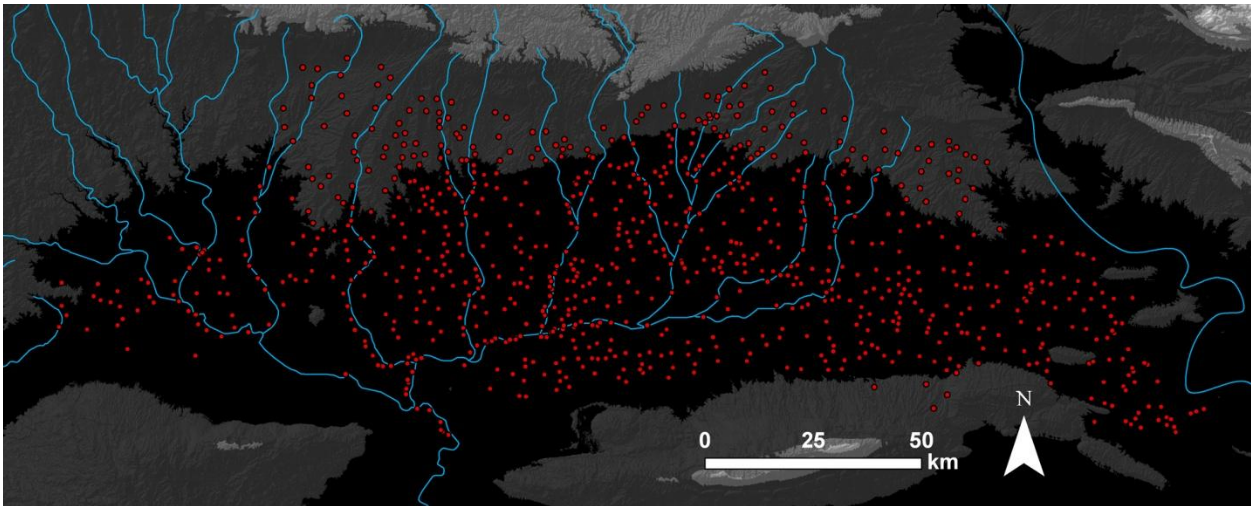

Figure 7.16. Final settlement system after data cleaning

Two statistical methods are used to further investigate the patterning in the region. First, a hot-spot analysis based on the extents of the settlements reveal a concentration of larger settlements in the eastern portion of the study area, an observation already indicated by the visual interpretation of settlements measuring 40 hectares or more. On the other hand, the analysis also reveals a lineation running in a southeast-northwest direction which cross-cuts the river system indicating the limited effect of the river system in the formation of settlement patterns.

A hot spot analysis is also performed in order to obtain a representation of high and low interaction sites within the settlement system: Hot spot analysis is based on a Getis-Ord statistic, which This statistic provides features with significantly high or low cluster values. This value is based on the level of interaction between the points of analysis. To become a high-valued point, the point itself as well as the points around it must have the same property as the central point. In this way, the Getis-Ord statistic can be used to determine the core of the settlement systems that is where it has the most weight.

Hot spot analysis reveals a significantly high z-value cluster at the center, with an easterly tendency. Tell Beydar, Tell Mozan, Tell Brak, Tell Leilan, and Hamoukar are located at the fringes of this core area as opposed to being central to it (Figure 7.17).

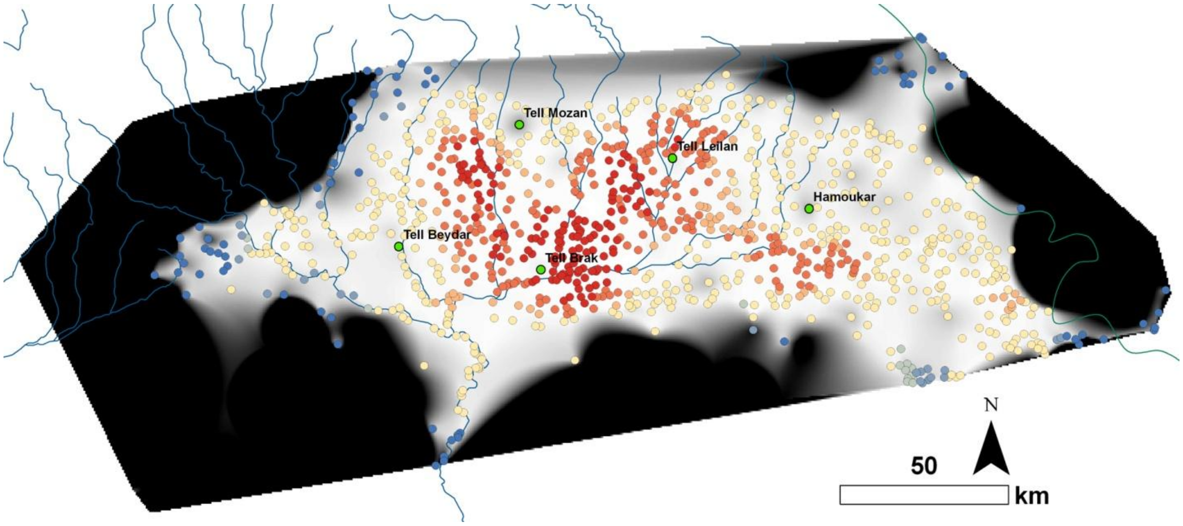

Figure 7.17. Getis-Ord statistic results to further refine the boundaries of settlement system

This can be explained by somewhat an equal sharing of powers in the third millennium BCE political landscape. Despite the evidence, for instance Tell Beydar is subjugated to Tell Brak, no settlement is in an advantageous position than others for being central to the connectivity of the settlement system. Significantly low z-values are observed at the peripheries, indicating connectivity is restricted at the fringes of the settlement system. However, these low values tend to occur more on the western fringes despite being closer to the core of the settlement system. At the eastern edge, a pocket of settlements at the northeast corner stands as an isolated group of settlements and they are disconnected from the settlement system as a whole. Also, a group of settlements with relatively high z-values infiltrate towards southeast. This might explain the higher integration of the settlement system in the eastern portion than the western portion. Archaeological interpretation of this observation can only remain speculative at the moment —so avoided as such.

The second statistical method used in exploring the structure of the Early Bronze Age settlement pattern is rank-size analysis (Johnson 1980; Falconer and Savage 1995). Rank-size analysis of settlement pattern data gives information on how settlement systems might have been politically or economically configured within a bounded region. In archaeological rank-size analysis, settlements are ordered with respect to their sizes and logarithmic transformation of these statistics is plotted against corresponding settlement ranks. This method provides an interpretable picture of the settlement hierarchy of the pattern and helps researchers to understand the underlying mechanisms which might have created these patterns at the first place.

The main premise of the method is that the second largest site in a settlement system is half the size of the first settlement, third largest settlement is one-third of the size of the first settlement, and so on. This ordering provides a template to compare against the actual settlement pattern data. Any major deviation from the template is an indication of a particular settlement distribution; so called primate, convex, and primo-convex (Johnson 1977).

A primate distribution is created by a configuration which has a smaller number of middle and larger settlements than rank-size analysis predicts, or in which the largest settlement is significantly larger than expected. This is taken as an indication of hierarchy in the settlement pattern with a dominant settlement acting as a center, for example Uruk in Southern Mesopotamia during the 4th millennium BCE (Adams 1981).

A convex distribution is created by a larger number of middle and large settlements than expected, or by a system that lacks a large primate settlement. This is interpreted as a result of less consolidation within the settlement system, in which there is less vertical integration than in a primate distribution. (Drennan and Peterson 2004, 543) reports a distinctively convex rank-size pattern in Santa Valley (Northern Peruvian Coast) after a hiatus in occupation. Cayhuamarca phase is characterized by local agriculturalist centers where according to Wilson (1988) Cayhuamarca society was a loosely integrated chiefdom. Drennan and Peterson's (2004) rank-size analysis also confirm this suggestion.

A primo-convex distribution, on the other hand, approximates a primate distribution at the large site size end and a concave distribution at the smaller site size end. This may be interpreted as the imposition of centralized primate systems over less consolidated convex systems (Falconer and Savage 1995, 41). Falconer and Savage (1995, 50) report a primo-convex ("double-convex") rank-size distribution for Levantine Bronze Age survey data. This configuration suggests that settlements were relatively independent from each other and the political landscape did not give advantages to particular settlements in the area. In return, Falconer and Savage (1995) proposes an urbanism different from the examples in other parts of Mesopotamia. A similar primo-convex distribution is also reported for Classic Tiwanaku (800-1000 CE) by (McAndrews, Albarracin-Jordan, and Bermann 1997). The primo-convex distribution is interpreted as Tiwanaku dominating the landscape, but there are also considerably large settlements, creating several autonomous subsystems (*ibid. 73*).

There are multiple methodological problems in rank-size analysis (Johnson 1980). The first problem is related to site size. Errors in the site size are immediately translated as a problem in rank-size analysis. Determination of site size is in general a problem in archaeological surveys. This error, however, may remain low since some accurate approximation of site size is usually possible. The biggest problem arrives when a large settlement is mistakenly withheld from the analysis. When Johnson (1980) pulls a primate settlement from the pattern the analysis immediately shows a convex distribution, the opposite of a primate distribution.

The second problem is related to contemporaneity of settlements. A distribution map is the relic of a settlement system, and without secure dating it is not always possible to determine if sites were occupied at the same time. Ceramic assemblages, bread and butter of an archaeological survey, are usually coarse, and thus, the accuracy of rank-size analysis drops as the assemblage gets coarser in predicting dates.

The last methodological problem is related to the ways in which the boundary of a settlement system is defined. Settlement pattern data may be missing data since they directly rely on archaeological surveys in their capabilities of documenting sites. Site taphonomies, coupled with geological and geomorphological processes may create biases towards or against a specific type of settlement, and thus, they are under-represented in the rank-size analysis. If indeed the analysis can explain hierarchical relations by comparing settlement sizes then the analysis will be reduced in explanatory power as long as there is a bias in the archaeological settlement record.

A deeper critique is given by Smith in his book, "The political landscape: Constellations of authority in early complex polities" (A. T. Smith 2003). He considers employing spatial methodologies like Thiessen polygons, central place modeling and rank-size analysis as mechanical absolutism, and claims these methodologies have:

> "a commitment to explaining regularities and variation in spatial patterns in terms of a universal geometry of settlement determined, in the last instance, by the logic of social evolutionary process. This evolutionary process holds no import for the fundamental nature of the spatial logic described the location theory" (A. T. Smith 2003, 42)

In this criticism, it is less clear if these mechanical spatial methodologies can be re-imagined in such ways that they transform into critical tools for understanding "the effects of the social world" (*ibid.*) —or if ontological differences are wider between spatial methodologies and their social critiques. Such divisions between paradigms are subject to debate (Wylie 1989; Hegmon 2003)

7.3.1. Inferences from the Rank-Size Analysis of Early Bronze Age Settlement System

In considering the Early Bronze Age settlement system in its entirety, a rank size plot of the settlements indicates a primo-convex system (Figure 7.18). Following Savage (1997), it is possible to suggest that two distinct settlement systems are in operation in the same region. The upper primate portion indicates a settlement system composed of large settlements with a centralized system superimposed over a loosely connected group of settlements with similar physical extents at lower end of settlement hierarchies. The even distribution of large settlements in the area supports this interpretation.

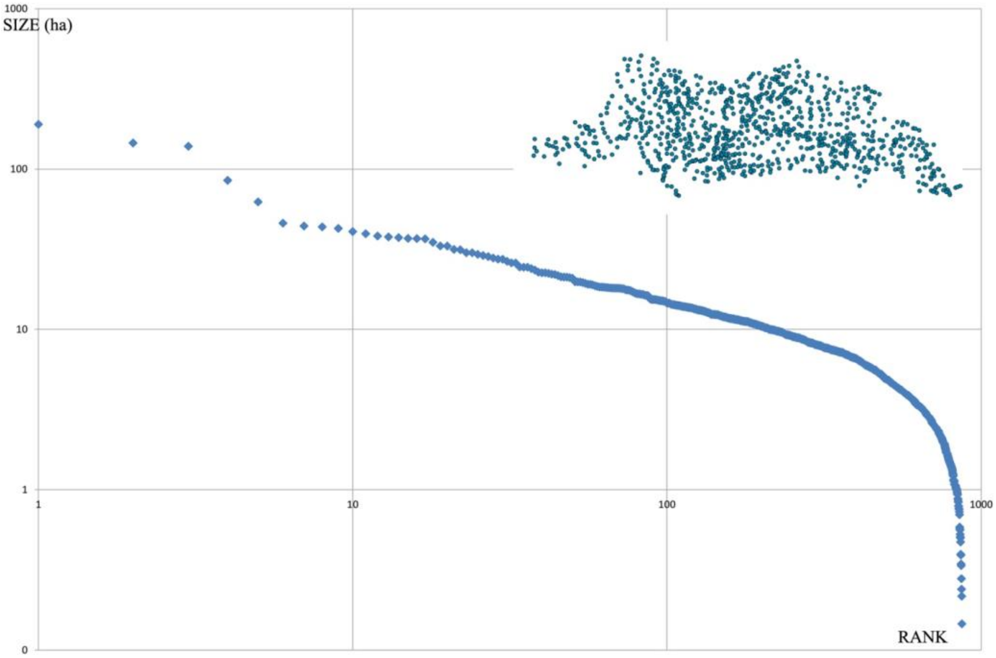

Figure 7.18. Rank size distribution for the whole settlement system

Urbanization as a continuous process has its material manifestations visible through the expansion of built environment, and thus, in the settlement size. Material manifestations urbanization created a specific configuration in the settlement pattern. Primo-convex distribution, the result of the rank analysis of settlement sizes, has two main implications in the late Early Bronze Age of Upper Mesopotamia. First, rank-size analysis suggests that some settlements are larger than expected. This favors the idea that settlements had different urbanization trajectories and some settlements grew larger than other settlements. However, rank-size analysis also suggests some consolidation among small and mediums sized settlements creating other forms within the political landscape.

To further investigate this pattern, groups of settlements from different sections of the region are pooled and their rank-size plots are drawn. Regardless of which area is analyzed, rank-size plots indicate a primo-convex shape, albeit in slightly different forms and strength (Figure 7.19a-d).

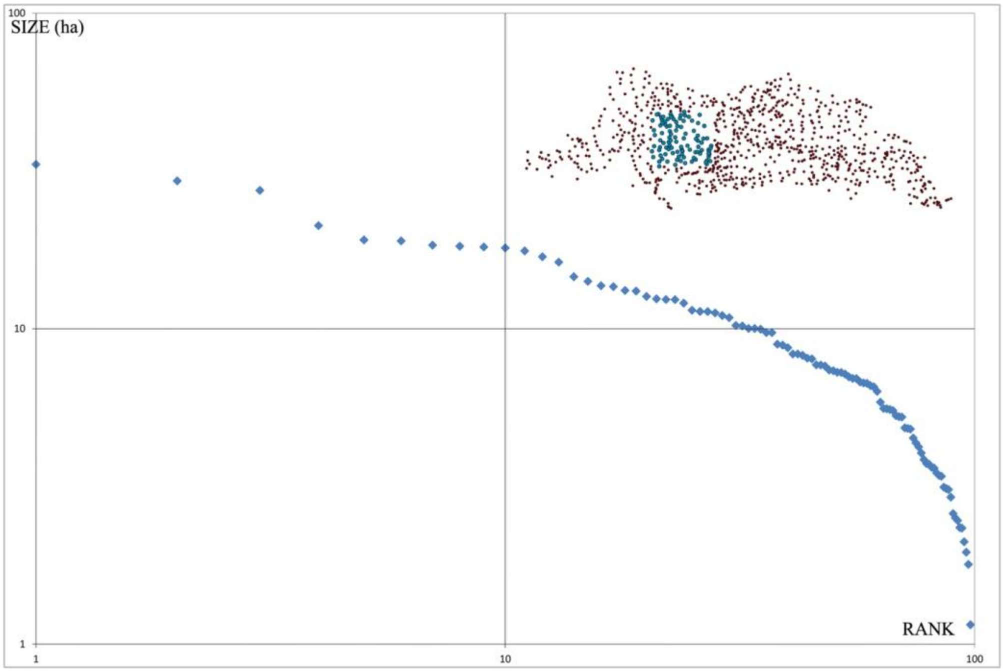

Figure 7.19a. Partial rank size distribution

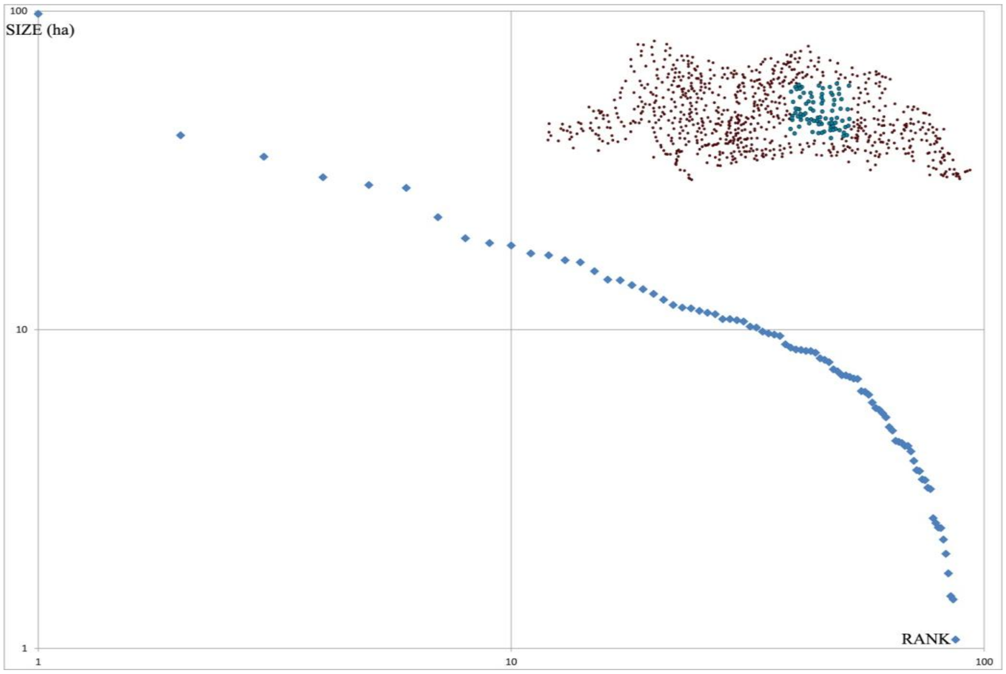

Figure 7.19b Partial rank size distribution

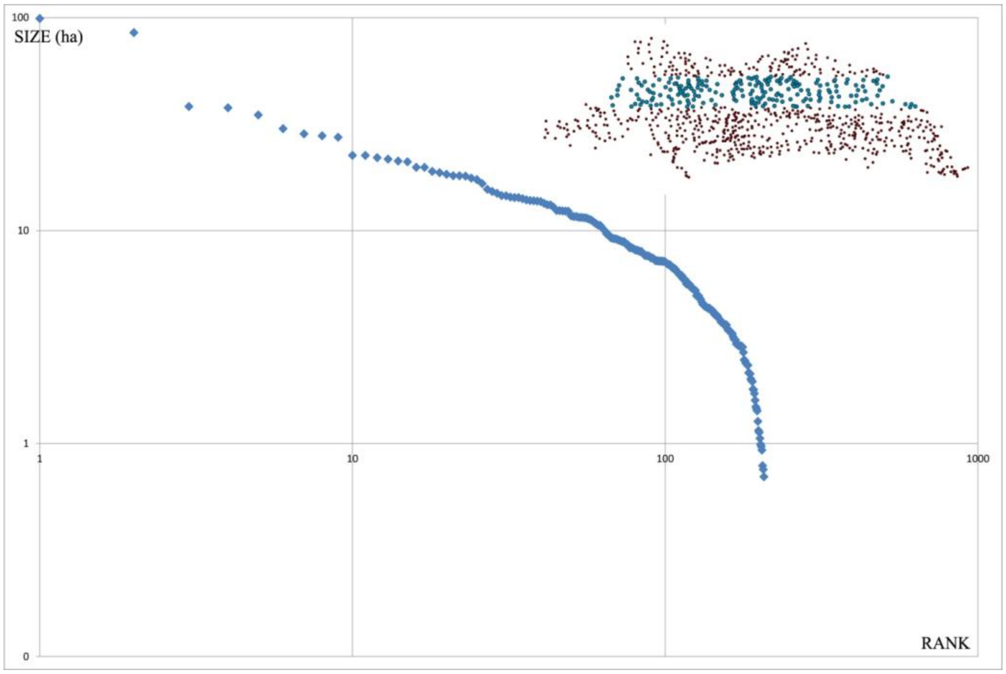

Figure 7.19c Partial rank size distribution

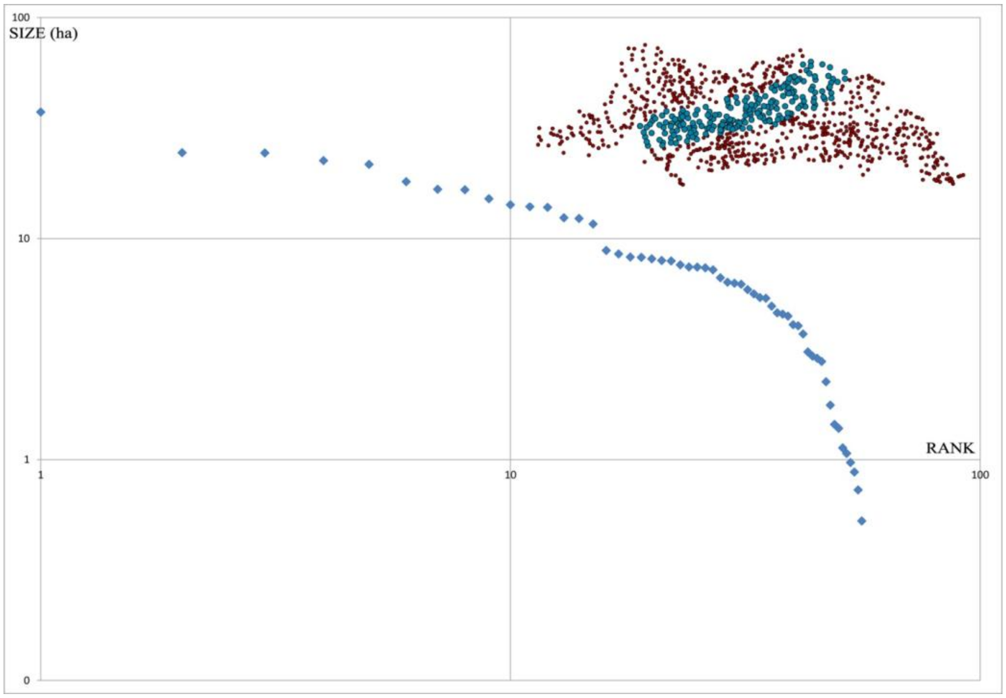

Figure 7.19d Partial rank size distribution

Each rank-size analysis produce similar configurations, suggesting that even though the complete settlement system was variable across the landscape, urbanization at local levels must have resulted in similar configurations in the settlement layout. If the settlement size can be considered a proxy for the "intensity" of urbanization then urban landscape of the Early Bronze Age indicates "homogenous intensity".

This framework suggests that the Upper Mesopotamian landscape was dotted with large urban centers with similar distances from each other. Smaller settlements in the hinterland surrounded these urban places (e.g., Ur and Wilkinson 2008) and become part of a larger kingdom-like socio-political system (e.g., Archi 1998). The number and layout of these settlements, reflected in rank-size analysis, suggest no regional control over long distances. Such centralized control has yet to be shown for immediate localities as well.

7.4. Discussions

In this chapter, settlement area and location data are used to model connectivity in arbitrarily selected sub-settlement systems. In doing so, regions of high-level connections are mapped in relation to areas characterized with low-level connections. This map provides a picture of high interaction areas which must have had the potential to form a core in the settlement system. This methodology excludes socio-political conditions of production of space at regional scales. Based on the results of rank-size analysis no primacy of a particular Early Bronze Age site can be suggested. This also signals the possibility for no strict boundaries at larger scales. The methodology, however, concentrates on the intensity of connectivity at local levels. High level local connectivity suggests a higher potential for the movement of goods between settlements. In these areas with higher connection potential, transportation of agricultural surplus from smaller settlements to central places might have required less organization, and thus, were more efficient. Settlements with low level connectivity had less contribution to the consolidation of landscapes of production movement. It is finally proposed that the boundary of productive urban settlement system was forming around high connectivity areas due to its higher efficiency.

The discussion on the boundary of the Early Bronze Age settlement system has the form of absolutist spatial ontology. No social, political or economic consideration is taken in defining the system boundary except for a model of movement. It is still acknowledged that Early Bronze Age settlement pattern of Upper Mesopotamia is the remnant of a long term political economies; all followed distinct production intensification, urbanization and state-formation processes. These processes must have actively created the conditions of connectivity between settlements at all scales, but at local levels, connectivity levels were not necessarily directly related to the geopolitical landscape. Therefore, the model only represents the potential volume of movement determined in relation to settlement sizes and their locations with respect to each other. Furthermore, in this methodological framework, larger urban settlements differed from other smaller settlements only in size, but otherwise, they were identical.

Due to its relatively flat and stable geomorphology, distance measurements between settlements were calculated under shortest-path principles. A.T. Smith (2003, 127) rightfully asks "what meaning do such distances actually hold for real networks of transport and communication?" This question is crucial for understanding the geopolitical landscapes. The network between larger urban places (e.g., between Nagar and Ebla) must have created and have affected from the geopolitical landscape. But, even at the local level, bulk transportation of agricultural surplus must have had constraints due to the costs of movement, both in time and value. And, no such central power was in effect in Upper Mesopotamia with the capacity to influence or manage local transportation connections other than the shortest distance between settlements. Maybe only with the Akkadian presence in the area, such changes might have occurred, while the character of these changes depends on the interaction between the Akkadian and already well-established urban system. However, independent of the form power relations operating over the landscape, surplus movement from peripheral to central places must have had occurred under specific spatial (i.e. shortest path) and temporal (i.e. cost of bulk movement) constraints.

These discussions should be concluded with a remark. Spatial extents of settlements and hollow ways, as mapped on CORONA imagery, are the largest measurements from these features. Boundaries, however, were most probably dynamic since production territories and density and extents of built environments fluctuated throughout the third millennium BCE. In this respect, archaeological data used in this dissertation considers urbanism process in its entirety. It should be also noted that dataset may be reflecting material conditions at the peak of urbanism, when settlement sizes and production territories were probably at their largest levels.

