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TRADITIONAL WATER HARVESTING SYSTEMS IN CLIMATE CHANGE ADAPTATION: INSIGHTS FROM A SEMI-ARID MEDITERRANEAN VILLAGE

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INTRODUCTION

Water has a crucial influence on the development of human settlements. While its abundance helped the flourishing of powerful states, its scarcity sometimes led to migrations. Historical evidence shows that societies developed resilience against water scarcity by strategies to maximize the use of available water, especially through water harvesting (WH) practices (Gautam et al., 2018). In the case of arid and semi-arid regions, where rainfall is either inadequate or erratic, Water Harvesting Systems (WHSs) have long been the cornerstone of survival as they provide water for drinking and domestic purposes. However, in the early 19th century, these traditional technologies were abandoned with the emerge of modern centralized water resources. Innovations such as deep groundwater pumps, dams and extensive networks of pipelines offered a seemingly more efficient solution by harnessing large quantities of water (Yannopoulos et al., 2019). This situation led to the abandoning of capital-poor, labor-intensive WHSs in favor of energy-intensive, capital-intensive ventures (Vetter and Rieger, 2019). Despite the global trend, traditional WHS has served as a testament to enduring resilience, notably in Asia's semi-arid regions (Zhou W. et al., 2024). Often lacking grandeur or notable architectural features, these WHSs aren't typically preserved like other cultural heritage sites (Vetter and Rieger, 2019), leading to their gradual disappearance over time.

In the wake of climate change and its adverse impact on water resources, however, learning from traditional WHSs gain significance. Although the effects of climate change vary from region to region (UN, 2019), the Mediterranean region's climate trend has been shifting towards aridification, which is characterized by rising average annual temperatures combined with decreasing precipitation, increasingly diverging from global warming patterns (Kertész and Mika, 1999; Balaban, 2012). The Mediterranean Experts on Climate and Environmental Change (MedECC)

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Network (2019) confirms this trend and predicts an escalation of temperature rise in the region, more intense and frequent heat waves and variably reduced precipitation patterns. Future projections based on the RCP 4.5 and RCP 8.5 climate scenarios and regional climate models indicate that parts of the Mediterranean could move into a semi-arid climate zone (Bsh), further underlining the region's vulnerability to 'aridification' (Barredo etal.2018). In the case of Türkiye, climate change is exerting a significant impact on settlements located along the west and south coasts, the regions bordering the Aegean Sea and the Mediterranean Sea (Gedikli, 2018). Since the Mediterranean region includes developed nations with high water demands in sectors such as agriculture and tourism, dependence on large-scale and complex water supply systems is increasing. These predominantly groundwater-based systems are not sustainable in the long term (Schwartz and Ibaraki,2011). It is therefore essential for climate change scenarios to look for alternative water resources such as seawater desalination. However, due to the high energy consumption and high costs, these alternatives are considered unsustainable (Ruiz Martínez and Cornejo Tueros,2022).

In this sense, the integration of indigenous knowledge into development practice, the combination of modern water systems and traditional WH methods or the modernization of existing WH knowledge have come to the fore (Akpinar-Ferrand and Cecunjanin, 2014; Zhou W. et.al.2024). However, comprehensive research on WH practices in the Mediterranean lags behind that of other arid regions, like North Africa, South Asia, the Middle East, and India, where such practices have been extensively documented for millennia (Prinz,1996; Oweis et.al.2004). Despite Türkiye and its Aegean areas' critical significance in the Mediterranean, detailed assessments of WHS remain scarce (Ruiz Martínez and Cornejo Tueros,2022). Acknowledging the significance of climate change impacts and the distinctive features of the region, there is need for more targeted research within the Mediterranean context, which has not been explored to the same extent as these other regions. Additionally, seminal reviews indicate that existing literature revolve around two aspects of WHSs; their potential use in modern society and their significance as cultural heritage (Zhou et al., 2023). First category covers issues such as system components, construction materials, water quantity and quality for domestic use, and optimality (Pandey 2003; Akpınar-Ferrand and Cecunjanin,2014; Lasage and Verburg, 2015; Mahaqi 2021), and second category their significance and recognition as cultural heritage (Mays et al; 2018; Mamun et al., 2020). However, comprehensive assessments of WHSs that encompass these two dimensions remain scarce.

In this regard, this study examines the water WHSs that have contributed to water resilience in Barbaros village, located in the Aegean region of the Mediterranean basin. The village has historically faced severe water scarcity due to inadequate supplies of groundwater and surface water, as well as the absence of piped water until the 1980s. Early settlers devised various WH techniques to gather and store water, which was crucial for surviving extended droughts and meeting basic needs. While these systems are mostly inactive today, they remain structurally sound and culturally significant. Moreover, Barbaros and its neighbouring villages, which share a water route (**1**), are recognized as the most water-scarce areas in the region (Yüceer et.al.2021). Given WH's pivotal role in climate resilience, a comprehensive assessment of the village's WHS typologies along with their physical, geological, hydrological, cultural, and socio-economic context is

1. Geological studies indicate that karstification in the Karaburun Platform has led to polje formations where groundwater is not retained, contributing to regional water scarcity. While villages such as Kadıovacık and Barbaros, located in polje areas, have historically struggled with limited water resources, other nearby settlements, such as İçmeler, Gülbahçe, and Ildırı, benefit from abundant water sources. In response to these contrasting conditions, communities developed a distinctive water heritage, evident in the spatial distribution of wells and related infrastructure. To highlight this under-recognized heritage, a thematic ecotourism initiative *the water route* has been proposed, linking these villages based on their hydrological and cultural significance.

imperative (Lasage and Verburg,2015). Accordingly, this research aims to understand the impacts of climate change, the vulnerability of the study area, and the potential of traditional WHSs to enhance adaptive capacity and resilience. It investigates whether the historical water storage systems in Barbaros can serve as a viable solution to future water scarcity resulting from climate change-induced declines in water resources. By examining the case of Barbaros, the research also seeks to document traditional water management knowledge and explore potential strategies for mitigating drought from a cultural heritage perspective.

METHODOLOGY

The research involves a multidisciplinary methodology integrating data relevant to topography, geology, hydrology, urban planning, architecture, anthropology, linguistics and heritage fields. Using both quantitative (e.g. hydrological data analysis, geographic information system (GIS) mapping) and qualitative methods (e.g. ethnographic study, narrative analysis), the aim is to provide a comprehensive assessment of the sustainability and adaptive capacity of local WHS and predict their role in coping with emerging climate-induced water scarcity. The methods followed are grouped under two headings.

Documentation and Characterization

1.Literature Review: A comprehensive analysis of secondary sources provides a foundational understanding of the region's WHSs, study area's physical characteristics and climatic patterns. For the historical background both secondary and primary sources are used from the archives.

2.Field Surveys: The region's on-site examinations to gather primary data on the spatial distribution, architectural integrity, and operational status of the WHSs. Investigating the geological substrates and topographical features that influence the design and function of the WHSs.

3.Interviews: Semi-structured interviews with local stakeholders, including residents, farmers, and experts in water management, contribute qualitative insights into the usage patterns, historical evolution, and communal significance of the WHSs. Eighteen residents, including fourteen individuals aged 65 and older, were interviewed for 45-60 minutes each. The interviews explored the villagers' practices surrounding water sources, particularly given the historical scarcity of water in Barbaros.

