

The Role of Urartian Hydraulic Infrastructure in Climate Resilience: A Synthesis of Centralized Authority and Local Initiative in Southwest Asia

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Abstract: The Kingdom of Urartu (860–590 BCE), with its mountainous territory in eastern Anatolia, thrived in a dry and semi-arid environment with variable water resources during the Late Iron Age. This paper argues that the hydraulic engineering systems in the Urartian Kingdom serve as the strongest indirect evidence for the existence of climatic fluctuations and significant environmental pressures during the 9th to 7th centuries BCE. To ensure survival and consolidate the state, the Urartians developed complex hydraulic infrastructures, including long canals, dams, and water storage reservoirs, which represented technological adaptations to the mountainous environment. This study evaluates the scholarly debate between two models: the "hydraulic society" (state-driven central control) and "local initiative" (indigenous roots), based on the analysis of archaeological evidence and royal inscriptions. Additionally, the dual economic function of these systems is examined: not only for food production for humans but also as a sophisticated risk management strategy for the production of fodder to feed livestock in an agropastoral economy. Ultimately, the paper concludes that the scale of these projects, which acted as multi-generational investments to create resilience against environmental uncertainties, reveals the intensity of the climate-related risks perceived by the rulers and society of Urartu.

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1. Introduction

To understand the complex strategies that ancient civilizations employed to cope with environmental challenges, it is essential to analyze their historical and geographical context. The Kingdom of Urartu, as a prominent case study, illustrates how an Iron Age state overcame the constraints of a dry and semi-arid mountainous environment through advanced hydraulic engineering and became a regional power. The Urartian Kingdom, referred to as "Biyani" in its inscriptions, was a significant mountainous empire in the ancient Near East, flourishing in the eastern Anatolian Highlands, adjacent to the Neo-Assyrian Empire, during the 9th and 8th centuries BCE, yet it began to decline in the 7th century BCE (Salvini, 2005). The central issue addressed by this research is how state-building and economic sustainability in this dry and semi-arid mountainous region, where rain-fed agriculture was highly unreliable, depended on the management of scarce and variable water resources. The paper posits that the monumental hydraulic engineering projects of the Urartians were not merely technological achievements but critical social-political strategies to address the climatic crises of the 8th and 6th centuries BCE, serving as the foundation for the governance of limited environmental resources. Studying these systems not only reveals the technical capabilities of the Urartians but also enhances our understanding of the nature of the state, economy, and royal ideology within this kingdom.

This scholarly discussion oscillates primarily between two perspectives: on one hand, the "hydraulic society" model, inspired by Wittfogel's theories, emphasizes the role of the centralized state in constructing and managing these infrastructures as tools for economic and political control, supported by royal inscriptions. On the other hand, there is the view that stresses

indigenous roots and local initiatives, a theory bolstered by scholars such as Charles Burney (1972) and Paul Zimansky (1985), which draws on older traditions of water management in the region. In this context, Oktay Belli's comprehensive catalog of water structures (Belli, 1997a,b,c) provides the necessary archaeological evidence to assess these perspectives. This paper, through the analysis of textual and archaeological evidence, revisits these theoretical debates while also examining the technical and economic dimensions of these systems. The structure of the paper begins with a description of the interdisciplinary methodology, followed by a discussion of some of the key paleoclimatic studies from the region, including those from Lake Urmia (Sharifi et al., 2023), Lake Neor in Ardabil (Sharifi et al., 2015), Lake Van in Turkey (Wick et al., 2003), the Kuna Ba Cave in northeastern Iraq (Sinha et al., 2019), the Sofular Cave in northwestern Turkey (Göktürk et al., 2011), and the Katalekhor Cave in Zanjan (Andrews et al., 2020). Subsequently, evidence related to the environment, hydraulic technology, and the economic and socio-political functions of these systems will be presented, culminating in a comprehensive conclusion that offers a comparative analysis of the role of water management in the resilience and power of Urartu. This approach allows us to move beyond mere descriptions of structures and gain a deeper understanding of the dynamic interaction between environment, technology, and society in this ancient civilization.

2. Methodology

Reconstructing ancient water management systems and understanding their climatic context requires an interdisciplinary approach that combines evidence from various disciplines to achieve a comprehensive and accurate picture (cf. Jacobson et al., 2024; Ortloff, 2023; Erkan, 2022; Lichtenberger, A., & Raja, 2020). This research adopts such an approach to analyze the hydraulic strategies in the Urartian Kingdom. The approach of this study is based on a combination of descriptive and analytical methods from archaeology and paleoclimatology. This approach enables a multifaceted analysis of climate change, water resource management, and a deeper understanding of their technological, economic, and political dimensions. Evidence related to water management in the Urartian period is drawn from both epigraphic documents and archaeological remains. Moreover, the quantity and clarity of paleoclimatic research within the Urartian territory and its surrounding regions are sufficient to reconstruct the climatic conditions of this approximately 270-year period. These studies, conducted in caves and lakes, reveal some details, such as instances of dry climatic events, in clear terms. This study, rather than attempting to definitively prove a specific climatic crisis, focuses on analyzing the adaptation and resilience strategies based on indirect archaeological and textual evidence. Within this framework, the presence of large-scale water management infrastructure is interpreted as a response to climatic fluctuations and environmental pressures perceived by the people of that era; these conditions are, of course, also traceable in high-resolution paleoclimatic research.