In the next chapter, paleoprecipitation reconstructions and extents of production territories will be used to model agricultural surplus available for each settlement. Using the boundaries of the Early Bronze Age settlement system, the relationship between the stability of agricultural production and persistence of settlement systems will be investigated.

CHAPTER 8: A Model for Early Bronze Age Food Balance

This chapter explores variation in Early Bronze Age food balances during the second half of the third millennium BCE. Investigating this variation at a landscape level might reveal further information on urbanization, agricultural intensification process as well as the reasons behind the structural transformations at the end of Early Bronze Age.

Calculating food balance requires knowledge on agricultural production and consumption levels. In the first half of the chapter, a remote sensing based production model is used to estimate Early Bronze Age barley production levels in weight (metric tons) per unit (hectares) area. Amount of production is related to available labor, size of production territory, geography, production strategy and many other factors of production and production relations. In a brief example, one should consider the fluctuations in the production of “cash-crops (e.g., J. McCorriston 1997). The transition from textile fiber to wool must have opened up agricultural spaces for food crops (*ibid.*). In return, different production strategies might have been emerged in relation to the changes in the political economy. In this complex setting, estimating ancient agricultural production levels will only be preliminary.

Determining consumption levels is more complicated. Diet is heavily influenced from economical constraints and possibilities, cultural practices, and religious norms. Such diverse variation must have been significantly influential on consumption levels. Non-human consumption of food-crops must have also affected surplus levels at settlements. Further integration with the pastoral economy (Porter 2012) must have extracted some parts of production as animal fodder or as other forms of commodity, entering the pastoral economy. How much land was potentially allocated for food production and how much of production was transformed to other economies remain unknown. Therefore, estimation of consumption levels remains simplistic at best. Nevertheless, two scenarios are tested to investigate consumption levels in different demographic and production contexts.

Food balance is the difference between the amount of production and the amount of consumption. This index can be used as a proxy variable in exploring the relationship between agricultural production and stability of settlement systems. Early Bronze Age settlements located in areas with constant food deficit may be investigated for their resiliency in more arid conditions. Surplus generating settlements can be studied for their sizes and the relationship between production levels and population can be explored. .

8.1. Production Model

In the production model, estimating agricultural staples levels requires two environmental variables: growing season precipitation and NDVI values. These variables are expressed in a formula as follows:

$$Yield = 10.5\,.\,(\,Growing\ Season\ Precipitation).\left(0.48 - 0.18\left(1 - \frac{NDVI_{post}}{NDVI_{pre}}\right)\right)$$

With this formula, it is possible to model barley production (metric tons/hectare) as long as both growing season precipitation and resultant NDVI values are known or can be estimated. In determining Early Bronze Age production, first, modern day production levels are calculated using modern growing season precipitation and NDVI values. This is a key step in the analysis since there is no methodology which can directly measure Early Bronze Age production. Creating a direct quantifiable relationship between precipitation levels and the agricultural staples makes it eliminate the use of NDVI values in modelling Early Bronze Age production. Another step involves elaborating the relationship between growing season precipitation and annual precipitation. Even though the yield formula dictates the use of growing season precipitation, such statistics are lacking for the Early Bronze Age where the highest resolution precipitation proxy dataset is multi-decadal in length at best. Fortunately, the high correlation between annual and growing season precipitation makes it possible to estimate growing season precipitation with the help of annual data. In the final step, Early Bronze Age production is calculated by using annual paleoprecipitation reconstruction values and the modern precipitation-production relationship, as discussed in Chapter 5.

Despite the number of unknown parameters in the model, the approach undertaken here offers a much better assessment of ancient agricultural production than otherwise possible because the model generates production values, specific to settlements. This is a superior approach than assigning static production values over extensive areas or assuming diminishing production levels as one gets further away from a settlement based. Thus, proposed production model has the potential to reveal local variations in the landscape and provide a more accurate picture of the socio-environmental conditions of production.

8.2. Modern Production

In calculating modern agricultural production, first, the study area is divided into 1 km grids. Second, these grids are collapsed into their centroids in order to generate a dense point pattern. Finally, the yield formula is applied to these sample points with already known NDVI and growing season precipitation values (Figure 8.1).

In the pattern, each point represents one hectare within a 1km by 1km (100ha) grid since the production formula predicts production metric ton per hectare. While grids in 1ha would have generated the most accurate model of production, the amount of computation is a constraining factor so that a compromise is made between representation and efficiency.

Nevertheless, the current sampling approach is sufficient to represent agricultural production because precipitation and NDVI values have small deviations across such short distances.

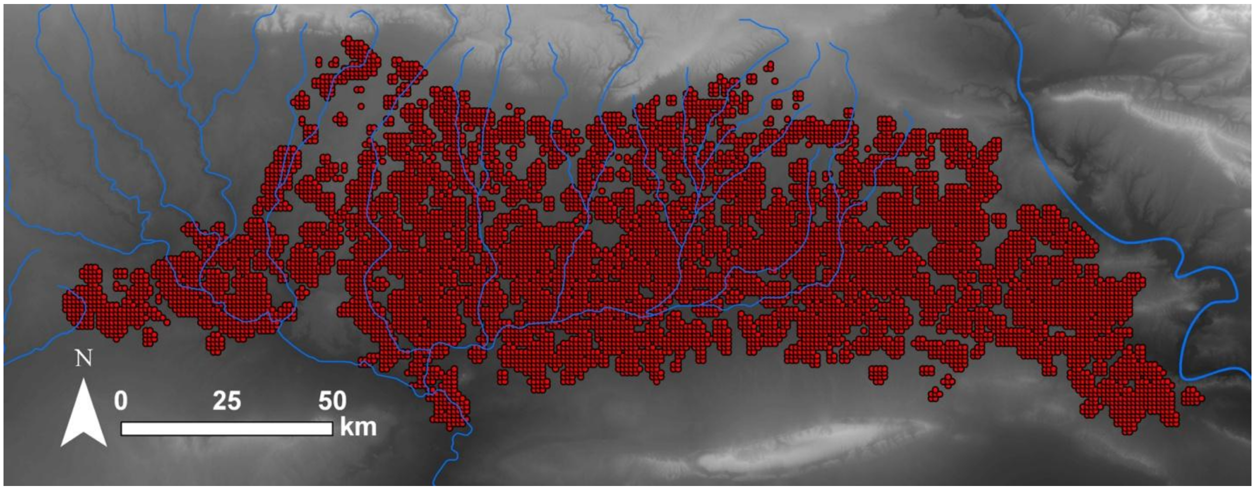

Figure 8.1. Production sample points based on production extents model

8.2.1. Model Results for Modern Production

Using the production formula, modern agricultural totals between 1985 and 2005 are estimated at 5 years intervals (Figure 8.2a-e). In 1985, a patchy distribution of production is evident in the study area. Productivity is the highest at the northern edges with a low production zone infiltrating to the north in the middle. There are also isolated pockets of high and low production, embedded within larger zones of more homogenous production values. In 1990, production variation represents agro-ecological zones more clearly. Production diminishes from north-east to south-west. This observation fits well with earlier reports on agro-climatic zones which suggest a similar separation (Hazell, Oram, and Chaherli 2001). The production model also roughly falls within the boundaries of FAO Syrian Agricultural Database (SAD) agro-ecological Zones 1 and 2 (Figure 5.17). However, the production model provides more information on local conditions and diachronic variability. For the years 1995, 2000 and 2005 a similar configuration of production zones is evident, but with changing boundaries.

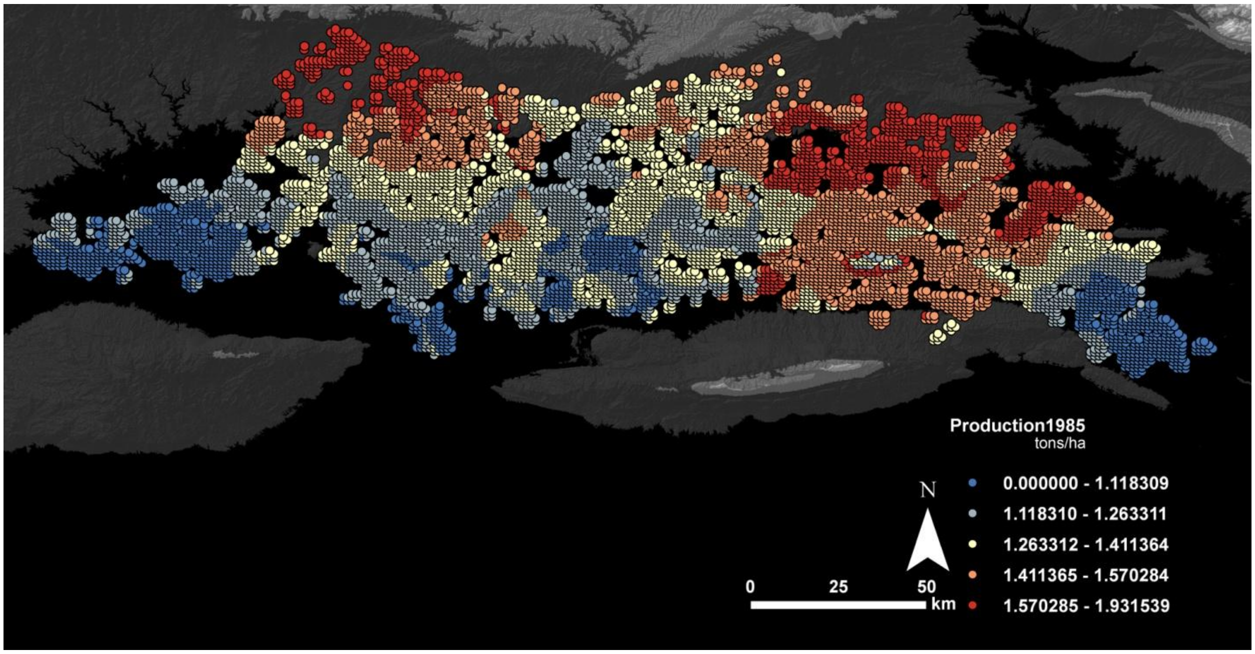

Figure 8.2a Estimated production in 1985

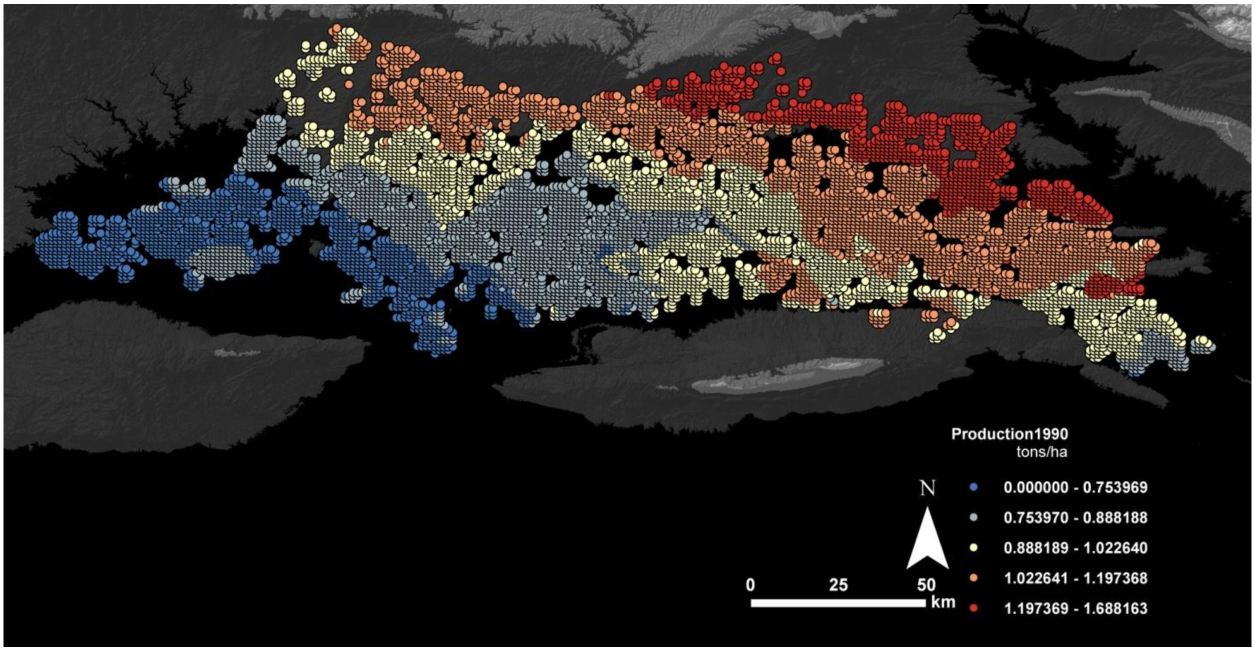

Figure 8.2b Estimated production in 1990

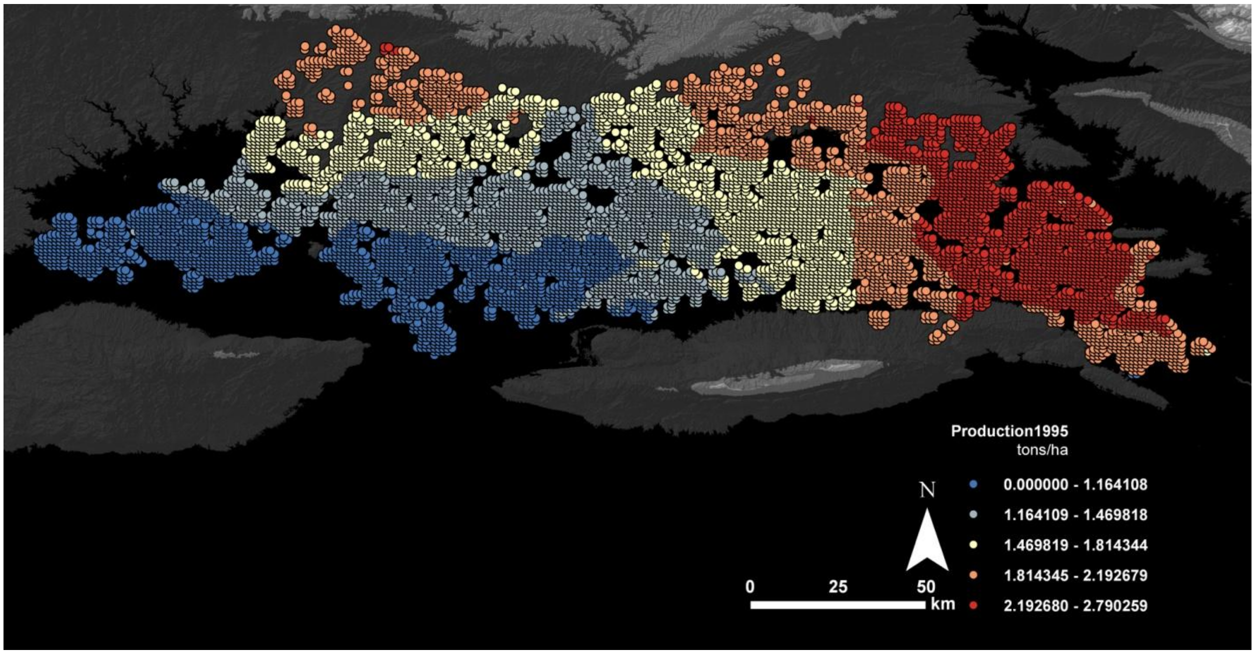

Figure 8.2c Estimated production in 1995

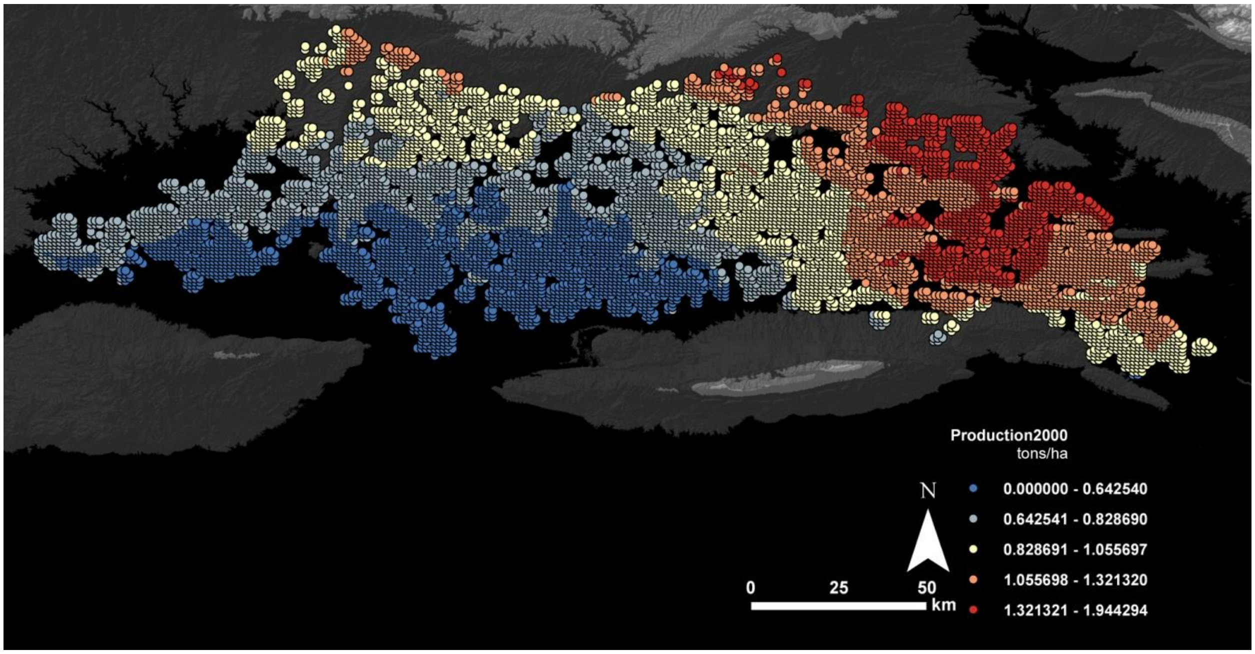

Figure 8.2d Estimated production in 2000

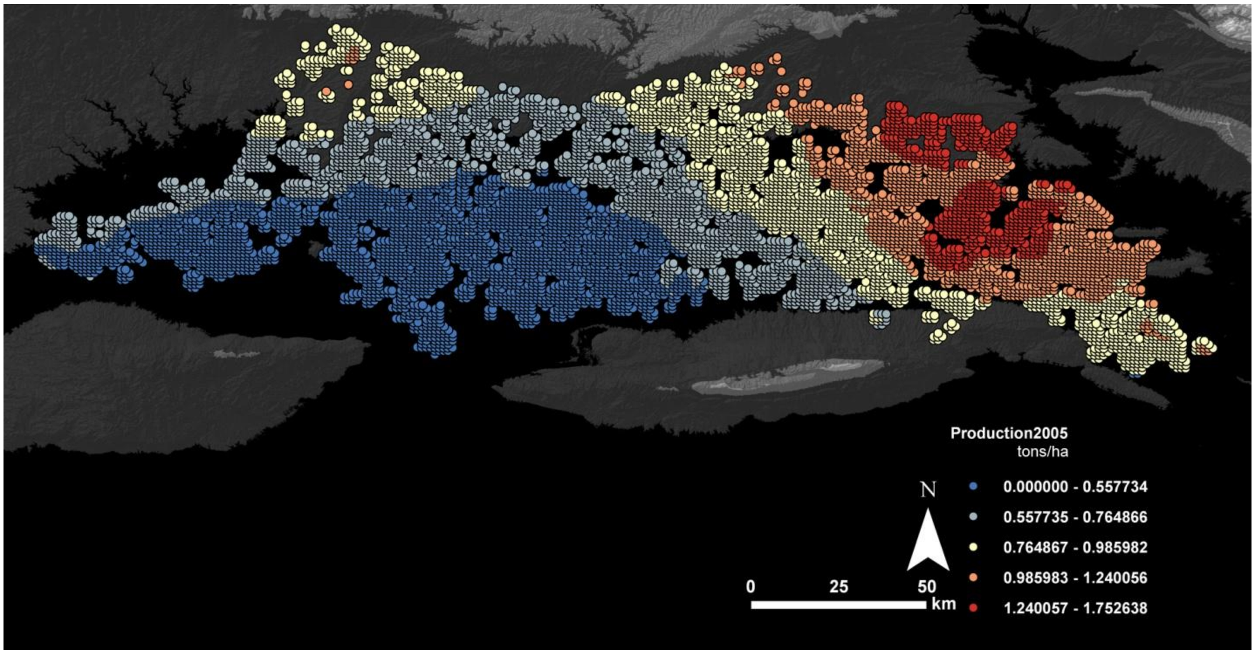

Figure 8.2e Estimated production in 2005

The trend towards more arid conditions in the area is reflected in lower production values. As of 1995, both the maximum amount of production as well as the area which provide high agricultural yields gets smaller. In 2005, high production only occurs in two constricted patches, closer to the Tigris River. Most probably in response to the arid trend, high production zone at the north-west corner of the study area completely disappears.

Results of the production model not only reflect agro-ecological zones more accurately than previously reported, but also provide more detail on productivity levels. Furthermore, the time series-based analysis of production is dynamic and thus reveals a trend which can be used to more accurately predict agricultural production in the area. The production model is actually a better representation of agro-ecological zones when directly compared against the NDVI time series data. Even though NDVI data reveal a picture of the Fertile Crescent belt (Figure 5.21), the immediate relationship between NDVI values and production levels is not clear, complicating direct use of the NDVI dataset in agro-climatic zoning.

No single year between 1982 and 2006 produces a geographic production pattern which corresponds to regional wadis, basins, artificial irrigation canals or other natural or cultural features. In light of this observation, it is further possible to claim that precipitation is still the prime determinant of production in the study area. Rather more correctly, geomorphology and modern technology have negligible effect on total production levels when investigated over extensive areas. However, it is also possible that spatial resolution of the remote sensing data (8km) is not capable of detecting local variations, and thus, these variations do not show up as production patterns.

8.2.2. Iteration of the Production Model

Because there is no ancient NDVI value to model Early Bronze Age production, the relation between precipitation and production must be established in order to eliminate the role of NDVI values in the yield formula. To accomplish this, six geographically representative sample locations are analyzed for the years between 1982 and 2006 (Figure 8.3).

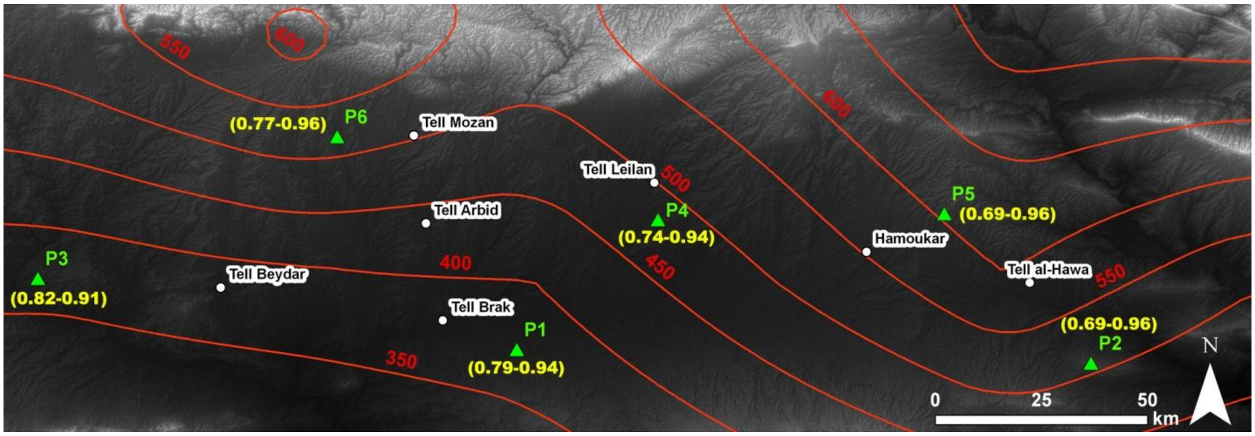

Figure 8.3. Sample locations for investigating the relationship between growing season precipitation and annual precipitation (column 1) and growing season precipitation and modeled staples production (column 2). Numbers are Pearson Correlation Coefficients.

Initial investigation suggests that total precipitation, growing season precipitation and staple production in a given location follow similar trends (Figure 8.4a-f).

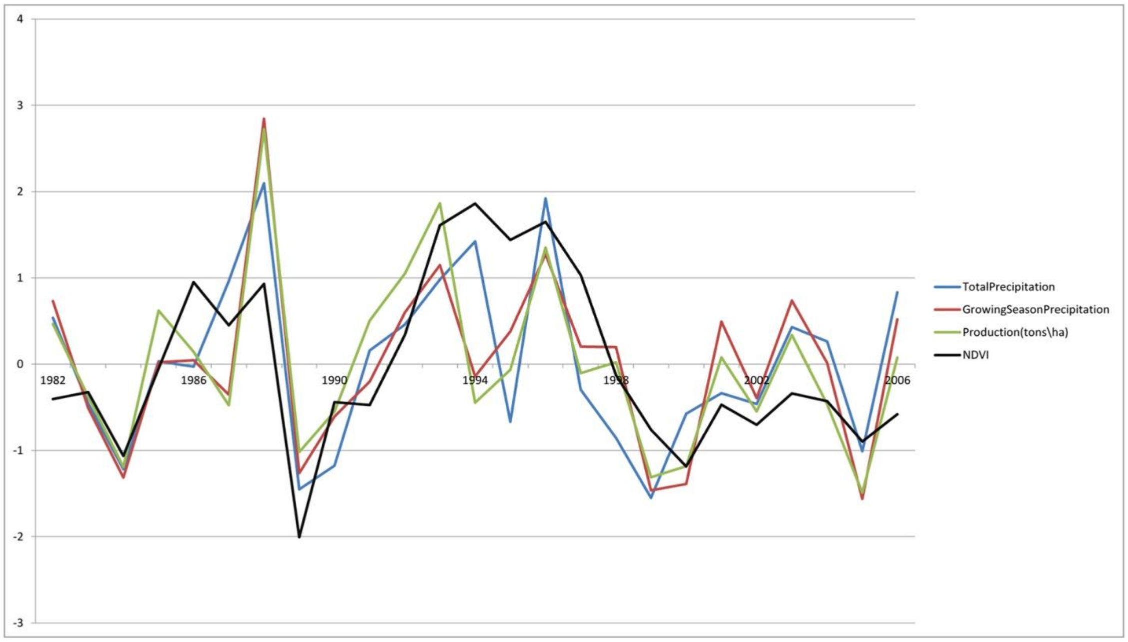

Figure 8.4a Data trends in sample #1 for annual precipitation, growing season precipitation, estimated production, and NDVI values.