4.Observational Analysis: Through direct observation, the present condition of the WHSs are documented and any evidence of traditional construction and maintenance practices are noted.

Climate Impact and Adaptive Capacity Assessment

In the second step, the interplay between WHSs and climate dynamics are explored:

1. Impact and Vulnerability Assessment: Climatological data and model future scenarios to predict how climate change may alter water availability in the region are analysed.

2. Adaptive Capacity Evaluation: Assessments on how the varying WHSs might buffer the community against these anticipated changes and which systems offer the most effective means for adaptation are carried out.

CHARACTERIZATION OF THE STUDY AREA

Geographical Features and the Brief History of the Study Area

Barbaros village is in the Urla district of İzmir province in Türkiye - geographically in the interior of the Karaburun Peninsula on the Aegean coast of the Mediterranean basin (**Figure 1**). The study area features hills encircling karst depressions, forming 'polje,' situated at altitudes ranging 145-400m. Barbaros settlement lies at the foothills of the Kocadağ Mountains, marking the beginning of the Barbaros polje. The natural vegetation comprises evergreen sclerophylls, garrigue, and coniferous forests.

Due to the limited water availability, there are no agricultural endeavours on the slopes surrounding the polje. However, there are fertile areas in the central and western sectors where alluvial soil and water resources converge. The Barbaros Polje has been continuously cultivated since

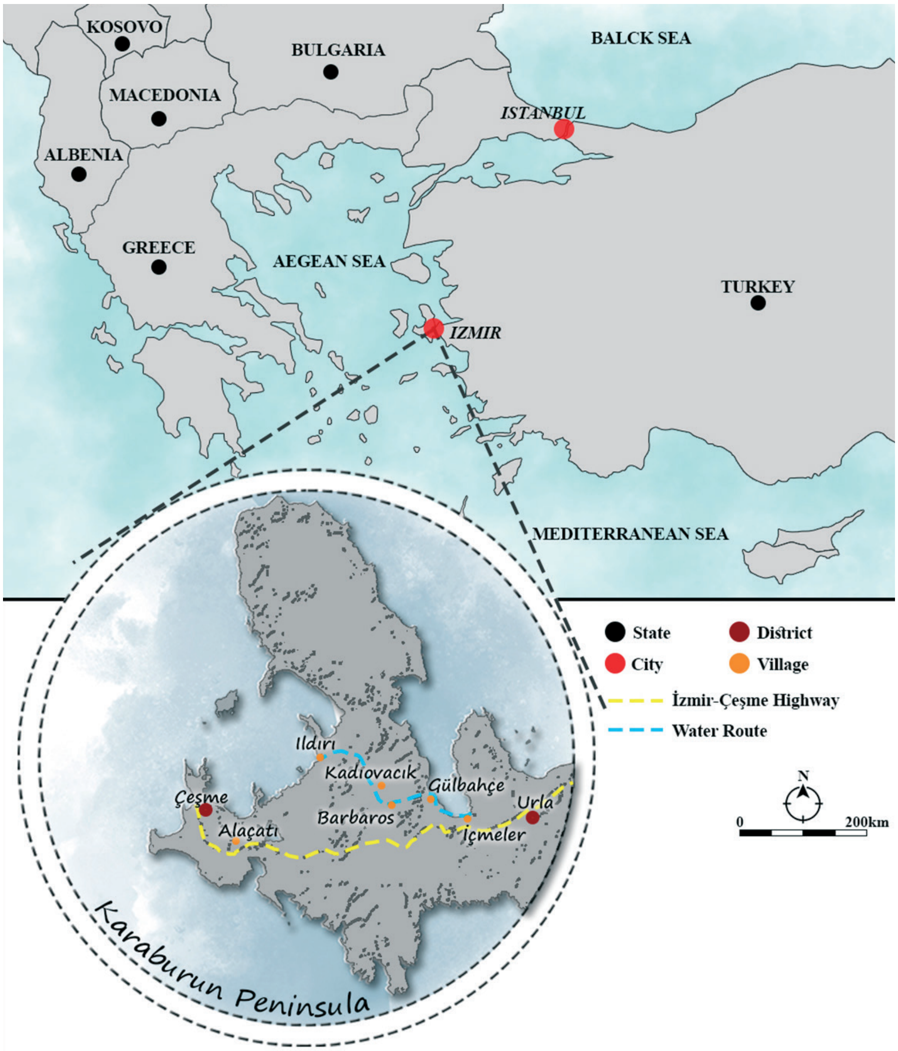


Figure 1. Location of study area

the beginning of settlement, as evidenced by the transformation of the maquis into arable land (Mater,1982). The agricultural mosaic within the polje includes olive groves, vineyards, and other crops adapted to the dry conditions, such as tomatoes and melons. This complex patchwork of cultivated land intersperses with fields that have been left to the invading natural flora and pastures that meander through them.

The study area has a rich historical background, located near two important ancient Ionian cities: Erythrae and Klazomenai, 10 and 19 km away respectively. After the era of city-states, the area was dominated by a series of different civilizations, Persians, Greeks, Romans and Byzantines. Turkish influence in western Anatolia grew during the Seljuk period, as Turkmen tribes migrated from Central Asia amid the Byzantine Empire's decline (Peacock,2010). According to oral history research, Barbaros has been predominantly a Turkmen (nomadic) village since the 19th century. The first inhabitants of the village are known to have come from Başköy, located in Tepeüstü overlooking the Barbaros Polje, nearly 1.5 km from the present-day settlement. Furthermore, findings belonging to the Neolithic period have been found in this region (Caymaz 2002). Although Greek communities were once widespread on the Karaburun peninsula, they were displaced by the compulsory population exchange between Greece and Turkey stipulated in the 1923 Treaty of Lausanne. This exchange simultaneously resulted in the migration of Balkan Muslims to Anatolia, leading to profound changes in the region's demographic, cultural, and ecological structure.

Historically, Barbaros's distance from administrative epicenters contributed to its marginalization. Even in modern times, the village is far from the main transportation arteries, and the lively tourism centers. Thus, agricultural traditions and rural dynamics continue to characterise the area, although their economic mainstay has declined compared to past.

Geological and Hydrological Characteristics of the Region

The section explains the nation of geological and hydrological features essential for the formation of the WHSs. In the Barbaros area, the geology consists of the overburden located centrally within the polje and along the eastern slopes of the Kocadağ Mountains. This area is characterized by impermeable volcanic material, mainly pyroclastic tuffs and clays, adjacent to Quaternary alluvium and debris (Çakmakoğlu and Bilgin 2006).

In addition, andesite formations derived from the volcanic activity of Kocadağ delimit the eastern boundary of the study area (Helvacı et.al. 2009). These formations contain fractured systems that can form local aquifers in certain areas. The volcanic formations and cover formations in the east are generally unfavourable for groundwater recharge due to rapid infiltration and deep water penetration through the andesites' fracture systems. Therefore, water reserves and wells must be constructed, except for some pond systems that lie on impermeable units. In contrast, the western part of the field offers a different scenario. Beyond the polje, to the west, the alluvial and colluvial material diminishes and exposes the underlying karstic limestones. These limestones exhibit numerous fractures that predominantly run along the north-south, northeast-southwest and northwest-southeast axes, with fault segments having a major influence on their orientation, as seen in geothermal systems around Gülbahçe in the east part of the study area (Uzelli et.al 2017).

