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KAREZES, ABANDONED AND ENDANGERED WATER RESOURCES IN SEMI-ARID REGIONS: CASE STUDY FROM SULAYMANIYAH CITY, IRAQ

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ABSTRACT

The growing water shortage resulting from the recent drought season spanning from the last decades in Sulaymaniyah City has led to resurfacing the question of water supply. To cover for the long, hot and dry seasons and to make use of the limited precipitation in the higher elevation areas of the city, tenths of man-made subterranean aqueducts known as Karez or Qanat have been developed throughout the history of the city. This paper provides an insight into the current status of Sulaymaniyah Karezes and their deteriorating conditions regarding structure and water quality due to unsustainable urbanization and improper licensing for land use in the city. Geological aspects with particular emphasis on hydrogeological conditions that made their construction and their long-term use possible have been examined. Terminology, function, and distribution of all infiltration Karezes have been recorded and previously drawn sketches reviewed. Water samples from Karez outlets are analysed for major, minor and trace elements and the results showed that some of them are polluted and not suitable for human consumption. It also advocates that some of them in the Sulaymaniyah City shouldn't only be protected as a great city heritage but also be refurbished and reconsidered as sustainable and eco-friendly water supply system for at least irrigation and industrial use if not drinking.

الكهاريز: مصدر مائي مهمل ومتعطل، دراسة في مدينة السليمانية، العراق

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المستخلص

أدى النقصان المائي المتزايد والناجم عن موسم الجفاف الأخير الممتد خلال العقود الماضية في مدينة السليمانية إلى إعادة النظر في طرح مسألة إمدادات المياه. لتغطية المواسم الطويلة والحارة والجافة والاستفادة من الأمطار المحدودة في المناطق المرتفعة في المدينة، تم تطوير العشرات من القنوات تحت السطحية الاصطناعية التي عرفت باسم كهريز أو قنات خلال التاريخ الطويل للمدينة. يتناول هذا البحث نظرة على الوضع الحالي للكهاريز في مدينة السليمانية وظروف تدهورها فيما يتعلق ببنيتها ونوعية المياه بسبب التمدن غير المستدام والترخيص غير المناسب لاستخدام الأراضي في المدينة. وقد تم فحص الجوانب الجيولوجية مع التركيز بشكل خاص على الظروف الهيدروجيولوجية التي جعلت بناءها واستخدامها على المدى الطويل ممكن. تم تدقيق المصطلحات والوظائف وتوزيع جميع الكهاريز وتم استعراض الاشكال المرسومة السابقة. تم تحليل نماذج المياه المأخوذة من فوهة الكهريز للعناصر الرئيسية والثانوية والنادرة وأظهرت النتائج أن معظمها ملوثة وغير مناسبة للاستهلاك البشري. وجدير بالذكر أن بعض هذه الكهاريز في السليمانية يجب حمايته ليس فقط كتراث مهم لمدينة السليمانية بل يجب أن يتم تجديده وإعادة النظر فيه كنظام إسالة مستدامة للمياه وصديق للبيئة وعلى الأقل يمكن الاستفادة منها لأغراض الري والاستخدام الصناعي لو لم تكن لأغراض الشرب.

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INTRODUCTION

Groundwater is one of the vital and most vulnerable sources of earth's fresh water. It is however, favored over surface water due to a number of specific properties including, higher quality, lower possibility of direct contamination, lesser vulnerability to seasonal and perennial fluctuations, and a balanced distribution over many regions of the world (Abdin, 2006). Among many skillful and engineering systems to manage and utilize groundwater developed over the years in human history, Karez is considered the most sophisticated and sustainable groundwater management system to date. It has contributed substantially to the development of human culture. Considering the global water shortage, especially within arid and semiarid areas, Karez systems represent an eco-friendly system with a considerable potential in the water supply. The system is also called Kariz in Persian, Qanats, Falaj or Foggara in Arabic and Subterranean or Ancient Aqueducts in English (Chiotis, and Marinos, 2012).

Karez is a system of water supply that consists of subsurface tunnels with a gradual slope, engineered to collect groundwater from mountainous or flat regions (Figure 1). Qanat efficiently delivers large quantities of water to canals on the surface without the need for pumping to provide fresh water to human settlements and agricultural fields and usually dug in hot, arid or semi-arid climates where there is no surface water. However, the still – functioning karezes often compete with pumped wells for limited groundwater resources and they are frequently abandoned as the water table drops. In order to ensure a steady and unobstructed water flow through the underground channel, it must be periodically cleaned and reinforced to repair collapsed wells and keep the tunnel clear of debris (Lightfoot, 2009). It should also be noted that in the portion of the karez below the water table, there will be gain in groundwater while in the portion above the water table, losses will occur. This situation could conceivably be improved by lining the unsaturated part of the karez with a blank pipe. Such lining with a pipe would also reduce the amount of maintenance necessary (Banks and Soldal, 2002).

Although originally invented by Iranians, Karez is found in 38 countries worldwide, in both western and eastern hemispheres, though most are concentrated in the Middle East region (Abdin, 2006). Among 638-infiltration karez recorded in the archives of the northern Iraq, 84% of them are solely located in the Governorate of Sulaymaniyah (Lightfoot, 2009). The relative stability in the Kurdistan Region of Iraq after 2003 led to a rapid economic growth and resulted in a boom in poorly planned and unregulated urbanization in the city and thus a sharp increase in demand for water. Among other options, groundwater from Karez was considered to respond to this spike in demand in Sulaymaniyah. Karezes here are made with stone roof supports. Regular cleaning maintenance and refurbishing are often required due to frequent collapses in the underground tunnels (Fig.2). Finishing the second Dokan pipeline project to supply the city with tap water, turned the focus away from karezes and even traditional maintenance routines were abandoned. The present work aims to have an insight into the current status of Sulaymaniyah City karezes and their deteriorating conditions, investigating geological and hydrogeological conditions that made their construction and their long-term use possible, examining water quality for physico-chemical characteristics and to assess the possible contribution of karez water to the whole water demand of the city.