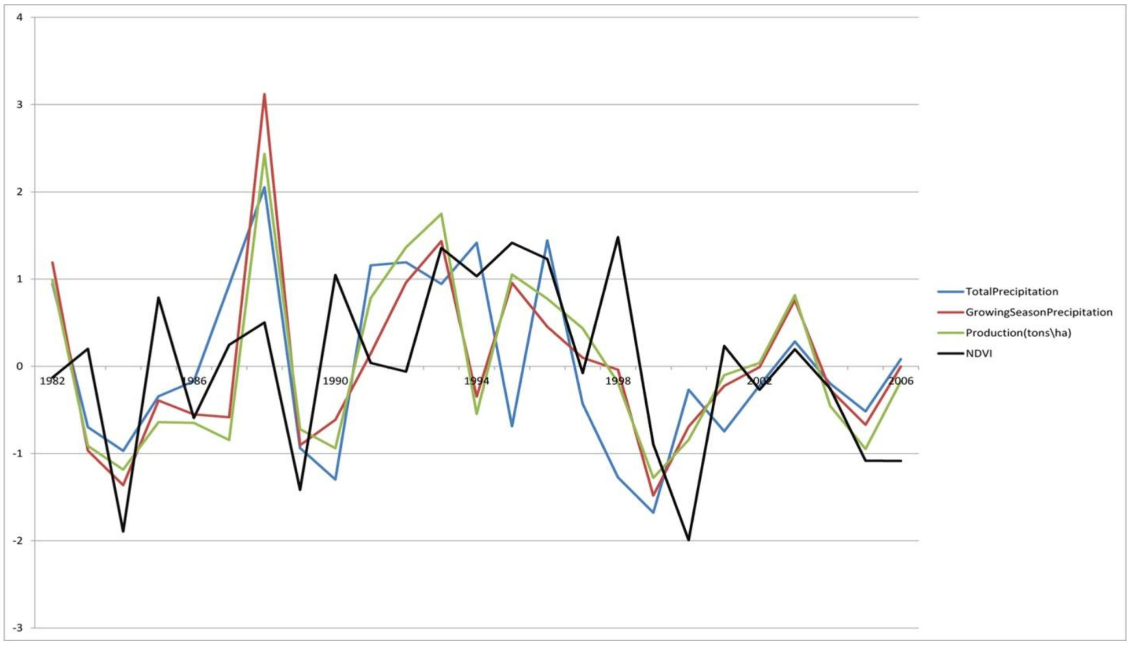

Figure 8.4b Data trends in sample #2 for annual precipitation, growing season precipitation, estimated production, and NDVI values.

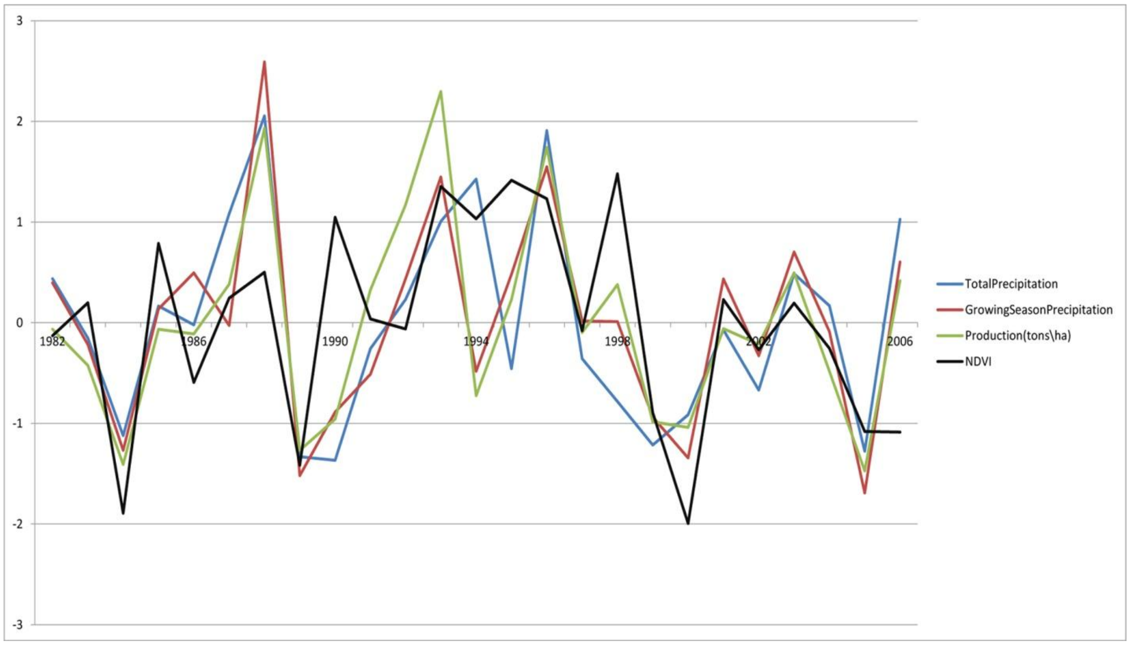

Figure 8.4c Data trends in sample #3 for annual precipitation, growing season precipitation, estimated production, and NDVI values.

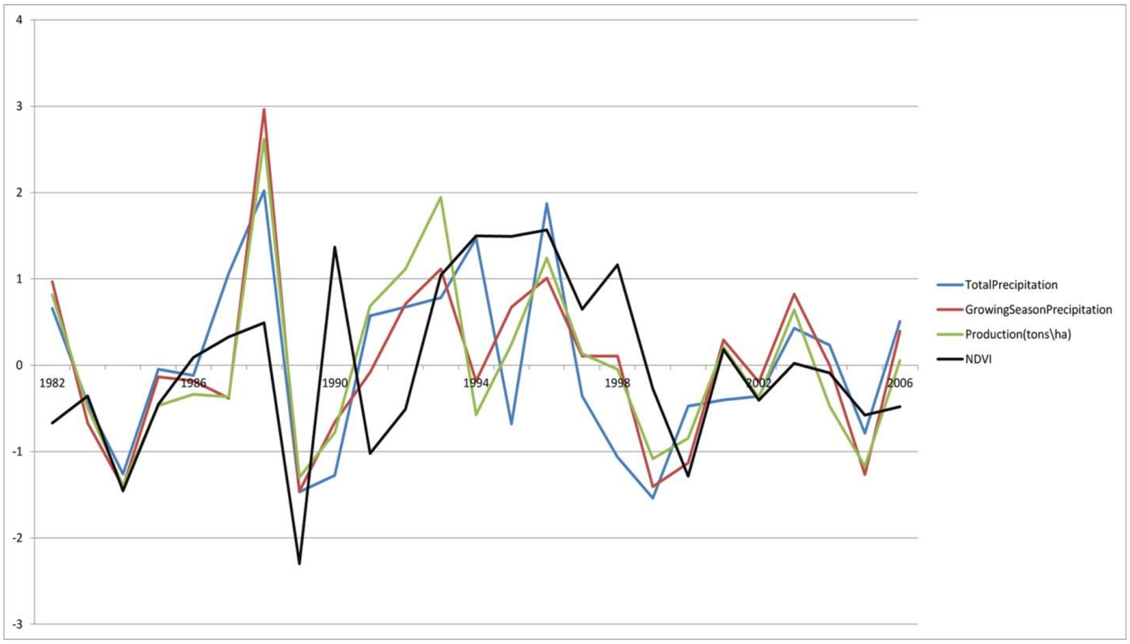

Figure 8.4d Data trends in sample #4 for annual precipitation, growing season precipitation, estimated production, and NDVI values.

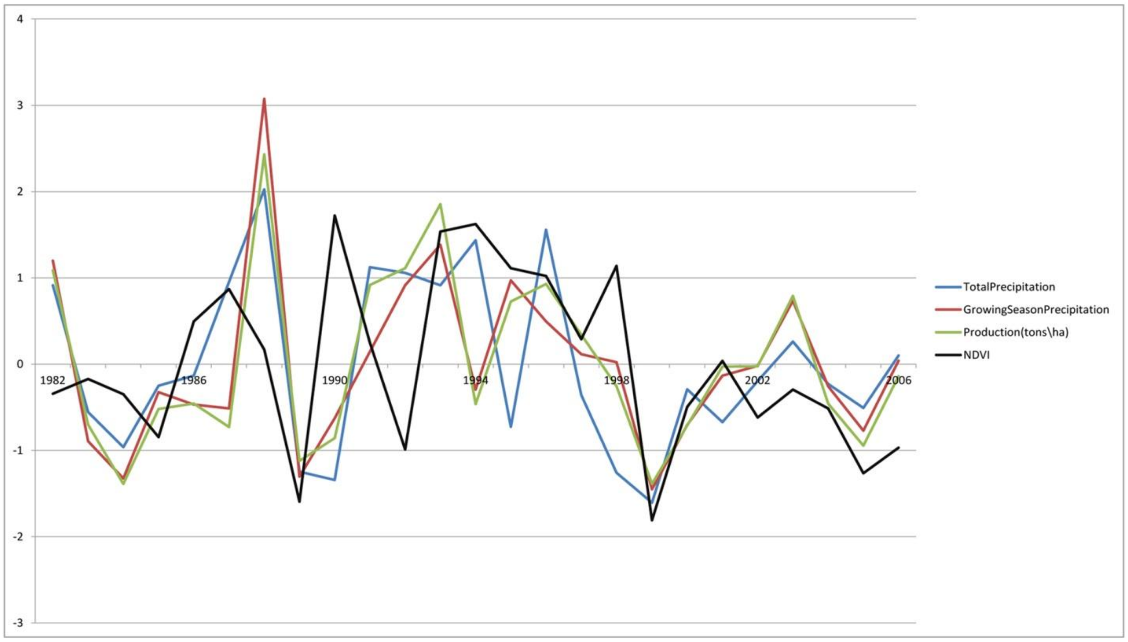

Figure 8.4e Data trends in sample #5 for annual precipitation, growing season precipitation, estimated production, and NDVI values.

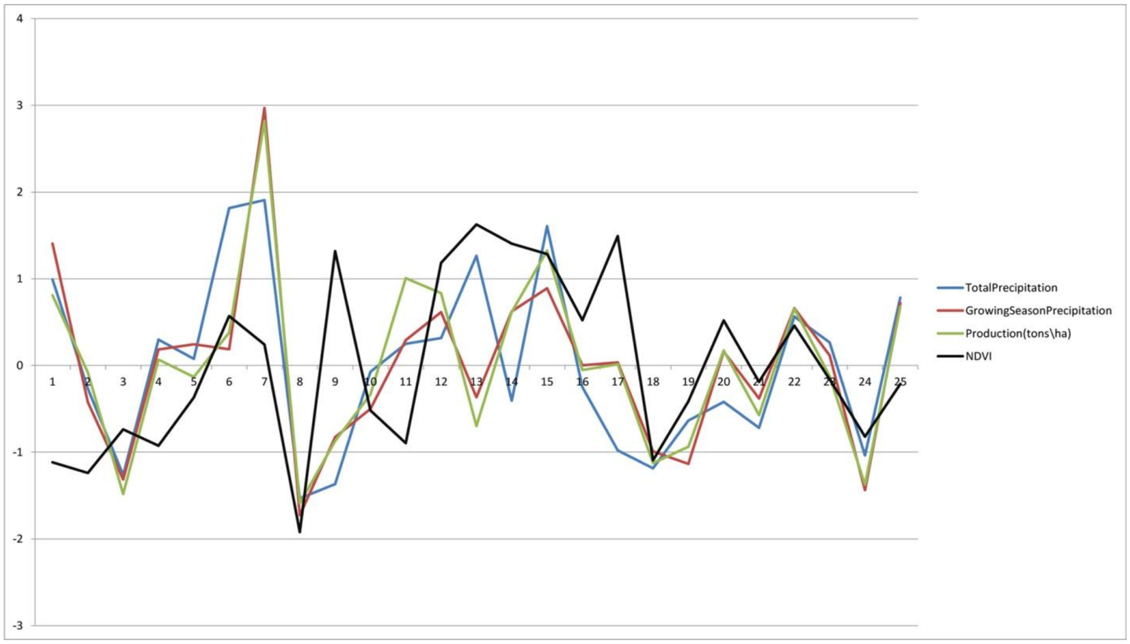

Figure 8.4f Data trends in sample #6 for annual precipitation, growing season precipitation, estimated production, and NDVI values.

This relationship is stronger between growing season precipitation and production values. On the other hand, corresponding NDVI values tend to diverge from the general pattern, especially around local minima and maxima of precipitation values. For instance, in 1988, precipitation and production are on a declining trend, while NDVI values peak in all locations except Point 1. To put the observation quantitatively, the correlation values between growing season precipitation and production values are as high as 0.96, and never fall below 0.94 (Figure 8.3). Therefore, if growing season precipitation data are available, then it is possible to estimate agricultural production, but only after the statistical relationship between precipitation and production is established with the help of NDVI values.

Another analysis involves understanding the meteorological relationship between growing season and annual precipitation. For years with low precipitation values, the difference between growing season precipitation and annual precipitation is low, but as annual precipitation increases, the discrepancy between annual and growing season precipitation also increases. Comparing linear trends of precipitation exemplifies this relationship (Figure 8.5a-f).

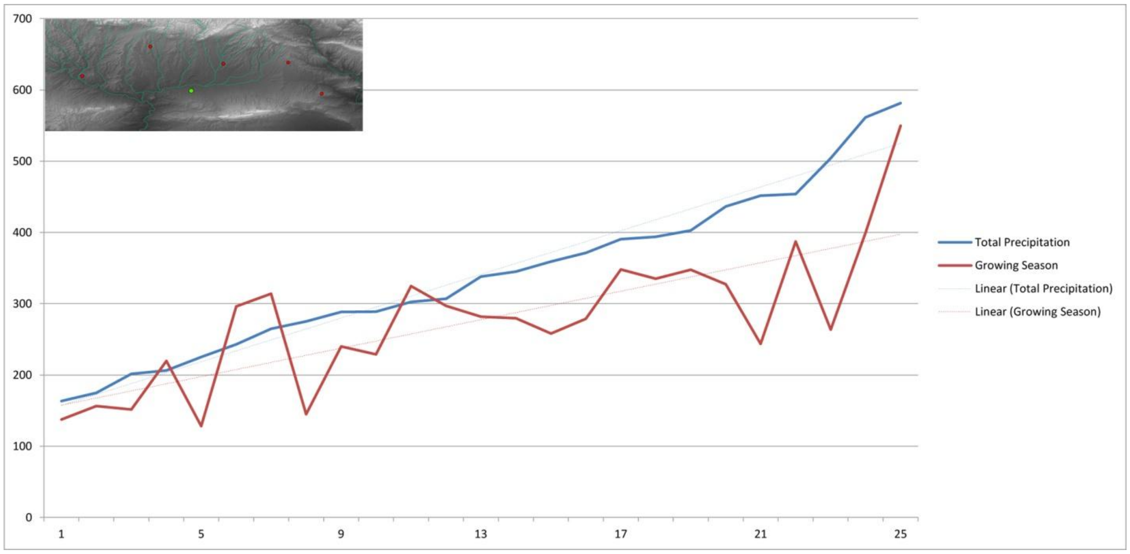

Figure 8.5a Separation of annual and growing season precipitation trends in sample #1

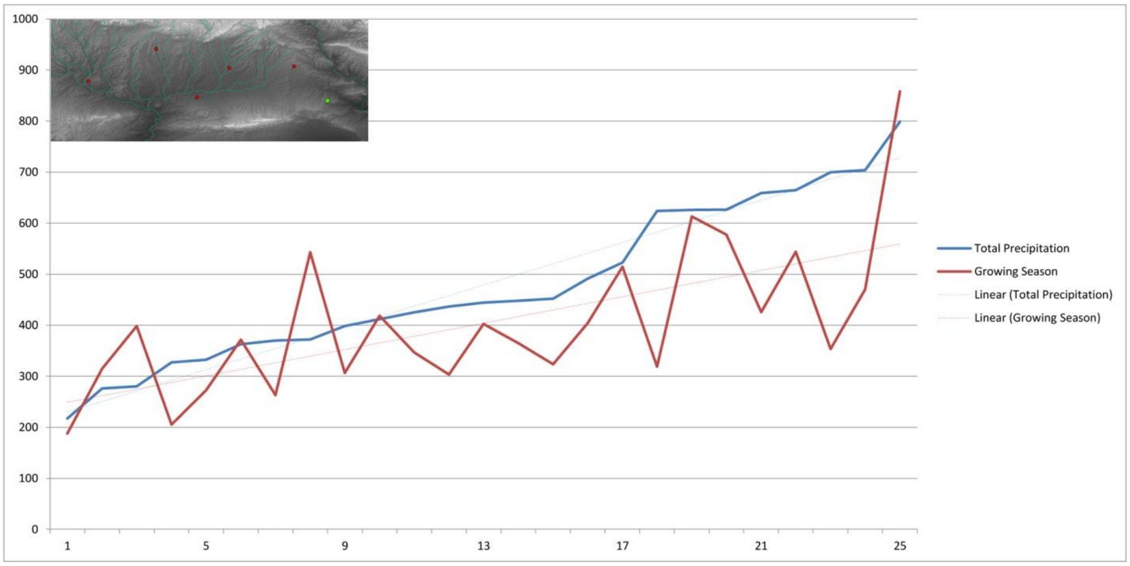

Figure 8.5b Separation of annual and growing season precipitation trends in sample #2

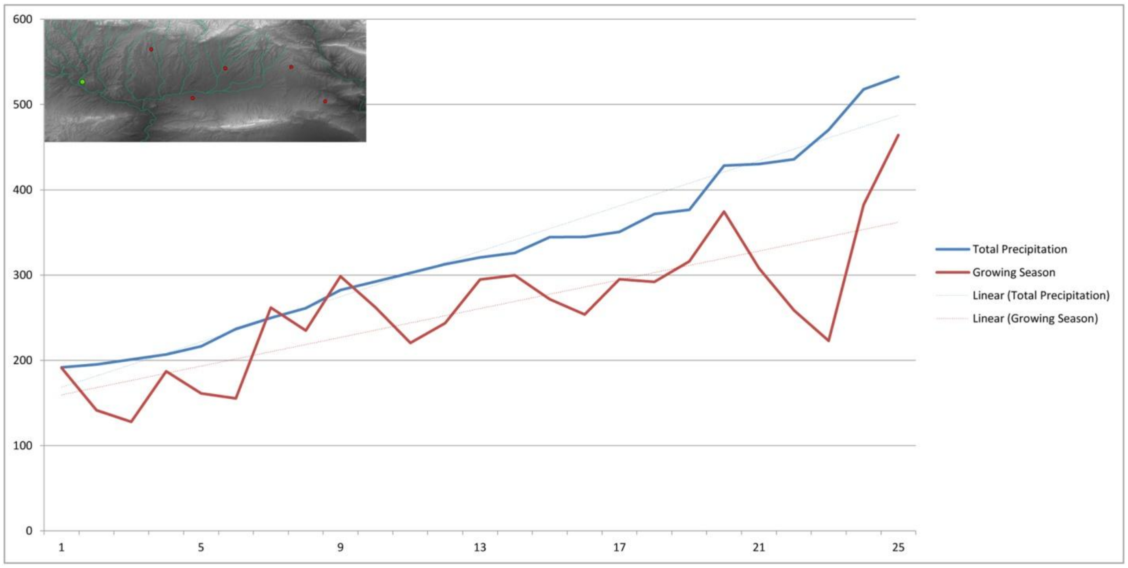

Figure 8.5c Separation of annual and growing season precipitation trends in sample #3

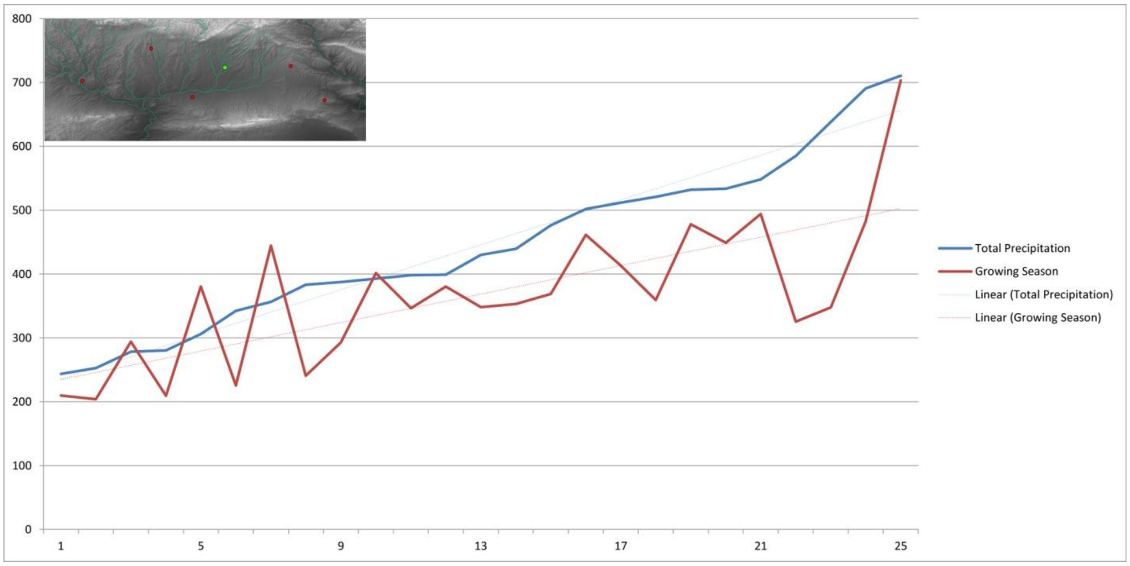

Figure 8.5d Separation of annual and growing season precipitation trends in sample #4

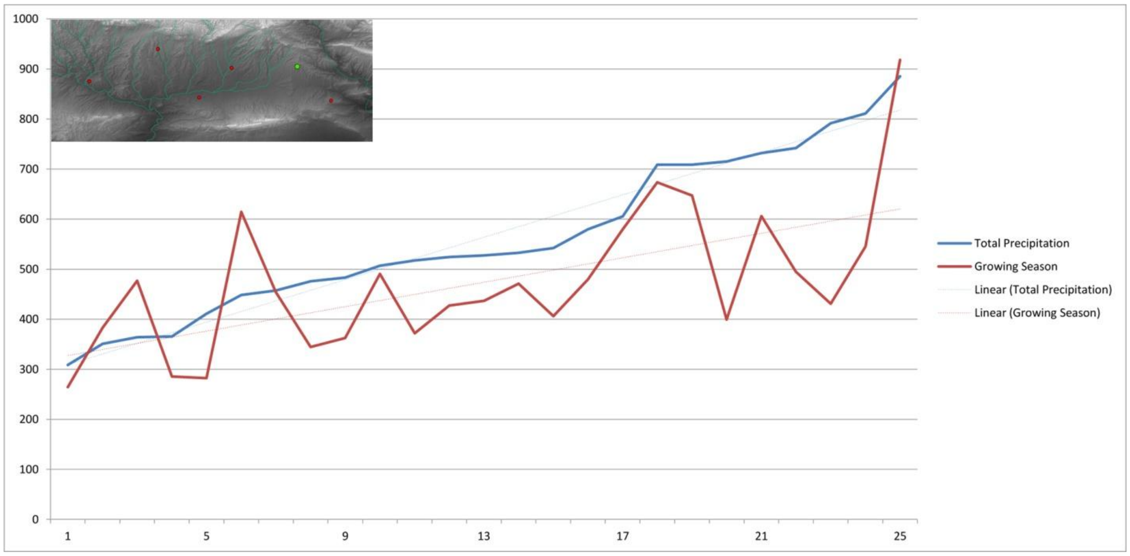

Figure 8.5e Separation of annual and growing season precipitation trends in sample #5

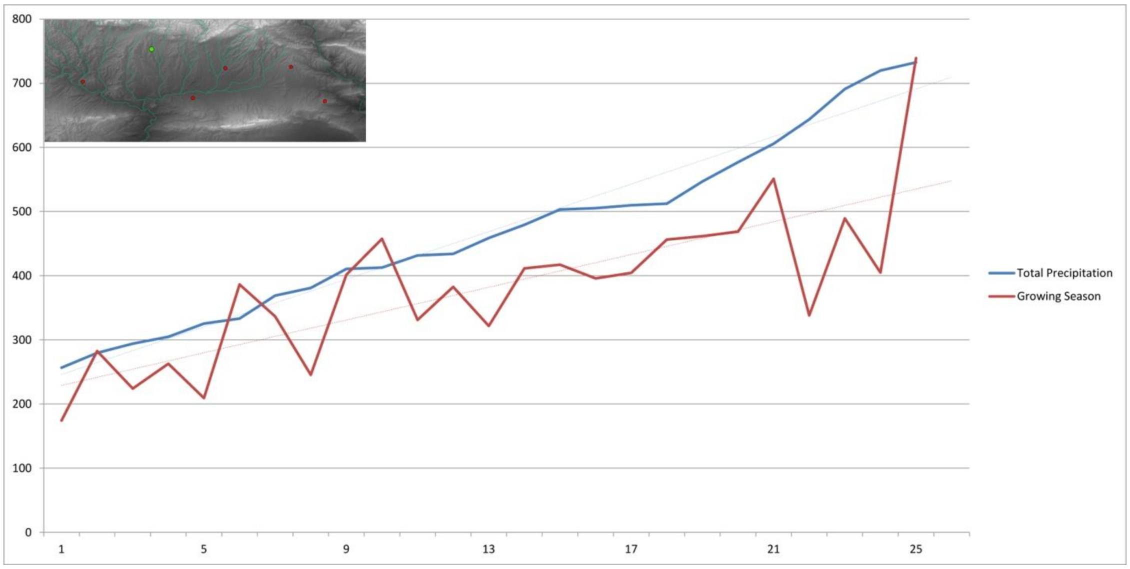

Figure 8.5f Separation of annual and growing season precipitation trends in sample #6

These trends clearly indicate divergence for higher precipitation values, but also show the possibility of establishing a linear relation between annual and growing season values. In fact, correlation values between seasonal and annual precipitation fluctuate between 0.68 and 0.81 for selected points in the study area (Figure 8.3). Even though these numbers are not high enough to suggest a perfect relationship, it is still possible to estimate growing season precipitation using annual precipitation values in a least squares sense.

