An exploration of irrigated land use in Egypt and Turkey during the Holocene

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Summary

Irrigation stands at the start of civilization, but further than that not much is known about historical irrigation. The aim of this research was to explore the irrigated land use in Egypt in Turkey. Through literature research and modeling a comprehensive overview was made. Starting points of irrigation for Egypt and Turkey were determined at 6000 BC and 3000 BC. Modeling was used to project historical irrigated land use based on the relationship between irrigated land and population growth. This was easier to do for Egypt than for Turkey. Different irrigation types in Egypt and Turkey were explored. All historic irrigation is a form of surface irrigation. In Egypt most prevalent was basin irrigation by flooding strengthened with both dams and lift irrigation. In Turkey it was a combination of basin and furrow irrigation through artificial dams and channels. Egypt's and Turkey's historical irrigation is comparable but to different to use the exact same methods of analyzing the actual land use.

Introduction

At the basis of life, water is found. It is one of the core requirements for life. Humanity depends on water in multiple ways. A primary way is food. In order to hold livestock or to grow crops water is a necessity. At the start of development of civilization irrigation is an instant occurrence. According to Klein Goldewijk et al. (2017) irrigation can be defined as adding water that is not rainfed to cropland in order to improve its yields. This can be done by either diverting natural water flow or by pumping water towards croplands. Without irrigation there is a limit to the amount of population an area is able to support.

Over our history civilizations have blossomed through irrigation, but this has also been their demise when their methods were not sustainable (Sojka et al., 2002). It is important to learn about historical irrigation to prevent making the same mistakes as those failing civilizations. Water management strategies have to take into account how much pressure is put onto the water systems, and how sustainable they are. If the water sources are exhausted this can lead to irreparable damage and unliveable circumstances. Learning about historical water systems and how they developed can guide methods and policies in current water management. This is key in working towards multiple of the Sustainability Development Goals (SDGs) (*figure* 1). The most relevant of these goals regarding irrigation are SDG 2: No hunger, SDG 6: Clean water and Sanitation, SDG 13: Climate action, and SDG 15: Life on land.

Figure 1: The SDG's. Source: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Space_for_Earth/ESA_and_the_Sustainable_Development_Goals

There is a lot of knowledge on the current land area equipped for irrigation on earth. However, it can be hard to predict the full impact of current water management strategies. In addition, not much is known about the early development of the land use type irrigation or how much land area was used for it. Some of the literature that is available is even in contradiction. Historians believe the birth of both agriculture and irrigation took place some 10,000 years ago in Mesopotamia, where current day Iraq and Iran are situated (Angelakıs et al., 2020) (*figure* 2).

Figure 2: Map showing the location of Mesopotamia, lain between and including the rivers Tigris and Euphrates . Source: http://mrscelis6.weebly.com/mesopotamia.html

One of the earliest civilizations irrigation moved to were the Egyptians, who lived west of Mesopotamia. With the manipulation of the river Nile they were able to sustain their society for millennia and achieve their many famous riches and accomplishments. Not far from Egypt in Turkey there is also a long history of irrigation. According to Özis (2015) Turkey has some of the oldest still used water works. Some proof of the start of irrigation in Turkey is almost 4 millennia old. While Egypt's irrigation systems were continuously relatively successful, Turkey's system was less consistent. This difference between two countries, separated mostly by one sea, and with irrigation systems close in age is interesting when learning about forming successful irrigation systems.

This study aims to learn more about the early development of irrigation in Egypt and Turkey and to investigate possibilities to expand and improve current databases of historical irrigation. To do this the following research questions have been assembled:

- What are the estimates in the existing literature of the start of irrigation in Egypt and Turkey?
- How did demand for irrigation develop (population density)?
- The types of irrigation have been used in Egypt and Turkey throughout history?
- What are the differences and similarities between the countries?

The answers to these research questions will be found through literature studies and modelling.

Egypt

Egypt is a transcontinental country lying on the north eastern point of the African continent and a southwest corner of Asia spreading out over 100.145 million ha (FAOSTAT, 2021). 0.6 million ha of this are inland waters. Egypt shares its boarders with the Gaza strip (Palestine), Israel, Sudan, and Libya. Its coasts lie towards the Mediterranean Sea, the Gulf of Suez, and the Red Sea. Egypt's current capital is Cairo.
According to Ayyad et al. (1986) the two main climates in Egypt are hyper arid and arid. In hyper arid areas winters are mild, the mean temperatures staying between 10 and 20 °C, and the summers are either very hot, with the mean temperature of the hottest month

exceeding 30 °C, or hot, with the mean temperature of the hottest month staying between 20 and 30 °C. The arid areas lie on the coast and have an annual rainfall of 20-100mm with mild winters and hot summers. The Mediterranean coastal land, lying in the north, receives the highest amounts of precipitation.

Egypt as a whole has an average precipitation of only 10mm (Zahran and Willis, 2008). The largest part of the country consists solely of deserts, with the exception of the area surrounding the river Nile. The river Nile is an accumulation from the White Nile, which is considered to be the headwaters stream, and the Blue Nile, which provides the largest body of water to the Nile. The White Nile originates in Lake Victoria in Uganda, Kenya, and Tanzania. The Blue Nile originates in Lake Tana in Ethiopia. These Rivers meet in Sudan and then run as the river Nile for 6650 km towards the Mediterranean Sea, 1530 km of this is within Egypt's boarders. The Western Desert covers over two thirds of the total land area, while the Eastern Desert almost a quarter of the total land area. As the Country is this dry (*figure* 3) and filled with desert, it is clear it is a challenge to grow crops without any means of artificial irrigation.

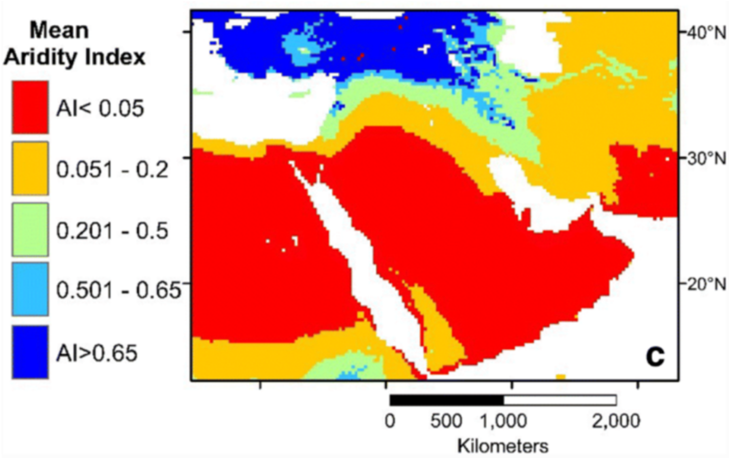


Figure 1: Map of Egypt and the Middle East showing the mean aridity index (AI). The AI has a scale of 0 to 1. 1 being hyper humid, 0 being hyper arid. Source: Sahour, H., Vazifedan, M., & Alshehri, F. (2020). Aridity trends in the Middle East and adjacent areas. Theoretical and Applied Climatiology, 142(3), 1039-1054.

