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Using electricity consumption as a tool for groundwater abstraction in Abu Dhabi Emirate farms, UAE

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ABSTRACT

Farm irrigation for agricultural crops such as vegetables, palm trees for date production, and Rhodes grass for camel fodder, currently (2019) is the largest use of groundwater in Abu Dhabi Emirate. Each farmer was permitted to drill two wells within the farm boundary for irrigation groundwater supply [1]. In practice, many farms have more than two wells because farmers drill new wells to replace dry or low-yielding wells, because of the belief that more wells increase the amount of groundwater available to the farm, and because there is no enforcement of the two-well rule. Because the farms are closely spaced in regular grids that extend over large areas, well interference can be substantial in and around the farming districts, and groundwater-level declines can be large. At present there are more than 24,000 farms in Abu Dhabi Emirate, consuming about 2,100 million m^3 of groundwater from more than 54,000 abstraction wells. Farm area in Abu Dhabi Emirate increased from 35,000 ha in 1996 to 120,000 ha in 2006, with most of the increase occurring in Al Ain region. The typical citizen farm was a 183-m by 183-m plot of leveled land surrounded by a concrete and block wall and date palm, fodders and vegetables were the primary crops. All of these have no water flow meters to measure the real abstraction. To estimate the groundwater abstraction, groundwater wells electric use records for 2011 to 2018 were used to estimate groundwater use at selected pilot farms in Al Ain region. The high correlation between the amount of irrigation groundwater produced and the amount of electricity consumed at the studied farms offered the possibility of using farm electric records to estimate historical and current groundwater abstraction in farming districts that have substantial concentrations of farms. The compiled records begin in 2011 and includes historical meter readings for about 20,000 farms, forests, and rural wells, comprising about 940,000 total readings. The data was filtered to extract only data for farms that were constructed as typical citizen farms with the combination of date palm and grass crops similar to the mixed farms previously studied and for which irrigation efficiency was estimated. Electric use for these farms was estimated on an annual basis for 2011–2018 for each of 9 farming districts in the pilot project. More than 900,000 farm electric meter readings were collected and analyses during this study. Based on a previous investigation that showed groundwater use and electric use, it has been found that trends were linear at mixed palm and grass farms and that the ratios of the trends yielded an average irrigation efficiency of 0.77 m^3/kWh. During the 8-y period of records, total annual groundwater uses for farms irrigation in the 9 farming districts pilot project increased from 581 to 743 Mm^3, with about 28% increase in groundwater use.

Keywords: Groundwater use; Water demand; Irrigation; Electrical use

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1. Introduction

Abu Dhabi Emirate, one of the seven Emirates which comprise the United Arab Emirates (UAE), occupies an area of 67,340 km^2, or about 80% of the total area of UAE as shown in Fig. 1. The Emirate has an arid climate with less than 100 mm/y average rainfall, a very high evaporation rate (2–3 m/y), a low groundwater recharge rate (<4% of total annual water used) and no reliable, perennial surface water resources. Furthermore, it is a downstream water user and shares trans-boundary water resources along common borders with Saudi Arabia and the Sultanate of Oman, 350 and 280 km in length respectively. Historically, all the Emirate's water requirements were met solely from groundwater obtained from shallow hand dug wells and the traditional Falaj system, comprising man–made channels used to collect groundwater, spring water and surface water and transport it, by gravity, to a demand area. Since the entire Emirate's Aflaj are now dry, a system of borehole support has been developed over the last 5–10 y. Over the last two to three decades, however, rapid economic development, coupled with sharp population increases and the development of a large agricultural sector, substantially supported from government subsidies, has meant an increasing reliance on unconventional water resources, such as desalination, and also the development of alternative conventional water supply measures, such as recharge dams, storage dams, recharge wells, interception of groundwater losses, re-use of wastewater and water transfers.