To sum up, the coarse paleoprecipitation data currently available means that establishing the relationship between growing season precipitation and agricultural production as well as the relationship between growing season precipitation and annual precipitation are both important for estimating agricultural production during the Early Bronze Age. Furthermore, the independence of NDVI values from precipitation suggests that it is possible to estimate ancient production even without such data for the Early Bronze Age. This is possible only when a statistical model is established between annual precipitation and agricultural production.

8.3. Ancient Production

In estimating agricultural production during the Early Bronze Age, a series of meteorological-agricultural production relations are used to project the yield formula yield formula from the present to the past, as discussed above. First, Early Bronze Age growing season precipitation values are estimated using modeled paleoprecipitation. In this step, modern day annual growing-season precipitation relations are used. Second, Early Bronze Age production is calculated by using the association between growing season precipitation and total agricultural production at sample locations based on modern observations.

In order to investigate general production trends throughout the third millennium BCE, production at eight speleothem years (2990, 2700, 2520, 2400, 2300, 2210, 2110 and 2010 BCEs) are calculated (Figure 8.6a-h). Conforming to ancient precipitation values, the highest production values are found at 2700 BCE with 2.14 tons per hectare. The lowest production values are found in 2210 BCE, at only 1.13 tons per hectare Similar to modern day observations, eastern sections of the study area are characterized by high levels of production, regardless of meteorological fluctuations throughout the millennium. However, this zone of high productivity, stretched between Hamoukar and Tell al-Hawa, was more compact and more stable by comparison to modern times. In some areas, pockets of high production are evident away from this core zone. A smaller high productivity zone was also located at the northwest corner of the study area.

The area surrounded by Tell Beydar, Tell Mozan and Tell Leilan is marked by low yields throughout the millennium. Notably, Tell Brak is located at the core of this low productivity zone. As one of the largest urbanite settlements of Upper Mesopotamia, the location of the site contradicts the hypothesized surplus needs of a non-food producing urban population. However, considering the number and density of satellite settlements in this region, the deficit may have been compensated for by hinterland production.

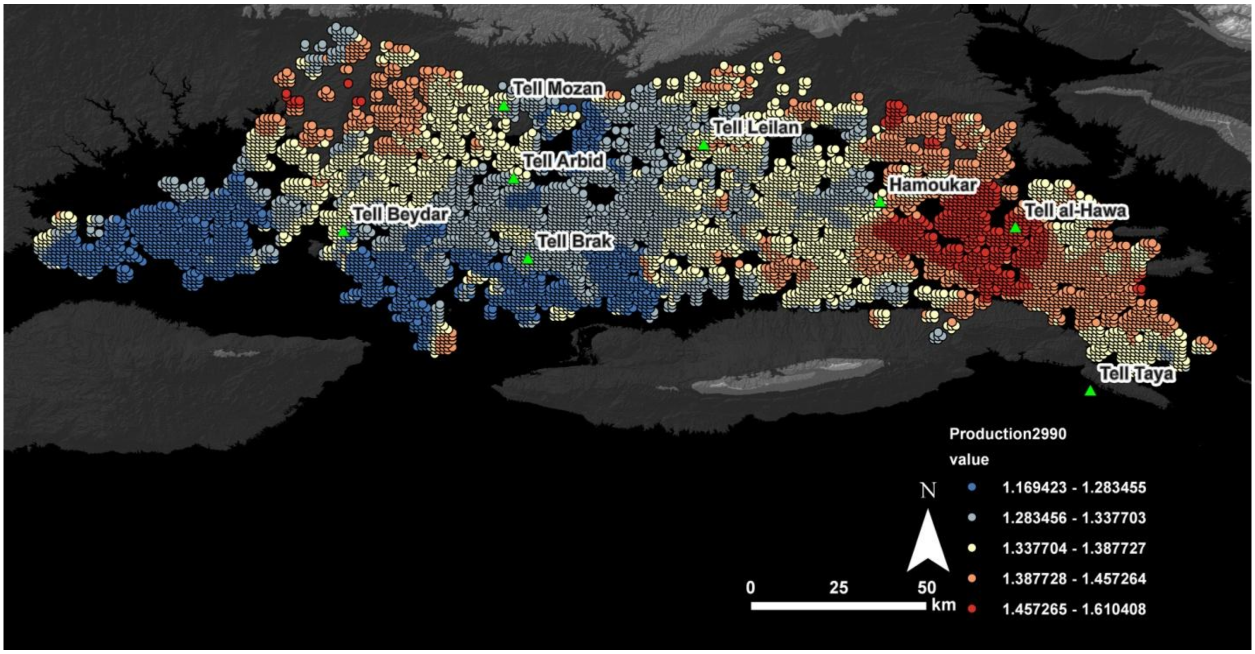

Figure 8.6a Agricultural production estimation in 2990 BCE (data are in metric tons/ha)

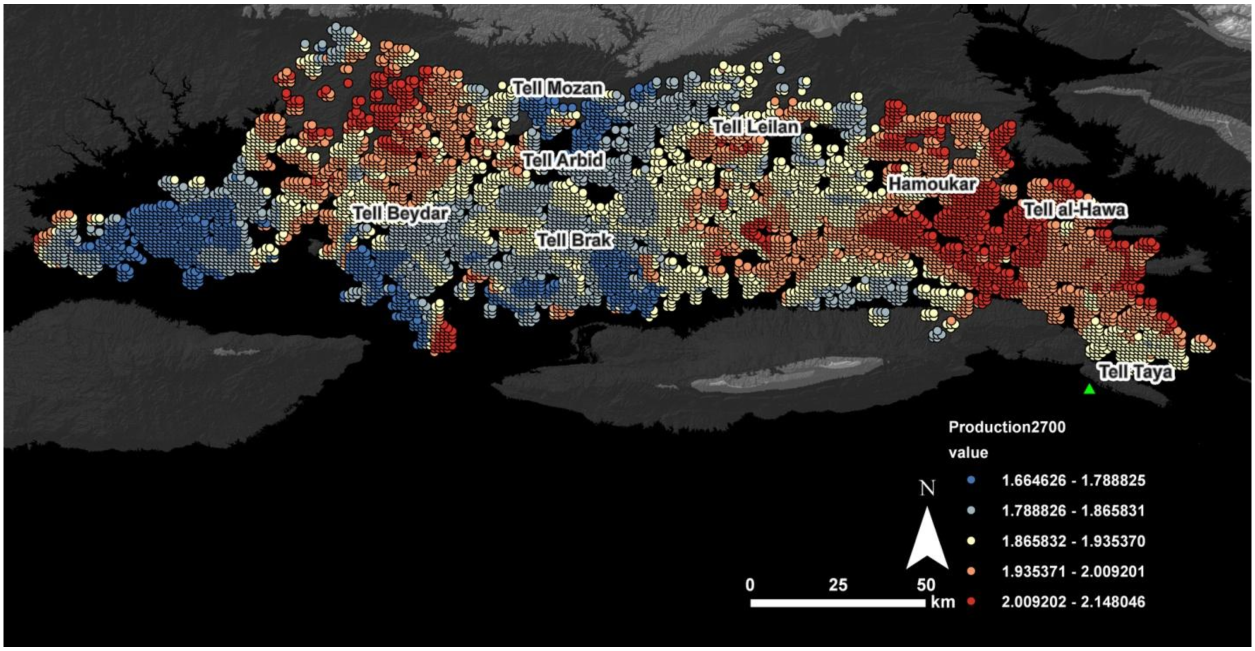

Figure 8.6b Agricultural production estimation in 2700 BCE (data are in metric tons/ha)

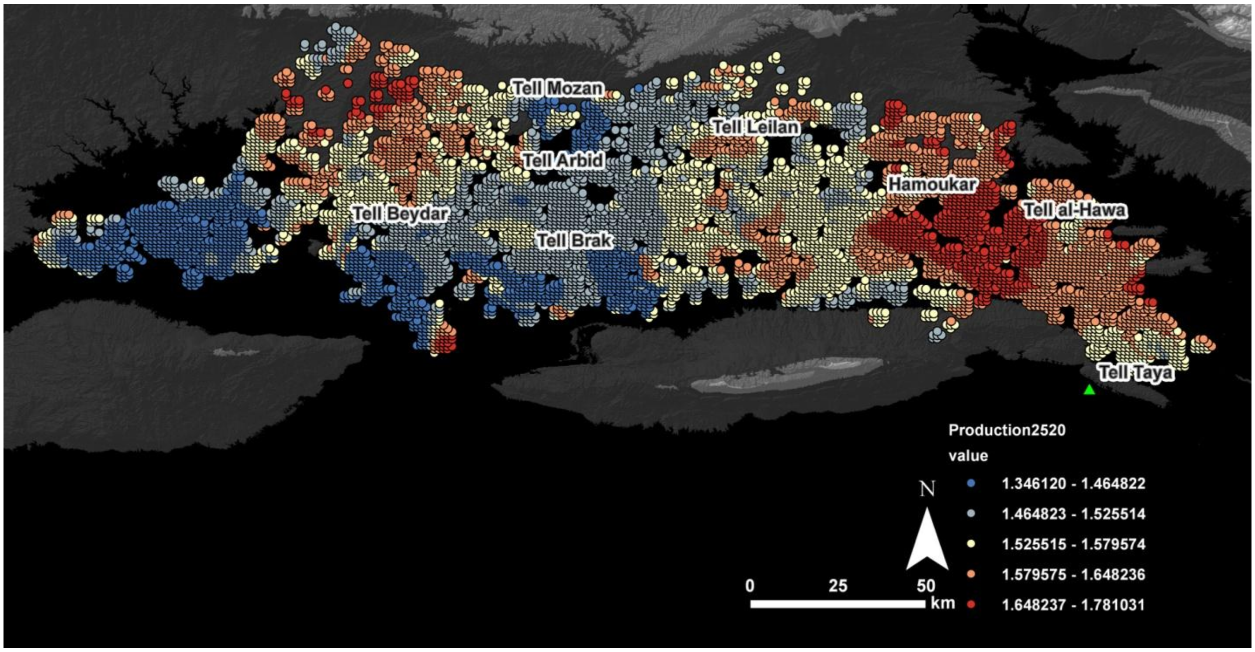

Figure 8.6c Agricultural production estimation in 2520 BCE (data are in metric tons/ha)

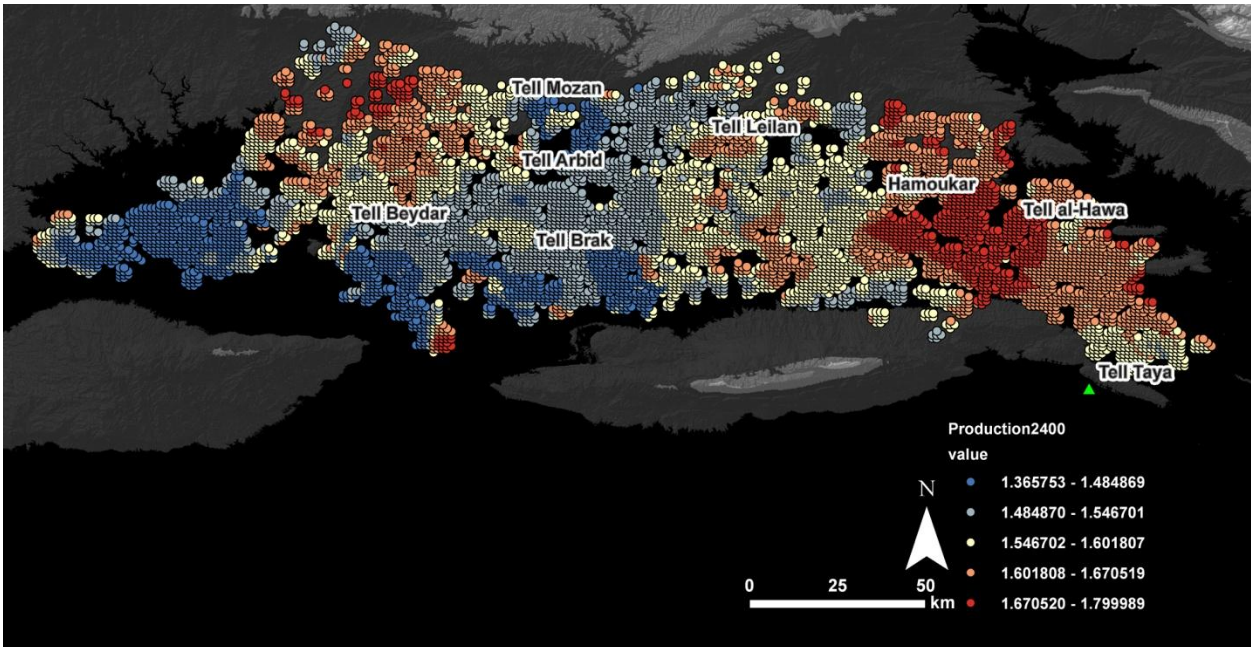

Figure 8.6d Agricultural production estimation in 2400 BCE (data are in metric tons/ha)

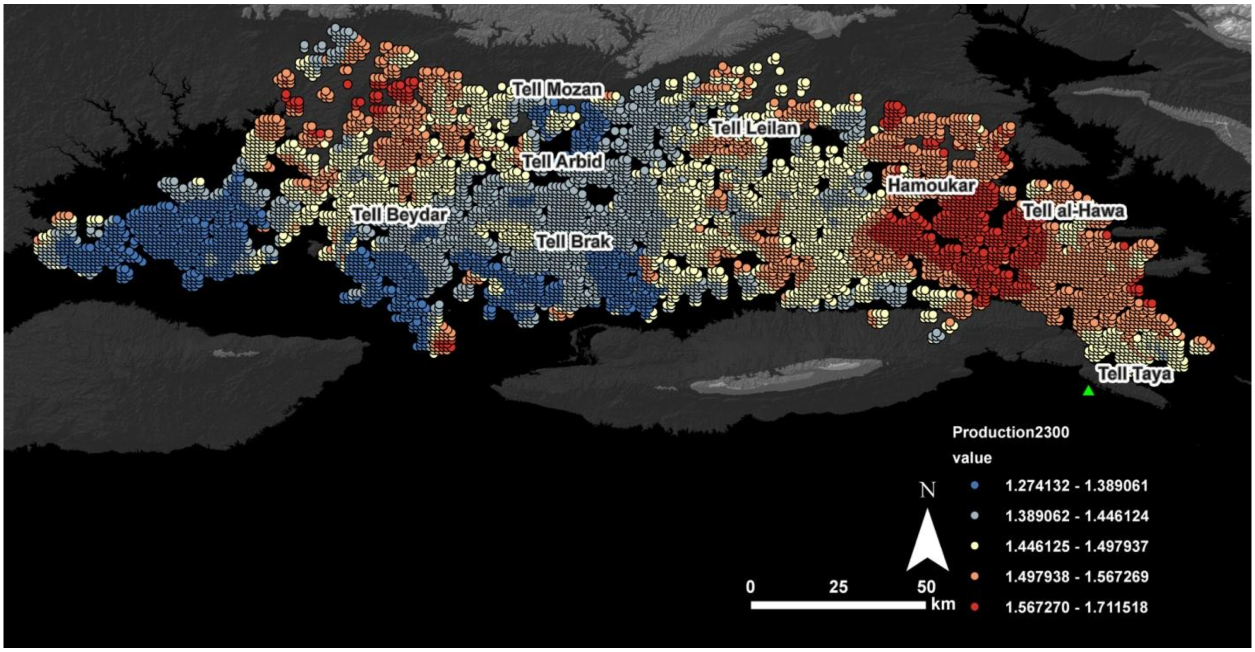

Figure 8.6e Agricultural production estimation in 2300 BCE (data are in metric tons/ha)

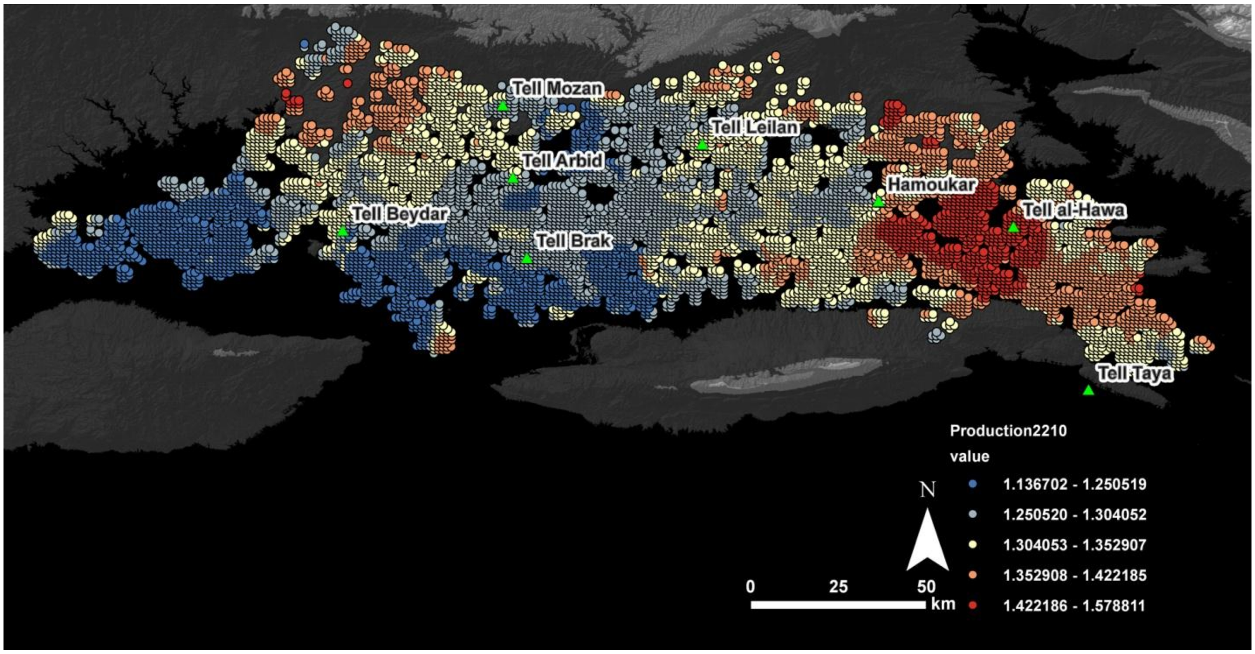

Figure 8.6f Agricultural production estimation in 2210 BCE (data are in metric tons/ha)

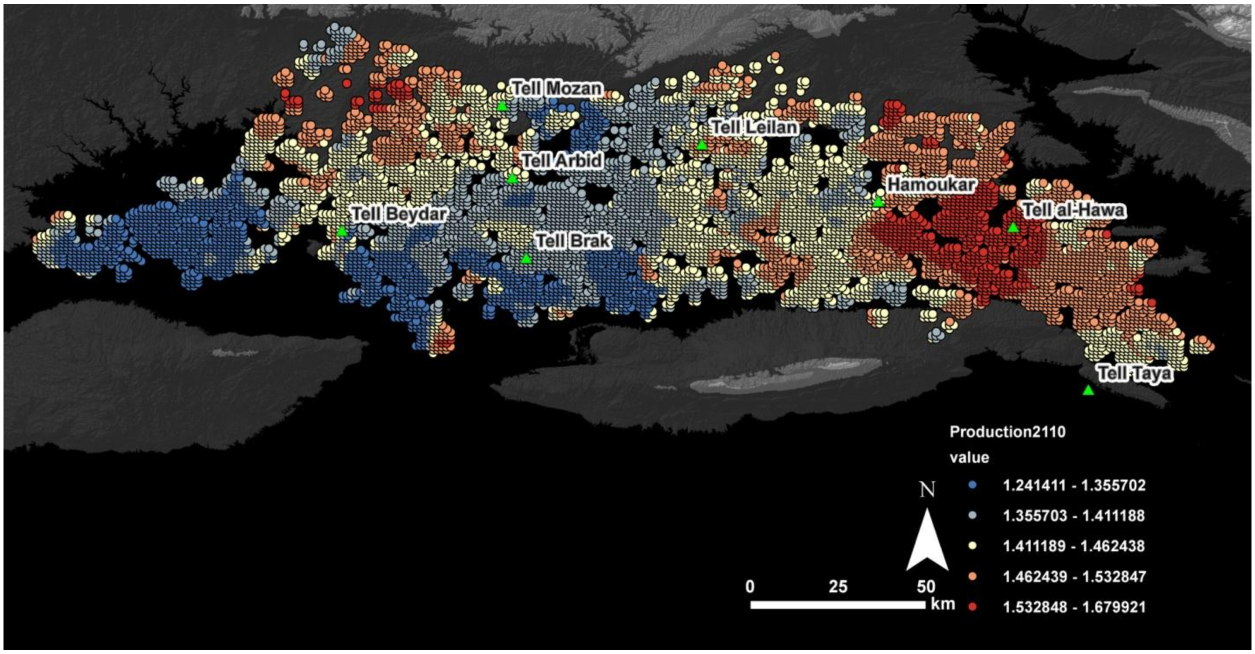

Figure 8.6g Agricultural production estimation in 2110 BCE (data are in metric tons/ha)

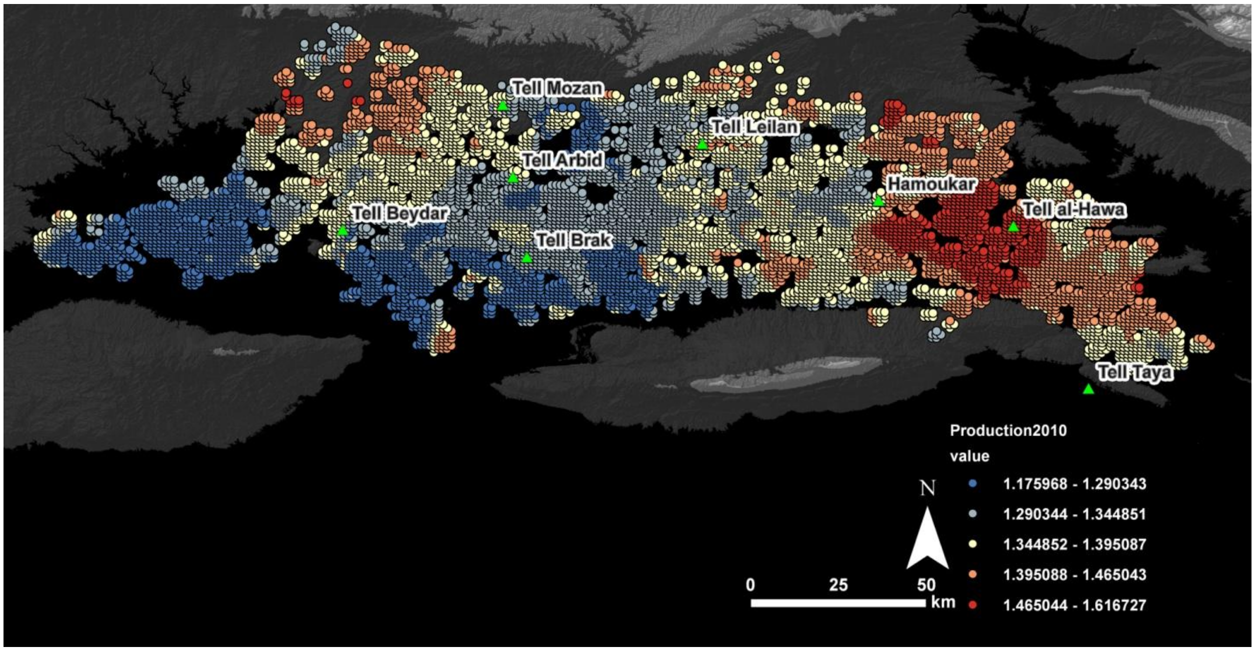

Figure 8.6h Agricultural production estimation in 2010 BCE (data are in metric tons/ha)

In estimating settlement-specific agricultural production, sample points not falling within modeled territorial boundaries of Early Bronze Age settlements are eliminated from the analysis

(Figure 8.7). In the next step, points are assigned to their corresponding settlements in order to calculate a mean production value specific to that settlement. To accomplish this, values of sample points falling within the production zone of a settlement are averaged. Finally, this average value is multiplied by the total production area of a settlement in order to estimate total production for a given year.

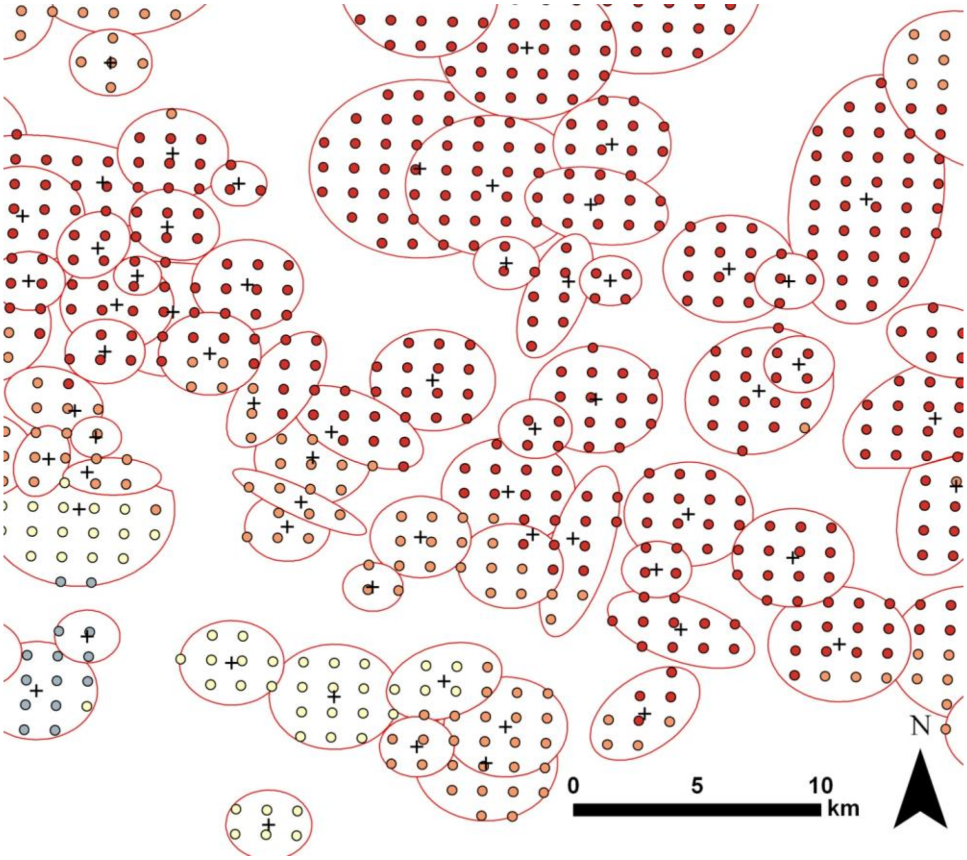

Figure 8.7 High resolution sample points from areas falling into modeled production zones

In this methodology, a distinction is made between settlements with hollow ways and settlements with no such features around them. As discussed earlier, a hollow way is a remnant of agricultural intensification in the area where the formation of hollow ways must have required the integration of sedentary and pastoral economies (Casana 2012). In this regard, Early Bronze Age settlements with hollow ways might also indicate higher availability of animal manure in a given settlement, and thus, higher potential for more yields at a given production cycle. To provide such difference, total production values are increased by 20percent for settlements with at least one documented hollow way. Even though this level of increase is selected arbitrarily, it still approaches to hypothetical reality.