When discussing different areas relative to the Nile this report will mention the Nile Delta, the Faiyum, the Nile valley and the Desert, which is a combination of the Western and the Eastern Desert as is shown in *figure* 4. The Nile valley encompasses the green areas surrounding the river with exception of the Nile Delta and the Faiyum (Butzer, 1980).

Figure 2: Map of Northern and Middle Egypt where green represents soil with water availability and light yellow represents sandy deserts. Source: https://www.studentsofhistory.com/ancient-egypt-s-geography

Turkey

Turkey is a transcontinental country lying on the peninsula of Anatolia in western Asia and east Thrace in southeast Europe with an area of 78.535 million ha according to FAOSTAT (2021). 1.572 million ha of this are inland waters. It shares its boarders with Greece, Bulgaria, Syria, Iraq, Iran, Azerbaijan, Armenia, and Georgia. Its coasts lie towards the Mediterranean Sea, the Aegean Sea, the Black Sea, and the Sea of Marmara. Turkey's current capital is Ankara.

According to Sensoy et al. (2008) Turkey's climate is quite diverse. The coastal areas enjoy a more mild climate, while the inland of the peninsula experiences more extreme climates. In the winter the mean temperature is usually below 5 °C. This is also the season which enjoys the most rainfall, especially the black sea coast, which receives 2,200 mm of rain annually. The summers are moderately arid and warm.

One of the diversifying elements of Turkey's climate is the varying topography. The mountains hold the rain clouds and the elevation causes freezing temperatures with minimum temperatures of -30 to -38 °C with heavy snowfall in the eastern mountains. The western coasts in comparison has winter temperatures of 4 °C and summer temperatures surrounding the 27 °C. The south coast has the highest average temperatures. There are several drier areas. Especially in the arid and semi-arid areas in the centre of Turkey (*figure* 5) it would be a challenge to grow crops without any form of artificial irrigation.

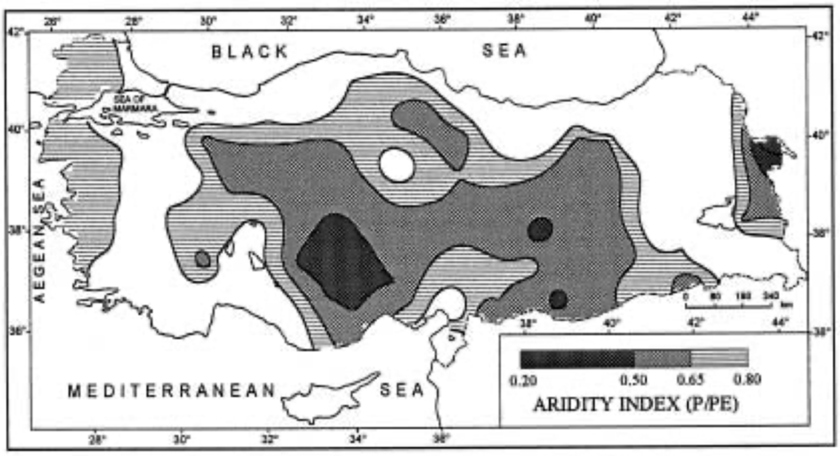


Figure 3: Map of Turkey showing the mean aridity index. Source: Türkeş, M. (1999). Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. Turkish Journal of Engineering and Environmental Sciences, 23(5), 363-380.

When discussing the different areas of Turkey in this report the following seven geographical regions as shown in *figure* 6 as determined by the First Geographical Conference in Ankara in 1941 will be used. These regions do not represent any administrative division and are used for geographical, demographical, and economical purposes.

Figure 4: Map showing the seven geographical regions of Turkey. Source: https://istanbulclues.com/anatolia-map-history-facts-asia-minor/

The land area and climates per region of Turkey are described in table 1.

Table 1: The land areas and diversity in climates of the different regions in Turkey. Source on land area is Sansal (n.d.) and the source on the climates is Kanber et al.(2015)

Regions	Land area (ha)	Climate
Marmara	6,730,000	Sub-tropical*/ Oceanic/Continental
Aegean	8,500,000	Sub-tropical/ Semi-arid continental
Mediterranean	12,210,000	Sub-tropical/ Semi-arid continental
Southeastern Anatolia	6,100,000	Semi-arid continental
East Anatolia	171,000	Continental
Black Sea	146,178	Oceanic
Middle Anatolia	162,000	Semi-arid continental

*Sub-tropical is here also known as Mediterranean climate.

Theory and concepts

When exploring historical irrigation it soon becomes clear that the History Database of the Global Environment (Hyde), a database on land use and population over the past 12,000 years is one of the main databases (Klein Goldewijk, 2017). In Hyde's estimations irrigated land appeared in Egypt between 7000 and 6000 BC surrounding the Nile and its delta. Irrigation focussed on rice in particular only appeared after 3000 BC and is concentrated near only the Nile's delta, not along the whole river. In Turkey irrigation appeared even earlier; between 8000 and 7000 BC. It appeared in two specific spots and then later expanded. This was in Nesa and south of Tuwanuwa (*figure* 7). Irrigation for rice specifically appeared only in the last hundred years in Turkey.

Figure 5: Map showing the locations of ancient areas and cities in modern Turkey. Source: https://istanbulclues.com/anatolia-map-history-facts-asia-minor/

However the Hyde estimations do not agree with all other literature. For example, Koç (2018) states that the Egyptians started diverting the Nile for agriculture around 5000 BC. First habitation in Turkey is estimated around 6000 BC, but the first more permanent, functioning settlements would not appear until 3000 BC in the bronze age (i.e. Troy on the west coast). The first proof of water management in Turkey stems from the rule of the Hittites, 1650 – 1178 BC, who had their own water administration. Their rule was in Central Anatolia. In addition the Urarta kingdom, which lies in the Eastern Anatolia, built irrigation facilities such as dams, ponds, and canals around 1000 BC (ibed.)

