



Water-Oriented Design Strategies and Rising Damp Mitigation in Anatolian Seljuk Period Architecture: Konya Ince Minareli Madrasa Review

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ARTICLE INFO

Article history:

Received 3 April 2025
Received in revised form 11 April 2026
Accepted 14 April 2026
Available online 25 June 2026

Keywords:

stone masonry, porosity, rising damp, water and moisture control

Doi: 10.24012/dumf.1669545

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ABSTRACT

Throughout history, water has emerged not only as a vital necessity but also as a guiding design principle in the construction and planning practices of civilizations. Decisions regarding the location of settlements and the construction of buildings reflect cultural relationships with water, particularly in terms of its supply, control, and discharge. This study aims to examine the water management infrastructure of the Anatolian Seljuk period through a multi-dimensional approach that integrates urban morphology, architectural configuration, material properties, and hydraulic components. In this context, the morphological structure and hydraulic potentials of Konya were first assessed. Within this scope, the Ince Minareli Madrasa was selected as a representative historical masonry building from the Seljuk period. The case study analysis includes an investigation of its water-regulating infrastructure together with its current structural condition and observable damage indicators. The primary construction material Sille stone (trachyte), exhibits high porosity and strong sensitivity to moisture. Rising damp, resulting from capillary water movement through porous walls in direct contact with the ground, causes salt accumulation and material deterioration over time. The hydraulic systems designed to control rising damp demonstrate the functional and environmental role of water management in Seljuk architecture. These findings offer valuable insights for the development of water-resistant design strategies and provide a holistic framework for interpreting the relationship between historical buildings and water.

Introduction

In the dynamic formation of cities, natural landscape transforms into cultural landscape, and in this transformation, “water” sets the rules. Water is an indispensable necessity, but at the same time, it is a risk factor that requires precautions due to its erosive effects. The interaction between water resources, environmental conditions, and construction technologies has therefore played a decisive role in shaping urban identity throughout history. The traces of the Anatolian Seljuks are clearly legible in the urban archaeology of Konya. The original configuration of hydraulic equipment in the structures of the period indicates architectural decisions taken with an awareness of water sources and soil conditions. Although Konya is located on a dry and arid plain, it has developed as an urban center sustained by groundwater and spring-fed water resources. The water management infrastructure developed in response to Konya’s hydrological potential was composed of an integrated system of channels, galleries, wells, cisterns, and fountains, enabling the supply, distribution, storage, and discharge of water across both urban and architectural scales.

However, despite this controlled relationship with water, historical buildings in Konya have been exposed to various

water-related deterioration processes over time. To examine this situation, a building in which water-related input–output effects can be clearly interpreted was selected as a model for analysis. The Ince Minareli Madrasa was chosen as the case study due to the strong body of existing literature that evaluates its material properties through engineering calculations and laboratory experiments, and documents deterioration patterns within the structure.

In particular, the Ince Minareli Madrasa presents a significant case, as it was originally equipped with a comprehensive water management infrastructure that regulated the supply, circulation, and discharge of water. Over time, however, the functional continuity of this system was disrupted; elements such as galleries and subsurface water channels lost their operability, and the broader hydraulic balance was altered or eliminated. This transformation has led to the accumulation of moisture within the building fabric and the emergence of structural and material deterioration problems. Due to the porous structure of the Sille stone used in this building, moisture rising from the ground through capillary action has led to material degradation, including salt crystallization, surface loss, and structural weakening. Observations indicate that deterioration is especially concentrated at the lower wall zones, the monumental portal (*taçkapi*) and the base of the

minaret, where prolonged exposures to moisture and inadequate drainage conditions have intensified decay mechanisms. Accordingly, the loss of hydraulic continuity has contributed to the emergence of deterioration processes by transforming water from a controlled architectural element into a source of material decay.

In this respect, the Ince Minareli Madrasa constitutes a representative case study, as it embodies both the original design strategies developed to manage water and the subsequent deterioration processes resulting from the loss of these systems. Similar water-related infrastructure elements and deterioration patterns can also be observed in other Anatolian Seljuk madrasas, such as Karatay and Sırçalı Madrasas, indicating that this issue is not isolated but rather reflects a broader architectural and conservation problem. Therefore, the selection of this structure as a case study enables a comprehensive evaluation of both historical water management strategies and their long-term performance in relation to material behavior and environmental conditions.

Accordingly, this study aims to examine the relationship between historical water management strategies, material properties, and water-induced deterioration processes to contribute to a more comprehensive understanding of water-oriented design principles in Anatolian Seljuk architecture.

Material and Methods

The methodological framework of the study is based on a multi-stage analytical approach that involves the collection of water management data at both urban and building scales, followed by the building-specific analysis of architectural characteristics, material behavior, and structural deterioration indicators.

In this framework, the study was structured in three main stages:

- (i) identification of Konya's hydrological and hydrogeological characteristics together with its water management elements at urban and building scales,
- (ii) determination of water-induced deterioration mechanisms in masonry structures based on material behavior, and
- (iii) a case study analysis to evaluate the consequences of the loss or deactivation of water management systems.

The original moisture removal systems found in historical buildings are based on three strategies: reducing the water source, interrupting water transmission, or eliminating moisture through evaporation. In historical buildings, rising damp caused by capillary movement of water from the ground into the walls can lead to various forms of deterioration. The deactivation of the original equipment systems has manifested in different types of deformation within porous materials. To define these deterioration processes, a review of existing studies on masonry materials was conducted, focusing on capillary water absorption, salt crystallization, and moisture transport

mechanisms. Accordingly, the hygroscopic properties of the materials and the current structural condition of the building were evaluated based on documented observations and existing datasets.

Subsequently, in the analysis phase focusing on the Ince Minareli Madrasa, material properties were evaluated through previously conducted engineering-based studies that include mechanical and physical analyses of building materials [Source 16,17,18]. These studies provide quantitative data on parameters such as porosity, water absorption capacity, and material strength. In addition, deformation assessments [Source 49,61,62] and documented surveys [Source 29, 45] specifically related to the Ince Minareli Madrasa were analyzed to identify deterioration patterns related to water and moisture within the structure.

Although the material analyses were not conducted directly within this study, the evaluated datasets are based on previously performed tests carried out in accordance with standard material testing procedures reported in the literature, ensuring the reliability and comparability of the results.

The collected data were comparatively assessed to establish a relationship between the original water management system and the current structural behavior of the building. In this context, material performance and observed deterioration patterns were interpreted together with the functionality or loss of functionality of water management elements.

The methodological findings were then synthesized to interpret the relationship between water management systems, material behavior, and deterioration processes. The findings also provide a basis for interpreting the relationship between water management strategies and the long-term performance of architectural systems in Anatolian Seljuk structures.