The separation between settlement with and without hollow ways might be arbitrary since not only the process of formation, but also preservation conditions determine what archaeologists observe today. Therefore, this suggested increase in ancient production levels due to manuring might not reflect the actual conditions of the third millennium BCE. On the other hand, this differential preservation conditions are hard to detect since settlements with no hollow ways are evenly distributed over the landscape, and unless local taphonomic processes were in effect differential preservation can be ignored for the sake of simplicity.

Production variation between settlements suggests that the highest variation was around 2430 BCE. After a sharp drop, production stabilized between 2370 and 2285 BCE, and another sharp drop is evident around 2225 BCE. These peak values at 2430 BCE and 2225 BCE are characterized by high and low precipitation years respectively (Figure 8.8).

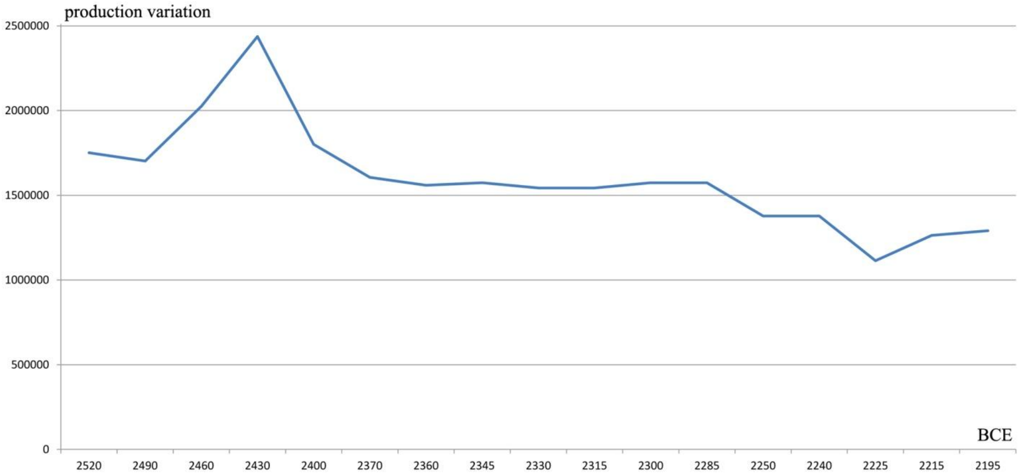

Figure 8.8. Production variations for the mid-to-late Early Bronze Age

Following these observations, production in 2520 (pre-dating change), 2430 (change), 2330 (stable), 2225 (change) and 2195 (post-dating change) BCEs are illustrated for the whole settlement system in order to provide an overview of the agricultural production (Figure 8.9a-e). At these times, the highest levels of production occur with ~9100 tons around 2430 BCE while the lowest production is observed around 2225 BCE with ~6700 tons. These two statistics follow the precipitation trend in the area.

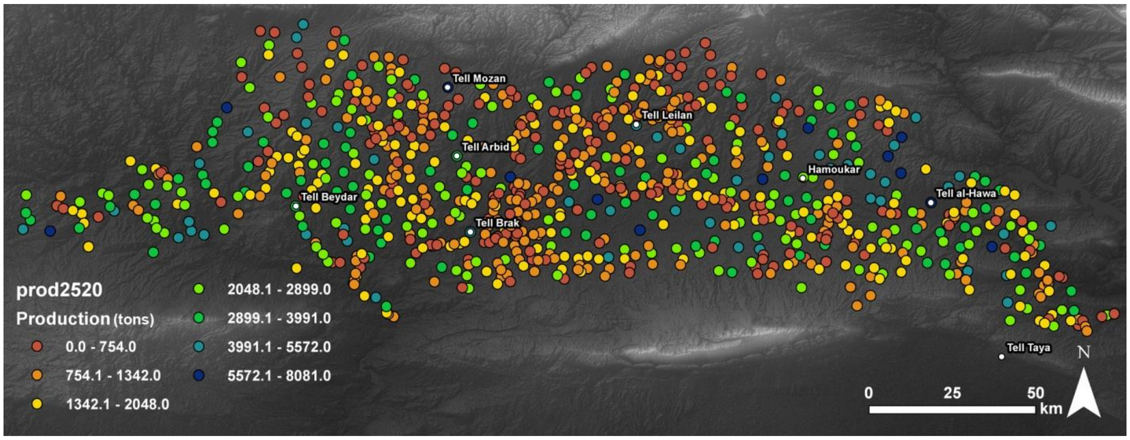

Figure 8.9a Estimated production in 2520 BCE

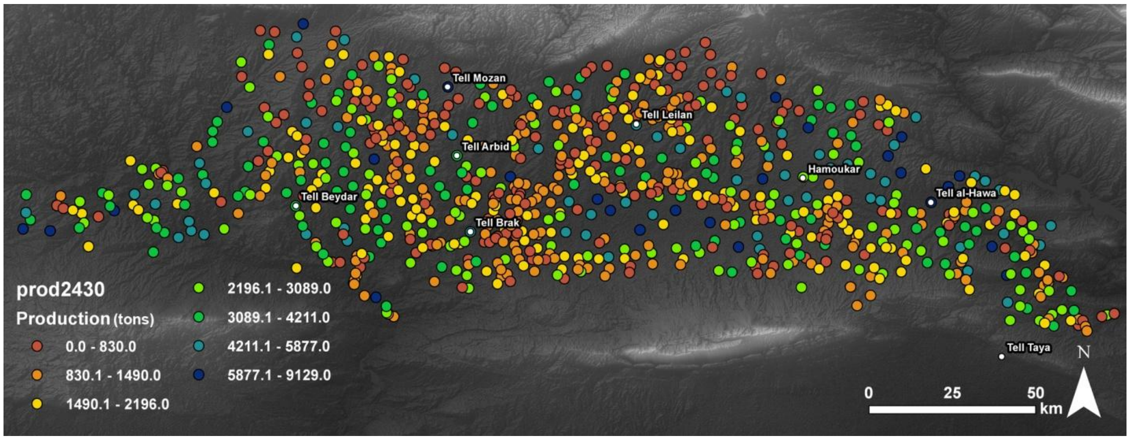

Figure 8.9b Estimated production in 2430 BCE

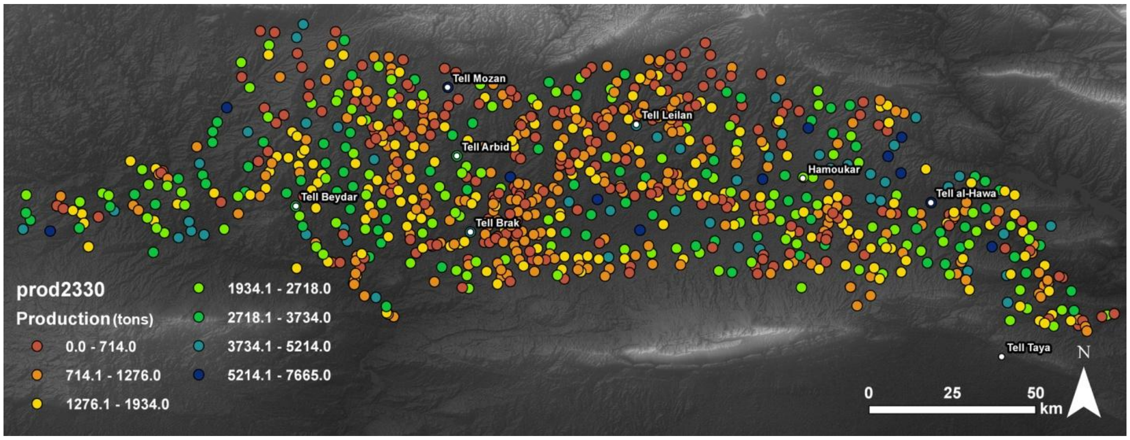

Figure 8.9c Estimated production in 2330 BCE

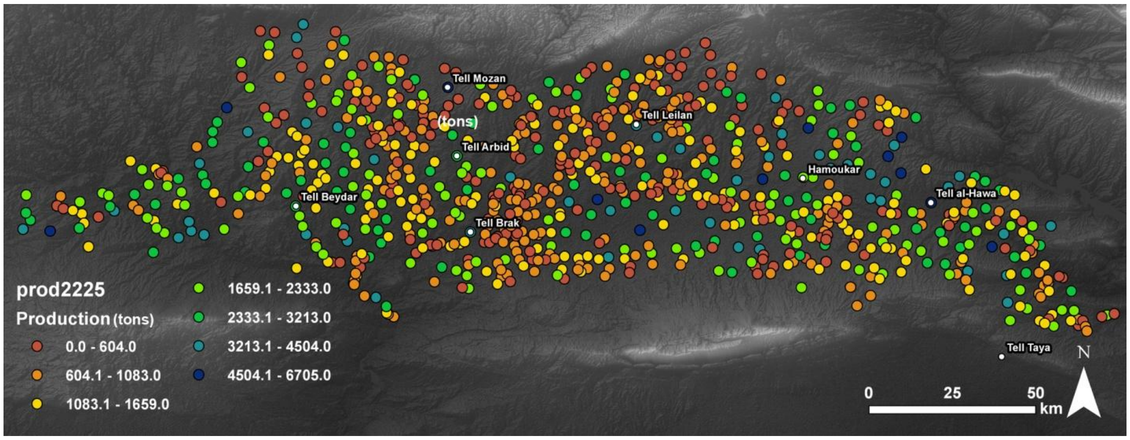

Figure 8.9d Estimated production in 2225 BCE

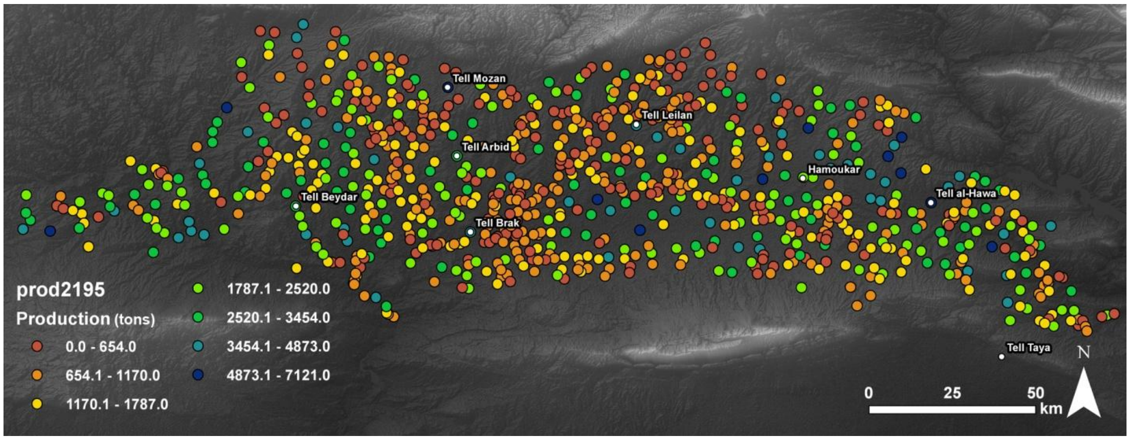

Figure 8.9e Estimated production in 2195 BCE

Production at urban central places also reflects meteorological changes in the area (Figure 8.10). Among these settlements, Tell Mozan has the highest production levels even though it is not located in the most productive agro-climatic zone. This observation can be explained by Tell Mozan’s large production area. At the opposite end of the spectrum, production at Tell Brak is relatively low in comparison to its extensive production zone due to the fact that the site is located in an area characterized by mid-to-low level productivity levels. But, with its sheer size, people of Tell Brak must have consumed more than they produced. To equalize this deficit, Tell Brak must have pulled agricultural surplus from its hinterland, but how much was this deficit and how many hinterland settlements were required to fulfill this deficit remains as an important question to answer.

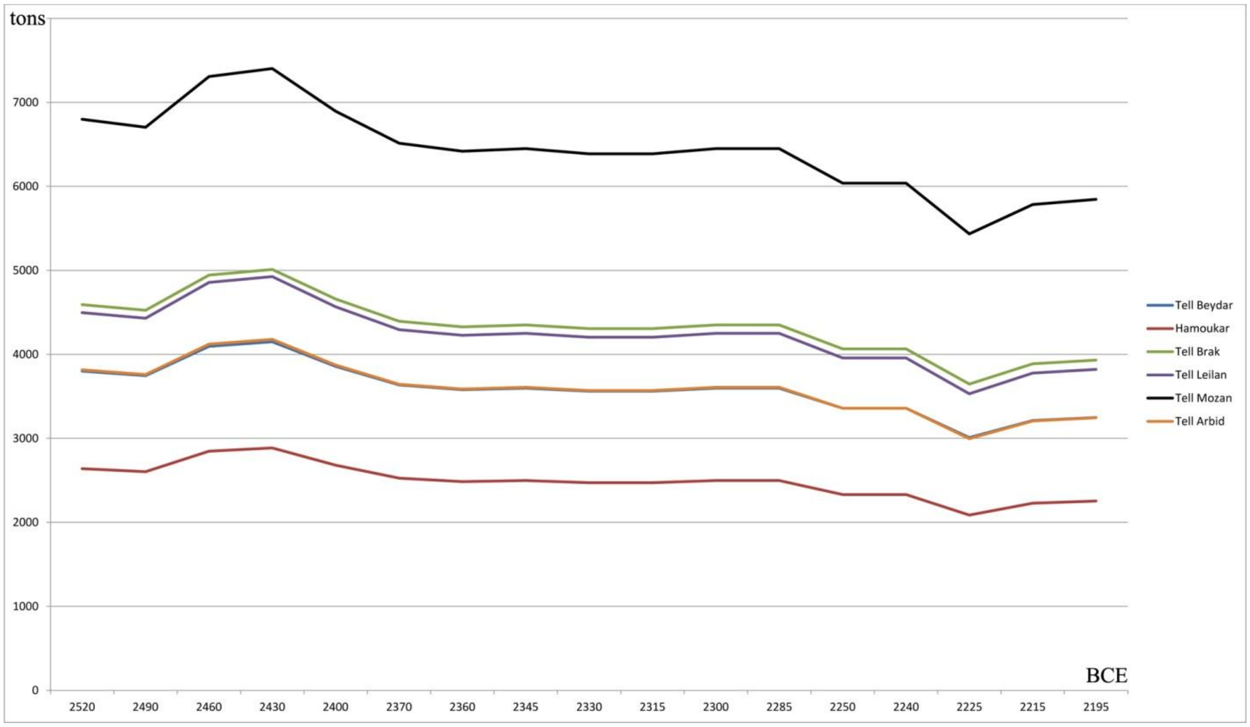

Figure 8.10. Estimated production for large settlements of the Early Bronze Age

There is another pattern in ancient production values. Mid-to-late Early Bronze Age settlements with high production totals were located in places with a low density of other settlements (Figure 8.11). This may indicate sparse occupation provided easier conditions for extending production zones —if or when necessary. The level of extension in these "free-to-move" areas must have also been determined by the available labor going into agricultural production. In this picture, land and labor both stands as the facilitator and the barrier of production. On the other hand, large production zones assigned to settlements might be an artifact of spatial modeling. Therefore, caution must be exercised before making further generalizations.

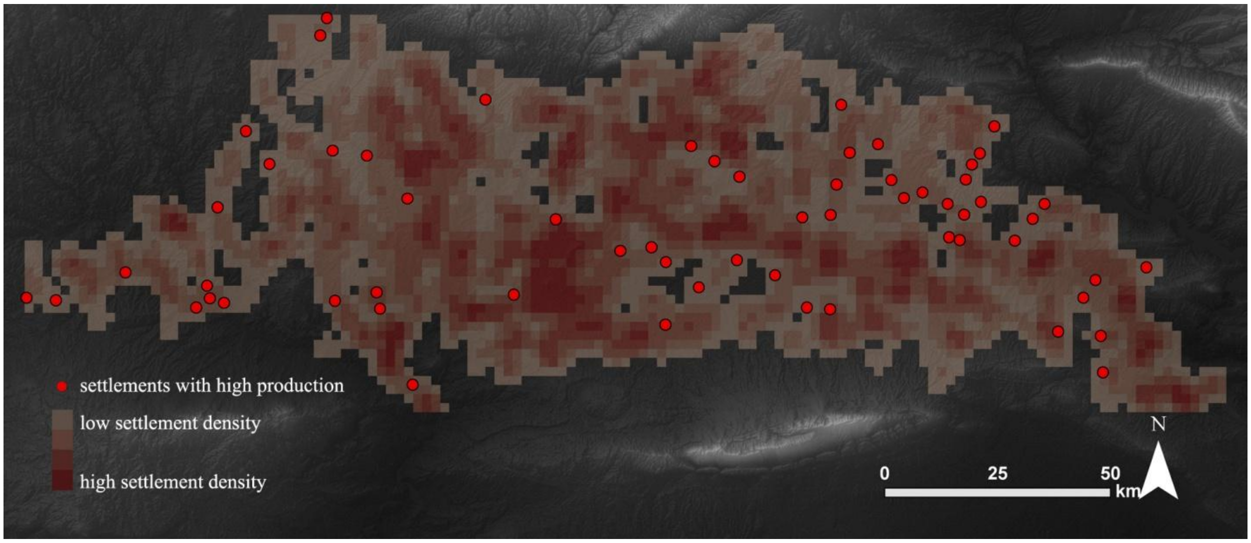

Figure 8.11. Settlement locations with high agricultural production in relation to the density map of settlement pattern

8.4. Ancient Consumption and Food Balance

Food consumption is a perhaps the most challenging variable to model because both the amount of consumption and diet are determined by cultural practices, religious norms and economic constraints. If the intention is to investigate the agricultural yield that went into circulation within the settlement system, one has to create a metric for consumption so that the net amount in the system can be calculated for a given year. In this project, the food balance is calculated by subtracting estimated consumption from estimated production.

Even though there are archaeological studies which focus on differences in diet (e.g., Wattenmaker 1987), the variability in the amount of consumption in different socio-cultural contexts remains largely unknown. When investigated, the amount of consumption is usually based on calorific needs of total population where a biological model is employed to determine the minimum amount necessary to feed populations (e.g., Deckers and Riehl 2008). While these studies suggest such a consumption minimum for a given settlement, there is no archaeological evidence for the exact amount of staples consumed per person in a variety of urban and rural settings. In fact, studies on modern urbanization suggest a complex consumption practice where more staple products are exhausted in rural areas even though urban centers have higher populations (e.g., H. H. Jensen, Johnson, and Stampley 1990; Wu, Li, and Samuel 1995; Garrett and Ruel 1999; Obayelu, Okoruwa, and Oni 2006; J. Li and Shangguan 2012). Although there is no immediate way to determine whether this was also the case during the mid-to-late Early Bronze Age, it suggests a possible consumption imbalance between central places and their corresponding satellite settlements, and thus, assigning same consumption values to different settlements reduces the power of these models.

In order to investigate possible forms of food balance, two different consumption scenarios are tested. The first scenario is built on the assumption that small settlements at the bottom of their settlement hierarchies produced and consumed food internally and did not contribute to flow. The second scenario relies on calorific assumptions of human consumption and demographic estimates based on settlement area. A range of population densities are employed in order to provide a non-static consumption metric.

8.4.1. Scenario 1: Productivity Based

In this scenario, it is assumed that settlements with the smallest sustaining areas (lowest 10 percent of the whole system) had 0 food balance in the production-consumption equation In other words, rural settlements at the lowest tier of the whole settlement system are treated as subsistence-level farmers and thus do not contribute to the flow of agricultural staples towards urban centers.

Small production territory, on the other hand, suggests that agricultural labor was limited in these Early Bronze Age settlements. Limited labor also indicates lower population levels when compared to other settlements with similar sizes. Furthermore, Wilkinson (1994, 496) argues that "[w]hen production falls below a certain figure, the labor force will harvest only enough to supply itself and the nonagricultural population with food". Considering low population levels with limited food supply may indeed indicate these settlements might have been small interest to the central urban centers of Upper Mesopotamia during the third millennium BCE.

The exclusion of smallest settlements with limited production territories from the larger productive economy is a strict assumption. There are numerous archaeological studies indicating small settlements were indeed part of larger economies. For instance, according to the census list and the list of agricultural holdings of Alalakh IV texts in the second millennium BCE, at least 168 settlements were part of the Mukish dominion. This large number suggests smaller villages and towns were also part of the Alalakh settlement system and they provided necessary goods and services to the Late Bronze Age center. Yet, in another example, Archi (2008) investigates Ebla archives and suggests that only a handful of settlements were part of the Kingdom of Nagar (Tell Brak) during the Early Bronze Age. In other words, despite the fact that Tell Brak was an important center of its time, this importance did not necessarily translate into complete domination of immediate landscapes. Furthermore, settlements with low production are evenly distributed over the landscape (Figure 8.9.a-e) and they do not necessarily fall into the territories of large urban centers which must have had the highest need of surplus flow, and thus, one can claim these settlements were producing for self-sufficiency.

For settlements with limited agricultural territories areas, production levels which are represented in the dense point pattern are averaged as a metric of consumption. The mean value represents the amount of food extracted (or consumed) from each production area. This value is extracted from all production data across the landscape, which results in another point pattern. This updated point pattern represents a metric for the food balance per unit area. Finally, these points are assigned to their corresponding settlements in order to estimate food balance for each settlement.

In this scenario, agro-climatic zones determine the food balance. The areas around Hamoukar and Tell-al-Hawa, as well as the north-west corner of the study area, all have positive balances throughout the mid-to-late Early Bronze Age. The biggest food deficit (~1900 tons) is observed in 2460BCE. The positive food balance for the entire system was around 900 tons, and this number remained stable until the abandonment of urban settlements at the end of the third millennium (Figure 8.12a-f).