According to Mays (2010) the shift from natural to artificial flood irrigation in Egypt was accomplished by the late Predynastic times, being 5000-4000 BC. Before this time the population density was not high enough to require artificial irrigation to meet crop demands. The earliest and most famous reference to irrigation in Egyptian archaeology has been found on the mace head of the Scorpion King, which has been roughly dated to about 3100 BC.

In i.e. the Mesopotamian valley the lack of understanding of hydrology and siltation lead to mismanagement, causing permanent impairment of the land, including reducing the productivity of the land and the capacity of the reservoirs to provide an adequate water supply (Sojka et al., 2002). In a large part of these areas, productivity began to fall. Irrigated lands are suffering from the salinization problem as it is in the ancient Mesopotamian societies. The negative effects of using water unconsciously and inefficiently are increasing in the world. These developments require more efficient use of water when considering that approximately 70% of water is used in agricultural irrigation (Koç, 2018).

To learn about different levels of effectiveness for irrigation methods they need to be explored. There are two basic ideas in irrigation (Klein Goldewijk et al., 2017). Diverting natural streams or bodies of water in order to irrigate crops, and to pump groundwater towards crop fields. However there are many different ways to actually apply the water to the crops. Some examples are basin or flood irrigation, sprinkler irrigation, subirrigation and more.

When retracing how high the demand for irrigation was in periods there is no exact data on there are many things to consider. Different sources try different calculations to estimate the area used for irrigation, but a starting point is often the population and the population density (Mays, 2010) (Klein Goldewijk et al., 2017). Other parameters to take into consideration are the closeness to natural fresh water bodies, the level of development of the civilization, and the climate, especially the aridity index (AI). The AI is an indicator to measure the climate's dryness. It is calculated as the ratio of P/PET. P being the average annual precipitation and PET the potential evapotranspiration (UNEP, 1997). This leads to a number between 0 and 1. Closer to zero being more arid, and being closer to one means more humid.

The analytical framework for this research in *figure* 8 shows how the different aspects and sub questions of this research contribute to answering the main research question.

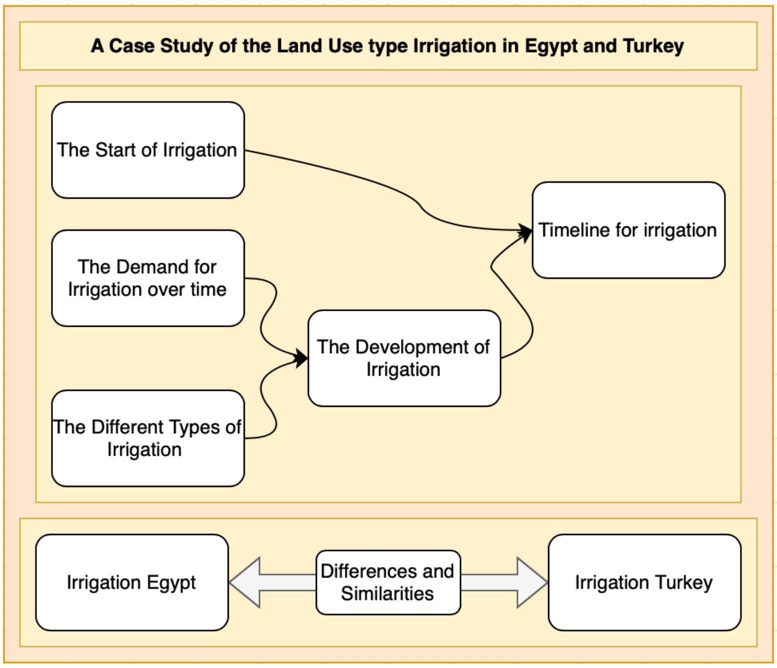


Figure 6: The analytical framework

Methods

Start of irrigation

In order to answer the question "What are the estimates in the existing literature of the start of irrigation in Egypt and Turkey?" literature research was done. In google scholar relevant sources were sought with the search terms "ancient irrigation" and "historical irrigation" in combination with both "Egypt" and "Turkey". In the results will be searched for different estimations for when irrigation was first developed and how these estimations were reached. For this it was often needed to explore deep within sources of sources to discover the how the estimation was established or calculated. Sources were selected having for having original/unique method to come to their conclusions on the start of irrigation. This led to 5 sources for Turkey and 7 sources for Egypt. These are compiled and then consensus between different literature on a starting point for irrigation was sought, or at least a range for it.

Irrigation demand development

Next the sub question on the development of demand for irrigation in Egypt and Turkey was explored. Here the relationship between irrigated land and population growth was determined for Egypt was used to explore the amounts of irrigated lands in Turkey. This was done be determining the trend of population growth from 10,000 BC to the year zero. The population trend was not taken further since population starts growing more rapidly with the increase in development. The data on population was taken from Hyde (Klein Goldewijk., 2017). This led to formula 1 for Egypt and formula 2 for Turkey.

Formula 1:

$$P_E = 4 * 10^6 * e^{0.0006y}$$

Formula 2:

$$P_T = 7 * 10^6 * e^{0.0005y}$$

The relationship between irrigated land and population growth was done by determining the amount of irrigated land per capita for Egypt using the estimated data on irrigated land in Butzer (1980). This led to the following trendline in formula 3.

Formula 3:

$$\frac{I}{C} = 6 * 10^{-6y} + 0.1748$$

Formulas 1 and 3 were then combined to determine the irrigated land in Egypt in formula 4. The same was done with formulas 2 and 3 for Turkey in formula 5.

Formula 4:

$$I_E = 4 * 10^6 * e^{0.0006y} * (6 * 10^{-6y} + 0.1748)$$

Formula 5:

$$I_T = 7 * 10^6 * e^{0.0005y} * (6 * 10^{-6y} + 0.1748)$$

Table 2: the parameters used in the formulas

Parameter	Parameter
P_E	Population Egypt
P_T	Population Turkey
y	Years
I	Irrigated land in ha
I_E	Irrigated land in ha in Egypt
I_T	Irrigated land in ha in Turkey
C	Capita

Irrigation types

In addition the different types of irrigation used in Egypt and Turkey have been explored. It was explored what types of irrigation existed, where they were used, what their positive effects were, and what their downsides were. This was done through literature research. In addition the development towards more modern times was explored.