Physical Geography and Water Potentials of Konya and Water Management Culture in Anatolian Seljuks

The architectural texture of the city is shaped by the economic, political and geographical conditions determined by water. Konya developed within a geomorphological setting where groundwater resources and spring systems played a decisive role in settlement formation. Water revitalized life in times of peace, and during sieges, it filled the canals surrounding the city walls to protect the city's borders [1]. In the foundation of the city, the Anatolian Seljuks created waterways in the form of beams emanating from the source, built buildings with various functions such as inns and caravanserais on these roads, and built wells in places where there was no water [2]. Konya is located on the edge of a plateau plain at an altitude of 1000 meters above sea level in the inner part of the mountain ranges extending in the east-west direction. This area, known as the Konya Plain, is a filled lake bottom and some parts of it were still swamps or lakes during this period. The most depressed part of the

Konya Plain is the Aslim Swamp, located north-east of the city. The slope rising from this swamp at 975m elevation reaches 1080m at Alaeddin Hill in the center of the city. The surrounding low hill ranges to the east and Mount Loras at 2010m above sea level and Mount Erenler at 2319m to the west defines a concave area [3]. Literary sources do not mention the presence of surface water in this basin, which is surrounded by mountains. In this closed basin system, urban morphology, lithology, and topographic depressions collectively determine groundwater movement and water accumulation patterns. The boundaries of the city are also legible through the spatial distribution of the city center and the development of the water supply network (Figure 1).

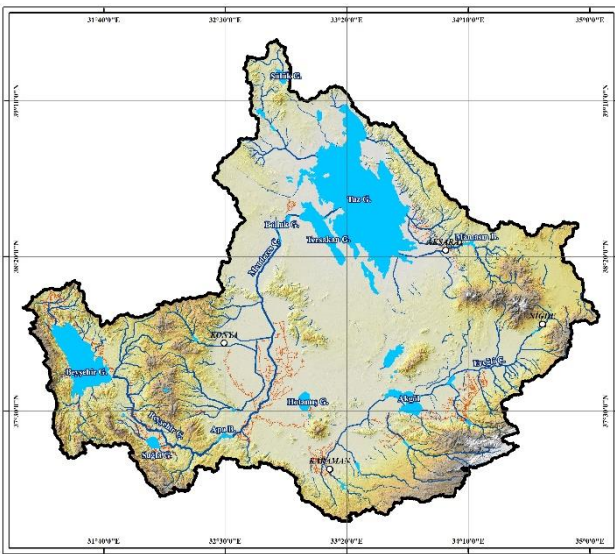


Figure 1. Hydrological characteristics of the Konya Closed Basin. The map illustrates a closed hydrological structure where surrounding topography limits drainage and leads to water accumulation and a relatively high groundwater level in certain areas [4]

The springs from the rivers and lakes around the city were transported to the center through canals and the surface water was discharged by connecting to springs. The water resources in the vicinity; Salt Lake, Beyşehir, Suğla, Ilgın and Akşehir Lakes and Meram Stream and Melendiz Stream have been utilized by creating water structures since the Neolithic Age [5].

There is also a period-specific infrastructure for water supply. The irrigation canal system, which was widely used in geographies where water was scarce and precious, is also found in Anatolian Seljuk architecture. The primordial application of the ancient irrigation system called Kanat is found in northern Iran and dates to around 3,000 years ago. The technology, consisting of tunnels connecting shafts designed to collect and transport water, spread over a wide area from Mesopotamia to the Mediterranean, from Egypt to Central Asia [7]. Although

there are traces of water being delivered to the city center through canals in the earlier civilizations that inhabited the city, the water system integrated with the built environment was established only during the Seljuk period. When the Seljuks conquered Konya, they first utilized the existing canal system, then the Seljuk Vizier Sahip Ata Fahrettin Ali added a canal called “Sahip Su Rulers” to this system and connected the whole system to a certain basis [8]. The water that fed these canals came from the mountains to the west of the city. Meram Water was conveyed from the river to the water distribution structure known as Havzan, located on the west gate of Konya Castle, from where it was collected and distributed by funnels. In the summer, when the water did not come down to the city, water was provided through wells and closets [2]. Within this hydrological framework, water management in Seljuk architecture involved both supply systems and discharge strategies. The integration of transmission lines with buildings ensured water supply, while drainage and moisture control solutions regulated excess water and groundwater effects.

In addition to water supply, the saturated soil profile due to groundwater and surface waters affecting the soil quality is the reason for the need for water management at the building and settlement scale. Floods and overflows caused by seasonal precipitation appear in the history of the city, which is a closed basin, as a water-related risk element that had to be managed. The city walls built by the Seljuk Sultan Alaeddin Keykubat I define the boundaries of the city not only for defense purposes, but also for the purpose of establishing a line surrounding the city with a ditch twenty *gez*/arches deep where flood waters are collected. The water collected in this ditch was discharged into the lake to the northeast [6]. This defensive and hydraulic system demonstrates that water management infrastructure in Konya addressed groundwater control, flood mitigation, and surface water distribution simultaneously.

Water management infrastructure developed for the discharge of water stands out as a crucial design value that has played a significant role in both the preservation of the structure to the present day and its secure transmission to the future. Within this infrastructure setup, two distinct systems are clearly discernible: one ensuring water supply and the other controlling moisture and humidity.

Within the broader architectural tradition of the Anatolian Seljuks, water-related elements such as pools, wells, canals, galleries, cisterns, and fountains formed an integrated hydraulic network responsible for water conveyance, collection, storage, and discharge. This functioning can be observed in surviving historical buildings equipped with water collection infrastructure.

Pools

The operation in which central water management elements such as pools and wells are placed at the heart of the structure achieves a functional balance within the spatial weight distribution, while also reflecting a continuation of tradition from a symbolic perspective. In Seljuk architecture, water elements function as symbolic components reinforcing spatial hierarchy. In this context, the central orientation tendency that dominates the spatial layout of Anatolian Seljuk madrasas is reinforced by the inclusion of elements such as pools or wells positioned along the central axis defined by the courtyard or dome. In a scheme where the single-domed space constitutes a center and the iwan forms a directional axis; the cultural significance of water finds meaningful expression in the reflections of symbolic imagination. The dome represents the heavens above the central space, and the pool beneath it brings together the elemental forces of sky, earth, and water [19]. This conceptual approach aligns with the ancient cosmological image of the "cosmic ocean surrounding the universe" [20]. Accordingly, the pool becomes both a spatial focal point and a hydraulic control element within the architectural composition. The centrally placed pool and associated infrastructure, located in the enclosed courtyard, are also found in Karatay, Sahip Ata, and Ali Gav Madrasas, in addition to Ince Minareli Madrasa. The domed central pool is a product of the Central Asian spatial tradition. The presence of similar dome-pool relationships in Afyon Çay, Isparta Ertokuş, and Kırşehir Carabey Madrasas reflects the ongoing architectural pursuit of the Anatolian Seljuks [21].

In the spatial organization of Anatolian madrasas, the search for center and direction comes to the fore. Water-related elements, such as pools or wells, also play a significant role in reinforcing this central organization. A comparative evaluation of Anatolian Seljuk structures in terms of their central spatial organization and water management components reveals the relationship between spatial configuration and hydraulic infrastructure.

