Bonu Azizova

Tegizamin: The Invisible Engineering of Ichan-kala, Khiva

Tegizamin: La ingeniería invisible de Ichan-kala, Jiva

Tegizamin: A engenharia invisível de Ichan-kala, Khiva

Keywords | Palabras clave | Palavras chave

Underground cisterns, Vernacular infrastructure, Water heritage, Urban hydrology, Islamic architecture

Cisternas subterráneas, Infraestructura vernácula, Patrimonio hidráulico, Hidrología urbana, Arquitectura islámica

Cisternas subterrâneas, Infraestrutura vernácula, Património hídrico, Hidrologia urbana, Arquitetura islâmica

Abstract | Resumen | Resumo

Khiva, a UNESCO World Heritage city, is widely known for its monumental architecture, but beneath its iconic madrasahs and minarets lies a lesser-known legacy: an intricate underground water infrastructure based on cisterns known as *tegizamins*. This article investigates the historical logic and material construction of Khiva's traditional buried cistern systems, essential for drainage, rainwater harvesting, and potable water storage from the eighteenth to the twentieth centuries, together with proposed pathways for studying and reviving them. The *tegizamin*, in conjunction with drainage elements such as those known as *gulbidav* and *adan*, exemplifies how Khivan builders developed climate-adaptive and circular water infrastructure using regionally available materials and passive engineering. The rediscovery of several cisterns during infrastructure works in recent decades has sparked renewed interest in their conservation. This in turn contributes to broader discussions on vernacular engineering, heritage-based sustainability, and the recovery of embedded environmental knowledge for contemporary urban resilience. Through archival manuscripts, historical cartography, and comparative analysis of Central Asian water systems, we reconstruct the *tegizamin*'s layered typology and hydraulic functions, proposing a methodological framework for stratigraphic investigation, material sampling, and non-invasive geophysical surveying to map Khiva's buried cistern networks.

Jiva, ciudad histórica que forma parte del Patrimonio de la Humanidad de la UNESCO, es famosa por su arquitectura monumental. Sin embargo, más allá de sus icónicas madrasas y alminares, hay un patrimonio menos conocido: una compleja infraestructura de aguas subterráneas denominada *tegizamin*. Este artículo investiga la lógica histórica, la construcción y las vías propuestas para estudiar y rehabilitar los sistemas tradicionales de cisternas subterráneas de Jiva, estructuras esenciales para el desagüe, la recogida de agua de lluvia y el almacenamiento de agua potable entre los siglos XVIII y XX. El *tegizamin*, junto con elementos internos de desagüe como el *gulbidav* y el *adan*, son un ejemplo de cómo los constructores locales desarrollaron infraestructuras hidráulicas circulares y adaptadas al clima mediante el uso de materiales locales y de estrategias de ingeniería pasiva. El redescubrimiento de varias cisternas durante las obras de infraestructura realizadas en las últimas décadas ha suscitado un interés renovado en su conservación. Dicho interés contribuye a ampliar el debate sobre la ingeniería vernácula, la sostenibilidad basada en el patrimonio y la recuperación los conocimientos medioambientales arraigados para la resiliencia urbana contemporánea. A partir de los manuscritos encontrados en archivos, la cartografía histórica y un análisis comparado de los sistemas de abastecimiento de agua en Asia Central, el estudio reconstruye las tipologías estratificadas y las funciones hidráulicas del *tegizamin*. Sin haber realizado una excavación arqueológica propiamente dicha, este estudio propone un marco metodológico para la investigación estratigráfica, el muestreo de materiales y el sondeo geofísico no invasivo con el fin de cartografiar las redes de cisternas subterráneas de Jiva.

Khiva, uma cidade Património Mundial da UNESCO, é amplamente conhecida pela sua arquitetura monumental, mas por baixo das suas icónicas madrassas e minaretes existe um legado menos conhecido: uma complexa infraestrutura subterrânea de água baseada em cisternas conhecidas como *tegizamins*. Este artigo investiga a lógica histórica e a construção material dos sistemas tradicionais de cisternas subterrâneas de Khiva, essenciais para a drenagem, captação de água da chuva e armazenamento de água potável entre os séculos XVIII e XX, juntamente com propostas para estudá-los e revitalizá-los. O *tegizamin*, em conjunto com elementos de drenagem como os conhecidos como *gulbidav* e *adan*, exemplifica como os construtores de Khiva desenvolveram infraestruturas hídricas circulares e adaptadas ao clima, utilizando materiais disponíveis na região e engenharia passiva. A redescoberta de várias cisternas durante obras de infraestrutura nas últimas décadas despertou um interesse renovado na sua conservação. Isto, por sua vez, contribui para discussões mais amplas sobre engenharia vernácula, sustentabilidade baseada no património e a recuperação de conhecimentos ambientais intrínsecos para a resiliência urbana contemporânea. Através de manuscritos de arquivo, cartografia histórica e análise comparativa dos sistemas hídricos da Ásia Central, reconstruímos a tipologia estratificada e as funções hidráulicas do tegizamin, propondo um quadro metodológico para investigação estratigráfica, amostragem de materiais e levantamentos geofísicos não invasivos para mapear as redes de cisternas enterradas de Khiva.

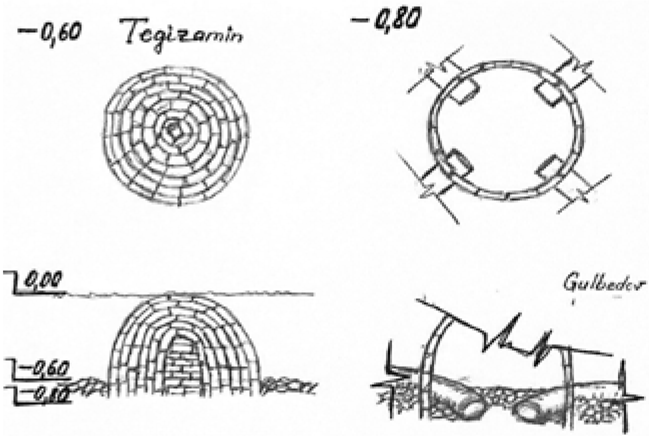
Introduction

Historic cities in Central Asia often invoke images of mosques and palaces, but Khiva in Uzbekistan is equally notable for its underground water infrastructure. Over centuries, the city relied on wells, cisterns, and irrigation canals for hygiene and resilience in an arid climate. Its technically accomplished hydraulic systems also supported social organization and political stability in the Khiva khanate, where water scarcity influenced daily life and governance. Khiva's waterworks deserve recognition alongside the town's monumental architecture, as the hidden key to its urban survival (Bichsel 2021).