Comparison between Egypt and Turkey

Finally, the differences and similarities between irrigation in Egypt and Turkey were explored by comparing the earlier results. Here the different parameters are put together so differences in effectiveness could be determined.

Results

Start of irrigation

These tables show the estimates of the start of irrigation in Egypt and Turkey, their sources and how those conclusions were drawn. This gives a clear overview of the ranges within the literature.

Egypt

Table 3: Overview literature Egypt

Source	Estimation	Method
Goldewijk et al. , 2017	7000-6000 BC	Estimation based on literature, Li et al
Mays, 2010	5000-4000 BC	Population density
Angelakis et al., 2020	5000 BC	-
Butzer, 1980	3100 BC	Accepts Mace head as earliest proof of artificial irrigation, using natural irrigation before that time
Zaghloul et al., 2013	6000 BC	Barley grown in areas with insufficient rainfall
Krzyzaniak, 1991	3800 BC	Some of the design motifs on Gerzean pots may be interpreted as canals
Hassan, 1988	1600-1100 BC	When it became a regular in the literature

The sources are mostly proof that irrigation existed in that moment. None of the sources discount the possibility that there was no irrigation before the mentioned moment. Therefore it seems most likely irrigation started appearing circa. 6000 BC in Egypt.

Turkey

Table 4: Overview literature Turkey

Source	Estimation	Method
Goldewijk et al., 2017	8000-7000 BC	Estimation based on literature, Li et al
Koç, 2018	1000 BC	-
Belli, 1999	830-810 BC	Based on kingdom and reign period of building a dam, its reservoir water was used for irrigation
Masi et al., 2014	2900-2800 BC	**Possibility** for irrigation based on isotope records from crops and regional climatic and environmental factors
Wilkinson, 1999	Ca. 2500 BC	Based on relict river channels for the lower Balikh (Syrian side, but next to Turkey

When reading the literature most evidence of irrigation starts appearing from 3000 BC which therefore seems like a likely starting point for irrigation in Turkey. This does not include the estimation from Goldewijk et al., 2017, but this is further elaborated on in the discussion.

Irrigation demand development

The results for irrigation demand development will be shown in graphs where the relation to the population density will be explored. It will be attempted to develop a calculation/model which might be applicable to other arid countries.

According to Butzer (1980) the first irrigation in Egypt took place along the river Nile; there was arable land in along the Nile in the Nile valley, in the plain of the Nile delta and in the Faiyum oasis. The Faiyum had both artificial and natural connections with the Nile to make irrigation possible (Boak, 1926). Butzer's (1980) historical data on cultivable land and population as shown in appendix I is the basis of the calculations used. The data on population is supplemented with the population estimates from Hyde (Klein Goldewijk, 2017). The exponential trendlines of this population growth led to the formulas 1 and 2 (*figure* 9).

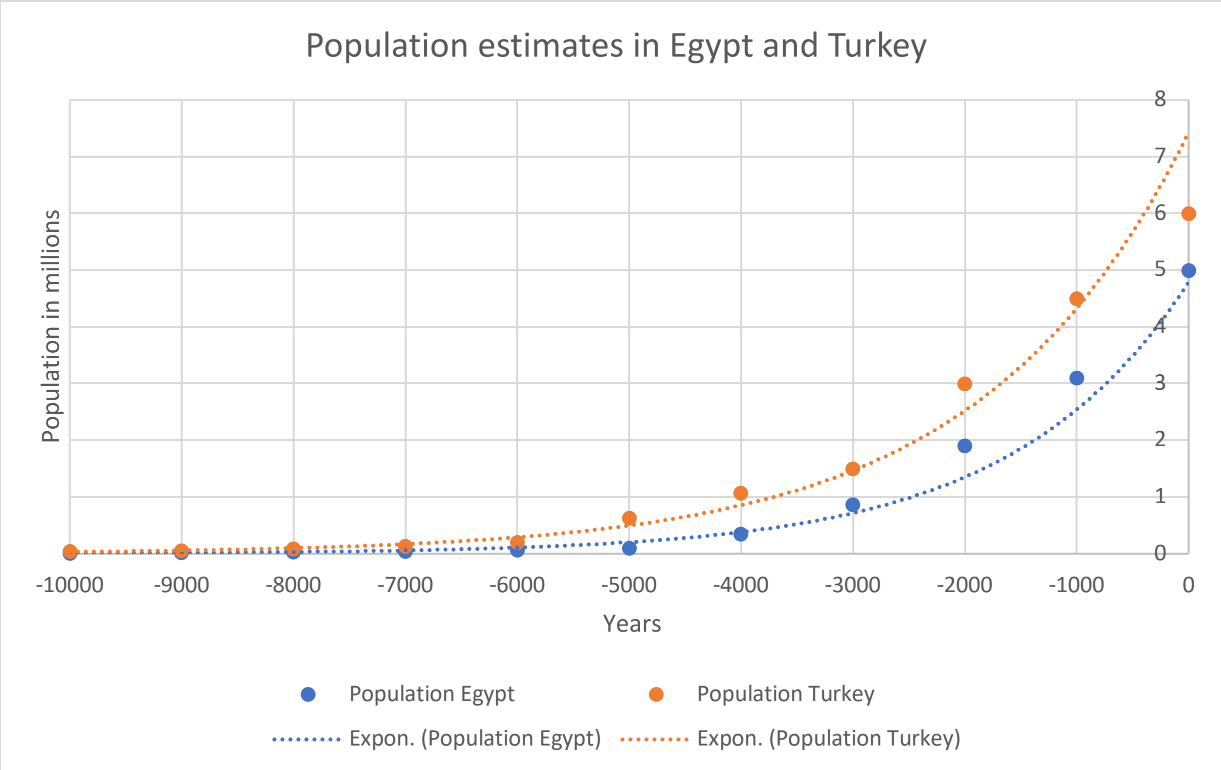


Figure 7: Graph showing population growth from 10,000 BC until the year 0 in both Egypt and Turkey. Source data: Butzer (1980) and Hyde (Klein Goldewijk, 2017)

With the trend in population in Egypt and Butzer's estimations of irrigated land the trend in irrigated land per capita was determined in formula 3 (*figure* 10).