These buildings, typically developed as domed and iwanned structures, follow a defined plan scheme while allowing variations in the arrangement of architectural elements. The domed madrasa plan emerged when the courtyard was covered with a dome. The first madrasas in Anatolia are domed type. The first example, the Bosra Gümüştekin Madrasa (1136), remained an isolated example without subsequent development. However, the domed madrasa organization that started in Anatolia afterwards showed a continuous development and formed a basis for a collective space solution [10]. The most prominent difference between the closed and open courtyard madrasa types used and developed in the Anatolian Seljuks is based on the fact that in the closed

courtyard type, the space in question is covered with a dome and developed in a square quadrangular plan layout, while in the open courtyard functioning fiction, the courtyard is mostly rectangular in the direction of the entrance axis [14]. This typological continuity demonstrates that the dome-pool relationship became a recurring architectural strategy. Although the centralized design of the dome is reminiscent of the Yağlıbasan Madrasas built in Tokat and Niksar in the 12th century and bearing traces of Central Asian residential structures, there is another experiment in which the domed closed madrasa plan and the open madrasa typology intersect. The only feature that distinguishes the Ince Minareli and Karatay Madrasas from open madrasas is the replacement of the courtyard with a domed volume [12]. In this configuration, the dome and centrally positioned pool together establish a spatial and hydraulic control system that guides water management within the structure.

The distribution of water management elements across different structures reveals that the dome-pool relationship forms the core of a recurring spatial and hydraulic organization observed throughout Anatolian Seljuk architecture. This configuration can also be observed in architectural applications in Konya, where similar spatial and hydraulic principles are maintained (Table 1).

Table 1. Anatolian Seljuk architecture demonstrates a strong relationship between centralized spatial organization and water-based architectural elements. This central configuration functions as a geometric and symbolic core, as well as a focal point for water collection and regulation

Structure / Location	Central Dome	Pool	Channel	Gallery	Well	Cistern
Ince Minareli Madrasa / Konya	•	•	•	•	-	•
Karatay Madrasa / Konya	•	•	•	•	-	-
Sırçalı Madrasa / Konya	-	•	•	•	-	-
Ali Gav Madrasa / Konya	•	•	•	•	-	-
Sahip Ata Hanchah / Konya	•	•	•	•	-	•
Yağlıbasan Madrasa / Tokat	•	•	-	-	-	-
Afyon Çay Madrasa / Afyonkarahisar	•	•	-	-	-	-
Ertokuş Madrasa / Isparta	•	•	•	-	-	-
Cacabey Madrasa / Kırşehir	•	•	•	-	-	-
Gök Madrasa / Amasya	•	•	-	-	-	-

Surface, ground, or spring waters were stored in open basins or pools constructed within designated spaces. In Anatolian Seljuk architecture, a certain geometric harmony was sought in pool design, typically based on the numbers 3-4-5 and their multiples or products. Often, a ratio of 1.618 between the sides was maintained [25]. The fountain structure with a spout, locally referred to as fountain nozzle (*büngüldek*), channels water into the pool via terracotta pipes (*künk*) running beneath the floor surface. Water flows into the pool through the *büngüldek*, and once the pool reaches capacity, the overflow is directed along an open channel surrounding the pool and is ultimately discharged through a drain carved into the pavement surface [22] (Figure 2). This system demonstrates that pools functioned as regulatory elements controlling water level and directing drainage.

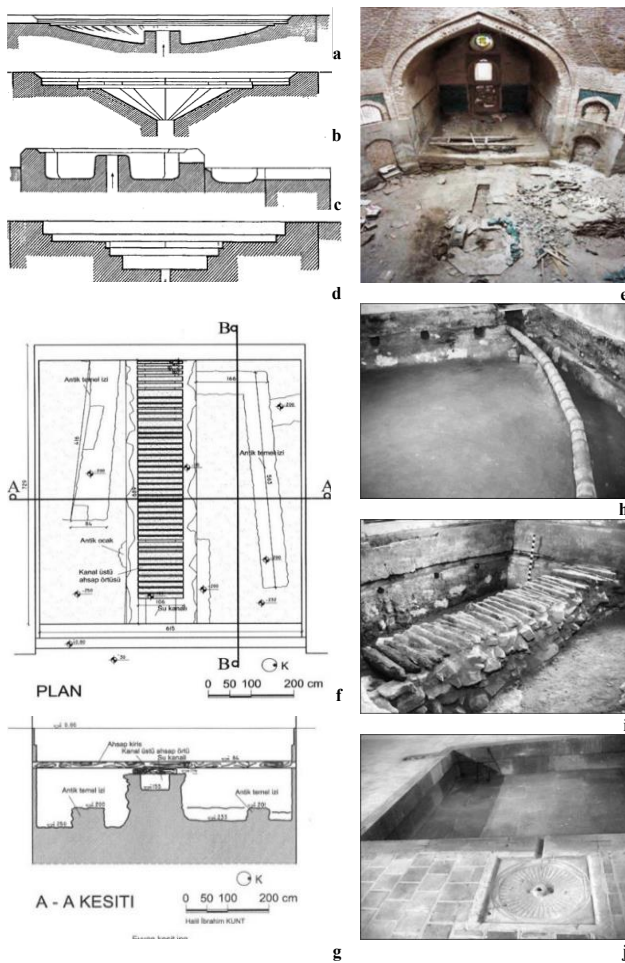


Figure 2. Differentiated applications of fountain basins with jets, embedded into the floor as pools, are observed in Seljuk Architecture, examples of systems contributing to moisture reduction through subfloor ventilation of the building. a- Curved pool surface, Karatay Madrasa in Konya, b- Chamfered pool surface, Gök Madrasa in Amasya, c- Flat pool surface, Hasip Dede Pavilion in Konya, d- Stepped pool surface, Fountain of the Hacı Bayram Retreat (Çilehane) in Ankara [22], e- Pool associated with the iwan, Sahip Ata Khanqah [23], f-

Intersection of channel and gallery in the main iwan plan, Karatay Madrasa, g- Section showing different elevation levels of channels and galleries, Karatay Madrasa, j- Fountain nozzle (*büngüldek*) and associated equipment of the Karatay Madrasa pool [24]

A representative example of a pool-centered infrastructure is evident in the Karatay Madrasa, a square-shaped pool with 3.75 m-long sides and a depth of 0.68 m lies directly beneath the central dome. On the southern edge of the pool, there is a square marble fountain nozzle (*büngüldek*). Water from the central fountain is collected into the pool through a narrow channel. On the western side, another channel with a reverse “S” shape facilitates the discharge of water. This form may have been designed to regulate the acoustic environment of Madrasa. Excavations have shown that terracotta pipes (*künk*) collecting water from this discharge channel exit beneath the threshold and are connected to an external drainage spout [24]. When considered together, the central pool, the freshwater inlet within the *eyvan*, and the drainage channel connecting to the exterior form a coherent and integrated infrastructure system.

This configuration demonstrates that the centrally positioned pool establishes an integrated organizational system by linking water supply, storage, circulation, and discharge elements within a unified spatial framework.

Channels and Galleries

Within the structure, the components of water infrastructure establish a flow network that connects interior fixtures and, on an urban scale, links buildings and spaces. Channels and galleries are essential for collecting and distributing water, thereby enabling water conveyance and collection. Interconnected channel systems prevent localized water accumulation and ensure controlled water movement within the structure. By regulating the water level and preventing it from rising excessively, the system reduces hydrostatic pressure on the building's foundations and walls. Collecting surface water into channels also minimizes capillary action within building materials. Thus, channels function as protective components that limit moisture-related deterioration.

