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ORIGINAL ARTICLE

Ancient karez systems in Şanlıurfa, Türkiye: detection, analysis, and sustainability of historical water supply networks

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Abstract

This study investigates the ancient karez water supply systems in the historical city of Şanlıurfa, Türkiye. Karezes are underground tunnels that collect groundwater and transport it via gravity to provide a reliable water source for urban settlements and agricultural irrigation in arid and semi-arid regions. The study focuses on three central karez systems in Şanlıurfa: Old Karez, New Karez, and Germuş Suyu. The research methodology involves establishing the location of water sources using GPS sensors, monitoring transmission routes, documenting the location of shafts and water structures, and computerizing the data using ArcGIS program. The karez network was spatially mapped using comprehensive field studies. In addition, the working system was analyzed based on the cross-sections and images of the system. The study evaluated historical information and current conditions of the water supply system. Comparison of the ancient and modern systems revealed that the resources continued but were not located in the current central business district. The research emphasizes preserving these ancient water supply systems as cultural heritage and sustainable water management in arid regions. Custom-made management models can facilitate protecting and reconstructing hydraulic infrastructures to optimize resource exploitation and increase the effectiveness of water supply systems in arid and semi-arid regions.

Keywords Geographic information systems · Geospatial mapping · Historical areas · Spatial networks · Urban analysis · Water supply system

1 Introduction

In arid and semi-arid regions, water accessibility is vital for survival, human settlement, and a technical necessity for efficient harvesting and transportation [1]. This is limited by the tiny amount of rainfall, which relies mainly on precipitation to feed underground sources and on snowmelt coming from adjacent mountainous areas, which is the significant supply recharging to the aquifers via rivers and streams in some areas [2]. Climate change can influence stream flow and the aquifer's recharge to the extent that meteoric precipitation during the winter months changes to precipitation that immediately runs off the snowpack that accumulates in winter and gradually dissolves in both spring and summer. It could be associated with a decrease in total rainfall and worsen the issue of water availability [3]. Moreover, underground water is typically restricted because recharge is limited in drought areas, so finances, infrastructure, and natural issues constrain water availability. In the past, efforts to bring groundwater to the land surface have resulted in technical difficulties in transporting water to where it is

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needed [4, 5]. Thus, the increased rate of evaporation inherent to arid environments has resulted in a loss of volume and elevated salinity in the transported inflow water, and water quality has deteriorated [6]. However, many current studies emphasize lands that become arid with changing climate conditions [7], acequia systems [8, 9], water supply networks [10] and urban water resource security [11]. As climate parameters change, effective water management becomes a more critical issue [12]. As human populations grow and occupy marginally productive land that requires more water, it becomes more difficult to sustain, and water becomes a finite, non-renewable supply [13, 14].

For centuries, droughty regions of the Middle East, Asia, and North Africa have utilized water-sourcing networks involving tunnels dug by hand in the alluvial fan deposits near mountains that supply groundwater from melting snow [15, 16]. The system, which was first developed 3000 years ago in Iran and has spread east, west, south, and north [17]. Intelligently designed structures to reduce evaporation loss to a minimal level by collecting groundwater through tunnels and delivering it close to the use site [18, 19]. As a historical water conservation heritage, flow roads [20] intercept groundwater with culverts and carry it to reservoirs for various purposes [21]. The names of these structures vary by region (Old Kehriz, New Kehriz, and Germuş Water) in Şanlıurfa, which this study focused on and has been hosting many civilizations since 11,500 BC. They will be referred to here as karez or kariz (Iran, Iraq, Afghanistan, Pakistan, Azerbaijan, and Turkmenistan), singular, aflaj, falaj (United Arab Emirates, Oman, and Afghanistan), Kanerjing (China), kahn (Baloch), qanat (Iran), Foggara (Algeria); Fughara, Khettara, and Iffeli (North Africa) [22–24]. It flows through the walls of a central well and is then transported along the karez channel by natural gravity flux. If a single tunnel cannot provide sufficient flow, other infiltration channels can be added to the main tunnel. Karezes are the most environmentally sound and balanced way of providing water to arid regions [25, 26]. Şanlıurfa, one of the World's oldest cities, has many old hydraulic constructions, such as aqueducts, tunnels, galleries, and cisterns dating back to ancient civilizations. The city's center is adorned with water buildings such as baths, aqueducts, water balance facilities, water distribution structures, wells, fountains, and cisterns. The city's water structures were positioned on the ancient water transmission system named "karez" in the old city center of Şanlıurfa and were fed from there. This study examines the water supply, distribution, storage, and utilization structures in Şanlıurfa; ancient water sources and their transmission lines, origin, location, and ancient and contemporary photographs and technical details are evaluated and documented. They are discovered in the Islamic World, the Far East, and some Western nations, which have standard features: a non-horizontal, gently slanting tube that touches the water table in an alluvial fan aquifer, vertical shafts typically near a mountain range for the original construction of the tunnel, access for ongoing maintenance and ventilation; and water transfer to the nearby terrestrial level utilization location further up the alluvial fan [27, 28]. They are conventionally established, service delivery is done without mobilized appliances, and water is transmitted solely by force of gravity. It keeps it a relatively cheap water source tailored for agricultural water supply and irrigation [29], especially in some developing nations [30]. The most flow from the karezes happens in spring and early summer, during the lowest runoff in late fall and winter, when cultivated crops need irrigation [31]. Such constructions are favorable over surface water supplies in many parts of Şanlıurfa because surface water supplies are usually wholly or partially dry during all or part of August-November due to low melting of snow and intensive irrigation.