The Emirate occurs in the subtropical arid climatic zone and is exposed to oceanic effects of the Arabian Gulf and Indian Ocean. Rainfall is erratic and unreliable. Orographic effects are clearly seen on the rainfall distribution. The Al Hajar mountains in neighboring Oman, which reach elevations in excess of 2,000 m.a.m.s.l, generate high rainfall incidents, especially in the winter months, which provide for the runoff to Wadis which cross over the border into Abu Dhabi Emirate. Within Abu Dhabi, this high elevation rain occurs only at Jebel Hafeet, which, at an elevation of 1,163 m (a.m.s.l), is the highest point in Abu Dhabi Emirate and the only high mountain massif within the Emirate. Mean annual rainfall within Abu Dhabi Emirate varies from 46 mm at Jebel Dhanna in the Western Region to 119 mm at Al Wigan, south of Al Ain, in the Eastern Region. The mean annual rainfall at Al Ain 1971–1994 is 96.4 mm with a maximum of 303 mm/y. The mean annual precipitation for Abu Dhabi Island is 87 mm with a maximum of 227 mm/y. Groundwater, albeit mostly brackish and saline in quality still provides around 80% of all water used in the Emirate [2]. No natural, perennial surface water resources exist within the Emirate, apart from the spring at Ain Al Fayda and it is therefore important to understand the various hydrologic processes and hydrogeological settings which control the extremely valuable groundwater resources.

The GWRP [3] and GWAP [4] have used different methods to calculate the groundwater in storage in the Emirate, but both have ultimately calculated average saturated aquifer thickness and specific yield to estimate stored volumes. The volume of fresh groundwater calculated differs by only 8%. It is not possible to compare the saline and brackish groundwater calculations, since different thresholds have been used to define this water quality. The GWRP calculated a total groundwater reserve of 253 km^3 (7% fresh and 93% brackish) as shown in Fig. 2 and the GWAP total estimate of 640 km^3 (79.4% saline) is much larger since groundwater of salinity of up to 100,000 mg/L TDS was included, whereas the GWRP included groundwater with less than 15,000 mg/L TDS. The most striking feature of both estimates is that the amount of fresh groundwater remaining in storage is very small, ranging from 2.6% to 7% of the total. According to the GWAP assessment more than three-quarters (12.5 km^3) of the fresh water in storage occurs in the Liwa lens and only about 4 km^3 in the Eastern region.

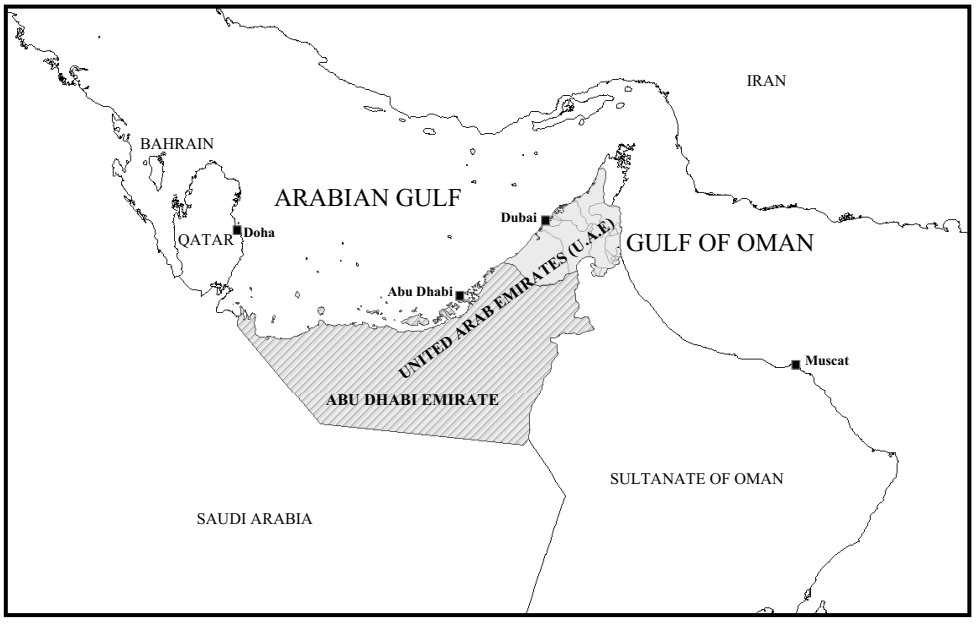

Fig. 1. Location of Abu Dhabi Emirate, United Arab Emirates.