In Anatolian Seljuk architecture, terracotta pipes (*künk* or *pöhrenk*, as commonly known) and open or closed channels were widely used. Water conveyed through these clay pipes was fed into buildings either from a single source or multiple points, rising vertically within walls and branching into secondary channels as needed, ultimately reaching a cistern, well, or open/closed pool for storage. Pipe segments were connected through interlocking joints to prevent leakage and maintain hydraulic continuity. Additionally, at points where the flow direction changed, particularly under increased pressure, custom shaped pipes in L, T, or Y forms or

monolithic stone components were employed [26]. These directional elements allowed controlled distribution of water. Galleries may either include terracotta pipes (*künk*) or, in cases where the goal is to collect seeping water along the route, be left unlined [27]. In addition to gathering and distributing water, galleries that surround the structure and extend beyond the building's footprint aid in reducing humidity-related impacts on the substructure by ventilating and removing moist air zones from the soil [28].

Cisterns

Cisterns are closed water storage reservoirs. Some cisterns are fed by channels connected to the water conveyance network, while others collect rainwater or are supplied by natural water sources. In settlements, water collected via drainage systems was often discharged into cisterns or fountain reservoirs [31]. Independent cistern systems provided both water storage and controlled discharge, ensuring hydraulic continuity during periods of limited supply or emergency conditions. Cisterns vary according to their structural configuration, including fully subterranean reservoirs, partially embedded systems, and above-ground storage components integrated with building substructures (Figure 3).

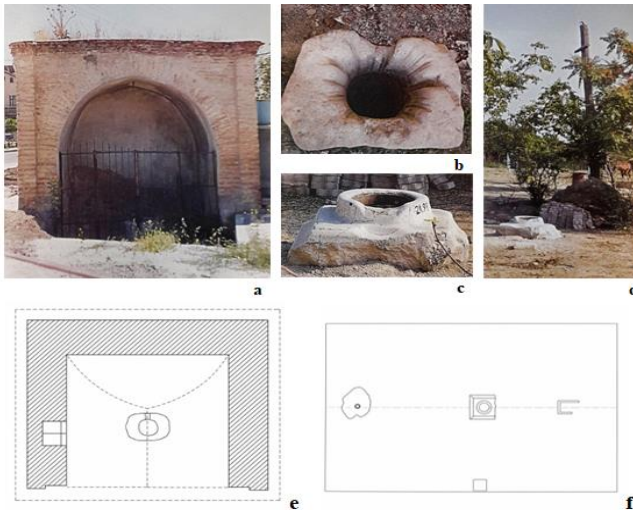


Figure 3. Examples of subterranean and above-ground cisterns of Konya. (a) Aksarnıç, (b) the collar of Aksarnıç, (c) the collar of Devler Cistern, (d) Winch (*çıkırık*) mechanism in Devler Cistern, (e) plan of Aksarnıç, (f) plan of Devler Cistern [32]

In Anatolian Seljuk architecture, cisterns were also constructed outside urban areas along caravan routes to meet the water needs of travelers and animals. Icehouses (*buzhane*), which share structural similarities with cisterns, served a comparable purpose. Functioning as cold storage units, icehouses were built underground and well-insulated to store snow and ice for use during the hot summer months. The main distinction between cisterns

and icehouses lies in the wall design: cisterns typically have perforated walls to allow the inflow of collected external water [32].

Numerous cisterns built of stone or brick can be found in and around Konya from the Seljuk period, particularly in areas with accessible water sources. Examples include the Hoca Fakih Cistern along the Konya-Beyşehir route and the Şerefeddin Cistern located on the Konya-Lâlebahçe Road. These were often constructed as freestanding storage units with earthen roofs, although in some cases, the water chambers were integrated into the basements of multifunctional buildings [33].

Fountains / Sabils

Fountains are above-ground water reservoirs that are either fed by a natural spring or connected to a water conveyance system. In terms of components, a typical fountain consists of a niche designed to hold a basin (*tekne*) and a spout (*lüle*) through which the water flows. In Seljuk architecture, fountains were commonly placed in public squares or courtyards of buildings. Additionally, wall fountains integrated into the façade of monumental structures became characteristic elements of architectural identity (Figure 4).

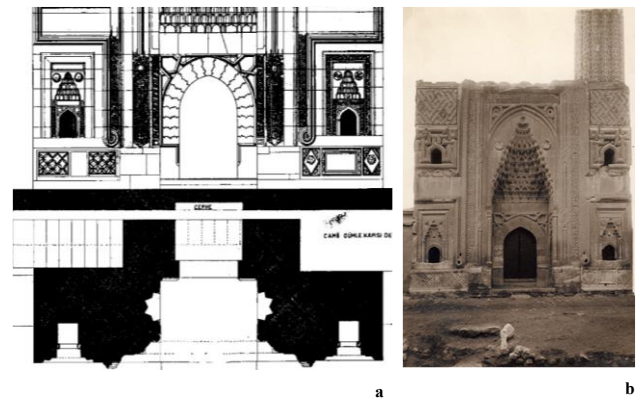


Figure 4. Wall Fountain of the Sâhip Ata Mosque. a- The location of the wall fountain in plan and elevation view [36], b- The monumental portal (*taç kapı*) and wall fountain [37]

One notable example is the fountain arrangement at the entrance of the complex commissioned by Sâhip Ata in 1258 in Konya, consisting of a mosque, *hankah*, and tomb. Beneath the twin minarets of the monumental entrance portal (*taçkapı*) are two water intake cells specifically designed for this purpose [35].

A common feature of exterior wall fountains in Seljuk architecture is their construction as shallow wall niches, despite variations in composition and design. In this system, the terracotta water pipe (*künk*) embedded within the wall does not directly discharge through the spout. Instead, the pipe first discharges into a small internal reservoir that regulates flow and allows sedimentation.

This prevents the formation of pressure due to dissolved air within the water, which could otherwise interrupt the flow. For this purpose, a carved stone basin was embedded into the wall at the fountain site. In some cases, repurposed ancient sarcophagi were used as basins. The integration of hollow stone reservoirs within the wall structure influenced façade design by combining hydraulic functionality with architectural composition. This system reflects a constructional logic in which hydraulic function and structural design were conceived together.

Wells

In the early 11th century, during the beginning of the Seljuk era, water wells (*kudug*) were among the most valuable sources of life in Anatolia, serving households, neighborhoods, and agricultural lands alike. After reaching the groundwater level, the shaft of the well was reinforced with stone lining, and the wellhead was constructed using masonry or perforated stone or wooden elements. To draw water, a wheel-and-axle system known as *çark* (commonly referred to as a water wheel or winch) was employed. A lever system, called a *seren* or *bastıran*, was positioned next to the well, providing support for the rotating arms of the winch and facilitating the vertical movement of the bucket [39]. These mechanical systems enabled controlled water extraction and contributed to groundwater regulation

Historical travel accounts report that there were approximately 2,700 wells in Konya [2], and that wells used for homes, gardens, and orchards were often notably deep [40]. Many of these wells were sealed after the introduction of piped water supply systems; however, their operation had previously contributed significantly to water management infrastructure (Figure 5).