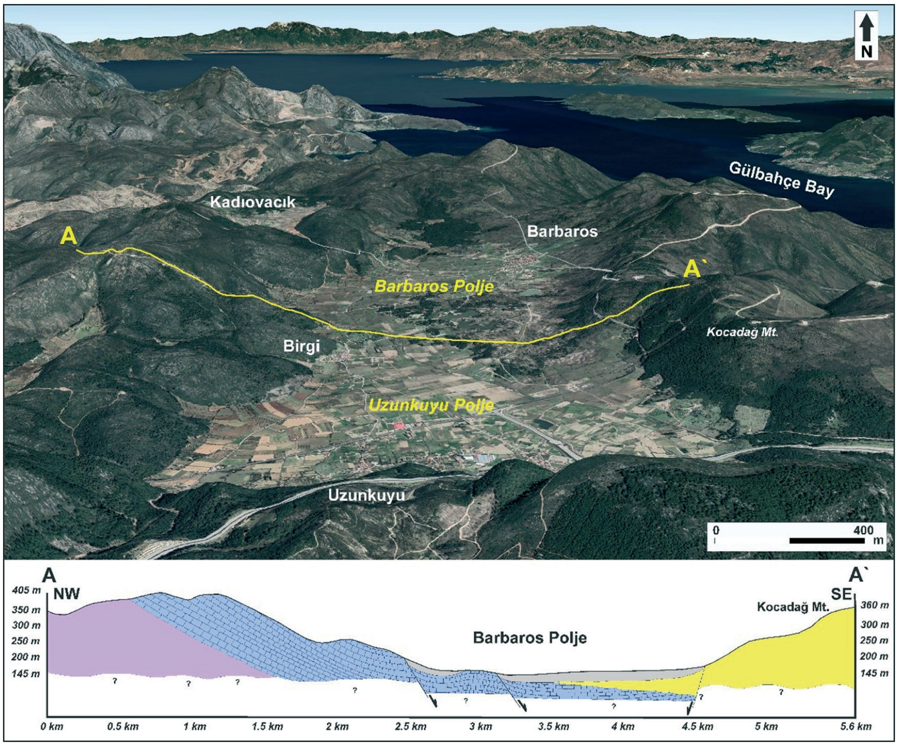


Figure 2. Geological cross-section and 3D-view of Barbaros Polje

The tectonic activities that led to the uplift have exposed the karstic limestone structures, especially in the western and southern parts. This exposure has accelerated the erosion of the overlying material, which has thinned over time, favouring the development of characteristic karst features such as poljes and uvalas along the contact lines and faults in the Jurassic and Triassic limestone. The karst structure is important in supplying the Ildırı springs is located in the western part of Barbaros polje (**Figure 2**). In addition, groundwater in these units can be reached through fractures in deep and occasionally shallow wells drilled in the study area.

The Barbaros polje is filled with alluvial and colluvial units that indicate the primary materials from which they were formed. Soil development in the polje was primarily characterised by erosion and depositional activities on Neogene surfaces and by the karst landscapes prevailing in the area. Under the influence of tectonics, the alluvial deposits within the polje have reached a considerable thickness. In the eastern and central regions of the polje, impermeable layers of ignimbrite, tuff and clay predominate. This impermeable cover prevents surface water from seeping into deeper layers. However, where the cover coalesces into concave formations, it facilitates the creation of temporary ponds and pans, especially during seasonal rainfall.

WATER HARVESTING IN THE STUDY AREA

Water harvesting (WH) is defined as ‘collecting runoff water for its productive use’ (Critchley and Siegert,1991). A more detailed definition describes WH as ‘the collection and management of floodwater or stormwater runoff to improve water availability for domestic and agricultural purposes and to conserve ecosystems’ (Mekdaschi Studer and Liniger,2013). These collection and management practices include various measures to make the runoff water usable. These include collecting, diverting, retaining in ponds, reservoirs or otherwise manipulating runoff -for example, diverting it to avert potential damage and turn it into a useful resource (Bruins et.al.1986). The harvested water serves diverse purposes, including human consumption (drinking and household needs), agricultural irrigation (crops, forage, pastures, gardens, trees), livestock care, and the management of environmental resources like forests, wildlife habitats, and ecosystems (Mekdaschi Studer and Liniger,2013).

Water Harvesting Systems (WHSs) and Typologies

Water Harvesting Systems (WHSs) are methods of capturing and storing runoff water that utilizes multiple techniques and tools as integral components (Frasier&Myers,1983). WHSs essentially consist of three critical elements:

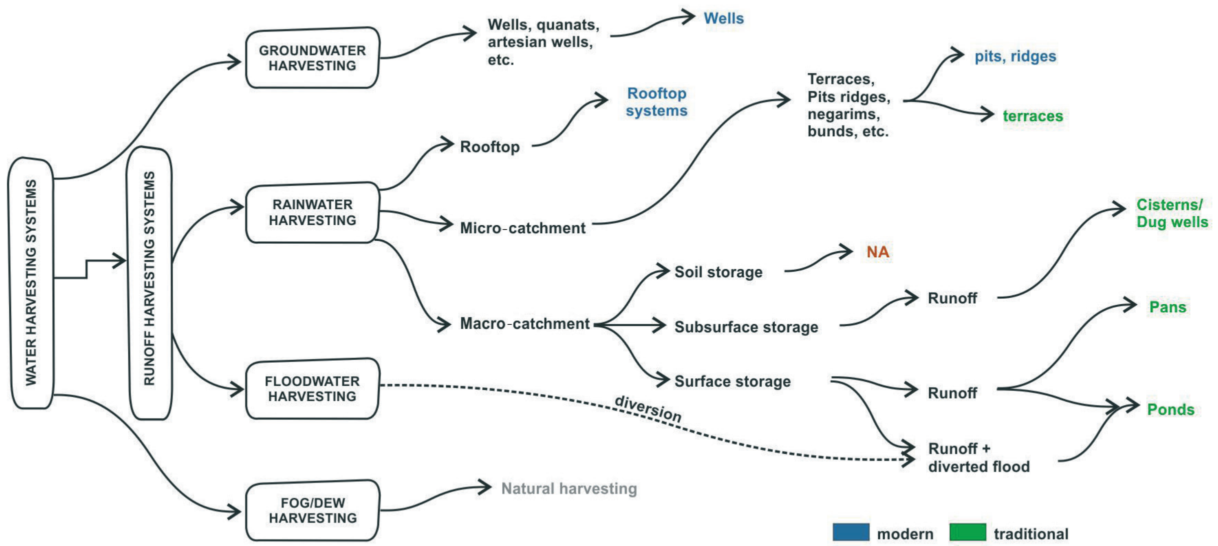
the catchment area that collects the water
the storage facility for water retention
the intended destination for the use of the collected water

Occasionally, the 'conveyance unit' —the intermediary between the catchment and the storage facility—is identified as an additional component of WHSs. WHSs can be classified according to various criteria, the most important of which is water source (Beckers et al.2013), catchment size and relief characteristics (Prinz,2002), and type of storage facility (Mati,2012).