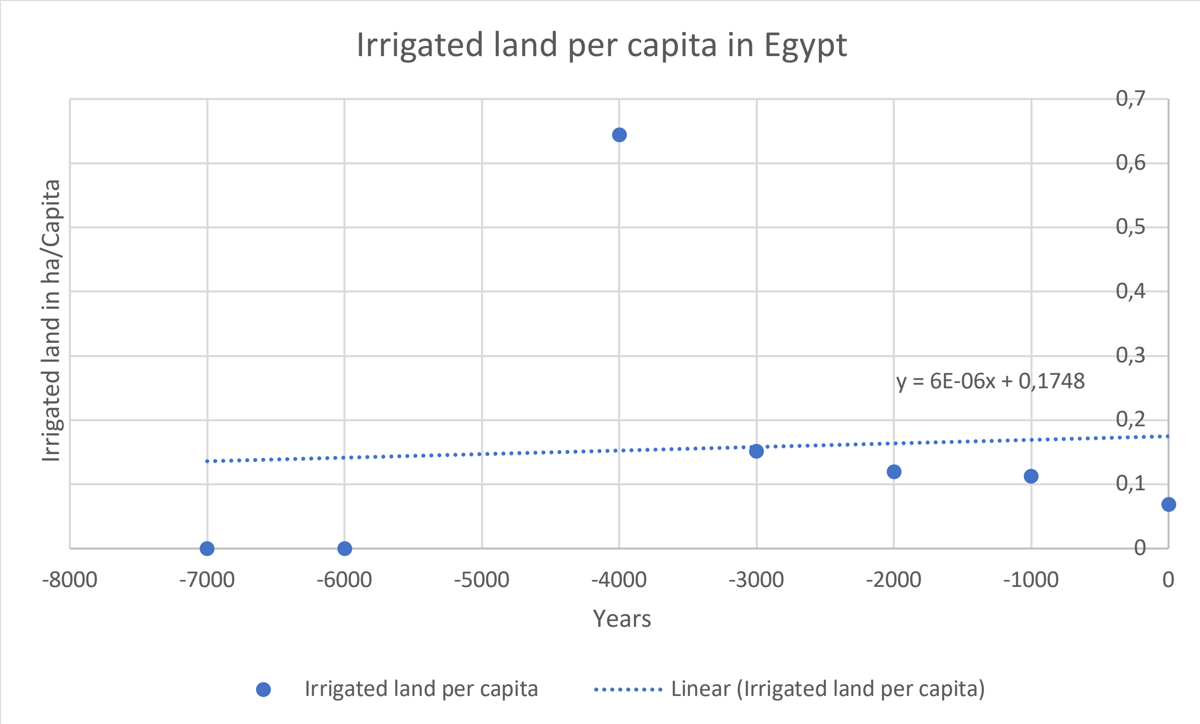
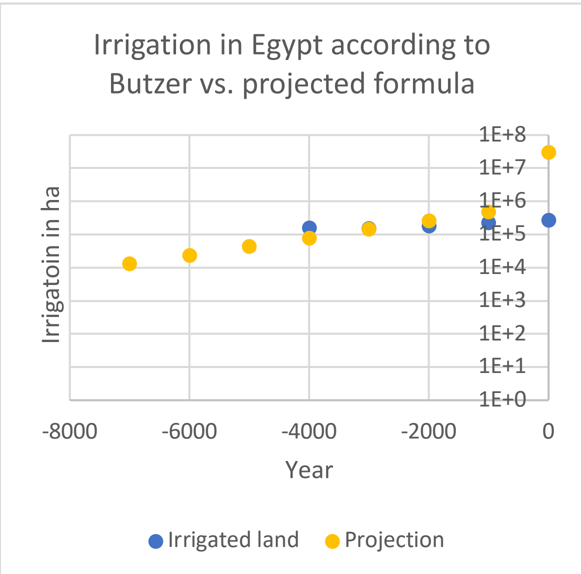
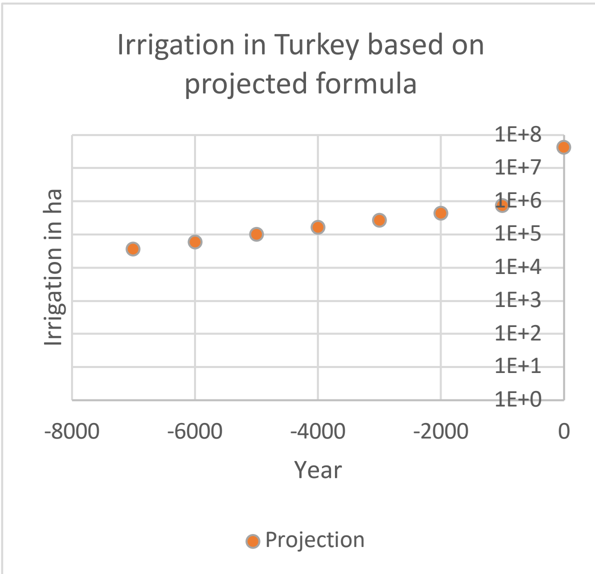


Figure 8: Trendline in irrigated land per capita in Egypt.

These trendlines were combined to form a projection of how irrigated lands could have developed in historical times in both Egypt and Turkey through formulas 4 and 5 (*figures* 11A and B).





Figures 9A and B: A shows the historical irrigation in Egypt with both the data from Butzer (1980) and the projection from formula 4. B shows the historical irrigation in Turkey projected by formula 5.

Irrigation types

The types of irrigation in Egypt and Turkey and their development are explored. First the early irrigation in Egypt and Turkey is explored. Then there are explanations on the most common types of irrigation, their positives and downsides, and their popularity in both Egypt and Turkey and their prospects of the future.

Egypt

Egypt's natural basin irrigation in the Nile's delta.

Under natural conditions the Nile would rise to bankfull stage in southern Egypt by mid-august, and then spread through the overflow channels and breaching the lower levees, to spill over into the successive flood basins. The most northern basins being filled 4 to 6 weeks later, so mid to late September. At the height of a normal flood all but the crests of the levees would be briefly flooded with an average water depth of 1.5 meters. Only about once every ten years the flood would be high enough to submerge even the higher levees. During a poor flood not all basins are flooded at all or flooded completely. After a span of several weeks or months water levels drop below the ground once more through the falling riverhead, evaporation, soil infiltration, and natural drainage back to the channels. This happens mostly between early October and late November. Crops can then be sown between November and January, to then grow on the fertile ground with high water levels during the dry winter months (Butzer, 1980).