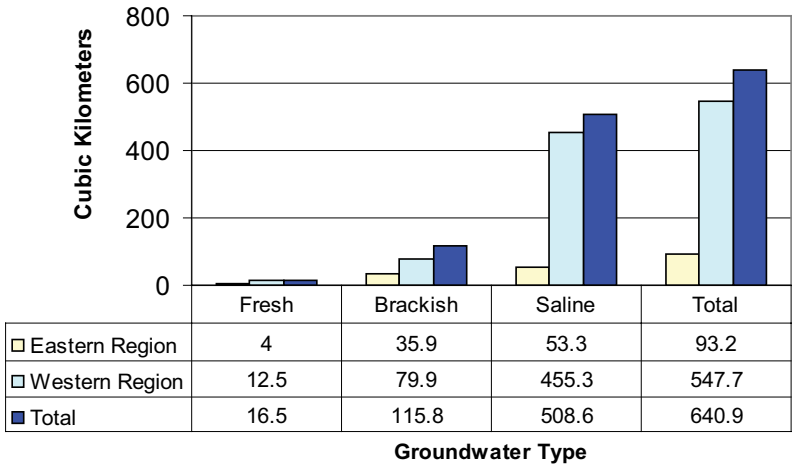

Fig. 2. Groundwater reserve aquifer systems.

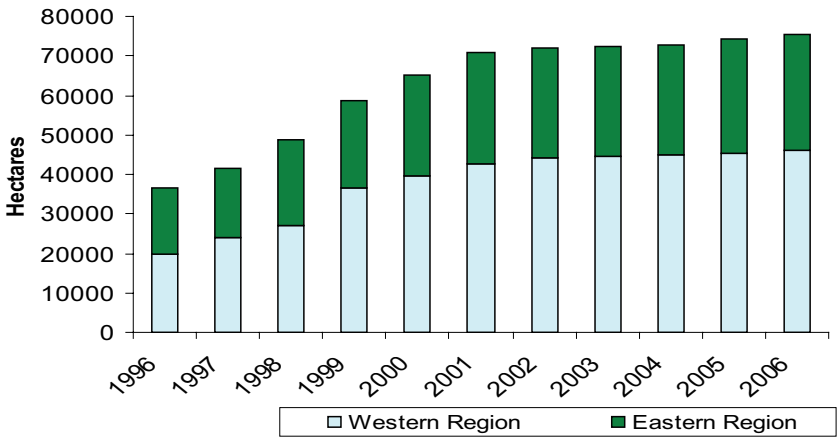

Fig. 3. Expansions of agriculture farms (1996–2006).

According to the GWRP assessment, at current groundwater abstraction rates, it is projected that the fresh and brackish groundwater resources will be depleted in 50 y.

It is estimated that the annual groundwater abstraction is about 2,100 million m^3. At present groundwater is utilized for irrigation by agriculture sector (83%), forestry (12%) and amenity plantation and road verges (4%) and industrial sectors (1%). Groundwater not used for domestic water supply since 2009 due to the deterioration of groundwater quality which is not in compliance with potable water quality guidelines and standers [5]. The estimated groundwater uses in agriculture sector is about 85% (1,750 million m^3/y). By the end of 2019, there were about 24,250 farms, occupying around 75,500 ha and a small number of large, state fodder (government) farms occupying about 17,000 ha [6] in addition to more than 320 afforested areas, amenity plantations. Fig. 3 shows the expansion in agriculture due to large government support. Citizen's farms are typically 2–3 ha in size and each has two drilled wells at opposite corners of the plot. A well supported system of subsidies promotes agricultural expansion to the tune of 3,000 new farms each year, although expansion is currently restricted due to exhaustion of groundwater supplies. The major limitations on agricultural development are lack of groundwater resources and high groundwater salinity used in irrigation. Close proximity of wells results in well interference effects and unrestricted irrigation causes extreme cones of depression as shown in Fig. 4 resulting in a deterioration in salinities, which are usually low brackish to high brackish to begin with.