1.1 Karez systems: a sustainable groundwater management technology

Many studies have reported that karezes have been the focus of civilization building in various parts of the World, as shown in Fig. 1, adopted from Macpherson et al. [32]. In the southern regions of Afghanistan, such as Kandahar, Uruzgan, Nimruz, and Helmand, karez facilities have existed for centuries [33]. In Azerbaijan, large areas such as Zanjan, Ganja, Karabakh, Nakhchivan, and Baku are irrigated by karezes. The Turpan Oasis built karez water canals 2500 years ago in Xinjiang Uyghur Autonomous Region, China, and some of these lines are still in use today [34, 35]. It is estimated that around 50,000 karezes were used in Iran in the mid-twentieth century. Features five medieval sites in Kazakhstan where karezes were used: Sauran, Turkestan, Chernak, Babaikorgan, and Karachi. In Syria, many cities have been found with a system of karezes, but widespread groundwater pumping arrangements have lowered the groundwater level and the water level in the karezes. Thus, the ambers dried up and were abandoned throughout the country. In the United Arab Emirates, following Al-Ayn, palm groves are still irrigated by traditional qanat schemes. Nearly 3000 karez systems are in use in Oman.

Karez systems stand out as an agriculturally focused water transportation method and a section of this is summarized in Fig. 2. The New Kehriz is a historical water source in the village of Aşık, 15 km north of the city and the same distance from the city center. It was carried through human-made channels for underground water. This reservoir water was transported through canals known as karez, which led to the aqueducts under the parapets of the Justinian Aqueduct and the Millet Bridge and then to the delivery point

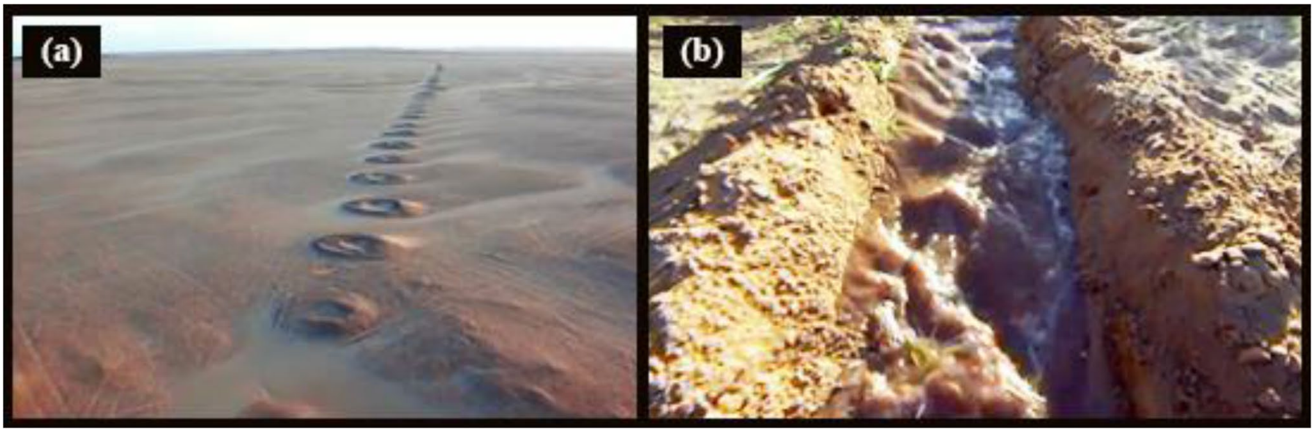

Fig. 1 Certain facts and figures about the Karez construction (**a**): top view, and (**b**): cross-sectional view [36] (BBC, 2011)