Basin irrigation

According to Butzer (1980) artificial irrigation in Egypt started as an expansion of the natural basin irrigation. The natural inundation got expanded by annual deepening or dredging of the overflow channels and breaking through the lower parts of the levees, creating and expanding on the flood basins. In addition, gathering streams were made into artificial drains with help of earthen dams. Lastly, water can be moved manually from residual ponds or natural channels towards adjacent fields. This basin irrigation is a form of surface irrigation.

Lift irrigation

In the course of time irrigation in Egypt got expanded by lift irrigation. This started with the manual transport of buckets of water, carried with the help of shoulder yokes between 2700 and 2215 BC. This was only workable on a very small scale and not very time or energy efficient. Ca. 1340 BC the shaduf, also known as a pole and bucket lever, was developed. This allowed the raising of containers filled with water over a meter in height. Between 323 and 30 BC it became possible to elevate substantial quantities of water with the development of the Saqiya; an animal drawn waterwheel that could move the water over 3,5 meters in height (Butzer, 1980). Lift irrigation further developed into pump irrigation, which keeps expanding its capibilities of both how much and far water can be transported.

Turkey

Development of surface irrigation in Turkey

The oldest proofs of irrigation show signs of adjustment to channels for deliberate water redirection and dams in the third millennium BC in the south east corner of Turkey by the Orentes rivers and in the Balikh valley (Wilkinson, 1999). In the Hittite areas in Central Anatolia in e.g. Çorum larger irrigation dams and channels were built in de second millennium BC. In Eastern Anatolia there many water structures were found, most of which were in the Van province, that were made by the Urartians, who lived from 323 to 30 BC (Kuşlu & Şahin, 2009). These were all forms of surface irrigation, with mostly basin irrigation as basis. More irrigation works were built by the Byzantines, Romans, and Ottomans adding to the dams and other water works in Turkey AD (ibed.).

Modern irrigation

Surface irrigation

Surface irrigation or gravity irrigation is by far the most used form and oldest form of irrigation in the world and also the most simple, often based on natural resources (Kanber et al. 2005). These irrigation systems require a smaller initial investment, but are quite labour intensive and do not spread water very efficiently. In addition, this system is causes soil salinization, especially in arid and semi-arid climates. This is harmful to crop production and causes drainage issues (Kendirli et al., 2005). Surface irrigation requires relatively uniform and flat surfaces and soil types with low to moderate infiltration rates.

Surface irrigation includes different forms like furrow irrigation, basin irrigation and border irrigation, pump irrigation and often makes use of dams. Pump irrigation is usually combined with other irrigation types and can be powered manually, or be diesel or electricity driven. There are even projects to power them via solar power to make them more environmentally friendly (Hossain et al., 2014). Basin irrigation floods entire fields. An extension of this is border irrigation, where the basins are on a slope with a drain exit at the lower end (Abdelhafez, 2020). Furrow irrigation makes use of small parallel channels throughout the fields in order to water the crops through soil infiltration. Both Egypt (Ouda, 2015) and Turkey (Kanber et al. 2005) use surface irrigation for over 80% of their irrigation.

Drip/micro irrigation

Also named trickle systems. This system uses a frequent, slow application of water directly into the root zone of the crop or to the earth surface. Drip irrigation is adaptable to different crops and land surfaces and very efficient. However, the system is also difficult to maintain since it needs very clean water in order not to become clogged (Burt, 1998) and economically costly. It is used very sparingly in Turkey (Kanber et al. 2005), but already seen as a great improvement in water efficiency in Egypt (Ali et al., 2020)

Sprinkler irrigation

Sprinkler irrigation uses sprinklers to spread rain like water droplets over the land surface with crops. Can be done with permanent of movable installations. An efficient, adaptable way of water distribution, needing relatively low labour, but high energy and economic cost. In Egypt it sprinkler irrigation is being researched extensively in order to improve water efficiency in irrigation (Badr et al., 2006) and in Turkey it already is slightly more popular than drip/micro irrigation in Turkey (Kanber et al., 2005).

Subirrigation

Subirrigation is a relatively new form of irrigation often used in greenhouses where water is administered to plants from below their containers (Ferrarezi et al., 2015). It can be useful in semi-arid areas since it can mitigate some of the issues that tend to come with using saline waters to irrigate crops. In addition, it is not labour intensive and water efficient. The investment in both the greenhouses and the subirrigation systems can be quite expensive. When used in the field it does require more intensive management, but can be beneficial. For now this type of irrigation is mostly practiced in the US, however application in both Egypt (Ghaffer & Wahba, 2006) and Turkey (Koc & Kadioglu, 2013) is being researched and could be a valuable option for the future.

Comparison between Egypt and Turkey

Finally a comparison of the countries is explored in table 5 to visualize the differences and similarities between irrigation in Egypt and Turkey and their development.

Table 5: Table comparing the main aspects of irrigation in Egypt and Turkey.

Factor	**Egypt**	**Turkey**
Start of irrigation	6000 BC	3000 BC
Size	100.145 million ha	78.535 million ha
Climate	Arid, semi-arid	Semi-arid, oceanic, Mediterranean, continental
Location	Surrounding the Nile	
Population growth	$P_E = 4 * 10^6 * e^{0.0006y}$	$P_T = 7 * 10^6 * e^{0.0005y}$
Irrigation development	$I_E = 4 * 10^6 * e^{0.0006y} * (6 * 10^{-6y} + 0.1748)$	$I_T = 7 * 10^6 * e^{0.0005y} * (6 * 10^{-6y} + 0.1748)$
Main forms of irrigation	Surface: Basin through flood and dams, Lift	Surface: Basin through dams
Extend of knowledge	Very extensive, also sources from historical times	Little true knowledge about historical times, most knowledge based on archaeological finds.

Though Egypt and Turkey were both really early in the use of the development of irrigation Egypt was considerably earlier. Both have large areas with arid to semi-arid climate forcing to use irrigation in order to be able to grow their populations, but this arid climates are smaller in Turkey, while the arid areas in Egypt where water cannot even reach are abundant in the Western and Eastern Deserts. The irrigated lands of Egypt are mostly concentrated around the Nile and in Turkey the irrigation is spread out over the country and uses multiple sources of water. Even though Turkey has a stronger population growth to support, Egypt does have more irrigated lands. Here it can be taken into account that Egypt has had longer to start increasing their irrigated lands. Both countries main form of irrigation is surface irrigation where flood irrigation managed with dams are prevalent. However Turkey lacks the extensive flooding Egypt enjoyed from the Nile.