At present there are no water flow meters to measure the real abstraction in agriculture sector. To estimate the groundwater abstraction, groundwater wells electric use records for 2011–2018 were used to estimate groundwater use at selected pilot farms in Al Ain region. The high correlation between the amount of irrigation groundwater produced and the amount of electricity consumed at the studied farms offered the possibility of using farm electric records to estimate historical and current groundwater abstraction in farming districts that have substantial concentrations of farms. The compiled records begin in 2011 and includes historical meter readings for about 20,000 farms, forests, and rural wells, comprising about 940,000 total readings. The high correlation between the amount of irrigation water produced and the amount of electricity consumed at the studied farms offered the possibility

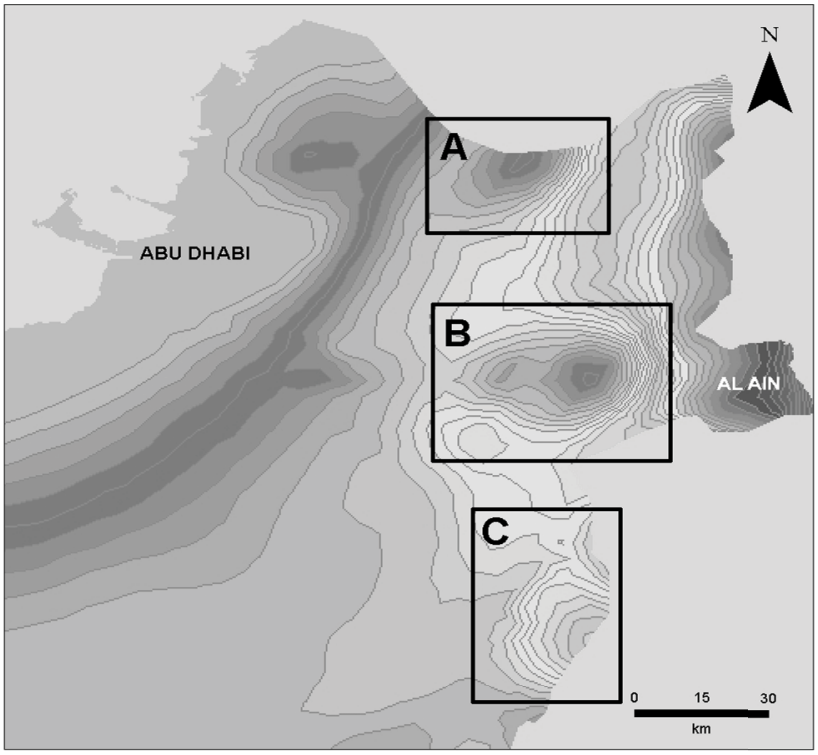

Fig. 4. Groundwater cones of depression (January 2019).

of using citizen farm electric records to estimate historical and current water use in farming districts that have substantial concentrations of citizen farms.

2. Using electric use records for groundwater estimation

At Al Ain region (east of Abu Dhabi) The massive farm construction program from the mid-1990s to the mid-2000s increased the number of mixed palm and grass farms from a few hundred to more than 7,000 in 9 farming districts (Al Aushush, Nahel North, Nahel South, Al Ankah, Al Dhahira East, Al Dhahira West, Al Ageer, Al Wagan North, and Al Wagan South). Al Ain Distribution Company (AADC) digital farm electric use records for 2004 to 2009 were used to estimate groundwater abstraction at these farms based on a previous investigation that showed groundwater use and electric use trends were linear at mixed palm and grass farms. A multi-year monitoring program of groundwater use and associated electric use at 14 selected farms started in June 2006. The general locations of the monitored farms are between Al Ain and Al Hayer, between Al Hayer and Nahel, west of Al Ain in Al Ankah, and south of Al Ain in Al Dhahira as shown in Fig. 5. The study concentrated on three farms devoted entirely to the production of date palm trees (palm farms), and 10 farms devoted to the production of date palms and grass fodder for animals (mixed palm and grass farms), and one farm devoted primarily to the production of roses. The three palm farms, as with many palm farms, are not constructed in the style of a typical citizen farm. However, because they are devoted to a single crop and because the total number of trees was fixed, they are ideal farms to study. By February 2010, the three palm farms had been monitored for a sufficient period to assess water use for palm trees [7]. By January 2011, the 10 mixed palm and grass farms and the rose farm had been monitored for a sufficient period to assess water use for mixed palm and grass farms.