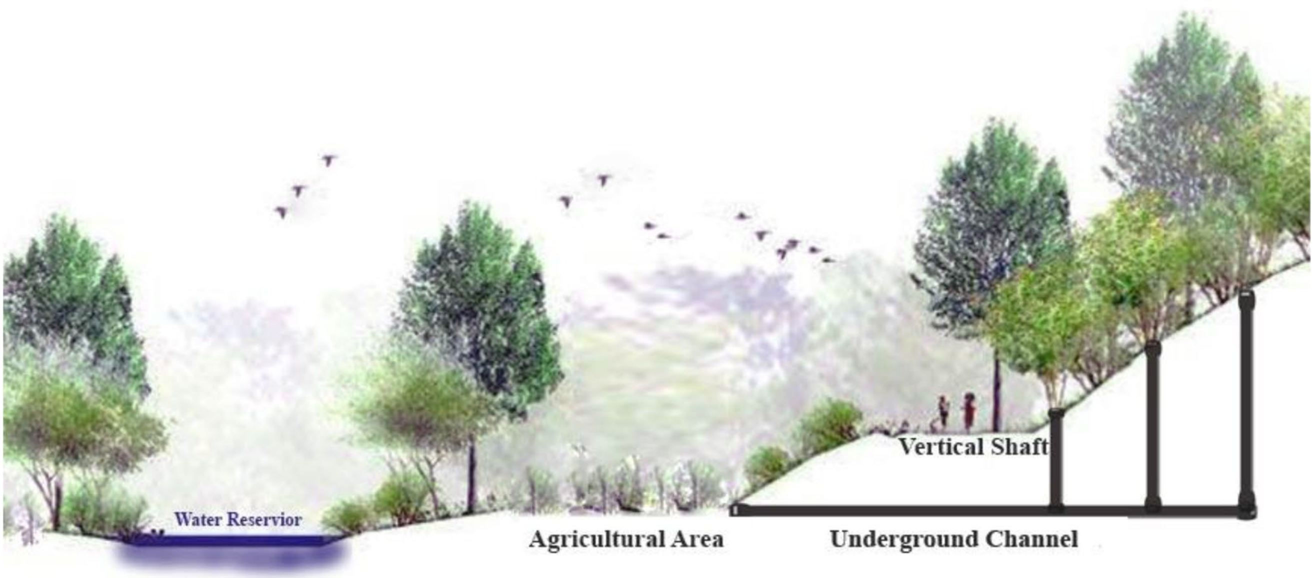

Fig. 2 Conceptual diagram of a karez network

in Water Square. At this point, three currents of flowing water are distributed through "pöhrenks" (a pottery water pipe with a diameter of 30–35 cm and a length of 15–20 cm) to some houses, mosques, and baths. Because the ends of these pipes are arranged as a diagonally arranged tube, the pipes are elongated until they are linked. The first line goes to Yusuf Pasha Mosque and Vezir Hamam, the second line to Adile Hanım Fountain on Kubbemescid Street and from there to Sakibiye Tekke, and the third line to Ulu Mosque, Firuz Bey Fountain and Ağ (Nimetullah) Mosque.

This paper briefly investigates how three ancient water sources and their conveyance systems were investigated and identified across the city of Şanlıurfa, Türkiye. Maps from the study have been produced that provide illustrations of the karez installations, most of which are dried, and the location and condition of the karezes in the city are shown, along with their additional structures. This research focuses on the relationship between the system created by past water infrastructure and land use. The network in Şanlıurfa, which includes the water supply systems built in ancient times and their transmission structures called karez, was examined and mapped. The study identifies, documents, and illustrates the structure, function, and distribution of all karezes in the city using fieldwork data. Throughout the city's history, various populations utilizing the urban area have erased many existing cultural forms of previous cultures. Nevertheless, whole societies have preserved and enhanced their water supply networks. For this reason, water facilities have survived to the present day, and some of these systems are still in use and give so much information about the past.

2 Materials and methods

2.1 Study area

Şanlıurfa is located in southeastern Türkiye, between longitudes 36 40−38 02 E and latitudes 37 50−40 12 N in Fig. 3. Şanlıurfa, considered one of the oldest provinces in the World, has been home to numerous cultures from the 11,500 BC to the present day.

Finding relevant quantitative, field-specific information for interpreting model input parameters and results in Şanlıurfa is difficult. So, several limitations and generalizations were identified. This section describes the methods for defining karezes in the field, databases and selecting groundwater model entries, and knowledge of population trends. In work carried out locally, an approach based on structures found observationally in the field is designed to recognize the shafts' location in a Geographic information systems (GIS). Initially, graphic descriptions of karez features (vertical reach shafts or chars) were captured with orthophotography, and the localities were recorded in a GIS tool. Karezes in Şanlıurfa shows a roughly circular plane of deposition surrounded by sediment, leading to a surface channel that supplies water to a whole village. The active and deserted pits were discriminated against according to whether the holes looked clear or collapsed.

2.2 Data detection and mapping

Based on the results of the research and extensive field studies conducted as part of an enormous scope on Şanlıurfa's ancient water resources and historical water structures, older local water supplies and distribution networks in the Şanlıurfa region have been defined as described next: (i) Establishing the location of the water sources via GPS sensors, (ii) Monitoring all paths of transmission routes of open or closed facilities,

Documentation of the location of all shafts (ventilation shafts), wells, water structures, etc., along the route, iii) Computerizing the data in NetCAD and ArcGIS programs. Measurement control points for Old and New Kehriz Waterways are in Fig. 4.

3 Results

3.1 Comparison of ancient hydraulic structures and current system in Şanlıurfa

The available evidence on the archaeological record shows that the city of Şanlıurfa had significant water supply and transmission experiences. Its elevation ranges between 500 and 1000 m. Until recently, there were many water sources such as Halil-i Rahman (Hz. İbrahim) and Karakoyun Stream (Daisan Water), Aynzeliha Lakes, and Devtesti, Cavsak, Direkli, Kehriz, Karaköprü Streams, Bamyasuyu in the city center and its immediate vicinity. In addition to these, Belih, Culmen, Esemkulu, Germuş, Golpinar, Kirkpinar, Kopruluk streams, Tatarhoyuk, Tulmen, Yukarikoymat, and Yarimtepe were the most critical water sources of Şanlıurfa. However, the reduction of precipitation and other factors have led to the drying up of many of these springs. Şanlıurfa's existing natural water resources are given in Fig. 5. Karez systems are visible on Google Earth and in low-altitude images of Şanlıurfa.

The Old Kehriz was a little flow that emerged from the Direkli source in the western side of the province and, according to local sources, combined with Halilu'r-Rahman water in the city center. The two karezes have been demolished and have primarily disappeared to date. Halilu'r-Rahman (Hz. İbrahim) Stream originated in the southern part of the city and connected to the Old Kehriz. It extends to the mosques and fountains on the line in the southern part of the city. In Fig. 6, households on all alignments utilized this water. The last ancient water source in the village of Germuş in the northeast of the city has survived. Except for this evidence, there is also a karez system named "kına" in Gilbas Village of Birecik District of Şanlıurfa. Karez-type systems like ancient water drains are reported to have been identified in the Suruc Plain near Şanlıurfa.