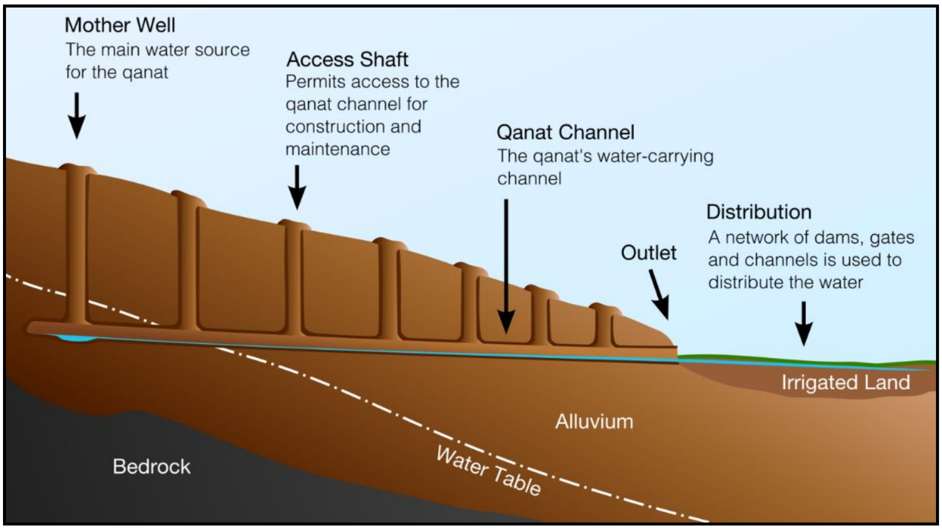

Fig.1: Cross section of a typical Karez (Angelakis *et al.*, 2017)

Fig.2: Photos showing the design of karez in the Sulaimaniyah City and its improper management

GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The area in question is located in Sulaymaniyah Governorate, NE of Iraq, between latitudes 3930000 – 3944000 N and 536000 – 545000 E, covering an area of about 95 Km^2 (Figure 3). Almost 23% of the area is considered as mountainous region which comprises Piramagrun, Azmir-Goizha, Sulaymaniyah anticlines, and Baranan Homocline, while central and southern parts of the area, which represents about 77%, is a gently dipping flat terrain (Qaradaghy, 2015). The trend of the anticlines and the strike of the strata are generally in NW – SE direction following the main trend of the Zagros folds, formed during the Alpine Orogeny of Cretaceous – Tertiary age (Al-Hakari, 2011). The Piramagrun anticline is traced by large fault in the right limb of the anticline trending NE – SW called Sulaymaniyah-Sitak fault. The plunging limb of the structure to the plain dictates the location, which is a classical situation for larger springs in the area like Sarchinar spring.