Discussion

The first clear difference between the results and the existing literature is the starting point of irrigation in Turkey determined in this research, being 3000 BC, and by the database Hyde (Klein Goldewijk, 2017), 8000-7000 BC. This is because the information in Hyde is based on information in Li et al. (2009), which mentions the start of irrigation in Mesopotamia in this time period. Even though the reach of Mesopotamia did cover parts of the Eastern side of current day Turkey, the start of irrigation happened downriver along the Tigris and the Euphrates to the east, which is not Turkish territory. Other sources explored do not mention anything related to irrigation from before the 3 millennium BC. The conclusion on the start of irrigation in Egypt did comply with Hyde's estimation and no sources where found that disproved this starting point.

The projections of historic irrigated land use are quite different from the estimates in Hyde (Klein Goldewijk, 2017), which is basically the only extensive source on historic irrigation that quantifies land use. This is for a number of reasons; Since the formula used is based on the exponential population growth trend, irrigated land use could never be zero. This is of course not realistic since it is known for certain that there has not always been irrigation. However, this does skew the results for irrigation to go further back then is known to be true. In addition, are the projections for the year zero too large to be true, exceeding even current irrigation land use numbers as shown in FAOSTAT (2021) 10 times. Nonetheless, the Egypt projection for 4000 BC until 1000 BC are close to the Butzer (1980) estimations, but smaller then Hyde's estimations, which could mean that with further adjustments and finetuning the formulas could become more accurate. However, the difference between the projection for Turkey and Hyde's estimation is so big it is very unlikely that the formula based on Egypt's irrigated land use could also be used for other arid areas. Lastly, it is harder to model the reduction of irrigated land use. This could be through high mortality rates reducing demand, collapsing of the irrigation system through salinization or earthquakes, etc.. These reductions are both hard to model, and not always known. These irrigation systems can then also be brought back by revival (Keatings et al., 2010).

This is the case because of more limitations than just the formula. One of the limitations is that though there are estimations of population for the world or for countries, it is harder to find accurate information on historical population in e.g. Turkey's regions. This prevented the focus on just the semi-arid regions of turkey, which would have been a better comparison to Egypt. Furthermore, the estimations of population available do already have large insecurities, which carries through in any calculation or model they are used in. Another limitation of this research was the large difference in knowledge about the countries; There is extensive research available on ancient Egypt, including source material from millennia ago. For Turkey this is not the case. Though there is definitely some information available, it reaches less far and more spread out over the country. In comparison, all information on Egypt is about the Nile or the areas close to it.

Hopefully this lack of knowledge and disbalance will not be there forever. There is a lot of promising research which could allow learning more about historical irrigation. Rosen and Weiner (1994) suggest the possibility to discover ancient irrigation in arid and semi-arid areas through silicification of archaeological sites where Emmer Wheat was grown. Bravard et al. (2016) use the idea of geomorphological interpretations of land forms can recognize former agricultural lands so it can be dated using C14 dating. These types of research give perspective that more is still to be learned about historical agriculture and irrigation. Furthermore, it could be interesting to expand the formula by modelling the growth of irrigation in a way that it parameters like closeness to water bodies could be taken into account in the projection.

Conclusions

The aim of this study was to learn more about the early development of irrigation in Egypt and Turkey and to investigate possibilities to expand and improve current databases of historical irrigation. Though some improvements of the Hyde database could be made due to this research, expansion requires further research.

Existing literature has different estimates on the starting point of irrigation for both Egypt and Turkey. Both countries have a large range of information in the literature. For Egypt the start of irrigation was determined as ca. 6000 BC and for Turkey the start of irrigation was determined as ca. 3000 BC.

A formula to project historical demand for irrigated land use was developed. Projections on likely amounts of irrigation for 10,000 BC to the year 0 based on the relationship between irrigated land and population were made. It was easier to project irrigated land use in Egypt than in Turkey.

Historic types of irrigation used in Egypt and Turkey were all some form of surface or gravitational irrigation. In Egypt this was mostly basin or flood irrigation, later expanded with lift irrigation. In Turkey the oldest waterworks were based around basin and furrow irrigation.

Though the historical irrigation in Egypt and Turkey lies relatively close together they can be considered too different to apply exactly the same methods of projection to.

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References

Abdelhafez, A. A., Metwalley, S. M., & Abbas, H. H. (2020). Irrigation: Water resources, types and common problems in Egypt. Technological and Modern Irrigation Environment in Egypt; Negm, A., Ed, 15-34.

Ali, A., Xia, C., Jia, C., & Faisal, M. (2020). Investment profitability and economic efficiency of the drip irrigation system: Evidence from Egypt. Irrigation and Drainage, 69(5), 1033-1050.

Angelakıs, A. N., Zaccaria, D., Krasilnikoff, J., Salgot, M., Bazza, M., Roccaro, P., ... & Fereres, E. (2020). Irrigation of world agricultural lands: Evolution through the Millennia. Water, 12(5), 1285.

Ayyad, M. A., Ghabbour, S. I., & Goodall, D. W. (1986). Hot deserts of Egypt and the Sudan. Ecosystems of the world, 12, 149-202.

Badr, A. E., Bakeer, G. A., El-Tantawy, M. T., & Awwad, A. H. (2006). Sprinkler and trickle irrigation affected by climatic conditions in upper Egypt. Misr J. Ag. Eng, 23(2), 346-361.

Belli, O. (1999). Dams, reservoirs and irrigation channels of the Van plain in the period of the Urartian kingdom. Anatolian studies, 49, 11-26.

Boak, A. E. (1926). Irrigation and Population in the Faiyum, the Garden of Egypt. Geographical Review, 16(3), 353-364.

Bravard, J. P., Mostafa, A., Garcier, R., Tallet, G., Ballet, P., Chevalier, Y., & Tronchère, H. (2016). Rise and fall of an Egyptian oasis: Artesian flow, irrigation soils, and historical agricultural development in El-deir, Kharga Depression, western desert of Egypt. Geoarchaeology, 31(6), 467-486.

Burt, C. M. (1998). Selection of irrigation methods for agriculture: Drip/micro irrigation. Bioresource and Agricultural Engineering, 68.

Butzer, K. (1980). Early Hydraulic Civilization in Egypt. A Study in Cultural Ecology. The University of Chicago Press.

FAOSTAT. (2021, July 19). [Land Use]. http://www.fao.org/faostat/en/#data/RL

Ferrarezi, R. S., Weaver, G. M., Van Iersel, M. W., & Testezlaf, R. (2015). Subirrigation: Historical overview, challenges, and future prospects. HortTechnology, 25(3), 262-276.