Khiva's architectural heritage, and particularly its underground water systems and construction techniques, remains underexplored compared to that of nearby historic cities such as Bukhara, Samarkand, and Kokand (Ahmedov 1995). Like these and other Silk Road towns, Khiva emerged at a junction of transcontinental trade routes (Allaeva 2019), serving as a hub for merchants and caravans (Khaitov and Aminova 2022). Yet it stands on relatively elevated and arid terrain, requiring creative and climate-adaptive water retention and sanitation solutions.

As Ahmedov (1995: 89-91) notes, the scarcity of surface water in the Khorezm region led Khivan builders to develop subterranean technologies integrated into domestic, religious, and urban architecture. According to the historian Komiljon Khudayberdiganov, the higher central part of Khiva—Ichan-kala—was built using red sand brought from afar, whose properties of neither absorbing water nor allowing it easily to percolate gave rise to several types of underground water structure. A prime example are cistern systems such as the *tegizamin*, which provided passive, decentralized water management throughout the city, collecting both wastewater and rainwater.

Figure 1: Craftsman and architect Abdulla Boltaev (Boltaev 2013)



2

3

Figure 2: Schematic view of a *tegizamin* and *gulbidav*

Figure 3: Dishan-kala (indicated in white) and Ichan-kala (in yellow) in Khiva (Google maps)

Despite their historical significance, Khiva's traditional hydraulic networks were neglected by the townspeople and largely destroyed during the Soviet era. Centralized planning resulted in widespread encroachment, abandonment, or destruction (Durdieva 2012). According to Ahmedov (1995), traditional engineering methods were disregarded in urban development after the 1930s, resulting in a loss of construction knowledge and the disappearance of manuscript records. Today, Khiva continues to suffer from seasonal flooding and infrastructure stress, partly due to the disruption of these historical systems (Amirova et al. 2022).

Figure 4: Schematic plan of Ichan-Kala illustrating the rediscovered underground structures of Khiva.

Legend:

1, 3, 6, 8: *Havuz* (pools)

2, 4, 5: *Tegizamin* (cisterns)

7: Well-like *Tegizamin*

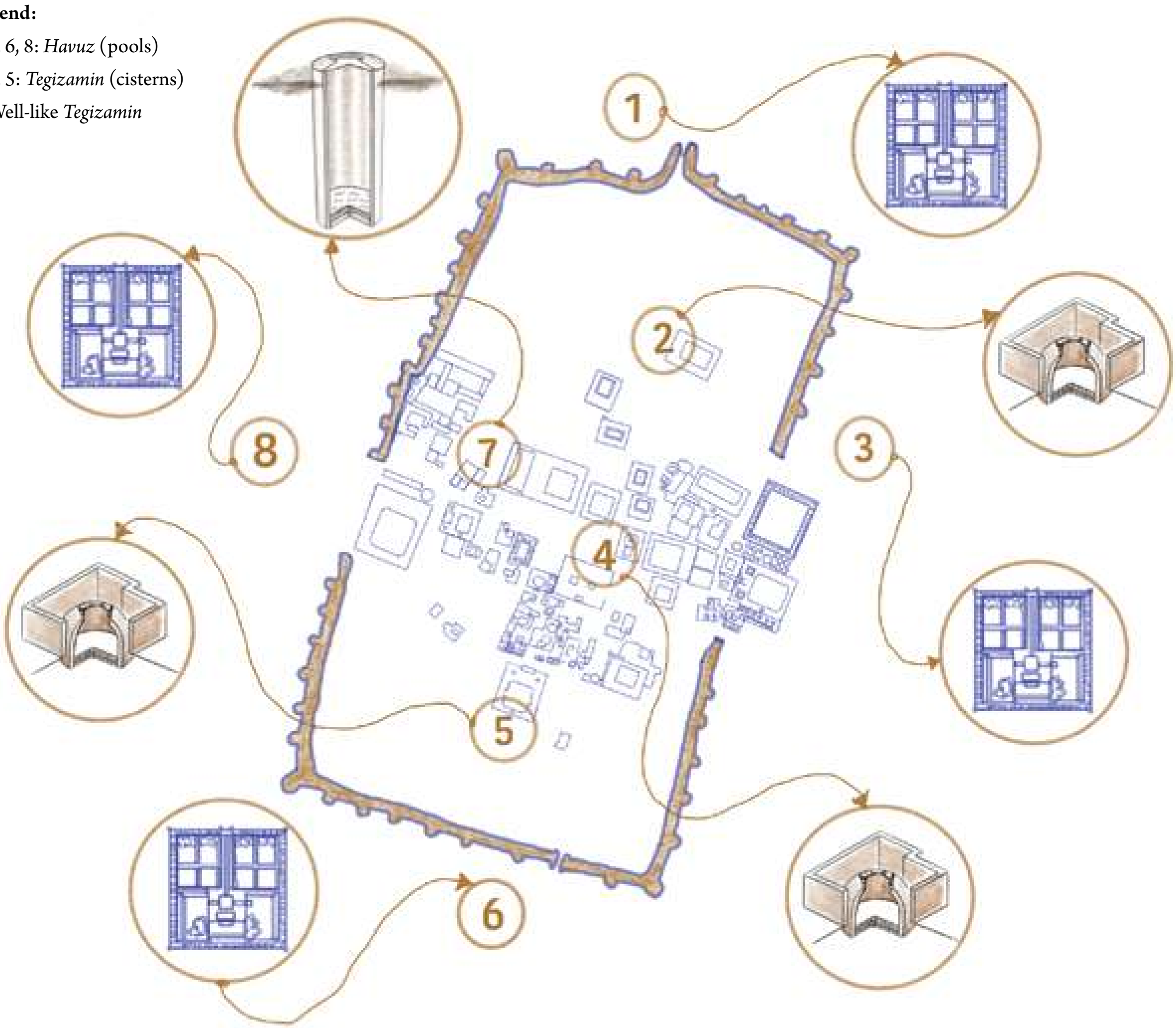


Figure 5: *Tegizamin* uncovered during the recent installation of communication cables near Matpanaboy Madrasah in Ichan-Kala, documented in 2022