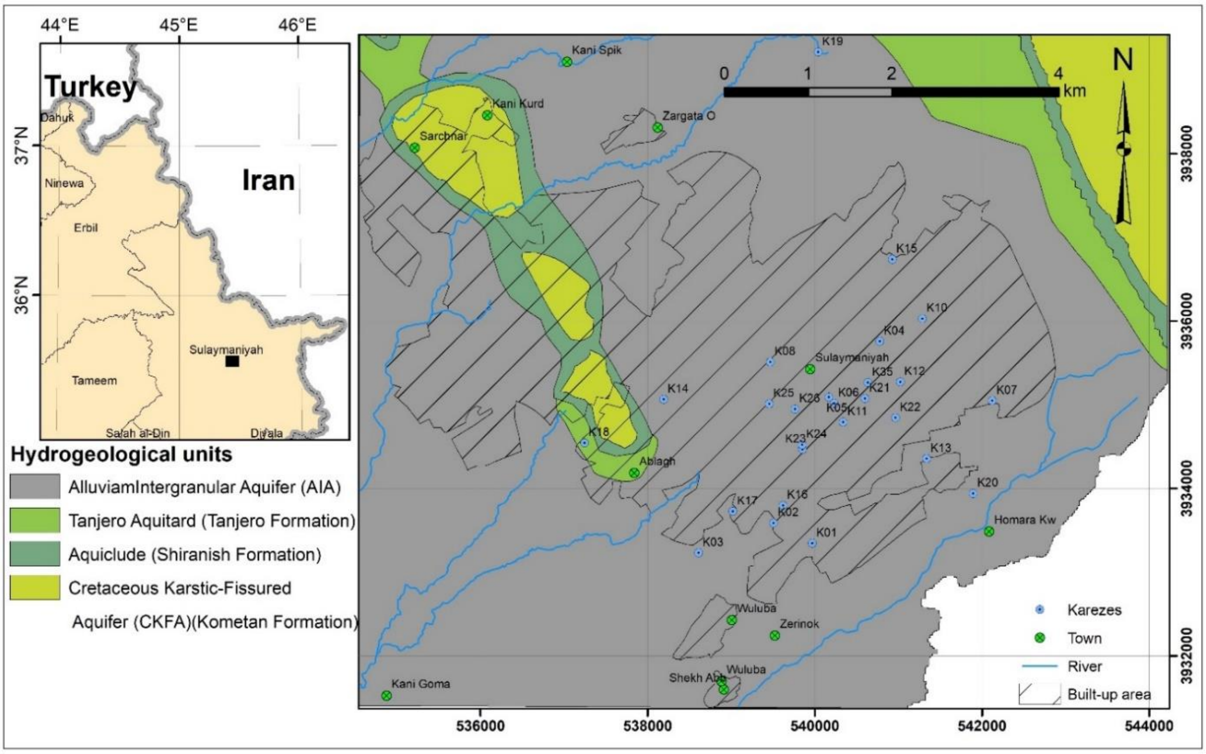

Fig.3: Location map shows the hydrogeological setting and the karezes sites

The geology of the area is characterized by the exposure of different stratigraphic units dated from early Cretaceous to Quaternary (Figure 3). The description of the formations is mainly based on previous work conducted by (Bellen *et al*., 1959; Aziz, 2001; Lawa, 2004; Karim and Ali, 2004; Jassim and Goff, 2006; Karim, 2004; Karim, 2006; Ali, 2007; Al-Hakari, 2011; and Qaradaghy, 2015). The main geological formations cropping out in the area of interest are briefly described from the oldest to the youngest in the Table (1). Hydrogeologically, the city is located within the Sulaimaniyah – Sharazoor basin (Ali, 2007). The situation of the aquifers exhibits three major inhomogeneous and anisotropic water-bearing units: Alluvium Intergranular (AIA), Karstic-fissured (KFA) and Complex aquifers (Hamamin *et al*., 2018). The principal productive aquifers are Karstic-fissured units represented by Kometan and Qamchuqa formations (Stevanovic and Markovic, 2004b). The Alluvium intergranular or quaternary aquifer appears in the area as alluvial fans, alluvium, and river terraces. The (AIA), which is formed within the pore spaces between granules, is acting as the second important aquifer in the area, while the Miocene Complex Aquifer (MCA) is considered as the least important aquifer in the area (Hamamin and Nadiri, 2018). The majority of water wells drilled in the area is penetrating the AIA, which supplies potable water for domestic and agricultural uses. The groundwater flow net direction is mainly from north and northwest towards the southeast of the area, which resembles the direction of the drainage pattern towards the Tanjero River. The net recharge from the precipitation to the aquifers varies from 14% for (AIA) to 31% for (KFA) respectively (Qaradaghy, 2015).

The hydrostratigraphy of the study area is summarized in (Table 2). The principal productive aquifers are the Kometan and Qamchuqa aquifers. These aquifers are overlain by the Shiranish aquiclude. A less productive aquifer is that of the Tanjero aquitard which overlies the Shiranish aquiclude and yields only small amounts of water. The Quaternary or intergranular aquifer appears in the area as alluvial fans, alluvium, and river terraces. It forms intergranular aquifer which is medium to highly productive. The majority of groundwater wells are drilled into this aquifer which supplies potable water for domestic use. The systematic distribution of potable water through networks in Sulaymaniyah City has only started in the early thirties of the twentieth century, prior to that, Karez system and few springs have been the only two sources of water supply for domestic, agricultural and industrial purposes in the city since its foundation. Having considered the morphology of the city and the fact that it is located on the foot zone of a more than 1000 m high mountain of Goizha and Azmar, the ancient inhabitants of Sulaymaniyah have soon imported the skills and even craftsmen (wasta) from the neighboring Iran to develop around 40 Karez in the city alone (Farhad, 2009).

Table 1: Lithostratigraphy of the exposed geological formations (Qaradaghy, 2015)

Period	Formation	Lithology	Thickness (m)
Quaternary	--	Consist of river terraces, slope deposits, alluvial deposits and composed of mud, silt, sand, and gravel	1 – 45
Late Paleocene – Early Eocene	Sinjar	Consists mainly of well bedded, dolomite limestone, marly limestone, sandstone, reefal limestone, fore reef limestone, and lagoonal dolomitic limestone	100 – 130
Paleocene – Lower Eocene	Kolosh	Consists of a rhythmic alternation of thin sandstone, siltstone, marlstone, and less common conglomerate and limestone with calcareous silt shale inter-layers	500 – 600
Late Campanian – Maastrichtian	Tanjero	Composed mainly of marl (blue and white) with marly limestone, glauconitic and bituminous	250 – 400
	Shiranish	It is mainly composed of an alternation of marl, siltstone, sandstone, conglomerate, and marly limestone	150 – 225
Late Turonian – Early Campanian	Kometan	Consists of white-to-light-gray, hard, uniform and medium-bedded limestone and chalky limestone	110
Hauterivian – Albian	Qamchuqa	Black bituminous and a continuous succession of massive limestone and dolomite	500
Valanginian – Turonian	Balambo	Composed of thinly bedded blue marls, radiolarian limestone with intercalations of olive green marls and dark blue shale, as well as thin bedded Globigerinal limestone	400

Table 2: Hydrostratigraphy and hydraulic properties of the aquifer system (Qaradaghy, 2015)

Aquifer type	Formations	Lithology	Porosity	Transmissivity (m^2/sec)	Storage Coefficient
Karstic-Fissured	Kometan, Balambo, and Qamchuqa	Limestone or Dolomite	Fractures, joints, and caverns	$7.5\times10^{-4} – 9.5\times10^{-3}$	3.2×10^{-4}
	Sinjar	Limestone and Dolomite	Fractures, joints, and caverns	$3\times10^{-5} – 3\times10^{-3}$	6×10^{-4}
Alluvium Intergranular	Quaternary	Quaternary sediments, including alluvial fans, flood plains, river deposits, buried valley sediments	Intergranular	$6.5\times10^{-6} – 1.6\times10^{-3}$	7.5×10^{-3}
Aquitard	Tanjero	Mainly sandstone, conglomerate, marllimestone	Fissures, joints occasionally with fault breccias	$4\times10^{-7} – 4\times10^{-4}$	1.12×10^{-3}
Aquiclude	Shiranish and Kolosh	Mainly marl, marly limestone, and shale	No effective porosity	--	--