3. Reconstruction of the Urartian Climate

One of the most significant challenges faced by human societies throughout history has been the occurrence of climatic events and prolonged, severe droughts, which, like a package filled with direct and indirect risks and the harmful domino effects, have often led to the decline and collapse of cultures and civilizations (Shaikh Baikloo Islam, 2023, 2024). Climate change, by altering rainfall patterns, including the quantity, intensity, timing, form, and variability, fundamentally impacts hydrological regimes, creating widespread consequences for the sustainability and accessibility of water resources (cf. Kumar et al., 2025; Mohammed & Scholz, 2019; Adams and Peck, 2008). These changes can either strengthen or weaken surface flows (peak flows and baseflows) and also alter the ratio and timing of groundwater recharge (from episodic recharge during heavy events to reduced recharge during prolonged drought periods) (Punia et al., 2022; Thomas et al., 2016). Climatic changes, by disrupting the water cycle and transforming rainfall, evaporation-transpiration, and surface flow patterns, not only profoundly affect the quantity and quality of water resources but also influence the livelihoods, health, and quality of life of human societies and the

balance of ecosystems (Šulyová et al., 2021). Given that some past climatic events have been able to weaken or change the economic and institutional structures of ancient societies, studying the history of these events and reconstructing their consequences on cultures and ancient water management systems—through interdisciplinary approaches that combine paleoclimatic data, technical archaeology, and textual sources—is essential for a better understanding of resource management mechanisms, identifying adaptive capacities and limitations, and deriving lessons that can be applied to current and future climatic conditions (Caretta et al., 2022).

To reconstruct the climate during the Urartian Kingdom (approximately 860–590 BCE), six paleoclimatic studies from Lake Urmia (Sharifi et al., 2023), Lake Neor in Ardabil (Sharifi et al., 2015), the Katalekhlor Cave in Zanjan (Andrews et al., 2020), Lake Van in eastern Turkey (Wick et al., 2003), the Sofular Cave in northwestern Turkey (Göktürk et al., 2011), and the Kuna Ba Cave in northeastern Iraq (Sinha et al., 2019) were utilized. These studies, due to their geographical location, can provide a sufficiently detailed chronological reconstruction of the climate in the Urartian territory during the targeted period. They were conducted on various proxies, and from the changes in the titanium content of sediments from the Neor and Urmia lakes, different inferences are drawn. Titanium levels in the sediments of Lake Neor, situated at higher altitudes, indicate increased dust activity due to wind during drought periods, while in Lake Urmia, it suggests a wetter period with increased rainfall and water flows. Paleoclimatic studies on oxygen isotope 18 in the Sofular Cave, Katalekhlor Cave, Lake Van, and Kuna Ba Cave reveal fluctuations in rainfall and environmental humidity (Fig. 1 and Fig. 2).

The results of these studies indicate:

1. Based on research from Lake Urmia and Kuna Ba Cave, highly moist conditions prevailed during the first half of the Urartian Kingdom. In the second half of the kingdom's period, moisture gradually declined sharply, with severe drought dominating the late phase of the political period. If these two studies are taken as a basis, it can even be inferred that the collapse of Urartu was linked to the dry event of 600 BCE.
2. Based on research from Lake Neor, Lake Van, and the Katalekhlor Cave, a dry fluctuation around 800 BCE coincides with the cold event of 2800 years ago (Event 2 Bond et al., 1997, 2001). Lake Urmia's study shows this fluctuation with less intensity.
3. The Lake Urmia study shows a reduction in Ti levels around 750 BCE, indicating arid climatic conditions. Neor, Kuna Ba, and Sofular reflect this fluctuation with a slight time lag between 720 and 700 BCE. This time frame coincides with the invasion of the Cimmerians into the southern regions and the Urartian territory.
4. Except for the Kuna Ba Cave study, it seems that climatic conditions in the first half of the 7th century BCE were relatively moist.
5. Based on studies from Lake Van, Neor, Urmia, and Kunaba Cave, moisture significantly decreased in the second half of the 7th century BCE, with drought peaking around 600 BCE. The Katalekhlor Cave study does not show this dry event, but it is observable with less intensity in the Sofular Cave study.

Some researchers believe that the dry event of 2600 years ago played a role in the collapse of Assyria (Sinha et al., 2019). It is likely that this severe climatic stress also contributed to the decline in the social-political flexibility of Urartu, leading to the disintegration and fall of the kingdom. Thus, the challenges faced by the Urartian Kingdom were not solely related to combating their fierce enemies, but they also had to adapt to the livelihood pressures caused by climatic fluctuations. Since the reign of King Argishti II (714–680 BCE), climate irregularities and the frequent occurrence of severe droughts intensified, and from this time onward, the decline of the kingdom accelerated.