Yet there has been a resurgence of scholarly and technical interest in recent years, particularly with the rediscovery by researchers at the Khorezm Mamun Academy of 80 handwritten notebooks by the Khorezmian builder Abdulla Boltaev (1965) (Fig.1), providing rare documentation of Khiva's underground cisterns and drainage practices including records of previously unknown structures and insights into their functional logic. Utility excavations revealing domed subterranean structures consistent with Boltaev's descriptions have corroborated these records. Among the most significant rediscoveries is the *tegizamin*, a vaulted cistern for rainwater harvesting and wastewater diversion, often connected to filtration basins (*adan*) and interior conduits (*gulbidav*), ensuring sanitation and flood control across domestic and public spaces (Fig. 2).

Building on this material and Boltaev's architectural-historical context, this article seeks to synthesize archival sources, construction analysis, and proposed archaeological methods to reframe the *tegizamin* as a model of vernacular water infrastructure.

Historical Context and Significance

In the historic city of Khiva, the water infrastructure was different in the two main urban areas: Dishan-kala (outer city) and Ichan-kala (inner city). In Dishan-kala, pools (*havuz*) were the dominant water features (Fig. 3). The water systems in Ichan-kala, built on red sand, included *tegizamin* cisterns, *gulbidav* drainage conduits, *adan* underground basins, *aryk* irrigation ditches, *havuz* pools, etc. (Zohidov, 1997; Allayeva, 2023) (Fig. 4). These components functioned in concert to regulate both domestic wastewater and rainwater, preserving hygiene in the dense inner town.

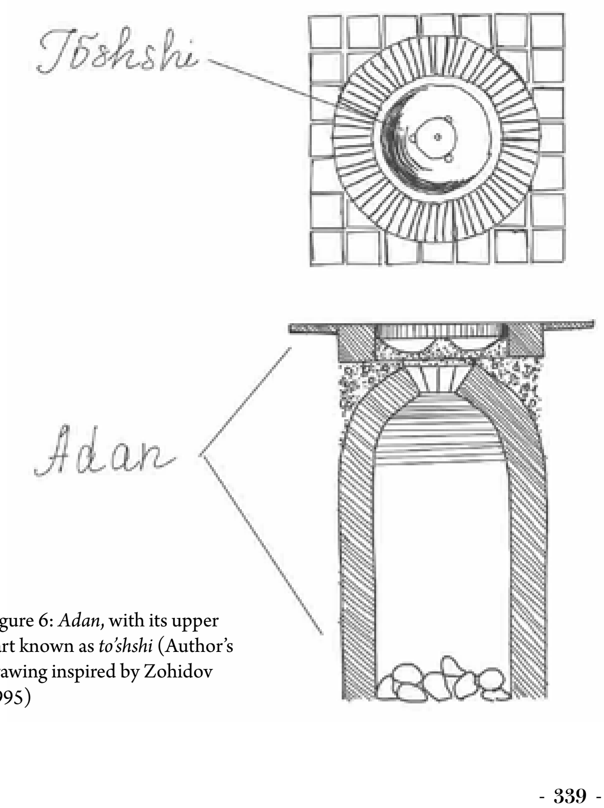


Figure 6: *Adan*, with its upper part known as *to'shshi* (Author's drawing inspired by Zohidov 1995)

Figure 7: *Sardoba* in the Kutlug Murod Inoq Madrasah courtyard in Ichan-kala

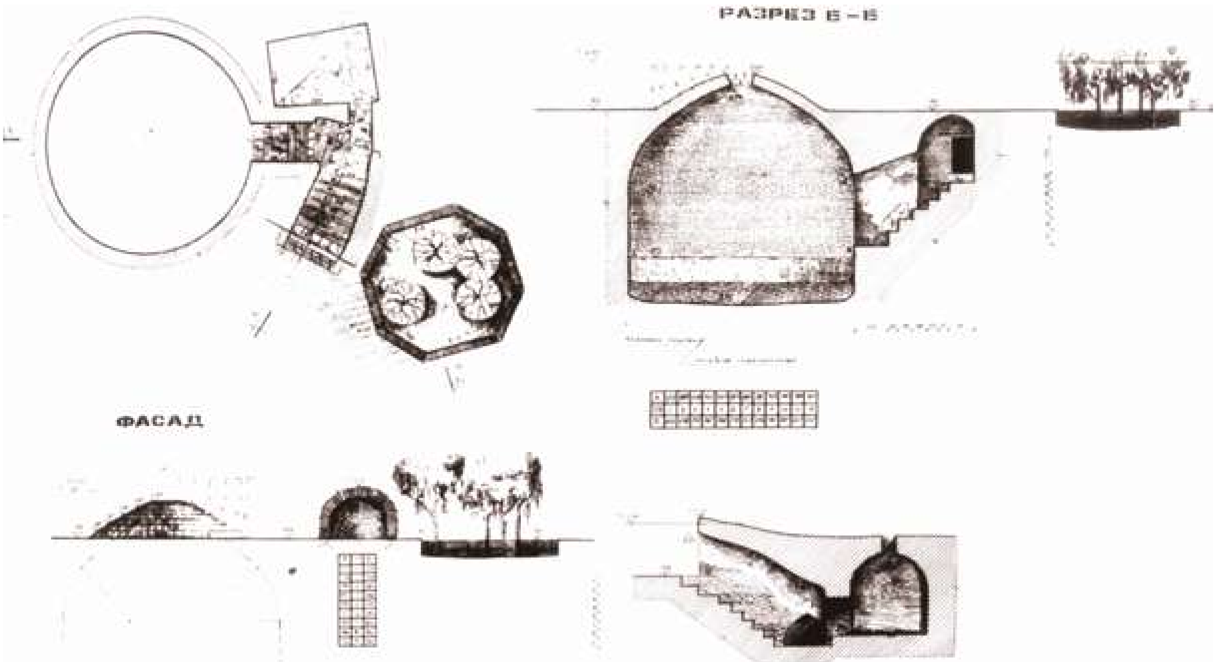


Figure 8: Hand-drawing of the *sardoba* at Kutlug Murod Inoq Madrasah, Ichan-kala (Notkin 1960)