WATER DEMAND

The rate of water demand has been progressively increasing in Sulaymaniyah City since the first available water demand record in 1957. The fairly small number of 57 liter/capita/day in 1957 has increased to reach 220 liter/capita/day in 2006 as cited in Farhad (2009). The consumption continued rising until it reached 250 liter/capita/day in 2010 according to Sharief (2013). If the population figures presented by Sulaymaniyah Statistic Directorate (SSD), of 895531 capita in 2017, and the forecasted 1040459 capita in 2022 are taken into consideration, it can be noted that, the bulk volume of water consumption has reached 9328 m^3/hour for 2017 and will rise to 10838 m^3/hour in 2022. Comparing water consumption in 1957 and that in 2010, shows that there is a considerable increase in water use. This increase has been attributed to changes in lifestyle, hygiene standards, increase in industrial consumption, rapid and most of the time unplanned urbanization. The rate of population growth in Sulaymaniyah City is said to be continuing and will be almost triple over the years 1988 – 2030 (Fathullah, 2000), as cited in Farhad (2009). Accordingly, a strategy for the sustainable water management of the four main sources of Dokan 1, Dokan 2, Sarchinar Karstic Spring and Well, together with utilizing the amount of water of the still active and clean karezes can supply, no matter how smaller amount that may be, would seem not only wise but the only available option to take the city out of a massive water shortage in the future.

METHODOLOGY

The initial site investigation was conducted in April 2016 to check the current situations and to record the necessary information of the area. Thereafter, estimating discharge rates and collecting water samples were carried out for the accessible karez points. Nine water samples were collected from the outlets using 250 ml and 50 ml polyethylene bottles for major and trace elements analyses respectively and were first filtered using 0.2 μm filter to get rid of colloids. The samples for trace elements analysis were acidified by adding few drops of high purity HNO_3 acid. All samples were then stored in a cool box at 4 °C until they were later analyzed in the laboratory. In situ field measurement were taken for temperature, electrical conductivity (EC), and pH using AP 85 and AP 75 Fisher Scientific Analyzer instruments and were fully calibrated before sampling. The analyses were carried out at Sulaymaniyah Health Protection Directorate and Sulaymaniyah Environment Directorate. The major ions (Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-) were analysed by titration, while (Na^+, K^+) were analysed by flame photometer. The (SO_4^{2-}, PO_4^{3-}, NO_3^-) were analyzed by colorimetry using American Public Health Association (APHA, 2005) standard methods. The concentrations of the trace elements (Zn^{2+}, Pb^{2+}, Cu^{2+}, Cr^{2+}, Cd^{2+}, Ni^{2+}) were determined by Atomic absorption spectrophotometer (Shimad 2u-AA 7000) model. A charge balance was calculated for each analysis to evaluate analytical error, and to determine if all the major ions were accounted for in the analysis. All values are below 5% which is considered acceptable for most water analyses. Physico-chemical data of the area were subjected to a graphical treatment by plotting them in an ion balance and Durov diagrams using Aq. QA, v.1.1 software. The previous hand-drawn sketches of the karezes with their subterranean channels and access shaft wells were obtained from the Sulaymaniyah Water Directorate (Table 3). They were georeferenced, digitized, and processed using integrated ArcGIS 10.5 (Figure 4).

Table 3: Names, locations, discharges, and conditions of karezes in Sulaymaniyah City

ID	Name	Longitude	Latitude	Elevation in meter(a.s.l)	Q ℓ/sec	Condition	Number of Access Shaft	Subsurface channel length (m)
K01	Khabat	539971	3933344	843	6.6	Good	5	500
K02	Dayky Pasha	539509	3933588	830	3.5	Good	18	650
K03	Mawlana	538610	3933230	787	4	Good	20	750
K04	Aziz Agha	540779	3935757	891	8	Good	13	635
K05	Ahmed Zangana	540168	3935090	870	7.35	Good	12	550
K06	Fatma Khan	540232	3935018	864	2	Good	20	600
K07	Ali Jola	542126	3935048	964	n.a	Dry	n.a	n.a
K08	KaniAskan	539470	3935511	857	15	Good	25	1002
K09	Majeed Beg	540171	3935550	899	10	Good	n.a	n.a
K10	Haji Beg	541289	3936030	919	10	Good	8	410
K11	Sayeed Hasan	540342	3934792	866	3	Good	25	500
K12	Darogha	541024	3935273	884	5	Good	20	560
K13	Mama Yara	541339	3934356	905	2	Good	14	500
K14	QoryaShkaw	538194	3935065	796	n.a	n.a	n.a	n.a
K15	Shekh Mahmood	540928	3936739	929	0.5	Bad	14	480
K16	Haji Fatah Mosque	539621	3933797	819	n.a	n.a	n.a	n.a
K17	Jwlakan	539022	3933725	804	n.a	n.a	n.a	n.a
K18	Ablagh	537247	3934544	787	n.a	n.a	n.a	n.a
K19	BnTabaq Mosque	540041	3939216	881	n.a	n.a	n.a	n.a
K20	Mufty	541896	3933941	886	n.a	n.a	n.a	n.a
K21	Haji Han	540603	3935075	869	n.a	n.a	n.a	n.a
K22	Haji Shekh Amin	540969	3934845	874	n.a	n.a	n.a	n.a
K23	Mawlana Khalid	539855	3934467	839	3	Good	20	750
K24	KhanaSutaw	539850	3934522	851	2	Good	16	500
K25	BakhyGshty	539456	3935012	990	n.a	n.a	n.a	n.a
K26	Shekh Mustafa Naqib	539766	3934948	940	n.a	n.a	n.a	n.a
K27	Saeed Beg	530188	3937123	825	n.a	n.a	n.a	n.a
K28	Hawary Shar 1	538247	3940888	904	7	Good	n.a	n.a
K29	Hawary Shar 2	538416	3940911	906	5.5	Good	n.a	n.a
K30	Hawary Shar 3	539011	3940943	929	5	Good	n.a	n.a
K31	Hawary Shar 4	539793	3941123	969	6.5	Good	n.a	n.a
K32	Hawary Shar 5	540469	3941443	1016	6	Good	n.a	n.a
K33	Hawary Shar 6	540806	3941744	1047	5.5	Good	n.a	n.a
K34	Hawary Shar 7	540407	3942572	1044	7	Good	n.a	n.a
K35	Malkandy	540638	3935265	887	0	Dry	n.a	n.a
K36	Berchawa	541957	3931771	850	0	Dry	n.a	n.a
K37	Qrga	543885	3932268	951	11	Good	n.a	n.a