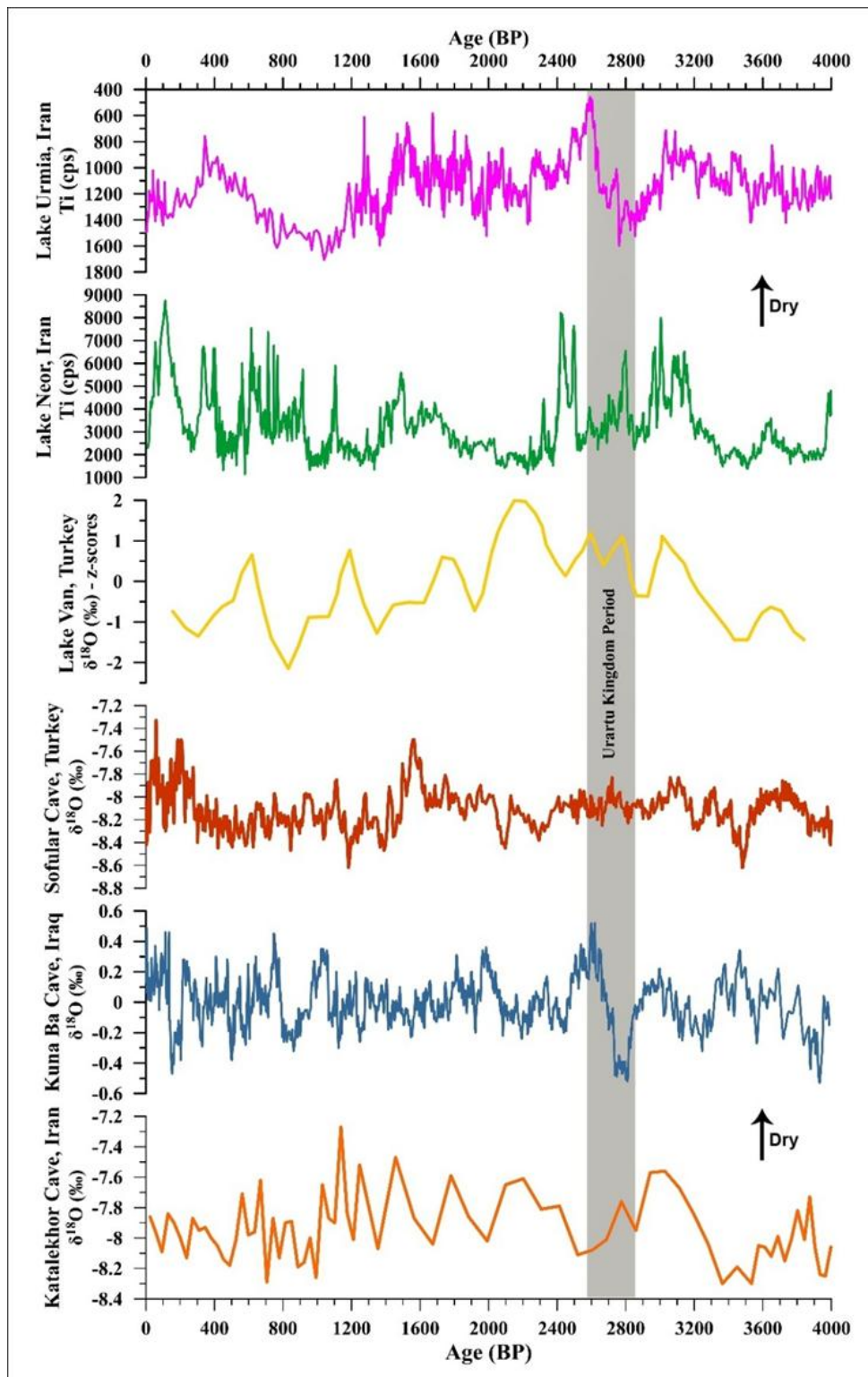


Figure 1. Fluctuations in Humidity Levels Over the Past 4000 Years Based on Paleoclimatic Research in the Near East. The gray bar represents the temporal range of the Urartian Kingdom, approximately 860 to 590 BCE. The Lake Urmia study, based on the frequency of titanium in lake sediments, indicates that higher titanium levels correlate with increased rainfall and greater sediment transport by runoff to the lake (Sharifi et al., 2023). The Lake Neor study in Ardabil, based on the frequency of titanium in aeolian sediments, suggests that higher titanium levels reflect increased wind activity and dust storms (Sharifi et al., 2015). The Lake Van study in eastern Turkey, based on oxygen isotope 18 changes, indicates that higher values are associated with increased aridity (Wick et al., 2003). The Sofular Cave study in northwestern Turkey, based on oxygen isotope 18 variations (Göktürk et al., 2011); the Kuna Ba Cave study in northeastern Iraq, based on oxygen isotope 18 variations (Sinha et al., 2019); and the Katalakhor Cave study in Zanzan, based on oxygen isotope 18 variations (Andrews et al., 2020), also provide evidence of climatic changes.