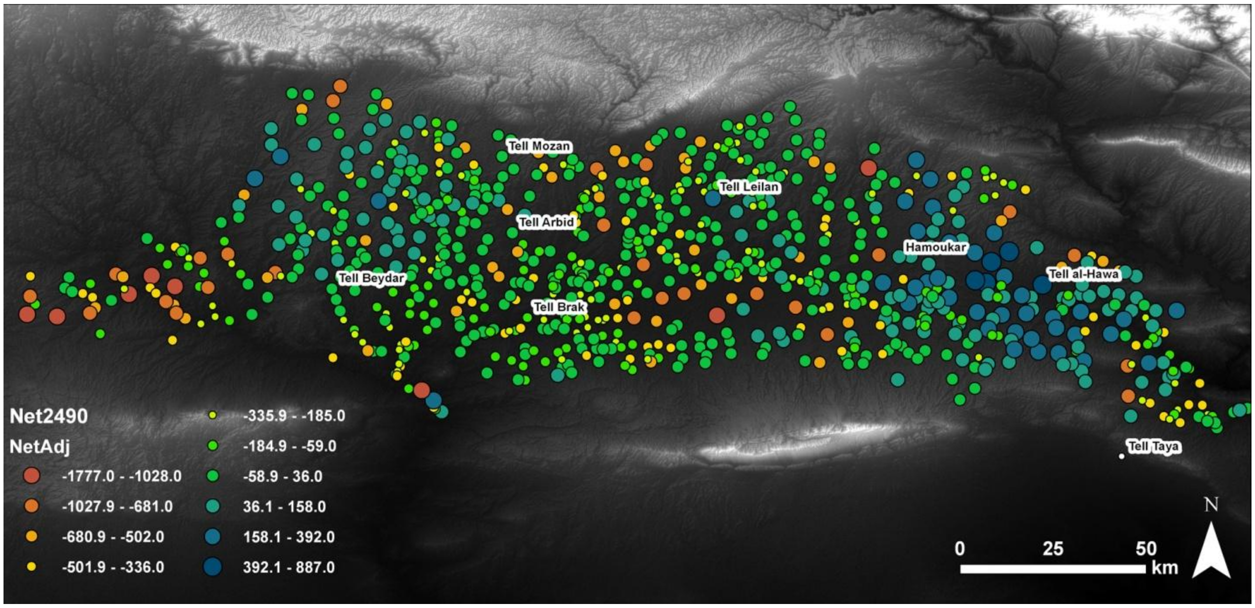

Figure 8.12a. Estimated food balance in 2490 BCE based on productivity scenario (data is in metric tons)

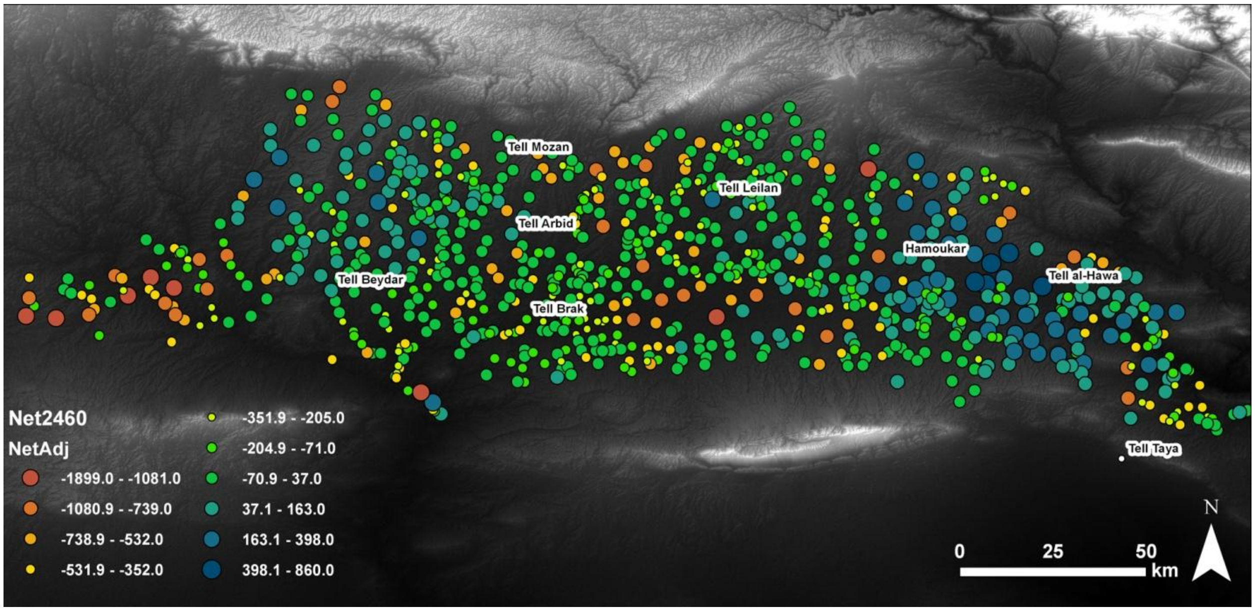

Figure 8.12b. Estimated food balance in 2460 BCE based on productivity scenario (data is in metric tons)

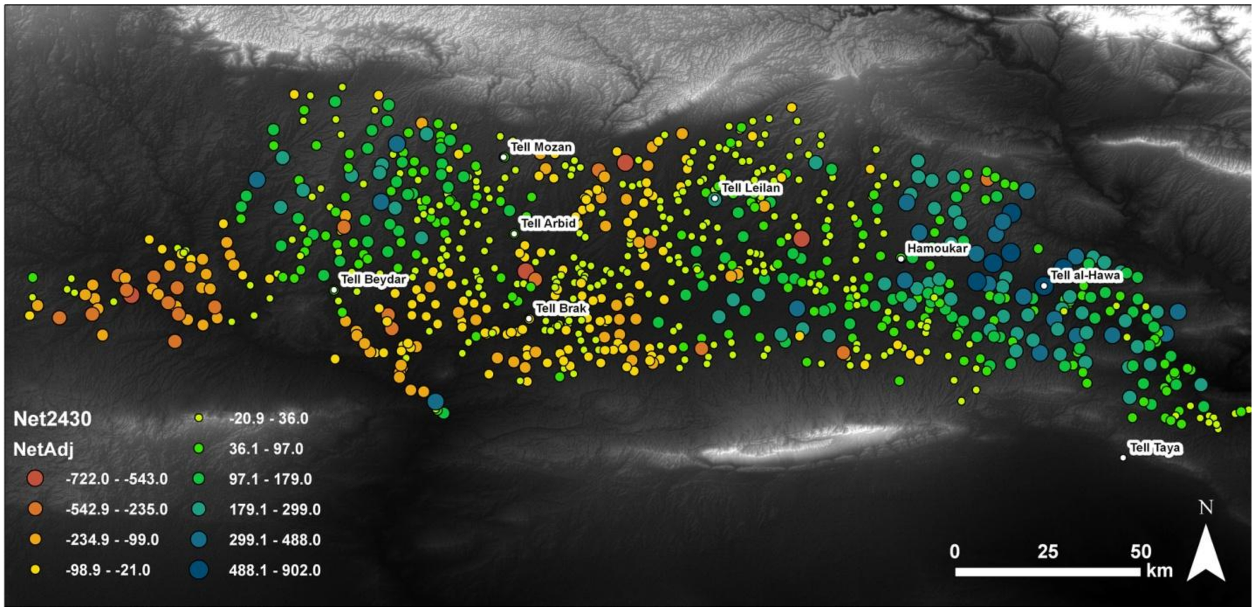

Figure 8.12c. Estimated food balance in 2430 BCE based on productivity scenario (data is in metric tons)

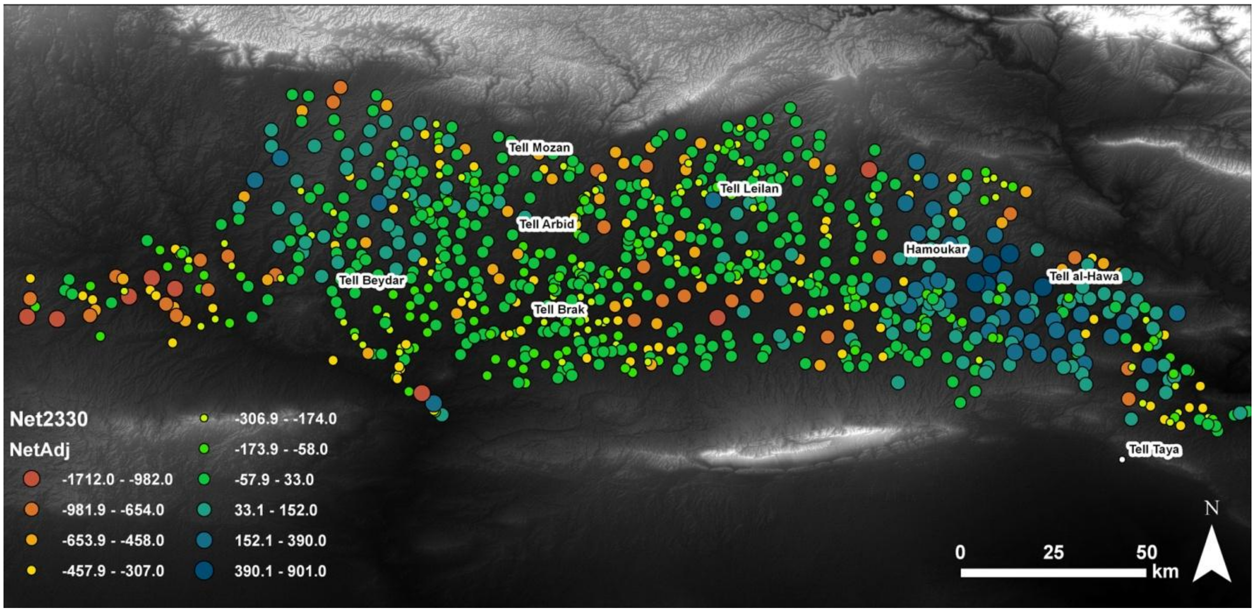

Figure 8.12d Estimated food balance in 2330 BCE based on productivity scenario (data is in metric tons)

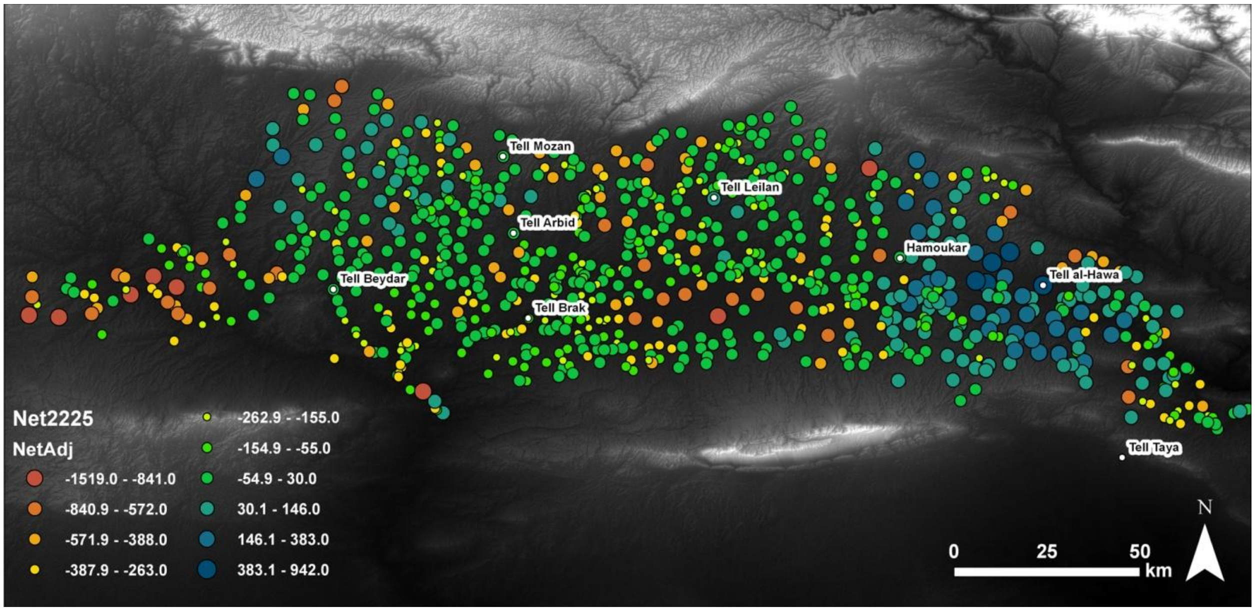

Figure 8.12e. Estimated food balance in 2225 BCE based on productivity scenario (data is in metric tons)

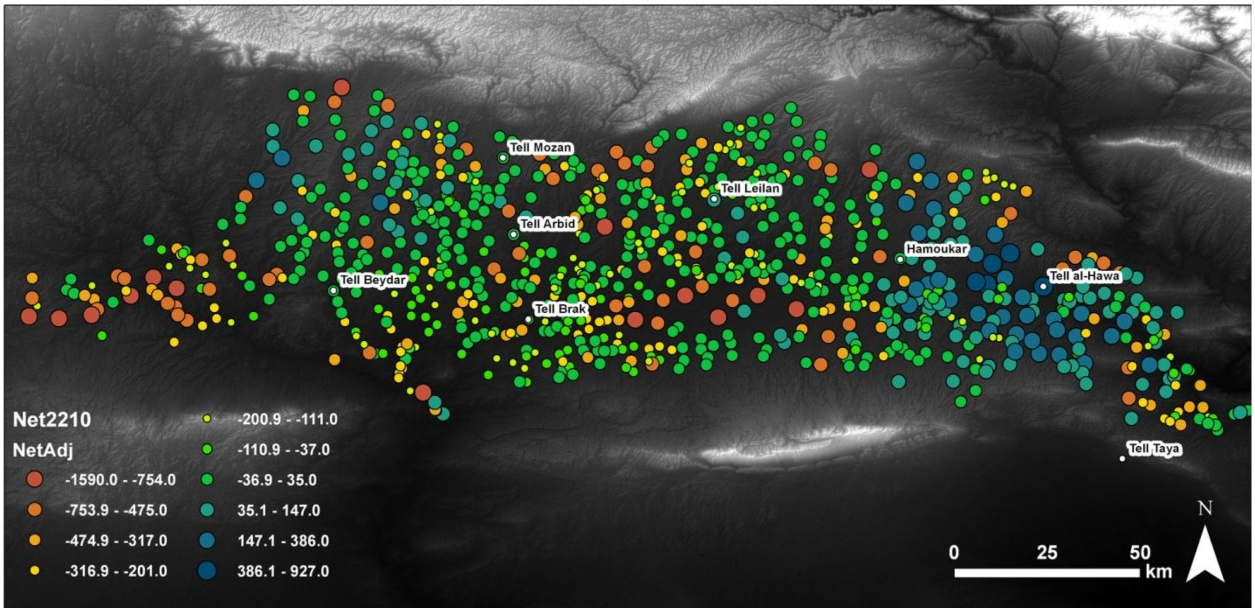

Figure 8.12f Estimated food balance in 2210 BCE based on productivity scenario (data is in metric tons)

In this consumption setting, central places have varying food balances (Figure 8.13). Throughout the mid-to-late Early Bronze Age, Tell Brak had a negative food balance, perhaps an indication of the constant demand for staples from its satellites. In contrast, Tell Mozan, Tell

Arbid, Tell Beydar and Hamoukar were mostly self sustainable, but also appear to have been at the limit of their respective productive capacities, as long argued by Wilkinson (1994).

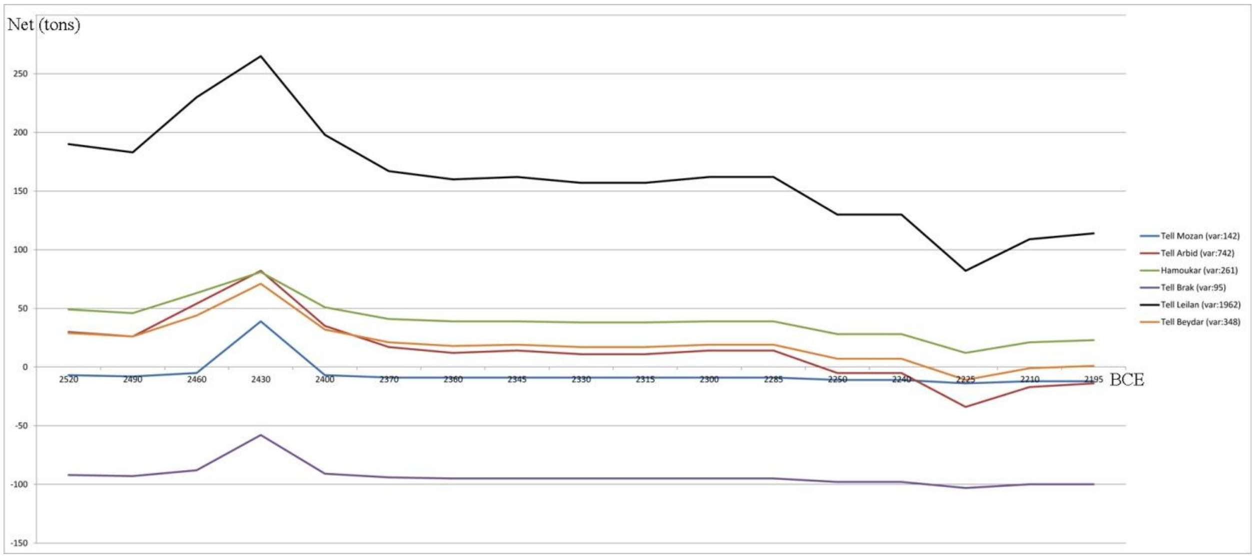

Figure 8.13. Productivity based food balance at central settlements

This productive system made large urban settlements constantly reliant on their smaller satellite settlements for excess agricultural products in order to provide stability and food security. Tell Leilan, on the other hand, diverges from other urban settlements with its positive food balance. Even at around 4.2ka BP, when modeled production plummeted due to a hypothesized decrease in precipitation, Tell Leilan still had positive food balance, contradicting previous studies (e.g. Weiss et al., 1993). On the other hand, considering the complexity of the economic relationships that made urban centers prosper, the decrease to only 100 to 250 tons of excess food may still have put Tell Leilan in a challenging position in terms of performing its central activities.

When the Early Bronze Age settlements system is investigated in its entirety for its food balance, the system appears to have been under constant deficit, except for the anomalous positive peak around 2430 BCE (Figure 8.14). This is a significant observation because 2430 BCE marks the earlier phases of the "[r]esurgence of urbanism and complexity" in Upper

Mesopotamia (Ur 2010a, 404). Even though it is not immediately possible to relate urbanism to the availability of food, this coincidence requires further attention.

In another examination of food balance, the net production values for each settlement are plotted for the years 2430, 2330 and 2225 BCE (Figure 8.15). The plot suggests that there were more settlements with food deficit than there were settlements with excess production. This trend is also evident in Figure 8.14, where net sum values are all below zero except for the year 2430 BCE. On the other hand, when settlements are investigated individually for their net food values, a slight break is visible for settlements with negative net values (Figure 8.15). For settlements below this break-line, the food deficit is more apparent than for settlements above the break-line, which tend to cluster with settlements with no food deficit.

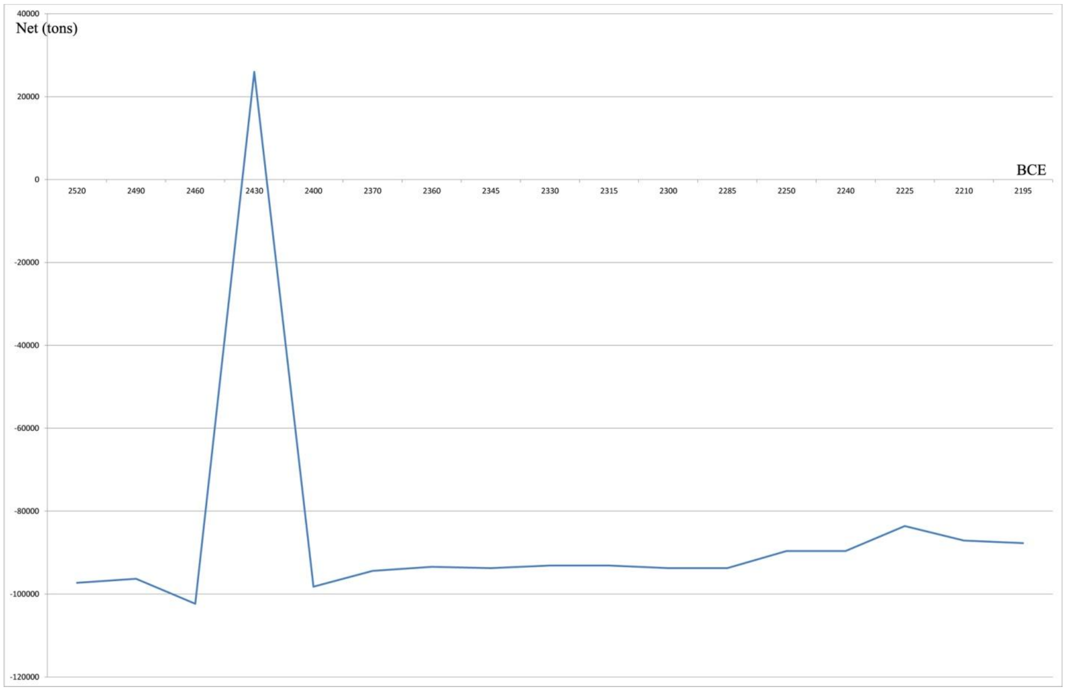

Figure 8.14 Total food balance for the complete settlement system

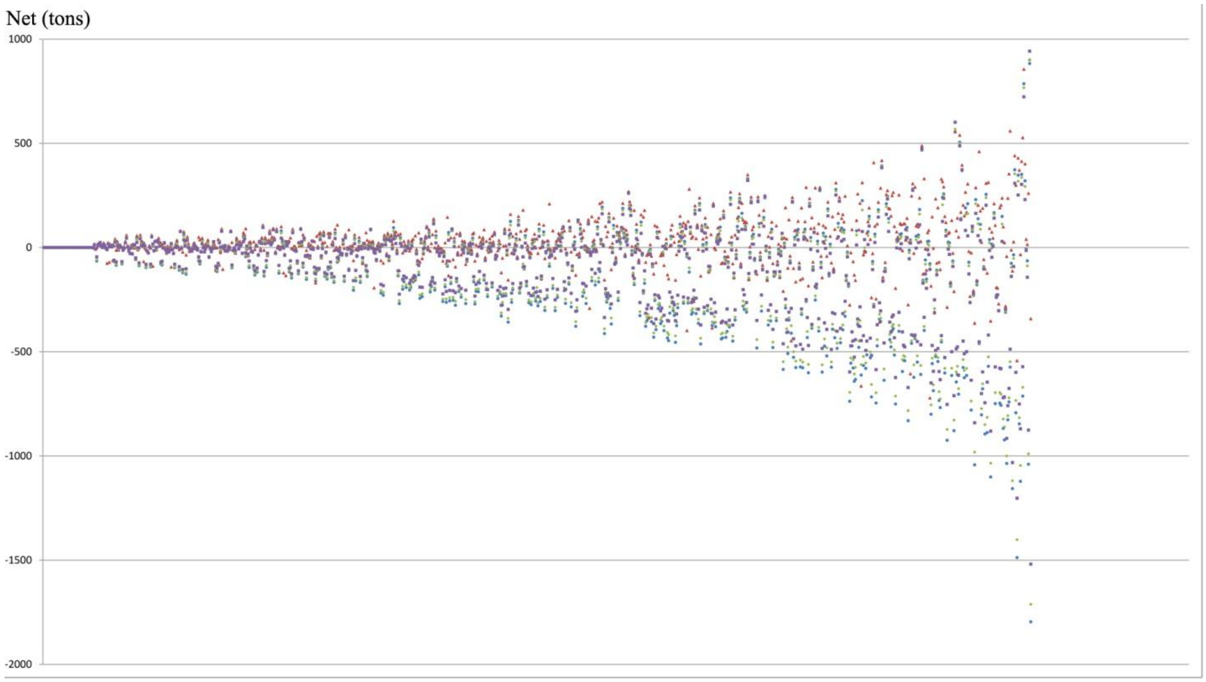

Figure 8.15 Consumer and surplus-generating settlements ordered with respect to their sizes. Different colors represent four different BCE years.

The separation is more pronounced when variation between settlements in their net food levels is investigated in relation to the extents of their production areas. For some settlements variations in the food balance remained low regardless of the size of the production area. However, for some settlements there is a clear exponential relationship between food levels and production areas (Figure 8.16). If the stability in food balance indeed contributes to stability in a political economy, as is likely the case in staple-financed systems like Early Bronze Age Mesopotamia (Stein 2004), then it can be argued that settlements which had stable food balance during the mid-to-late Early Bronze Age would have been likely to be more resistant to dissolution or "collapse". In order to test this claim, archaeological surveys which provide reasonably secure dates for settlements with stable food balance are evaluated (e.g., Ristvet, 2005; Ur, 2004). Modeled production values suggest that settlements which continued to be occupied after the "collapse" of the system at the end of the third millennium BCE do not show any relation with the stability of food balance. That is to say, there is no apparent difference in modeled food production at sites which continued to be occupied versus those that were abandoned. In addition, when agriculturally stable settlements are investigated for their spatial distribution, no visible pattern emerges as an indication of a spatial clustering based on productivity levels in the area (Figure 8.17). Therefore, it can be suggested that there is no conclusive evidence for directly associating food balance stability with the stability of the urban system.

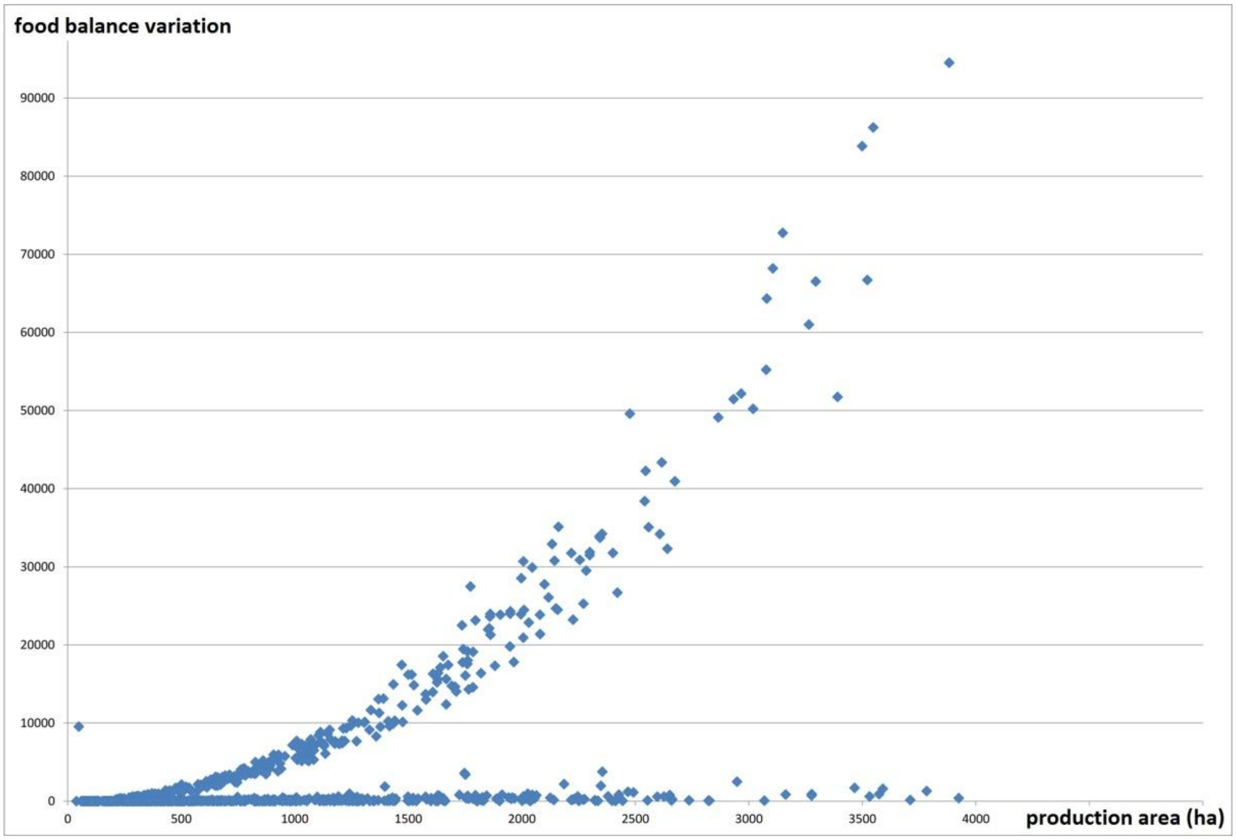

Figure 8.16 Comparison of food balance variation and production area

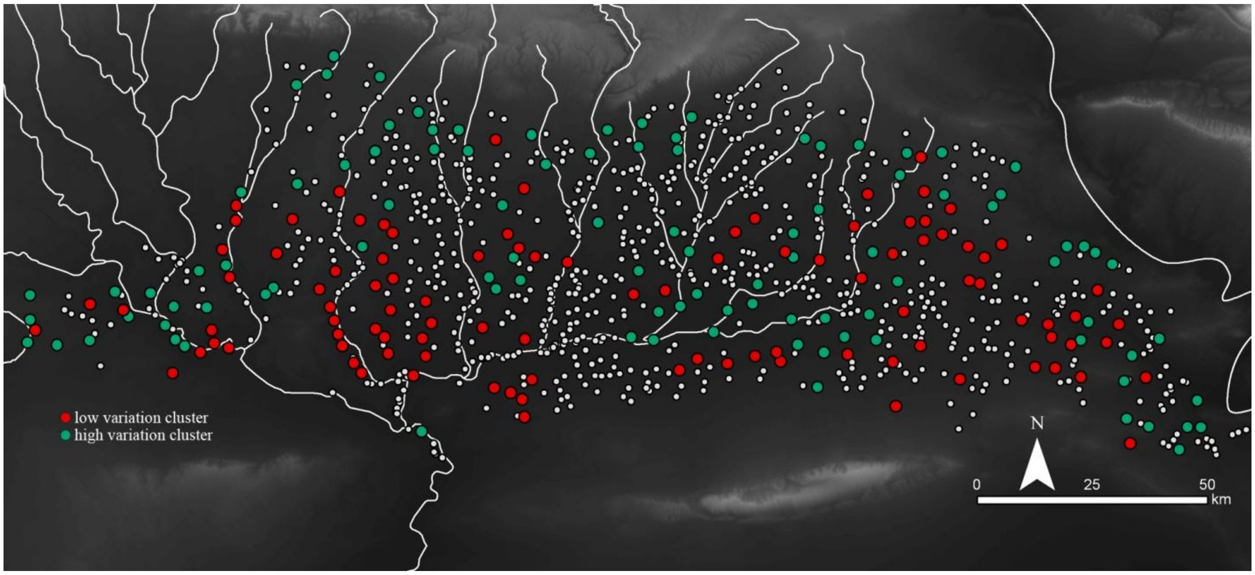

Figure 8.17 Distribution of high production sites with respect to variation levels

8.4.2. Scenario 2: Calorific Assumptions

In this scenario, following Deckers and Riehl (2008) in their hypothetical food consumption levels, for a single person 2200kcal/day is assumed. They also suggest ~70% of the ancient calorie input was based on cereals, other cultivated and wild plant food (*ibid.*, 176). Also, based on United States Department of Agriculture (USDA) Nutrient Database for Standard Reference, 100.0 g pearled and cooked barley provides 123kcal energy. In this consumption setting, the total staples required for 1 person in a year is 457 kilograms.