The New Kehriz (the longest ancient canal in the city and comes from the village of Aşık), the Old Kehriz (originates from the Direkli region and reaches the Halilu'r-Rahman Stream known as the Holy Pool of Prophet Abraham), and the Germuş Water (extends from the village of Germuş and continues in an open channel) are shown together.

Figure 7 depicts the New Kehriz network and its details. The system begins at Aşık Village northwest of the city and reaches from Kadioglu Maksem to the water-sharing point at Water Square. Along the road were two bridges to divert water to the former city center: The historic bridges, Justinian Aqueduct and Millet Bridge, were constructed on the Justinian water system and are still in use. As an ancient flood control system, the Justinian system comprised several bridges and an artificial channel called the Karakoyun River, which was simultaneously built in the first half of the 6th century. The complex was built by Justinian, a productive developer among the Roman Emperors [38]. Following the Water Square's circulation system, it reaches many public fountains, baths, mosques, and houses.

The majority of karezes in Şanlıurfa are positioned parallel to the river channels. It shows that the alluvial aquifers fed by New Kehriz, Old Kehriz, and Germuş Water are mainly provided by streams and rivers from Aşık Village,

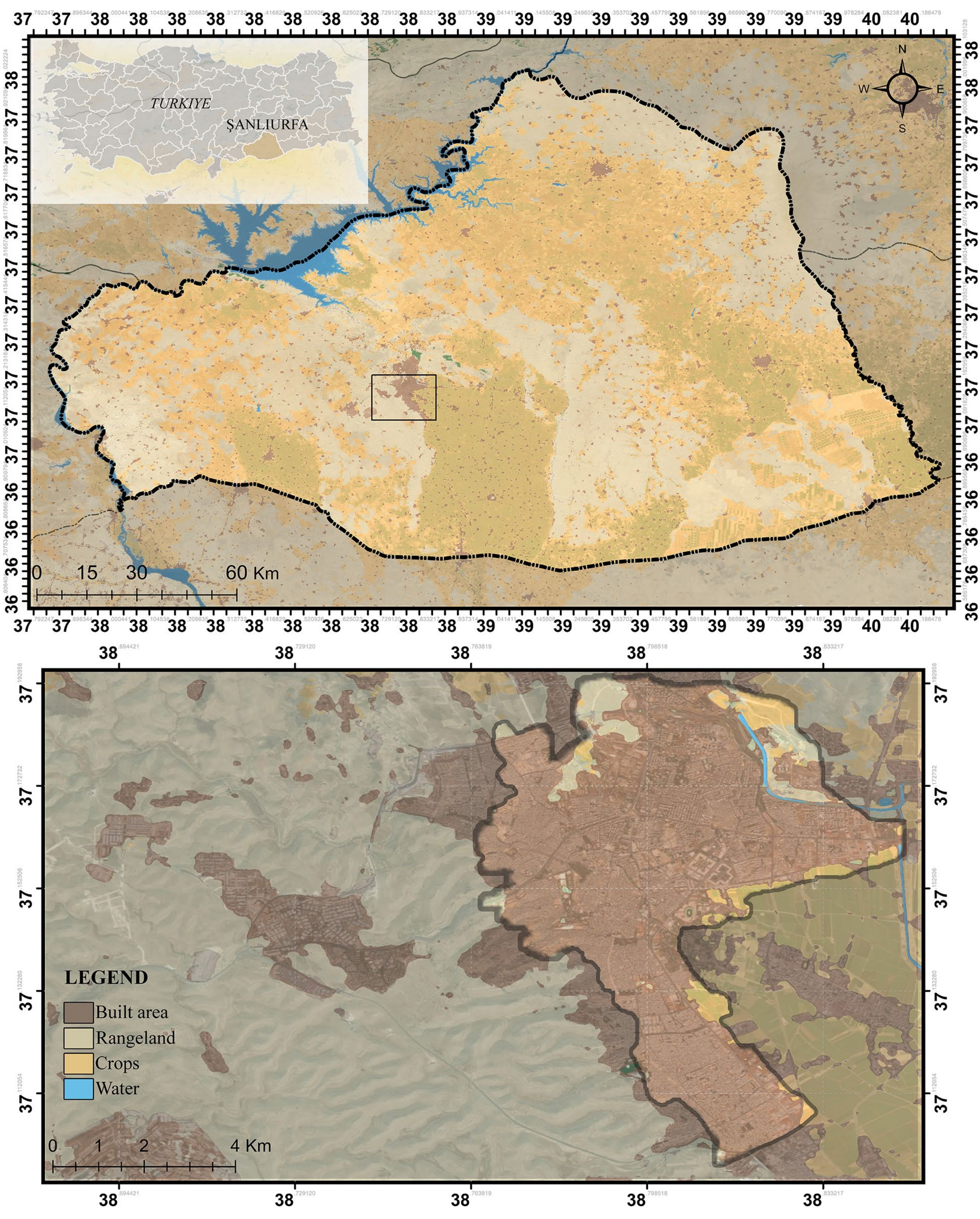

Fig. 3 Location map of study area

Direkli region, and Germuş Village. It does not consider the contribution of the discovered cisterns to the recharge of a river. Instead, it examines water transmission to a hypothetical cistern with fixed head boundaries both upstream and downstream. To make sense of the water supply function of Kehriz, model sensitivity to several model index elements is first addressed. Subsequently, since water availability in karezes-hosting alluvial aquifers depends on recharge,