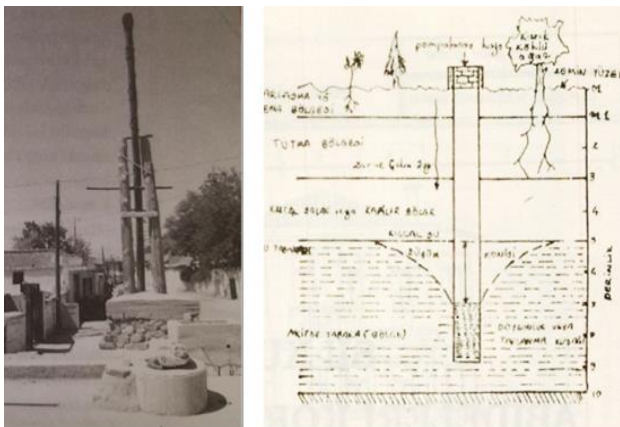


Figure 5. Examples of well systems used for water capture: (a) A well application incorporating a lever mechanism with a well winch in Konya [30]; (b) Vertical section/analysis of a well [41]

As water is captured from the aquifer, the local water level drops, resulting in a decrease in pressure within the well chamber. Meanwhile, the surrounding water-bearing formation maintains its original pressure. This difference in pressure between the well cavity and its surroundings enables the accumulation of water within the well chamber [41]. This practice, developed with a keen understanding of both water behavior and mechanical systems, is noteworthy not only for its effective use of the water table as a source but also for its contribution to drainage within the water infrastructure network. Each of the water features in Seljuk architecture provides a solution for collecting, accumulating, or discharging water (Table 2).

Table 1. Water management infrastructure and their contribution to buildings

Element	Function
Pools	Central collection of rainwater and canal water
Channels	Conveyance and discharge of surface or groundwater through directed drainage
Galleries	Removal of moisture through ventilation
Cistern	Storage of water via aboveground/underground reservoirs
Fountains	Storage of water via aboveground reservoirs
Wells	Balancing fluctuations in the water table

Physical Geography and Water Potentials of Konya and Water Management Culture in Anatolian Seljuks

In heritage buildings, where water infrastructure is integrated into the architecture, the risk of water-related decay is particularly important. The continued functioning of the infrastructure requires drainage and ventilation, and water and moisture control. If these systems lose functionality, moisture accumulation may occur at foundation and wall levels, accelerating deterioration processes.

Water and moisture are among the leading causes of material and structural deterioration in historic masonry structures. Natural building stones undergo physical, chemical, and biological deterioration over time due to atmospheric and biological effects [65]. Water-induced deterioration in building materials is not limited to liquid water penetration; it also includes vapor diffusion, condensation, and hygroscopic moisture absorption. Moisture can originate from atmospheric conditions (rain, humidity), ground sources, or indoor activities, and may enter materials through capillary transport, vapor diffusion, or air movement [58]. The rate of moisture movement depends on environmental conditions and material porosity. If not effectively controlled, moisture can seep into building components through capillary action, rising damp, groundwater intrusion, roof leaks, or

inadequate drainage systems. This can lead to a wide range of problems such as salt efflorescence, plaster flaking, biological growth (mold, algae, moss), metal corrosion, freeze-thaw cycles in cold climates, and general weakening of building materials such as brick, stone and mortar. Various strategies have been developed to control rising damp: drainage systems to reduce water ingress, physical section reduction to decrease wall capillary water absorption, plasters and ventilation systems that promote evaporation, as well as active and passive methods based on physical principles [42] (Figure 6).

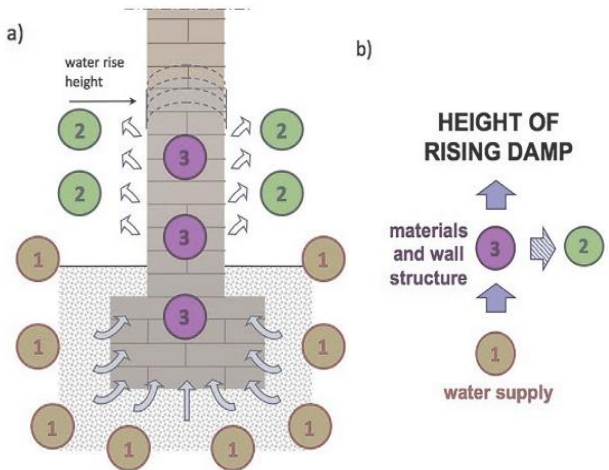


Figure 6. Capillary rise phenomenon in masonry:

(a) representation of moisture movement due to capillary action; (b) conceptual diagram illustrating the equilibrium height of rising damp [43]

Beyond material-level deterioration, water-related processes should also be evaluated within the broader framework of soil-structure interaction. Fluctuations in the groundwater table, variations in soil moisture content, and cyclic wetting-drying processes directly influence the mechanical behavior of both the ground and the structure. Changes in water content may reduce shear strength and increase pore water pressure, directly affecting the bearing capacity of the soil and thus the stability of masonry structures [55]. These interactions indicate that moisture acts as both a material-level and structural-level deterioration factor.

Field studies on historic masonry structures further demonstrate that inadequate subsoil conditions and moisture-related weakening can lead to differential settlements between structural elements, resulting in severe cracking and structural deformation. For example, in the case of the Konya Alaeddin Mosque, long-term moisture exposure and subsoil instability were identified as primary causes of differential settlement in columns and walls, ultimately leading to significant structural damage [59], (Figure 7).

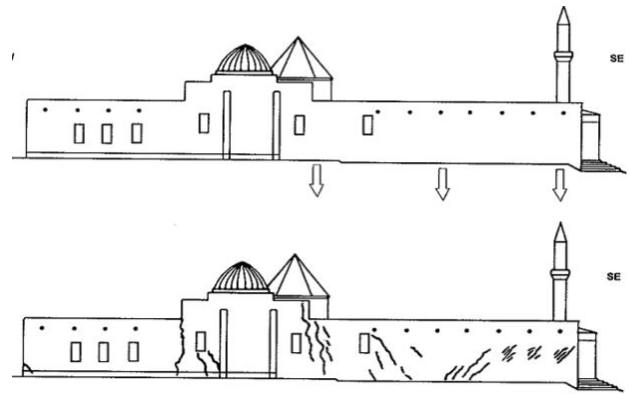


Figure 7. Settlement mechanism and resulting crack pattern at Konya Alaeddin Mosque [59]

Periodic changes in soil saturation may result in settlement patterns such as uniform or differential settlement, leading to structural responses such as inclination, cracking or rotation in vertical elements. Particularly in slender architectural components, these movements may evolve into torsional or overturning effects [56]. In this context, water acts as a surface-level decay agent and as a dynamic factor affecting the stability of the entire building system.

Water and moisture can cause various types of deterioration in load bearing masonry structures. Moisture rising through capillarity can dissolve the binder materials and lead to swelling or detachment of building components [47]. During wetting-drying cycles, temperature variations can also cause frost action. In freeze-thaw processes, salts that crystallize within the pores of materials contribute to surface erosion [50]. Chemical reactions between water and the mineral content in stone may produce salt crystals, leading to efflorescence on the surface [52]. Deterioration may remain superficial or penetrate deeper into the section, resulting in relief-type decay characterized by flaking, scaling, or laminar peeling [51]. Chemical interactions between stone minerals and water-borne elements may alter the material at the atomic level. In capillary pathways, silica can react with lime ($\text{Ca}(\text{OH})_2$), causing volumetric expansion, while CO_2 drawn into the material during groundwater fluctuations forms calcium carbonate (CaCO_3) [57]. As these processes progress into the material, they may lead to irreversible deterioration such as disintegration, material loss, and sub-surface salt crystallization, resulting in detachment.