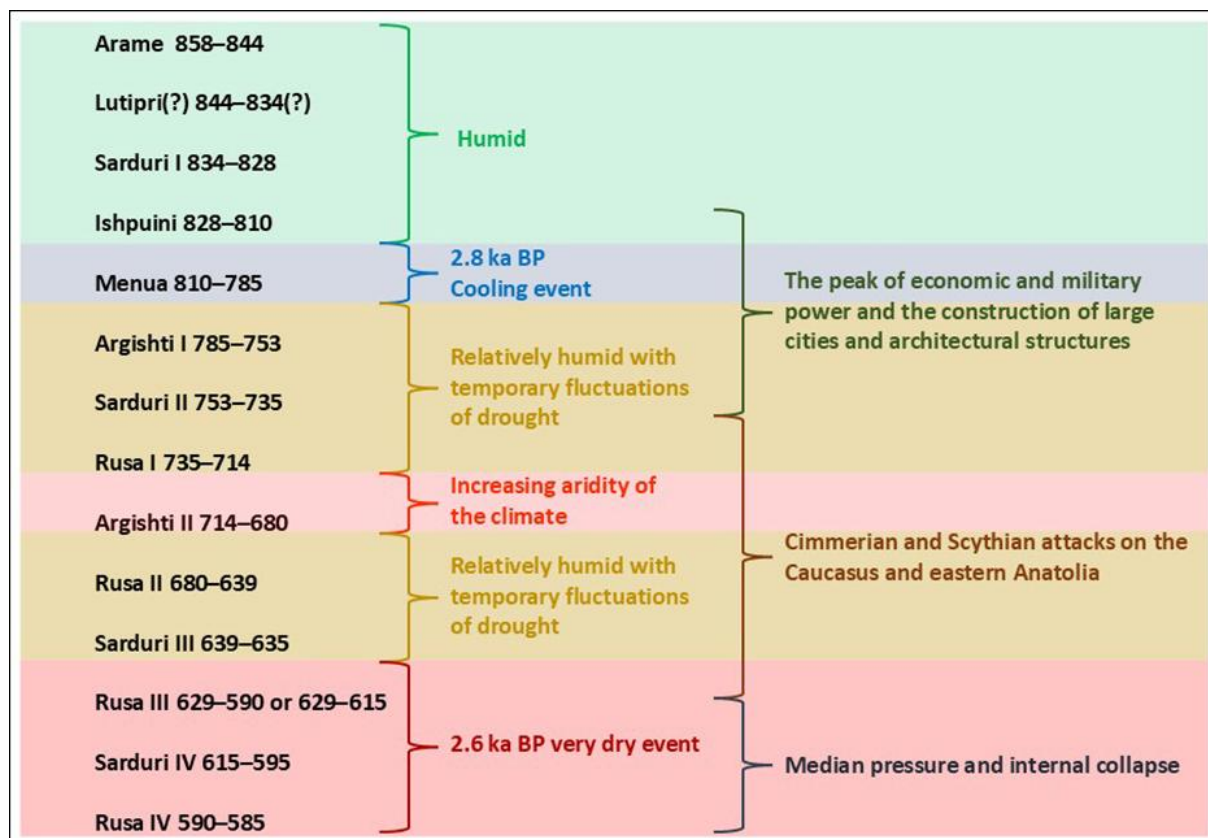


Figure 2. The Urartian Kingdom and Its Correlation with Climatic Fluctuations.

The years between 715 and 700 BCE constituted a particularly difficult period for Urartu, marked by Sargon II's Assyrian campaign against the kingdom as well as invasions by the Cimmerians into Anatolia. Between 700 and 680 BCE, the Scythians crossed the Caucasus and advanced into the northern and northeastern territories of Urartu, initiating a series of incursions into the region. They remained active in these areas until approximately 630/620 BCE, playing a significant role in the eventual collapse of the Urartian state (Author).

3. Discussion

This section provides an in-depth examination of key evidence related to water management in the Urartian Kingdom. By analyzing the environment, hydraulic technology, and the economic and socio-political dimensions, it offers a comprehensive picture of how this civilization confronted its environmental challenges and sets the stage for the final analysis.

3.1. Environment and Climatic Context of Urartu

The geography of the Urartian Kingdom was characterized by small, navigable plains surrounded by steep mountains such as Mount Ereğ (approximately 3,200 meters) and limited agricultural potential (Belli, 1999). This fragmented landscape posed significant challenges for political integration and centralized food production (Fig. 3). The regional climate was primarily arid to semi-arid, with cold, snowy winters and hot, dry summers. These conditions made rain-fed (dryland) agriculture highly unreliable and placed crop yields at substantial risk.

To overcome these environmental constraints, the Urartians constructed an extensive network of dams, reservoirs, and irrigation channels, many of which have remained largely intact for nearly 3,000 years (Çifci & Greaves, 2013; Orhan et al., 2006; Burney, 1972). The need for such expansive and sophisticated water management systems provides strong evidence for significant seasonal or annual variability in rainfall. In fact, the massive labor and resource investments required to build canals and reservoirs indicate that the Urartian society faced considerable climatic variability. In other words, the construction of hydraulic infrastructure, with its substantial costs, was not merely an effort to expand agricultural production; it represented vital strategies for mitigating climatic risk and ensuring food security in a challenging semi-arid environment (Kennett & Marwan, 2015).



Figure 3. Approximate Territory of the Urartian Kingdom (c. 860–590 BCE), Showing the Core Area (yellow circle surrounding Lake Van) and Maximum Extent (pale yellow). Red circles indicate the locations of the paleoclimatic sites referenced in this study. In this 2025 satellite image, Lake Urmia is unfortunately dried up (Author).

3.2. Urartian Hydraulic Engineering: Archaeological and Textual Evidence

Archaeological remains and royal inscriptions provide a clear picture of the diversity and complexity of water management structures in Urartu. The hydraulic constructions designed and executed by the Urartians demonstrate their advanced understanding of hydraulic engineering and their ability to implement solutions tailored to the geographic and social needs of the various regions under their control. This classification not only reveals the technical capabilities of the Urartians but also helps us better understand the multifaceted purposes of these monumental projects, ranging from irrigating agricultural fields to supplying water to fortresses during sieges.