n.a: not available

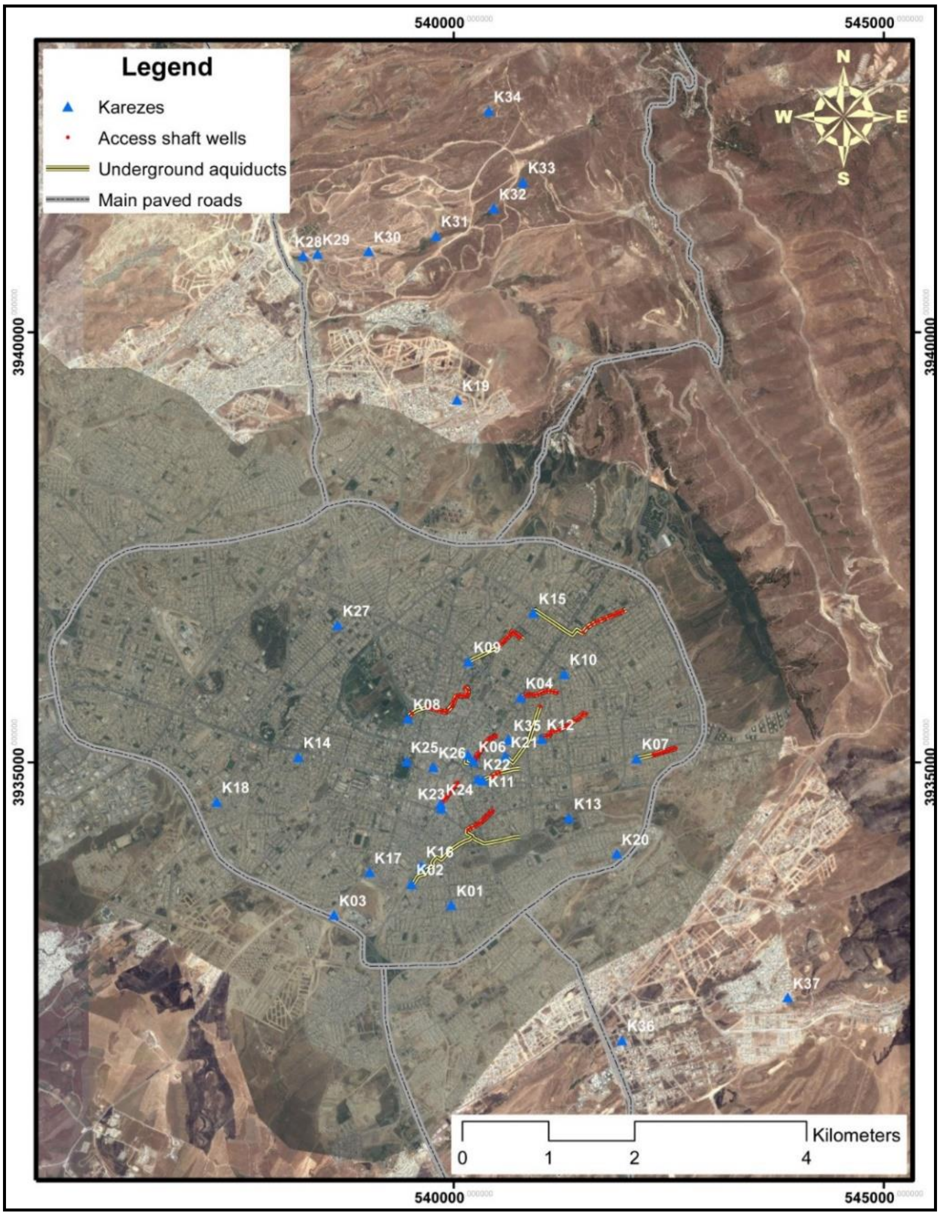

Fig.4: Location of karez's subsurface channels and their access shaft wells

RESULTS AND DISCUSSION

The chemical analysis indicates that Ca^{2+} and HCO_3^- are the dominant ions. The second species in abundance are Mg^{2+} for cations and SO_4^{2-} for anions (Table 4 and Figure 5). Furthermore, when the water samples are plotted on the Durov diagram, all of them are located in the zone number two which means Ca and HCO_3 ions dominating water type (Figure 6). The relatively high concentration of (Ca^{2+}, HCO_3^-) is expected to be issued from carbonate layers of the Cretaceous limestone rocks, while the elevated concentration of (SO_4^{2-} and Cl^-) for some sites is attributed mostly to the anthropogenic activities within the Sulaymaniyah City. Relatively high TDS concentration (>500 ppm) appears in the southwest part of the city and decreases toward the central part (Figure 7).