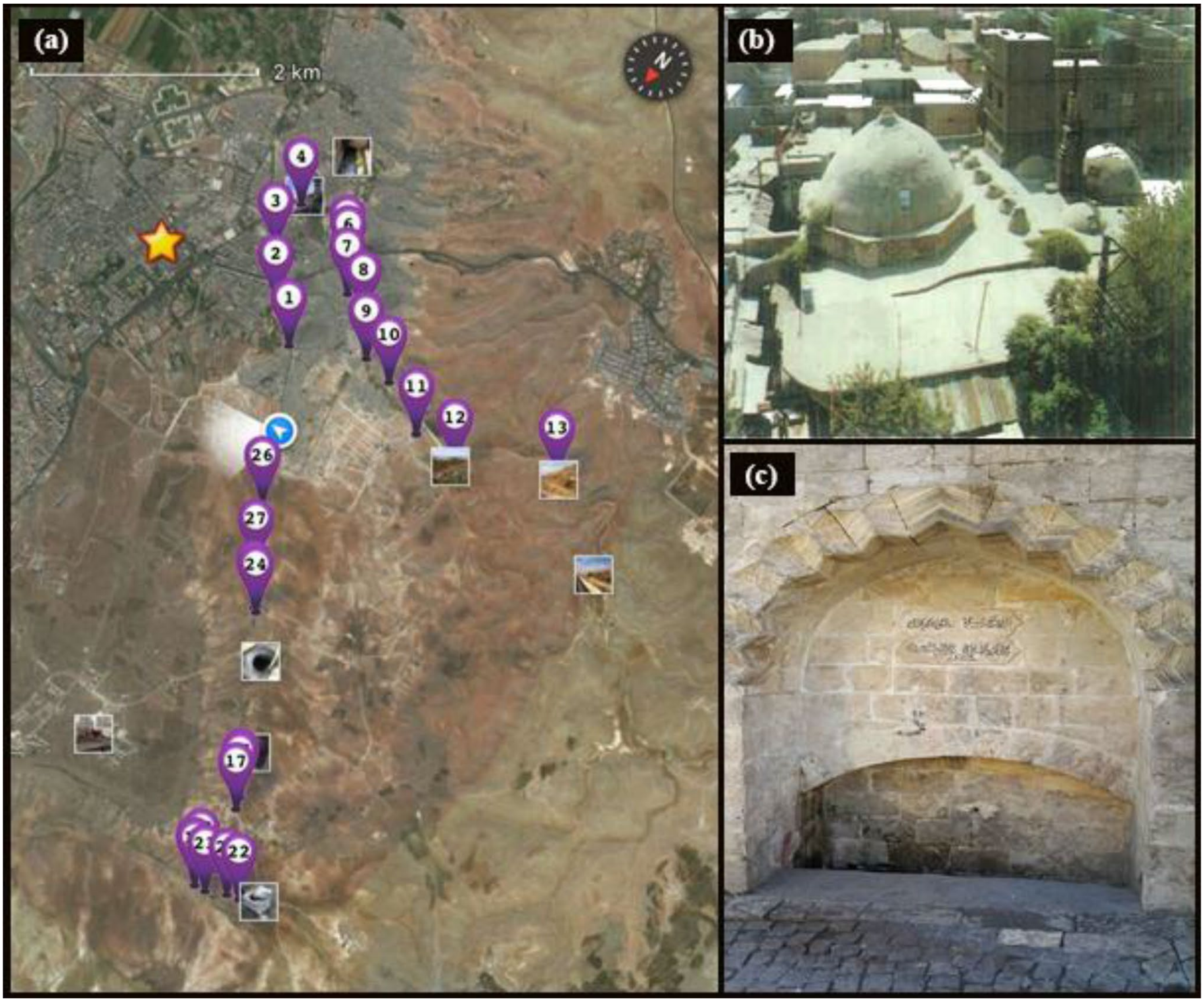

Fig. 4 Measurement technique details (**a**): Control points for Old and New Kehriz Waterways, (**b**): The Vezir Bath is set on the route of the New Kehriz, (**c**): Kadıoğlu Fountain and Water Maksem (distribution) system at Water Square

long-term trends in precipitation, especially in Şanlıurfa, are shown, and variations in aquifer refill are estimated.

Furthermore, as water use also impacts aquifer maintenance, trends in population development in a selected representative area are displayed, and potential impacts on water use, wastewater generation, and blackwater discharge rates resulting from this population growth are considered. The analysis examines how increases in population size and water demand can affect the sustainability of the local aquifer system, including the recharge rates and overall water balance. Scenarios are developed to quantify the potential impacts of population growth on freshwater withdrawals and wastewater discharge, which are critical factors in maintaining the long-term viability of the karezes and the groundwater resources they depend on Old Kehriz, and its details are shown in Fig. 8. Located on the west side of the city center, it starts at the source of Direkli Water. It is pictured with Halilu'r-Rahman Spring, the Holy Pool of Prophet Abraham.