3.2.1. Canals

Canals were among the most common and critical components of the Urartian water supply system (Belli, 1997a). These structures were constructed to convey water to cities, fortresses, agricultural lands, and orchards, playing a vital role in the kingdom's economic prosperity (Çifçi & Greaves, 2013: 200). According to Grekyan, archaeological surveys have so far identified approximately 40 Urartian canals, reflecting the extensive scale of this network. Of these, 21 canals date to the 7th century BCE, 13 to the 9th and 8th centuries BCE, and 6 remain undated (Grekyan, 2013–2014: 62). Numerous inscriptions also attest to canal construction during the reigns of different kings.

a) Minua Canal (Semiramis/Shamiram Canal)

The most famous Urartian canal, over 50 kilometers in length, 3–4 meters in width, and 1.5–2 meters in depth, was constructed to irrigate orchards and fields in the southern Van Plain and remains operational to this day. Sourced from the Gurpinar Spring (Semiramis) in the southeastern part of Lake Van, it served as the region's largest water supply (Belli, 2001: 360, 362), delivering water to the capital, the fortress of Tushpa (Van Fortress), and the surrounding plains. Sections of the canal were carved directly into rock, demonstrating high levels of technical skill and labor organization. Most inscriptions related to canal construction date to the reign of King Minua (c. 810/780–785 BCE) (Salvini, 2008). This monumental project not only ensured water security for the capital but also functioned as a multi-generational investment, fostering socio-ecological

resilience against environmental uncertainty and strengthening the economic foundation of the state (Fig. 4 and Fig. 5).

c) Canals of Argishti I

At Sardarabad, an inscription from the reign of Argishti I (c. 785/780–756 BCE) mentions four canals in the western Aras region (Salvini, 2008: A 8–16). In his annals (Salvini, 2008: A 8–3 IV, §72–74), the king records the construction of a canal from the Manas (or Aras) River to irrigate the land of Aza.

b) Canals of Rusa I

Although no Urartian inscriptions from Rusa I have been preserved, Sargon II of Assyria refers in a letter to a canal constructed by Rusa I to supply water to the city of Ulhu (Luckenbill, 1927: 86–87, 160–162).

d) Canals of Rusa II

An inscription from this king mentions the construction of a canal from the Hrazdan River to irrigate vineyards and agricultural lands (Salvini, 2008: A 12–14, §8, 17). In addition, other canals were identified for transferring water from artificial lakes to fortresses such as Ayaniš and for supplying the Tushpa citadel (Çifçi & Greaves, 2013: 194, 196). According to Belli (1994: 108–109), clay water pipes and stone channels were constructed to convey water from Lake Aygır, located northwest of Van. Similar clay pipes have been found at Anzavurtepe (Balkan, 1960: 137) and Ayaniš (Çifçi & Greaves, 2013: 194) for transporting water to fortresses. Another canal, originating from the Ereğ highlands, supplied water to Lake Rusa and Siheke, extending all the way to Tushpa (Çifçi & Greaves, 2013: 196). Additionally, an underground canal was identified at Meryam Dağı Kalası (Sevin et al., 2013: Fig. 13).



Figure 4. Location of the Minua Canal (Çifçi & Greaves, 2013: 211, fig. 1) and Image of the Minua Canal (Kuşlu & Şahin, 2009: 2112, fig. 4).

3.2.2. Water Reservoirs and Dams

In addition to water conveyance, Urartian kings demonstrated expertise in water storage. One of their key strategies was the construction of elevated reservoirs (dams and artificial lakes) in the highlands to capture meltwater during spring and early summer. This seasonal storage allowed them to transfer water to downstream plains during the dry season for irrigation purposes (Çifçi, 2014; Belli, 1999, 1997b,c). Such a strategy represents a prominent example of strategic adaptation to the hydrological cycles of a mountainous climate.

The most notable example is the construction of the artificial Keşiş Gölü reservoir (Fig. 6), referred to in inscriptions as “Lake Rusa” (Salvini, 2008: A 14-1, §§34–55). This reservoir was commissioned by King Rusa III to supply water to Rusakhinili (Toprakkale), near Tushpa, and was likely critical for irrigating the surrounding area. An inscription discovered by the German scholar Waldemar Belck in the late 19th century clearly conveys the purpose of this project (Belck & Lehmann-Haupt, 1892). In the inscription, Rusa claims that the previously “uncultivated” land was transformed, through the construction of the lake and its associated canal, into “fields, orchards, and vineyards” (Grekyan, 2013–2014: 60–61; Belli, 2001: 359, 364). This assertion exemplifies a classic manifestation of royal ideology, in which the king is portrayed as the creator of abundance and order in the face of natural drought and disorder, demonstrating his capacity to establish a strategic buffer against climatic shocks.