In this study, WHSs were classified based on the source of the extracted water (1st level), the size and type of catchment (2nd level) and the storage facility (3rd level). The categories and subcategories based on the adopted classification scheme and the names of the categories, including local names, are shown in **Figure 3**. Based on the water source they harvest, the WHSs in the study area are categorized:

groundwater harvesting
rainwater harvesting
floodwater harvesting
fog/dew water harvesting

Figure 3. WHSs classification typologies and observed types in the study area



Groundwater Harvesting

One category of water abstraction based on catchment type is 'groundwater abstraction', where harvested surface runoff can recharge and replenish groundwater (MekdashiStuder and Liniger,2013). In the study area, the geomorphology and hydrogeology, characterized by a series of faults and fractures, cause all infiltrating groundwater to percolate away from the polje and migrate towards the village of Ildırı to the northwest. This phenomenon restricts access to groundwater exclusively to the wells in the western sector of the polje. In the past, it was not possible to drill deep wells due to technical limitations, so the groundwater was not accessible. Only in the last ten years have wells been successfully drilled along the fault line in the western part of the study area, some of which reach a depth of 200 meters. According to the measurements carried out as part of the geohydrological investigations in this study, the static water table height is 18.72 m with a gradient of 3.65 m and a yield of 15 L/s. The specific yield of the well is 4.11 L/sec/m and the permeability is 182 m3/day/m.

In the past, the locals used the water from the dug wells for domestic and agricultural purposes. Today, 100% of the village's drinking and utility water supply is provided by water from a well drilled into a fault. However, a large part of the irrigation of the agricultural land is provided by artificial ponds and a few dug wells. The area has a polje character, thus, very little water can be obtained from the groundwater wells. However, around 20% of the agricultural land is irrigated with water from deep wells. It is planned to drill deep groundwater wells in new areas for agricultural activities in the region.

Rainwater Harvesting

Systems that harvest runoff from natural land surfaces such as hillslopes or artificial surfaces are generally categorized as rainwater harvesting (Critchley and Siegert,1991). Rainwater harvesting from natural land surfaces is categorized into micro and macro catchments based on the size of the catchment area (Prinz,2002). Rainwater can also be harvested from artificial surfaces.

Micro-catchment Harvesting

Micro-catchment harvesting is an *in-situ* rainwater harvesting method for agriculture. It aims to catch the rain where it falls and prevent runoff. This technique captures runoff water on small, prepared areas (from 1 to 1000m^2) to benefit adjacent cropland or individual plants (Prinz,2002). Micro-catchments are relatively rare in the study area, and any that once existed have largely disappeared over time because they are ephemeral and require constant maintenance. The terraces are the only permanent example from earlier times in the study area. These are 'contour terraces' built from dry, stacked local stones without mortar and are up to 1m high. Some of the terraces are now planted with olive trees, while others, which are not planted, were probably once used as vineyards.

Macro-catchment Harvesting

Macro-catchment harvesting systems collect runoff in larger catchments, such as hillsides with long slopes. As opposed to micro-catchment harvesting, their construction is more sophisticated, and maintenance is more labour-intensive (Prinz,2002). Macro-catchment harvesting based on storage utility can be subcategorized as soil profile, surface, and subsurface (underground) storage (Weis and Hachum,2009).

a. Soil Profile storage

Although common in arid to semi-arid landscapes, this type of storage is not practiced in the study area.

b. Surface storage

The study area has surface reservoirs consisting of natural and hand-dug open reservoirs that store water collected from the macro-catchments. There are about 20 such reservoirs near the village of Barbaros, which are mainly used to meet the water needs of the cattle herds. Due to their size and geographical location, the surface storage systems in this region can be divided into two groups: Ponds within the polje and pans on the surrounding hillslopes.

Ponds in the polje, including natural or artificially enlarged lakes, are catchment areas for rainwater from mountainous hillslopes (**Figure 4a,b**). Rainwater either drains naturally or is diverted to these ponds by ephemeral streams using conveyance systems like artificial channels, gullies, and arches. With effective sedimentation basins, these ponds can store rainwater efficiently. The clay and silt content of polje soil naturally line the ponds, aiding self-sealing. Some ponds are artificially sealed with clayey and silty materials to reduce seepage, the main cause of water loss. However, evaporation persists, causing noticeable water loss, especially during summer irrigation. Man-made ponds, known as farm ponds, are smaller and typically located near homesteads (Wisser et al.2010), primarily serving irrigation and livestock water needs (**Figure 4c**).

Often smaller than ponds, pans are fashioned on mountain slopes, encircled by stone or earth walls to collect rainwater. Their widespread use in arid to semi-arid regions stems from their simplicity, cost-effectiveness, and efficiency in rainwater collection. Known by various names like *johads* in India (Gupta, 2011), *hafir* in Arab countries, and *Roman ponds* elsewhere (Oweis et al.2004), some pans in the study area are historically linked to Greek communities inhabiting the surrounding settlements prior to 1922. They are typically crescent-shaped and comprise mounded earth and stones, forming a semi-circular barrier about 1 to 2m high. Pans in the study area are installed on andesite units associated with Kocadağ volcanism in the eastern area, featuring impermeable surface layers and rock outcrops. Ranging 50-500m² in surface area, they can store an

Figure 4. a) Kocagöl/Çamlıgöl, b) Büyük gölet, c) Farm Pond (irrigation pond)

estimated 10-100m^3 of water. Notably, water volume gradually diminishes in late summer without the pans completely drying out. Traditionally, these pans were used for watering livestock and were not intended for irrigation or domestic purposes.

To work in practice, the surface structure of the pools should exhibit a lower infiltration rate than the rainfall intensity, while the area's topography should facilitate continuous runoff for even drainage (Bruins,2012). Both sumps and ponds gather water from catchment hillslopes, primarily composed of impermeable volcanic and sedimentary rock, making them highly efficient at collecting runoff. Previous inhabitants cleared these watersheds' prevalent maquis and garrigue vegetation to create smoother surfaces with improved water permeability, facilitating better runoff collection.

c. Subsurface storage

The overflow in the study area is directed from the foot slopes into the underground storage units called *kuyu*, a general Turkish name used to designate well-like structures. However, these facilities differ from wells because underground water does not feed them. Typically, shallow and manually dug, they are located far from the water table. Conversely, they resemble cisterns in storing collected rainwater. However, cisterns are sealed structures preventing water seepage. In the Mediterranean, historical cisterns are mostly lined to ensure water tightness. Underground storage systems in the study area resemble traditional Mediterranean cisterns, like those in Greece, but also receive water from their walls via leakage after rainfall. Sometimes termed *shallow dug wells* (Shemsanga et.al.2018), in this study, we categorize them as cistern-like structures yet consider *dug wells* more fitting as they lack waterproofing.

A survey revealed 369 dug wells throughout Barbaros, located in residential yards, orchards and along mountain slopes (Sarıbekiroğlu,2017). The spatial distribution of these dug wells varies. Some are grouped together, labelled as zones A-Mehmetler, B-Mintanlar, C, D, E-Kocataşlar and F, while others are isolated in gardens yards or private properties (**Figure 5**). The area labelled *E* contains the highest concentration of dug wells and is the subject of special consideration (**Figure 6a**). The dug wells in zone E are in sloping terrain next to a small canal that was once a natural watercourse (**Figure 6b**).

These WHSs were built with minimal effort and using local expertise. They form cylindrical pits dug into the earth, with the walls reinforced by the insertion of indigenous stone using dry stone walling methods. The system is designed to collect rainwater through two primary mechanisms: First, runoff from the sloping terrain is directed to the mouth of the dug well and enters the catchment basin directly; second, rainwater seeps into the ground and passes through the walls into the reservoir below. To collect the overflow between the structures, shallow water channels connect neighbouring dug wells (Yüceer and Güler, 2021).