From a material science perspective, these deterioration processes can be classified into physical, chemical, mechanical, and biological categories. Physical effects include freeze-thaw damage and thermal expansion; chemical effects involve salt crystallization, carbonation, and dissolution processes; mechanical effects are associated with stress redistribution due to settlement; while biological effects emerge through the growth of

microorganisms facilitated by moisture presence. These processes often act simultaneously, producing compound deterioration patterns rather than isolated damage mechanisms. Water-stone interactions may trigger chemical alterations at the mineral level, including dissolution, oxidation, and the formation of new compounds, which further accelerate long-term deterioration [60]. These processes demonstrate that moisture-induced deterioration operates across multiple scales, from microstructural changes to structural implications.

Therefore, water-related deterioration in historic masonry buildings acts as a multi-scalar process, operating simultaneously at the levels of material microstructure, building components, and ground-structure interaction (Table 3).

Table 3. Classification of water- and moisture-induced deterioration mechanisms in masonry structures

Deterioration Type	Mechanism / Cause	Observed Effects on Material	
Capillary Rise / Rising Damp	Groundwater rises through porous materials via capillary action	Dissolution of binders, swelling, detachment of material layers	[47]
Freeze-Thaw Action	Expansion of water within pores during freezing	Cracking, surface scaling, material loss	[50]
Salt Crystallization	Crystallization of dissolved salts within pore spaces	Internal stress, surface erosion, material weakening	[60]
Efflorescence	Chemical interaction between water and mineral content of stone	Salt deposits on surface, discoloration	[52]
Surface Degradation	Repeated wetting-drying cycles and internal stress development	Flaking, scaling, laminar peeling	[51]
Chemical Deterioration	Water-mineral interactions	Internal material weakening, loss of cohesion	[57]
Biological Growth	Presence of moisture and limited sunlight	Surface colonization, material degradation	[53]
Mold Formation	High humidity and insufficient ventilation	Surface staining, material decay, indoor air quality issues	[54]
General Material Weakening	Continuous moisture exposure and water infiltration	Strength loss in brick, stone, and mortar	[42]
Soil-Structure Interaction Effects	Fluctuations in groundwater level and soil moisture	Settlement, cracking, rotation	[55] [56] [59]

Moreover, under conditions where moisture is present and sunlight is limited, microorganisms may develop and cause lichenic formations on the material surface in shades of yellow, green, brown, pink, or gray [53]. If relative humidity and temperature increase and ventilation is insufficient, mold growth can also occur [54]. These biological formations contribute to deeper material degradation. Plant roots and microorganisms can penetrate pore structures, widen microcracks, and accelerate material disintegration [51]. Thus, moisture-driven biological activity can be considered a significant deterioration mechanism within masonry systems.

CASE STUDY: Architectural Configuration and Water Infrastructure of the Ince Minaret Madrasa

The Ince Minareli Madrasa was selected as a case study because it offers a rare and clearly readable example in which architectural configuration, material characteristics, and water management infrastructure can be evaluated together within a single monumental Seljuk building. The structure is particularly suitable for this study due to the coexistence of a centralized domed scheme, an integrated pool and channel system, locally sourced porous stone material, and clearly documented moisture-related deterioration processes. In this respect, the madrasa provides a representative and analytically rich case for examining how historical water management strategies were embedded in architectural design and how the loss of these systems has affected the long-term conservation of the building.

Ince Minareli Madrasa is located on the west side of Alaaddin Hill on the Sultan Gate Road. It was built by the Seljuk vizier Fahreddin Ali bin Hüseyin, known as Sahip Ata, as Darül Hadis. Its architect is Kölüg bin Abdullah [9]. The building, which today functions as the Museum of Stone and Wooden Works, is the only surviving unit of the complex of which it was a part. The portico of the masjid, which was demolished to the north of the madrasah at its foundation, is adjacent to the minaret. In 1901, the brick minaret, the upper part of which was destroyed by lightning, has two balconies [11]. There are a crown door and an entrance space solution connected to it that distinguishes the building from other applications. Such a composition is not encountered during or after the Seljuk Period. There is no other example of a madrasa with a masjid placed next to it [12]. In addition to these distinctive features, it is noteworthy that in the Ince Minareli Madrasa, architectural decisions associated with the centralized spatial organization widely adopted in Anatolian Seljuk building tradition are maintained both in the construction of the dome and in the integration of water management infrastructure.

In this context, the Ince Minareli Madrasa represents a hybrid spatial configuration in which the traditional open-

courtyard madrasa scheme is transformed into a centralized domed and enclosed space. Instead of an open courtyard, the main gathering area is covered by a single dome, while the surrounding cells maintain the conventional madrasa layout. This arrangement reflects an experimental interpretation in which the courtyard is replaced by a domed volume, forming a centralized spatial organization within the Seljuk architectural tradition [10]. In terms of spatial configuration, the structure consists of a portal (*taçkapı*), a passage, a domed central space and surrounding cells. From the portal, the main volume is entered through a passage. From here, one passes into the space covered by a single dome. The glazed brick dome in the center is complemented by a skylight element. The 10.90×10.90 m space has a pool in the center. This arrangement was integrated into the original construction phase of the building rather than being a later addition [2] (Figure 8).

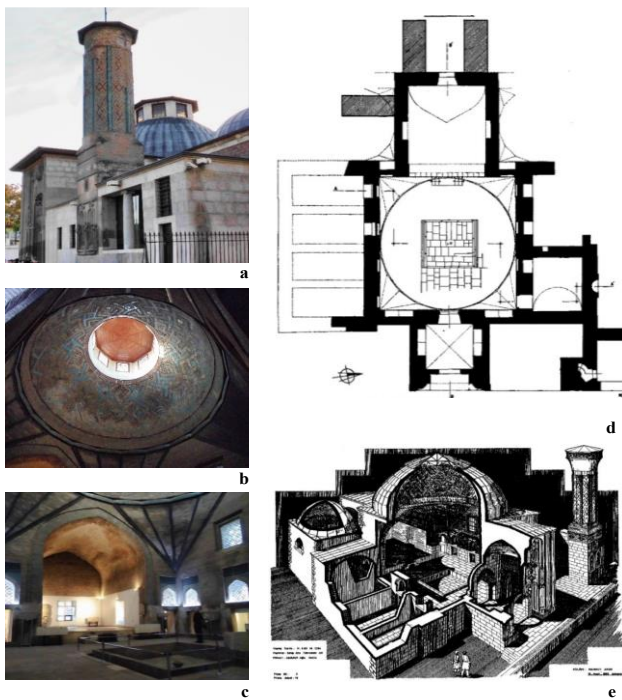


Figure 8. Ince Minareli Madrasa. a-portal (*taçkapı*) and minaret, b-dome, c-pool and supporting channel, d, e-plan and axonometric perspective [13]