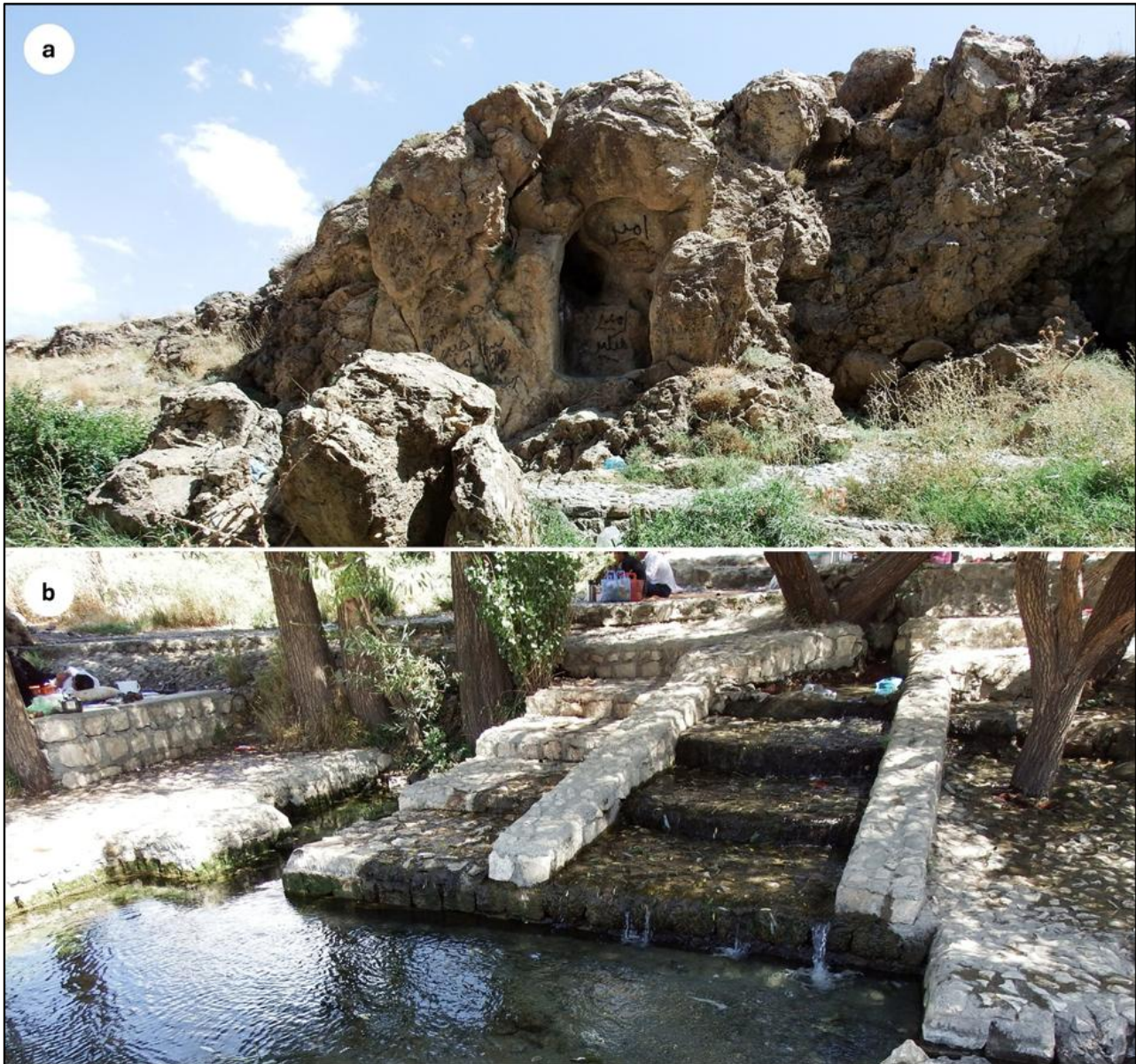


Figure 5. The Azhdahabolaghi Inscription (a) Next to the Minua Spring (b), Dated to c. 810–785/780 BCE (Photograph by Maryam Dara).



Figure 6. The Artificial Keşiş/Turna Gölü Lake (Google Earth, July 2013), located in the Erek Mountains at an Elevation of approximately 2,540 m. This reservoir not only supplied irrigation water to the Van Plain during the Urartian period but also provided drinking and domestic water for local inhabitants (Elmacı, 2010: 290, Resim 1).

Several other significant reservoirs from the early Urartian kings have been identified, including the Azab reservoir from the reign of Ishpuini and the Memedik reservoir from the period of Minua. In addition, large reservoirs have been documented at sites such as the Baghazi Plain, Subhan Dağı, Korubaş, and Ya'qub (Grekyan, 2013–2014: 61; Belli, 2004: 360–361; Belli, 2001: 359–364). Grekyan (2013–2014: 69) also mentions major water reservoirs in the city of Argishti'inili. At the entrance to the city of Sarduri'inili, a reservoir was constructed to collect rainwater. Springs were tapped in locations such as Toprakkale, Zivistan (Burney & Lawson, 1960: Fig. 177f), Bostankaya (Burney & Lawson, 1960: Fig. 196), Kalecik, and Pağın (Burney, 1957: 52, Fig. 15).

Dam construction represents another advanced aspect of Urartian hydraulic engineering, vital for controlling river flow and storing large volumes of water. The most notable example is the dam built by Rusa II in the Köşebaşı area, which fed the Siheke reservoir. This dam is recognized as the largest and widest in eastern Anatolia during antiquity and exemplifies the peak of Urartian technical prowess in hydraulic engineering (Belli, 2001: 359, 363–364).

3.2.3. Groundwater-Fed Canals

Unlike Assyrian water networks, which often relied on direct river diversions and surface water channels (Bonacossi & Qasim, 2022; Ur, 2005), archaeological evidence indicates that some Urartian irrigation systems were fed directly by springs, small reservoirs, and groundwater sources. Field surveys in Tushpa and the Van Plain show that Urartian canals often originated from “perennial springs and local reservoirs,” thereby providing a more stable and independent water source compared to seasonal river flows (Burney, 1972; Garbrecht, 1980; Çifçi & Greaves, 2013). This ingenious approach reduced the dependence of the Urartian water system on rivers and allowed for efficient water management throughout the year—even during drought periods.