As *tegizamin* cisterns (Fig. 5) collected wastewater and rainwater with the support of *gulbidav* and *adan* drainage systems (Fig. 6), open conduits carried excess water away from residential areas (Kantarci et al. 2015). A second type of *tegizamin*, also known as *sardoba*, stored drinking water in public courtyards, such as in madrasahs or mosques. These were domed to limit evaporation and prevent contamination (Fig. 7). The dome also signaled the presence of stored water and often had ventilation and access shafts for maintenance.

Historical records and archaeological parallels suggest that such domed cisterns were used across Central Asia as early as the Achaemenid period (Masson 1976), later spreading through Persian, Timurid, and Khorezmian building traditions. One notable example in Khiva is the *tegizamin* in the courtyard of the Kutlug Murad Inoq Madrasah, constructed in 1809, reflecting the continuity of this architectural type into the nineteenth century (Figs. 7–8).

The large open pools in Dishan-kala also fell into disuse in the twentieth century. One example is the *Soqiyo* reservoir, which collapsed in 1926 and was gradually filled in, symbolizing the broader erosion of Khiva's traditional water systems through modernization and neglect.

Together, these systems reveal a highly localized form of hydraulic engineering, structurally efficient and embedded in urban planning and social practice. Their partial rediscovery today invites renewed appreciation of how water infrastructure shaped life from beneath the famed Khivan townscape.

Etymology and Terminology

The terminology of Khiva's historic water infrastructure reflects an intertwining of functional utility, regional dialect, and cultural memory. *Tegizamin* is believed to derive Khorezmian *teg* (to place or store) and *zamin* (ground)—hence "placed underground" or "underground storage." This distinguishes it from the more widely used Persian term *sardoba*, which translates as "cold water structure" and typically refers to the domed cisterns along caravan routes (Fig. 9).

The preference of the term *tegizamin* to *sardoba* in Khorezm reflects a region-specific adaptation of water terminology differing from that of other parts of Central Asia, indicating that local communities used a lexicon for hydraulic technologies tailored to their distinct topography and social practices.

In this context, *adan* would refer to shallow domestic or communal catchment pools designed to channel surface runoff, and *gulbidav* to the subterranean conduits or sand-filled filtration chambers often preceding a cistern's intake point (Zohidov 1996).

Other terms encountered in oral accounts include *tuproq suv ombori* (clay water reservoir) and *suv to'planmasi* (water accumulation chamber), indicating a living tradition of describing such elements in contemporary Uzbek dialects. These terms document a historically embedded knowledge of water management, highlighting the importance of linguistic preservation in understanding heritage.

Construction Techniques

The *tegizamin* cistern (like a Persian *sardoba*) is a sophisticated response to the environmental challenges of Khiva's sandy and elevated terrain. The city lacked natural runoff paths, making it vulnerable to rainwater accumulation and unsanitary conditions, particularly in the wet season. This situation became more acute in the 1830s–40s, when government officials such as Hasan Murad *Kushbegi* and Ata Murad *Kushbegi* commissioned large residences around the Kuhna Ark castle. These obstructed pre-existing subterranean drainage routes, necessitating a new system for managing urban runoff and wastewater (Khaitov and Aminova 2022; Mutalov 2005: 29-30; Boltaev 1965: 64).

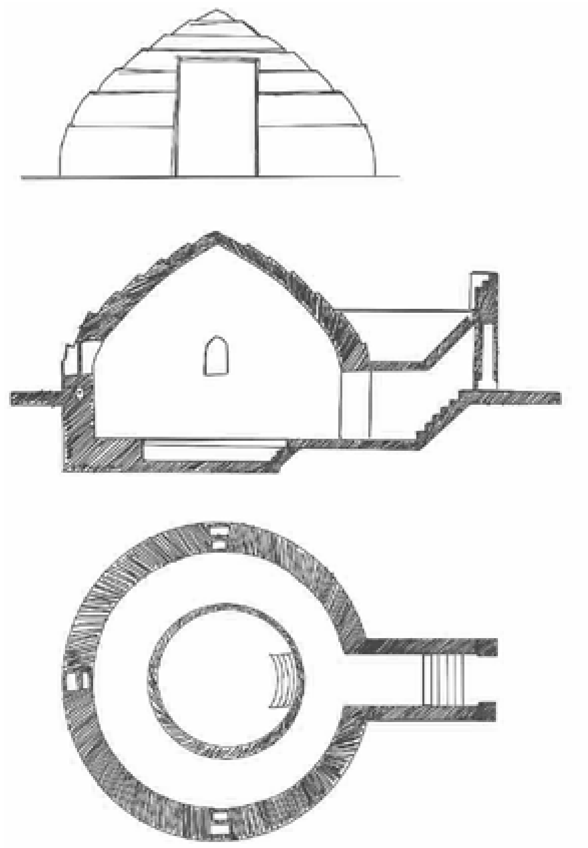


Figure 9: Plan and elevation of an ordinary Central Asian *sardoba* for water storage (Author's drawing inspired by Zohidov 1995)

In response, Khiva's master builders built a network of domed underground cisterns—*tegizamins*—with precisely engineered methods rooted in local knowledge of hydrology and construction. They first dug a circular pit some 3 to 5 meters deep and up to 15 meters in diameter. The interior was lined with concentric layers of fired clay bricks and a dome was built at ground level in the form of a load-bearing vault (Figs. 10-11). The walls were commonly built 1.2 to 1.5 meters thick, ensuring thermal insulation and mechanical stability (Azizova 2017).