Settlement sizes, obtained by the analysis of CORONA satellite imagery, are used to estimate ancient population levels. In order to provide a dynamic picture, population densities, ranging from 100 to 250 persons per hectare are employed. This wide range covers population estimates from Wilkinson (1994) and Casana (1999). On the other hand, densities are fixed and they exclude the possibility that different-sized settlements might have had different population densities (Casana 1999, 30). 250 persons per hectare statistics are also provided to investigate an extreme consumption case to include other possible non-human consumption use of agricultural production. In the next step, total consumption per settlement is calculated for different population densities. Finally, food balance is estimated by subtracting ancient consumption from production values.

For representational purposes, net food balance for the years 2430 (wettest year), 2330 (stable precipitation) and 2225 (driest year) BCE are plotted for each settlement in the study area with 200 people per hectare population density levels (Figure 8.18a-c). A high deficit is observed at large settlements, reaching as high as 13000 tons at around 2225 BCE. Despite fluctuating rainfall regime, the deficit for any settlement in the system never goes below 12,000 tons. For this population density, Tell Arbid and Tell Beydar were surplus producers (but also see, (Ur and Wilkinson 2008)).

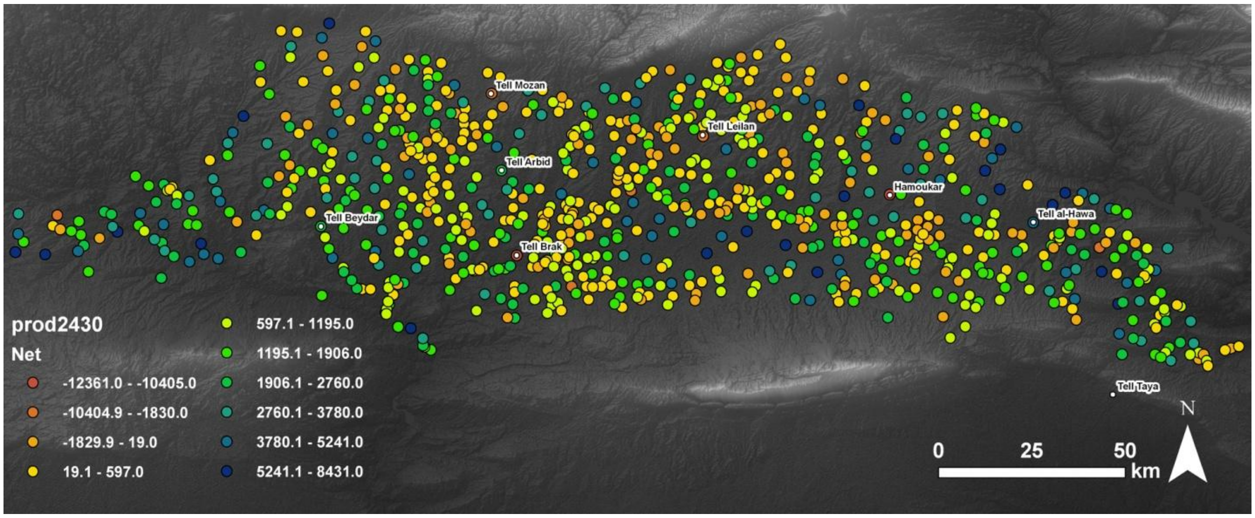

Figure 8.18a Food balance based on calorific consumption scenario in 2430 BCE (data is in metric tons)

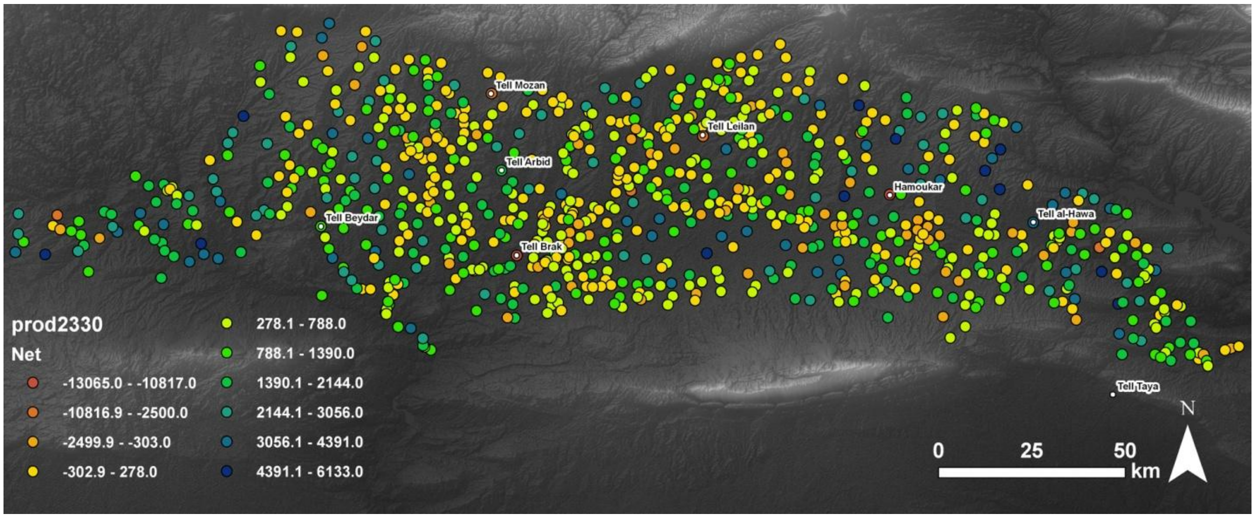

Figure 8.18b Food balance based on calorific consumption scenario in 2330 BCE (data is in metric tons)

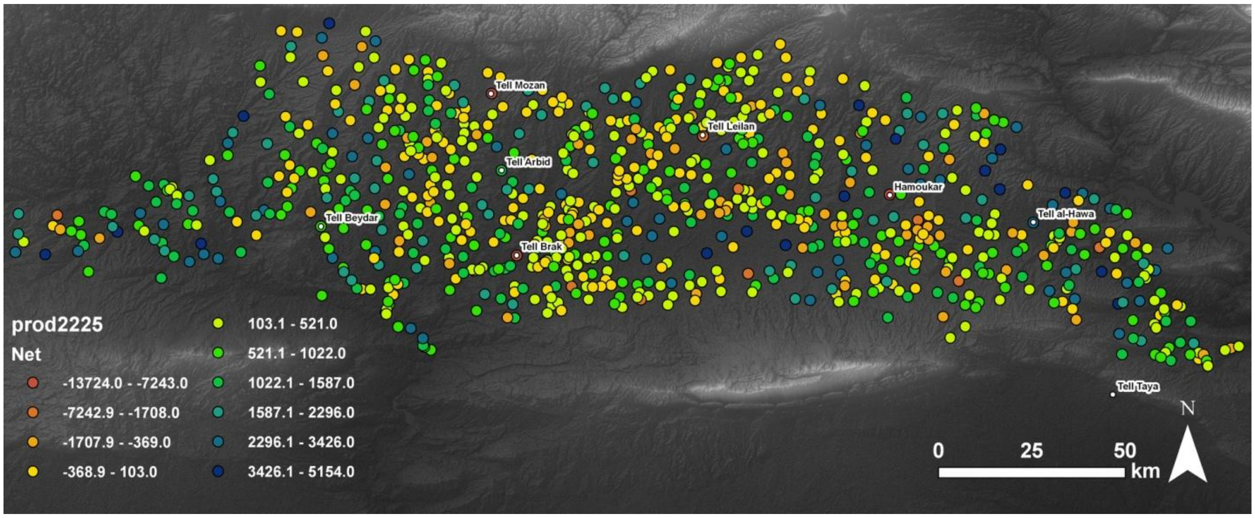

Figure 8.18c Food balance based on calorific consumption scenario in 2225 BCE (data is in metric tons)

On the other hand, Tell Leilan, Tell Mozan, Hamoukar and especially Tell Brak must have required constant flow of foodstuffs to feed their populations (Figure 8.19). Despite the constant food deficit at large settlements, the settlement system as a whole was able to produce more than it was consuming. Even during the driest years of the mid-to-late Early Bronze Age, a large amount of surplus (~600,000 tons) is estimated for the whole settlement system (Figure 8.20).

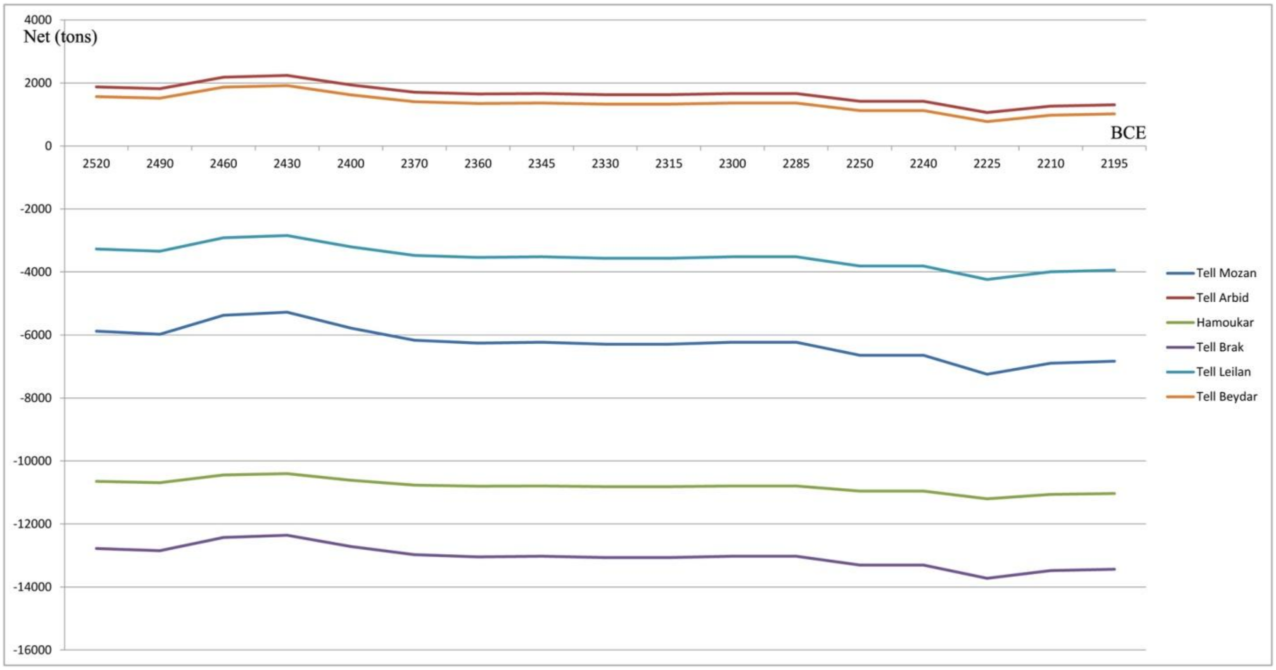

Figure 8.19. Food balance for large settlements of mid-to-late Early Bronze Age based on calorific consumption scenario

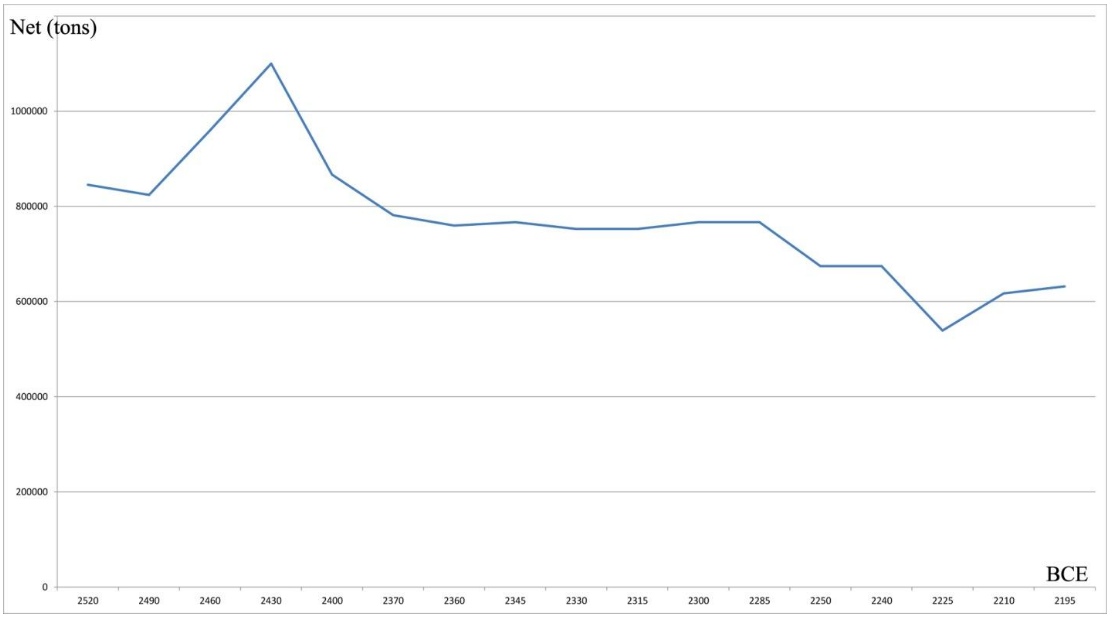

Figure 8.20 Total food balance for the complete settlement system based on calorific consumption scenario

If indeed large settlements were able to easily extract surplus from their satellite settlements then it is possible to suggest a configuration of settlements around a central settlement which nullifies the deficit at that central settlements. Making this suggestion is possible since each settlement has a statistic which models food balance for any speleothem year. To pursue the analysis, it is further assumed that settlements with food deficits exploited the spatially closest satellite settlements if they were surplus producers. To visualize this, a settlement configuration which provides a zero sum around central urban settlement with a food deficit is mapped. This method is applied to years 2520 (wettest year), 2330 (stable precipitation) and 2225 (driest year). The number and configuration of settlements are documented for 200persons/ha density level at Tell Brak, Tell Leilan and Tell Mozan. These settlements were constantly in high deficit, but they were also important actors in the political landscape of the time. (Figure 8.21a-c).

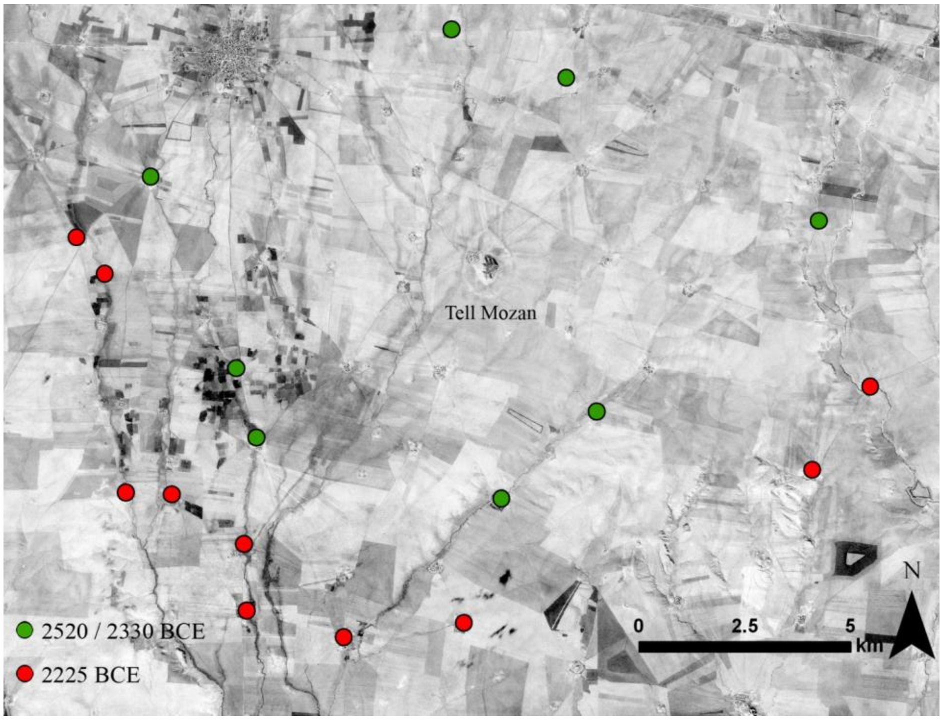

Figure 8.21a Surplus generating satellite sites for Tell Mozan

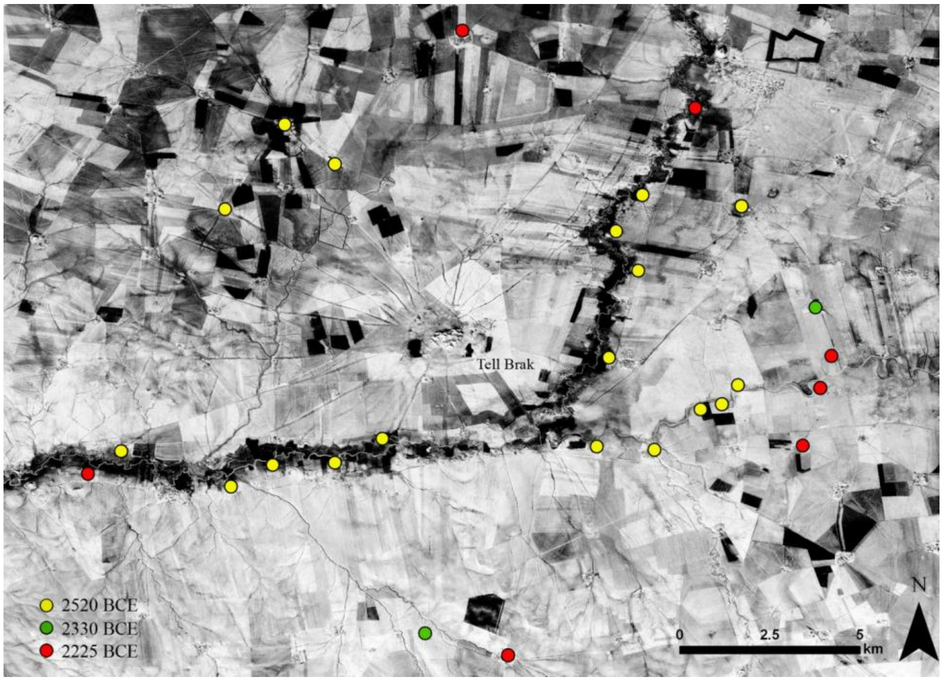

Figure 8.21b Surplus generating satellite sites for Tell Brak

Figure 8.21c Surplus generating satellite sites for Tell Leilan

According to the model, in 2520 and 2330 BCEs, Tell Mozan must have been relying on eight satellite settlements for their surplus production. This number reaches to 18 in 2225 BCE when the precipitation hit the lowest values. For Tell Brak, 18, 20 and 27 satellite settlements must have been mobilized for their surplus during the years 2520, 2330 and 2225 BCEs respectively. For Tell Leilan, the number of contributing settlements to the central settlement is significantly lower when compared to Tell Mozan and Tell Brak. Only six settlements would have been required to send surplus to Tell Leilan in the wettest years of the mid-to-late Early Bronze Age (2520 BCE), while in the driest year, only 9 were necessary.

Brak	**2520**	**2430**	**2330**	**2225**	**2195**		**Leilan**	**2520**	**2430**	**2330**	**2225**	**2195**
100	3	3	5	7	6		100	1	1	1	1	1
150	10	7	13	16	15		150	1	1	3	5	4
200	18	13	20	27	24		200	6	3	9	9	9
250	27	20	41	55	51		250	9	9	10	28	22
Mozan	**2520**	**2430**	**2330**	**2225**	**2195**		**Hmkr.**	**2520**	**2430**	**2330**	**2225**	**2195**
100	1	1	1	5	3		100	2	2	3	3	3
150	5	5	6	7	7		150	5	3	5	6	5
200	8	7	8	18	14		200	7	5	7	9	8
250	18	8	22	28	25		250	9	7	13	35	16
Arbid	**2520**	**2430**	**2330**	**2225**	**2195**		**Beydar**	**2520**	**2430**	**2330**	**2225**	**2195**
100	1	1	1	1	1		100	1	1	1	1	1
150	1	1	1	1	1		150	1	1	1	1	1
200	1	1	1	1	1		200	1	1	1	1	1
250	1	1	1	1	1		250	1	1	1	1	1

Table 2: Columns are dates in BCE. Rows are population densities in person per hectare.

In the pressure scenario (250pe/ha), Tell Brak must have required the largest number of contributing satellite settlements in order to equalize its deficit. During the low production year (2225 BCE) 55 settlements should have been in charge of sending surplus production to Tell Brak. Wright et al. (2006) reports at least 90 sites dated to later Early Dynastic III, Akkadian and Post-Akkadian periods. Thus, pressure scenario which suggests the exploitation of 55 settlements remains as a possibility. For population densities 100 and 150 pe/ha, the number of sustaining settlements ranges between 7 and 16 for the driest year.

In the driest year, Tell Leilan is predicted to have necessitated a flow of agricultural staples from at least 28 settlements in the extreme population pressure scenario. This is a more managable number when compared against the necessary pull required by Tell Brak. However, if the population densities of settlements were in the more likely range between 100 and 150 pe/ha, then merely 5 satellite settlements would have been enough to support Tell Leilan in the driest years. This is a contradictory evidence for the landscape collapse hypothesis, suggested by Weiss et al. (1993), since it can be suggested that 5 satellite settlements could have been easily controlled by Tell Leilan for surplus production. In fact, when approached from a broader perspective, the productive landscape around Tell Leilan was a surplus generator (Figure 8.22.).

For Tell Mozan, the maximum number of satellite settlements which must have been mobilized for their surplus production is 28 for the driest year in the pressure scenario (250 pe/ha). This number is the same as in the Tell Leilan case even though Tell Mozan and Tell Leilan had different sizes, and thus, different population estimations. However, once the pressure is relaxed it becomes clear that Tell Mozan must have required more staples flow from its satellites when compared to Tell Leilan, but never as much as Tell Brak.

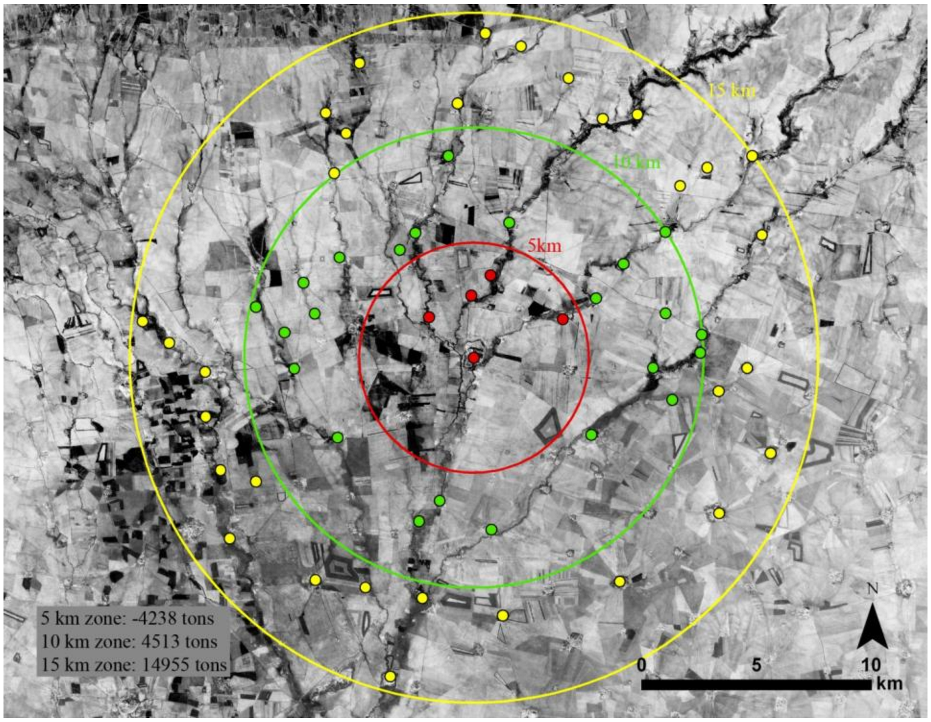

Figure 8.22 Delineation of Tell Leilan production landscapes based on arbitrarily selected (5, 10, 15 km) distances from the center and corresponding food balances.

The dependency of Hamoukar on its satellite settlements was similarly the highest during the driest years of the second half of the third millennium. For the 250pe/ha population density case, Hamoukar is predicted to have required a flow of staples from 35 settlements. For this high population density level, the number of satellite settlements providing surplus production was most probably around 7 in wettest years. Even though such a high population density was unlikely the case for the third millennium BCE, the local settlement system around Hamoukar had the capacity to absorb high populations at the beginning of the urbanization phase.

Despite their relatively large sizes, and thus high consumption levels, net food balance values at Tell Arbid and Tell Beydar were always stable, and the model suggests that neither of these settlements required significant amount of staples flow from other over-producing settlements. For different population densities and for different intensities of aridity only a single satellite settlement might have been enough to keep the food balance at zero levels. This is contrary to the general understanding that urban centers were in need for external food surplus produced in smaller settlements in the hinterland (e.g. Stein and Wattenmaker 2003). The contradiction arises when local productivity conditions are integrated into the model and fixed production is relaxed for its value. However, proposed production model in this study does not take fallowing into consideration. For instance, if Tell Beydar was following a biennial fallowing strategy, proposed production levels should be hypothetically halved —which would put the site back into an "importer" category (Ur and Wilkinson 2008, 313).