3.2.4. Spring Maintenance

Urartian kings, especially during the reigns of Ishpuini and Minua, paid special attention to preparing springs for easy public access. The process of clearing and constructing related structures ensured access to clean and reliable water. The earliest inscription concerning spring construction dates to the joint reign of Ishpuini and Minua (c. 820–810 BCE) at Pirabat (Salvini, 2008: A 3–6, §6). Minua's reign marked the peak of these activities, with multiple inscriptions

identified at Van, Anzaf, Azhdahabolaghi (in present-day Iran), Kadambas, Edremit, and other locations. Later, during the reign of Rusa III, an inscription regarding the construction of a spring at Estel Gulik (Keşiş Gölü) was discovered (Salvini, 2008; Dara, 2017: 60). It should be noted that there is scholarly debate regarding the use and development of qanat systems during the Urartian period. Although archaeological evidence does not directly support this, some researchers suggest that the Urartians may have utilized qanats (Grekyan, 2013–2014: 58). However, it is proposed that they likely did not excavate these tunnels themselves, but rather made use of qanats constructed by local populations in newly conquered territories (Çifçi & Greaves, 2013: 205). In contrast, Salvini argues that the extensive surface water networks of the Urartians eliminated the need for long underground tunnels (qanats) (Salvini, 2001: 145–146).

Table 1. Chronological Overview of Urartian Hydraulic Constructions

Apart from the constructions listed in the “Archaeological Evidence” column, six additional sites have been reported without precise dating (cf. Grekyan, 2013–2014; Belli, 1994, 1997a,b,c, 1999, 2001, 2004, 2005, 2008; Ögün, 1970; Salvini, 1992; Kleiss, 1970, 1976, 1979).

Urartian King	Reign (Approx.)	Hydraulic Constructions Based on Textual Evidence	Hydraulic Constructions Based on Archaeological Evidence	Climatic Conditions
Ishpuini & Minua	c. 820–810 BCE	Springs: Inscription recording spring construction at Pirabat	9th–8th centuries BCE: Dams, reservoirs, artificial lakes: 31; Canals: 13	Increasing cold and aridity associated with the 2800 BP event
Minua	c. 810–785 BCE	Canals: Peak of canal construction (e.g., Minua Canal) with multiple inscriptions. Springs: Numerous inscriptions documenting spring construction in various locations Reservoirs: Construction of Memedik Reservoir		
Argishti I	c. 785–753 BCE	Canals: Four inscriptions related to canal construction in the Sardarabad region (west of the Aras River)		Relatively wet with intermittent dry fluctuations
Sarduri II	c. 753–730 BCE	No direct inscriptions for hydraulic constructions; existing evidence indicates silos and vineyards		
Rusa I	c. 730–714 BCE	Canals: No Urartian inscriptions; however, according to Assyrian King Sargon II, a canal was built for the city of Ulhu		
Argishti II	c. 714–680 BCE	No direct inscriptions for hydraulic constructions; evidence suggests water management and vineyard irrigation	7th century BCE: Dams, reservoirs, artificial lakes: 78; Canals: 21	Increasing aridity (centered ca. 700 BCE)
Rusa II	c. 680–645/639 BCE	Canals: Inscription of a canal constructed from the Hrazdan River Dams: Construction of the largest known Urartian dam (Köşebaşı Dam)		Relatively wet with dry fluctuations; severe drought beginning in the late 7th century BCE, peaking around 600 BCE
Sarduri III	c. 639–635 BCE	No inscriptions		
Rusa III	Late 7th century BCE	Artificial lake: Inscription at Stel Gulik regarding the construction of “Rusa Lake.” Springs: Inscription documenting spring construction at the same site		

3.3. Economic Functions of Irrigation Systems

The primary role of irrigation systems in the Kingdom of Urartu was the intensification of agricultural production. Urartian inscriptions repeatedly refer to the establishment of “grain fields” and “vineyards” through these irrigation projects. These products were not only essential for feeding urban and military populations but also formed a significant part of the economic foundation of Urartian power.

However, some scholars, notably Emily Hammer, have proposed that the function of Urartian irrigation extended beyond mere crop cultivation. She argues that a critical objective of these hydraulic constructions was the cultivation of fodder to support livestock, particularly horses for the army and flocks of sheep and cattle. In an agropastoral economy in mountainous regions, securing fodder during dry seasons was a vital challenge. By irrigating plains to grow alfalfa or other forage plants, the Urartian state enhanced the economic resilience of the kingdom against climatic variability and ensured year-round sustenance for its cavalry (Hammer, 2022).

This perspective is supported by archaeological and ethnographic studies indicating that many Urartian irrigation systems may have been designed not merely for arable crops but to boost livestock productivity (Çifçi & Greaves, 2013). Zooarchaeological evidence further underscores the centrality of pastoralism in the Urartian economy. Animal remains, particularly of sheep, cattle, and horses, reveal large herds and structured grazing patterns (Çifçi, 2015). These findings highlight that Urartian irrigation served not only agricultural production but also the livestock system, representing a sophisticated strategy for managing climatic risk.

3.4. Social and Political Organization of Water Management in Urartu

The construction and management of these extensive infrastructures have generated scholarly debates, highlighting two contrasting models:

Hydraulic Society Model: Inspired by Karl Wittfogel's classical theory, this model posits that large-scale control over water resources (dams, canals) led to the emergence of centralized political systems with strong bureaucracies (Wittfogel, 1953, 1955; Bichsel, 2016). In Urartu, textual evidence, including royal inscriptions, demonstrates that kings implemented massive hydraulic projects. These works involved considerable labor (likely including conscripted or captive workers), centralized organization, and royal supervision (Çifçi & Greaves, 2013). The objective was to ensure food security for large populations, generate agricultural surpluses, and support the army and state projects. In this framework, irrigation technology enabled the central government not only to supply agricultural produce to cities and elites but also to use control over water as a primary instrument of political legitimacy and territorial integration (Hammer, 2022).