The dug wells vary in size, with a diameter of around 1.97-2.50m and a depth of 6-9m. Their capacity is around 10-20m^3. Type 1 is characterised by an opening closed with irregular stones set directly on the ground, as is the case in some wells in zone A (**Figure 7a**). In contrast, type 2 is characterised by a raised opening standing on a cylindrical base supported by a step of two stones (**Figure 7b**). Most Barbaros wells correspond to Type 2, except for E11, which is sealed with cement and has a protective wooden

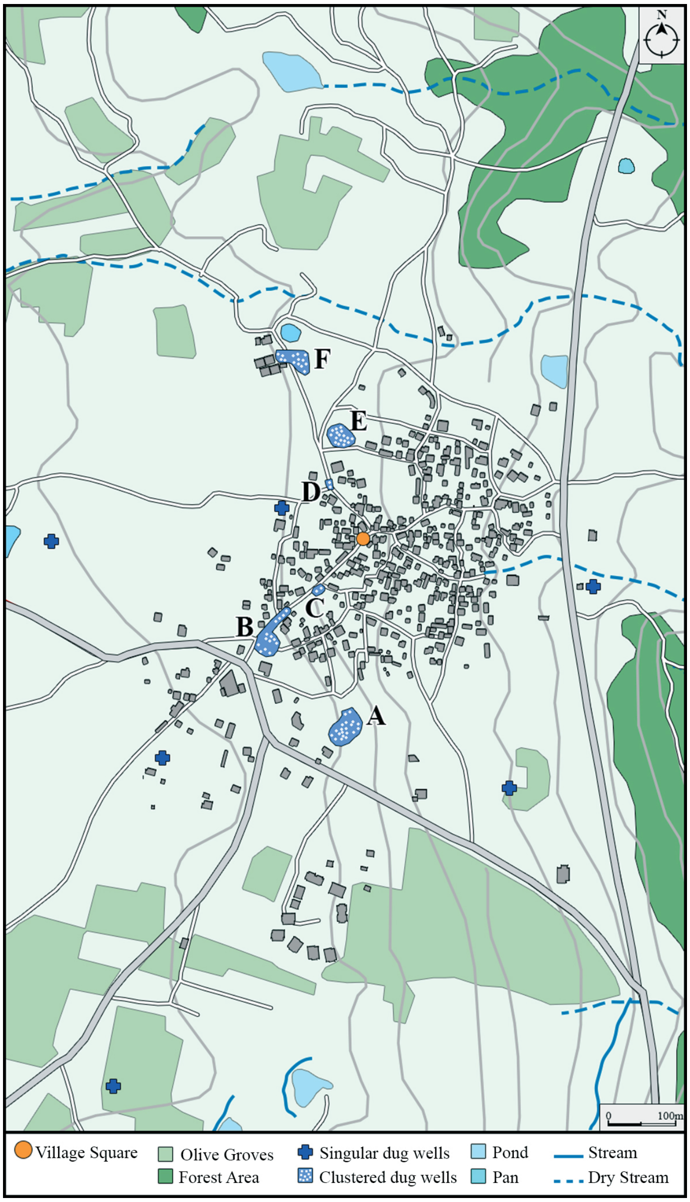


Figure 5. Barbaros Village Settlement and the clusters of dug wells

Figure 6. a) Dug wells in cluster E, b) Site plan of cluster E

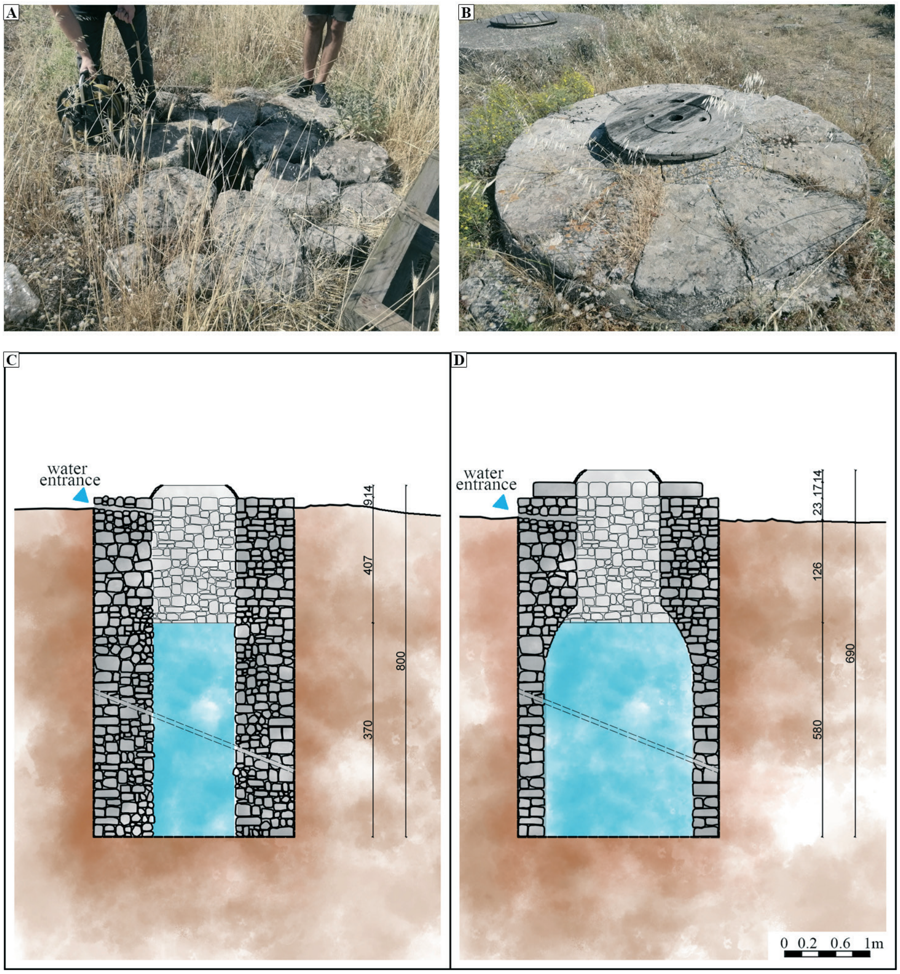


Figure 7. a,b) two typologies of dug wells' mouths, c,d) two typologies of dug wells' interior

cover over its raised opening. Despite these differences, all wells have a cylindrical standard shaft at the top and widens just below the surface, with the diameter remaining larger at the base (**Figure 7c,d**).

Concern for water hygiene was just as important in the past as it is today. To ensure cleanliness, the original builders developed methods to divert the initial flow of rainwater away from the mouth of the well or, if necessary, to seal the mouth completely. This measure prevented pollutants, potential pathogens and excessive silt from contaminating the pumped water.