Germuş Village is situated northeast of the city center and is 15 km away. It is an ancient village with several large stone buildings and the historic Germuş Church. It is recognized that there were three karezes, which were nourished from the water sources to the north and east of Germuş. They were covered with debris and built in the form of arches. One can walk through them easily for cleaning and maintenance. Above the galleries, there are regularly spaced ventilation shafts. The karez system in Germuş Village has been an essential part of the region's water management for centuries. These underground tunnels have provided a reliable water source for irrigation and domestic use, even in extreme arid conditions. Similarly, the qanat system in Iran

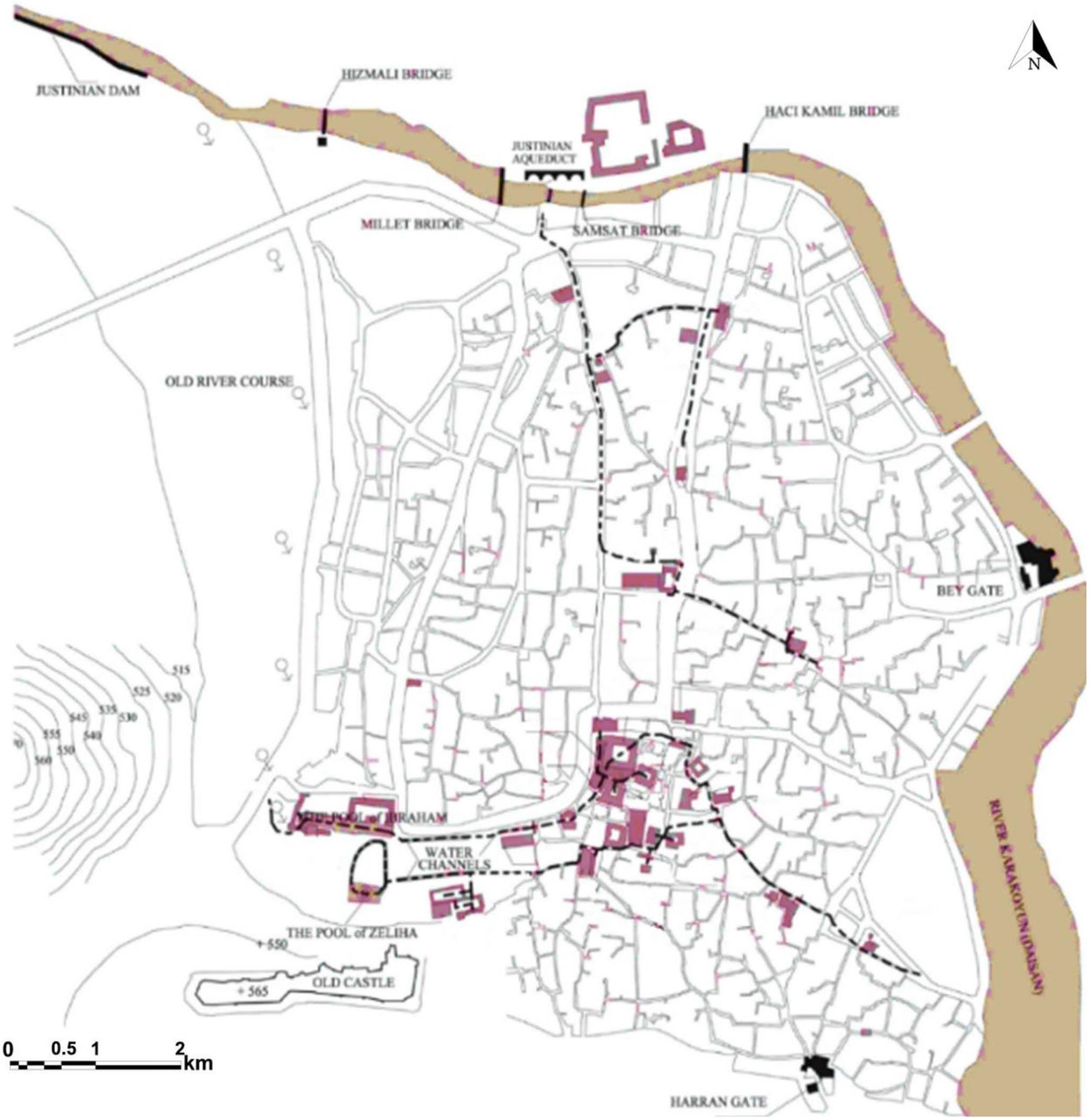

Fig. 5 The routes of the water distribution system in the old city center [37]

has been a traditional water supply method for nearly 3000 years, with the current study highlighting the effectiveness of these systems in extracting water from challenging rock terrains. These traditional underground water conveyance systems have been crucial for generations, sustaining agricultural and community activities in water-scarce regions like Şanlıurfa.

4 Discussion

To better understand the water supply function of Kehriz, the model's sensitivity to several index elements is first addressed. Subsequently, as water availability in karezes-hosting alluvial aquifers depends on recharge, long-term trends in precipitation, especially in Şanlıurfa, are analyzed, and variations in aquifer refill are estimated [39, 40]. Furthermore, as water use also impacts aquifer maintenance,