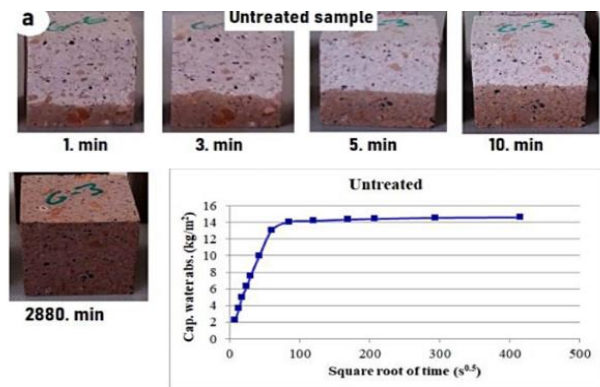
From a construction and material perspective, the Ince Minareli Madrasa was built using a stone masonry system. The stone material used in the structure is locally sourced *Sille* stone, which is also referred to in the literature as *Kiçi Muhsine* stone. In the Ince Minareli Madrasa, *Sille* stone processed as cut stone was preferred up to a certain height on the entrance façades. It was applied with white lime mortar at the base of the minaret, on the eastern façade, and in the entrance space [63]. In the foundation excavations, a mortar containing ash, charcoal fragments, and clay was identified [64]. In terms of masonry arrangement, an irregular bonding pattern is

observed, in which stone blocks of unequal dimensions and varying heights were placed in horizontal courses.

Sille stone is a type of andesite, widely used since antiquity, and is found not only in the Ince Minareli Madrasa but also in many other architectural works within Konya's historical fabric [16]. Locally known as *Sille taşı*, trachyte is generally gray in color, of magmatic origin, and contains 62–64% silica. Like other magmatic rocks, it exhibits fractures in various directions [17]. The trachyte used in the structure has been found to have high porosity, needle-like mineral formations, and mineral diameters as small as $1\mu\text{m}$. These physical characteristics facilitate the absorption of water into the material and initiate processes of both physical and chemical deterioration [18]. Therefore, the primary construction material of the building can be considered highly sensitive to moisture and water exposure.

Experimental laboratory and engineering-based studies [15] conducted on *Sille* stone indicate that the material exhibits high water absorption capacity and a significantly porous internal structure. Physical and mechanical tests, particularly those evaluating open and total porosity, demonstrate pronounced capillary water absorption behavior. This condition increases the tendency of the stone to retain moisture and facilitates the movement of water within the material, accelerating both physical and chemical deterioration processes. Therefore, the material characteristics of *Sille* stone can be considered one of the primary factors increasing the vulnerability of the building to moisture and water-related deterioration (Table 4).

Table 4. The view of the capillary water absorption levels according to a time interval of untreated material. Physical and mechanical properties of material [15]



b Tests	Mean	Deviation
Real density (kg/m^3)	2565.5	6.72
Water absorption by weight (%)	17.18	0.99
Open porosity (%)	25.74	2.40
Total porosity (%)	41.89	1.54
Ultrasound pulse velocity (km/s)	2.36	0.11
Compressive strength (MPa)	20.80	3.05

In relation to material behavior, a design approach that achieves high durability through material selection and detailed construction solutions against the erosive effects of water is evident. The traditional building techniques, developed through long-term experience, reflect a process in which the strengths and weaknesses of materials were consciously acknowledged. Water adheres to building materials at varying rates. This variability depends on the material's water absorption capacity, the porosity of its particles, and their geometric distribution. Due to their porous internal structure, masonry materials are particularly vulnerable to water effects. These pores store water through capillary pathways.

Within this material context, water management becomes a fundamental architectural necessity. An examination of the building's water management infrastructure reveals a clearly readable system designed for water collection, drainage, and moisture control. In the Ince Minareli Madrasa, there is an *opaion* at the center of the dome, and directly beneath it, an impluvium (a pool designed to collect rainwater) [12]. The side of the pool parallel to the entrance measures 3.93 meters, while the other side is 3.86 meters. Its depth is 0.57 meters. On the right and left sides, relative to the entrance, there are gutters 0.26 meters wide designed to collect excess water [21]. At the center of the pool, a fountain basin is located.

The functionality of this system is supported by subsurface infrastructure. During the restoration work of Ince Minareli Madrasa conducted in 2001, excavations revealed the original water conveyance system of the pool [8]. Beneath the *eyvan* floor, an approximately 30 cm-wide channel [23] supplying water to the pool was identified. Further investigations demonstrated that an open channel connected to the pool and terracotta pipe systems were used for both water supply and discharge. These pipes consist of modular cylindrical segments with diameters between 13-17 cm and lengths of 39-42 cm, connected through a sleeve-like joint system [29]. At a larger scale, the presence of a cistern adjoining the southern foundation wall indicates that the building incorporated a combined system of water collection, storage and drainage. Measuring approximately 10.60 × 3.80 meters and covered with a pointed barrel vault, this structure reflects an integrated substructural water management strategy [34]. No direct documentation confirms the presence of a well in the immediate vicinity of the Ince Minareli Madrasa. However, architectural elements such as niches near the entrance support suggest possible fountain installations [38]. This configuration clearly demonstrates a deliberately engineered hydraulic network (Figure 9).

Despite the presence of an advanced water management system, the infrastructure is no longer in active use, and its components are exhibited only as museum objects.



Figure 9. The pool, water channel, and drainage hole of Ince Minareli Madrasa (Author,2026), d- Terracotta pipes of the subsurface canal network of the Ince Minareli Madrasa [29], e,f- open canal [30]

As a result, water-related deterioration emerged over time as a persistent and structural problem in the Ince Minareli Madrasa. Within the scope of this case study, deterioration indicators were identified through a combined evaluation of on-site observations, excavation findings, archival repair records, and relevant academic studies, enabling a multi-layered understanding of the processes affecting the structure.

Moisture-related deterioration in historical masonry buildings is largely associated with disruptions in underground water balance, the loss of functionality in historical drainage systems, and changes in ground conditions [41]. In particular, the failure of drainage systems and the continued presence of ground moisture have been identified as key factors contributing to persistent dampness in the structure [49].

Archival records confirm that the Ince Minareli Madrasa has undergone numerous repairs throughout its history due to these very causes. During the Ottoman period, significant repairs and reinforcements were documented in 1876 and 1899 [44]. In the early Republican era, interventions conducted between 1960 and 1974 were thoroughly examined and documented by Mahmut Akok [45]. Nevertheless, the deterioration process has continued both on the exterior facades and in the interior spaces, particularly in the entrance hall, the vaulted iwan, the central dome, and the pool area [46], indicating that the problem is systemic rather than localized.

Recurring damage has been observed in the Ince Minareli Madrasa following post-1975 restoration interventions.

When assessing the chronic deterioration threatening monumental buildings in Konya and its surroundings, particularly the excessive dampness caused by rising moisture from the ground, it becomes evident that structures built with Sille stone exhibit a heightened vulnerability to humidity. This vulnerability is directly related to the porous structure and high-water absorption capacity of the material, which makes it particularly susceptible to moisture-driven deterioration mechanisms. These findings support the conclusion that master builders of the period, who had an in-depth understanding of both architecture and stone masonry, devised specific solutions to manage the effects of water and moisture in buildings constructed with highly absorbent materials such as this stone [41]. Accordingly, it can be argued that the original design incorporated an integrated water management strategy based on controlled collection, storage, and discharge systems.