The hydrological study investigated the water quality of various rainwater catchment systems in the region. Four water samples were taken: two from dug wells near the village labelled Köy and Mehmetler and two from the largest water bodies, the ponds labelled Çamlıgöl and Büyük Gölet. The electrical conductivity (EC) values of these water sources were between 163.2 and 322µS/cm. The pH values of all the bore wells were slightly alkaline and were all just above 7.46, although they were within the acceptable groundwater pH range of 6.5–8.5. These values are consistent with national and international standards for potable water (ITASHY,2005) Additionally, these water samples underwent testing for toxic elements, with concentrations compared to maximum levels set by national and international guidelines for drinking water quality. Only the Köy dug well exhibited an arsenic concentration above the safe limit (10.43μg/L), slightly exceeding the recommended limit for drinking water.

All data is compared with the classification of the International Association of Hydrogeologists (1979). Accordingly, the water from the wells is of the Ca-HCO_3 type and the water from the ponds is of the Ca-Na-HCO_3 type. While the water from the boreholes corresponds to the calcium bicarbonate type, the water from the lakes is relatively close to the mixed water type, which results from different evaporation and surface input. The results provide insights about the hydrological source of water. Therefore, the water in the wells is fed from the soil profile, where limestones form a high topography around the western part of the polje, which allows them to reach higher Ca-Mg and HCO_3 concentrations. The water in the ponds was mainly influenced by the surface water and the water emerging from the jointed volcanic rocks.

Roofs and Courtyards

In the past, even without sophisticated systems, residents collected rainwater in buckets and canisters for domestic use. Currently, there are no public water supply systems outside the village center and tap water is not readily available. As a result, rooftop rainwater harvesting has become common, especially in modern homes and huts scattered across the agricultural land of the polje. The rainwater is collected and stored in plastic tanks with a capacity of up to $20m^3$ in the courtyards of the houses.

Floodwater harvesting

Systems that use runoff from watercourses are classified under floodwater harvesting (Critchley and Siegert, 1991). They are usually practiced in a valley-ridge topography. Unlike rainwater harvesting, water flowing in rivulets and smaller channels can back up into a gully and stream and become a flash flood in larger catchments such as valleys, which is sometimes severe and unpredictable (Beckers et.al.2013). Although it relies on the same water source as rainwater harvesting, flood harvesting is hardly practiced in the study area. This can be attributed to the poor drainage system of the landscape and the relatively small catchments that are unable to generate runoff that accumulates into flash floods.

Fog/dew harvesting

Fog and dew, commonly referred to as rain-free water, are important components of the hydrological cycle in arid to semi-arid regions (Kaseke et.al.2007). Fog and dew can be collected using harvesting devices, e.g. nets, and used as an additional drinking water resource. Some authors prefer to exclude fog/dew from WHSs due to its limited water collection capacity (Yannopoulos et.al.2019) and the controversies (Beckers et.al.2013). Although fog/dew is not harvested with specialized equipment, its presence in the study area helps to meet the water needs during the critical growing stages of the crops and allows them to survive without water. The hot and humid air that stagnates in the *polje* surrounded by hills condenses when interacting with the cold surface, especially in the morning, and produces dew, which is the water of life for the plants. Due to this unique microclimate in the region, this cultivation practice, which allows the produce to grow despite the dry periods, is called waterless agriculture. Waterless agriculture is still effective, and the villagers widely use local seeds. The indigenous seeds can withstand extreme environmental conditions as they have been adapted over time and are expected to withstand the dry conditions in the study area. The commonly grown crops usually require less water, e.g. tomatoes, okra and melons.

WHSs in Historical Process and Cultural Practices

As descendants of nomadic Turks, the inhabitants of Barbaros village hold water in reverence within their mythology, symbolizing life's essence and purity, thus considering it a sacred resource (Şayhan,2018). In an environment where water is a precious commodity, the villagers, whose culture and traditions are strongly characterised by the need to adapt, have developed a deep connection to water and its collection and protection habits.

In-depth interviews were conducted during the fieldwork, each lasting 45-60 minutes, to explore the historical use of WHSs by the villagers of Barbaros and the importance of the systems in their collective memory as cultural heritage. Eighteen people were interviewed, 14 of whom were 65 years or older and had actively engaged with WHSs. To cope with the scarcity of water in Barbaros, the community relied on ponds and pans to quench the thirst of their livestock. The goats used to drink from the ponds on the hillside while grazing. As goat farming has declined sharply, these ponds are no longer used today. However, they continue to function without maintenance and provide water for wild animals such as foxes, boars and birds. The village's dug wells were also used to supply drinking water (Gönülal and Uştuk, 2021).

Water scarcity disproportionately affected women, reflecting a gendered division of roles where women were responsible for water-dependent activities like washing, cleaning, and cooking. While men predominantly built the wells, women frequently integrated their use into daily routines, making multiple trips to the wells each day, often riding on donkeys accompanied by their children carrying barrels. During periods of water scarcity, clothes were washed with lye, a practice known as *boğata yapmak*, like the Italian term *bucato* (Gönülal, 2021).

Another efficient method to utilise the limited water is to connect nearby dug wells with a gutter. In this way, the locals managed to divert water from one dug well to another when the water ran out. After opening channels for the surface runoff from the surrounding hills flowing toward lower elevations, they filtered the dirty water with pyrene bush, a rare species found in the heathland south of the village of Barbaros, so that goat dung etc. could not mix with the water. Once the water was clear, they took it to the dug wells. It is also worth noting that drawing water from a dug well requires skill. The only way to fill the bucket is to turn it upside down and dip it into the water. At present, the mouths of the dug wells are completely closed for safety reasons.

In Barbaros, some dug wells are not just water sources, but landmarks that are named and steeped in local folklore, passed down orally from generation to generation. In earlier times, brides were ceremoniously brought to the wells to perform the henna ritual to the sound of trumpets. The villagers would sip water from the bride's hands and ask for good luck and divine blessings while murmuring their prayers. Meanwhile, the wells were shrouded in mystery and were believed to be haunted after dark (Yaka,2016). Our observations suggest a nuanced perception of the WHSs in Barbaros, particularly in relation to dug wells. Even though the memory of these structures may be reminiscent of past struggles, there is a palpable appreciation for their existence, as they convey a sense of security against future water shortages.

WHSs' in the Face of Development, Trends and Pressures

In the past, villagers in Barbaros skilfully coped with water scarcity through indigenous water harvesting practices until the village was connected to the municipal water grid in the 1980s. Subsequently, the traditional WHSs, especially the dug wells, were no longer used and were largely left out of service. In the west of the study area, along the northeast fault line, artesian wells are tapped to provide water for residential and agricultural purposes. However, excessive abstraction poses a risk of salinization due to the connection between the fault line and the sea. Although there are various water sources in the region, their availability is finite, and the water supply is reaching critical limits.

Barbaros polje is experiencing a trend towards dispersed development, marked by settlement on farms and abandoned agricultural land. This area mainly attracts newcomers drawn to the rustic lifestyle and authenticity of the village, with people often residing in their houses seasonally. Many of these newer constructions, built within the last decade, feature water-intensive amenities, consuming significant water resources, including drinking water used to irrigate the fields. Moreover, with increased water and electricity demands and the need for waste and sewage disposal services, especially for units outside administrative boundaries, environmental challenges for the area are anticipated.

Despite the restrictions imposed by existing planning law, which discourages residential conversion, escalating land prices in the study area signal strong demand and pressure for residential development. Most WHS are not under official protection and are consequently at risk of deterioration or destruction.