Among nine water samples analysed for NO_3^-, only two samples (K11 and K22) exceed 50 mg/l. Although nitrate is rather stable in groundwater, it changes seasonally to some extent

(Chen *et al*., 2007). The spatial distribution of nitrate map indicates that the concentration increases toward the city center (Figure 8). The previous work of Hamamin *et al*. (2016), which included analysis of about 100 water samples collected from domestic and agriculture water wells, karezes and springs, revealed NO_3 concentration in the range of 0.5 to 70 mg/l for the whole sub-basin, but for the entire city it was below 50 ppm. The relatively high concentration of NO_3 in the central part of the area may refer to the leakage and contamination by municipal wastewater system. This conclusion was confirmed by previous works conducted by Hamamin *et al*. (2016), Mustafa (2006), Al-Manmi (2002). The analysis of heavy metals (Zn^{2+}, Pb^{2+}, Cu^{2+}, Cr^{2+}, Cd^{2+}, and Ni^{2+}) (Table 5), show almost all the water samples are within the permissible limits of WHO (2011) and IQS (2001) standards. Accordingly, no heavy metal-related health hazard in the karez water of the area is anticipated.

Table 4: Physical Parameters and Major Ions Concentrations in Karez Water Samples

No.	**T°C**	**pH**	**EC µs/cm**	**TDS mg/l**	**Unit**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**SUM**	**$SO4^{2-}$**	**Cl^-**	**HCO_3^-**	**CO_3^{2-}**	**SUM**
K11	20.2	7.0	678	434	mg/l	79	20	16	1.33	116.3	68	35	210	0.0	313
					meq/l	3.95	1.67	0.7	0.03	6.35	1.42	0.97	3.4	0.0	5.83
					% meq/l	62.2	26.3	10.96	0.54	100	24.3	16.67	59	0.0	100
K22	20	7.21	329	211	mg/l	36	12	4.5	0.3	52.8	40	21	113	0.0	174
					meq/l	1.8	1.0	0.20	0.01	3.0	0.83	0.58	1.85	0.0	3.27
					% meq/l	59.9	33.3	6.51	0.26	100	25.5	17.8	56.7	0.0	10
K05	20.4	6.82	334	214	mg/l	33	10.5	3.8	0.5	47.8	15	23	123	0.0	161
					meq/l	1.65	0.88	0.17	0.01	2.7	0.31	0.64	2.02	0.0	2.97
					% meq/l	61	32.37	6.11	0.47	100	10.53	21.5	67.9	0.0	100
K06	21.6	6.84	321	206	mg/l	33	9	3.4	0.6	46	33	18	103	0.0	154
					meq/l	1.65	0.75	0.15	0.02	2.56	0.69	0.5	1.7	0.0	2.88
					% meq/l	64.4	29.26	5.77	0.60	100	23.9	17.4	58.7	0.0	100
K23	21.6	7.06	385	246.4	mg/l	45.6	12.3	3.1	0.2	61.2	76.3	10	115	0.0	201.3
					meq/l	2.28	1.03	0.13	0.01	3.44	1.59	0.28	1.89	0.0	3.75
					% meq/l	66.2	29.75	3.91	0.15	100	42.4	7.40	50.2	0.0	100
K37	19.3	7.01	342	219	mg/l	36.3	11.2	2	0.4	49.9	21.5	18.6	125	0.0	165.1
					meq/l	1.82	0.93	0.09	0.01	2.85	0.45	0.52	2.05	0.0	3.01
					% meq/l	63.8	32.8	3.06	0.36	100	14.86	17.1	68	0.0	100
K16	20.4	6.99	799	511	mg/l	88	32	16	1.2	137.2	80.3	65	220	0.0	365.3
					meq/l	56.5	34.2	8.93	0.39	100	23.6	25.5	50.9	0.0	100
					% meq/l	4.4	2.67	0.70	0.03	7.79	1.67	1.8	3.6	0.0	7.09
K03	20.1	7.25	810	518.4	mg/l	100	29	20	1.9	150.9	98	70	229	0.0	397
					meq/l	5.0	2.4	0.87	0.05	8.33	2.04	1.94	3.75	0.0	7.74
					% meq/l	60	28.99	10.4	0.58	100	26.4	25.1	48.5	0.0	100
K29	19.3	7.65	569	381.4	mg/l	56	14.5	13	0.9	84.4	38	33	198	0.0	269
					meq/l	2.8	1.21	0.57	0.02	4.6	0.79	0.92	3.25	0.0	4.95
					% meq/l	60.9	26.29	12.30	0.5	100	15.98	18.5	65.52	0.0	100
Min.	19.3	6.82	321	205.4	mg/l	33	9	2	0.2	46	15	10	103	0.0	154
					meq/l	1.65	0.75	0.09	0.01	2.56	0.31	0.28	1.69	0.0	2.88
					%epm	56.5	26.26	3.06	0.15	100.00	10.53	7.4	48.5	0.0	100
Max.	21.6	7.7	810	518.4	mg/l	100	32	20	1.9	150	98	70	229	0.0	397
					meq/l	1.65	0.75	0.09	0.01	2.56	2.04	1.94	3.75	0.0	7.74
					% meq/l	66.2	34.22	12.3	0.60	100.00	42.36	25.5	68	0.0	100
Mean	20.3	7.15	527.4	337.5	mg/l	56.3	16.2	9	0.81	83	52.3	32.6	159.6	0.0	244.4
					meq/l	2.8	1.39	0.40	0.02	4.63	1.09	0.91	2.62	0.0	4.6
					% meq/l	61.7	30.36	7.55	0.43	100.00	23.05	18.6	58.4	0.0	100