Ghaffer, E. A., & Wahba, M. A. S. (2006). Possibility of watertable management through sub-irrigation in egypt. In Tenth int. water tech. conf., iwtc (Vol. 10).

Hassan, F. A. (1988). The predynastic of Egypt. Journal of world prehistory, 2(2), 135-185.

Hossain, M. A., Hassan, M. S., Ahmmed, S., & Islam, M. S. (2014). Solar pump irrigation system for green agriculture. Agricultural Engineering International: CIGR Journal, 16(4), 1-15.

Kanber, R., Ünlü, M., Cakmak, E. H., & Tüzün, M. (2005). Irrigation systems performance: Turkey country report. Irrigation Systems Performance, 205-226.

Keatings, K., Holmes, J., Flower, R., Horne, D., Whittaker, J. E., & Abu-Zied, R. H. (2010). Ostracods and the Holocene palaeolimnology of Lake Qarun, with special reference to past human–environment interactions in the Faiyum (Egypt). Hydrobiologia, 654(1), 155-176.

Kendirli, B., Cakmak, B., & Ucar, Y. (2005). Salinity in the Southeastern Anatolia Project (GAP), Turkey: issues and options. Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage, 54(1), 115-122.

Klein Goldewijk, K., Beusen, A., Doelman, J., & Stehfest, E. (2017). Anthropogenic land use estimates for the Holocene–HYDE 3.2. Earth System Science Data, 9(2), 927-953.

Klein Goldewijk, Dr. ir. C.G.M. (Utrecht University) (2017): Anthropogenic land-use estimates for the Holocene; HYDE 3.2. DANS.
Data retrieved from https://doi.org/10.17026/dans-25g-gez3

Koç, C. (2018). The Past and Present of Irrigation Services in Turkey. Agricultural Research, 7(4), 480-489.

Koc, A., & Kadioglu, S. (2013). Some Vegetation Characteristics of an Upland Rangelandin Eastern Anatolia. Dry Grasslands of Europe: Grazing and Ecosystem Services, 180.

Krzyżaniak, L. (1991). Early farming in the Middle Nile Basin: Recent discoveries at Kadero (Central Sudan). Antiquity, 65(248), 515-532.
doi: 10.1017/S0003598X0008011X

Kuşlu, Y., & Şahin, Ü. (2009). Water Structures in Anatolia from Past to Present. Journal of Applied Sciences Research, 5(12), 2109-2116.

Land Use. (2021, July 19). FOASTAT. Retrieved December 1, 2021, from https://www.fao.org/faostat/en/#data/RL

Li, Y. J., Thenkabail, P. S., Biradar, C. M., Noojipady, P., Dheeravath, V., Velpuri, M., ... & Cai, X. (2009). A history of irrigated areas of the world. Remote Sensing of Global Croplands for Food Security, 13-38.

Masi, A., Sadori, L., Restelli, F. B., Baneschi, I., & Zanchetta, G. (2014). Stable carbon isotope analysis as a crop management indicator at Arslantepe (Malatya, Turkey) during the Late Chalcolithic and Early Bronze Age. Vegetation History and Archaeobotany, 23(6), 751-760.

Ouda, S. (2015). Major crops and water scarcity in Egypt: irrigation water management under changing climate. Springer.

Öziş, Ü. (2015). Water Works Through Four Millenia in Turkey. Environmental Processes, 2(3), 559-573.

Rosen, A. M., & Weiner, S. (1994). Identifying ancient irrigation: a new method using opaline phytoliths from emmer wheat. Journal of archaeological Science, 21(1), 125-132.

Sansal, B. (n.d.). Regions of Turkey | All About Turkey. AllAboutTurkey.Com. Retrieved January 25, 2022, from https://www.allaboutturkey.com/regions.html

Sensoy, S., Demircan, M., Ulupinar, Y., & Balta, I. (2008). Climate of turkey. Turkish state meteorological service, 401.

Sojka, R. E., Bjorneberg, D. L., and Entry, J. A.: Irrigation: an historical perspective, in: Encyclopedia of Soil Science, Marcel Dekker Inc., 2002. Tanton, J. H.: End of the migration epoch, The Social Contract, IV and V, 1995.

United Nations Environment Programme (UNEP); Middleton, N. , & Thomas, D. (1997). Atlas of Desertification. John Wiley.

Wilkinson, T. J. (1999). Holocene valley fills of southern Turkey and northwestern Syria: recent geoarchaeological contributions. Quaternary Science Reviews, 18(4-5), 555-571.

Zahran, M. A., & Willis, A. J. (2008). The vegetation of Egypt (Vol. 2). Springer Science & Business Media.

Zaghloul, E. A., Hassan, S. M., El-Dein, A. B., & Elbeih, S. F. (2013). Detection of ancient irrigation canals of Deir El-Hagar playa, Dakhla Oasis, Egypt, using Egyptsat-1 data. The Egyptian Journal of Remote Sensing and Space Science, 16(2), 153-161.

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http://mrscelis6.weebly.com/mesopotamia.html

Figure 3:
Sahour, H., Vazifedan, M., & Alshehri, F. (2020). Aridity trends in the Middle East and adjacent areas. Theoretical and Applied Climatology, 142(3), 1039-1054.

Figure 4:
https://www.studentsofhistory.com/ancient-egypt-s-geography

Figure 5:
Türkeş, M. (1999). Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. Turkish Journal of Engineering and Environmental Sciences, 23(5), 363-380.

Figure 6:
https://istanbulclues.com/anatolia-map-history-facts-asia-minor/

Figure 7:
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Appendix I

Table from Butzer (1980) with both cultivable land in squared kilometres and the population in thousands.

Region	4000 BC			3000 BC			2500 BC			1800 BC			1250 BC			150 BC		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Valley	8000	30	240	8000	75	600	8000	130	1040	8000	140	1120	9000	180	1620	10000	240	2400
Faiyum	100	30	3	100	60	6	100	90	9	450	135	61	400	180	72	1300	240	312
Delta	8000	10	80	7000	30	210	9000	60	540	10000	75	750	13000	90	1170	16000	135	2160
Dessert			25			50			25			25			25			50
Total (millions)	0.35			0.87			1.6			2.0			2.9			4.9		

A = area of cultivable land in square kilometers, B = population density per square kilometer, C = hypothetical population in thousands.