According to Ahmedov (1995: 89-91), similar construction techniques—thick brick walls, radial vaulting, and *ganch* (lime-ash) plaster—were common in Khorezmian architecture, including monumental and utility structures. The walls were often more than a meter thick, for insulation and stability, while the domes minimized evaporation and external contamination.

Material choice was highly selective. Clay sourced from the lower Amu Darya region, valued for its moisture resistance,

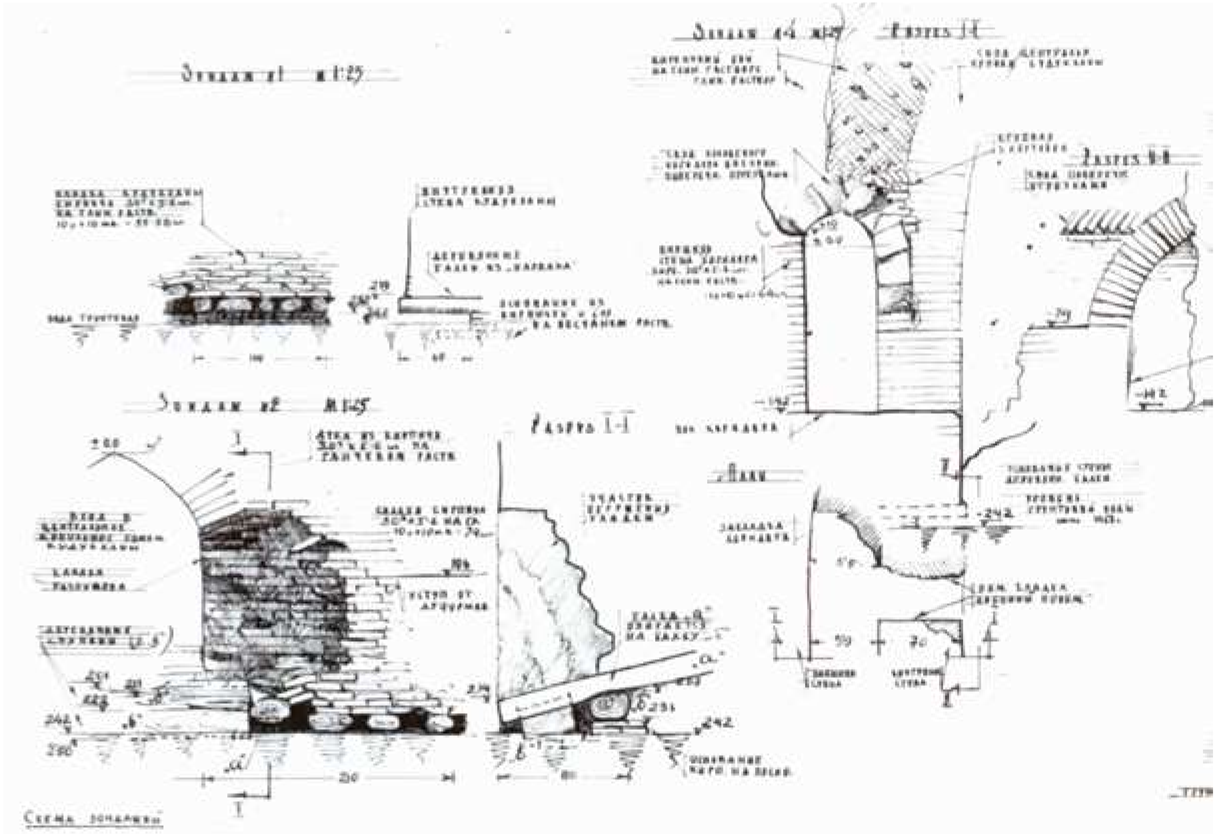


Figure 10: Hand-drawing of fired-clay brickwork in the *tegizamin* of Kutlug Murod Inoq Madrasah, Ichan-kala (Notkin 1960)

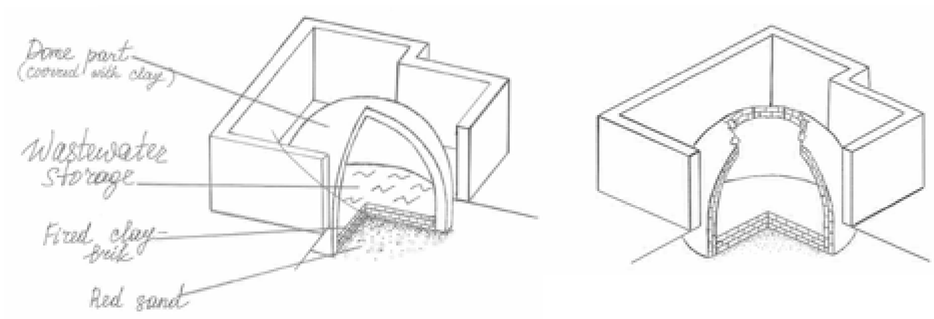


Figure 11: Cutaway of the *Tegizamin* dome near Matpanaboy Madrasah in Ichan-Kala. Left: closed during wastewater collection; right: in open position

was mixed with natural additives such as camel wool and mare's milk for cohesion and elasticity. Bricks were sun-dried for up to a year and selected for firing only if free of cracks and warping. Foundations were laid using *ganj* mortar, a lime-based plaster often enriched with casein or wool fiber to enhance durability and water resistance (Azizova and Osello 2020).

Tegizamins were located in such a way as to optimize natural runoff. Channels were dug with care so as not to breach impermeable soil layers, directing rainwater and wastewater to the cistern. The surrounding soil stored and gradually absorbed the water under the protective dome.

Although no cistern has yet been fully excavated, evidence from surface features and historical references suggests that many domes were constructed using radial bricklaying techniques, possibly with earthen supports or wooden centering.