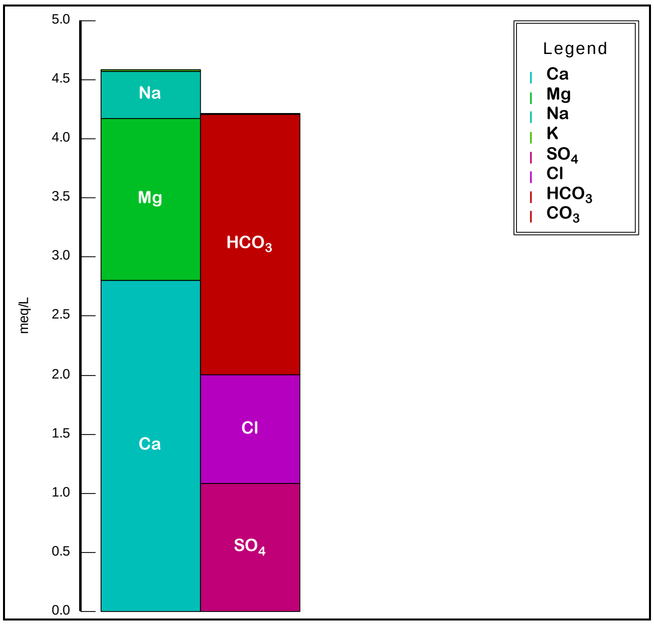

Fig.5: Ionic balance diagram of the Karez average water samples

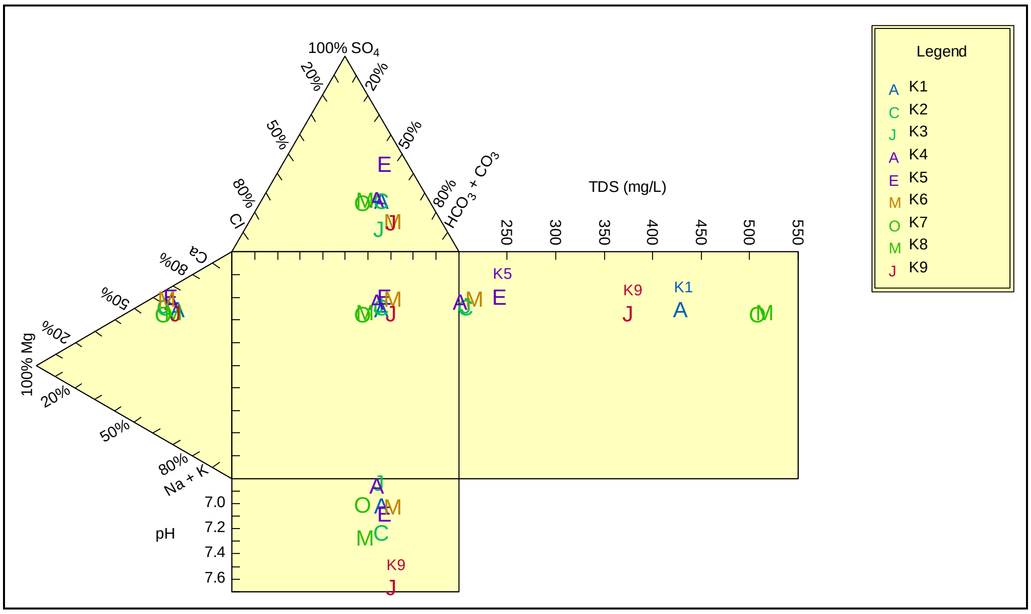

Fig.6: Durov diagram of the karez water samples

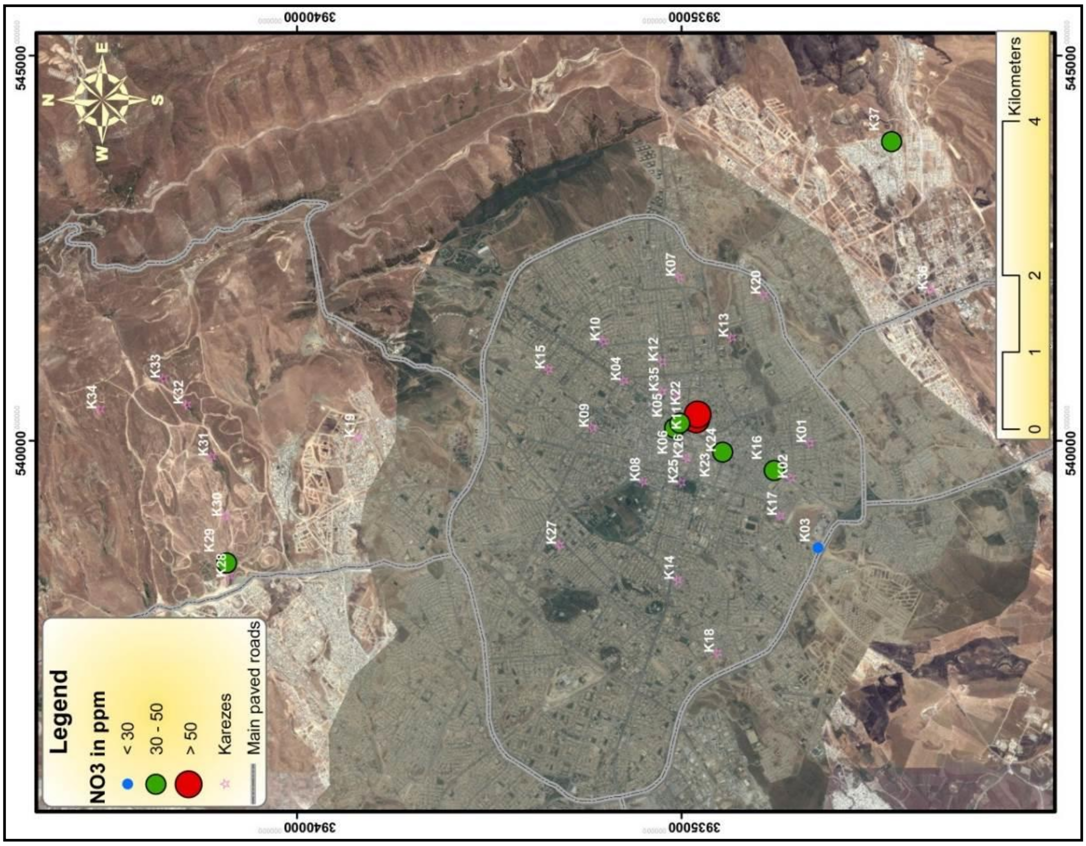

Fig.8: Point map of NO_3 concentration of the Karezes

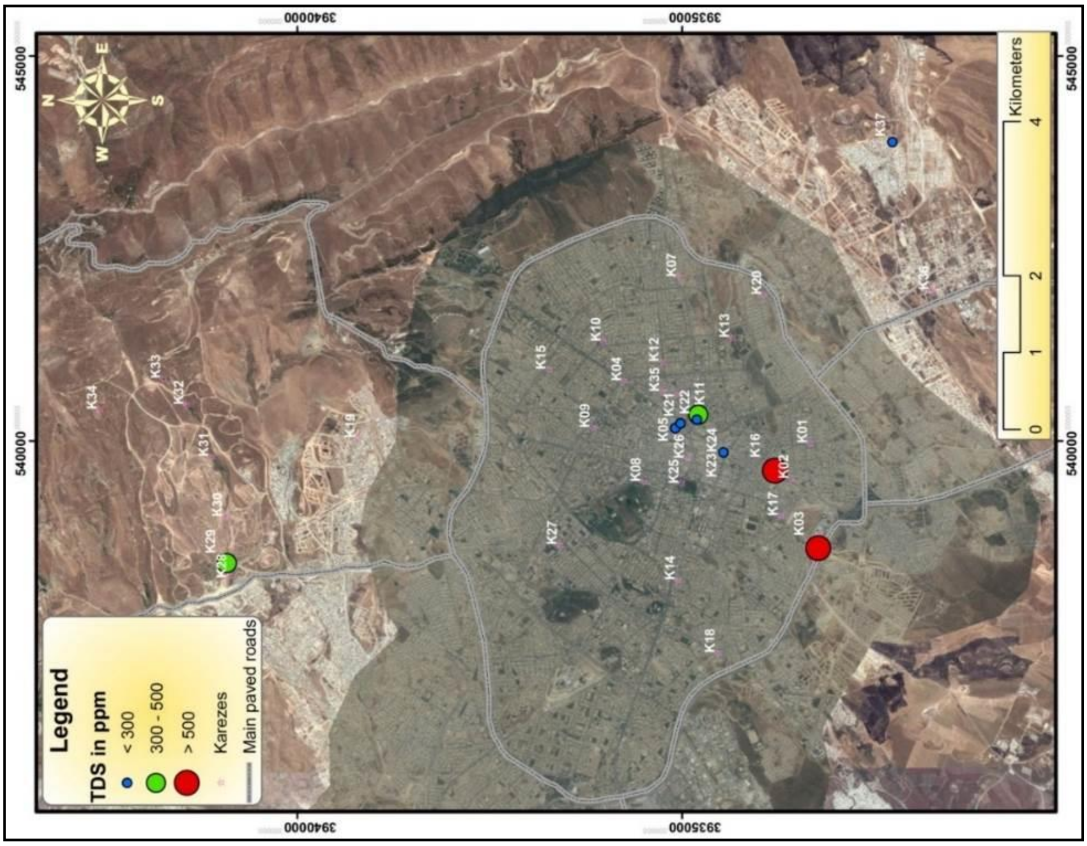

Fig.7: Point map of TDS of Karez water samples

Table 5: Heavy metals, PO_4^{3-} and NO_3^- concentrations in (mg/l) for karez water samples

Sample ID	Zn^{2+}	Pb^{2+}	Cu^{2+}	Cr^{2+}	Cd^{2+}	Ni^{2+}	PO_4^{3-}	NO_3^-
K11	0.02	0.002	0.001	0.004	0.001	0.004	0.25	52
K22	n.d	n.d	0.002	n.d	n.d	0.003	0.32	63
K05	n.d	n.d	n.d	n.d	n.d	n.d	0.02	38
K06	n.d	n.d	0.003	n.d	n.d	n.d	0.05	38
K23	n.d	n.d	n.d	n.d	n.d	n.d	0.09	34
K37	n.d	n.d	n.d	n.d	n.d	n.d	0.08	34
K16	n.d	n.d	n.d	n.d	n.d	n.d	0.18	42
K03	0.05	0.01	0.03	0.02	0.002	0.0016	n.d	18
K29	0.04	n.d	n.d	n.d	n.d	n.d	0.15	35

CONCLUSIONS AND RECOMMENDATIONS

Karez is considered to be energy saving; as pumping is not required, thus no extra energy input is needed and very efficient; no evaporation takes place, meaning minimum loss of water. The current work assessed the status of Sulaymaniyah City karezes and their deteriorating conditions regarding structure and water quality due to the unsustainable urbanization and improper licensing for land use in the city. The total water discharge from the whole number of Karezes in Sulaymaniyah City is estimated by 12000 m^3/day which makes around 10% of the total water demand of the city. The estimated threefold increase in the population growth rate in Sulaymaniyah city by 2030 necessitates a new and sustainable approach of water management of the four main water resources of Dokan 1, Dokan 2, Sarchinar karstic spring and wells. Utilizing every other available source, such as the contribution of the still active and clean karezes, can participate in avoiding a water crisis in waiting.

In the light of this study, the following points are recommended:

1) Periodic analyses of complete chemical and physical water quality parameters are recommended to assure that no serious problems arise in the remaining karezes in the area of interest.
2) Delineation of karez protection zones should be promoted, typically 60 m radius around the source area.
3) The related water authorities in Sulaymaniyah City should consider using karez as a vital resource especially in the dry seasons when water shortage becomes a daily problem.
4) The Archeology Directorate of Sulaymaniyah Governorate should also consider refurbishing at least one of the still-functioning karezes as a heritage site.
5) Carrying out geoelectrical surveys to investigate undiscovered channels of some old karez that may be covered and buried due to urbanization activities.

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