Data from two of the ten mixed farms were not analyzed because it was later determined that these farms were receiving water from wells that were located outside of the farm and operated by a different electrical circuit. For palm farms, the average long-term groundwater use rate was 0.156 m^3/d/tree (156 L/d/tree) and the average long-term electric-use rate was 0.37 kWh/d/tree. This measured water-use rate compares favorably with published estimated palm tree water-use requirements of 112 to 314 L/d/tree [8] determined from research conducted in Saudi Arabia. The average irrigation efficiency was 0.49 m^3/kWh [9]. For mixed palm and grass farms, average total farm long-term water use was 354 m^3/d with a standard deviation of 218 m^3/d. Water use for grass only was estimated by subtracting total tree water-use (using the palm farm data analysis) from total irrigation water use [10]. The average long-term grass water use for mixed farms was 207 m^3/d/ha with a standard deviation of 110 m^3/d/ha. On average, water use for grass was 86% of total irrigation water use at mixed farms. Average long-term farm electric use at mixed farms was 536 kWh/d with a standard deviation of 377 kWh/d. Average irrigation efficiency was 0.77 m^3/kWh with standard deviation of 0.23 m^3/kWh. The average farm groundwater uses in the Al Aushush farming district increased from 225 m^3/d in 2004 to 250 m^3/d in 2009, with the number of farms for