The use of lime-ash plaster (*chilpiq*) to seal interior walls is consistent with traditional practices observed in other Central Asian water systems. This waterproofing technique likely contributed to the durability of these structures, even with fluctuating groundwater levels.

One critical aspect of the *tegizamin* system was its restricted accessibility. The exact location of a *tegizamin* dome was known only to the appointed master craftsman and a few trusted individuals. To preserve the secret, the master would pass the information on to a chosen successor before death. Every ten years or so, the dome's upper layers would be partially dismantled to remove accumulated sediment and silt (Fig. 11). The excavated material, rich in organic matter, would be repurposed by farmers as fertilizer. This practice reflects an early form of circular urban resource management (Boltaev 1965). The *tegizamin* was regarded as a crucial structure for both collecting rainwater and treating wastewater.

Future research, particularly if supported by archaeological excavation and material analysis, may help clarify the range of construction techniques employed, including possible typological distinctions between cisterns for wastewater and drinking water. Such studies would provide valuable data on the adaptability and performance of historical Khorezmian water infrastructure in this challenging desert climate.

These construction practices illustrate a holistic understanding of material behavior, climate response, and infrastructure resilience. The *tegizamin* is a prime example of how traditional Khorezmian builders synthesized empirical knowledge with functional design to create robust and adaptable systems, essential to the sustainability of historic Khiva.

Structural and Functional Analysis

The Khivan *tegizamin* system represents a comprehensive, historically advanced solution for urban water management, fulfilling three primary functions: rainwater retention, wastewater drainage, and potable water storage. These underground cisterns were embedded in the urban layout and vital to maintaining sanitary and sustainable living conditions from the eighteenth to the twentieth centuries.

In both Ichan-kala and Dishan-kala, *tegizamins* were directly connected to interior drainage by means of *adans* and *gulbidavs*, funneling wastewater and graywater from kitchens, ablution areas, etc., to the cisterns. This gravitational system had no need for pumps and leveraged Khiva's permeable sandy soil for natural filtration in a passive and eco-efficient infrastructure model.

Functionally, Khiva's underground systems were zoned by water type (Fig. 12):

- Wastewater *tegizamins* were often located in domestic courtyards: dome-covered pits with diameters of 10 to 15 meters and depths of 3 to 5 meters. They received domestic graywater and rainwater, allowing gradual percolation into the subsoil.

- Drinking-water *tegizamins* (*sardoba*), on the other hand, were usually integrated into public buildings, such as Kutlug Murad Inoq Madrasah (its *tegizamin* was built in 1810), and included stairs for controlled access. Domes prevented contamination and evaporation. According to Islamic jurisprudence, cisterns with a surface area exceeding 100 m^2 were deemed fit for supplying *halal* drinking water, even when sealed for long periods (Stephan 2023; Haddad 2021).

A notable case is the Turt Shahboz *tegizamin* in Dishan-kala, which remained in use until the 1930s. With users estimated in the hundreds, it was a major water source. After its dome collapsed, residents had recourse to a nearby

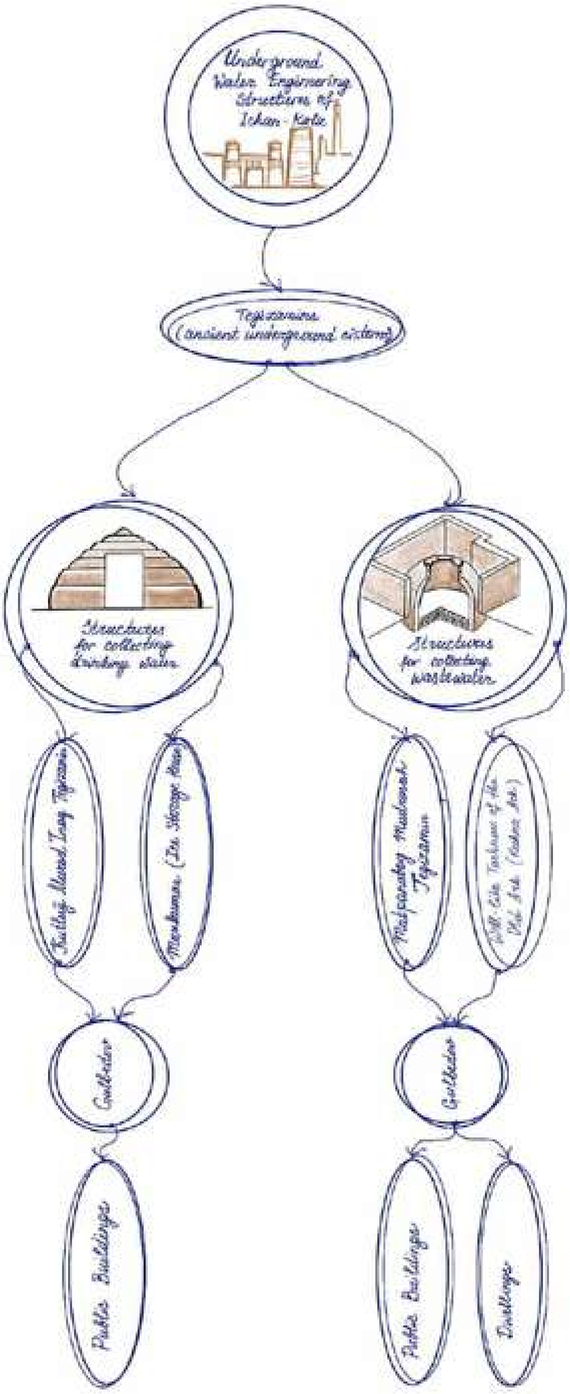


Figure 12: Diagram of the *tegizamins* of Ichan-kala

pool, although when the feeder channel (*aryk*) got blocked, this too became unusable. Yet restoration of the *tegizamin* in the early twenty-first century helped reinstate its historical function and significance within the Turt Shahboz complex (Mamun Academy 2018).