To summarize, even at large centers with population densities ranging from 100 to 200 persons per hectare, the production model employed herein suggests that the agricultural food deficit could easily have been compensated for with the help of a relatively small number of satellite settlements. Results suggest that the widely held assumption that large Early Bronze Age settlements must have required extra staples to sustain themselves (e.g., Stein and Wattenmaker, 2003; Ur, 2010a) may be incorrect. Even in dry years, and under moderate to high population densities, some urban centers could have been sustained by additional food imports from a single satellite settlement (e.g. Tell Beydar and Tell Arbid). Considering the ability of large urban centers to exercise power over their hinterlands, as well as the historically documented practice of food importation to these cities, it appears unlikely that large settlements in the area would have faced a significant food crisis. Even under the years of low agricultural production, model data suggests that neither these central settlements nor the settlement system as a whole would have suffered calorific crisis resulting from low barley yields, as it has been widely argued before (Weiss et al., 1993). This argument, however, based on the assumption that agricultural product was directly consumed by local populations. Commonly used ancient population densities ranging from 100 to 200 pe/ha do not create a system under considerable stress. However, once consumption patterns are extended to include animals and other potential uses of staples then it can be suggested that climate variation might have indeed had an impact ancient economies. For a given settlement, if a high population density level (200 to 250 pe/ha) is considered as a proxy scenario for non-human consumptions of staple product then such economies would likely to suffer from climate change. In this regard, this dissertation provides empirical support to Wilkinson's perspective of third millennium BCE collapse; "Bronze Age settlement and land-use systems of upper Mesopotamia were brittle systems and were therefore vulnerable to collapse" (1997, 67). Vulnerability of the mid-to-late Early Bronze Age settlement system must have increased when political economy was rearranged to conform to the changes in everyday life due to a unique combination of urbanization, wool based textile production, integration with the pastoral economy and the Akkadian presence towards the end of the third millennium BCE.

CHAPTER 9: Conclusions

This study investigates the relationship between rain-fed agricultural production and stability of settlement systems throughout the Upper Mesopotamia during the Early Bronze Age (Third Millennium BCE). The area during this time period was characterized by rapid urbanization and intensification of agricultural production. Towards the end of the millennium, the urban system dissolved into new conditions —or "collapsed". The reasons behind this transformation are widely discussed (e.g., Weiss et al. 1993; Butzer 1997; Wilkinson 1997; Ur 2010).

Rain-fed agricultural production was the backbone of the Early Bronze Age economy in Upper Mesopotamia. Agricultural production was intensified, most probably due to a set of complex developments in the region, including rapid urbanization and aridification of climate. In this complex socio-environmental setting, variations in agricultural production levels must have —directly or indirectly— affected the components of the brittle Early Bronze Age economy (Wilkinson 1997). Evidence for the presence of the Akkadian Empire as an external political entity in Upper Mesopotamia further complicates the discussion since it is not completely clear that if the Akkadian presence was hegemonic in nature (Ur 2010, 407). Therefore, it cannot be immediately suggested that Akkadian presence exerted pressure on agricultural production for surplus extraction.

A settlement system, as specifically investigated in this study, encompasses a complete set of connections between settlements at local and regional levels forming an inter-connectivity that enables flow of agricultural product on a supply and demand system. The classical understanding in archaeology suggests that larger urban settlements were in states of constant need of food surplus available being produced in rural settlements of the hinterland (e.g., Stein and Wattenmaker 2003; Ur and Wilkinson 2008). The position presented herein, build upon the traditional archaeological perspective of hinterland to urban surplus flow as the crux of settlement system stability. Given a constant flow of the needed goods from surrounding areas Early Bronze Age settlements could maintain their hierarchal structure despite ever-changing socio-political conditions. A disruption in settlement connectivity, (or agricultural surplus flow between them), must have had drastic effects on the stability of settlement systems, to the point of a dissolution in urbanized areas across the region —as suggested by Weiss et al. (1993).

Modelling the potential flow, effects of flow disruption and influences that could cause fluctuations in surplus connectivity between settlements require an innovative workflow. In order to accomplish such a task a series of methodological steps are given. First, modern-day precipitation is reconstructed in order to establish a quantitative relationship between rainfall amount and agricultural production levels. Second, paleoprecipitation is reconstructed for the Early Bronze Age using proxy paleoclimatic data. Third, extents of agricultural production territories are modeled using off-site archaeological features. that requires demarcating the settlement system in its entirety. Fourth, Early Bronze Age agricultural production at each settlement is estimated using the data constructed from step one above (i.e., modern precipitation production relationships). Fifth, ancient consumption levels are modeled in two distinct scenarios; the first being productivity based and the second being a calorific consumption model. Sixth, food budget is calculated for each settlement that can indicate stability of the urban settlement system under conditions of food surplus and deficit.

This study provides two main contributions to scholarship regarding settlement systems of the Early Bronze Age in Upper Mesopotamia. First, it takes a critical position towards the assumption traditionally held that settlement system were in a state of constant demand for food.

Through this critical lens the proposed production-consumption model reveals a much more complicated picture at both the local and regional scale. By relaxing the assumed fixed-productivity levels for individual settlements and allowing for dynamic variations according to defined parameters of production potential and consumption, it becomes clear that larger settlements were not always under constant demand for surplus elsewhere in the system. As a result of this approach, an Early Bronze Age city could be both a producer and consumer of surplus agricultural goods. Corresponding intensification strategies were widely adopted throughout Upper Mesopotamia that created a unique agricultural production landscape. This was characterized by larger urban areas acting central cities, surrounded by smaller sites along the peripheries of the settlement system. As shown the urban centers within the system can also be primary producers, rather than strict consumers, that are therefore not necessarily dependent on the rural settlements totally. Because of this changing supply-demand relationship for agricultural production between large and settlements it prompts a need to further investigate other commonly held archaeological theories such as the urban-rural dichotomy.

The second outcome of this study is related to the “collapse” of urban settlement system at around 4.2kBP (Weiss et al. 1993). Climatic explanation of collapse has been a subject of critical debate in the archaeological and environmental literature in Upper Mesopotamia and elsewhere (e.g. Weiss et al. 1993; Butzer 1997; Wilkinson 1997; Booth et al. 2005; Ristvet and Weiss 2005; Magny et al. 2009; Huang et al. 2011; Riehl and Deckers 2012). When variations in ancient precipitation levels are translated into the variations in production levels as suggested in this study, it becomes clear that the impact of climate change did not have the intensity to cause a collapse of urban settlement systems. Despite deteriorating environment production, landscapes still had the potential to provide surplus —if and when necessary. Increased aridity might have been a factor in the transformation of urban socio-political systems, but only when it is reevaluated under the light of brittle Early Bronze Age economies (Wilkinson 1997).

9.1. Inferences

State formation and urbanization in Upper Mesopotamia during the mid-to-late Early Bronze Age has been studied with focus primarily given to large central places, but peripheral and smaller settlements around these centers should also be included in archaeological analyses. If included in archaeological analysis, these peripheral sites provided enough agricultural goods to support larger urban centers and sustain overall social complexity (e.g., Appleby 1976; Fall, Lines, and Falconer 1998, 111). This is based on a theoretical framework that urbanization process constantly requires solving the revenue increase problem which requires intensification of production (Blanton 2010, 45). As a result of these processes, the ancient city transforms into an ideal consumer agent in the landscape in frequent need of external sources of food. However, agricultural production during urbanization in Upper Mesopotamia suggests that large urban centers were also food producers and intensified their productions as in other smaller settlements. This immediately brings the question of what other economies had similarities between urban and rural settlements. In support of this question, Stein and Blackman (1993) demonstrate that sila bowls at Tell Leilan were produced by different households, indicating a diverse rather than centralized production. Without centralization, the boundary between urban and rural production economies gets becomes vague, and thus, the settlement size becomes an important of parameter only on terms of magnitude in production; not only for its style or relations.

Another problem in this theoretical framework is that agricultural flow from a secondary rural settlement to a central place is considered as a mere systemic input to the urbanized system. In a satellite settlement, the difference between the amount of foodstuffs produced and consumed is called the surplus. Surplus moves from its production point at the periphery to its final destination at the center. In this idealized system, production relations which generate surplus are disregarded, and thus, surplus becomes a precondition of a complex urban system, but not its producer. Therefore, one of the ways to understand urbanization —as a process— is to make the surplus production central to the discussion, not tangential to it.

There is little doubt that food was constantly flowing to urban from their peripheral settlements, but why this flow exists and how it was secured and sustained still remains as a key question. Surplus, its transformation into other commodities, and its constant (re)distribution has material and social reflections in the agricultural production economy. But, before considering the problematic in the flow of surplus between settlements, prior conditions of material availability should be evaluated. Without estimating the amount of foodstuffs produced by each settlement, discussions on surplus, its movement and redistribution will remain hypothetical.

Urban-rural relations must have always been truly complex. Both textual and archaeological evidence from Mesopotamia suggest some degree of autonomy of the rural from the urban (Stein, 1987). Discussions on the structure of political organizations in Upper Mesopotamia further complicate the problem. Whether it is a centralized state system or an emergent bottom-up society, hypothesized forms of autonomy and elite power drastically changes the ways urban rural relationships are studied. In (dis)solving this dichotomy, studies on intensification of agricultural production during urbanism and state formation in Upper Mesopotamia provide a research arena.

Considering intensification process developed side by side with Early Bronze Age urbanization, it is likely that urbanization process provided incentives of the intensification strategy and vice versa. Cities exist within the network of other cities, and rural hinterlands are culturally constructed landscapes within which cities are located (Emberling 2003, 56). Under this theoretical framework, intensification and urbanization were cultural projects, transforming occupation styles production landscapes.

Urbanization crated nucleated tell-based settlements. The variation in the sizes of settlements resulted in size hierarchies, reflected in settlement patterns. Rank-size analysis of Early Bronze Age settlement pattern reveals similar primo-convex distributions for different parts of Upper Mesopotamia. Processes which persistently generated this specific distribution must be truly complex in nature. But due to this recurrence, it may be suggested that at the regional level urbanization process appears as a spatially homogenous process. This is not to say urbanization is external to socio-political conditions that generated such phenomenon. On the contrary, urbanization must have been actively created; but not only under the guidance of central sites —as they appear to the researcher as large sites on maps— but also through the active role of settlements at lower orders. Unless surplus was obtained through force, flow of agricultural product from rural to urban settlements during Early Bronze Age indicates this active role, peripheral settlements played. Urbanized central settlements in the landscape attain large sizes, albeit with a 100-120ha limit (Wilkinson 1994). Primo-convex curves from different parts of Upper Mesopotamia may be interpreted as lower order settlements, though smaller in size were also players of the emerging urban landscape. Due to their localized, but dense networks, lower order settlements must have also determined the growth of an urban center at the regional scale. If the size is an indication of the centrality of a settlement, then discussions on centrality should also include conflict, compromise, and cooperation relationships between centers and smaller settlements located around them.

Increased social complexity comes with a cost, and this cost includes expenditures in energy, labor and time (Tainter 2000, 7). Cost also comes from the increasing amount of transactions between and within the components of a complex system. In Upper Mesopotamian urbanism, the cost must have been satisfied via intensification of agricultural production. Variations in climatic conditions, especially variations in the rainfall, would amplify or reduce the level of production intensification to gain intended returns. Intentions for higher return include keeping a stable political economy. In this respect, climate is not a causal agent, but another variable in the system related to politico-economic.

One of these agricultural variables of production is the availability of land. The amount of production can be increased by exploiting more land. In the case of a land constraint, the production strategy may favor intensification in order to cope with the increasing demand. Boundary modeling for production areas around Early Bronze Age settlements suggests small land was available for expanding the production. This is especially pronounced at the core of Khabur Plains where Early Bronze Age settlement pattern is denser. Overlapping production territories, as they are modeled in Chapter 7, might be an indication of the land shortage problem.

Stein (2004, 68) compares Upper Mesopotamian agricultural production levels with Southern Mesopotamia and suggests Upper Mesopotamia had more opportunities for expanding production territories. Model results from this dissertation show that Upper Mesopotamian landscapes were also constricted in expanding production areas, but as in Southern Mesopotamia, this pressure on land might have acted as one of the driving forces of intensification. A second problem arises when pastoral economies are also considered in the overall picture. If flock sizes were in considerable numbers (Porter 2012; Casana 2012) they must have also required extensive areas for grazing. Considering dense settlement patterning in the Khabur Plain and sizes of their production zones, land must have been a source of socio-economic issues between pastoral and sedentary communities. Therefore, the relationship between pastoral and sedentary communities —with integral (Khazanov 1984; Porter 2012) or contradictory characters (Lyonnet 2009, 179) —must have created a social dynamic, requiring close attention and active management. Tainter (2006b) observes social complexity in the number of problems, solved by an ancient society. An effort in the solution of a problem increases social complexity, and in return, "both enhances and undermines sustainability, depending on a number of factors" (*ibid.* 92). In Upper Mesopotamia during the mid-to-late Early Bronze Age, the integration (or active exclusion) of a pastoral economy with (or from) a sedentary economy might have eventually lead into intensification of agricultural production.

As highest return strategies are exhausted, resulting in only the less efficient and costly strategies of production, a complex system transforms from being adaptive to brittle. As an example, it has been widely accepted that Third Dynasty of Ur collapsed while aiming for high revenues through intensification of production that resulted in extreme soil salinization and eventual loss of production capacity. Before the advent of this dynasty in the third millennium BCE, soil was generating crops as high as 2030 liters per hectare. The number was reduced to 1134 liters per hectare at the end of the same millennium (Tainter, 2000: 12). To compensate for this reduction as well as to support bureaucratic apparatus of the state, production was intensified significantly until the ultimate collapse of an ability to produce any sufficient levels from the desolate land. When the bureaucratic apparatus indeed collapsed, production potential was reduced to 718 liters per hectare. The means of production, which enabled a large bureaucratic system constantly, undermined the system.

A similar solution (i.e. intensification of production) in Upper Mesopotamian mid-to-late Early Bronze Age might have also increased input, but in the expense of making the structure of dry-farming more fragile (Wilkinson 1994). In states of fragility, any factor, aridity being one of them (Weiss et al. 1993), may appear as a causal factor regardless of its intensity.

The area surrounded by Tell Beydar, Tell Mozan and Tell Leilan is marked by low yields throughout the millennium. Notably, Tell Brak is located at the core of this low productivity zone. As one of the largest urbanite settlements of Upper Mesopotamia, the location of the site suggests more satellite settlements must have mobilized for their surplus production than other central places in the study area. Finally, Archi (1998: 7-8) proposes that 17 settlements documented in Ebla archives were all integrated into the Nagar Kingdom. According to the results of food balance calculations, Tell Brak must have required surplus production from (a range of) 7 (100 pe/ha), 16 (150 pe/ha), or 27 (200 pe/ha) peripheral settlements when the precipitation levels were at the lowest. This range is well around the number reported by Archi (1998, 7–8).

And finally, regardless of the structure of the social system (emergent or centralized) urbanism works in consolidating new forms of relations revolving around an urban ethos. As Early Bronze Age urbanization prevailed:

> “[b]asic activities related to the production of food, its distribution, and consumption become increasingly separated from household units and transformed into distinct set of activities conducted by segregated groups of specialist, provisioning a network of people engaged in the production of goods and provision of services totally unrelated to subsistence”(Zeder, 2003: 157).

As such, urbanization process created the conditions of yet another unique socio-political generation of human kind. Newly emerging, but possibly overlapping sectors must have contributed to the structuration of the Early Bronze Age society during the third millennium

BCE. Specifically, inhabitants of this new urban place (*burgeis*) must have contributed to the further separation of sectors in some respects (e.g., labor time), but not in others (e.g., family time). In and of itself, the emerging *burgeis* might have laid social, political, and economic foundations of class formation.

9.2. Reevaluation of Assumptions and Methods

While the results outlined above offer valuable insights into the probable relationships among climate variability, agricultural production, and settlement sustainability in northern Mesopotamia, the model is far from perfect. Assumptions and tools used in building production and consumption levels have inherent flaws and considerable margins of estimation errors. Environmental and archaeological information is patchy for a completely accurate representation of ancient agricultural production in the area.

The first problem is related to the determination of settlement sizes on satellite imagery. Even though boundaries of cultural material are relatively easy to recognize on CORONA imagery, and measurements made by this method correspond well to the metrics reported in survey results, pre- or post-EBA occupation of some sites or post-occupational erosion could exaggerate site size in some cases. Settlement extent, as visible on CORONA imagery is used as a variable in the model of potential flow rates between settlements so that these statistics are influential on defining the settlement systems boundary as discussed in Chapter 7. Settlement extents are also used to calculate Early Bronze Age population levels, and thus, determine the level of consumption. Thus, modeled results are assumed to represent the maximum extent of Early Bronze Age habitation at the peak of urbanism. Smaller site sizes, and therefore population levels, would only reduce the overall food stress on the system and thereby reinforce key findings of the model.

It is not for certain if settlements were inhabited in their entirety during the mid-to-late Early Bronze Age. Settlement extents mapped on CORONA imagery are the remnants of millennia length occupation so that the separation between different phases of occupation is blurred. Some sections of settlements might have in fact remained unoccupied so that size of a settlement may not be necessarily an accurate representation of Early Bronze Age habitation. However, urbanization process clearly left a significant mark on these settlements. There is no period other than mid-to-late Early Bronze Age in Upper Mesopotamia caused a drastic growth in the sizes of nucleated tell-based settlements. Thus, it should be safe to assume that the largest extent of a tell settlement —as it appears on CORONA imagery— represent the time when urbanization was at the peak so that settlement size remains useful as a proxy variable. Later urbanization periods in the area created other distinct morphological characters. In many cases, later settlements dwarf Early Bronze Age occupation in size, but they are separable from Early Bronze Age sites.

Modeling the extents of agricultural intensification during the urbanization period heavily relies on mapping the hollow ways, and this is another source of potential error in the model. Wilkinson (1994) persuasively argues that hollow way terminal points represent the boundaries of intensive agricultural production. If these hollow ways are in fact related to another past phenomenon, then the gross agricultural production estimations based on hollow ways will be invalid. On the other hand, regardless of what process formed hollow way, the model-based remote sensing data and paleoprecipitation reconstructions remain valid as they are independent of boundary conditions of production. The remote sensing model can be modified accordingly for other boundary conditions.

One further problem in considering settlements in a consumption-production setting is that other possible types of settlement functionalities are disregarded. For instance, Hazna, a small settlement in the Khabur Basin was a ritual site with a temple complex (Ristvet, 2011: 15). Most probably, this settlement had a distinct agricultural economy, if it even had permanent residents. Detection of such settlement functionalities through remote sensing is an impossible task. Nevertheless, the number of non-food producing settlements within the Early Bronze Age settlement system must have been significantly low, and their impact on the analysis is disregarded.

Overlapping production zones are also enigmatic, and there is no archaeological evidence to assign these overlapping zones to particular settlements. In cases where a daughter settlement’s production zone is surrounded by the parent settlement it seems logical to suggest that the overlapping area belonged to the daughter settlement. On the other hand, when two neighboring settlements share some portions of a production zone there is no clear means to assign overlapping areas to one settlement or another. To be consistent throughout the study, overlaps are assigned to the smaller settlement of the pair, sharing the same production zone with another large settlement. But this remains an arbitrary selection.

Because the Early Bronze Age production model in Upper Mesopotamia is based on modern environmental variables for the years between 1981 and 2010, there may be some differences between ancient and modern agricultural practices that it does not reflect. Large scale dam projects, irrigation systems, chemical fertilizers and many other scientific and technological components create new forms of agricultural production that might significantly change both measured NDVI data. Agricultural production in the Early Bronze Age was rain-fed, and thus, the comparison between modern and ancient practices requires further evaluation. This evaluation is provided by the examination of agricultural output statistics, which suggest that even though irrigation agriculture is employed in the region, its contribution to total output is minimal, except in the areas where dry-farming is climatically not possible (e.g., Der-Zor). Therefore, the assumption which dictates precipitation is one of the main determinants of production remains valid. Yet another assumption in the Early Bronze Age-modern day production association is harder to verify. In order to set precipitation as the prime variable of production other variables are fixed in space and time. For instance, differential access to chemical manure by modern agriculturalists is shaped by modern social and economic conditions of the region. This variation likely to create differences in production levels, but they are ignored in this study. Also, governmental policies which include subsidies, direct intervention or regulation affect what to produce and how much to produce. It is highly possible that the results of these policies are reflected in the production statistics. However, in this study, a homogenous land use practice with a single agricultural decision making agency is assumed for the sake of simplicity.

The strength of the relation between Soreq Cave and Upper Mesopotamia precipitation reconstructions also affect the accuracy of the production model. Located closer to the Mediterranean Sea, Soreq Cave gets more rain throughout the year and north-south running mountains act like a barrier when weather system moves inland. Other climate systems affect Upper Mesopotamia more than the largely Mediterranean system of the Levantine coast. Despite this complexity, there is some correlation between the amount of rain in Soreq Cave area and Upper Mesopotamia, and this relation is used to reconstruct Early Bronze Age precipitation levels. Error analysis of the proposed modern day reconstruction suggests a discrepancy around 70mm per annum for the core of the study area. This error is large enough to shift the limits of dry farming limits to the south of the study area. However, the spatial manifestation of this 70mm discrepancy is not large. In fact, for the Khabur Basin and its eastern portions the impact of model error is even less which also indicates small spatial shift in the location of dry-farming belt.

Another important factor to take into account for paleoprecipitation reconstruction is the relationship between oxygen isotope accumulation in speleothems and the amount of precipitation. A cave environment is a complex micro-system with a large number of variables. The regression model used to investigate the association between isotope measurements and precipitation levels assumes that other environmental variables in the cave were fixed since the Early Bronze Age and up until recent times so that the rate of oxygen isotope formation truly reflects the changes in past precipitation variations. Checking the accuracy of this assumption is beyond the scope of this study, but there is reasonable doubt that some of untestable error in the production model originates from this uncertainty.

Speleothem data from Soreq Cave has an average of 20 years temporal resolution during the Early Bronze Age. Even after disregarding possible errors stemming from dating the samples, this temporal resolution is not tight enough to detect annual, let alone seasonal, precipitation changes in the region, but it does provides information on trend at a medium-scale. Linear interpolation which is used to create a complete paleoprecipitation dataset doesn’t take into account the complex nature of the climate, and thus, although the model provides statistical information for annual gross agricultural production during the Early Bronze Age it is inherently deterministic. Also, when there is data, it represents annual rather than seasonal measurements. As a result, agricultural production estimations which are based on growing season statistics suffer from the coarseness of palaeoclimate data. On the other hand, investigations into the relation between annual and growing season precipitation values suggest a relationship, and this relationship is used to estimate ancient production.

Another problem in the proposed model is the way consumption levels are calculated. This stems from two basic problems. First, there is no well defined statistic for population densities during Early Bronze Age in Upper Mesopotamia, and when provided, these are estimations based on recent historical studies in the area. Also, it is very likely that urban centers and their satellite settlements had different occupational densities. If this was indeed the case then the proposed model is an optimistic model where food deficit is underestimated. To ease the problems in demographic assumptions, food balance is calculated at a range rather than solely relying on fixed values. In this range, the extreme population pressure case (250pe/ha) sets an unrealistic ceiling, but also encompasses the errors and flaws in the overall model. A second problem is related to consumption, because even if one assumes that population densities used in this study are accurate, the ways in which these populations consumed agricultural staples must have varied greatly. Neither productivity nor calorific based scenarios can therefore be relied upon as a complete consumption model. The productivity-based scenario assumes a static political economy throughout the region, while the calorific-based scenario assumes a strict one-to-one relationship between the biological consumer agent and the amount of foodstuffs used at a given time and space.

Another problem in the proposed model is the way consumption levels are calculated. This stems from two basic problems. First, there is no exact statistic for population densities during Early Bronze Age, and when provided, these are estimations based on recent historical studies in the area. Also, it is very likely that urban centers and their satellite settlements had different occupation densities. If this variation in occupation was indeed the case then the proposed model is an optimistic one and food deficit may be underestimated. To alleviate these problems in demographic assumptions, food balance is calculated at a range.

Second problem is related to the complexity in consumption forms. Even if population densities are accurate, the ways in which populations consumed agricultural staples must have varied greatly. Neither productivity nor calorific based scenarios can fully embrace a complete consumption model where agricultural product becomes a commodity in other sectors of political economy. Productivity based scenario is based on a very static production economy throughout the region and calorific based scenario assumes a strict one-to-one relationship between the biological consumer agent and the amount of available foodstuffs.

There must be ways to reduce the effect of these problems in the production-consumption balance. For instance, the population pressure case (250pe/ha) sets an unrealistic human consumption ceiling, but in doing so, it may also encompass other errors and flaws in the overall production model. High calorific consumption might be replaced by another category, encompassing human (food) and non-human consumption patterns (fodder, linen material) at the same time. Using human and non-human consumption pattern in the same scale is possible only when there is a common unit of measurement. In this respect, unit amount of energy (kcal) which a unit amount of barley (grams) may provide insights for this common unit.

Even though the number and intensity of issues in this dissertation clearly decreases the power of proposed food balance model, these problems also show that the model is open to improvements. Even in its current form this study provides insights regarding the urbanization process, the stability of agricultural production systems as well as the “collapse” of urbanized systems under detrimental environmental conditions. A better model will only refine these speculations.

9.3. Future Prospects

Based on the discussion above, the proposed production-consumption model in this study is open to improvements. These improvements include a refinement of paleoprecipitation reconstruction by integrating other available proxy paleoclimatic data in the area. Furthermore, a better prediction of production values may be possible by using dynamic global vegetation models, such as Lund-Potsdam-Jena Dynamic Global Model (LPJ) and MC1 Dynamic Vegetation Model. These models require a wide range of environmental, geographical, and geological input, including rainfall, temperature, wind speed, and solar radiation, soil texture, rock fraction and depth to bedrock. Compilation and simulation of these variables is a challenging task, but not impossible.

Having produced an estimate for how much excess production was available at each settlement in Upper Mesopotamia during the Early Bronze Age, the next question is why this excess production was made available to large urban centers by their peripheral settlements. A complete investigation of the stability of the Early Bronze Age settlement system not only requires knowledge on production potential of agricultural landscapes, but also calls for an understanding on conflict, compromise, and cooperative relationships between settlements.

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