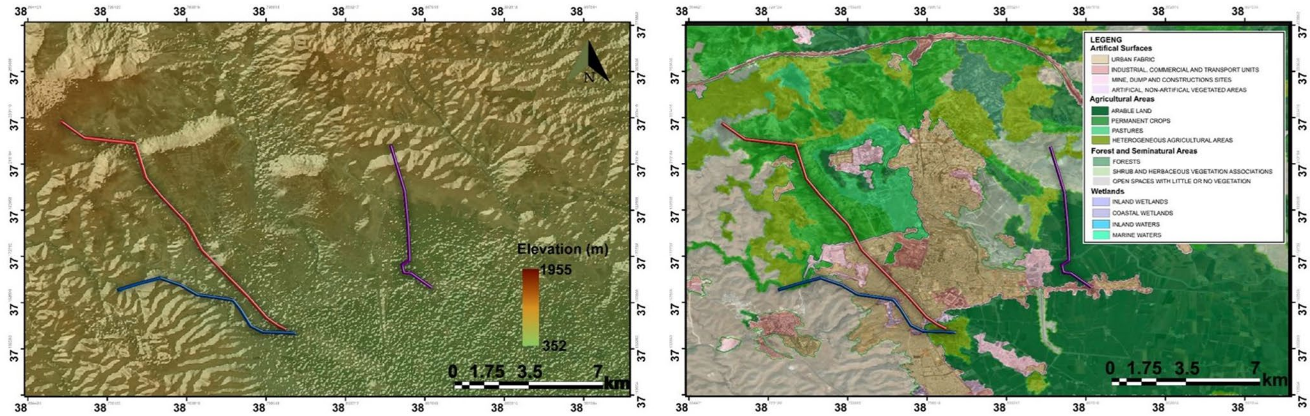

Fig. 6 Şanlıurfa's ancient waterways with origin and destinations

trends in population development in a selected representative area are displayed. Potential impacts on water use and blackwater discharge rates resulting from this population growth are considered [41–43]. The karezes feed the Middle, and Great Springs originate from the mountains' hillsides on the settlement's north side. These springs were operational in the 1990s and can be entered and cleaned. Both of these springs are linked to one another by internal links. Along the route, there are air chimneys (ventilation shafts). In most of the houses in the village, these structures also served to provide water for the homes and wells. Most of these wells, though, have been completed because of neglect. These wells were mostly made of regular ashlar stone, and water was obtained by descending with a ladder. After leaving the village, this water continues downward as an open channel. The first channel that takes water from Küçük Pınar is from the town of Diphisar, 25–30 km north-east of Germuş. This gallery, which previously provided water for sprinkling, has dried up due to a lack of maintenance. The water transmission function of the Kehriz system is influenced by various factors, including aquifer properties, recharge rates, and hydraulic gradients [44]. To assess the sensitivity of the model to these parameters, a series of simulations were conducted to evaluate the impact of changes in these elements on the water supply capacity of the karezes [45]. As the population in the study area has grown, the demand for water resources has increased accordingly. This has the potential to strain the delicate balance of the Kehriz water supply system, as increased water usage and wastewater discharge could impact the aquifer recharge rates and overall sustainability of the system.

According to our results, qanats (or kehrizes - karezes) are a sustainable groundwater management technology suitable for arid regions and stringent social, environmental, and economic conditions [46]. Much research about karez systems is illustrated in several locations and recognized as the groundwater reserve by Sala et al. [47], Maierdan et al. [48], and Ebrahimi et al. [49]. Also, the karez database was utilized for new explorations. On the other hand, many irrigation systems in the Republic of Uzbekistan are primitive and disorganized, leading to huge water waste due to uneven terrain and insufficient planning. Furthermore, the water crisis in Iran has been attributed to a combination of factors, including poor spatial planning, mismanagement, political decisions on water allocation, and insufficient pricing policies. These studies demonstrate the need for integrated water resource management plans and technological solutions to ensure the rational and sustainable use of limited water resources in these regions. The successful implementation of such solutions in arid and semi-arid areas can help address the growing water crisis and ensure food and water security in the long term. Barbaix et al. [45] examined the karezes and their settlements by Corona KH4B-, Landsat 8-, and Pleiades 1- views. They found a relationship between the natural landscape and the karezes in the Turpan Basin. Khan et al. [50] researched Karez irrigation systems where Afghanistan has a traditional water management network that includes operation, maintenance, and distribution. Throughout the city's history, the inhabitants have preserved and developed water supply systems, even though they eradicated many of the cultural structures of previous civilizations. Historical sources have been crucial in understanding the development and functioning of karez systems in Turpan, China.

In conclusion, the research on karez and qanat systems in Turpan, China, Iran, and Uzbekistan demonstrates the importance of these traditional water management techniques in arid regions. These underground water supply systems have been used for centuries to address water scarcity and ensure reliable access to water for agriculture and domestic use. However, many of these systems have been neglected or abandoned, leading to water waste and inefficient use of limited water resources. To address these challenges, integrated water resource management plans and