These subterranean structures exhibit a high degree of adaptability and structural foresight. The builders would anticipate seasonal shifts, urban settlement trends, and maintenance needs. Thus, as mentioned, many *tegizamins* were designed for periodic cleaning: the top two meters of the dome would be dismantled once a decade to remove silt, used as fertilizer.

Similar to the structures of early Khorezm, which Ahmedov (1995) describes as domed cisterns of adobe and baked brick for both religious and household purposes, the Khivan *tegizamin* reflects a continuous evolution of vernacular engineering. Such systems not only served practical needs but were connected to ritual practices, public hygiene, and urban cosmology—characteristics also seen in the monumental *sardobas* and seasonal reservoirs of the early Bukhara and Karshi settlements (Ahmedov 1995: 34–36).

Khivan *tegizamins* were often cylindrical or conical in section, echoing earlier Central Asian cistern types, with vaulted access corridors and sedimentation basins. Their domes, often finished with lime plaster or terracotta tiles, helped regulate internal temperature and control growth of organisms. Similar protective strategies were used in the fire temples and domestic underground cooling systems of the early feudal period (Ahmedov 1995: 135–137).

All these systems reflect a layered logic of functional zoning, environmental synergy, and low-impact engineering. Although the familiar imagery of Khiva's architectural legacy is of minarets and madrasahs, the town's resilience resided in these buried structures—durable, adaptive, and integral to public health and sustainability. Their rediscovery and potential reactivation involve insights into pre-modern eco-design and urban resilience strategies relevant to present-day climate-adaptive urban planning.

Excavation and Proposed Restoration

To date, no systematic archaeological survey has been undertaken to study the *tegizamin* systems of Khiva (Fig. 13). Thus, future research might uncover the construction methods, typological diversity, and hydrological logic embedded in these buried cisterns. Future excavation efforts could begin with detailed stratigraphic analysis to determine chronological sequences and structural integrity. In line with regional comparative examples, such cisterns may feature rounded brick vaults constructed above cylindrical or conical chambers, with estimated

Figure 13: Restored *tegizamin* near the Matpanaboy Madrasah in Ichan-kala

dimensions of 3 to 5 meters in depth and 10 to 15 meters in diameter. Their internal walls may have been coated with *chilpiq* clay and plant-ash plaster to reduce percolation and protect stored drinking water from contamination.

According to Boltayev's manuscripts (1965), test excavations along historical routes between madrasahs such as Khojamberdibai and Allakulikhan in the densely populated part of Ichan-kala may reveal the existence of underground systems for two purposes—separate cisterns for graywater and drinking water.

These might be connected to domestic inlet channels (*adan*) and sand-filtration basins (*gulbidav*), suggesting a discerning approach to water segregation and hygiene. Evidence of phased construction from the late eighteenth to the early twentieth centuries could indicate customary practices of maintenance, adaptation, and community involvement.

Materials analysis should be integrated into the excavation methodology, with attention to the possible presence of glazed ceramic drainage conduits, stone overflow spouts, and sealing slabs. Soil sampling at the cistern base could reveal natural filtration substrates such as charcoal or fine-grain sand, pointing to an empirical understanding of passive purification methods.

To avoid intrusive impacts on built heritage, non-invasive techniques such as ground-penetrating radar, 3D photogrammetry, and soil resistivity surveys should be employed to detect subsurface features. These tools would support the mapping of Khiva's buried hydrological infrastructure and clarify the extent to which the *tegizamin* system was integrated into overall urban planning.

Finally, findings from such investigations could support the development of a classification system distinguishing cisterns by function, volume, shaft geometry, and type of water treatment. This taxonomy would aid heritage conservation initiatives and serve as a model in the revision of Khiva's urban development plans, particularly in efforts to enhance sustainable water use and resilience to climate variability.

Discussion

Khiva's historical underground water systems offer valuable insights for sustainable urbanism today. Their passive, low-energy design aligns with modern climate adaptation and water resilience goals. Comparable to Persian *qanats* and Moroccan *khettaras* (Walker 2022), *tegizamins* demonstrate how localized hydrological knowledge can shape durable infrastructure. Reviving such systems may inspire context-sensitive solutions in contemporary towns and cities facing similar environmental challenges (Bahraseman et al. 2024). As Ahmedov notes, Central Asian cities historically developed layered spatial and infrastructural organization systems, and in particular underground and courtyard-based water management suited to arid climates. These systems constituted technical solutions and typological and urbanistic patterns integrating water with domestic, religious, and public architecture (Ahmedov 1995). This historical precedent supports the notion that Khiva's infrastructure was not an exception but rather part of a broader cultural and environmental intelligence in pre-modern Central Asia.

Ahmedov (1995) also notes that pre-Soviet city planning in Khorezm incorporated decentralized water structures into each *mahalla* (neighborhood), facilitating resilience against drought and social cohesion through shared resources. Such distributed, community-based models echo modern principles of sustainable and inclusive design.

Moreover, the material and construction logic of *tegizamins,* based on resource-efficient, biodegradable, and regionally sourced materials, resonates with contemporary principles of circular construction and carbon minimization.

In this light, Khiva's historical subterranean water systems are a potential prototype. They offer strategies applicable in urban areas struggling with water scarcity, climate stress, and heritage preservation. They challenge modern planners to see infrastructure as both a utility and an embedded cultural and ecological system.

Conclusions

Our research has shown that Khiva's underground water systems, and particularly its *tegizamin* cisterns, embody a refined synthesis of environmental adaptation, material intelligence, and infrastructural foresight. These systems, built in response to the city's sandy terrain and seasonal flooding, reflect a pragmatic and sustainable approach to urban water management. The discovery of underground engineering structures in Khiva is the first known case of such findings in Uzbekistan. Although our research is ongoing and many other subterranean structures mentioned in historical manuscripts have yet to be unearthed, it suggests the likely existence of similar underground systems beneath other historic cities in the region. This study is thus a contribution to understanding Khiva's hydraulic heritage and a prelude to future research projects across Uzbekistan.