CLIMATE CHANGE RISK AND RESILIENCE

Currently, the village's tap water is primarily drawn from groundwater reserves some distance away, with more than half of İzmir province's tap water coming from such aquifers. This supply is sufficient to meet the needs of households, but in the summer -when tourist resorts such as Çeşme and Alaçatı are heavily visited- water shortages become increasingly common. The study area is also experiencing climatic changes that are driving it towards greater aridity. Although many WHSs in the region are obsolete, the remnants of these structures, along with associated cultural practices and collective memory, have been well preserved.

Considering these circumstances, numerous international organizations -including the FAO, the IPCC, UN-Water and initiatives under the Sustainable Development Goals (SDGs)- are advocating for the expansion of WHS practices to strengthen climate resilience as a core component of climate adaptation efforts. With the recognition of WH as a viable water source, there is a growing trend towards the adoption and implementation of WH practices for sustainability and to enhance resilience. Therefore, assessing WHSs, selecting appropriate water harvesting methods and investigating their practicality are crucial steps towards adapting to our changing climate.

Climate Change Impact and Vulnerability

Climate change poses a significant threat, further straining the scarce water resources in the study area. With a typical Mediterranean climate (Csa), there's a trend towards reduced rainfall coupled with rising temperatures. These changes indicate a potential shift in the local climate toward heightened aridity (Kertész andMika,1999).

The warmest months in the village are July and August, which are typically dry. Average summer temperatures often rise to around 27°C. Remarkably, rainfall in July, August and September combined is only 25.8mm, which is just 3.98% of the annual average. This low rainfall leads to periods of drought, severely affecting the region's important agricultural activities. The prevailing climatic challenge is the acute water shortage. For more than half of the year, rainfall is insufficient to meet the demand for evapotranspiration, an exacerbated shortage in the humid summer months. The region's WHSs are suitable for arid to sub-humid conditions, typically characterised by low annual rainfall of no more than 700mm. The study site often suffers from unpredictable rainfall and cyclical droughts, with observed average annual rainfall below 600mm (MEVBIS).

Climate change will exacerbate the changes in the hydrological cycle, exerting particular impacts as reported European Commission and UN documents (EC, UN). In **Table 1**, we list a range of those potential risks to the village as impacts and linked vulnerabilities, encapsulating the direct effects of climate change on the rural landscape. These anticipated impacts extend across various dimensions— including the social fabric, cultural norms, and economic stability—of rural communities, underscoring the profound and extensive consequences (Atkinson and Atkinson,2023).

Climate Change and Adaptive Capacity of the WHSs

Adaptive capacity is defined as the ability of a system to anticipate, prepare for and respond to the impacts of climate change (Smith et.al.2001). Within the climate-related risks depicted in **Table 1**, water scarcity emerges as the most critical threat, affecting drinking water supply, household use, irrigation and livestock production. Water scarcity not only leads to direct challenges but also exacerbates risks such as recurring droughts, changes in vegetation patterns, soil erosion, land degradation, and disruptions to ecosystems. **Table 2** illustrates the climate-related risks in conjunction with a qualitative assessment of the adaptive capacity of various water harvesting systems (WHS) present in the study area based on extensive research, field observations and interviews with residents.

Regarding water scarcity, in rural developing areas, harvested rainwater plays a central role as it often serves as the primary source of drinking water (Dao et.al.2021; Pineda et.al.2021) and for other domestic needs such as washing and sanitation. (Preeti et.al.2021). Data from several local WHSs of type dug wells in the study area indicates that the quality of harvested water is close to that of drinking water, showcasing its potential in water scarcity issues, whereas other WHS sourced water can be used after a sanitation process.

Central to mitigating environmental problems such as droughts, changes in vegetation, wild fires, and floods are the pans and ponds in the region, where ponds can store significant amounts of water. In addition, the large number of smaller ponds maintain ecological functions and are vital for pastoral communities. These water bodies are strategically used to

Climate Change Risks	Climate Change Impacts	Climate Change Vulnerability
Water scarcity	Climate change can intensify water scarcity by reduced rainfall and increased evaporation. This reduce surface water fed resources and reduce ground water levels in the local environment. Water supply from the infrastructure may also be cut off for the same reason as the broader region is subject to climate change impacts and there are cities and destinations in need of critical and priority water supply.	The village is highly vulnerable to water scarcity. Water for drinking is of vital importance. Limitation of water for irrigation and livestock is also a substantial threat on livelihoods of the village.
Droughts	Climate change can intensify droughts and extend their duration.	Crops and livestock may struggle to survive without sufficient water which in turn lead decreased food production and reduced income that heavily relies on agriculture. Prolonged droughts may lead to displacement of community.
Changes in vegetation	Climate change can alter the distribution and composition of vegetation. Increased temperatures and reduced precipitation may cause local plant species struggle to survive while others may become invasive.	Village community is vulnerable to conditions in vegetation useful for agriculture and husbandry. Vegetation change may affect cultivation as well as grazing for livestock.
Erosion and land degradation	Intense rainfall events, combined with dry periods contribute to soil erosion and land degradation in semiarid areas. Erosion of topsoil can be observed.	Erosion leads to reduced agricultural productivity which can further challenge the sustenance of rural settlements.
Ecosystem disruption	Projections indicate that the future disruption of ecological assemblages due to climate change will be sudden and unanticipated.	The loss or disruption of species and populations does not occur in isolation. Thus, this jeopardises the functioning of ecosystems, and hence their capacity to deliver ecosystem services.
Wildfires	Warmer temperatures and reduced moisture content contribute to the increased incidences of wildfires.	Wildfires pose a threat to the communitiy and the environment. Wildfires have the potential to destroy local acquisitions, including agriculture and husbandry, for the short to long term.
Floods	Warmer temperatures lead to increased moisture concentration in the atmosphere. This causes erratic or sudden rainfall that lead to flash flooding. Also, vegetation and soil conditions in the catchment area determine water retention and evaporation processes.	Heavy rainfall in short periods that are erratic in nature may cause excessive damage to livelihoods, cultivated products and husbandry stock in rural settlements.

Table 1. Climate change risks, their impacts and vulnerabilities in the rural case area

Climate Change Risks	wells	rooftop	terraces	Dug wells	pans	ponds
Water scarcity	**	***		***	**	***
Droughts	**	*	*	***	***	***
Changes in vegetation			*		***	**
Erosion and land degradation			**		**	*
Ecosystem disruption					*	*
Wildfires		*			***	**
Flood				*	**	***

Table 2. Adaptive capacity of the WHSs in the study area
*** high capacity, ** moderate capacity, * low capacity

manage water runoff — capturing runoff to store it and mitigate potential flood damage (Bruins et.al.1986). During intense, short-duration rainfall, characteristic of the study area, pans and especially ponds prove to be efficient. The locals have adapted their practices and channel the initial debris- laden rain streams into these ponds. The pans and ponds in the study area also serve as important water sources for emergency services, e.g., for extinguishing forest fires.

Rooftop water harvesting is a modern WH technique in the region that significantly reduces public water consumption (Abdulla andAl-Sharef,2009). By supplementing water demand with WHSs, rural regions reduce the demand for water resources and thus ensure the sustainability of urban supply and productive activities.

Despite their limited volume for domestic use, pots and ponds are immensely useful in counteracting the effects of climate change risks with their higher rating of adaptive capacity. Therefore, they are considered indispensable components of any climate change adaptation strategy based on the findings of this study.