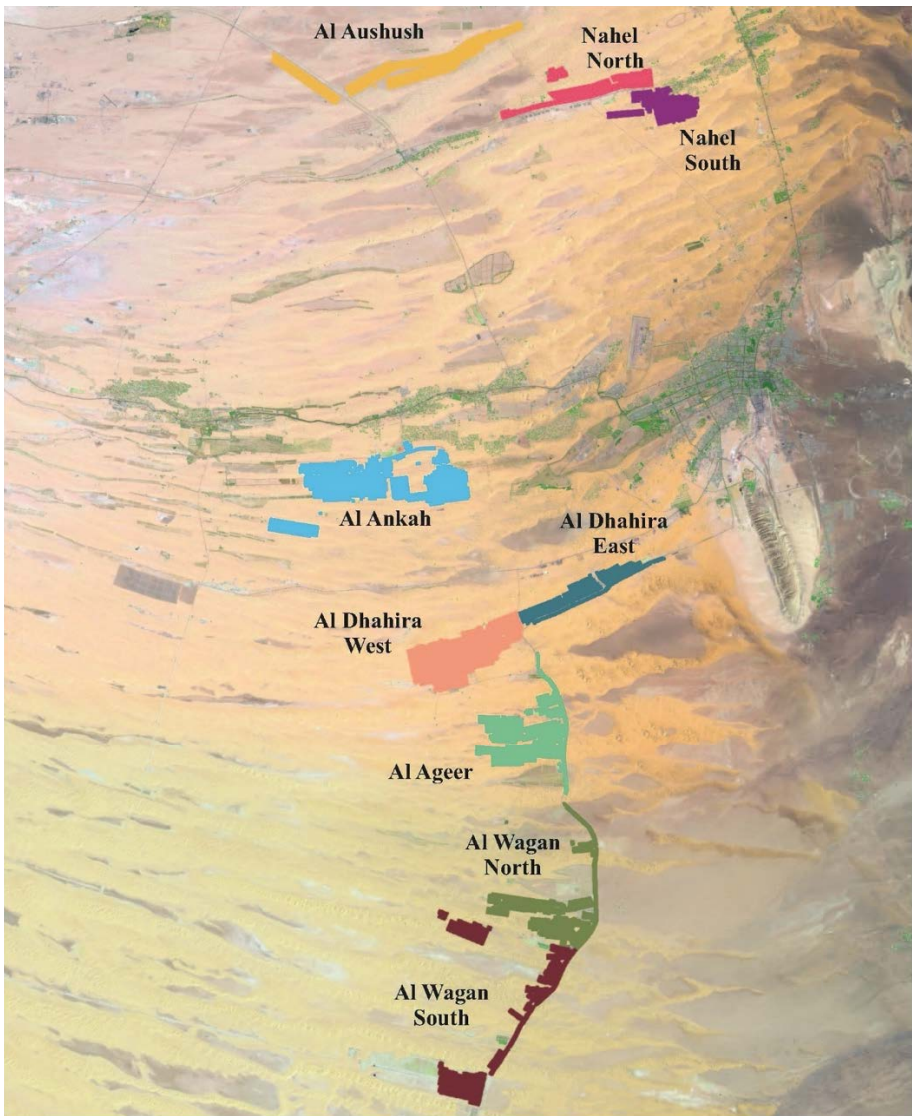

Fig. 5. Location of 9 farming districts for which electric meter readings were analyzed.

which electric meter reading data was available increasing from 810 to 915 during the same period. From 2004 to 2009, the percentage of farms using between about 150 and 350 m^3/d of irrigation water increased from 72% to 79%, with most of the increase occurring from 2004 to 2005. This probably was caused by the abrupt increase in new farms in late 2004 and early 2005 [11]. The percentage of farms using less than 150 m^3/d declined from about 20% in 2004 to about 10% in 2009. Total farm district groundwater uses in 2009 was 229,000 m^3/d or 83.7 Mm^3/y, which was a 26% increase over the annual 2004 groundwater use as shown in Table 1. Fig. 6 shows the annual groundwater use by farms in each farming district.

3. Results and outcomes

The 3-y study of 10 citizen farms in eastern Abu Dhabi Emirate that focused on the production of date palms and grass fodder for animals concluded that groundwater use and electric use generally exhibited linear trends in time. Because of this relationship, it was possible to determine average farm irrigation efficiency (0.77 m^3/kWh) as the ratio of total amount of irrigation water distributed to crops to total farm electric use, and it was possible to use compiled farm electric records to estimate historical and current water use in farming districts that have substantial concentrations of citizen farms. Farm electric-use records obtained from the Al Ain Distribution Company (AADC) were used to estimate water use in 9 farming districts (Al Aushush, Nahel North, Nahel South, Al Ankah, Al Dhahira East, Al Dhahira West, Al Ageer, Al Wagan North, and Al Wagan South) during the period for which digital electric-use data was available (2004–2009). The growth history of each farming district was determined by extrapolating the slope of first linear segment of each farms electric-meter reading data backwards in time to the predicted time of the zero reading. All of the districts exhibited similar growth trends, with growth at 2 farming districts being fairly constant from