Our findings highlight the sophistication of Khiva's historical water infrastructure, not as isolated technical features but as integral components of urban design. The rediscovery and analysis of these systems illustrate climate-responsive, passive, and low-energy solutions that remain relevant for today's arid and semi-arid cities.

By integrating such heritage-based practices into modern infrastructure planning, Khiva offers a scalable model for sustainable development, combining heritage preservation with innovation. In doing so, it supports the notion that ancient cities were not only culturally rich in their townscapes but also structurally and functionally advanced below ground.

References | Referencias | Referências

Ahmedov, Mukhammad. 1995. *History of the Central Asian Architecture*. Tashkent: Uzbekistan.

Allaeva, Nigora. 2018. *Khiva honligi diplomatiyasi (XVI–XIX asrlar)*. Tashkent: Adabiyot uchkunlari.

Allaeva, Nigora. 2019. *Khiva honligi diplomatiyasi va savdo alokalari (XVI–XIX asrlar)*. Tashkent: Academnashr.

Allaeva, Nigora. 2023. *Khorazm va Eron: XVI–XIX asrlarda savdo-diplomatik alokalar dinamasi*. Tashkent: Fan.

Amirova, Iroda; Petrick, Martin; Djanibekov, Nodir. 2022. *Community, state and market: Understanding historical water governance evolution in Central Asia*. Halle: IAMO.

Azizova, Bonu. 2015. Modern Architecture of Uzbekistan. *Architectural Engineering Technology*. http://dx.doi.org/10.4172/2168-9717.1000146

Azizova, Bonu. 2017a. Architectural Longevity-in the Case of the Summer Palace Chandra-Hauly in Khiva City, Uzbekistan. *MOJ Civil Engineering*. http://dx.doi.org/10.15406/mojce.2017.02.00045

Azizova, Bonu. 2017b. Architectural Longevity-in the Case of the Summer Palace Chandra-Hauly in Khiva City, Uzbekistan. *MOJ Civil Engineering*, 2, 5: 158-160.

Azizova, Bonu. 2023. Energy-efficient residential building in Uzbekistan using local renewable. *Journal of Physics: Conference Series*, 2600. Lausanne: IOP Conf Series.

Azizova, Bonu; Osello, Anna. 2020. Integration of Natural Elements into the Traditional House (of Khorezm Region, Uzbekistan) for Climate Improvement. *Environmental Engineering - Inženjerstvo okoliša*, 7, 1: 43-49.

Bichsel, Christine. 2021. The history of water politics in Central Asia. In Laruelle, A. C. (ed.), *Routledge Handbook of Contemporary Central Asia*, 14. London: Routledge.

Boltaev, Abdulla. 2013. *Xiva memoriy qoidalari [Architectural rules of Khiva]*. Khorezm: Khorezm.

Durdieva, Gavhar. 2012. Environmental Change as a Threat to the Khorezm Heritage. *Disaster by Design: The Aral Sea and its Lessons for Sustainability (Research in Social Problems and Public Policy)*, 20, 291-304. Leeds: Emerald Group Publishing Limited.

Durdieva, Gavhar; Azizova, Bonu. 2021. Significance of Ancient "Zakhkash-Zovur" around "Ichan-kala" in life extension of Architectural Monuments. *Design Engineering*, 9: 10200-10206.

Esfandiari Bahraseman, Sasan; Firoozzare, Ali; Zhang, Can; Yousefian, Nazanin; Skominas, Rytis; Barati, Reza; and Azadi, Hossein. 2024. Reviving the forgotten legacy: Strategies for reviving qanats as sustainable. *Water Research*, 265: 1-13.

Haddad, Marwan. 2021. Water supply, sanitation, hygienic considerations and practices in Muslim civilizations. https://muslimheritage.com/water-supply-sanitation (consulted on 09/04/2021).

Kantarci, Kemal; Uysal, Muzaffer; and Magnini, Vincent P. 2015. *Tourism in Central Asia: Cultural potential and challenges*. Toronto: Apple Academic Press.

Khaitov, Orif Bolikulovych; Aminova, Rukhshona. 2022a. Tourism and problems of development of historical cities (on the example of the city Khiva). *International Engineering Journal for Research & Development*, 7, 3: 5-8.

Knobloch, Edgar. 2001. *Monuments of Central Asia: A guide to the archaeology, art, and architecture of Turkestan*. London: I.B. Tauris.

Kutlug Murad Complex. 2007. https://people-travels.com/sights/kutlug-murad-complex (consulted on 02/05/2025).

Masson, Mikhail Yevgenyevich. 1976. *From the memoirs of a Central Asian archaeologist*. Tashkent: Gafur Ghulam Literature and Art Publishing House.

Mutalov, Oybek. 2005. *The Khiva Khanate during the reign of Allakulikhan*. Tashkent.

Notkin, Iosif Isaakovich. 1960. *Stroitel'nye priemy i konstruktsii v arkhitekture Khivi [Building techniques and structures in the architecture of Khiva]*. Tashkent: Izd-vo Akademii Nauk Uzbekskoi SSR.

Stephan, Raya Marina. 2023. Overview of Islamic water law. *XIX World Water Congress, International Water Resources Association (IWRA)*. Beijing: IWRA XVIIIth World Water Congress.

Walker, Katharine. 2022. Ancient systems keep water flowing. *Nature Middle East*. https://www.natureasia.com/en/nmiddleeast/article/10.1038/nmiddleeast.2022.72 (consulted on 02/05/2025)

Zohidov, Pulat. 1996. *Me'mor olami*. Tashkent.

Zohidov, Pulat. 1997. *Xiva: Ochiq osmon ostidagi muzey*. Tashkent.

Biography | Biografía | Biografia

Bonu Azizova

Bonu Azizova is a doctoral researcher in sustainable architecture at the Technical University of Berlin. She holds a prior PhD in architecture from the Tashkent Institute of Architecture and Construction. Her research explores the intersection of vernacular heritage, traditional water systems, and low-carbon housing in Central Asia. She has participated in international initiatives focused on energy-efficient construction and heritage preservation, and has presented her work at academic conferences across Europe and the United States.