CONCLUSIONS

The WHSs in the study area represent relationship between the inhabitants and their environment and embody the indigenous knowledge of the community and the long-standing principles of the WH. Despite the persistent scarcity of water, the locals have always made Barbaros their home and have creatively adapted to the difficult conditions. Of all the WHS in the region, the dug wells are particularly noteworthy. These wells, a characteristic feature of the landscape, are mainly located in groups around the village. Although the wells bring to mind memories of past challenges, their continued presence provides a sense of reassurance and appreciation to the local community in light of potential future water scarcity. Today, most of them have withstood the ravages of time and neglect and have retained their structural integrity. Nevertheless, the local population appears content to have access to these wells in the event of a future water shortage. Historically, the scarcity of water resources was such that the village required as many as 400 wells to meet its water needs. This underscores the profound and emotive significance of water to the community, which is further compounded by its historical role in their lives. Analysis of the water from these wells shows that it is almost drinkable, which is an unexpected revelation. However, the ponds and pans outperform dug wells and other WHS when it comes to adaptability. Ponds provide water that is suitable for both irrigation and consumption after initial treatment. And even if their water is not suitable for human consumption, ponds play a critical role in providing water for wild and domestic animals, promoting ecosystem sustainability and supporting local livelihoods dependent on livestock.

Today, the WHSs of the study area are under increasing pressure from the expansion of settlements and the intensification of agricultural practices, which have a particular impact on the dug wells. These activities are straining the delicate balance of the polje's environment and threatening the soil and water resources, and therefore the WHS, on which the community depends. Without formal protection or conservation measures, there is a real risk that these systems will deteriorate, leading to physical and cultural erosion over time.

WHSs are important in difficult and marginal environments due to their independence and decentralization. These systems offer a viable alternative to scarce or inadequate water sources and solve problems such as scarcity, salinity, pollution, prohibitive drilling costs and limited public water supply. The resurgence of WHSs could be an important lifeline, cushioning periods of drought and serving as an additional or emergency water reserve in regions increasingly facing drought, such as the Mediterranean. At the intersection of escalating water and food insecurity, accelerated by climate change, traditional WHSs should be considered not only as historical or architecturally significant relics, but as examples of sustainable water management practices. Our research highlights the diversity of these systems as well as their design and adaptability to the local context and offers insights that can provide strategies for water security. These may involve preserving traditional practices or ingeniously combining them with modern technologies.

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Anahtar Sözcükler: Su hasadı sistemleri; su kıtlığı; su mirası;; iklim dirençliliği, kültürel miras

İKLİM DEĞİŞİKLİĞİNE UYUMDA GELENEKSEL SU HASADI SİSTEMLERİ: YARI KURAK BİR AKDENİZ KÖYÜNDEN ÇIKARIMLAR

Geçmiş medeniyetler tarafından yüzyıllar boyunca geliştirilen geleneksel su hasadı sistemleri (SHS), yarı kurak bölgelerde su kıtlığıyla baş etmede önemli bir rol oynamıştır. Bu sistemler -modern su altyapısının yaygınlaşmasıyla birlikte ihmal edilmiş olsalar da- günümüzde özellikle iklim değişikliği karşısında su yönetimiyle ilgili zorlukların üstesinden gelmek için hâlâ geçerliliğini koruyan önemli bilgi ve uygulamaları içeren değerli bir mirastır. Geleneksel su hasadı sistemleri (SHS) farklı bölgelerde incelenmiş olsa da, bu sistemlerin biçim ve işlevleri; iklimsel, jeolojik, hidrojeolojik ve kültürel koşullardaki farklılıklardan dolayı önemli ölçüde değişiklik göstermektedir. Akdeniz bağlamında ise, küçük ölçekli SHS'ler özellikle çağdaş kullanıma yönelik yeniden işlevlendirme ile tarihî ve kültürel önemini birlikte ele alan çalışmalar açısından görece sınırlı ilgi görmüştür. Bu çalışma söz konusu boşluğu doldurmayı ve Türkiye'nin Ege kıyısında yarı kurak bir köy olan Barbaros'taki küçük ölçekli su hasadı sistemlerine odaklanarak mevcut literatüre katkı sağlamayı amaçlamaktadır. Barbaros, özel jeolojik koşulları nedeniyle farklılık arz etmektedir; zira gözenekli toprak yapısı suyun tutulmasını zorlaştırmakta ve bu durum geleneksel SHS'lerin önemini artırmaktadır. Bu bağlamda, araştırmanın temel amacı alanın topoğrafya ve jeolojik özellikleri ile SHS yapım teknikleri ve nesiller boyunca aktarılan yerel bilgiyi göz önünde bulundurarak bu sistemleri kapsamlı bir şekilde değerlendirmektir. Çalışmada, literatür taraması, saha gözlemleri, uzman anketleri ve uzun süredir bölgede yaşayan bireylerle yapılan mülakatları içeren disiplinlerarası bir yaklaşım benimsenmiştir. Böylece, geleneksel SHS'lerin tipolojisi, mevcut durumu ve sosyo-kültürel evrimi detaylı olarak analiz edilmiştir. Bu sistemlerin derinlemesine anlaşılması, özellikle kuraklık yönetimi açısından, iklim değişikliğine uyum sağlamadaki dirençliliklerini ve günümüz su yönetimi bağlamındaki geçerliliklerini değerlendirmek için kritik öneme sahiptir. Çalışmanın bulguları, kısmen terk edilmiş olmalarına rağmen, Barbaros'taki geleneksel SHS'lerin sürdürülebilir su yönetimi konusunda önemli çıkarımlar sunduğunu ve günümüz su sorunlarına yönelik uygulanabilir modeller olarak değerlendirilebileceğini ortaya koymaktadır.

TRADITIONAL WATER HARVESTING SYSTEMS IN CLIMATE CHANGE ADAPTATION: INSIGHTS FROM A SEMI-ARID MEDITERRANEAN VILLAGE

Traditional water harvesting systems (WHS), developed over centuries by past civilizations, have long played a crucial role in addressing water scarcity in semi-arid regions. Although these systems have been largely neglected with the expansion of modern water infrastructure, they remain a valuable heritage containing significant knowledge and practices that are still relevant today, particularly in overcoming water management challenges in the face of climate change. Although traditional WHSs have been studied across various regions, their forms and functions vary significantly due to unique climatic, geological, and cultural conditions. In the Mediterranean context, small-scale WHSs have received comparatively limited attention—particularly studies that integrate both their revitalization for contemporary use and their historical and cultural significance. This study aims to help bridge that gap and contribute the existing literature by focusing on the WHSs in Barbaros, a semi-arid village on the Aegean coast of Turkey. Barbaros is particularly unique due to its special geological conditions, as the porous soil makes water retention difficult, which adds to the importance of traditional WHSs. In this context, the main objective of this research is to comprehensively assess these systems, by considering the area's topography, geological features, WHS construction techniques, and local knowledge transmitted across generations. This multidisciplinary approach, combining a literature review, field observations, expert surveys and interviews with long-time residents, enables a comprehensive analysis of the typologies, current state and socio-cultural evolution of these systems. A thorough understanding of these systems is essential to assess their resilience and relevance for climate change adaptation, especially with regard to drought management. The study concludes that, despite their partial abandonment, the traditional WHSs in Barbaros offer valuable insights into sustainable water management and demonstrate their potential as practical models for addressing today's water challenges.

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