Local Initiative Model: Conversely, some researchers argue that many Urartian water management technologies were not inventions of a centralized state but evolved from older local traditions present in Bronze and Early Iron Age communities. According to this view, numerous smaller canals and dams were likely constructed by local rulers or rural communities for their own needs, with the Urartian state later incorporating, expanding, or integrating these systems. This perspective emphasizes the role of local institutions in resource management. Some of these hydraulic facilities may have been primarily intended for livestock use (e.g., grazing in upland areas) rather than for arable farming (Çifçi & Greaves, 2013).

A key critique of the royal-centered model is that the inscriptions were often ideological rather than administrative records. In other words, these texts do not merely document technical projects but serve as symbolic assertions of power: the king is depicted as "bringing water to uncultivated lands," demonstrating his ability to overcome destructive natural forces and provide abundance for his people, thereby legitimizing his rule (Hammer, 2022).

The reality likely reflects a combination of both models. The Urartian state directed major infrastructural projects with centralized oversight, while local communities participated in the construction and management of portions of the network, and some smaller-scale hydraulic facilities had roots in pre-state local traditions. For instance, Çifçi and Gökçe's study of Urartian fortifications shows that water storage within citadels relied more on underground chambers and pithoi than on large aqueducts, suggesting local management and flexibility in meeting specific needs (Çifçi & Gökçe, 2023). Furthermore, recent analyses indicate that Urartian hydraulic infrastructures were not merely technical instruments but elements of socio-political interaction; their development reflected a combination of central authority and local participation in water resource management (Preiser-Kapeller, 2024).

4. Analysis

Our comparative assessment of Urartian irrigation systems and those of their powerful southern neighbor, Neo-Assyria, reveals notable contrasts and challenges the long-held assumption that Urartu merely imitated Assyrian hydraulic practices. Although the Assyrians also constructed large-scale irrigation works—most prominently during the reign of Sennacherib in the late eighth and early seventh centuries BCE—evidence indicates that major Urartian projects predate them. The Minua Canal, built in the ninth century BCE, precedes Sennacherib’s engineering achievements by over a century. More importantly, Urartian hydraulic technology was uniquely adapted to the mountainous landscapes of the region. Whereas Assyrian canals primarily branched off major rivers, Urartian systems specialized in the capture of water derived mainly from snowmelt, stored in high-altitude reservoirs, and in the exploitation of groundwater resources. These sophisticated adaptations point to an indigenous and autonomous engineering tradition shaped by the environmental demands of the region, rather than the emulation of an external political model. This distinction underscores the argument that Urartian hydraulic strategies emerged as localized responses to specific ecological pressures.

The relationship between water management, state formation, and social complexity in Urartu is multifaceted. Although the Urartian polity does not fully conform to Wittfogel’s classical “hydraulic society” model, in which bureaucratic control over water inevitably produces state despotism, there is no doubt that royal sponsorship of hydraulic resources formed a cornerstone of political authority and state ideology. The ability to “turn wilderness into arable land,” as proclaimed in the inscriptions of Rusa, constituted a potent political claim to legitimacy. By providing water and ensuring food security, the king portrayed himself as a just and capable ruler favored by the gods, particularly the national deity Haldi. These projects also enabled state expansion by facilitating the settlement of populations in newly irrigated territories and generating the agricultural surplus necessary to sustain the military and administrative apparatus.

Ultimately, the most critical conclusion drawn from the analysis of these complex systems is their value as environmental indicators. These monumental and resource-intensive constructions stand as the strongest indirect evidence for significant climatic pressures and environmental fluctuations during the Iron Age (Dara & Shaikh Baikloo, 2022). The scale of labor and material investment clearly reflects the degree of risk perceived by Urartian rulers and communities. Faced with the uncertainties of periodic droughts and irregular precipitation, they developed long-term, sustainable engineering solutions that became defining features of their civilization. The study of Urartian hydraulics thus reveals not only a history of technological innovation but also a narrative of human resilience in the face of challenging environmental conditions.

5. Conclusion

This article examined water-management strategies in the Kingdom of Urartu as a prominent case study of human–environment adaptation within arid mountain landscapes of the ancient world. The findings demonstrate that Urartu developed a unique and highly sophisticated hydraulic system—including long-distance canals, dams, and innovative techniques for water storage and groundwater exploitation—in response to the challenges posed by a variable environment. The major hydraulic works were undertaken during climatically favorable periods that coincided with economic prosperity. These investments reflected both foresight and risk anticipation, as the considerable costs could only be sustained during prosperous times, while the absence of such infrastructure would have threatened royal legitimacy during episodes of drought.

The results further suggest a dual economic function for these systems: beyond enhancing agricultural production, they played a vital role in securing fodder for livestock, thereby reducing risk in a mixed agro-pastoral economy. The socio-political dimension of water management was equally complex. Royal inscriptions served less as administrative records and more as powerful instruments of political discourse and legitimization. Most importantly, this study argues that the

immense scale of these infrastructures constitutes the strongest indirect evidence for significant climatic fluctuations and environmental pressures during the period.

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Conflict of Interest

This article was authored by a single researcher and involves no conflict of interest.

Availability of Supplementary Data

All paleoclimate datasets referenced in this study have been publicly shared online by their original researchers. The author can provide access to these datasets upon request.

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