Table 1
Results of groundwater use analysis for all farming districts

Farms	Year					
	2004	2005	2006	2007	2008	2009
			Al Aushush			
Number of farms	810	908	917	921	926	915
Average use (m^3/d/farm)	225	234	246	247	246	250
Minimum use (m^3/d/farm)	1	1	10	10	5	2
Maximum use (m^3/d/farm)	651	620	620	620	622	738
Standard deviation (m^3/d)	97	87	84	84	88	88
Total daily use (m^3)	182,000	213,000	225,000	227,000	228,000	229,000
Total annual use (Mm^3)	66.6	77.8	82.4	83	83.2	83.7
			Al Nahel North			
Number of farms	366	385	393	395	397	392
Average use (m^3/d/farm)	178	177	179	183	184	190
Minimum use (m^3/d/farm)	13	1	13	1	2	3
Maximum use (m^3/d/farm)	663	556	556	556	557	691
Standard deviation (m^3/d)	93	89	90	92	94	99
Total daily use (m^3)	65,000	68,000	70,000	72,000	73,000	74,000
Total annual use (Mm^3)	23.8	24.9	25.6	26.4	26.7	27.2
			Al Nahel South			
Number of farms	318	338	358	327	307	289
Average use (m^3/d/farm)	142	125	119	119	118	121
Minimum use (m^3/d/farm)	8	2	1	1	4	1
Maximum use (m^3/d/farm)	757	624	624	624	626	624
Standard deviation (m^3/d)	95	87	82	84	85	85
Total daily use (m^3)	45,000	42,000	42,000	39,000	36,000	35,000
Total annual use (Mm^3)	16.5	15.5	15.5	14.2	13.3	12.8
			Al Ankah South			
Number of farms	1,032	1,304	1,352	1,357	1,346	1,327
Average use (m^3/d/farm)	286	283	302	304	310	315
Minimum use (m^3/d/farm)	1	1	3	7	2	5
Maximum use (m^3/d/farm)	976	974	974	974	976	974
Standard deviation (m^3/d)	127	116	112	112	111	109
Total daily use (m^3)	295,000	369,000	408,000	413,000	417,000	418,000
Total annual use (Mm^3)	107.9	134.7	149.2	150.7	152.4	152.7
			Al Dhahira East			
Number of farms	386	391	462	467	469	475
Average use (m^3/d/farm)	292	291	277	302	309	312
Minimum use (m^3/d/farm)	1	1	9	9	7	5
Maximum use (m^3/d/farm)	703	701	878	933	936	952
Standard deviation (m^3/d)	145	145	143	149	151	158
Total daily use (m^3)	113,000	114,000	128,000	141,000	145,000	148,000
Total annual use (Mm^3)	41.1	41.6	46.8	51.6	52.9	54.1

early 1990 to 2006, one farming district showing slightly increased growth from the late 1990s to 2006, and 6 farming districts showing rapid growth from the late 1990s to 2006. The 8 farming districts showing the most rapid overall growth also exhibited abrupt smaller increases in numbers of farms around 2004 to 2006, and all farming districts show nearly flat growth from 2006 to 2009 [12].

Average groundwater uses per farm at the Al Aushush farming district (about 1,200 electric meters) increased from 225 to 250 m^3/d from 2004 to 2009, with total farm-district

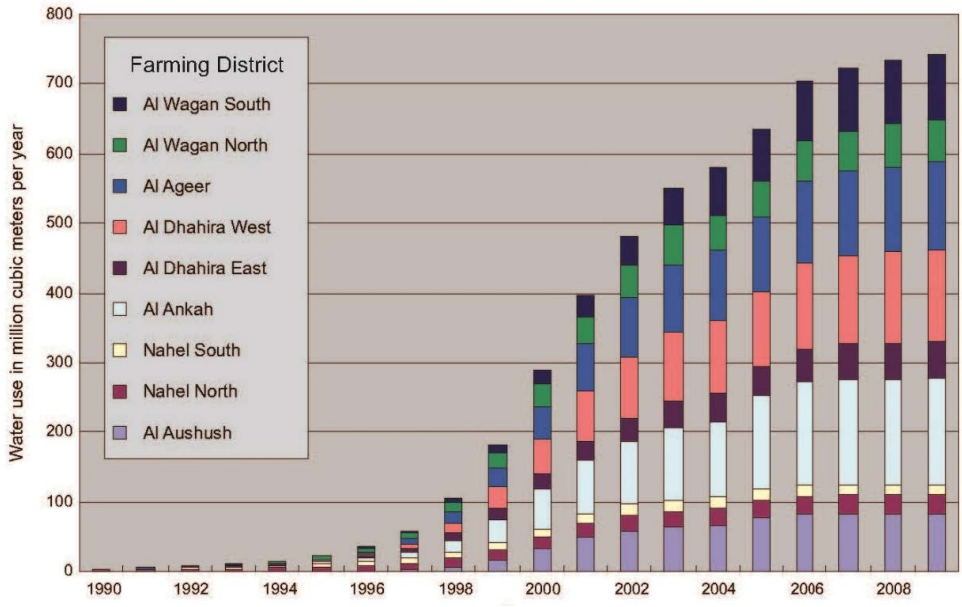

Fig. 6. Annual water use by citizen farms in each farming district.