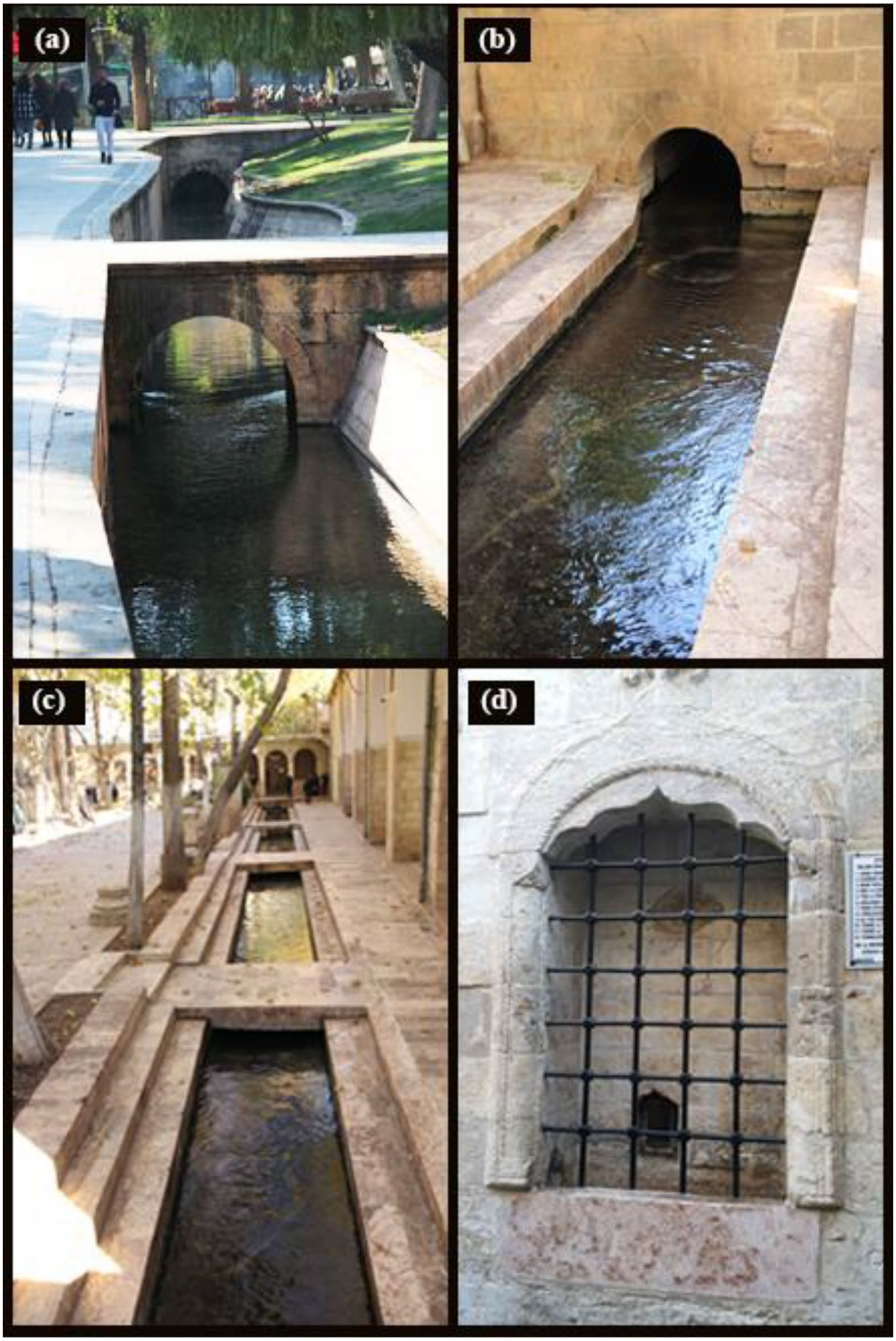

Fig. 7 Old kehriz details (**a**): The connection point to the Halilu'r-Rahman Water (it is believed to be sacred), (**b**): Exit to the water structures, (**c**): The open section of the Halilu'r-Rahman Water in Hasan Pasha Mosque, (**d**): The Dabbakhane Fountain on the water line of Halilu'r-Rahman Water

Fig. 8 The details of karez galleries of Little and Middle Springs of Germuş Water; **a**-**d**. Views of Circular Galleries and Stone Braid Walls of Tunnels, from Site Study of the Authors

technological solutions are needed to revive and modernize these traditional water management systems. Our database depicts them as straight paths stretching from the primary well to the outlet, so each core is identified by a beginning and an endpoint (the outlet). Also, karez water is currently primarily used for irrigation in agricultural fields. This has ensured that water structures have survived to the present day, and interestingly, some of these systems are still in use. As a cultural heritage, karezes still tell us about our past and roots.

5 Conclusion

In ancient times, Şanlıurfa experienced higher rainfall levels than today. However, this changed around 4000 BC as the mid-Holocene humid phase ended, leading to a much drier climate. For millennia, people living in arid regions have developed innovative water capture and utilization technologies, including the karez system. This system plays a vital role in utilizing groundwater, supporting agriculture, domestic use, and conserving the unique oasis ecosystem in Şanlıurfa. The study findings demonstrate the beneficial outcomes of the karez system. The traditional karez principles can be adapted to modern irrigation systems, offering long-term advantages and opportunities for urban infrastructure and rural agriculture development. The karez system provides a logical solution for safe water transportation, addressing critical global issues like drought, food insecurity, and climate change-induced extreme weather events. It ensures water source sustainability, is economical due to its gravity-fed technology, reduces evaporation and pollution, and is resilient to natural disasters. Overall, the karez system enables sustainable water resource management in dry climates. This investigation shows that karezes are limited to specific landscapes, but their characteristics and associated settlement patterns vary considerably. The absence of karezes in some areas is often due to the presence of surface water or lack of suitable agricultural land, suggesting the knowledge and planning required to build an efficient karez system. However, the location of the land cannot fully explain all aspects of karez construction, indicating that the natural landscape is not the sole determinant. These findings provide insights into the character of the Şanlıurfa karezes and can inform future research, monitoring, and planning efforts. Governments can contribute by creating a comprehensive local database to support proper karez maintenance, which could benefit academic studies aimed at improving the efficiency of this primary water source for irrigation and domestic needs. Local communities should also engage in protecting these significant water systems.

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Data availability The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare that they have no competing interests.

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