One of the most critical deterioration mechanisms observed in the structure is capillary rise. Moisture originating from the ground ascends through the porous stone fabric, particularly affecting the lower sections of the portal (*taçkapi*) and the base of the minaret, and progressively advancing upward over time. Capillary water carries dissolved salts into the pore structure of the material, and these salts crystallize during evaporation, generating internal mechanical stresses that lead to cracking, surface detachment, and material loss [61]. These processes are directly reflected in observable deterioration patterns such as efflorescence, discoloration, surface scaling, and material fragmentation, especially in transitional and circulation spaces within the building (Figure 10).

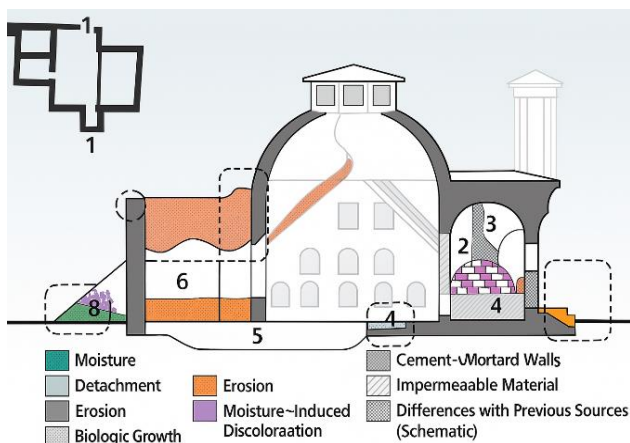


Figure 10. Deterioration and potential sources of damage in the Ince Minareli Madrasa [49]. Capillary water movement within porous stone material, salt crystallization, surface discoloration, material loss, and deterioration concentrated around the portal, minaret base, and lower wall zones

To mitigate this issue, the structure must be protected from rainwater, as well as from the general effects of moisture and dampness. Restoration efforts should not focus solely on visual preservation, but also include measures aimed at diverting and managing water around the foundation level [48].

Due to moisture and water-related problems originating from the ground, excavations were carried out in 2001 in the *eyvan* flooring of the Ince Minareli Madrasa, which led to the discovery of a channel that had historically supplied water to the central pool [29]. At the time of its exposure, the channel was found to be dry and structurally damaged and therefore considered non-functional. As a result, the *eyvan* floor was elevated, and the channel was preserved and displayed as part of the building's presentation. This finding clearly indicates that the original water management system has lost its functional continuity, leading to uncontrolled moisture accumulation within the structure (Figure 11).



Figure 11. Visibly observed deterioration in the Ince Minareli Madrasa. a- Salt efflorescence on the corridor walls, b- Hairline cracks and surface delamination at the entrance base, c- Rising damp effects on the portal/*taçkapi* (author, 2023), d- Surface detachment, and losses in stone carvings observed at the entrance of the portal and at the base of the minaret, e- Discoloration on the exterior walls of the madrasa [61]

Field observations emphasize that the loss of functionality in historical water conveyance and drainage systems plays a decisive role in moisture-related deterioration processes. In addition to salt-related decay, environmental factors further intensify deterioration. In porous stone materials, the presence of moisture combined with temperature fluctuations can lead to freeze-thaw cycles, during which water expands upon freezing and creates internal stresses that result in cracking and material disintegration [61].

In the vaulted transitional area of the Ince Minareli Madrasa, efflorescence and discoloration are clearly observable indicators of such moisture-related effects

These indicators correspond to salt crystallization processes, where moisture transported to the surface evaporates and leaves crystalline deposits behind, weakening the material and causing surface detachment. However, changing environmental conditions may have caused intermittent or continuous water flow to resume within the channel. This possibility should be considered during efforts to identify the current source of the madrasa's persistent moisture issues [49].

In this context, integrated water management through collection, storage, and discharge, supported by ventilation and water table control, has been essential for the long-term preservation of cultural heritage structures.

Results

This study demonstrates that water management systems developed in Konya during the Anatolian Seljuk period were addressed through an integrated approach at both urban and architectural scales. The city's water infrastructure was organized as a comprehensive system that ensured supply, storage, and controlled distribution of water through channels, galleries, wells, cisterns, and fountains. This system was developed in relation to hydraulic movement, ground conditions, and environmental factors, reflecting a multi-layered organization extending from settlement decisions to building-scale applications.

Within this general framework, the Ince Minareli Madrasa provides a critical case that illustrates how water management systems were constructed at the building scale and how they gradually lost functionality over time. The original design of the structure incorporated an integrated hydraulic system composed of a central pool, subsurface channels, and drainage components that ensured controlled water circulation and moisture balance within the building.

With the loss of functionality of this system, water ceased to function as a controlled architectural element and became a primary factor triggering deterioration processes. The failure of drainage and channel systems has led to the accumulation of moisture within the building fabric, accelerating deterioration mechanisms

such as capillary rise, salt crystallization, and material loss.

In this context, the case of the Ince Minareli Madrasa demonstrates that the relationship between water management systems and material behavior directly affects the durability of historic masonry structures. The use of Sille stone, characterized by high porosity and water absorption capacity, increased the structure's sensitivity to moisture and made deterioration processes more pronounced.

The persistence of deterioration despite repeated repair and restoration interventions indicates that the problem is systemic rather than superficial. This condition reveals that interventions limited to material repair are insufficient and highlight the necessity of restoring the functionality of water management systems.

The case-specific evaluation of the Ince Minareli Madrasa reveals the following structural and architectural findings:

- The original design includes a centrally organized water collection system consisting of an *opaion*, impluvium pool, and drainage channels.
- Subsurface channels identified beneath the *eyvan* floor indicate controlled water conveyance and discharge.
- The cistern adjoining the southern foundation wall demonstrates an integrated storage and drainage strategy.
- The loss of hydraulic continuity in these elements has led to uncontrolled moisture accumulation within the structure.
- Deterioration is concentrated in lower wall zones, the monumental portal, and the base of the minaret, corresponding to capillary rise areas.
- The porous structure of Sille stone has accelerated moisture transport and salt crystallization processes.
- Repeated restoration interventions did not address the underlying hydraulic problem, resulting in recurring damage.
- The current condition indicates that the original water management system is no longer functioning as an environmental control mechanism.

Accordingly, conservation approaches for similar cultural heritage structures should prioritize the reactivation of original water management systems. In this context, the following strategies are essential:

- Documentation and mapping of the original water management network

- Assessment of subsurface channel functionality and hydraulic continuity
- Rehabilitation of historical drainage and water conveyance systems
- Control of groundwater-related moisture at foundation level
- Improvement of subfloor ventilation to reduce humidity accumulation
- Use of repair materials compatible with the porosity of Sille stone
- Monitoring moisture movement in portal and minaret base zones

In conclusion, the Ince Minareli Madrasa demonstrates that water should be considered an active design and management component in the conservation of historic structures. The findings show that the durability of the structure depends directly on the functionality of the original hydraulic infrastructure and its interaction with material behavior. This approach provides a comprehensive framework for improving the long-term performance and durability of cultural heritage buildings.

Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared.

There is no conflict of interest with any person / institution in the article prepared.

Acknowledgement

This study was developed from the presentation at the 7th International Symposium on Strengthening Historical Buildings and Transferring them Safely to the Future (September 27–28, 2024, Diyarbakır).

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