water use increasing 26% to 83.7 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Nahel North farming district (about 700 electric meters) increased from 178 to 190 m^3/d from 2004 to 2009, with total farm-district water use increasing 14% to 27.2 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Nahel South farming district (about 700 electric meters) decreased from 142 to 121 m^3/d from 2004 to 2009, with total farm-district water use decreasing 22% to 12.8 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Al Ankah farming district (about 1,600 electric meters) increased from 286 to 315 m^3/d from 2004 to 2009, with total farm district water use increasing 42% to 152.7 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Al Dhahira East farming district (about 500 electric meters) increased from 292 to 312 m^3/d from 2004 to 2009, with total farm-district water use increasing 25% to 54.1 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Al Dhahira West farming district (about 1,200 electric meters) increased from 296 to 332 m^3/d from 2004 to 2009, with total farm-district water use increasing 27% to 131.1 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Al Ageer farming district (about 1,150 electric meters) increased from 319 to 346 m^3/d from 2004 to 2009, with total farm district groundwater use increasing 22% to 125.5 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Al Wagan North farming district (about 900 electric meters) increased from 272 to 296 m^3/d from 2004 to 2009, with total farm district groundwater use increasing 28% to 61.7 Mm^3/y from 2004 to 2009. Average groundwater uses per farm at the Al Wagan South farming district (about 900 electric meters) increased from 295 to 321 m^3/d from 2004 to 2009, with total farm district groundwater use increasing 34% to 94.3 Mm^3/y from 2004 to 2009. Total annual groundwater uses for citizen farms in the 9 farming districts during the 6-y study period increased from 581 Mm^3/y in 2004 to 743 Mm^3/y in 2009.

References

[1] M.A. Dawoud, Groundwater economics in arid regions: Abu Dhabi Emirate case study, Desal. Water Treat., 176 (2020) 84–93.
[2] Environment Agency – Abu Dhabi (EAD), Groundwater Atlas, 2019, 119 p.
[3] U. S. Geological Survey and National Drilling Company (NDC), Hydrologic Data for 1995, Abu Dhabi Emirate, 1996, 91 p.
[4] GTZ/Dornier Consult/ADNOC 2005 Status Report Phases 1Xa, 1Xb and 1Xc for Groundwater Assessment Project Abu Dhabi.
[5] M.A. Dawoud, Water Resources of Abu Dhabi Emirate, Sector Paper: Environmental Agency, Abu Dhabi, 2018, 167 p.
[6] M.A. Dawoud, The role of desalination in augmentation of water supply in GCC countries, Desalination, 186 (2006) 187–198.
[7] J.L. Imes, D.W. Clark, Estimated Predevelopment and 2005 Volumes of Usable Ground Water, by Water Type, Stored in the Surficial Aquifer of Abu Dhabi Emirate, United Arab Emirates: NDC-USGS Technical Series Administrative Report 2006-001, 2006, 42 p.
[8] A.I. Al Amoud, Performance of Bubbler Irrigation System as Compared to Trickle for Large Size Date Palm Tree Farm: The Canadian Society for Bioengineering, Paper No. CSBE 08-172, 1999.
[9] J.L. Imes, I. Tawfiq, Water use by Palm Farms in Abu Dhabi Emirate, United Arab Emirates: NDC-USGS Technical Series Administrative Report 2010-001, 2010, 28 p.
[10] J.L. Imes, I. Tawfiq, Water use by Mixed Palm and Grass Farms in Abu Dhabi Emirate, United Arab Emirates: NDC-USGS Technical Series Administrative Report, 2011-002, 2011, 55 p.
[11] M. Brook, Water Resources of Abu Dhabi Emirate, U.A.E.: Environmental Agency Abu Dhabi, Water Resources Department, 2006, 167 p.
[12] J.L. Imes, Groundwater-Level Changes in the Shallow Aquifer from Historical Predevelopment Conditions and 2005 Conditions to 2010, NDC-USGS Technical Series Administrative Report 2012-001, Abu Dhabi Emirate, United Arab Emirates, 2012, 26 p.